

WCSLIB

8.5

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# 1 WCSLIB 8.5 and PGSBOX 8.5

## 1.1 Contents

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## 1.2 Copyright

WCSLIB 8.5 - an implementation of the FITS WCS standard.  
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\$Id: mainpage.dox,v 8.5 2025/12/06 13:47:42 mcalabre Exp \$

## 1.3 Introduction

WCSLIB is a C library, supplied with a full set of Fortran wrappers, that implements the "World Coordinate System" (WCS) standard in FITS (Flexible Image Transport System). It also includes a [PGPLOT](#)-based routine, [PGSBOX](#), for drawing general curvilinear coordinate gratitudes, and also a number of utility programs.

The FITS data format is widely used within the international astronomical community, from the radio to gamma-ray regimes, for data interchange and archive, and also increasingly as an online format. It is described in

- "Definition of The Flexible Image Transport System (FITS)", FITS Standard, Version 3.0, 2008 July 10.

available from the FITS Support Office at <http://fits.gsfc.nasa.gov>.

The FITS WCS standard is described in

- "Representations of world coordinates in FITS" (Paper I), Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061-1075
- "Representations of celestial coordinates in FITS" (Paper II), Calabretta, M.R., & Greisen, E.W. 2002, A&A, 395, 1077-1122
- "Representations of spectral coordinates in FITS" (Paper III), Greisen, E.W., Calabretta, M.R., Valdes, F.G., & Allen, S.L. 2006, A&A, 446, 747
- "Representations of distortions in FITS world coordinate systems", Calabretta, M.R. et al. (WCS Paper IV, draft dated 2004/04/22), available from <http://www.atnf.csiro.au/people/Mark.Calabretta>
- "Mapping on the HEALPix Grid" (HPX, Paper V), Calabretta, M.R., & Roukema, B.F. 2007, MNRAS, 381, 865
- "Representing the 'Butterfly' Projection in FITS: Projection Code XPH" (XPH, Paper VI), Calabretta, M.R., & Lowe, S.R. 2013, PASA, 30, e050
- "Representations of time coordinates in FITS: Time and relative dimension in space" (Paper VII), Rots, A.H., Bunclark, P.S., Calabretta, M.R., Allen, S.L., Manchester R.N., & Thompson, W.T. 2015, A&A, 574, A36

Reprints of all published papers may be obtained from NASA's Astrophysics Data System (ADS), <http://adsabs.harvard.edu/>. Reprints of Papers I, II (including HPX & XPH), and III are available from <http://www.atnf.csiro.au/people/Mark.Calabretta>. This site also includes errata and supplementary material for Papers I, II and III.

Additional information on all aspects of FITS and its various software implementations may be found at the FITS Support Office <http://fits.gsfc.nasa.gov>.

## 1.4 FITS-WCS and related software

Several implementations of the FITS WCS standards are available:

- The [WCSLIB](#) software distribution (i.e. this library) may be obtained from <http://www.atnf.csiro.au/people/Mark.Calabretta/WCS/>. The remainder of this manual describes its use.

WCSLIB is included in the Astrophysics Source Code Library (**ASCL** <https://ascl.net>) as record ascl:1108.003 (<https://ascl.net/1108.003>), and in the Astrophysics Data System (**ADS** <https://ui.adsabs.harvard.edu>) with bibcode 2011ascl.soft08003C (<https://ui.adsabs.harvard.edu/abs/2011ascl.soft08003C>).

- **wcstools**, developed by Jessica Mink, may be obtained from <http://tdc-www.harvard.edu/software/wcstools/>.  
ASCL: <https://ascl.net/1109.015>  
ADS: <https://ui.adsabs.harvard.edu/abs/2011ascl.soft09015M>
- **AST**, developed by David Berry within the U.K. Starlink project, <http://www.starlink.ac.uk/ast/> and now supported by JAC, Hawaii <http://starlink.jach.hawaii.edu/starlink/>. A useful utility for experimenting with FITS WCS descriptions (similar to *wcsgrid*) is also provided; go to the above site and then look at the section entitled "FITS-WCS Plotting Demo".  
ASCL: <https://ascl.net/1404.016>  
ADS: <https://ui.adsabs.harvard.edu/abs/2014ascl.soft04016B>
- **SolarSoft**, <http://sohowww.nascom.nasa.gov/solarsoft/>, primarily an IDL-based system for analysis of Solar physics data, contains a module written by Bill Thompson oriented towards Solar coordinate systems, including spectral, <http://sohowww.nascom.nasa.gov/solarsoft/gen/idl/wcs/>.  
ASCL: <https://ascl.net/1208.013>  
ADS: <https://ui.adsabs.harvard.edu/abs/2012ascl.soft08013F>
- The IDL Astronomy Library, <http://idlastro.gsfc.nasa.gov/>, contains an independent implementation of FITS-WCS in IDL by Rick Balsano, Wayne Landsman and others. See <http://idlastro.gsfc.nasa.gov/contents.html#C5>.

Python wrappers to **WCSSLIB** are provided by

- The **Kapteyn Package** <http://www.astro.rug.nl/software/kapteyn/> by Hans Terlouw and Martin Vogelaar.  
ASCL: <https://ascl.net/1611.010>  
ADS: <https://ui.adsabs.harvard.edu/abs/2016ascl.soft11010T>
- **pywcs**, <http://stdas.stsci.edu/astrolib/pywcs/> by Michael Droettboom, which is distributed within Astropy, <https://www.astropy.org>.  
ASCL (Astropy): <https://ascl.net/1304.002>  
ADS (Astropy): <https://ui.adsabs.harvard.edu/abs/2013ascl.soft04002G>

Java is supported via

- CADC/CCDA Java Native Interface (JNI) bindings to **WCSSLIB** 4.2 <http://www.cadc-ccda.hia-ihp.nrc-cnrc.gc.ca/cadc/source/> by Patrick Dowler.

and Javascript by

- **wcsjs**, <https://github.com/astrojs/wcsjs>, a port created by Amit Kapadia using Emscripten, an LLVM to Javascript compiler. wcsjs provides a code base for running **WCSSLIB** on web browsers.

Julia wrappers ([https://en.wikipedia.org/wiki/Julia\\_\(programming\\_language\)](https://en.wikipedia.org/wiki/Julia_(programming_language))) are provided by

- **WCS.jl**, <https://github.com/JuliaAstro/WCS.jl>, a component of Julia Astro, <https://github.com/JuliaAstro>.

An interface for the R programming language ([https://en.wikipedia.org/wiki/R\\_\(programming\\_language\)](https://en.wikipedia.org/wiki/R_(programming_language))) is available at

- **Rwcs**, <https://github.com/asgr/Rwcs/> by Aaron Robotham.

Recommended WCS-aware FITS image viewers:

- Bill Joye's **DS9**, <http://hea-www.harvard.edu/RD/ds9/>, and  
ASCL: <https://ascl.net/0003.002>  
ADS: <https://ui.adsabs.harvard.edu/abs/2000ascl.soft03002S>
- **Fv** by Pan Chai, <http://heasarc.gsfc.nasa.gov/ftools/fv/>.  
ASCL: <https://ascl.net/1205.005>  
ADS: <https://ui.adsabs.harvard.edu/abs/2012ascl.soft05005P>

both handle 2-D images.

Currently (2013/01/29) I know of no image viewers that handle 1-D spectra properly nor multi-dimensional data, not even multi-dimensional data with only two non-degenerate image axes (please inform me if you know otherwise).

Pre-built **WCSLIB** packages are available, generally a little behind the main release (this list will probably be stale by the time you read it, best do a web search):

- archlinux (tgz), <https://www.archlinux.org/packages/extra/i686/wcslib>.
- Debian (deb), <http://packages.debian.org/search?keywords=wcslib>.
- Fedora (RPM), <https://admin.fedoraproject.org/pkgdb/package/wcslib>.
- Fresh Ports (RPM), <http://www.freshports.org/astro/wcslib>.
- Gentoo, <http://packages.gentoo.org/package/sci-astronomy/wcslib>.
- Homebrew (MacOSX), <https://github.com/Homebrew/homebrew-science>.
- RPM (general) <http://rpmfind.net/linux/rpm2html/search.php?query=wcslib>,  
<http://www.rpmseek.com/rpm-pl/wcslib.html>.
- Ubuntu (deb), <https://launchpad.net/ubuntu/+source/wcslib>.

Bill Pence's general FITS IO library, **CFITSIO** is available from <http://heasarc.gsfc.nasa.gov/fitsio/>. It is used optionally by some of the high-level WCSLIB test programs and is required by two of the utility programs.

ASCL: <https://ascl.net/1010.001>  
ADS: <https://ui.adsabs.harvard.edu/abs/2010ascl.soft10001P>

**PGPLOT**, Tim Pearson's Fortran plotting package on which **PGSBOX** is based, also used by some of the WCSLIB self-test suite and a utility program, is available from <http://astro.caltech.edu/~tjp/pgplot/>.

ASCL: <https://ascl.net/1103.002>  
ADS: <https://ui.adsabs.harvard.edu/abs/2011ascl.soft03002P>

## 1.5 Overview of WCSLIB

WCSLIB is documented in the prologues of its header files which provide a detailed description of the purpose of each function and its interface (this material is, of course, used to generate the doxygen manual). Here we explain how the library as a whole is structured. We will normally refer to WCSLIB 'routines', meaning C functions or Fortran 'subroutines', though the latter are actually wrappers implemented in C.

WCSLIB is layered software, each layer depends only on those beneath; understanding WCSLIB first means understanding its stratigraphy. There are essentially three levels, though some intermediate levels exist within these:

- The **top layer** consists of routines that provide the connection between FITS files and the high-level WCSLIB data structures, the main function being to parse a FITS header, extract WCS information, and copy it into a `wcsprm` struct. The lexical parsers among these are implemented as Flex descriptions (source files with `.l` suffix) and the C code generated from these by Flex is included in the source distribution.
  - `wcshdr.h,c` – Routines for constructing `wcsprm` data structures from information in a FITS header and conversely for writing a `wcsprm` struct out as a FITS header.
  - `wcspih.l` – Flex implementation of `wcspih()`, a lexical parser for WCS "keyrecords" in an image header. A **keyrecord** (formerly called "card image") consists of a **keyword**, its value - the **keyvalue** - and an optional comment, the **keycomment**.
  - `wcsbth.l` – Flex implementation of `wcsbth()` which parses binary table image array and pixel list headers in addition to image array headers.
  - `getwcstab.h,c` – Implementation of a -TAB binary table reader in `CFITSIO`.

A generic FITS header parser is also provided to handle non-WCS keyrecords that are ignored by `wcspih()`:

- `fitshdr.h,l` – Generic FITS header parser (not WCS-specific).

The philosophy adopted for dealing with non-standard WCS usage is to translate it at this level so that the middle- and low-level routines need only deal with standard constructs:

- `wcsfix.h,c` – Translator for non-standard FITS WCS constructs (uses `wcsutrne()`).
- `wcsutrn.l` – Lexical translator for non-standard units specifications.

As a concrete example, within this layer the `CTYPEi` keyvalues would be extracted from a FITS header and copied into the `ctype[]` array within a `wcsprm` struct. None of the header keyrecords are interpreted.

- The **middle layer** analyses the WCS information obtained from the FITS header by the top-level routines, identifying the separate steps of the WCS algorithm chain for each of the coordinate axes in the image. It constructs the various data structures on which the low-level routines are based and invokes them in the correct sequence. Thus the `wcsprm` struct is essentially the glue that binds together the low-level routines into a complete coordinate description.
  - `wcs.h,c` – Driver routines for the low-level routines.
  - `wcsunits.h,c` – Unit conversions (uses `wcsulexe()`).
  - `wcsulex.l` – Lexical parser for units specifications.

To continue the above example, within this layer the `ctype[]` keyvalues in a `wcsprm` struct are analysed to determine the nature of the coordinate axes in the image.

- Applications programmers who use the top- and middle-level routines generally need know nothing about the **low-level routines**. These are essentially mathematical in nature and largely independent of FITS itself. The mathematical formulae and algorithms cited in the WCS Papers, for example the spherical projection equations of Paper II and the lookup-table methods of Paper III, are implemented by the routines in this layer, some of which serve to aggregate others:

- [cel.h,c](#) – Celestial coordinate transformations, combines [prj.h,c](#) and [sph.h,c](#).
- [spc.h,c](#) – Spectral coordinate transformations, combines transformations from [spx.h,c](#).

The remainder of the routines in this level are independent of everything other than the grass-roots mathematical functions:

- [lin.h,c](#) – Linear transformation matrix.
- [dis.h,c](#) – Distortion functions.
- [log.h,c](#) – Logarithmic coordinates.
- [prj.h,c](#) – Spherical projection equations.
- [sph.h,c](#) – Spherical coordinate transformations.
- [spx.h,c](#) – Basic spectral transformations.
- [tab.h,c](#) – Coordinate lookup tables.

As the routines within this layer are quite generic, some, principally the implementation of the spherical projection equations, have been used in other packages (AST, wcstools) that provide their own implementations of the functionality of the top and middle-level routines.

- At the **grass-roots level** there are a number of mathematical and utility routines.

When dealing with celestial coordinate systems it is often desirable to use an angular measure that provides an exact representation of the latitude of the north or south pole. The WCSLIB routines use the following trigonometric functions that take or return angles in degrees:

- [cosd\(\)](#), [sind\(\)](#), [sincosd\(\)](#), [tand\(\)](#), [acosd\(\)](#), [asind\(\)](#), [atand\(\)](#), [atan2d\(\)](#)

These "trigd" routines are expected to handle angles that are a multiple of 90° returning an exact result. Some C implementations provide these as part of a system library and in such cases it may (or may not!) be preferable to use them. `wcstrig.c` provides wrappers on the standard trig functions based on radian measure, adding tests for multiples of 90°.

However, [wcstrig.h](#) also provides the choice of using preprocessor macro implementations of the trigd functions that don't test for multiples of 90° (compile with `-DWCSSTRIG_MACRO`). These are typically 20% faster but may lead to problems near the poles.

- [wcsmath.h](#) – Defines mathematical and other constants.
- [wcstrig.h,c](#) – Various implementations of trigd functions.
- [wcsutil.h,c](#) – Simple utility functions for string manipulation, etc. used by WCSLIB.

Complementary to the C library, a set of wrappers are provided that allow all WCSLIB C functions to be called by Fortran programs, see below.

Plotting of coordinate graticules is one of the more important requirements of a world coordinate system. WCSLIB provides a [PGPLOT](#)-based subroutine, [PGSBOX](#) (Fortran), which handles general curvilinear coordinates via a user-supplied function - `PGWCSL` provides the interface to WCSLIB. A C wrapper, [cpgsbox\(\)](#), is also provided, see below.

Several utility programs are distributed with WCSLIB:

- `wcsgrid` extracts the WCS keywords for an image from the specified FITS file and uses [cpgsbox\(\)](#) to plot a 2-D coordinate graticule for it. It requires WCSLIB, [PGSBOX](#) and [CFITSIO](#).
- `wcsware` extracts the WCS keywords for an image from the specified FITS file and constructs `wcsprm` structs for each coordinate representation found. The structs may then be printed or used to transform pixel coordinates to world coordinates. It requires WCSLIB and [CFITSIO](#).

- *HPXcvt* reorganises HEALPix data into a 2-D FITS image with HPX coordinate system. The input data may be stored in a FITS file as a primary image or image extension, or as a binary table extension. Both NESTED and RING pixel indices are supported. It uses [CFITSIO](#).
- *fitshdr* lists headers from a FITS file specified on the command line, or else on stdin, printing them as 80-character keyrecords without trailing blanks. It is independent of WCSLIB.

## 1.6 WCSLIB data structures

The WCSLIB routines are based on data structures specific to them: *wcsprm* for the [wcs.h](#), *celprm* for [cel.h](#), and likewise *spcprm*, *linprm*, *prjprm*, *tabprm*, and *disprm*, with struct definitions contained in the corresponding header files: [wcs.h](#), [cel.h](#), etc. The structs store the parameters that define a coordinate transformation and also intermediate values derived from those parameters. As a high-level object, the *wcsprm* struct contains *linprm*, *tabprm*, *spcprm*, and *celprm* structs, and in turn the *linprm* struct contains *disprm* structs, and the *celprm* struct contains a *prjprm* struct. Hence the *wcsprm* struct contains everything needed for a complete coordinate description.

Applications programmers who use the top- and middle-level routines generally only need to pass *wcsprm* structs from one routine that fills them to another that uses them. However, since these structs are fundamental to WCSLIB it is worthwhile knowing something about the way they work.

Three basic operations apply to all WCSLIB structs:

- Initialize. Each struct has a specific initialization routine, e.g. [wcsinit\(\)](#), [celini\(\)](#), [spcini\(\)](#), etc. These allocate memory (if required) and set all struct members to default values.
- Fill in the required values. Each struct has members whose values must be provided. For example, for *wcsprm* these values correspond to FITS WCS header keyvalues as are provided by the top-level header parsing routine, [wcspih\(\)](#).
- Compute intermediate values. Specific setup routines, e.g. [wcsset\(\)](#), [celset\(\)](#), [spcset\(\)](#), etc., compute intermediate values from the values provided. In particular, [wcsset\(\)](#) analyses the FITS WCS keyvalues provided, fills the required values in the lower-level structs contained in *wcsprm*, and invokes the setup routine for each of them.

Each struct contains a *flag* member that records its setup state. This is cleared by the initialization routine and checked by the routines that use the struct; they will invoke the setup routine automatically if necessary, hence it need not be invoked specifically by the application programmer. However, if any of the required values in a struct are changed then either the setup routine must be invoked on it, or else the *flag* must be zeroed to signal that the struct needs to be reset.

The initialization routine may be invoked repeatedly on a struct if it is desired to reuse it. However, the *flag* member of structs that contain allocated memory (*wcsprm*, *linprm*, *tabprm*, and *disprm*) must be set to -1 before the first initialization to initialize memory management, but not subsequently or else memory leaks will result.

Each struct has one or more service routines: to do deep copies from one to another, to print its contents, and to free allocated memory. Refer to the header files for a detailed description.

## 1.7 Memory management

The initialization routines for certain of the WCSLIB data structures allocate memory for some of their members:

- `wcsinit()` optionally allocates memory for the *crpix*, *pc*, *cdelt*, *crval*, *cunit*, *ctype*, *pv*, *ps*, *cd*, *crota*, *colax*, *cname*, *crder*, and *csyer* arrays in the *wcsprm* struct (using `lininit()` for certain of these). Note that `wcsinit()` does not allocate memory for the *tab* array - refer to the usage notes for `wcstab()` in `wcshdr.h`. If the *pc* matrix is not unity, `wcsset()` (via `linset()`) also allocates memory for the *piximg* and *imgpix* arrays.
- `lininit()`: optionally allocates memory for the *crpix*, *pc*, and *cdelt* arrays in the *linprm* struct. If the *pc* matrix is not unity, `linset()` also allocates memory for the *piximg* and *imgpix* arrays. Typically these would be used by `wcsinit()` and `wcsset()`.
- `tabini()`: optionally allocates memory for the *K*, *map*, *crval*, *index*, and *coord* arrays (including the arrays referenced by *index*[]) in the *tabprm* struct. `tabmem()` takes control of any of these arrays that may have been allocated by the user, specifically in that `tabfree()` will then free it. `tabset()` also allocates memory for the *sense*, *p0*, *delta* and *extrema* arrays.
- `disinit()`: optionally allocates memory for the *dtype*, *dp*, and *maxdis* arrays. `disset()` also allocates memory for a number of arrays that hold distortion parameters and intermediate values: *axmap*, *Nhat*, *offset*, *scale*, *iparm*, and *dparm*, and also several private work arrays: *disp2x*, *disx2p*, and *tmpmem*.

The caller may load data into these arrays but must not modify the struct members (i.e. the pointers) themselves or else memory leaks will result.

`wcsinit()` maintains a record of memory it has allocated and this is used by `wcsfree()` which `wcsinit()` uses to free any memory that it may have allocated on a previous invocation. Thus it is not necessary for the caller to invoke `wcsfree()` separately if `wcsinit()` is invoked repeatedly on the same *wcsprm* struct. Likewise, `wcsset()` deallocates memory that it may have allocated on a previous invocation. The same comments apply to `lininit()`, `linfree()`, and `linset()`, to `tabini()`, `tabfree()`, and `tabset()`, and to `disinit()`, `disfree()` and `disset()`.

A memory leak will result if a *wcsprm*, *linprm*, *tabprm*, or *disprm* struct goes out of scope before the memory has been *free'd*, either by the relevant routine, `wcsfree()`, `linfree()`, `tabfree()`, or `disfree()` or otherwise. Likewise, if one of these structs itself has been *malloc'd* and the allocated memory is not *free'd* when the memory for the struct is *free'd*. A leak may also arise if the caller interferes with the array pointers in the "private" part of these structs.

Beware of making a shallow copy of a *wcsprm*, *linprm*, *tabprm*, or *disprm* struct by assignment; any changes made to allocated memory in one would be reflected in the other, and if the memory allocated for one was *free'd* the other would reference unallocated memory. Use the relevant routine instead to make a deep copy: `wcssub()`, `lincpy()`, `tabcpy()`, or `discpy()`.

## 1.8 Diagnostic output

All **WCSLIB** functions return a status value, each of which is associated with a fixed error message which may be used for diagnostic output. For example

```
int status;
struct wcsprm wcs;

...

if ((status = wcsset(&wcs)) {
    fprintf(stderr, "ERROR %d from wcsset(): %s.\n", status, wcs_errmsg[status]);
    return status;
}
```

This might produce output like

```
ERROR 5 from wcsset(): Invalid parameter value.
```

The error messages are provided as global variables with names of the form *cel\_errmsg*, *prj\_errmsg*, etc. by including the relevant header file.

As of version 4.8, courtesy of Michael Droettboom ([pywcs](#)), WCSLIB has a second error messaging system which provides more detailed information about errors, including the function, source file, and line number where the error occurred. For example,

```
struct wcsprm wcs;

/* Enable wcserr and send messages to stderr. */
wcserr_enable(1);
wcsprintf_set(stderr);

...

if (wcsset(&wcs) {
    wcspperr(&wcs);
    return wcs.err->status;
}
```

In this example, if an error was generated in one of the [prjset\(\)](#) functions, [wcspperr\(\)](#) would print an error traceback starting with [wcsset\(\)](#), then [celset\(\)](#), and finally the particular projection-setting function that generated the error. For each of them it would print the status return value, function name, source file, line number, and an error message which may be more specific and informative than the general error messages reported in the first example. For example, in response to a deliberately generated error, the `twcs` test program, which tests `wcserr` among other things, produces a traceback similar to this:

```
ERROR 5 in wcsset() at line 1564 of file wcs.c:
  Invalid parameter value.
ERROR 2 in celset() at line 196 of file cel.c:
  Invalid projection parameters.
ERROR 2 in bonset() at line 5727 of file prj.c:
  Invalid parameters for Bonne's projection.
```

Each of the [structs](#) in [WCSLIB](#) includes a pointer, called *err*, to a `wcserr` struct. When an error occurs, a struct is allocated and error information stored in it. The `wcserr` pointers and the [memory](#) allocated for them are managed by the routines that manage the various structs such as [wcsinit\(\)](#) and [wcsfree\(\)](#).

`wcserr` messaging is an opt-in system enabled via [wcserr\\_enable\(\)](#), as in the example above. If enabled, when an error occurs it is the user's responsibility to free the memory allocated for the error message using [wcsfree\(\)](#), [celfree\(\)](#), [prjfree\(\)](#), etc. Failure to do so before the struct goes out of scope will result in memory leaks (if execution continues beyond the error).

## 1.9 Vector API

WCSLIB's API is vector-oriented. At the least, this allows the function call overhead to be amortised by spreading it over multiple coordinate transformations. However, vector computations may provide an opportunity for caching intermediate calculations and this can produce much more significant efficiencies. For example, many of the spherical projection equations are partially or fully separable in the mathematical sense, i.e.  $(x, y) = f(\phi)g(\theta)$ , so if  $\theta$  was invariant for a set of coordinate transformations then  $g(\theta)$  would only need to be computed once. Depending on the circumstances, this may well lead to speedups of a factor of two or more.

WCSLIB has two different categories of vector API:

- Certain steps in the WCS algorithm chain operate on coordinate vectors as a whole rather than particular elements of it. For example, the linear transformation takes one or more pixel coordinate vectors, multiplies by the transformation matrix, and returns whole intermediate world coordinate vectors.

The routines that implement these steps, `wcsp2s()`, `wcss2p()`, `linp2x()`, `linx2p()`, `tabx2s()`, `tabs2x()`, `disp2x()` and `disx2p()` accept and return two-dimensional arrays, i.e. a number of coordinate vectors. Because WCSLIB permits these arrays to contain unused elements, three parameters are needed to describe them:

- *naxis*: the number of coordinate elements, as per the FITS `NAXIS` or `WCSAXES` keyvalues,
- *ncoord*: the number of coordinate vectors,
- *nelem*: the total number of elements in each vector, unused as well as used. Clearly, *nelem* must equal or exceed *naxis*. (Note that when *ncoord* is unity, *nelem* is irrelevant and so is ignored. It may be set to 0.)

*ncoord* and *nelem* are specified as function arguments while *naxis* is provided as a member of the `wcspprm` (or `linprm` or `disprm`) struct.

For example, `wcss2p()` accepts an array of world coordinate vectors, `world[ncoord][nelem]`. In the following example, *naxis* = 4, *ncoord* = 5, and *nelem* = 7:

```
s1  x1  y1  t1  u   u   u
s2  x2  y2  t2  u   u   u
s3  x3  y3  t3  u   u   u
s4  x4  y4  t4  u   u   u
s5  x5  y5  t5  u   u   u
```

where *u* indicates unused array elements, and the array is laid out in memory as

```
s1  x1  y1  t1  u   u   u  s2  x2  y2  ...
```

**Note** that the `stat[]` vector returned by routines in this category is of length *ncoord*, as are the intermediate `phi[]` and `theta[]` vectors returned by `wcsp2s()` and `wcss2p()`.

**Note** also that the function prototypes for routines in this category have to declare these two-dimensional arrays as one-dimensional vectors in order to avoid warnings from the C compiler about declaration of "incomplete types". This was considered preferable to declaring them as simple pointers-to-double which gives no indication that storage is associated with them.

- Other steps in the WCS algorithm chain typically operate only on a part of the coordinate vector. For example, a spectral transformation operates on only one element of an intermediate world coordinate that may also contain celestial coordinate elements. In the above example, `spcx2s()` might operate only on the *s* (spectral) coordinate elements.

Routines like `spcx2s()` and `celx2s()` that implement these steps accept and return one-dimensional vectors in which the coordinate element of interest is specified via a starting address, a length, and a stride. To continue the previous example, the starting address for the spectral elements is *s1*, the length is 5, and the stride is 7.

### 1.9.1 Vector lengths

Routines such as `spcx2s()` and `celx2s()` accept and return either one coordinate vector, or a pair of coordinate vectors (one-dimensional C arrays). As explained above, the coordinate elements of interest are usually embedded in a two-dimensional array and must be selected by specifying a starting point, length and stride through the array. For routines such as `spcx2s()` that operate on a single element of each coordinate vector these parameters have a straightforward interpretation.

However, for routines such as `celx2s()` that operate on a pair of elements in each coordinate vector, WCSLIB allows these parameters to be specified independently for each input vector, thereby providing a much more general interpretation than strictly needed to traverse an array.

This is best described by illustration. The following diagram describes the situation for `celx2x()`, as a specific example, with *nlng* = 5, and *nlat* = 3:

		lng[0]	lng[1]	lng[2]	lng[3]	lng[4]
		-----	-----	-----	-----	-----
lat[0]		x, y[0]	x, y[1]	x, y[2]	x, y[3]	x, y[4]
lat[1]		x, y[5]	x, y[6]	x, y[7]	x, y[8]	x, y[9]
lat[2]		x, y[10]	x, y[11]	x, y[12]	x, y[13]	x, y[14]

In this case, while only 5 longitude elements and 3 latitude elements are specified, the world-to-pixel routine would calculate  $n\text{lng} * n\text{lat} = 15$  (x,y) coordinate pairs. It is the responsibility of the caller to ensure that sufficient space has been allocated in **all** of the output arrays, in this case *phi[]*, *theta[]*, *x[]*, *y[]* and *stat[]*.

Vector computation will often be required where neither *lng* nor *lat* is constant. This is accomplished by setting *nlat* = 0 which is interpreted to mean *nlat* = *nlng* but only the matrix diagonal is to be computed. Thus, for *nlng* = 3 and *nlat* = 0 only three (x,y) coordinate pairs are computed:

		lng[0]	lng[1]	lng[2]
		-----	-----	-----
lat[0]		x, y[0]		
lat[1]			x, y[1]	
lat[2]				x, y[2]

Note how this differs from *nlng* = 3, *nlat* = 1:

		lng[0]	lng[1]	lng[2]
		-----	-----	-----
lat[0]		x, y[0]	x, y[1]	x, y[2]

The situation for [celx2s\(\)](#) is similar; the x-coordinate (like *lng*) varies fastest.

Similar comments can be made for all routines that accept arguments specifying vector length(s) and stride(s). ([tabx2s\(\)](#) and [tabs2x\(\)](#) do not fall into this category because the `-TAB` algorithm is fully *N*-dimensional so there is no way to know in advance how many coordinate elements may be involved.)

The reason that WCSLIB allows this generality is related to the aforementioned opportunities that vector computations may provide for caching intermediate calculations and the significant efficiencies that can result. The high-level routines, [wcsp2s\(\)](#) and [wcsp2p\(\)](#), look for opportunities to collapse a set of coordinate transformations where one of the coordinate elements is invariant, and the low-level routines take advantage of such to cache intermediate calculations.

### 1.9.2 Vector strides

As explained above, the vector stride arguments allow the caller to specify that successive elements of a vector are not contiguous in memory. This applies equally to vectors given to, or returned from a function.

As a further example consider the following two arrangements in memory of the elements of four (x,y) coordinate pairs together with an *s* coordinate element (e.g. spectral):

- *x1 x2 x3 x4 y1 y2 y3 y4 s1 s2 s3 s4*  
the address of *x[]* is *x1*, its stride is 1, and length 4,  
the address of *y[]* is *y1*, its stride is 1, and length 4,  
the address of *s[]* is *s1*, its stride is 1, and length 4.
- *x1 y1 s1 x2 y2 s2 x3 y3 s3 x4 y4 s4*  
the address of *x[]* is *x1*, its stride is 3, and length 4,  
the address of *y[]* is *y1*, its stride is 3, and length 4,  
the address of *s[]* is *s1*, its stride is 3, and length 4.

For routines such as [cels2x\(\)](#), each of the pair of input vectors is assumed to have the same stride. Each of the output vectors also has the same stride, though it may differ from the input stride. For example, for [cels2x\(\)](#) the input *lng[]* and *lat[]* vectors each have vector stride *sll*, while the *x[]* and *y[]* output vectors have stride *sxy*. However, the intermediate *phi[]* and *theta[]* arrays each have unit stride, as does the *stat[]* vector.

If the vector length is 1 then the stride is irrelevant and so ignored. It may be set to 0.

## 1.10 Thread-safety

WCSLIB is thread-safe as long as the following provisos are observed:

- The WCSLIB structs - `wcsprm`, `linprm`, `disprm`, `tabprm`, `spcprm`, `celprm`, and `prjprm` - contain parameter values that must be provided by the user and intermediate values that are computed from them by the setup routines - `wcsset()`, `linset()`, `disset()`, `tabset()`, `spcset()`, `celset()`, and `prjset()`.

Once the structs have been set up they essentially become read-only objects as far as the WCSLIB routines are concerned. This must be done once and for all before threaded execution commences. Note that the setup routines themselves are not thread-safe unless the struct has been put into "bypass" mode.

Thus, if, for some reason, calls to a setup routine, for example `wcsset()`, can't be avoided during threaded execution, then the struct must be put into bypass mode. This is done by setting the flag member to 1, e.g. `wcsprm::flag = 1` (rather than 0) before calling `wcsset()`. Then, after setting up the struct, `wcsset()` will reset the flag to a special value that causes it to return immediately if reinvoked on that struct.

To take a struct out of bypass mode, simply reset the flag member to zero. This, of course, must be done during non-threaded execution. See also `wcsenq()`.

- The low-level routines `wcsnpv()`, `wcsnps()`, and `disndp()` are not thread-safe, but they are not used within WCSLIB itself other than to get (not set) the values of the global variables `NPVMAX`, `NPSMAX`, and `NDPMAX`. `wcsinit()`, `lininit`, `lindist()`, and `disinit()` only do so to get default values if the relevant parameters are not provided as function arguments. Note that `wcsini()` invokes `wcsinit()` with defaults which cause this behavior, as does `linini()` invoking `lininit()`, `lindis()` invoking `lindist()`, and `disini()` invoking `disinit()`.

The preset values of `NPVMAX`(=64), `NPSMAX`(=8), and `NDPMAX`(=256) are large enough to cover most practical cases. However, it may be desirable to tailor them to avoid allocating memory that remains unused. If so, and thread-safety is an issue, then use `wcsinit()` and `disinit()` instead with the relevant values specified. This is what WCSLIB routines, such as the header parsers `wcspih()` and `wcsbth()`, do to avoid wasting memory.

- `wcserr_enable()` sets a static variable and so is not thread-safe. However, the error reporting facility is not intended to be used dynamically. If detailed error messages are required, enable `wcserr` when execution starts and don't change it.
- The Flex scanners were made reentrant at release 5.18 and consequently should be thread-safe. This was achieved by rewriting them as thin wrappers (with the same API) over scanners that were modified (with changed API), as required to use Flex's "reentrant" option.

Note that diagnostic routines that print the contents of the various structs, namely `celprt()`, `disprt()`, `linprt()`, `prjprt()`, `spcprt()`, `tabprt()`, `wcspprt()`, and `wcsperr()` use `printf()` which is thread-safe by the POSIX requirement on `stdio`. However, this is only at the function level. Where multiple threads invoke these routines simultaneously their output is likely to be interleaved.

## 1.11 Limits

While the FITS WCS standard imposes a limit of 99 on the number of image coordinate axes, WCSLIB has a limit of 32 on the number it can handle – enforced by `wcsset()`, though allowed by `wcsinit()`. This arises in `wcsp2s()` and `wcss2p()` from the use of the `stat[]` vector as a bit mask to indicate invalid pixel or world coordinate elements.

In the unlikely event that it ever becomes necessary to handle more than 32 axes, it would be a simple matter to modify the `stat[]` bit mask so that bit 32 applies to all axes beyond 31. However, it was not considered worth introducing the various tests required just for the sake of pandering to unrealistic possibilities.

In addition, `wcssub()` has a hard-coded limit of 32 coordinate elements (matching the `stat[]` bit mask), and likewise for `tabs2p()` (via a static helper function, `tabvox()`). While it would be a simple matter to generalise this by allocating memory from the heap, since `tabvox()` calls itself recursively and needs to be as fast as possible, again it was not considered worth pandering to unrealistic possibilities.

## 1.12 Example code, testing and verification

WCSLIB has an extensive test suite that also provides programming templates as well as demonstrations. Test programs, with names that indicate the main WCSLIB routine under test, reside in `./{C,Fortran}/test` and each contains a brief description of its purpose.

The high- and middle-level test programs are more instructive for applications programming, while the low-level tests are important for verifying the integrity of the mathematical routines.

- High level:

*twcstab* provides an example of high-level applications programming using WCSLIB and [CFITSIO](#). It constructs an input FITS test file, specifically for testing TAB coordinates, partly using `wcstab.keyrec`, and then extracts the coordinate description from it following the steps outlined in [wchdr.h](#).

*tpih1* and *tpih2* verify [wcspih\(\)](#). The first prints the contents of the structs returned by [wcspih\(\)](#) using [wcsprt\(\)](#) and the second uses *cpgsbox()* to draw coordinate graticules. Input for these comes from a FITS WCS test header implemented as a list of keyrecords, `wcs.keyrec`, one keyrecord per line, together with a program, *tofits*, that compiles these into a valid FITS file.

*tbth1* tests [wcsbth\(\)](#) by reading a test header and printing the resulting `wcsprm` structs. In the process it also tests [wcsfix\(\)](#).

*tfithdr* also uses `wcs.keyrec` to test the generic FITS header parsing routine.

*twcsfix* sets up a `wcsprm` struct containing various non-standard constructs and then invokes [wcsfix\(\)](#) to translate them all to standard usage.

*twcslint* tests the syntax checker for FITS WCS keyrecords (`wcsware -l`) on a specially constructed header riddled with invalid entries.

*tdis3* uses `wcsware` to test the handling of different types of distortion functions encoded in a set of test FITS headers.

- Middle level:

*twcs* tests closure of [wcss2p\(\)](#) and [wcsp2s\(\)](#) for a number of selected projections. *twcsmix* verifies [wscsmix\(\)](#) on the 1° grid of celestial longitude and latitude for a number of selected projections. It plots a test grid for each projection and indicates the location of successful and failed solutions. *tdis2* and *twcssub* test the extraction of a coordinate description for a subimage from a `wcsprm` struct by [wcssub\(\)](#).

*tunits* tests [wcsutrne\(\)](#), [wcsunitse\(\)](#) and [wcsulexe\(\)](#), the units specification translator, converter and parser, either interactively or using a list of units specifications contained in `units_test`.

*twcscompare* tests particular aspects of the comparison routine, [wcscompare\(\)](#).

- Low level:

*tdis1*, *tlin*, *tlog*, *tpri1*, *tspc*, *tsph*, *tspc*, and *ttab1* test "closure" of the respective routines. Closure tests apply the forward and reverse transformations in sequence and compare the result with the original value. Ideally, the result should agree exactly, but because of floating point rounding errors there is usually a small discrepancy so it is only required to agree within a "closure tolerance".

*tpri1* tests for closure separately for longitude and latitude except at the poles where it only tests for closure in latitude. Note that closure in longitude does not deal with angular displacements on the sky. This is appropriate for many projections such as the cylindricals where circumpolar parallels are projected at the same length as the equator. On the other hand, *tsph* does test for closure in angular displacement.

The tolerance for reporting closure discrepancies is set at  $10^{-10}$  degree for most projections; this is slightly less than 3 microarcsec. The worst case closure figure is reported for each projection and this is usually better than the reporting tolerance by several orders of magnitude. *tpri1* and *tsph* test closure at all

points on the  $1^\circ$  grid of native longitude and latitude and to within  $5^\circ$  of any latitude of divergence for those projections that cannot represent the full sphere. Closure is also tested at a sequence of points close to the reference point (*tprj1*) or pole (*tsph*).

Closure has been verified at all test points for SUN workstations. However, non-closure may be observed for other machines near native latitude  $-90^\circ$  for the zenithal, cylindrical and conic equal area projections (**ZE**A, **CE**A and **CO**E), and near divergent latitudes of projections such as the azimuthal perspective and stereographic projections (**AZ**P and **ST**G). Rounding errors may also carry points between faces of the quad-cube projections (**C**SC, **Q**SC, and **T**SC). Although such excursions may produce long lists of non-closure points, this is not necessarily indicative of a fundamental problem.

Note that the inverse of the COBE quad-cube projection (**C**SC) is a polynomial approximation and its closure tolerance is intrinsically poor.

Although tests for closure help to verify the internal consistency of the routines they do not verify them in an absolute sense. This is partly addressed by *tcel1*, *tcel2*, *tprj2*, *ttab2* and *ttab3* which plot graticules for visual inspection of scaling, orientation, and other macroscopic characteristics of the projections.

There are also a number of other special-purpose test programs that are not automatically exercised by the test suite.

## 1.13 WCSLIB Fortran wrappers

The Fortran subdirectory contains wrappers, written in C, that allow Fortran programs to use WCSLIB. The wrappers have no associated C header files, nor C function prototypes, as they are only meant to be called by Fortran code. Hence the C code must be consulted directly to determine the argument lists. This resides in files with names of the form *\*\_f.c*. However, there are associated Fortran `INCLUDE` files that declare function return types and various parameter definitions. There are also `BLOCK DATA` modules, in files with names of the form *\*\_data.f*, used solely to initialise error message strings.

A prerequisite for using the wrappers is an understanding of the usage of the associated C routines, in particular the data structures they are based on. The principle difficulty in creating the wrappers was the need to manage these C structs from within Fortran, particularly as they contain pointers to allocated memory, pointers to C functions, and other structs that themselves contain similar entities.

To this end, routines have been provided to set and retrieve values of the various structs, for example `WCSPUT` and `WCSGET` for the `wcsprm` struct, and `CELPUT` and `CELGET` for the `celprm` struct. These must be used in conjunction with wrappers on the routines provided to manage the structs in C, for example `WCSINIT`, `WCSSUB`, `WCSCOPY`, `WCSFREE`, and `WCSVRT` which wrap `wcsinit()`, `wcssub()`, `wcscopy()`, `wcsfree()`, and `wcsprt()`.

Compilers (e.g. `gfortran`) may warn of inconsistent usage of the third argument in the various `*PUT` and `*GET` routines, and as of `gfortran 10`, these warnings have been promoted to errors. Thus, type-specific variants are provided for each of the `*PUT` routines, `*PTI`, `*PTD`, and `*PTC` for `int`, `double`, or `char[]`, and likewise `*GTI`, `*GTD`, and `*GTC` for the `*GET` routines. While, for brevity, we will here continue to refer to the `*PUT` and `*GET` routines, as compilers are generally becoming stricter, use of the type-specific variants is recommended.

The various `*PUT` and `*GET` routines are based on codes defined in Fortran include files (*\*.inc*). If your Fortran compiler does not support the `INCLUDE` statement then you will need to include these manually in your code as necessary. Codes are defined as parameters with names like `WCS_CRPIX` which refers to `wcsprm::crpix` (if your Fortran compiler does not support long symbolic names then you will need to rename these).

The include files also contain parameters, such as `WCSLEN`, that define the length of an `INTEGER` array that must be declared to hold the struct. This length may differ for different platforms depending on how the C compiler aligns data within the structs. A test program for the C library, *twcs*, prints the size of the struct in `sizeof(int)` units and the values in the Fortran include files must equal or exceed these. On some platforms, such as Suns, it is important that the start of the `INTEGER` array be **aligned on a DOUBLE PRECISION boundary**, otherwise a mysterious `BUS` error may result. This may be achieved via an `EQUIVALENCE` with a `DOUBLE PRECISION`

variable, or by sequencing variables in a COMMON block so that the INTEGER array follows immediately after a DOUBLE PRECISION variable.

The \*PUT routines set only one element of an array at a time; the final one or two integer arguments of these routines specify 1-relative array indices (N.B. not 0-relative as in C). The one exception is the `prjprm::pv` array.

The \*PUT routines also reset the *flag* element to signal that the struct needs to be reinitialized. Therefore, if you wanted to set `wcsprm::flag` itself to -1 prior to the first call to `WCSINIT`, for example, then that `WCSPUT` must be the last one before the call.

The \*GET routines retrieve whole arrays at a time and expect array arguments of the appropriate length where necessary. Note that they do not initialize the structs, i.e. via `wcsset()`, `prjset()`, or whatever.

A basic coding fragment is

```

INTEGER  LNGIDX, STATUS
CHARACTER CTYPE1*72

INCLUDE 'wcs.inc'

*   WCSLEN is defined as a parameter in wcs.inc.
INTEGER  WCS(WCSLEN)
DOUBLE PRECISION DUMMY
EQUIVALENCE (WCS, DUMMY)

*   Allocate memory and set default values for 2 axes.
STATUS = WCSPTI (WCS, WCS_FLAG, -1, 0, 0)
STATUS = WCSINI (2, WCS)

*   Set CRPIX1, and CRPIX2; WCS_CRPIX is defined in wcs.inc.
STATUS = WCSPTD (WCS, WCS_CRPIX, 512D0, 1, 0)
STATUS = WCSPTD (WCS, WCS_CRPIX, 512D0, 2, 0)

*   Set PC1_2 to 5.0 (I = 1, J = 2).
STATUS = WCSPTD (WCS, WCS_PC, 5D0, 1, 2)

*   Set CTYPE1 to 'RA---SIN'; N.B. must be given as CHARACTER*72.
CTYPE1 = 'RA---SIN'
STATUS = WCSPTC (WCS, WCS_CTYPE, CTYPE1, 1, 0)

*   Use an alternate method to set CTYPE2.
STATUS = WCSPTC (WCS, WCS_CTYPE, 'DEC--SIN'//CHAR(0), 2, 0)

*   Set PV1_3 to -1.0 (I = 1, M = 3).
STATUS = WCSPTD (WCS, WCS_PV, -1D0, 1, 3)

etc.

*   Initialize.
STATUS = WCSSET (WCS)
IF (STATUS.NE.0) THEN
    CALL FLUSH (6)
    STATUS = WCSPERR (WCS, 'EXAMPLE: ' //CHAR(0))
ENDIF

*   Find the "longitude" axis.
STATUS = WCSGTI (WCS, WCS_LNG, LNGIDX)

*   Free memory.
STATUS = WCSFREE (WCS)

```

Refer to the various Fortran test programs for further programming examples. In particular, *twcs* and *twcsmix* show how to retrieve elements of the `celprm` and `prjprm` structs contained within the `wcsprm` struct.

Treatment of CHARACTER arguments in wrappers such as `SPCTYPE`, `SPECX`, and `WCSSPTR`, depends on whether they are given or returned. Where a CHARACTER variable is returned, its length must match the declared length in the definition of the C wrapper. The terminating null character in the C string, and all following it up

to the declared length, are replaced with blanks. If the Fortran `CHARACTER` variable were shorter than the declared length, an out-of-bounds memory access error would result. If longer, the excess, uninitialized, characters could contain garbage.

If the `CHARACTER` argument is given, a null-terminated `CHARACTER` variable may be provided as input, e.g. constructed using the Fortran `CHAR(0)` intrinsic as in the example code above. The wrapper makes a character-by-character copy, searching for a NULL character in the process. If it finds one, the copy terminates early, resulting in a valid C string. In this case any trailing blanks before the NULL character are preserved if it makes sense to do so, such as in setting a prefix for use by the `*PERR` wrappers, such as `WCSPERR` in the example above. If a NULL is not found, then the `CHARACTER` argument must be at least as long as the declared length, and any trailing blanks are stripped off. Should a `CHARACTER` argument exceed the declared length, the excess characters are ignored.

There is one exception to the above caution regarding `CHARACTER` arguments. The `WCSLIB_VERSION` wrapper is unusual in that it provides for the length of its `CHARACTER` argument to be specified, and only so many characters as fit within that length are returned.

Note that the data type of the third argument to the `*PUT` (or `*PTI`, `*PTD`, or `*PTC`) and `*GET` (or `*GTI`, `*GTD`, or `*GTC`) routines differs depending on the data type of the corresponding C struct member, be it *int*, *double*, or *char[]*. It is essential that the Fortran data type match that of the C struct for *int* and *double* types, and be a `CHARACTER` variable of the correct length for *char[]* types, or else be null-terminated, as in the coding example above. As a further example, in the two equivalent calls

```
STATUS = PRJGET (PRJ, PRJ_NAME, NAME)
STATUS = PRJGTC (PRJ, PRJ_NAME, NAME)
```

which return a character string, `NAME` must be a `CHARACTER` variable of length 40, as declared in the `prjprm` struct, no less and no more, the comments above pertaining to wrappers that contain `CHARACTER` arguments also applying here. However, a few exceptions have been made to simplify coding. The relevant `*PUT` (or `*PTC`) wrappers allow unterminated `CHARACTER` variables of less than the declared length for the following: `prjprm::code` (3 characters), `spcprm::type` (4 characters), `spcprm::code` (3 characters), and `fitskeyid::name` (8 characters). It doesn't hurt to specify longer `CHARACTER` variables, but the trailing characters will be ignored. Notwithstanding this simplification, the length of the corresponding variables in the `*GET` (or `*GTC`) wrappers must match the length declared in the struct.

When calling wrappers for C functions that print to *stdout*, such as `WCSPRT`, and `WCSPERR`, or that may print to *stderr*, such as `WCSPH`, `WCSBTH`, `WCSULEXE`, or `WCSUTRNE`, it may be necessary to flush the Fortran I/O buffers beforehand so that the output appears in the correct order. The wrappers for these functions do call `fflush` ( $\leftrightarrow$  NULL), but depending on the particular system, this may not succeed in flushing the Fortran I/O buffers. Most Fortran compilers provide the non-standard intrinsic `FLUSH()`, which is called with unit number 6 to flush *stdout* (as in the example above), and unit 0 for *stderr*.

A basic assumption made by the wrappers is that an `INTEGER` variable is no less than half the size of a `DOUBLE PRECISION`.

## 1.14 PGSBOX

`PGSBOX`, which is provided as a separate part of `WCSLIB`, is a `PGPLOT` routine (`PGPLOT` being a Fortran graphics library) that draws and labels curvilinear coordinate grids. Example `PGSBOX` grids can be seen at <http://www.atnf.csiro.au/people/Mark.Calabretta/WCS/PGSBOX/index.html>.

The prologue to `pgsbox.f` contains usage instructions. `pgtest.f` and `cpgtest.c` serve as test and demonstration programs in Fortran and C and also as well- documented examples of usage.

`PGSBOX` requires a separate routine, `EXTERNAL NLFUNC`, to define the coordinate transformation. Fortran sub-routine `PGCRFN` (`pgcrfn.f`) is provided to define separable pairs of non-linear coordinate systems. Linear, logarithmic

and power-law axis types are currently defined; further types may be added as required. A C function, *pgwcsl\_()*, with Fortran-like interface defines an `NLFUNC` that interfaces to WCSLIB 4.x for PGSBOX to draw celestial coordinate grids.

PGPLOT is implemented as a Fortran library with a set of C wrapper routines that are generated by a software tool. However, PGSBOX has a more complicated interface than any of the standard PGPLOT routines, especially in having an `EXTERNAL` function in its argument list. Consequently, PGSBOX is implemented in Fortran but with a hand-coded C wrapper, *cpgsbox()*.

As an example, in this suite the C test/demo program, *cpgtest*, calls the C wrapper, *cpgsbox()*, passing it a pointer to *pgwcsl\_()*. In turn, *cpgsbox()* calls PGSBOX, which invokes *pgwcsl\_()* as an `EXTERNAL` subroutine. In this sequence, a complicated C struct defined by *cpgtest* is passed through PGSBOX to *pgwcsl\_()* as an `INTEGER` array.

While there are no formal standards for calling Fortran from C, there are some fairly well established conventions. Nevertheless, it's possible that you may need to modify the code if you use a combination of Fortran and C compilers with linkage conventions that differ from that of the GNU compilers, gcc and g77.

## 1.15 WCSLIB version numbers

The full WCSLIB/PGSBOX version number is composed of three integers in fields separated by periods:

- **Major:** the first number changes only when the ABI changes, a rare occurrence (and the API never changes). Typically, the ABI changes when the contents of a struct change. For example, the contents of the *linprm* struct changed between 4.25.1 and 5.0.

In practical terms, this number becomes the major version number of the WCSLIB sharable library, **libwcs.so.<major>**. To avoid possible segmentation faults or bus errors that may arise from the altered ABI, the dynamic (runtime) linker will not allow an application linked to a sharable library with a particular major version number to run with that of a different major version number.

Application code must be recompiled and relinked to use a newer version of the WCSLIB sharable library with a new major version number.

- **Minor:** the second number changes when existing code is changed, whether due to added functionality or bug fixes. This becomes the minor version number of the WCSLIB sharable library, **libwcs.so.<major>.<minor>**.

Because the ABI remains unchanged, older applications can use the new sharable library without needing to be recompiled, thus obtaining the benefit of bug fixes, speed enhancements, etc.

Application code written subsequently to use the added functionality would, of course, need to be recompiled.

- **Patch:** the third number, which is often omitted, indicates a change to the build procedures, documentation, or test suite. It may also indicate changes to the utility applications (*wcsware*, *HPXcvt*, etc.), including the addition of new ones.

However, the library itself, including the definitions in the header files, remains unaltered, so there is no point in recompiling applications.

The following describes what happens (or should happen) when WCSLIB's installation procedures are used on a typical Linux system using the GNU gcc compiler and GNU linker.

The sharable library should be installed as **libwcs.so.<major>.<minor>**, say **libwcs.so.5.4** for concreteness, and a number of symbolic links created as follows:

```
libwcs.so      -> libwcs.so.5
libwcs.so.5    -> libwcs.so.5.4
libwcs.so.5.4
```

When an application is linked using '-lwcs', the linker finds libwcs.so and the symlinks lead it to libwcs.so.5.4. However, that library's SONAME is actually 'libwcs.so.5', by virtue of linker options used when the sharable library was created, as can be seen by running

```
readelf -d libwcs.so.5.4
```

Thus, when an application that was compiled and linked to libwcs.so.5.4 begins execution, the dynamic linker, ld.so, will attempt to bind it to libwcs.so.5, as can be seen by running

```
ldd <application>
```

Later, when WCSLIB 5.5 is installed, the library symbolic links will become

```
libwcs.so      -> libwcs.so.5
libwcs.so.5    -> libwcs.so.5.5
libwcs.so.5.4
libwcs.so.5.5
```

Thus, even without being recompiled, existing applications will link automatically to libwcs.so.5.5 at runtime. In fact, libwcs.so.5.4 would no longer be used and could be deleted.

If WCSLIB 6.0 were to be installed at some later time, then the libwcs.so.6 libraries would be used for new compilations. However, the libwcs.so.5 libraries must be left in place for existing executables that still require them:

```
libwcs.so      -> libwcs.so.6
libwcs.so.6    -> libwcs.so.6.0
libwcs.so.6.0
libwcs.so.5    -> libwcs.so.5.5
libwcs.so.5.5
```

## 2 Deprecated List

### Global [celini\\_errmsg](#)

Added for backwards compatibility, use [cel\\_errmsg](#) directly now instead.

### Global [celprt\\_errmsg](#)

Added for backwards compatibility, use [cel\\_errmsg](#) directly now instead.

### Global [cels2x\\_errmsg](#)

Added for backwards compatibility, use [cel\\_errmsg](#) directly now instead.

### Global [celset\\_errmsg](#)

Added for backwards compatibility, use [cel\\_errmsg](#) directly now instead.

### Global [celx2s\\_errmsg](#)

Added for backwards compatibility, use [cel\\_errmsg](#) directly now instead.

### Global [cylfix\\_errmsg](#)

Added for backwards compatibility, use [wcsfix\\_errmsg](#) directly now instead.

**Global [FITSHDR\\_CARD](#)**

Added for backwards compatibility, use [FITSHDR\\_KEYREC](#) instead.

**Global [lincpy\\_errmsg](#)**

Added for backwards compatibility, use [lin\\_errmsg](#) directly now instead.

**Global [linfree\\_errmsg](#)**

Added for backwards compatibility, use [lin\\_errmsg](#) directly now instead.

**Global [linini\\_errmsg](#)**

Added for backwards compatibility, use [lin\\_errmsg](#) directly now instead.

**Global [linp2x\\_errmsg](#)**

Added for backwards compatibility, use [lin\\_errmsg](#) directly now instead.

**Global [linprt\\_errmsg](#)**

Added for backwards compatibility, use [lin\\_errmsg](#) directly now instead.

**Global [linset\\_errmsg](#)**

Added for backwards compatibility, use [lin\\_errmsg](#) directly now instead.

**Global [linx2p\\_errmsg](#)**

Added for backwards compatibility, use [lin\\_errmsg](#) directly now instead.

**Global [prjini\\_errmsg](#)**

Added for backwards compatibility, use [prj\\_errmsg](#) directly now instead.

**Global [prjpri\\_errmsg](#)**

Added for backwards compatibility, use [prj\\_errmsg](#) directly now instead.

**Global [prjs2x\\_errmsg](#)**

Added for backwards compatibility, use [prj\\_errmsg](#) directly now instead.

**Global [prjset\\_errmsg](#)**

Added for backwards compatibility, use [prj\\_errmsg](#) directly now instead.

**Global [prjx2s\\_errmsg](#)**

Added for backwards compatibility, use [prj\\_errmsg](#) directly now instead.

**Global [spcini\\_errmsg](#)**

Added for backwards compatibility, use [spc\\_errmsg](#) directly now instead.

**Global [spcpri\\_errmsg](#)**

Added for backwards compatibility, use [spc\\_errmsg](#) directly now instead.

**Global [spcs2x\\_errmsg](#)**

Added for backwards compatibility, use [spc\\_errmsg](#) directly now instead.

**Global [spcset\\_errmsg](#)**

Added for backwards compatibility, use [spc\\_errmsg](#) directly now instead.

**Global [spcx2s\\_errmsg](#)**

Added for backwards compatibility, use [spc\\_errmsg](#) directly now instead.

**Global [tabcpy\\_errmsg](#)**

Added for backwards compatibility, use [tab\\_errmsg](#) directly now instead.

**Global [tabfree\\_errmsg](#)**

Added for backwards compatibility, use [tab\\_errmsg](#) directly now instead.

**Global [tabini\\_errmsg](#)**

Added for backwards compatibility, use [tab\\_errmsg](#) directly now instead.

**Global [tabprt\\_errmsg](#)**

Added for backwards compatibility, use [tab\\_errmsg](#) directly now instead.

**Global [tabs2x\\_errmsg](#)**

Added for backwards compatibility, use [tab\\_errmsg](#) directly now instead.

**Global [tabset\\_errmsg](#)**

Added for backwards compatibility, use [tab\\_errmsg](#) directly now instead.

**Global [tabx2s\\_errmsg](#)**

Added for backwards compatibility, use [tab\\_errmsg](#) directly now instead.

**Global [wcscopy\\_errmsg](#)**

Added for backwards compatibility, use [wcs\\_errmsg](#) directly now instead.

**Global [wcsfree\\_errmsg](#)**

Added for backwards compatibility, use [wcs\\_errmsg](#) directly now instead.

**Global [wcsini\\_errmsg](#)**

Added for backwards compatibility, use [wcs\\_errmsg](#) directly now instead.

**Global [wcsmix\\_errmsg](#)**

Added for backwards compatibility, use [wcs\\_errmsg](#) directly now instead.

**Global [wcsp2s\\_errmsg](#)**

Added for backwards compatibility, use [wcs\\_errmsg](#) directly now instead.

**Global [wcsprt\\_errmsg](#)**

Added for backwards compatibility, use [wcs\\_errmsg](#) directly now instead.

**Global [wcsp2p\\_errmsg](#)**

Added for backwards compatibility, use [wcs\\_errmsg](#) directly now instead.

**Global [wcsset\\_errmsg](#)**

Added for backwards compatibility, use [wcs\\_errmsg](#) directly now instead.

**Global [wcsub\\_errmsg](#)**

Added for backwards compatibility, use [wcs\\_errmsg](#) directly now instead.

## 3 Directory Hierarchy

### 3.1 Directories

<b>C</b>	<b>24</b>
<b>cel.h</b>	<b>95</b>
<b>dis.h</b>	<b>111</b>
<b>fitshdr.h</b>	<b>142</b>
<b>getwcstab.h</b>	<b>152</b>
<b>lin.h</b>	<b>156</b>
<b>log.h</b>	<b>179</b>
<b>prj.h</b>	<b>184</b>
<b>spc.h</b>	<b>232</b>
<b>sph.h</b>	<b>260</b>
<b>spx.h</b>	<b>268</b>
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<b>wcshdr.h</b>	<b>387</b>
<b>wcsmath.h</b>	<b>432</b>
<b>wcsprintf.h</b>	<b>434</b>
<b>wcstrig.h</b>	<b>439</b>
<b>wcsunits.h</b>	<b>446</b>
<b>wcsutil.h</b>	<b>462</b>
<b>wtbarr.h</b>	<b>478</b>

## 4 Data Structure Index

### 4.1 Data Structures

Here are the data structures with brief descriptions:

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<b>disprm</b>	Distortion parameters	30
<b>dpkey</b>	Store for DPja and DQia keyvalues	35
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## 5 File Index

### 5.1 File List

Here is a list of all files with brief descriptions:

<a href="#">cel.h</a>	95
<a href="#">dis.h</a>	111
<a href="#">fitshdr.h</a>	142
<a href="#">getwcstab.h</a>	152
<a href="#">lin.h</a>	156
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<a href="#">spc.h</a>	232
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<a href="#">wcsutil.h</a>	462
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## 6 Directory Documentation

### 6.1 C Directory Reference

#### Files

- file [cel.h](#)
- file [dis.h](#)
- file [fitshdr.h](#)
- file [getwcstab.h](#)
- file [lin.h](#)
- file [log.h](#)
- file [prj.h](#)
- file [spc.h](#)

- file [sph.h](#)
- file [spx.h](#)
- file [tab.h](#)
- file [wcs.h](#)
- file [wcserr.h](#)
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- file [wcsmath.h](#)
- file [wcsprintf.h](#)
- file [wcstrig.h](#)
- file [wcsunits.h](#)
- file [wcsutil.h](#)
- file [wtbarr.h](#)

## 7 Data Structure Documentation

### 7.1 auxprm Struct Reference

Additional auxiliary parameters.

```
#include <wcs.h>
```

#### Data Fields

- double [rsun\\_ref](#)
- double [dsun\\_obs](#)
- double [crln\\_obs](#)
- double [hgl\\_n\\_obs](#)
- double [hgt\\_obs](#)
- double [a\\_radius](#)
- double [b\\_radius](#)
- double [c\\_radius](#)
- double [blon\\_obs](#)
- double [blat\\_obs](#)
- double [bdis\\_obs](#)
- double [dummy](#) [2]

#### 7.1.1 Detailed Description

Additional auxiliary parameters.

The **auxprm** struct holds auxiliary coordinate system information of a specialist nature. It is anticipated that this struct will expand in future to accomodate additional parameters.

All members of this struct are to be set by the user.

### 7.1.2 Field Documentation

#### **rsun\_ref**

```
double auxprm::rsun_ref
```

(Given, auxiliary) Reference radius of the Sun used in coordinate calculations (m).

#### **dsun\_obs**

```
double auxprm::dsun_obs
```

(Given, auxiliary) Distance between the centre of the Sun and the observer (m).

#### **crln\_obs**

```
double auxprm::crln_obs
```

(Given, auxiliary) Carrington heliographic longitude of the observer (deg).

#### **hgln\_obs**

```
double auxprm::hgln_obs
```

(Given, auxiliary) Stonyhurst heliographic longitude of the observer (deg).

#### **hglt\_obs**

```
double auxprm::hglt_obs
```

(Given, auxiliary) Heliographic latitude (Carrington or Stonyhurst) of the observer (deg).

#### **a\_radius**

```
double auxprm::a_radius
```

Length of the semi-major axis of a triaxial ellipsoid approximating the shape of a body (e.g. planet) in the solar system (m).

#### **b\_radius**

```
double auxprm::b_radius
```

Length of the intermediate axis, normal to the semi-major and semi-minor axes, of a triaxial ellipsoid approximating the shape of a body (m).

**c\_radius**

```
double auxprm::c_radius
```

Length of the semi-minor axis, normal to the semi-major axis, of a triaxial ellipsoid approximating the shape of a body (m).

**blon\_obs**

```
double auxprm::blon_obs
```

Bodycentric longitude of the observer in the coordinate system fixed to the planet or other solar system body (deg, in range 0 to 360).

**blat\_obs**

```
double auxprm::blat_obs
```

Bodycentric latitude of the observer in the coordinate system fixed to the planet or other solar system body (deg).

**bdis\_obs**

```
double auxprm::bdis_obs
```

Bodycentric distance of the observer (m).

**dummy**

```
double auxprm::dummy[2]
```

**7.2 celprm Struct Reference**

Celestial transformation parameters.

```
#include <cel.h>
```

**Data Fields**

- int [flag](#)
- int [offset](#)
- double [phi0](#)
- double [theta0](#)
- double [ref](#) [4]
- struct [prjprm](#) [prj](#)
- double [euler](#) [5]
- int [latpreq](#)
- int [isolat](#)
- struct [wcserr](#) \* [err](#)
- void \* [padding](#)

### 7.2.1 Detailed Description

Celestial transformation parameters.

The **celprm** struct contains information required to transform celestial coordinates. It consists of certain members that must be set by the user (*given*) and others that are set by the WCSLIB routines (*returned*). Some of the latter are supplied for informational purposes and others are for internal use only.

Returned **celprm** struct members must not be modified by the user.

### 7.2.2 Field Documentation

#### flag

```
int celprm::flag
```

(Given and returned) This flag must be set to zero (or 1, see [celset\(\)](#)) whenever any of the following **celprm** struct members are set or changed:

- [celprm::offset](#),
- [celprm::phi0](#),
- [celprm::theta0](#),
- [celprm::ref\[4\]](#),
- [celprm::prj](#):
  - [prjprm::code](#),
  - [prjprm::r0](#),
  - [prjprm::pv\[\]](#),
  - [prjprm::phi0](#),
  - [prjprm::theta0](#).

This signals the initialization routine, [celset\(\)](#), to recompute the returned members of the **celprm** struct. [celset\(\)](#) will reset flag to indicate that this has been done.

#### offset

```
int celprm::offset
```

(Given) If true (non-zero), an offset will be applied to  $(x, y)$  to force  $(x, y) = (0, 0)$  at the fiducial point,  $(\phi_0, \theta_0)$ . Default is 0 (false).

#### phi0

```
double celprm::phi0
```

(Given) The native longitude,  $\phi_0$  [deg], and ...

**theta0**

```
double celprm::theta0
```

(Given) ... the native latitude,  $\theta_0$  [deg], of the fiducial point, i.e. the point whose celestial coordinates are given in `celprm::ref[1:2]`. If undefined (set to a magic value by `prjini()`) the initialization routine, `celset()`, will set this to a projection-specific default.

**ref**

```
double celprm::ref[4]
```

(Given) The first pair of values should be set to the celestial longitude and latitude of the fiducial point [deg] - typically right ascension and declination. These are given by the **CRVAL<sub>i</sub>a** keywords in FITS.

(Given and returned) The second pair of values are the native longitude,  $\phi_p$  [deg], and latitude,  $\theta_p$  [deg], of the celestial pole (the latter is the same as the celestial latitude of the native pole,  $\delta_p$ ) and these are given by the FITS keywords **LONPOLE<sub>a</sub>** and **LATPOLE<sub>a</sub>** (or by **PV<sub>i</sub>\_2a** and **PV<sub>i</sub>\_3a** attached to the longitude axis which take precedence if defined).

**LONPOLE<sub>a</sub>** defaults to  $\phi_0$  (see above) if the celestial latitude of the fiducial point of the projection is greater than or equal to the native latitude, otherwise  $\phi_0 + 180$  [deg]. (This is the condition for the celestial latitude to increase in the same direction as the native latitude at the fiducial point.) `ref[2]` may be set to **UNDEFINED** (from `wcsmath.h`) or 999.0 to indicate that the correct default should be substituted.

$\theta_p$ , the native latitude of the celestial pole (or equally the celestial latitude of the native pole,  $\delta_p$ ) is often determined uniquely by **CRVAL<sub>i</sub>a** and **LONPOLE<sub>a</sub>** in which case **LATPOLE<sub>a</sub>** is ignored. However, in some circumstances there are two valid solutions for  $\theta_p$  and **LATPOLE<sub>a</sub>** is used to choose between them. **LATPOLE<sub>a</sub>** is set in `ref[3]` and the solution closest to this value is used to reset `ref[3]`. It is therefore legitimate, for example, to set `ref[3]` to +90.0 to choose the more northerly solution - the default if the **LATPOLE<sub>a</sub>** keyword is omitted from the FITS header. For the special case where the fiducial point of the projection is at native latitude zero, its celestial latitude is zero, and **LONPOLE<sub>a</sub>** =  $\pm 90.0$  then the celestial latitude of the native pole is not determined by the first three reference values and **LATPOLE<sub>a</sub>** specifies it completely.

The returned value, `celprm::latpreq`, specifies how **LATPOLE<sub>a</sub>** was actually used.

**prj**

```
struct prjprm celprm::prj
```

(Given and returned) Projection parameters described in the prologue to `prj.h`.

**euler**

```
double celprm::euler[5]
```

(Returned) Euler angles and associated intermediaries derived from the coordinate reference values. The first three values are the  $Z$ -,  $X$ -, and  $Z'$ -Euler angles [deg], and the remaining two are the cosine and sine of the  $X$ -Euler angle.

**latpreq**

```
int celprm::latpreq
```

(*Returned*) For informational purposes, this indicates how the **LATPOLE<sub>a</sub>** keyword was used

- 0: Not required,  $\theta_p$  ( $= \delta_p$ ) was determined uniquely by the **CRVAL<sub>ia</sub>** and **LONPOLE<sub>a</sub>** keywords.
- 1: Required to select between two valid solutions of  $\theta_p$ .
- 2:  $\theta_p$  was specified solely by **LATPOLE<sub>a</sub>**.

**isolat**

```
int celprm::isolat
```

(*Returned*) True if the spherical rotation preserves the magnitude of the latitude, which occurs iff the axes of the native and celestial coordinates are coincident. It signals an opportunity to cache intermediate calculations common to all elements in a vector computation.

**err**

```
struct wcserr* celprm::err
```

(*Returned*) If enabled, when an error status is returned, this struct contains detailed information about the error, see [wcserr\\_enable\(\)](#).

**padding**

```
void* celprm::padding
```

(An unused variable inserted for alignment purposes only.)

## 7.3 disprm Struct Reference

Distortion parameters.

```
#include <dis.h>
```

**Data Fields**

- int [flag](#)
- int [naxis](#)
- char(\* [dtype](#) )[72]
- int [ndp](#)
- int [ndpmax](#)
- struct [dpkey](#) \* [dp](#)
- double [totdis](#)
- double \* [maxdis](#)
- int \* [docorr](#)
- int \* [Nhat](#)
- int \*\* [axmap](#)
- double \*\* [offset](#)
- double \*\* [scale](#)
- int \*\* [iparm](#)
- double \*\* [dparm](#)
- int [i\\_naxis](#)
- int [ndis](#)
- struct [wcserr](#) \* [err](#)
- int(\*\* [disp2x](#) )(DISP2X\_ARGS)
- int(\*\* [disx2p](#) )(DISX2P\_ARGS)
- int [m\\_flag](#)
- int [m\\_naxis](#)
- char(\* [m\\_dtype](#) )[72]
- struct [dpkey](#) \* [m\\_dp](#)
- double \* [m\\_maxdis](#)

**7.3.1 Detailed Description**

Distortion parameters.

The **disprm** struct contains all of the information required to apply a set of distortion functions. It consists of certain members that must be set by the user (*given*) and others that are set by the WCSLIB routines (*returned*). While the addresses of the arrays themselves may be set by [disinit\(\)](#) if it (optionally) allocates memory, their contents must be set by the user.

**7.3.2 Field Documentation****flag**

```
int disprm::flag
```

(Given and returned) This flag must be set to zero (or 1, see [disset\(\)](#)) whenever any of the following **disprm** members are set or changed:

- [disprm::naxis](#),
- [disprm::dtype](#),
- [disprm::ndp](#),
- [disprm::dp](#).

This signals the initialization routine, [disset\(\)](#), to recompute the returned members of the **disprm** struct. [disset\(\)](#) will reset flag to indicate that this has been done.

**PLEASE NOTE:** flag must be set to -1 when [disinit\(\)](#) is called for the first time for a particular **disprm** struct in order to initialize memory management. It must ONLY be used on the first initialization otherwise memory leaks may result.

**naxis**

```
int disprm::naxis
```

(Given or returned) Number of pixel and world coordinate elements.

If [disinit\(\)](#) is used to initialize the **disprm** struct (as would normally be the case) then it will set naxis from the value passed to it as a function argument. The user should not subsequently modify it.

**dtype**

```
char(* disprm::dtype)[72]
```

(Given) Pointer to the first element of an array of char[72] containing the name of the distortion function for each axis.

**ndp**

```
int disprm::ndp
```

(Given) The number of entries in the [disprm::dp\[\]](#) array.

**ndpmax**

```
int disprm::ndpmax
```

(Given) The length of the [disprm::dp\[\]](#) array.

ndpmax will be set by [disinit\(\)](#) if it allocates memory for [disprm::dp\[\]](#), otherwise it must be set by the user. See also [disndp\(\)](#).

**dp**

```
struct dpkey* disprm::dp
```

(Given) Address of the first element of an array of length ndpmax of dpkey structs.

As a FITS header parser encounters each **DP<sub>ja</sub>** or **DQ<sub>ia</sub>** keyword it should load it into a dpkey struct in the array and increment ndp. However, note that a single **disprm** struct must hold only **DP<sub>ja</sub>** or **DQ<sub>ia</sub>** keyvalues, not both. [disset\(\)](#) interprets them as required by the particular distortion function.

**totdis**

```
double disprm::totdis
```

(Given) The maximum absolute value of the combination of all distortion functions specified as an offset in pixel coordinates computed over the whole image.

It is not necessary to reset the **disprm** struct (via [disset\(\)](#)) when [disprm::totdis](#) is changed.

**maxdis**

```
double* disprm::maxdis
```

(*Given*) Pointer to the first element of an array of double specifying the maximum absolute value of the distortion for each axis computed over the whole image.

It is not necessary to reset the **disprm** struct (via `disset()`) when `disprm::maxdis` is changed.

**docorr**

```
int* disprm::docorr
```

(*Returned*) Pointer to the first element of an array of int containing flags that indicate the mode of correction for each axis.

If docorr is zero, the distortion function returns the corrected coordinates directly. Any other value indicates that the distortion function computes a correction to be added to pixel coordinates (prior distortion) or intermediate pixel coordinates (sequent distortion).

**Nhat**

```
int* disprm::Nhat
```

(*Returned*) Pointer to the first element of an array of int containing the number of coordinate axes that form the independent variables of the distortion function for each axis.

**axmap**

```
int** disprm::axmap
```

(*Returned*) Pointer to the first element of an array of int\* containing pointers to the first elements of the axis mapping arrays for each axis.

An axis mapping associates the independent variables of a distortion function with the 0-relative image axis number. For example, consider an image with a spectrum on the first axis (axis 0), followed by RA (axis 1), Dec (axis2), and time (axis 3) axes. For a distortion in (RA,Dec) and no distortion on the spectral or time axes, the axis mapping arrays, `axmap[j][]`, would be

```
j=0: [-1, -1, -1, -1] ...no distortion on spectral axis,
1: [ 1,  2, -1, -1] ...RA distortion depends on RA and Dec,
2: [ 2,  1, -1, -1] ...Dec distortion depends on Dec and RA,
3: [-1, -1, -1, -1] ...no distortion on time axis,
```

where -1 indicates that there is no corresponding independent variable.

**offset**

```
double** disprm::offset
```

(*Returned*) Pointer to the first element of an array of double\* containing pointers to the first elements of arrays of offsets used to renormalize the independent variables of the distortion function for each axis.

The offsets are subtracted from the independent variables before scaling.

**scale**

```
double** disprm::scale
```

(*Returned*) Pointer to the first element of an array of double\* containing pointers to the first elements of arrays of scales used to renormalize the independent variables of the distortion function for each axis.

The scale is applied to the independent variables after the offsets are subtracted.

**iparm**

```
int** disprm::iparm
```

(*Returned*) Pointer to the first element of an array of int\* containing pointers to the first elements of the arrays of integer distortion parameters for each axis.

**dparm**

```
double** disprm::dparm
```

(*Returned*) Pointer to the first element of an array of double\* containing pointers to the first elements of the arrays of floating point distortion parameters for each axis.

**i\_naxis**

```
int disprm::i_naxis
```

(*Returned*) Dimension of the internal arrays (normally equal to naxis).

**ndis**

```
int disprm::ndis
```

(*Returned*) The number of distortion functions.

**err**

```
struct wcserr* disprm::err
```

(*Returned*) If enabled, when an error status is returned, this struct contains detailed information about the error, see [wcserr\\_enable\(\)](#).

**disp2x**

```
int (** disprm::disp2x) (DISP2X_ARGS)
```

(For internal use only.)

**disx2p**

```
int (** disprm::disx2p) (DISX2P_ARGS)
```

(For internal use only.)

**m\_flag**

```
int disprm::m_flag
```

(For internal use only.)

**m\_naxis**

```
int disprm::m_naxis
```

(For internal use only.)

**m\_dtype**

```
char (* disprm::m_dtype) [72]
```

(For internal use only.)

**m\_dp**

```
struct dpkey* disprm::m_dp
```

(For internal use only.)

**m\_maxdis**

```
double* disprm::m_maxdis
```

(For internal use only.)

## 7.4 dpkey Struct Reference

Store for **DP**<sub>ja</sub> and **DQ**<sub>ia</sub> keyvalues.

```
#include <dis.h>
```

## Data Fields

- char `field` [72]
- int `j`
- int `type`
- union {
  - int `i`
  - double `f`
- } `value`

### 7.4.1 Detailed Description

Store for `DPja` and `DQia` keyvalues.

The `dpkey` struct is used to pass the parsed contents of `DPja` or `DQia` keyrecords to `disset()` via the `disprm` struct. A `disprm` struct must hold only `DPja` or `DQia` keyvalues, not both.

All members of this struct are to be set by the user.

### 7.4.2 Field Documentation

#### `field`

```
char dpkey::field[72]
```

(*Given*) The full field name of the record, including the keyword name. Note that the colon delimiter separating the field name and the value in record-valued keyvalues is not part of the field name. For example, in the following:

```
DP3A = 'AXIS.1: 2'
```

the full record field name is "`DP3A.AXIS.1`", and the record's value is 2.

#### `j`

```
int dpkey::j
```

(*Given*) Axis number (1-relative), i.e. the `j` in `DPja` or `i` in `DQia`.

#### `type`

```
int dpkey::type
```

(*Given*) The data type of the record's value

- 0: Integer (stored as an int),
- 1: Floating point (stored as a double).

**i**`int dpkey::i`**f**`double dpkey::f`**[union]**`union { ... } dpkey::value`*(Given)* A union comprised of

- `dpkey::i`,
- `dpkey::f`,

the record's value.

## 7.5 fitskey Struct Reference

Keyword/value information.

`#include <fitshdr.h>`

### Data Fields

- int `keyno`
- int `keyid`
- int `status`
- char `keyword` [12]
- int `type`
- int `padding`
- union {
  - int `i`
  - int64 `k`
  - int `l` [8]
  - double `f`
  - double `c` [2]
  - char `s` [72]
 } `keyvalue`
- int `ulen`
- char `comment` [84]

### 7.5.1 Detailed Description

Keyword/value information.

`fitshdr()` returns an array of **fitskey** structs, each of which contains the result of parsing one FITS header keyrecord. All members of the **fitskey** struct are returned by `fitshdr()`, none are given by the user.

### 7.5.2 Field Documentation

#### keyno

```
int fitskey::keyno
```

*(Returned)* Keyrecord number (1-relative) in the array passed as input to `fitshdr()`. This will be negated if the keyword matched any specified in the `keyids[]` index.

#### keyid

```
int fitskey::keyid
```

*(Returned)* Index into the first entry in `keyids[]` with which the keyrecord matches, else -1.

#### status

```
int fitskey::status
```

*(Returned)* Status flag bit-vector for the header keyrecord employing the following bit masks defined as preprocessor macros:

- `FITSHDR_KEYWORD`: Illegal keyword syntax.
- `FITSHDR_KEYVALUE`: Illegal keyvalue syntax.
- `FITSHDR_COMMENT`: Illegal keycomment syntax.
- `FITSHDR_KEYREC`: Illegal keyrecord, e.g. an **END** keyrecord with trailing text.
- `FITSHDR_TRAILER`: Keyrecord following a valid **END** keyrecord.

The header keyrecord is syntactically correct if no bits are set.

#### keyword

```
char fitskey::keyword[12]
```

*(Returned)* Keyword name, null-filled for keywords of less than eight characters (trailing blanks replaced by nulls).

Use

```
sprintf(dst, "%.8s", keyword)
```

to copy it to a character array with null-termination, or

```
sprintf(dst, "%8.8s", keyword)
```

to blank-fill to eight characters followed by null-termination.

**type**

```
int fitskey::type
```

(Returned) Keyvalue data type:

- 0: No keyvalue (both the value and type are undefined).
- 1: Logical, represented as int.
- 2: 32-bit signed integer.
- 3: 64-bit signed integer (see below).
- 4: Very long integer (see below).
- 5: Floating point (stored as double).
- 6: Integer complex (stored as double[2]).
- 7: Floating point complex (stored as double[2]).
- 8: String.
- 8+10\*n: Continued string (described below and in [fitshdr\(\)](#) note 2).

A negative type indicates that a syntax error was encountered when attempting to parse a keyvalue of the particular type.

Comments on particular data types:

- 64-bit signed integers lie in the range

```
(-9223372036854775808 <= int64 < -2147483648) ||
(+2147483647 < int64 <= +9223372036854775807)
```

A native 64-bit data type may be defined via preprocessor macro WCSLIB\_INT64 defined in wcsconfig.h, e.g. as 'long long int'; this will be typedef'd to 'int64' here. If WCSLIB\_INT64 is not set, then [int64](#) is typedef'd to [int\[3\]](#) instead and [fitskey::keyvalue](#) is to be computed as

```
((keyvalue.k[2]) * 1000000000 +
 keyvalue.k[1]) * 1000000000 +
 keyvalue.k[0]
```

and may reported via

```
if (keyvalue.k[2]) {
    printf("%d%09d%09d", keyvalue.k[2], abs(keyvalue.k[1]),
           abs(keyvalue.k[0]));
} else {
    printf("%d%09d", keyvalue.k[1], abs(keyvalue.k[0]));
}
```

where `keyvalue.k[0]` and `keyvalue.k[1]` range from -999999999 to +999999999.

- Very long integers, up to 70 decimal digits in length, are encoded in `keyvalue.l` as an array of `int[8]`, each of which stores 9 decimal digits. [fitskey::keyvalue](#) is to be computed as

```
(((((keyvalue.l[7]) * 1000000000 +
 keyvalue.l[6]) * 1000000000 +
 keyvalue.l[5]) * 1000000000 +
 keyvalue.l[4]) * 1000000000 +
 keyvalue.l[3]) * 1000000000 +
 keyvalue.l[2]) * 1000000000 +
 keyvalue.l[1]) * 1000000000 +
 keyvalue.l[0]
```

- Continued strings are not reconstructed, they remain split over successive **fitskey** structs in the `keys[]` array returned by [fitshdr\(\)](#). [fitskey::keyvalue](#) data type, 8 + 10n, indicates the segment number, n, in the continuation.

**padding**

```
int fitskey::padding
```

(An unused variable inserted for alignment purposes only.)

**i**

```
int fitskey::i
```

(*Returned*) Logical ([fitskey::type == 1](#)) and 32-bit signed integer ([fitskey::type == 2](#)) data types in the [fitskey::keyvalue](#) union.

**k**

```
int64 fitskey::k
```

(*Returned*) 64-bit signed integer ([fitskey::type == 3](#)) data type in the [fitskey::keyvalue](#) union.

**l**

```
int fitskey::l[8]
```

(*Returned*) Very long integer ([fitskey::type == 4](#)) data type in the [fitskey::keyvalue](#) union.

**f**

```
double fitskey::f
```

(*Returned*) Floating point ([fitskey::type == 5](#)) data type in the [fitskey::keyvalue](#) union.

**c**

```
double fitskey::c[2]
```

(*Returned*) Integer and floating point complex ([fitskey::type == 6 || 7](#)) data types in the [fitskey::keyvalue](#) union.

**s**

```
char fitskey::s[72]
```

(*Returned*) Null-terminated string ([fitskey::type == 8](#)) data type in the [fitskey::keyvalue](#) union.

**[union]**

```
union { ... } fitskey::keyvalue
```

(*Returned*) A union comprised of

- `fitskey::i`,
- `fitskey::k`,
- `fitskey::l`,
- `fitskey::f`,
- `fitskey::c`,
- `fitskey::s`,

used by the **fitskey** struct to contain the value associated with a keyword.

**ulen**

```
int fitskey::ulen
```

(*Returned*) Where a keycomment contains a units string in the standard form, e.g. [m/s], the ulen member indicates its length, inclusive of square brackets. Otherwise ulen is zero.

**comment**

```
char fitskey::comment[84]
```

(*Returned*) Keycomment, i.e. comment associated with the keyword or, for keyrecords rejected because of syntax errors, the complete keyrecord itself with null-termination.

Comments are null-terminated with trailing spaces removed. Leading spaces are also removed from keycomments (i.e. those immediately following the '/' character), but not from **COMMENT** or **HISTORY** keyrecords or keyrecords without a value indicator ("= " in columns 9-80).

## 7.6 fitskeyid Struct Reference

Keyword indexing.

```
#include <fitshdr.h>
```

**Data Fields**

- char `name` [12]
- int `count`
- int `idx` [2]

### 7.6.1 Detailed Description

Keyword indexing.

`fitshdr()` uses the `fitskeyid` struct to return indexing information for specified keywords. The struct contains three members, the first of which, `fitskeyid::name`, must be set by the user with the remainder returned by `fitshdr()`.

### 7.6.2 Field Documentation

#### **name**

```
char fitskeyid::name[12]
```

(*Given*) Name of the required keyword. This is to be set by the user; the '.' character may be used for wildcarding. Trailing blanks will be replaced with nulls.

#### **count**

```
int fitskeyid::count
```

(*Returned*) The number of matches found for the keyword.

#### **idx**

```
int fitskeyid::idx[2]
```

(*Returned*) Indices into `keys[]`, the array of `fitskey` structs returned by `fitshdr()`. Note that these are 0-relative array indices, not keyrecord numbers.

If the keyword is found in the header the first index will be set to the array index of its first occurrence, otherwise it will be set to -1.

If multiples of the keyword are found, the second index will be set to the array index of its last occurrence, otherwise it will be set to -1.

## 7.7 linprm Struct Reference

Linear transformation parameters.

```
#include <lin.h>
```

**Data Fields**

- int [flag](#)
- int [naxis](#)
- double \* [crpix](#)
- double \* [pc](#)
- double \* [cdelt](#)
- struct [disprm](#) \* [dispre](#)
- struct [disprm](#) \* [disseq](#)
- double \* [piximg](#)
- double \* [imgpix](#)
- int [i\\_naxis](#)
- int [unity](#)
- int [affine](#)
- int [simple](#)
- struct [wcserr](#) \* [err](#)
- double \* [dummy](#)
- int [m\\_flag](#)
- int [m\\_naxis](#)
- double \* [m\\_crpix](#)
- double \* [m\\_pc](#)
- double \* [m\\_cdelt](#)
- struct [disprm](#) \* [m\\_dispre](#)
- struct [disprm](#) \* [m\\_disseq](#)

**7.7.1 Detailed Description**

Linear transformation parameters.

The **linprm** struct contains all of the information required to perform a linear transformation. It consists of certain members that must be set by the user (*given*) and others that are set by the WCSLIB routines (*returned*).

**7.7.2 Field Documentation****flag**

```
int linprm::flag
```

(Given and returned) This flag must be set to zero (or 1, see [linset\(\)](#)) whenever any of the following **linprm** members are set or changed:

- [linprm::naxis](#) (q.v., not normally set by the user),
- [linprm::pc](#),
- [linprm::cdelt](#),
- [linprm::dispre](#).
- [linprm::disseq](#).

This signals the initialization routine, [linset\(\)](#), to recompute the returned members of the **linprm** struct. [linset\(\)](#) will reset flag to indicate that this has been done.

**PLEASE NOTE:** flag should be set to -1 when [lininit\(\)](#) is called for the first time for a particular **linprm** struct in order to initialize memory management. It must ONLY be used on the first initialization otherwise memory leaks may result.

**naxis**

```
int linprm::naxis
```

(Given or returned) Number of pixel and world coordinate elements.

If `lininit()` is used to initialize the `linprm` struct (as would normally be the case) then it will set `naxis` from the value passed to it as a function argument. The user should not subsequently modify it.

**crpix**

```
double* linprm::crpix
```

(Given) Pointer to the first element of an array of double containing the coordinate reference pixel, **CRPIX**<sub>*j*a</sub>.

It is not necessary to reset the `linprm` struct (via `linset()`) when `linprm::crpix` is changed.

**pc**

```
double* linprm::pc
```

(Given) Pointer to the first element of the **PC**<sub>*i*\_\_j</sub><sub>a</sub> (pixel coordinate) transformation matrix. The expected order is

```
struct linprm lin;  
lin.pc = {PC1_1, PC1_2, PC2_1, PC2_2};
```

This may be constructed conveniently from a 2-D array via

```
double m[2][2] = {{PC1_1, PC1_2},  
                  {PC2_1, PC2_2}};
```

which is equivalent to

```
double m[2][2];  
m[0][0] = PC1_1;  
m[0][1] = PC1_2;  
m[1][0] = PC2_1;  
m[1][1] = PC2_2;
```

The storage order for this 2-D array is the same as for the 1-D array, whence

```
lin.pc = *m;
```

would be legitimate.

**cdelt**

```
double* linprm::cdelt
```

(Given) Pointer to the first element of an array of double containing the coordinate increments, **CDELTA**<sub>*i*a</sub>.

**dispre**

```
struct disprm* linprm::dispre
```

(Given) Pointer to a **disprm** struct holding parameters for prior distortion functions, or a null (0x0) pointer if there are none.

Function **lindist()** may be used to assign a **disprm** pointer to a **linprm** struct, allowing it to take control of any memory allocated for it, as in the following example:

```
void add_distortion(struct linprm *lin)
{
    struct disprm *dispre;

    dispre = malloc(sizeof(struct disprm));
    dispre->flag = -1;
    lindist(1, lin, dispre, ndpmax);
    :
    (Set up dispre.)
    :

    return;
}
```

Here, after the distortion function parameters etc. are copied into **dispre**, **dispre** is assigned using **lindist()** which takes control of the allocated memory. It will be freed later when **linfree()** is invoked on the **linprm** struct.

Consider also the following erroneous code:

```
void bad_code(struct linprm *lin)
{
    struct disprm dispre;

    dispre.flag = -1;
    lindist(1, lin, &dispre, ndpmax); // WRONG.
    :

    return;
}
```

Here, **dispre** is declared as a struct, rather than a pointer. When the function returns, **dispre** will go out of scope and its memory will most likely be reused, thereby trashing its contents. Later, a segfault will occur when **linfree()** tries to free **dispre**'s stale address.

**disseq**

```
struct disprm* linprm::disseq
```

(Given) Pointer to a **disprm** struct holding parameters for sequent distortion functions, or a null (0x0) pointer if there are none.

Refer to the comments and examples given for **disprm::dispre**.

**piximg**

```
double* linprm::piximg
```

(Returned) Pointer to the first element of the matrix containing the product of the **CDELTA** diagonal matrix and the **PCi\_ja** matrix.

**imgpix**

```
double* linprm::imgpix
```

(*Returned*) Pointer to the first element of the inverse of the [linprm::piximg](#) matrix.

**i\_naxis**

```
int linprm::i_naxis
```

(*Returned*) The dimension of [linprm::piximg](#) and [linprm::imgpix](#) (normally equal to naxis).

**unity**

```
int linprm::unity
```

(*Returned*) True if the linear transformation matrix is unity.

**affine**

```
int linprm::affine
```

(*Returned*) True if there are no distortions.

**simple**

```
int linprm::simple
```

(*Returned*) True if unity and no distortions.

**err**

```
struct wcserr* linprm::err
```

(*Returned*) If enabled, when an error status is returned, this struct contains detailed information about the error, see [wcserr\\_enable\(\)](#).

**dummy**

```
double* linprm::dummy
```

(For internal use only.)

**m\_flag**

```
int linprm::m_flag
```

(For internal use only.)

**m\_naxis**

```
int linprm::m_naxis
```

(For internal use only.)

**m\_crpix**

```
double* linprm::m_crpix
```

(For internal use only.)

**m\_pc**

```
double * linprm::m_pc
```

(For internal use only.)

**m\_cdelt**

```
double * linprm::m_cdelt
```

(For internal use only.)

**m\_dispre**

```
struct disprm* linprm::m_dispre
```

(For internal use only.)

**m\_disseq**

```
struct disprm * linprm::m_disseq
```

(For internal use only.)

## 7.8 prjprm Struct Reference

Projection parameters.

```
#include <prj.h>
```

## Data Fields

- int [flag](#)
- char [code](#) [4]
- double [r0](#)
- double [pv](#) [PVN]
- double [phi0](#)
- double [theta0](#)
- int [bounds](#)
- char [name](#) [40]
- int [category](#)
- int [pvrage](#)
- int [simplezen](#)
- int [equiareal](#)
- int [conformal](#)
- int [global](#)
- int [divergent](#)
- double [x0](#)
- double [y0](#)
- struct [wcserr](#) \* [err](#)
- void \* [padding](#)
- double [w](#) [10]
- int [m](#)
- int [n](#)
- int(\* [prjx2s](#) )(PRJX2S\_ARGS)
- int(\* [prjs2x](#) )(PRJS2X\_ARGS)

### 7.8.1 Detailed Description

Projection parameters.

The **prjprm** struct contains all information needed to project or deproject native spherical coordinates. It consists of certain members that must be set by the user (*given*) and others that are set by the WCSLIB routines (*returned*). Some of the latter are supplied for informational purposes while others are for internal use only.

### 7.8.2 Field Documentation

#### **flag**

```
int prjprm::flag
```

(Given and returned) This flag must be set to zero (or 1, see [prjset\(\)](#)) whenever any of the following **prjprm** members are set or changed:

- [prjprm::code](#),
- [prjprm::r0](#),
- [prjprm::pv](#)[],
- [prjprm::phi0](#),
- [prjprm::theta0](#).

This signals the initialization routine ([prjset\(\)](#) or [???set\(\)](#)) to recompute the returned members of the **prjprm** struct. flag will then be reset to indicate that this has been done.

Note that flag need not be reset when [prjprm::bounds](#) is changed.

**code**

```
char prjprm::code[4]
```

(Given) Three-letter projection code defined by the FITS standard.

**r0**

```
double prjprm::r0
```

(Given) The radius of the generating sphere for the projection, a linear scaling parameter. If this is zero, it will be reset to its default value of  $180^\circ/\pi$  (the value for FITS WCS).

**pv**

```
double prjprm::pv[PVN]
```

(Given) Projection parameters. These correspond to the **PV*i*\_ma** keywords in FITS, so pv[0] is **PV*i*\_0a**, pv[1] is **PV*i*\_1a**, etc., where *i* denotes the latitude-like axis. Many projections use pv[1] (**PV*i*\_1a**), some also use pv[2] (**PV*i*\_2a**) and **SZP** uses pv[3] (**PV*i*\_3a**). **ZPN** is currently the only projection that uses any of the others.

Usage of the pv[] array as it applies to each projection is described in the prologue to each trio of projection routines in prj.c.

**phi0**

```
double prjprm::phi0
```

(Given) The native longitude,  $\phi_0$  [deg], and ...

**theta0**

```
double prjprm::theta0
```

(Given) ... the native latitude,  $\theta_0$  [deg], of the reference point, i.e. the point  $(x, y) = (0, 0)$ . If undefined (set to a magic value by [prjini\(\)](#)) the initialization routine will set this to a projection-specific default.

**bounds**

```
int prjprm::bounds
```

(Given) Controls bounds checking. If bounds&1 then enable strict bounds checking for the spherical-to-Cartesian (s2x) transformation for the **AZP**, **SZP**, **TAN**, **SIN**, **ZPN**, and **COP** projections. If bounds&2 then enable strict bounds checking for the Cartesian-to-spherical transformation (x2s) for the **HPX** and **XPX** projections. If bounds&4 then the Cartesian- to-spherical transformations (x2s) will invoke [prjbchk\(\)](#) to perform bounds checking on the computed native coordinates, with a tolerance set to suit each projection. bounds is set to 7 by [prjini\(\)](#) by default which enables all checks. Zero it to disable all checking.

It is not necessary to reset the **prjprm** struct (via [prjset\(\)](#) or [???set\(\)](#)) when [prjprm::bounds](#) is changed.

The remaining members of the **prjprm** struct are maintained by the setup routines and must not be modified elsewhere:

**name**

```
char prjprm::name[40]
```

*(Returned)* Long name of the projection.

Provided for information only, not used by the projection routines.

**category**

```
int prjprm::category
```

*(Returned)* Projection category matching the value of the relevant global variable:

- ZENITHAL,
- CYLINDRICAL,
- PSEUDOCYLINDRICAL,
- CONVENTIONAL,
- CONIC,
- POLYCONIC,
- QUADCUBE, and
- HEALPIX.

The category name may be identified via the `prj_categories` character array, e.g.

```
struct prjprm prj;  
...  
printf("%s\n", prj_categories[prj.category]);
```

Provided for information only, not used by the projection routines.

**pvrage**

```
int prjprm::pvrage
```

*(Returned)* Range of projection parameter indices: 100 times the first allowed index plus the number of parameters, e.g. **TAN** is 0 (no parameters), **SZP** is 103 (1 to 3), and **ZPN** is 30 (0 to 29).

Provided for information only, not used by the projection routines.

**simplezen**

```
int prjprm::simplezen
```

*(Returned)* True if the projection is a radially-symmetric zenithal projection.

Provided for information only, not used by the projection routines.

**equiareal**

```
int prjprm::equiareal
```

*(Returned)* True if the projection is equal area.

Provided for information only, not used by the projection routines.

**conformal**

```
int prjprm::conformal
```

*(Returned)* True if the projection is conformal.

Provided for information only, not used by the projection routines.

**global**

```
int prjprm::global
```

*(Returned)* True if the projection can represent the whole sphere in a finite, non-overlapped mapping.

Provided for information only, not used by the projection routines.

**divergent**

```
int prjprm::divergent
```

*(Returned)* True if the projection diverges in latitude.

Provided for information only, not used by the projection routines.

**x0**

```
double prjprm::x0
```

*(Returned)* The offset in  $x$ , and ...

**y0**

```
double prjprm::y0
```

*(Returned)* ... the offset in  $y$  used to force  $(x, y) = (0, 0)$  at  $(\phi_0, \theta_0)$ .

**err**

```
struct wcserr* prjprm::err
```

(*Returned*) If enabled, when an error status is returned, this struct contains detailed information about the error, see [wcserr\\_enable\(\)](#).

**padding**

```
void* prjprm::padding
```

(An unused variable inserted for alignment purposes only.)

**w**

```
double prjprm::w[10]
```

(For internal use only.) Intermediate floating-point values derived from the projection parameters by [prjset\(\)](#), cached here to save recomputation.

Usage of the `w[]` array as it applies to each projection is described in the prologue to each trio of projection routines in `prj.c`.

**m**

```
int prjprm::m
```

(See next ...) (For internal use only.) Intermediate integer values set by [prjset\(\)](#) (used only for the **ZPN** and **HPX** projections).

**n**

```
int prjprm::n
```

**prjx2s**

```
int (* prjprm::prjx2s) (PRJX2S_ARGS)
```

(For internal use only.) Pointer to the spherical projection ...

**prjs2x**

```
int (* prjprm::prjs2x) (PRJS2X_ARGS)
```

(For internal use only.) ... and deprojection routines.

## 7.9 pscard Struct Reference

Store for **PSi\_ma** keyrecords.

```
#include <wcs.h>
```

### Data Fields

- int **i**
- int **m**
- char **value** [72]

#### 7.9.1 Detailed Description

Store for **PSi\_ma** keyrecords.

The **pscard** struct is used to pass the parsed contents of **PSi\_ma** keyrecords to [wcsset\(\)](#) via the **wcsprm** struct.

All members of this struct are to be set by the user.

#### 7.9.2 Field Documentation

**i**

```
int pscard::i
```

(*Given*) Axis number (1-relative), as in the FITS **PSi\_ma** keyword.

**m**

```
int pscard::m
```

(*Given*) Parameter number (non-negative), as in the FITS **PSi\_ma** keyword.

**value**

```
char pscard::value[72]
```

(*Given*) Parameter value.

## 7.10 pvcard Struct Reference

Store for **PVi\_ma** keyrecords.

```
#include <wcs.h>
```

## Data Fields

- int *i*
- int *m*
- double *value*

### 7.10.1 Detailed Description

Store for **PV***i\_ma* keyrecords.

The **pvc**ard struct is used to pass the parsed contents of **PV***i\_ma* keyrecords to [wcsset\(\)](#) via the **wcsprm** struct.

All members of this struct are to be set by the user.

### 7.10.2 Field Documentation

**i**

```
int pvcard::i
```

(*Given*) Axis number (1-relative), as in the FITS **PV***i\_ma* keyword. If *i* == 0, [wcsset\(\)](#) will replace it with the latitude axis number.

**m**

```
int pvcard::m
```

(*Given*) Parameter number (non-negative), as in the FITS **PV***i\_ma* keyword.

**value**

```
double pvcard::value
```

(*Given*) Parameter value.

## 7.11 spcprm Struct Reference

Spectral transformation parameters.

```
#include <spc.h>
```

**Data Fields**

- int [flag](#)
- char [type](#) [8]
- char [code](#) [4]
- double [crval](#)
- double [restfrq](#)
- double [restwav](#)
- double [pv](#) [7]
- double [w](#) [6]
- int [isGrism](#)
- int [padding1](#)
- struct [wcserr](#) \* [err](#)
- void \* [padding2](#)
- int(\* [spxX2P](#) )(SPX\_ARGS)
- int(\* [spxP2S](#) )(SPX\_ARGS)
- int(\* [spxS2P](#) )(SPX\_ARGS)
- int(\* [spxP2X](#) )(SPX\_ARGS)

**7.11.1 Detailed Description**

Spectral transformation parameters.

The **spcprm** struct contains information required to transform spectral coordinates. It consists of certain members that must be set by the user (*given*) and others that are set by the WCSLIB routines (*returned*). Some of the latter are supplied for informational purposes while others are for internal use only.

**7.11.2 Field Documentation****flag**

```
int spcprm::flag
```

(Given and returned) This flag must be set to zero (or 1, see [spcset\(\)](#)) whenever any of the following **spcprm** members are set or changed:

- [spcprm::type](#),
- [spcprm::code](#),
- [spcprm::crval](#),
- [spcprm::restfrq](#),
- [spcprm::restwav](#),
- [spcprm::pv\[\]](#).

This signals the initialization routine, [spcset\(\)](#), to recompute the returned members of the **spcprm** struct. [spcset\(\)](#) will reset flag to indicate that this has been done.

**type**

```
char spcprm::type[8]
```

(Given) Four-letter spectral variable type, e.g "ZOPT" for **CTYPE<sub>ia</sub>** = 'ZOPT-F2W'. (Declared as char[8] for alignment reasons.)

**code**

```
char spcprm::code[4]
```

(Given) Three-letter spectral algorithm code, e.g "F2W" for **CTYPE<sub>ia</sub>** = 'ZOPT-F2W'.

**crval**

```
double spcprm::crval
```

(Given) Reference value (**CRVAL<sub>ia</sub>**), SI units.

**restfrq**

```
double spcprm::restfrq
```

(Given) The rest frequency [Hz], and ...

**restwav**

```
double spcprm::restwav
```

(Given) ... the rest wavelength in vacuo [m], only one of which need be given, the other should be set to zero. Neither are required if the  $X$  and  $S$  spectral variables are both wave-characteristic, or both velocity-characteristic, types.

**pv**

```
double spcprm::pv[7]
```

(Given) Grism parameters for 'GRI' and 'GRA' algorithm codes:

- 0:  $G$ , grating ruling density.
- 1:  $m$ , interference order.
- 2:  $\alpha$ , angle of incidence [deg].
- 3:  $n_r$ , refractive index at the reference wavelength,  $\lambda_r$ .
- 4:  $n'_r$ ,  $dn/d\lambda$  at the reference wavelength,  $\lambda_r$  (/m).
- 5:  $\epsilon$ , grating tilt angle [deg].
- 6:  $\theta$ , detector tilt angle [deg].

The remaining members of the **spcprm** struct are maintained by [spcset\(\)](#) and must not be modified elsewhere:

**w**

```
double spcprm::w[6]
```

(*Returned*) Intermediate values:

- 0: Rest frequency or wavelength (SI).
- 1: The value of the  $X$ -type spectral variable at the reference point (SI units).
- 2:  $dX/dS$  at the reference point (SI units).

The remainder are grism intermediates.

**isGrism**

```
int spcprm::isGrism
```

(*Returned*) Grism coordinates?

- 0: no,
- 1: in vacuum,
- 2: in air.

**padding1**

```
int spcprm::padding1
```

(An unused variable inserted for alignment purposes only.)

**err**

```
struct wcserr* spcprm::err
```

(*Returned*) If enabled, when an error status is returned, this struct contains detailed information about the error, see [wcserr\\_enable\(\)](#).

**padding2**

```
void* spcprm::padding2
```

(An unused variable inserted for alignment purposes only.)

**spxX2P**

```
int (* spcprm::spxX2P) (SPX_ARGS)
```

(For internal use only) The first and ...

**spxP2S**

```
int (* spcprm::spxP2S) (SPX_ARGS)
```

(For internal use only) ... the second of the pointers to the transformation functions in the two-step algorithm chain  $X \rightsquigarrow P \rightarrow S$  in the pixel-to-spectral direction where the non-linear transformation is from  $X$  to  $P$ . The argument list, SPX\_ARGS, is defined in [spx.h](#).

**spxS2P**

```
int (* spcprm::spxS2P) (SPX_ARGS)
```

(For internal use only) The first and ...

**spxP2X**

```
int (* spcprm::spxP2X) (SPX_ARGS)
```

(For internal use only) ... the second of the pointers to the transformation functions in the two-step algorithm chain  $S \rightarrow P \rightsquigarrow X$  in the spectral-to-pixel direction where the non-linear transformation is from  $P$  to  $X$ . The argument list, SPX\_ARGS, is defined in [spx.h](#).

## 7.12 spxprm Struct Reference

Spectral variables and their derivatives.

```
#include <spx.h>
```

**Data Fields**

- double [restfrq](#)
- double [restwav](#)
- int [wavetype](#)
- int [velotype](#)
- double [freq](#)
- double [afrq](#)
- double [ener](#)
- double [wavn](#)
- double [vrad](#)
- double [wave](#)
- double [vopt](#)
- double [zopt](#)
- double [awav](#)
- double [velo](#)
- double [beta](#)
- double [dfreqafrq](#)
- double [dafrqfreq](#)
- double [dfreqener](#)
- double [denerrfreq](#)
- double [dfreqwavn](#)

- double [dwavnfreq](#)
- double [dfreqvrad](#)
- double [dvradfreq](#)
- double [dfreqwave](#)
- double [dwavefreq](#)
- double [dfreqawav](#)
- double [dawavfreq](#)
- double [dfreqvelo](#)
- double [dvelofreq](#)
- double [dwavevopt](#)
- double [dvoptwave](#)
- double [dwavezopt](#)
- double [dzoptwave](#)
- double [dwaveawav](#)
- double [dawavwave](#)
- double [dwavevelo](#)
- double [dvelowave](#)
- double [dawavvelo](#)
- double [dveloawav](#)
- double [dvelobeta](#)
- double [dbetavelo](#)
- struct [wcserr](#) \* [err](#)
- void \* [padding](#)

### 7.12.1 Detailed Description

Spectral variables and their derivatives.

The **spxprm** struct contains the value of all spectral variables and their derivatives. It is used solely by [specx\(\)](#) which constructs it from information provided via its function arguments.

This struct should be considered read-only, no members need ever be set nor should ever be modified by the user.

### 7.12.2 Field Documentation

#### restfrq

```
double spxprm::restfrq
```

(*Returned*) Rest frequency [Hz].

#### restwav

```
double spxprm::restwav
```

(*Returned*) Rest wavelength [m].

**wavetype**

```
int spxprm::wavetype
```

(Returned) True if wave types have been computed, and ...

**velotype**

```
int spxprm::velotype
```

(Returned) ... true if velocity types have been computed; types are defined below.

If one or other of [spxprm::restfrq](#) and [spxprm::restwav](#) is given (non-zero) then all spectral variables may be computed. If both are given, restfrq is used. If restfrq and restwav are both zero, only wave characteristic xor velocity type spectral variables may be computed depending on the variable given. These flags indicate what is available.

**freq**

```
double spxprm::freq
```

(Returned) Frequency [Hz] (*wavetype*).

**afrq**

```
double spxprm::afrq
```

(Returned) Angular frequency [rad/s] (*wavetype*).

**ener**

```
double spxprm::ener
```

(Returned) Photon energy [J] (*wavetype*).

**wavn**

```
double spxprm::wavn
```

(Returned) Wave number [1/m] (*wavetype*).

**vrad**

```
double spxprm::vrad
```

(Returned) Radio velocity [m/s] (*velotype*).

**wave**

```
double spxprm::wave
```

(Returned) Vacuum wavelength [m] (*wavetype*).

**vopt**

```
double spxprm::vopt
```

(Returned) Optical velocity [m/s] (*velotype*).

**zopt**

```
double spxprm::zopt
```

(Returned) Redshift [dimensionless] (*velotype*).

**awav**

```
double spxprm::awav
```

(Returned) Air wavelength [m] (*wavetype*).

**velo**

```
double spxprm::velo
```

(Returned) Relativistic velocity [m/s] (*velotype*).

**beta**

```
double spxprm::beta
```

(Returned) Relativistic beta [dimensionless] (*velotype*).

**dfreqafrq**

```
double spxprm::dfreqafrq
```

(Returned) Derivative of frequency with respect to angular frequency [rad] (constant, =  $1/2\pi$ ), and ...

**dafrqfreq**

```
double spxprm::dafrqfreq
```

(Returned) ... vice versa [rad] (constant, =  $2\pi$ , always available).

**dfreqener**

```
double spxprm::dfreqener
```

(Returned) Derivative of frequency with respect to photon energy [J/s] (constant, =  $1/h$ ), and ...

**denerfreq**

```
double spxprm::denerfreq
```

(Returned) ... vice versa [Js] (constant, =  $h$ , Planck's constant, always available).

**dfreqwavn**

```
double spxprm::dfreqwavn
```

(Returned) Derivative of frequency with respect to wave number [m/s] (constant, =  $c$ , the speed of light in vacuo), and ...

**dwavnfreq**

```
double spxprm::dwavnfreq
```

(Returned) ... vice versa [s/m] (constant, =  $1/c$ , always available).

**dfreqvrad**

```
double spxprm::dfreqvrad
```

(Returned) Derivative of frequency with respect to radio velocity [/m], and ...

**dvradfreq**

```
double spxprm::dvradfreq
```

(Returned) ... vice versa [m] (*wavetype* && *velotype*).

**dfreqwave**

```
double spxprm::dfreqwave
```

(Returned) Derivative of frequency with respect to vacuum wavelength [/m/s], and ...

**dwavefreq**

```
double spxprm::dwavefreq
```

(Returned) ... vice versa [m s] (wavetype).

**dfreqawav**

```
double spxprm::dfreqawav
```

(Returned) Derivative of frequency with respect to air wavelength, [m/s], and ...

**dawavfreq**

```
double spxprm::dawavfreq
```

(Returned) ... vice versa [m s] (wavetype).

**dfreqvelo**

```
double spxprm::dfreqvelo
```

(Returned) Derivative of frequency with respect to relativistic velocity [m], and ...

**dvelofreq**

```
double spxprm::dvelofreq
```

(Returned) ... vice versa [m] (wavetype && velotype).

**dwavevopt**

```
double spxprm::dwavevopt
```

(Returned) Derivative of vacuum wavelength with respect to optical velocity [s], and ...

**dvoptwave**

```
double spxprm::dvoptwave
```

(Returned) ... vice versa [s] (wavetype && velotype).

**dwavezopt**

```
double spxprm::dwavezopt
```

(Returned) Derivative of vacuum wavelength with respect to redshift [m], and ...

**dzoptwave**

```
double spxprm::dzoptwave
```

(Returned) ... vice versa [m] (*wavetype* && *velotype*).

**dwaveawav**

```
double spxprm::dwaveawav
```

(Returned) Derivative of vacuum wavelength with respect to air wavelength [dimensionless], and ...

**dawavwave**

```
double spxprm::dawavwave
```

(Returned) ... vice versa [dimensionless] (*wavetype*).

**dwavevelo**

```
double spxprm::dwavevelo
```

(Returned) Derivative of vacuum wavelength with respect to relativistic velocity [s], and ...

**dvelowave**

```
double spxprm::dvelowave
```

(Returned) ... vice versa [s] (*wavetype* && *velotype*).

**dawavvelo**

```
double spxprm::dawavvelo
```

(Returned) Derivative of air wavelength with respect to relativistic velocity [s], and ...

**dveloawav**

```
double spxprm::dveloawav
```

(Returned) ... vice versa [s] (*wavetype* && *velotype*).

**dvelobeta**

```
double spxprm::dvelobeta
```

(Returned) Derivative of relativistic velocity with respect to relativistic beta [m/s] (constant, =  $c$ , the speed of light in vacuo), and ...

**dbetavelo**

```
double spxprm::dbetavelo
```

(Returned) ... vice versa [s/m] (constant, =  $1/c$ , always available).

**err**

```
struct wcserr* spxprm::err
```

(Returned) If enabled, when an error status is returned, this struct contains detailed information about the error, see [wcserr\\_enable\(\)](#).

**padding**

```
void* spxprm::padding
```

(An unused variable inserted for alignment purposes only.)

**7.13 tabprm Struct Reference**

Tabular transformation parameters.

```
#include <tab.h>
```

**Data Fields**

- int [flag](#)
- int [M](#)
- int \* [K](#)
- int \* [map](#)
- double \* [crval](#)
- double \*\* [index](#)
- double \* [coord](#)
- int [nc](#)
- int [padding](#)
- int \* [sense](#)
- int \* [p0](#)
- double \* [delta](#)
- double \* [extrema](#)
- struct [wcserr](#) \* [err](#)
- int [m\\_flag](#)
- int [m\\_M](#)
- int [m\\_N](#)
- int [set\\_M](#)
- int \* [m\\_K](#)
- int \* [m\\_map](#)
- double \* [m\\_crval](#)
- double \*\* [m\\_index](#)
- double \*\* [m\\_indxs](#)
- double \* [m\\_coord](#)

### 7.13.1 Detailed Description

Tabular transformation parameters.

The **tabprm** struct contains information required to transform tabular coordinates. It consists of certain members that must be set by the user (*given*) and others that are set by the WCSLIB routines (*returned*). Some of the latter are supplied for informational purposes while others are for internal use only.

### 7.13.2 Field Documentation

#### flag

```
int tabprm::flag
```

(Given and returned) This flag must be set to zero (or 1, see [tabset\(\)](#)) whenever any of the following **tabprm** members are set or changed:

- [tabprm::M](#) (q.v., not normally set by the user),
- [tabprm::K](#) (q.v., not normally set by the user),
- [tabprm::map](#),
- [tabprm::crval](#),
- [tabprm::index](#),
- [tabprm::coord](#).

This signals the initialization routine, [tabset\(\)](#), to recompute the returned members of the **tabprm** struct. [tabset\(\)](#) will reset flag to indicate that this has been done.

**PLEASE NOTE:** flag should be set to -1 when [tabini\(\)](#) is called for the first time for a particular **tabprm** struct in order to initialize memory management. It must ONLY be used on the first initialization otherwise memory leaks may result.

#### M

```
int tabprm::M
```

(Given or returned) Number of tabular coordinate axes.

If [tabini\(\)](#) is used to initialize the **tabprm** struct (as would normally be the case) then it will set M from the value passed to it as a function argument. The user should not subsequently modify it.

#### K

```
int* tabprm::K
```

(Given or returned) Pointer to the first element of a vector of length [tabprm::M](#) whose elements  $(K_1, K_2, \dots, K_M)$  record the lengths of the axes of the coordinate array and of each indexing vector.

If [tabini\(\)](#) is used to initialize the **tabprm** struct (as would normally be the case) then it will set K from the array passed to it as a function argument. The user should not subsequently modify it.

**map**

```
int* tabprm::map
```

(Given) Pointer to the first element of a vector of length [tabprm::M](#) that defines the association between axis  $m$  in the  $M$ -dimensional coordinate array ( $1 \leq m \leq M$ ) and the indices of the intermediate world coordinate and world coordinate arrays,  $x[]$  and  $world[]$ , in the argument lists for [tabx2s\(\)](#) and [tabs2x\(\)](#).

When  $x[]$  and  $world[]$  contain the full complement of coordinate elements in image-order, as will usually be the case, then  $map[m-1] == i-1$  for axis  $i$  in the  $N$ -dimensional image ( $1 \leq i \leq N$ ). In terms of the FITS keywords

```
map[PVi_3a - 1] == i - 1.
```

However, a different association may result if  $x[]$ , for example, only contains a (relevant) subset of intermediate world coordinate elements. For example, if  $M == 1$  for an image with  $N > 1$ , it is possible to fill  $x[]$  with the relevant coordinate element with  $nelem$  set to 1. In this case  $map[0] = 0$  regardless of the value of  $i$ .

**crval**

```
double* tabprm::crval
```

(Given) Pointer to the first element of a vector of length [tabprm::M](#) whose elements contain the index value for the reference pixel for each of the tabular coordinate axes.

**index**

```
double** tabprm::index
```

(Given) Pointer to the first element of a vector of length [tabprm::M](#) of pointers to vectors of lengths  $(K_1, K_2, \dots, K_M)$  of 0-relative indexes (see [tabprm::K](#)).

The address of any or all of these index vectors may be set to zero, i.e.

```
index[m] == 0;
```

this is interpreted as default indexing, i.e.

```
index[m][k] = k;
```

**coord**

```
double* tabprm::coord
```

(Given) Pointer to the first element of the tabular coordinate array, treated as though it were defined as

```
double coord[K_M] ... [K_2] [K_1] [M];
```

(see [tabprm::K](#)) i.e. with the  $M$  dimension varying fastest so that the  $M$  elements of a coordinate vector are stored contiguously in memory.

**nc**

```
int tabprm::nc
```

(Returned) Total number of coordinate vectors in the coordinate array being the product  $K_1 K_2 \dots K_M$  (see [tabprm::K](#)).

**padding**

```
int tabprm::padding
```

(An unused variable inserted for alignment purposes only.)

**sense**

```
int* tabprm::sense
```

(*Returned*) Pointer to the first element of a vector of length [tabprm::M](#) whose elements indicate whether the corresponding indexing vector is monotonic increasing (+1), or decreasing (-1).

**p0**

```
int* tabprm::p0
```

(*Returned*) Pointer to the first element of a vector of length [tabprm::M](#) of interpolated indices into the coordinate array such that  $\Upsilon_m$ , as defined in Paper III, is equal to  $(p0[m] + 1) + \text{tabprm::delta}[m]$ .

**delta**

```
double* tabprm::delta
```

(*Returned*) Pointer to the first element of a vector of length [tabprm::M](#) of interpolated indices into the coordinate array such that  $\Upsilon_m$ , as defined in Paper III, is equal to  $(\text{tabprm::p0}[m] + 1) + \text{delta}[m]$ .

**extrema**

```
double* tabprm::extrema
```

(*Returned*) Pointer to the first element of an array that records the minimum and maximum value of each element of the coordinate vector in each row of the coordinate array, treated as though it were defined as

```
double extrema[K_M]...[K_2][2][M]
```

(see [tabprm::K](#)). The minimum is recorded in the first element of the compressed  $K_1$  dimension, then the maximum. This array is used by the inverse table lookup function, [tabs2x\(\)](#), to speed up table searches.

**err**

```
struct wcserr* tabprm::err
```

(*Returned*) If enabled, when an error status is returned, this struct contains detailed information about the error, see [wcserr\\_enable\(\)](#).

**m\_flag**

```
int tabprm::m_flag
```

(For internal use only.)

**m\_M**

```
int tabprm::m_M
```

(For internal use only.)

**m\_N**

```
int tabprm::m_N
```

(For internal use only.)

**set\_M**

```
int tabprm::set_M
```

(For internal use only.)

**m\_K**

```
int* tabprm::m_K
```

(For internal use only.)

**m\_map**

```
int * tabprm::m_map
```

(For internal use only.)

**m\_crval**

```
double* tabprm::m_crval
```

(For internal use only.)

**m\_index**

```
double ** tabprm::m_index
```

(For internal use only.)

**m\_indxs**

```
double ** tabprm::m_indxs
```

(For internal use only.)

**m\_coord**

```
double * tabprm::m_coord
```

(For internal use only.)

## 7.14 wcserr Struct Reference

Error message handling.

```
#include <wcserr.h>
```

**Data Fields**

- int [status](#)
- int [line\\_no](#)
- const char \* [function](#)
- const char \* [file](#)
- char \* [msg](#)

### 7.14.1 Detailed Description

Error message handling.

The **wcserr** struct contains the numeric error code, a textual description of the error, and information about the function, source file, and line number where the error was generated.

### 7.14.2 Field Documentation

**status**

```
int wcserr::status
```

Numeric status code associated with the error, the meaning of which depends on the function that generated it. See the documentation for the particular function.

**line\_no**

```
int wcserr::line_no
```

Line number where the error occurred as given by the `__LINE__` preprocessor macro.

const char \*function Name of the function where the error occurred.

const char \*file Name of the source file where the error occurred as given by the `__FILE__` preprocessor macro.

**function**

```
const char* wcserr::function
```

**file**

```
const char* wcserr::file
```

**msg**

```
char* wcserr::msg
```

Informative error message.

## 7.15 wcsprm Struct Reference

Coordinate transformation parameters.

```
#include <wcs.h>
```

**Data Fields**

- int [flag](#)
- int [naxis](#)
- double \* [crpix](#)
- double \* [pc](#)
- double \* [cdelt](#)
- double \* [cval](#)
- char(\* [cunit](#) )[72]
- char(\* [ctype](#) )[72]
- double [lonpole](#)
- double [latpole](#)
- double [restfrq](#)
- double [restwav](#)
- int [npv](#)
- int [npvmax](#)
- struct [pvcard](#) \* [pv](#)
- int [nps](#)
- int [npsmax](#)
- struct [pscard](#) \* [ps](#)
- double \* [cd](#)
- double \* [crota](#)
- int [altlin](#)
- int [velref](#)
- char [alt](#) [4]
- int [colnum](#)
- int \* [colax](#)
- char(\* [cname](#) )[72]
- double \* [cder](#)

- double \* [csyer](#)
- double \* [czphs](#)
- double \* [cperi](#)
- char [wcsname](#) [72]
- char [timesys](#) [72]
- char [trefpos](#) [72]
- char [trefdir](#) [72]
- char [plephem](#) [72]
- char [timeunit](#) [72]
- char [dateref](#) [72]
- double [mjdfref](#) [2]
- double [timeoffs](#)
- char [dateobs](#) [72]
- char [datebeg](#) [72]
- char [dateavg](#) [72]
- char [dateend](#) [72]
- double [mjdots](#)
- double [mjdbeg](#)
- double [mjdagv](#)
- double [mjddend](#)
- double [jepoch](#)
- double [bepoch](#)
- double [tstart](#)
- double [tstop](#)
- double [xposure](#)
- double [telapse](#)
- double [timsyer](#)
- double [timrder](#)
- double [timedel](#)
- double [timepixr](#)
- double [obsgeo](#) [6]
- char [obsorbit](#) [72]
- char [radesys](#) [72]
- double [equinox](#)
- char [specsyst](#) [72]
- char [ssysobs](#) [72]
- double [velosyst](#)
- double [zsource](#)
- char [ssysrc](#) [72]
- double [velangl](#)
- struct [auxprm](#) \* [aux](#)
- int [ntab](#)
- int [nwtb](#)
- struct [tabprm](#) \* [tab](#)
- struct [wtbarr](#) \* [wtb](#)
- char [lngtyp](#) [8]
- char [lattyp](#) [8]
- int [lng](#)
- int [lat](#)
- int [spec](#)
- int [time](#)
- int [cubeface](#)
- int [chksum](#)
- int \* [types](#)
- struct [linprm](#) [lin](#)

- struct [celprm](#) cel
- struct [spcprm](#) spc
- struct [wcserr](#) \* err
- int [m\\_flag](#)
- int [m\\_naxis](#)
- double \* [m\\_crpix](#)
- double \* [m\\_pc](#)
- double \* [m\\_cdelt](#)
- double \* [m\\_crval](#)
- char(\* [m\\_cunit](#))[72]
- char((\* [m\\_ctype](#))[72]
- struct [pvcard](#) \* [m\\_pv](#)
- struct [pscard](#) \* [m\\_ps](#)
- double \* [m\\_cd](#)
- double \* [m\\_crota](#)
- int \* [m\\_colax](#)
- char(\* [m\\_cname](#))[72]
- double \* [m\\_order](#)
- double \* [m\\_csyer](#)
- double \* [m\\_czphs](#)
- double \* [m\\_cperi](#)
- struct [auxprm](#) \* [m\\_aux](#)
- struct [tabprm](#) \* [m\\_tab](#)
- struct [wtbarr](#) \* [m\\_wtb](#)

### 7.15.1 Detailed Description

Coordinate transformation parameters.

The **wcsprm** struct contains information required to transform world coordinates. It consists of certain members that must be set by the user (*given*) and others that are set by the WCSLIB routines (*returned*). While the addresses of the arrays themselves may be set by [wcsinit\(\)](#) if it (optionally) allocates memory, their contents must be set by the user.

Some parameters that are given are not actually required for transforming coordinates. These are described as "auxiliary"; the struct simply provides a place to store them, though they may be used by [wcsndo\(\)](#) in constructing a FITS header from a **wcsprm** struct. Some of the returned values are supplied for informational purposes and others are for internal use only as indicated.

In practice, it is expected that a WCS parser would scan the FITS header to determine the number of coordinate axes. It would then use [wcsinit\(\)](#) to allocate memory for arrays in the **wcsprm** struct and set default values. Then as it reread the header and identified each WCS keyrecord it would load the value into the relevant **wcsprm** array element. This is essentially what [wcspih\(\)](#) does - refer to the prologue of [wcsHdr.h](#). As the final step, [wcsset\(\)](#) is invoked, either directly or indirectly, to set the derived members of the **wcsprm** struct. [wcsset\(\)](#) strips off trailing blanks in all string members and null-fills the character array.

### 7.15.2 Field Documentation

#### flag

```
int wcsprm::flag
```

(Given and returned) This flag must be set to zero (or 1, see [wcsset\(\)](#)) whenever any of the following **wcsprm** members are set or changed:

- [wcsprm::naxis](#) (q.v., not normally set by the user),
- [wcsprm::crpix](#),
- [wcsprm::pc](#),
- [wcsprm::cdelt](#),
- [wcsprm::crval](#),
- [wcsprm::cunit](#),
- [wcsprm::ctype](#),
- [wcsprm::lonpole](#),
- [wcsprm::latpole](#),
- [wcsprm::restfrq](#),
- [wcsprm::restwav](#),
- [wcsprm::npv](#),
- [wcsprm::pv](#),
- [wcsprm::nps](#),
- [wcsprm::ps](#),
- [wcsprm::cd](#),
- [wcsprm::crota](#),
- [wcsprm::altlin](#),
- [wcsprm::ntab](#),
- [wcsprm::nwtb](#),
- [wcsprm::tab](#),
- [wcsprm::wtb](#).

This signals the initialization routine, [wcsset\(\)](#), to recompute the returned members of the `linprm`, `celprm`, `spcprm`, and `tabprm` structs. [wcsset\(\)](#) will reset flag to indicate that this has been done.

**PLEASE NOTE:** flag should be set to -1 when [wcsinit\(\)](#) is called for the first time for a particular **wcsprm** struct in order to initialize memory management. It must **ONLY** be used on the first initialization otherwise memory leaks may result.

**naxis**

```
int wcsprm::naxis
```

(Given or returned) Number of pixel and world coordinate elements.

If `wcsinit()` is used to initialize the `linprm` struct (as would normally be the case) then it will set `naxis` from the value passed to it as a function argument. The user should not subsequently modify it.

**crpix**

```
double* wcsprm::crpix
```

(Given) Address of the first element of an array of double containing the coordinate reference pixel, **CRPIX**<sub>*j*</sub><sub>*a*</sub>.

**pc**

```
double* wcsprm::pc
```

(Given) Address of the first element of the **PC**<sub>*i*</sub><sub>*j*</sub><sub>*a*</sub> (pixel coordinate) transformation matrix. The expected order is

```
struct wcsprm wcs;
wcs.pc = {PC1_1, PC1_2, PC2_1, PC2_2};
```

This may be constructed conveniently from a 2-D array via

```
double m[2][2] = {{PC1_1, PC1_2},
                  {PC2_1, PC2_2}};
```

which is equivalent to

```
double m[2][2];
m[0][0] = PC1_1;
m[0][1] = PC1_2;
m[1][0] = PC2_1;
m[1][1] = PC2_2;
```

The storage order for this 2-D array is the same as for the 1-D array, whence

```
wcs.pc = *m;
```

would be legitimate.

**cdelt**

```
double* wcsprm::cdelt
```

(Given) Address of the first element of an array of double containing the coordinate increments, **CDELTA**<sub>*i*</sub><sub>*a*</sub>.

**crval**

```
double* wcsprm::crval
```

(Given) Address of the first element of an array of double containing the coordinate reference values, **CRVAL**<sub>*i*</sub><sub>*a*</sub>.

## cunit

```
char(* wcsprm::cunit) [72]
```

(Given) Address of the first element of an array of char[72] containing the **CUNIT**<sub>ia</sub> keyvalues which define the units of measurement of the **CRVAL**<sub>ia</sub>, **CDELTA**<sub>ia</sub>, and **CDI**<sub>ja</sub> keywords.

As **CUNIT**<sub>ia</sub> is an optional header keyword, cunit[[72] may be left blank but otherwise is expected to contain a standard units specification as defined by WCS Paper I. Utility function [wcsutrn\(\)](#), described in [wcsunits.h](#), is available to translate commonly used non-standard units specifications but this must be done as a separate step before invoking [wcsset\(\)](#).

For celestial axes, if cunit[[72] is not blank, [wcsset\(\)](#) uses [wcsunits\(\)](#) to parse it and scale cdelt[], crval[], and cd[[\*] to degrees. It then resets cunit[[72] to "deg".

For spectral axes, if cunit[[72] is not blank, [wcsset\(\)](#) uses [wcsunits\(\)](#) to parse it and scale cdelt[], crval[], and cd[[\*] to SI units. It then resets cunit[[72] accordingly.

[wcsset\(\)](#) ignores cunit[[72] for other coordinate types; cunit[[72] may be used to label coordinate values.

These variables accomodate the longest allowed string-valued FITS keyword, being limited to 68 characters, plus the null-terminating character.

## ctype

```
char(* wcsprm::ctype) [72]
```

(Given) Address of the first element of an array of char[72] containing the coordinate axis types, **CTYPE**<sub>ia</sub>.

The ctype[[72] keyword values must be in upper case and there must be zero or one pair of matched celestial axis types, and zero or one spectral axis. The ctype[[72] strings should be padded with blanks on the right and null-terminated so that they are at least eight characters in length.

These variables accomodate the longest allowed string-valued FITS keyword, being limited to 68 characters, plus the null-terminating character.

## lonpole

```
double wcsprm::lonpole
```

(Given and returned) The native longitude of the celestial pole,  $\phi_p$ , given by **LONPOLE**<sub>a</sub> [deg] or by **PVi\_2a** [deg] attached to the longitude axis which takes precedence if defined, and ...

## latpole

```
double wcsprm::latpole
```

(Given and returned) ... the native latitude of the celestial pole,  $\theta_p$ , given by **LATPOLE**<sub>a</sub> [deg] or by **PVi\_3a** [deg] attached to the longitude axis which takes precedence if defined.

lonpole and latpole may be left to default to values set by [wcsinit\(\)](#) (see [celprm::ref](#)), but in any case they will be reset by [wcsset\(\)](#) to the values actually used. Note therefore that if the **wcsprm** struct is reused without resetting them, whether directly or via [wcsinit\(\)](#), they will no longer have their default values.

**restfrq**

```
double wcsprm::restfrq
```

(Given) The rest frequency [Hz], and/or ...

**restwav**

```
double wcsprm::restwav
```

(Given) ... the rest wavelength in vacuo [m], only one of which need be given, the other should be set to zero.

**npv**

```
int wcsprm::npv
```

(Given) The number of entries in the [wcsprm::pv\[\]](#) array.

**npvmax**

```
int wcsprm::npvmax
```

(Given or returned) The length of the [wcsprm::pv\[\]](#) array.

npvmax will be set by [wcsinit\(\)](#) if it allocates memory for [wcsprm::pv\[\]](#), otherwise it must be set by the user. See also [wcsnpv\(\)](#).

**pv**

```
struct pvcards* wcsprm::pv
```

(Given) Address of the first element of an array of length npvmax of pvcards structs.

As a FITS header parser encounters each **PVi\_ma** keyword it should load it into a pvcards struct in the array and increment npv. [wcsset\(\)](#) interprets these as required.

Note that, if they were not given, [wcsset\(\)](#) resets the entries for **PVi\_1a**, **PVi\_2a**, **PVi\_3a**, and **PVi\_4a** for longitude axis **i** to match **phi\_0** and **theta\_0** (the native longitude and latitude of the reference point), **LONPOLEa** and **LATPOLEa** respectively.

**nps**

```
int wcsprm::nps
```

(Given) The number of entries in the [wcsprm::ps\[\]](#) array.

**npsmax**

```
int wcsprm::npsmax
```

(Given or returned) The length of the `wcsprm::ps[]` array.

`npsmax` will be set by `wcsinit()` if it allocates memory for `wcsprm::ps[]`, otherwise it must be set by the user. See also `wcsnps()`.

**ps**

```
struct pscard* wcsprm::ps
```

(Given) Address of the first element of an array of length `npsmax` of `pscard` structs.

As a FITS header parser encounters each `PSi_ma` keyword it should load it into a `pscard` struct in the array and increment `nps`. `wcsset()` interprets these as required (currently no `PSi_ma` keyvalues are recognized).

**cd**

```
double* wcsprm::cd
```

(Given) For historical compatibility, the `wcsprm` struct supports two alternate specifications of the linear transformation matrix, those associated with the `CDi_ja` keywords, and ...

**crota**

```
double* wcsprm::crota
```

(Given) ... those associated with the `CROTAi` keywords. Although these may not formally co-exist with `PCi_ja`, the approach taken here is simply to ignore them if given in conjunction with `PCi_ja`.

**altlin**

```
int wcsprm::altlin
```

(Given) `altlin` is a bit flag that denotes which of the `PCi_ja`, `CDi_ja` and `CROTAi` keywords are present in the header:

- Bit 0: `PCi_ja` is present.
- Bit 1: `CDi_ja` is present.

Matrix elements in the IRAF convention are equivalent to the product  $CDi\_ja = CDELTia * PCi\_ja$ , but the defaults differ from that of the `PCi_ja` matrix. If one or more `CDi_ja` keywords are present then all unspecified `CDi_ja` default to zero. If no `CDi_ja` (or `CROTAi`) keywords are present, then the header is assumed to be in `PCi_ja` form whether or not any `PCi_ja` keywords are present since this results in an interpretation of `CDELTia` consistent with the original FITS specification.

While `CDi_ja` may not formally co-exist with `PCi_ja`, it may co-exist with `CDELTia` and `CROTAi` which are to be ignored.

- Bit 2: **CROTA<sub>i</sub>** is present.

In the AIPS convention, **CROTA<sub>i</sub>** may only be associated with the latitude axis of a celestial axis pair. It specifies a rotation in the image plane that is applied AFTER the **CDELTA<sub>i</sub>**; any other **CROTA<sub>i</sub>** keywords are ignored.

**CROTA<sub>i</sub>** may not formally co-exist with **PC<sub>i\_\_ja</sub>**.

**CROTA<sub>i</sub>** and **CDELTA<sub>i</sub>** may formally co-exist with **CD<sub>i\_\_ja</sub>** but if so are to be ignored.

- Bit 3: **PC<sub>i\_\_ja</sub>** + **CDELTA<sub>i</sub>** was derived from **CD<sub>i\_\_ja</sub>** by **wcspx()**.

This bit is set by **wcspx()** when it derives **PC<sub>i\_\_ja</sub>** and **CDELTA<sub>i</sub>** from **CD<sub>i\_\_ja</sub>** via an orthonormal decomposition. In particular, it signals **wcsset()** not to replace **PC<sub>i\_\_ja</sub>** by a copy of **CD<sub>i\_\_ja</sub>** with **CDELTA<sub>i</sub>** set to unity.

**CD<sub>i\_\_ja</sub>** and **CROTA<sub>i</sub>** keywords, if found, are to be stored in the **wcsprm::cd** and **wcsprm::crota** arrays which are dimensioned similarly to **wcsprm::pc** and **wcsprm::cdelt**. FITS header parsers should use the following procedure:

- Whenever a **PC<sub>i\_\_ja</sub>** keyword is encountered:

```
altlin |= 1;
```

- Whenever a **CD<sub>i\_\_ja</sub>** keyword is encountered:

```
altlin |= 2;
```

- Whenever a **CROTA<sub>i</sub>** keyword is encountered:

```
altlin |= 4;
```

If none of these bits are set the **PC<sub>i\_\_ja</sub>** representation results, i.e. **wcsprm::pc** and **wcsprm::cdelt** will be used as given.

These alternate specifications of the linear transformation matrix are translated immediately to **PC<sub>i\_\_ja</sub>** by **wcsset()** and are invisible to the lower-level WCSLIB routines. In particular, unless bit 3 is also set, **wcsset()** resets **wcsprm::cdelt** to unity if **CD<sub>i\_\_ja</sub>** is present (and no **PC<sub>i\_\_ja</sub>**).

If **CROTA<sub>i</sub>** are present but none is associated with the latitude axis (and no **PC<sub>i\_\_ja</sub>** or **CD<sub>i\_\_ja</sub>**), then **wcsset()** reverts to a unity **PC<sub>i\_\_ja</sub>** matrix.

## velref

```
int wcsprm::velref
```

(Given) AIPS velocity code **VELREF**, refer to **spcaips()**.

It is not necessary to reset the **wcsprm** struct (via **wcsset()**) when **wcsprm::velref** is changed.

## alt

```
char wcsprm::alt[4]
```

(Given, auxiliary) Character code for alternate coordinate descriptions (i.e. the 'a' in keyword names such as **CTYPE<sub>i</sub>**). This is blank for the primary coordinate description, or one of the 26 upper-case letters, A-Z.

An array of four characters is provided for alignment purposes, only the first is used.

It is not necessary to reset the **wcsprm** struct (via **wcsset()**) when **wcsprm::alt** is changed.

**colnum**

```
int wcsprm::colnum
```

(Given, auxiliary) Where the coordinate representation is associated with an image-array column in a FITS binary table, this variable may be used to record the relevant column number.

It should be set to zero for an image header or pixel list.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::colnum](#) is changed.

**colax**

```
int* wcsprm::colax
```

(Given, auxiliary) Address of the first element of an array of int recording the column numbers for each axis in a pixel list.

The array elements should be set to zero for an image header or image array in a binary table.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::colax](#) is changed.

**cname**

```
char (* wcsprm::cname) [72]
```

(Given, auxiliary) The address of the first element of an array of char[72] containing the coordinate axis names, **CNAME**<sub>ia</sub>.

These variables accomodate the longest allowed string-valued FITS keyword, being limited to 68 characters, plus the null-terminating character.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::cname](#) is changed.

**crder**

```
double* wcsprm::crder
```

(Given, auxiliary) Address of the first element of an array of double recording the random error in the coordinate value, **CRDER**<sub>ia</sub>.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::crder](#) is changed.

**csyer**

```
double* wcsprm::csyer
```

(Given, auxiliary) Address of the first element of an array of double recording the systematic error in the coordinate value, **CSYER**<sub>ia</sub>.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::csyer](#) is changed.

**czphs**

```
double* wcsprm::czphs
```

(Given, auxiliary) Address of the first element of an array of double recording the time at the zero point of a phase axis, CZPHS<sub>a</sub>.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::czphs](#) is changed.

**cperi**

```
double* wcsprm::cperi
```

(Given, auxiliary) Address of the first element of an array of double recording the period of a phase axis, CPERI<sub>a</sub>.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::cperi](#) is changed.

**wcsname**

```
char wcsprm::wcsname[72]
```

(Given, auxiliary) The name given to the coordinate representation, **WCSNAME**<sub>a</sub>. This variable accomodates the longest allowed string-valued FITS keyword, being limited to 68 characters, plus the null-terminating character.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::wcsname](#) is changed.

**timesys**

```
char wcsprm::timesys[72]
```

(Given, auxiliary) **TIMESYS** keyvalue, being the time scale (UTC, TAI, etc.) in which all other time-related auxiliary header values are recorded. Also defines the time scale for an image axis with **CTYPE**<sub>1a</sub> set to 'TIME'.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::timesys](#) is changed.

**trefpos**

```
char wcsprm::trefpos[72]
```

(Given, auxiliary) **TREFPOS** keyvalue, being the location in space where the recorded time is valid.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::trefpos](#) is changed.

**trefdir**

```
char wcsprm::trefdir[72]
```

(Given, auxiliary) **TREFDIR** keyvalue, being the reference direction used in calculating a pathlength delay.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::trefdir](#) is changed.

### plephem

```
char wcsprm::plephem[72]
```

(Given, auxiliary) **PLEPHEM** keyvalue, being the Solar System ephemeris used for calculating a pathlength delay.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::plephem](#) is changed.

### timeunit

```
char wcsprm::timeunit[72]
```

(Given, auxiliary) **TIMEUNIT** keyvalue, being the time units in which the following header values are expressed: **TSTART**, **TSTOP**, **TIMEOFFS**, **TIMSYER**, **TIMRDER**, **TIMEDEL**. It also provides the default value for **CUNIT**ia for time axes.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::timeunit](#) is changed.

### dateref

```
char wcsprm::dateref[72]
```

(Given, auxiliary) **DATEREF** keyvalue, being the date of a reference epoch relative to which other time measurements refer.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::dateref](#) is changed.

### mjdref

```
double wcsprm::mjdref[2]
```

(Given, auxiliary) **MJDREF** keyvalue, equivalent to **DATEREF** expressed as a Modified Julian Date (MJD = JD - 2400000.5). The value is given as the sum of the two-element vector, allowing increased precision.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::mjdref](#) is changed.

### timeoffs

```
double wcsprm::timeoffs
```

(Given, auxiliary) **TIMEOFFS** keyvalue, being a time offset, which may be used, for example, to provide a uniform clock correction for times referenced to **DATEREF**.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::timeoffs](#) is changed.

### dateobs

```
char wcsprm::dateobs[72]
```

(Given, auxiliary) **DATE-OBS** keyvalue, being the date at the start of the observation unless otherwise explained in the **DATE-OBS** keycomment, in ISO format, *yyyy-mm-ddThh:mm:ss*.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::dateobs](#) is changed.

**datebeg**

```
char wcsprm::datebeg[72]
```

(Given, auxiliary) **DATE-BEG** keyvalue, being the date at the start of the observation in ISO format, *yyyy-mm-ddThh:mm:ss*.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::datebeg](#) is changed.

**dateavg**

```
char wcsprm::dateavg[72]
```

(Given, auxiliary) **DATE-AVG** keyvalue, being the date at a representative mid-point of the observation in ISO format, *yyyy-mm-ddThh:mm:ss*.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::dateavg](#) is changed.

**dateend**

```
char wcsprm::dateend[72]
```

(Given, auxiliary) **DATE-END** keyvalue, being the date at the end of the observation in ISO format, *yyyy-mm-ddThh:mm:ss*.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::dateend](#) is changed.

**mjdobs**

```
double wcsprm::mjdobs
```

(Given, auxiliary) **MJD-OBS** keyvalue, equivalent to **DATE-OBS** expressed as a Modified Julian Date (MJD = JD - 2400000.5).

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::mjdobs](#) is changed.

**mjdbeg**

```
double wcsprm::mjdbeg
```

(Given, auxiliary) **MJD-BEG** keyvalue, equivalent to **DATE-BEG** expressed as a Modified Julian Date (MJD = JD - 2400000.5).

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::mjdbeg](#) is changed.

**mjdavg**

```
double wcsprm::mjdavg
```

(Given, auxiliary) **MJD-AVG** keyvalue, equivalent to **DATE-AVG** expressed as a Modified Julian Date (MJD = JD - 2400000.5).

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::mjdavg](#) is changed.

### **mjdend**

```
double wcsprm::mjdend
```

(Given, auxiliary) **MJD-END** keyvalue, equivalent to **DATE-END** expressed as a Modified Julian Date ( $\text{MJD} = \text{JD} - 2400000.5$ ).

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::mjdend](#) is changed.

### **jepoch**

```
double wcsprm::jepoch
```

(Given, auxiliary) **JEPOCH** keyvalue, equivalent to **DATE-OBS** expressed as a Julian epoch.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::jepoch](#) is changed.

### **bepoch**

```
double wcsprm::bepoch
```

(Given, auxiliary) **BEPOCH** keyvalue, equivalent to **DATE-OBS** expressed as a Besselian epoch

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::bepoch](#) is changed.

### **tstart**

```
double wcsprm::tstart
```

(Given, auxiliary) **TSTART** keyvalue, equivalent to **DATE-BEG** expressed as a time in units of **TIMEUNIT** relative to **DATEREF+TIMEOFFS**.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::tstart](#) is changed.

### **tstop**

```
double wcsprm::tstop
```

(Given, auxiliary) **TSTOP** keyvalue, equivalent to **DATE-END** expressed as a time in units of **TIMEUNIT** relative to **DATEREF+TIMEOFFS**.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::tstop](#) is changed.

### **xposure**

```
double wcsprm::xposure
```

(Given, auxiliary) **XPOSURE** keyvalue, being the effective exposure time in units of **TIMEUNIT**.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::xposure](#) is changed.

**telapse**

```
double wcsprm::telapse
```

(Given, auxiliary) **TELAPSE** keyvalue, equivalent to the elapsed time between **DATE-BEG** and **DATE-END**, in units of **TIMEUNIT**.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::telapse](#) is changed.

**timsyer**

```
double wcsprm::timsyer
```

(Given, auxiliary) **TIMSYER** keyvalue, being the absolute error of the time values, in units of **TIMEUNIT**.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::timsyer](#) is changed.

**timrder**

```
double wcsprm::timrder
```

(Given, auxiliary) **TIMRDER** keyvalue, being the accuracy of time stamps relative to each other, in units of **TIMEUNIT**.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::timrder](#) is changed.

**timedel**

```
double wcsprm::timedel
```

(Given, auxiliary) **TIMEDEL** keyvalue, being the resolution of the time stamps.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::timedel](#) is changed.

**timepixr**

```
double wcsprm::timepixr
```

(Given, auxiliary) **TIMEPIXR** keyvalue, being the relative position of the time stamps in binned time intervals, a value between 0.0 and 1.0.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::timepixr](#) is changed.

**obsgeo**

```
double wcsprm::obsgeo[6]
```

(Given, auxiliary) Location of the observer in a standard terrestrial reference frame. The first three give ITRS Cartesian coordinates **OBSGEO-X** [m], **OBSGEO-Y** [m], **OBSGEO-Z** [m], and the second three give **OBSGEO-L** [deg], **OBSGEO-B** [deg], **OBSGEO-H** [m], which are related through a standard transformation.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::obsgeo](#) is changed.

**obsorbit**

```
char wcsprm::obsorbit[72]
```

(Given, auxiliary) **OBSORBIT** keyvalue, being the URI, URL, or name of an orbit ephemeris file giving spacecraft coordinates relating to **TREFPOS**.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::obsorbit](#) is changed.

**radesys**

```
char wcsprm::radesys[72]
```

(Given, auxiliary) The equatorial or ecliptic coordinate system type, **RADESYS**<sub>a</sub>.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::radesys](#) is changed.

**equinox**

```
double wcsprm::equinox
```

(Given, auxiliary) The equinox associated with dynamical equatorial or ecliptic coordinate systems, **EQUINOX**<sub>a</sub> (or **EPOCH** in older headers). Not applicable to ICRS equatorial or ecliptic coordinates.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::equinox](#) is changed.

**specsyst**

```
char wcsprm::specsyst[72]
```

(Given, auxiliary) Spectral reference frame (standard of rest), **SPECSYST**<sub>a</sub>.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::specsyst](#) is changed.

**ssysobs**

```
char wcsprm::ssysobs[72]
```

(Given, auxiliary) The spectral reference frame in which there is no differential variation in the spectral coordinate across the field-of-view, **SSYSOBS**<sub>a</sub>.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::ssysobs](#) is changed.

**velosyst**

```
double wcsprm::velosyst
```

(Given, auxiliary) The relative radial velocity [m/s] between the observer and the selected standard of rest in the direction of the celestial reference coordinate, **VELOSYST**<sub>a</sub>.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::velosyst](#) is changed.

**zsource**

```
double wcsprm::zsource
```

(Given, auxiliary) The redshift, **ZSOURCE**<sub>a</sub>, of the source.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::zsource](#) is changed.

**ssysrc**

```
char wcsprm::ssysrc[72]
```

(Given, auxiliary) The spectral reference frame (standard of rest), **SSYSSRC**<sub>a</sub>, in which [wcsprm::zsource](#) was measured.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::ssysrc](#) is changed.

**velangl**

```
double wcsprm::velangl
```

(Given, auxiliary) The angle [deg] that should be used to decompose an observed velocity into radial and transverse components.

It is not necessary to reset the **wcsprm** struct (via [wcsset\(\)](#)) when [wcsprm::velangl](#) is changed.

**aux**

```
struct auxprm* wcsprm::aux
```

(Given, auxiliary) This struct holds auxiliary coordinate system information of a specialist nature. While these parameters may be widely recognized within particular fields of astronomy, they differ from the above auxiliary parameters in not being defined by any of the FITS WCS standards. Collecting them together in a separate struct that is allocated only when required helps to control bloat in the size of the **wcsprm** struct.

**ntab**

```
int wcsprm::ntab
```

(Given) See [wcsprm::tab](#).

**nwtb**

```
int wcsprm::nwtb
```

(Given) See [wcsprm::wtb](#).

**tab**

```
struct tabprm* wcsprm::tab
```

(*Given*) Address of the first element of an array of ntab tabprm structs for which memory has been allocated. These are used to store tabular transformation parameters.

Although technically `wcsprm::ntab` and `tab` are "given", they will normally be set by invoking `wcstab()`, whether directly or indirectly.

The tabprm structs contain some members that must be supplied and others that are derived. The information to be supplied comes primarily from arrays stored in one or more FITS binary table extensions. These arrays, referred to here as "wcstab arrays", are themselves located by parameters stored in the FITS image header.

**wtb**

```
struct wtbar* wcsprm::wtb
```

(*Given*) Address of the first element of an array of nwtb wtbar structs for which memory has been allocated. These are used in extracting wcstab arrays from a FITS binary table.

Although technically `wcsprm::nwtb` and `wtb` are "given", they will normally be set by invoking `wcstab()`, whether directly or indirectly.

**lngtyp**

```
char wcsprm::lngtyp[8]
```

(*Returned*) Four-character WCS celestial longitude and ...

**lattyp**

```
char wcsprm::lattyp[8]
```

(*Returned*) ... latitude axis types. e.g. "RA", "DEC", "GLON", "GLAT", etc. extracted from 'RA-', 'DEC-', 'GLON', 'GLAT', etc. in the first four characters of `CTYPEia` but with trailing dashes removed. (Declared as char[8] for alignment reasons.)

**lng**

```
int wcsprm::lng
```

(*Returned*) Index for the longitude coordinate, and ...

**lat**

```
int wcsprm::lat
```

(*Returned*) ... index for the latitude coordinate, and ...

**spec**

```
int wcsprm::spec
```

(Returned) ... index for the spectral coordinate, and ...

**time**

```
int wcsprm::time
```

(Returned) ... index for the time coordinate in the `imgcrd[][]` and `world[][]` arrays in the API of [wcsp2s\(\)](#), [wcss2p\(\)](#) and [wscsmix\(\)](#).

These may also serve as indices into the `pixcrd[][]` array provided that the `PCi_ja` matrix does not transpose axes.

**cubeface**

```
int wcsprm::cubeface
```

(Returned) Index into the `pixcrd[][]` array for the **CUBEFACE** axis. This is used for quadcube projections where the cube faces are stored on a separate axis (see [wcs.h](#)).

**chksum**

```
int wcsprm::chksum
```

(Returned) Checksum of keyvalues provided (see [wcsprm::flag](#)). Used by [wcsenq\(\)](#) to validate the self-consistency of the struct. Note that the checksum incorporates addresses and is therefore highly specific to the instance of the **wcsprm** struct.

**types**

```
int* wcsprm::types
```

(Returned) Address of the first element of an array of int containing a four-digit type code for each axis.

- First digit (i.e. 1000s):
  - 0: Non-specific coordinate type.
  - 1: Stokes coordinate.
  - 2: Celestial coordinate (including **CUBEFACE**).
  - 3: Spectral coordinate.
  - 4: Time coordinate.
- Second digit (i.e. 100s):
  - 0: Linear axis.
  - 1: Quantized axis (**STOKES**, **CUBEFACE**).

- 2: Non-linear celestial axis.
  - 3: Non-linear spectral axis.
  - 4: Logarithmic axis.
  - 5: Tabular axis.
- Third digit (i.e. 10s):
  - 0: Group number, e.g. lookup table number, being an index into the `tabprm` array (see above).
- The fourth digit is used as a qualifier depending on the axis type.
  - For celestial axes:
    - \* 0: Longitude coordinate.
    - \* 1: Latitude coordinate.
    - \* 2: **CUBEFACE** number.
  - For lookup tables: the axis number in a multidimensional table.

**CTYPE**<sub>ia</sub> in "4-3" form with unrecognized algorithm code will have its type set to -1 and generate an error.

## lin

```
struct linprm wcsprm::lin
```

(*Returned*) Linear transformation parameters (usage is described in the prologue to [lin.h](#)).

## cel

```
struct celprm wcsprm::cel
```

(*Returned*) Celestial transformation parameters (usage is described in the prologue to [cel.h](#)).

## spc

```
struct spcprm wcsprm::spc
```

(*Returned*) Spectral transformation parameters (usage is described in the prologue to [spc.h](#)).

## err

```
struct wcserr* wcsprm::err
```

(*Returned*) If enabled, when an error status is returned, this struct contains detailed information about the error, see [wcserr\\_enable\(\)](#).

## m\_flag

```
int wcsprm::m_flag
```

(For internal use only.)

**m\_naxis**

```
int wcsprm::m_naxis
```

(For internal use only.)

**m\_crpix**

```
double* wcsprm::m_crpix
```

(For internal use only.)

**m\_pc**

```
double * wcsprm::m_pc
```

(For internal use only.)

**m\_cdelt**

```
double * wcsprm::m_cdelt
```

(For internal use only.)

**m\_crval**

```
double * wcsprm::m_crval
```

(For internal use only.)

**m\_cunit**

```
char (* wcsprm::m_cunit) [72]
```

(For internal use only.)

**m\_ctype**

```
char ((* wcsprm::m_ctype) [72])
```

(For internal use only.)

**m\_pv**

```
struct pvcard* wcsprm::m_pv
```

(For internal use only.)

**m\_ps**

```
struct pscard* wcsprm::m_ps
```

(For internal use only.)

**m\_cd**

```
double* wcsprm::m_cd
```

(For internal use only.)

**m\_crota**

```
double * wcsprm::m_crota
```

(For internal use only.)

**m\_colax**

```
int* wcsprm::m_colax
```

(For internal use only.)

**m\_cname**

```
char (* wcsprm::m_cname) [72]
```

(For internal use only.)

**m\_crder**

```
double* wcsprm::m_crder
```

(For internal use only.)

**m\_csyer**

```
double * wcsprm::m_csyer
```

(For internal use only.)

**m\_czphs**

```
double * wcsprm::m_czphs
```

(For internal use only.)

**m\_cperi**

```
double * wcsprm::m_cperi
```

(For internal use only.)

**m\_aux**

```
struct auxprm* wcsprm::m_aux
```

**m\_tab**

```
struct tabprm* wcsprm::m_tab
```

(For internal use only.)

**m\_wtb**

```
struct wtbarr* wcsprm::m_wtb
```

(For internal use only.)

**7.16 wtbarr Struct Reference**

Extraction of coordinate lookup tables from BINTABLE.

```
#include <getwcstab.h>
```

**Data Fields**

- int `i`
- int `m`
- int `kind`
- char `extnam` [72]
- int `extver`
- int `extlev`
- char `ttype` [72]
- long `row`
- int `ndim`
- int \* `dimlen`
- double \*\* `arrayp`

### 7.16.1 Detailed Description

Extraction of coordinate lookup tables from BINTABLE.

Function [wcstab\(\)](#), which is invoked automatically by [wcspih\(\)](#), sets up an array of **wtbarr** structs to assist in extracting coordinate lookup tables from a binary table extension (BINTABLE) and copying them into the tabprm structs stored in wcsprm. Refer to the usage notes for [wcspih\(\)](#) and [wcstab\(\)](#) in [wcshdr.h](#), and also the prologue to [tab.h](#).

For C++ usage, because of a name space conflict with the **wtbarr** typedef defined in CFITSIO header fitsio.h, the **wtbarr** struct is renamed to **wtbarr\_s** by preprocessor macro substitution with scope limited to **wtbarr.h** itself, and similarly in [wcs.h](#).

### 7.16.2 Field Documentation

**i**

```
int wtbarr::i
```

(Given) Image axis number.

**m**

```
int wtbarr::m
```

(Given) wcstab array axis number for index vectors.

**kind**

```
int wtbarr::kind
```

(Given) Character identifying the wcstab array type:

- c: coordinate array,
- i: index vector.

**extnam**

```
char wtbarr::extnam
```

(Given) **EXTNAME** identifying the binary table extension.

**extver**

```
int wtbarr::extver
```

(Given) **EXTVER** identifying the binary table extension.

**extlev**

```
int wt barr::extlev
```

(Given) **EXTLEV** identifying the binary table extension.

**ttype**

```
char wt barr::ttype
```

(Given) **TTYPEn** identifying the column of the binary table that contains the wcstab array.

**row**

```
long wt barr::row
```

(Given) Table row number.

**ndim**

```
int wt barr::ndim
```

(Given) Expected dimensionality of the wcstab array.

**dimlen**

```
int * wt barr::dimlen
```

(Given) Address of the first element of an array of int of length ndim into which the wcstab array axis lengths are to be written.

**arrayp**

```
double ** wt barr::arrayp
```

(Given) Pointer to an array of double which is to be allocated by the user and into which the wcstab array is to be written.

## 8 File Documentation

### 8.1 cel.h File Reference

```
#include "prj.h"
```

## Data Structures

- struct `celprm`  
*Celestial transformation parameters.*

## Macros

- #define `CELLEN` (sizeof(struct `celprm`)/sizeof(int))  
*Size of the `celprm` struct in int units.*
- #define `celini_errmsg cel_errmsg`  
*Deprecated.*
- #define `celprt_errmsg cel_errmsg`  
*Deprecated.*
- #define `celset_errmsg cel_errmsg`  
*Deprecated.*
- #define `celx2s_errmsg cel_errmsg`  
*Deprecated.*
- #define `cels2x_errmsg cel_errmsg`  
*Deprecated.*

## Enumerations

- enum `celenq_enum` { `CELENQ_SET` = 2 , `CELENQ_BYP` = 4 }
- enum `cel_errmsg_enum` {  
    `CELERR_SUCCESS` = 0 , `CELERR_NULL_POINTER` = 1 , `CELERR_BAD_PARAM` = 2 , `CELERR_BAD_COORD_TRANS`  
    = 3 ,  
    `CELERR_ILL_COORD_TRANS` = 4 , `CELERR_BAD_PIX` = 5 , `CELERR_BAD_WORLD` = 6 }

## Functions

- int `celini` (struct `celprm` \*cel)  
*Default constructor for the `celprm` struct.*
- int `celfree` (struct `celprm` \*cel)  
*Destructor for the `celprm` struct.*
- int `celsize` (const struct `celprm` \*cel, int sizes[2])  
*Compute the size of a `celprm` struct.*
- int `celenq` (const struct `celprm` \*cel, int enquiry)  
*enquire about the state of a `celprm` struct.*
- int `celprt` (const struct `celprm` \*cel)  
*Print routine for the `celprm` struct.*
- int `celperr` (const struct `celprm` \*cel, const char \*prefix)  
*Print error messages from a `celprm` struct.*
- int `celset` (struct `celprm` \*cel)  
*Setup routine for the `celprm` struct.*
- int `celx2s` (struct `celprm` \*cel, int nx, int ny, int sxy, int sll, const double x[], const double y[], double phi[], double theta[], double lng[], double lat[], int stat[])  
*Pixel-to-world celestial transformation.*
- int `cels2x` (struct `celprm` \*cel, int nlng, int nlat, int sll, int sxy, const double lng[], const double lat[], double phi[], double theta[], double x[], double y[], int stat[])  
*World-to-pixel celestial transformation.*

## Variables

- `const char * cel\_errmsg []`  
*Status return messages.*

### 8.1.1 Detailed Description

Routines in this suite implement the part of the FITS World Coordinate System (WCS) standard that deals with celestial coordinates, as described in

"Representations of world coordinates in FITS",  
Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)

"Representations of celestial coordinates in FITS",  
Calabretta, M.R., & Greisen, E.W. 2002, A&A, 395, 1077 (WCS Paper II)

These routines define methods to be used for computing celestial world coordinates from intermediate world coordinates (a linear transformation of image pixel coordinates), and vice versa. They are based on the [celprm](#) struct which contains all information needed for the computations. This struct contains some elements that must be set by the user, and others that are maintained by these routines, somewhat like a C++ class but with no encapsulation.

Routine [celini\(\)](#) is provided to initialize the [celprm](#) struct with default values, [celfree\(\)](#) reclaims any memory that may have been allocated to store an error message, [celsize\(\)](#) computes its total size including allocated memory, [celenq\(\)](#) returns information about the state of the struct, and [celprt\(\)](#) prints its contents.

[celperr\(\)](#) prints the error message(s), if any, stored in a [celprm](#) struct and the [prjprm](#) struct that it contains.

A setup routine, [celset\(\)](#), computes intermediate values in the [celprm](#) struct from parameters in it that were supplied by the user. The struct always needs to be set up by [celset\(\)](#) but it need not be called explicitly - refer to the explanation of [celprm::flag](#).

[celx2s\(\)](#) and [cels2x\(\)](#) implement the WCS celestial coordinate transformations. In fact, they are high level driver routines for the lower level spherical coordinate rotation and projection routines described in [sph.h](#) and [prj.h](#).

### 8.1.2 Macro Definition Documentation

#### CELLEN

```
#define CELLEN (sizeof(struct celprm)/sizeof(int))
```

Size of the [celprm](#) struct in *int* units.

Size of the [celprm](#) struct in *int* units, used by the Fortran wrappers.

#### celini\_errmsg

```
#define celini_errmsg cel\_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [cel\\_errmsg](#) directly now instead.

**celprt\_errmsg**

```
#define celprt_errmsg cel_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [cel\\_errmsg](#) directly now instead.

**celset\_errmsg**

```
#define celset_errmsg cel_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [cel\\_errmsg](#) directly now instead.

**celx2s\_errmsg**

```
#define celx2s_errmsg cel_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [cel\\_errmsg](#) directly now instead.

**cels2x\_errmsg**

```
#define cels2x_errmsg cel_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [cel\\_errmsg](#) directly now instead.

### 8.1.3 Enumeration Type Documentation

**celenq\_enum**

```
enum celenq_enum
```

**Enumerator**

CELENQ_SET	
------------	--

CELENQ_BYP	
------------	--

## cel\_errmsg\_enum

enum [cel\\_errmsg\\_enum](#)

### Enumerator

CELERR_SUCCESS	
CELERR_NULL_POINTER	
CELERR_BAD_PARAM	
CELERR_BAD_COORD_TRANS	
CELERR_ILL_COORD_TRANS	
CELERR_BAD_PIX	
CELERR_BAD_WORLD	

## 8.1.4 Function Documentation

### celini()

```
int celini (  
    struct celprm * cel)
```

Default constructor for the [celprm](#) struct.

**celini()** sets all members of a [celprm](#) struct to default values. It should be used to initialize every [celprm](#) struct.

**PLEASE NOTE:** If the [celprm](#) struct has already been initialized, then before reinitializing, it [celfree\(\)](#) should be used to free any memory that may have been allocated to store an error message. A memory leak may otherwise result.

### Parameters

out	<i>cel</i>	Celestial transformation parameters.
-----	------------	--------------------------------------

### Returns

Status return value:

- 0: Success.
- 1: Null [celprm](#) pointer passed.

### celfree()

```
int celfree (  
    struct celprm * cel)
```

---

Destructor for the [celprm](#) struct.

**Parameters**

<code>in, out</code>	<code>cel</code>	Celestial transformation parameters.
----------------------	------------------	--------------------------------------

**Returns**

Status return value:

- 0: Success.
- 1: Null `celprm` pointer passed.

**celsize()**

```
int celsize (  
    const struct celprm * cel,  
    int sizes[2])
```

Compute the size of a `celprm` struct.

**celsize()** computes the full size of a `celprm` struct, including allocated memory.

**Parameters**

<code>in</code>	<code>cel</code>	Celestial transformation parameters. If NULL, the base size of the struct and the allocated size are both set to zero.
<code>out</code>	<code>sizes</code>	The first element is the base size of the struct as returned by <code>sizeof(struct celprm)</code> . The second element is the total allocated size, in bytes. This figure includes memory allocated for the constituent struct, <code>celprm::err</code> . It is not an error for the struct not to have been set up via <code>celset()</code> .

**Returns**

Status return value:

- 0: Success.

**celenq()**

```
int celenq (  
    const struct celprm * cel,  
    int enquiry)
```

enquire about the state of a `celprm` struct.

**celenq()** may be used to obtain information about the state of a `celprm` struct. The function returns a true/false answer for the enquiry asked.

**Parameters**

in	<i>cel</i>	Celestial transformation parameters.
in	<i>enquiry</i>	Enquiry according to the following parameters: <ul style="list-style-type: none"> <li>• CELENQ_SET: the struct has been set up by <a href="#">celset()</a>.</li> <li>• CELENQ_BYP: the struct is in bypass mode (see <a href="#">celset()</a>).</li> </ul>

**Returns**

Enquiry result:

- 0: No.
- 1: Yes.

**celprt()**

```
int celprt (
    const struct celprm * cel)
```

Print routine for the [celprm](#) struct.

**celprt()** prints the contents of a [celprm](#) struct using [wcsprintf\(\)](#). Mainly intended for diagnostic purposes.

**Parameters**

in	<i>cel</i>	Celestial transformation parameters.
----	------------	--------------------------------------

**Returns**

Status return value:

- 0: Success.
- 1: Null [celprm](#) pointer passed.

**celperr()**

```
int celperr (
    const struct celprm * cel,
    const char * prefix)
```

Print error messages from a [celprm](#) struct.

**celperr()** prints the error message(s), if any, stored in a [celprm](#) struct and the [prjprm](#) struct that it contains. If there are no errors then nothing is printed. It uses [wcserr\\_prt\(\)](#), q.v.

**Parameters**

in	<i>cel</i>	Coordinate transformation parameters.
in	<i>prefix</i>	If non-NULL, each output line will be prefixed with this string.

**Returns**

Status return value:

- 0: Success.
- 1: Null [celprm](#) pointer passed.

**celset()**

```
int celset (  
    struct celprm * cel)
```

Setup routine for the [celprm](#) struct.

**celset()** sets up a [celprm](#) struct according to information supplied within it.

Note that this routine need not be called directly; it will be invoked by [celx2s\(\)](#) and [cels2x\(\)](#) if [celprm::flag](#) is anything other than a predefined magic value.

**celset()** normally operates regardless of the value of [celprm::flag](#); i.e. even if a struct was previously set up it will be reset unconditionally. However, a [celprm](#) struct may be put into "bypass" mode by invoking **celset()** initially with [celprm::flag](#) == 1 (rather than 0). **celset()** will return immediately if invoked on a struct in that state. To take a struct out of bypass mode, simply reset [celprm::flag](#) to zero. See also [celenq\(\)](#).

**Parameters**

in, out	<i>cel</i>	Celestial transformation parameters.
---------	------------	--------------------------------------

**Returns**

Status return value:

- 0: Success.
- 1: Null [celprm](#) pointer passed.
- 2: Invalid projection parameters.
- 3: Invalid coordinate transformation parameters.
- 4: Ill-conditioned coordinate transformation parameters.

For returns > 1, a detailed error message is set in [celprm::err](#) if enabled, see [wcserr\\_enable\(\)](#).

**celx2s()**

```
int celx2s (
    struct celprm * cel,
    int nx,
    int ny,
    int sxy,
    int sll,
    const double x[],
    const double y[],
    double phi[],
    double theta[],
    double lng[],
    double lat[],
    int stat[])
```

Pixel-to-world celestial transformation.

**celx2s()** transforms  $(x, y)$  coordinates in the plane of projection to celestial coordinates  $(\alpha, \delta)$ .

**Parameters**

in, out	<i>cel</i>	Celestial transformation parameters.
in	<i>nx, ny</i>	Vector lengths.
in	<i>sxy, sll</i>	Vector strides.
in	<i>x, y</i>	Projected coordinates in pseudo "degrees".
out	<i>phi, theta</i>	Longitude and latitude ( $\phi, \theta$ ) in the native coordinate system of the projection [deg].
out	<i>lng, lat</i>	Celestial longitude and latitude ( $\alpha, \delta$ ) of the projected point [deg].
out	<i>stat</i>	Status return value for each vector element: <ul style="list-style-type: none"> <li>• 0: Success.</li> <li>• 1: Invalid value of <math>(x, y)</math>.</li> </ul>

**Returns**

Status return value:

- 0: Success.
- 1: Null [celprm](#) pointer passed.
- 2: Invalid projection parameters.
- 3: Invalid coordinate transformation parameters.
- 4: Ill-conditioned coordinate transformation parameters.
- 5: One or more of the  $(x, y)$  coordinates were invalid, as indicated by the stat vector.

For returns  $> 1$ , a detailed error message is set in [celprm::err](#) if enabled, see [wcserr\\_enable\(\)](#).

**cels2x()**

```
int cels2x (
    struct celprm * cel,
    int nlng,
    int nlat,
    int sll,
    int sxy,
    const double lng[],
    const double lat[],
    double phi[],
    double theta[],
    double x[],
    double y[],
    int stat[])
```

World-to-pixel celestial transformation.

**cels2x()** transforms celestial coordinates  $(\alpha, \delta)$  to  $(x, y)$  coordinates in the plane of projection.

**Parameters**

in, out	<i>cel</i>	Celestial transformation parameters.
in	<i>nlng, nlat</i>	Vector lengths.
in	<i>sll, sxy</i>	Vector strides.
in	<i>lng, lat</i>	Celestial longitude and latitude $(\alpha, \delta)$ of the projected point [deg].
out	<i>phi, theta</i>	Longitude and latitude $(\phi, \theta)$ in the native coordinate system of the projection [deg].
out	<i>x, y</i>	Projected coordinates in pseudo "degrees".
out	<i>stat</i>	Status return value for each vector element: <ul style="list-style-type: none"> <li>• 0: Success.</li> <li>• 1: Invalid value of <math>(\alpha, \delta)</math>.</li> </ul>

**Returns**

Status return value:

- 0: Success.
- 1: Null [celprm](#) pointer passed.
- 2: Invalid projection parameters.
- 3: Invalid coordinate transformation parameters.
- 4: Ill-conditioned coordinate transformation parameters.
- 6: One or more of the  $(\alpha, \delta)$  coordinates were invalid, as indicated by the stat vector.

For returns  $> 1$ , a detailed error message is set in [celprm::err](#) if enabled, see [wcserr\\_enable\(\)](#).

### 8.1.5 Variable Documentation

#### cel\_errmsg

```
const char* cel_errmsg[] [extern]
```

Status return messages.

Status messages to match the status value returned from each function.

## 8.2 cel.h

[Go to the documentation of this file.](#)

```
00001 /*=====
00002  WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003  Copyright (C) 1995-2025, Mark Calabretta
00004
00005  This file is part of WCSLIB.
00006
00007  WCSLIB is free software: you can redistribute it and/or modify it under the
00008  terms of the GNU Lesser General Public License as published by the Free
00009  Software Foundation, either version 3 of the License, or (at your option)
00010  any later version.
00011
00012  WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013  WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
00014  FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015  more details.
00016
00017  You should have received a copy of the GNU Lesser General Public License
00018  along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020  Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021  http://www.atnf.csiro.au/people/Mark.Calabretta
00022  $Id: cel.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023 *=====
00024 *
00025 * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026 * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027 * overview of the library.
00028 *
00029 *
00030 * Summary of the cel routines
00031 * -----
00032 * Routines in this suite implement the part of the FITS World Coordinate
00033 * System (WCS) standard that deals with celestial coordinates, as described in
00034 *
00035 * "Representations of world coordinates in FITS",
00036 * Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)
00037 *
00038 * "Representations of celestial coordinates in FITS",
00039 * Calabretta, M.R., & Greisen, E.W. 2002, A&A, 395, 1077 (WCS Paper II)
00040 *
00041 * These routines define methods to be used for computing celestial world
00042 * coordinates from intermediate world coordinates (a linear transformation
00043 * of image pixel coordinates), and vice versa. They are based on the celprm
00044 * struct which contains all information needed for the computations. This
00045 * struct contains some elements that must be set by the user, and others that
00046 * are maintained by these routines, somewhat like a C++ class but with no
00047 * encapsulation.
00048 *
00049 * Routine celini() is provided to initialize the celprm struct with default
00050 * values, celfree() reclaims any memory that may have been allocated to store
00051 * an error message, celsize() computes its total size including allocated
00052 * memory, celeng() returns information about the state of the struct, and
00053 * celprt() prints its contents.
00054 *
00055 * celperr() prints the error message(s), if any, stored in a celprm struct and
00056 * the prjprm struct that it contains.
00057 *
00058 * A setup routine, celset(), computes intermediate values in the celprm struct
00059 * from parameters in it that were supplied by the user. The struct always
00060 * needs to be set up by celset() but it need not be called explicitly - refer
00061 * to the explanation of celprm::flag.
00062 *
00063 * celx2s() and cels2x() implement the WCS celestial coordinate
```

```

00064 * transformations. In fact, they are high level driver routines for the lower
00065 * level spherical coordinate rotation and projection routines described in
00066 * sph.h and prj.h.
00067 *
00068 *
00069 * celini() - Default constructor for the celprm struct
00070 * -----
00071 * celini() sets all members of a celprm struct to default values. It should
00072 * be used to initialize every celprm struct.
00073 *
00074 * PLEASE NOTE: If the celprm struct has already been initialized, then before
00075 * reinitializing, it celfree() should be used to free any memory that may have
00076 * been allocated to store an error message. A memory leak may otherwise
00077 * result.
00078 *
00079 * Returned:
00080 *   cel      struct celprm*
00081 *           Celestial transformation parameters.
00082 *
00083 * Function return value:
00084 *   int      Status return value:
00085 *           0: Success.
00086 *           1: Null celprm pointer passed.
00087 *
00088 *
00089 * celfree() - Destructor for the celprm struct
00090 * -----
00091 * celfree() frees any memory that may have been allocated to store an error
00092 * message in the celprm struct.
00093 *
00094 * Given and returned:
00095 *   cel      struct celprm*
00096 *           Celestial transformation parameters.
00097 *
00098 * Function return value:
00099 *   int      Status return value:
00100 *           0: Success.
00101 *           1: Null celprm pointer passed.
00102 *
00103 *
00104 * celsize() - Compute the size of a celprm struct
00105 * -----
00106 * celsize() computes the full size of a celprm struct, including allocated
00107 * memory.
00108 *
00109 * Given:
00110 *   cel      const struct celprm*
00111 *           Celestial transformation parameters.
00112 *
00113 *           If NULL, the base size of the struct and the allocated
00114 *           size are both set to zero.
00115 *
00116 * Returned:
00117 *   sizes    int[2]    The first element is the base size of the struct as
00118 *                     returned by sizeof(struct celprm). The second element
00119 *                     is the total allocated size, in bytes. This figure
00120 *                     includes memory allocated for the constituent struct,
00121 *                     celprm::err.
00122 *
00123 *           It is not an error for the struct not to have been set
00124 *           up via celset().
00125 *
00126 * Function return value:
00127 *   int      Status return value:
00128 *           0: Success.
00129 *
00130 *
00131 * celenq() - enquire about the state of a celprm struct
00132 * -----
00133 * celenq() may be used to obtain information about the state of a celprm
00134 * struct. The function returns a true/false answer for the enquiry asked.
00135 *
00136 * Given:
00137 *   cel      const struct celprm*
00138 *           Celestial transformation parameters.
00139 *
00140 *   enquiry  int      Enquiry according to the following parameters:
00141 *                     CELENQ_SET: the struct has been set up by celset().
00142 *                     CELENQ_BYB: the struct is in bypass mode (see
00143 *                     celset()).
00144 *
00145 * Function return value:
00146 *   int      Enquiry result:
00147 *           0: No.
00148 *           1: Yes.
00149 *
00150 *

```

```

00151 * celprt() - Print routine for the celprm struct
00152 * -----
00153 * celprt() prints the contents of a celprm struct using wcsprintf().  Mainly
00154 * intended for diagnostic purposes.
00155 *
00156 * Given:
00157 *   cel          const struct celprm*
00158 *                   Celestial transformation parameters.
00159 *
00160 * Function return value:
00161 *   int          Status return value:
00162 *                   0: Success.
00163 *                   1: Null celprm pointer passed.
00164 *
00165 *
00166 * celperr() - Print error messages from a celprm struct
00167 * -----
00168 * celperr() prints the error message(s), if any, stored in a celprm struct and
00169 * the prjprm struct that it contains.  If there are no errors then nothing is
00170 * printed.  It uses wcserr_prt(), q.v.
00171 *
00172 * Given:
00173 *   cel          const struct celprm*
00174 *                   Coordinate transformation parameters.
00175 *
00176 *   prefix       const char *
00177 *                   If non-NULL, each output line will be prefixed with
00178 *                   this string.
00179 *
00180 * Function return value:
00181 *   int          Status return value:
00182 *                   0: Success.
00183 *                   1: Null celprm pointer passed.
00184 *
00185 *
00186 * celset() - Setup routine for the celprm struct
00187 * -----
00188 * celset() sets up a celprm struct according to information supplied within
00189 * it.
00190 *
00191 * Note that this routine need not be called directly; it will be invoked by
00192 * celx2s() and cels2x() if celprm::flag is anything other than a predefined
00193 * magic value.
00194 *
00195 * celset() normally operates regardless of the value of celprm::flag; i.e.
00196 * even if a struct was previously set up it will be reset unconditionally.
00197 * However, a celprm struct may be put into "bypass" mode by invoking celset()
00198 * initially with celprm::flag == 1 (rather than 0).  celset() will return
00199 * immediately if invoked on a struct in that state.  To take a struct out of
00200 * bypass mode, simply reset celprm::flag to zero.  See also celenq().
00201 *
00202 * Given and returned:
00203 *   cel          struct celprm*
00204 *                   Celestial transformation parameters.
00205 *
00206 * Function return value:
00207 *   int          Status return value:
00208 *                   0: Success.
00209 *                   1: Null celprm pointer passed.
00210 *                   2: Invalid projection parameters.
00211 *                   3: Invalid coordinate transformation parameters.
00212 *                   4: Ill-conditioned coordinate transformation
00213 *                      parameters.
00214 *
00215 *                   For returns > 1, a detailed error message is set in
00216 *                   celprm::err if enabled, see wcserr_enable().
00217 *
00218 *
00219 * celx2s() - Pixel-to-world celestial transformation
00220 * -----
00221 * celx2s() transforms (x,y) coordinates in the plane of projection to
00222 * celestial coordinates (lng,lat).
00223 *
00224 * Given and returned:
00225 *   cel          struct celprm*
00226 *                   Celestial transformation parameters.
00227 *
00228 * Given:
00229 *   nx,ny        int          Vector lengths.
00230 *
00231 *   sxy,sll       int          Vector strides.
00232 *
00233 *   x,y           const double[]
00234 *                   Projected coordinates in pseudo "degrees".
00235 *
00236 * Returned:
00237 *   phi,theta     double[]     Longitude and latitude (phi,theta) in the native

```

```

00238 *                      coordinate system of the projection [deg].
00239 *
00240 *   lng,lat   double[]  Celestial longitude and latitude (lng,lat) of the
00241 *                      projected point [deg].
00242 *
00243 *   stat      int[]     Status return value for each vector element:
00244 *                      0: Success.
00245 *                      1: Invalid value of (x,y).
00246 *
00247 * Function return value:
00248 *   int       Status return value:
00249 *           0: Success.
00250 *           1: Null celprm pointer passed.
00251 *           2: Invalid projection parameters.
00252 *           3: Invalid coordinate transformation parameters.
00253 *           4: Ill-conditioned coordinate transformation
00254 *              parameters.
00255 *           5: One or more of the (x,y) coordinates were
00256 *              invalid, as indicated by the stat vector.
00257 *
00258 *           For returns > 1, a detailed error message is set in
00259 *           celprm::err if enabled, see wcserr_enable().
00260 *
00261 *
00262 * cels2x() - World-to-pixel celestial transformation
00263 * -----
00264 * cels2x() transforms celestial coordinates (lng,lat) to (x,y) coordinates in
00265 * the plane of projection.
00266 *
00267 * Given and returned:
00268 *   cel      struct celprm*
00269 *           Celestial transformation parameters.
00270 *
00271 * Given:
00272 *   nlng,nlat int      Vector lengths.
00273 *
00274 *   sll,sxy   int      Vector strides.
00275 *
00276 *   lng,lat   const double[]
00277 *           Celestial longitude and latitude (lng,lat) of the
00278 *           projected point [deg].
00279 *
00280 * Returned:
00281 *   phi,theta double[] Longitude and latitude (phi,theta) in the native
00282 *                      coordinate system of the projection [deg].
00283 *
00284 *   x,y       double[] Projected coordinates in pseudo "degrees".
00285 *
00286 *   stat      int[]     Status return value for each vector element:
00287 *                      0: Success.
00288 *                      1: Invalid value of (lng,lat).
00289 *
00290 * Function return value:
00291 *   int       Status return value:
00292 *           0: Success.
00293 *           1: Null celprm pointer passed.
00294 *           2: Invalid projection parameters.
00295 *           3: Invalid coordinate transformation parameters.
00296 *           4: Ill-conditioned coordinate transformation
00297 *              parameters.
00298 *           6: One or more of the (lng,lat) coordinates were
00299 *              invalid, as indicated by the stat vector.
00300 *
00301 *           For returns > 1, a detailed error message is set in
00302 *           celprm::err if enabled, see wcserr_enable().
00303 *
00304 *
00305 * celprm struct - Celestial transformation parameters
00306 * -----
00307 * The celprm struct contains information required to transform celestial
00308 * coordinates. It consists of certain members that must be set by the user
00309 * ("given") and others that are set by the WCSLIB routines ("returned"). Some
00310 * of the latter are supplied for informational purposes and others are for
00311 * internal use only.
00312 *
00313 * Returned celprm struct members must not be modified by the user.
00314 *
00315 *   int flag
00316 *   (Given and returned) This flag must be set to zero (or 1, see celset())
00317 *   whenever any of the following celprm struct members are set or changed:
00318 *
00319 *   - celprm::offset,
00320 *   - celprm::phi0,
00321 *   - celprm::theta0,
00322 *   - celprm::ref[4],
00323 *   - celprm::prj:
00324 *   - prjprm::code,

```

```

00325 *      - prjprm::r0,
00326 *      - prjprm::pv[],
00327 *      - prjprm::phi0,
00328 *      - prjprm::theta0.
00329 *
00330 *      This signals the initialization routine, celset(), to recompute the
00331 *      returned members of the celprm struct. celset() will reset flag to
00332 *      indicate that this has been done.
00333 *
00334 *      int offset
00335 *      (Given) If true (non-zero), an offset will be applied to (x,y) to
00336 *      force (x,y) = (0,0) at the fiducial point, (phi_0,theta_0).
00337 *      Default is 0 (false).
00338 *
00339 *      double phi0
00340 *      (Given) The native longitude, phi_0 [deg], and ...
00341 *
00342 *      double theta0
00343 *      (Given) ... the native latitude, theta_0 [deg], of the fiducial point,
00344 *      i.e. the point whose celestial coordinates are given in
00345 *      celprm::ref[1:2]. If undefined (set to a magic value by prjini()) the
00346 *      initialization routine, celset(), will set this to a projection-specific
00347 *      default.
00348 *
00349 *      double ref[4]
00350 *      (Given) The first pair of values should be set to the celestial
00351 *      longitude and latitude of the fiducial point [deg] - typically right
00352 *      ascension and declination. These are given by the CRVALia keywords in
00353 *      FITS.
00354 *
00355 *      (Given and returned) The second pair of values are the native longitude,
00356 *      phi_p [deg], and latitude, theta_p [deg], of the celestial pole (the
00357 *      latter is the same as the celestial latitude of the native pole,
00358 *      delta_p) and these are given by the FITS keywords LONPOLEa and LATPOLEa
00359 *      (or by PVi_2a and PVi_3a attached to the longitude axis which take
00360 *      precedence if defined).
00361 *
00362 *      LONPOLEa defaults to phi_0 (see above) if the celestial latitude of the
00363 *      fiducial point of the projection is greater than or equal to the native
00364 *      latitude, otherwise phi_0 + 180 [deg]. (This is the condition for the
00365 *      celestial latitude to increase in the same direction as the native
00366 *      latitude at the fiducial point.) ref[2] may be set to UNDEFINED (from
00367 *      wcsmath.h) or 999.0 to indicate that the correct default should be
00368 *      substituted.
00369 *
00370 *      theta_p, the native latitude of the celestial pole (or equally the
00371 *      celestial latitude of the native pole, delta_p) is often determined
00372 *      uniquely by CRVALia and LONPOLEa in which case LATPOLEa is ignored.
00373 *      However, in some circumstances there are two valid solutions for theta_p
00374 *      and LATPOLEa is used to choose between them. LATPOLEa is set in ref[3]
00375 *      and the solution closest to this value is used to reset ref[3]. It is
00376 *      therefore legitimate, for example, to set ref[3] to +90.0 to choose the
00377 *      more northerly solution - the default if the LATPOLEa keyword is omitted
00378 *      from the FITS header. For the special case where the fiducial point of
00379 *      the projection is at native latitude zero, its celestial latitude is
00380 *      zero, and LONPOLEa = +/- 90.0 then the celestial latitude of the native
00381 *      pole is not determined by the first three reference values and LATPOLEa
00382 *      specifies it completely.
00383 *
00384 *      The returned value, celprm::latpreg, specifies how LATPOLEa was actually
00385 *      used.
00386 *
00387 *      struct prjprm prj
00388 *      (Given and returned) Projection parameters described in the prologue to
00389 *      prj.h.
00390 *
00391 *      double euler[5]
00392 *      (Returned) Euler angles and associated intermediaries derived from the
00393 *      coordinate reference values. The first three values are the Z-, X-, and
00394 *      Z'-Euler angles [deg], and the remaining two are the cosine and sine of
00395 *      the X-Euler angle.
00396 *
00397 *      int latpreg
00398 *      (Returned) For informational purposes, this indicates how the LATPOLEa
00399 *      keyword was used
00400 *      - 0: Not required, theta_p (== delta_p) was determined uniquely by the
00401 *      CRVALia and LONPOLEa keywords.
00402 *      - 1: Required to select between two valid solutions of theta_p.
00403 *      - 2: theta_p was specified solely by LATPOLEa.
00404 *
00405 *      int isolat
00406 *      (Returned) True if the spherical rotation preserves the magnitude of the
00407 *      latitude, which occurs iff the axes of the native and celestial
00408 *      coordinates are coincident. It signals an opportunity to cache
00409 *      intermediate calculations common to all elements in a vector
00410 *      computation.
00411 *

```

```

00412 *   struct wcserr *err
00413 *       (Returned) If enabled, when an error status is returned, this struct
00414 *       contains detailed information about the error, see wcserr_enable().
00415 *
00416 *   void *padding
00417 *       (An unused variable inserted for alignment purposes only.)
00418 *
00419 *
00420 * Global variable: const char *cel_errmsg[] - Status return messages
00421 * -----
00422 * Status messages to match the status value returned from each function.
00423 *
00424 * =====*/
00425
00426 #ifndef WCSLIB_CEL
00427 #define WCSLIB_CEL
00428
00429 #include "prj.h"
00430
00431 #ifdef __cplusplus
00432 extern "C" {
00433 #endif
00434
00435 enum celeng_enum {
00436     CELENQ_SET = 2,           // celprm struct has been set up.
00437     CELENQ_BYF = 4,           // celprm struct is in bypass mode.
00438 };
00439
00440 extern const char *cel_errmsg[];
00441
00442 enum cel_errmsg_enum {
00443     CELERR_SUCCESS           = 0, // Success.
00444     CELERR_NULL_POINTER      = 1, // Null celprm pointer passed.
00445     CELERR_BAD_PARAM         = 2, // Invalid projection parameters.
00446     CELERR_BAD_COORD_TRANS   = 3, // Invalid coordinate transformation
00447                                // parameters.
00448     CELERR_ILL_COORD_TRANS   = 4, // Ill-conditioned coordinated transformation
00449                                // parameters.
00450     CELERR_BAD_PIX           = 5, // One or more of the (x,y) coordinates were
00451                                // invalid.
00452     CELERR_BAD_WORLD         = 6, // One or more of the (lng,lat) coordinates
00453                                // were invalid.
00454 };
00455
00456 struct celprm {
00457     // Initialization flag (see the prologue above).
00458     //-----
00459     int    flag;                // Set to zero to force initialization.
00460
00461     // Parameters to be provided (see the prologue above).
00462     //-----
00463     int    offset;              // Force (x,y) = (0,0) at (phi_0,theta_0).
00464     double phi0, theta0;        // Native coordinates of fiducial point.
00465     double ref[4];              // Celestial coordinates of fiducial
00466                                // point and native coordinates of
00467                                // celestial pole.
00468
00469     struct prjprm prj;          // Projection parameters (see prj.h).
00470
00471     // Information derived from the parameters supplied.
00472     //-----
00473     double euler[5];            // Euler angles and functions thereof.
00474     int    latpreg;             // LATPOLEa requirement.
00475     int    isolat;              // True if |latitude| is preserved.
00476
00477     // Error messaging, if enabled.
00478     //-----
00479     struct wcserr *err;         // Error handling, if enabled.
00480
00481     //-----
00482     // Private - the remainder are for internal use.
00483     //-----
00484     void *padding;              // (Dummy inserted for alignment purposes.)
00485 };
00486
00487 // Size of the celprm struct in int units, used by the Fortran wrappers.
00488 #define CELLEN (sizeof(struct celprm)/sizeof(int))
00489
00490
00491 int celini(struct celprm *cel);
00492
00493 int celfree(struct celprm *cel);
00494
00495 int celsize(const struct celprm *cel, int sizes[2]);
00496
00497 int celeng(const struct celprm *cel, int enquiry);
00498

```

```

00499 int celprt(const struct celprm *cel);
00500
00501 int celperr(const struct celprm *cel, const char *prefix);
00502
00503 int celset(struct celprm *cel);
00504
00505 int celx2s(struct celprm *cel, int nx, int ny, int sxy, int sll,
00506           const double x[], const double y[],
00507           double phi[], double theta[], double lng[], double lat[],
00508           int stat[]);
00509
00510 int cels2x(struct celprm *cel, int nlng, int nlat, int sll, int sxy,
00511           const double lng[], const double lat[],
00512           double phi[], double theta[], double x[], double y[],
00513           int stat[]);
00514
00515
00516 // Deprecated.
00517 #define celini_errmsg cel_errmsg
00518 #define celprt_errmsg cel_errmsg
00519 #define celset_errmsg cel_errmsg
00520 #define celx2s_errmsg cel_errmsg
00521 #define cels2x_errmsg cel_errmsg
00522
00523 #ifdef __cplusplus
00524 }
00525 #endif
00526
00527 #endif // WCSLIB_CEL

```

## 8.3 dis.h File Reference

### Data Structures

- struct [dpkey](#)  
*Store for  $DP_{ja}$  and  $DQ_{ia}$  keyvalues.*
- struct [disprm](#)  
*Distortion parameters.*

### Macros

- #define [DISP2X\\_ARGS](#)
- #define [DISX2P\\_ARGS](#)
- #define [DPLEN](#) (sizeof(struct [dpkey](#))/sizeof(int))
- #define [DISLEN](#) (sizeof(struct [disprm](#))/sizeof(int))

### Enumerations

- enum [disenq\\_enum](#) { [DISENQ\\_MEM](#) = 1 , [DISENQ\\_SET](#) = 2 , [DISENQ\\_BYN](#) = 4 }
- enum [dis\\_errmsg\\_enum](#) {  
[DISERR\\_SUCCESS](#) = 0 , [DISERR\\_NULL\\_POINTER](#) = 1 , [DISERR\\_MEMORY](#) = 2 , [DISERR\\_BAD\\_PARAM](#)  
= 3 ,  
[DISERR\\_DISTORT](#) = 4 , [DISERR\\_DEDISTORT](#) = 5 }

## Functions

- int **disndp** (int n)  
*Memory allocation for **DP**<sub>ja</sub> and **DQ**<sub>ia</sub>.*
- int **dpfill** (struct **dpkey** \*dp, const char \*keyword, const char \*field, int j, int type, int i, double f)  
*Fill the contents of a dpkey struct.*
- int **dpkeyi** (const struct **dpkey** \*dp)  
*Get the data value in a dpkey struct as int.*
- double **dpkeyd** (const struct **dpkey** \*dp)  
*Get the data value in a dpkey struct as double.*
- int **disini** (int alloc, int naxis, struct **disprm** \*dis)  
*Default constructor for the **disprm** struct.*
- int **disinit** (int alloc, int naxis, struct **disprm** \*dis, int ndpmax)  
*Default constructor for the **disprm** struct.*
- int **discpy** (int alloc, const struct **disprm** \*dissrc, struct **disprm** \*disdst)  
*Copy routine for the **disprm** struct.*
- int **disfree** (struct **disprm** \*dis)  
*Destructor for the **disprm** struct.*
- int **dissize** (const struct **disprm** \*dis, int sizes[2])  
*Compute the size of a **disprm** struct.*
- int **disenq** (const struct **disprm** \*dis, int enquiry)  
*enquire about the state of a **disprm** struct.*
- int **disprt** (const struct **disprm** \*dis)  
*Print routine for the **disprm** struct.*
- int **disperr** (const struct **disprm** \*dis, const char \*prefix)  
*Print error messages from a **disprm** struct.*
- int **dishdo** (struct **disprm** \*dis)  
*write FITS headers using **TPD**.*
- int **disset** (struct **disprm** \*dis)  
*Setup routine for the **disprm** struct.*
- int **disp2x** (struct **disprm** \*dis, const double rawcrd[], double discrd[])  
*Apply distortion function.*
- int **disx2p** (struct **disprm** \*dis, const double discrd[], double rawcrd[])  
*Apply de-distortion function.*
- int **diswarp** (struct **disprm** \*dis, const double pixblc[], const double pixtrc[], const double pixsamp[], int \*nsamp, double maxdis[], double \*maxtot, double avgdis[], double \*avgtot, double rmsdis[], double \*rmstot)  
*Compute measures of distortion.*

## Variables

- const char \* **dis\_errmsg** []  
*Status return messages.*

### 8.3.1 Detailed Description

Routines in this suite implement extensions to the FITS World Coordinate System (WCS) standard proposed by

"Representations of distortions in FITS world coordinate systems",  
Calabretta, M.R. et al. (WCS Paper IV, draft dated 2004/04/22),  
available from <http://www.atnf.csiro.au/people/Mark.Calabretta>

In brief, a distortion function may occupy one of two positions in the WCS algorithm chain. Prior distortions precede the linear transformation matrix, whether it be **PCi\_ja** or **CDi\_ja**, and sequent distortions follow it. WCS Paper IV defines FITS keywords used to specify parameters for predefined distortion functions. The following are used for prior distortions:

```
CPDISja ... (string-valued, identifies the distortion function)
DPja ... (record-valued, parameters)
CPERRja ... (floating-valued, maximum value)
```

Their counterparts for sequent distortions are **CQDISia**, **DQia**, and **CQERRia**. An additional floating-valued keyword, **DVERRa**, records the maximum value of the combined distortions.

**DPja** and **DQia** are "record-valued". Syntactically, the keyvalues are standard FITS strings, but they are to be interpreted in a special way. The general form is

```
DPja = '<field-specifier>: <float>'
```

where the field-specifier consists of a sequence of fields separated by periods, and the ':' between the field-specifier and the floating-point value is part of the record syntax. For example:

```
DP1 = 'AXIS.1: 1'
```

Certain field-specifiers are defined for all distortion functions, while others are defined only for particular distortions. Refer to WCS Paper IV for further details. **wcspih()** parses all distortion keywords and loads them into a **disprm** struct for analysis by **disset()** which knows (or possibly does not know) how to interpret them. Of the Paper IV distortion functions, only the general Polynomial distortion is currently implemented here.

#### TPV - the TPV "projection":

The distortion function component of the **TPV** celestial "projection" is also supported. The **TPV** projection, originally proposed in a draft of WCS Paper II, consists of a **TAN** projection with sequent polynomial distortion, the coefficients of which are encoded in **PVi\_ma** keyrecords. Full details may be found at the registry of FITS conventions:

<http://fits.gsfc.nasa.gov/registry/tpvwcs/tpv.html>

Internally, **wcsset()** changes **TPV** to a **TAN** projection, translates the **PVi\_ma** keywords to **DQia** and loads them into a **disprm** struct. These **DQia** keyrecords have the form

```
DQia = 'TPV.m: <value>'
```

where i, a, m, and the value for each **DQia** match each **PVi\_ma**. Consequently, WCSLIB would handle a FITS header containing these keywords, along with **CQDISia** = **'TPV'** and the required **DQia.NAXES** and **DQia.AXIS.i** keywords.

Note that, as defined, **TPV** assumes that **CDi\_ja** is used to define the linear transformation. The section on historical idiosyncrasies (below) cautions about translating **CDi\_ja** to **PCi\_ja** plus **CDELTia** in this case.

#### SIP - Simple Imaging Polynomial:

These routines also support the Simple Imaging Polynomial (**SIP**), whose design was influenced by early drafts of WCS Paper IV. It is described in detail in

<http://fits.gsfc.nasa.gov/registry/sip.html>

**SIP**, which is defined only as a prior distortion for 2-D celestial images, has the interesting feature that it records an approximation to the inverse polynomial distortion function. This is used by **disx2p()** to provide an initial estimate for its more precise iterative inversion. The special-purpose keywords used by **SIP** are parsed and translated by **wcspih()** as follows:

```
A_p_q = <value> -> DP1 = 'SIP.FWD.p_q: <value>'
AP_p_q = <value> -> DP1 = 'SIP.REV.p_q: <value>'
B_p_q = <value> -> DP2 = 'SIP.FWD.p_q: <value>'
BP_p_q = <value> -> DP2 = 'SIP.REV.p_q: <value>'
```

```
A_DMAX = <value>  ->  DPERR1 = <value>
B_DMAX = <value>  ->  DPERR2 = <value>
```

**SIP**'s **A\_ORDER** and **B\_ORDER** keywords are not used. WCSLIB would recognise a FITS header containing the above keywords, along with **CPDIS**<sub>ja</sub> = '**SIP**' and the required **DP**<sub>ja</sub>.**NAXES** keywords.

#### DSS - Digitized Sky Survey:

The Digitized Sky Survey resulted from the production of the Guide Star Catalogue for the Hubble Space Telescope. Plate solutions based on a polynomial distortion function were encoded in FITS using non-standard keywords. Sect. 5.2 of WCS Paper IV describes how **DSS** coordinates may be translated to a sequent Polynomial distortion using two auxiliary variables. That translation is based on optimising the non-distortion component of the plate solution.

Following Paper IV, **wcspih()** translates the non-distortion component of **DSS** coordinates to standard WCS keywords (**CRPIX**<sub>ja</sub>, **PCi**<sub>ja</sub>, **CRVAL**<sub>ia</sub>, etc), and fills a **wcsprm** struct with their values. It encodes the **DSS** polynomial coefficients as

```
AMDxm = <value>  ->  DQ1 = 'AMD.m: <value>'
AMDym = <value>  ->  DQ2 = 'AMD.m: <value>'
```

WCSLIB would recognise a FITS header containing the above keywords, along with **CQDIS**<sub>ia</sub> = '**DSS**' and the required **DQ**<sub>ia</sub>.**NAXES** keywords.

#### WAT - the TNX and ZPX "projections":

The **TNX** and **ZPX** "projections" add a polynomial distortion function to the standard **TAN** and **ZPN** projections respectively. Unusually, the polynomial may be expressed as the sum of Chebyshev or Legendre polynomials, or as a simple sum of monomials, as described in

```
http://fits.gsfc.nasa.gov/registry/tnx/tnx-doc.html
http://fits.gsfc.nasa.gov/registry/zpxwcs/zpx.html
```

The polynomial coefficients are encoded in special-purpose **WATi**<sub>n</sub> keywords as a set of continued strings, thus providing the name for this distortion type. **WATi**<sub>n</sub> are parsed and translated by **wcspih()** into the following set:

```
DQi = 'WAT.POLY: <value>'
DQi = 'WAT.XMIN: <value>'
DQi = 'WAT.XMAX: <value>'
DQi = 'WAT.YMIN: <value>'
DQi = 'WAT.YMAX: <value>'
DQi = 'WAT.CHBV.m_n: <value>' or
DQi = 'WAT.LEGR.m_n: <value>' or
DQi = 'WAT.MONO.m_n: <value>'
```

along with **CQDIS**<sub>ia</sub> = '**WAT**' and the required **DP**<sub>ja</sub>.**NAXES** keywords. For **ZPX**, the **ZPN** projection parameters are also encoded in **WATi**<sub>n</sub>, and **wcspih()** translates these to standard **PVi**<sub>ma</sub>.

Note that, as defined, **TNX** and **ZPX** assume that **CDi**<sub>ja</sub> is used to define the linear transformation. The section on historical idiosyncrasies (below) cautions about translating **CDi**<sub>ja</sub> to **PCi**<sub>ja</sub> plus **CDEL**<sub>ia</sub> in this case.

#### TPD - Template Polynomial Distortion:

The "Template Polynomial Distortion" (**TPD**) is a superset of the **TPV**, **SIP**, **DSS**, and **WAT** (**TNX** & **ZPX**) polynomial distortions that also supports 1-D usage and inversions. Like **TPV**, **SIP**, and **DSS**, the form of the polynomial is fixed (the "template") and only the coefficients for the required terms are set non-zero. **TPD** generalizes **TPV** in going to 9th degree, **SIP** by accomodating **TPV**'s linear and radial terms, and **DSS** in both respects. While in theory the degree of the **WAT** polynomial distortion is unconstrained, in practice it is limited to values that can be handled by **TPD**.

Within WCSLIB, **TPV**, **SIP**, **DSS**, and **WAT** are all implemented as special cases of **TPD**. Indeed, **TPD** was developed precisely for that purpose. **WAT** distortions expressed as the sum of Chebyshev or Legendre polynomials are expanded for **TPD** as a simple sum of monomials. Moreover, the general Polynomial distortion is translated and implemented internally as **TPD** whenever possible.

However, WCSLIB also recognizes '**TPD**' as a distortion function in its own right (i.e. a recognized value of **CPDIS**<sub>ja</sub> or **CQDIS**<sub>ia</sub>), for use as both prior and sequent distortions. Its **DP**<sub>ja</sub> and **DQ**<sub>ia</sub> keyrecords have the form

```
DPja = 'TPD.FWD.m: <value>'
```

```
DPja = 'TPD.REV.m: <value>'
```

for the forward and reverse distortion functions. Moreover, like the general Polynomial distortion, **TPD** supports auxiliary variables, though only as a linear transformation of pixel coordinates (p1,p2):

```
x = a0 + a1*p1 + a2*p2
y = b0 + b1*p1 + b2*p2
```

where the coefficients of the auxiliary variables (x,y) are recorded as

```
DPja = 'AUX.1.COEFF.0: a0'      ...default 0.0
DPja = 'AUX.1.COEFF.1: a1'      ...default 1.0
DPja = 'AUX.1.COEFF.2: a2'      ...default 0.0
DPja = 'AUX.2.COEFF.0: b0'      ...default 0.0
DPja = 'AUX.2.COEFF.1: b1'      ...default 0.0
DPja = 'AUX.2.COEFF.2: b2'      ...default 1.0
```

Though nowhere near as powerful, in typical applications **TPD** is considerably faster than the general Polynomial distortion. As **TPD** has a finite and not too large number of possible terms (60), the coefficients for each can be stored (by `disset()`) in a fixed location in the `disprm::dparm[]` array. A large part of the speedup then arises from evaluating the polynomial using Horner's scheme.

Separate implementations for polynomials of each degree, and conditionals for 1-D polynomials and 2-D polynomials with and without the radial variable, ensure that unused terms mostly do not impose a significant computational overhead.

The **TPD** terms are as follows

0: 1	4: xx	12: xxxx	24: xxxxxx	40: xxxxxxxx
	5: xy	13: xxxy	25: xxxxxy	41: xxxxxxxy
1: x	6: yy	14: xxyy	26: xxxxyy	42: xxxxxxxy
2: y		15: xyxy	27: xxxyyy	43: xxxxxxxy
3: r	7: xxx	16: yyyx	28: xxyyyy	44: xxxxyyyy
	8: xxy		29: xyxyyy	45: xxxxyyyy
	9: xyy	17: xxxxx	30: yyyxyy	46: xxxxyyyy
	10: yyy	18: xxxxy		47: xyxyyyy
	11: rrr	19: xxxyy	31: xxxxxxx	48: yyyxyyyy
		20: xxyyy	32: xxxxxxxy	
		21: xyyyy	33: xxxxxxxy	49: xxxxxxxx
		22: yyyyy	34: xxxxyyy	50: xxxxxxxy
		23: rrrrr	35: xxxxyyy	51: xxxxxxxy
			36: xxyyyyy	52: xxxxxxxy
			37: xyxyyyy	53: xxxxyyyy
			38: yyyxyyy	54: xxxxyyyy
			39: rrrrrrr	55: xxxxyyyy
				56: xxyyyyyy
				57: xyxyyyyy
				58: yyyxyyyy
				59: rrrrrrrr

where  $r = \sqrt{x^2 + y^2}$ . Note that even powers of  $r$  are excluded since they can be accommodated by powers of  $(x^2 + y^2)$ .

Note here that "x" refers to the axis to which the distortion function is attached, with "y" being the complementary axis. So, for example, with longitude on axis 1 and latitude on axis 2, for **TPD** attached to axis 1, "x" refers to axis 1 and "y" to axis 2. For **TPD** attached to axis 2, "x" refers to axis 2, and "y" to axis 1.

**TPV** uses all terms up to 39. The  $m$  in its `PV_i_ma` keywords translates directly to the **TPD** coefficient number.

**SIP** uses all terms except for 0, 3, 11, 23, 39, and 59, with terms 1 and 2 only used for the inverse. Its `A_p_q`, etc. keywords must be translated using a map.

**DSS** uses terms 0, 1, 2, 4, 5, 6, 7, 8, 9, 10, 17, 19, and 21. The presence of a non-zero constant term arises through the use of auxiliary variables with origin offset from the reference point of the **TAN** projection. However, in the translation given by WCS Paper IV, the distortion polynomial is zero, or very close to zero, at the reference pixel itself. The mapping between **DSS's** `AMDxm` (or `AMDym`) keyvalues and **TPD** coefficients, while still simple, is not quite as straightforward as for **TPV** and **SIP**.

**WAT** uses all but the radial terms, namely 3, 11, 23, 39, and 59. While the mapping between **WAT's** monomial coefficients and **TPD** is fairly simple, for its expression in terms of a sum of Chebyshev or Legendre polynomials it is much less so.

### Historical idiosyncrasies:

In addition to the above, some historical distortion functions have further idiosyncrasies that must be taken into account when translating them to **TPD**.

WCS Paper IV specifies that a distortion function returns a correction to be added to pixel coordinates (prior distortion) or intermediate pixel coordinates (sequent distortion). The correction is meant to be small so that ignoring the distortion function, i.e. setting the correction to zero, produces a commensurately small error.

However, rather than an additive correction, some historical distortion functions (**TPV**, **DSS**) define a polynomial that returns the corrected coordinates directly.

The difference between the two approaches is readily accounted for simply by adding or subtracting 1 from the coefficient of the first degree term of the polynomial. However, it opens the way for considerable confusion.

Additional to the formalism of WCS Paper IV, both the Polynomial and **TPD** distortion functions recognise a keyword

```
DPja = 'DOCCORR: 0'
```

which is meant to apply generally to indicate that the distortion function returns the corrected coordinates directly. Any other value for **DOCCORR** (or its absence) indicates that the distortion function returns an additive correction.

WCS Paper IV also specifies that the independent variables of a distortion function are pixel coordinates (prior distortion) or intermediate pixel coordinates (sequent distortion).

On the contrary, the independent variables of the **SIP** polynomial are pixel coordinate offsets from the reference pixel. This is readily handled via the renormalisation parameters

```
DPja = 'OFFSET.jhat: <value>'
```

where the value corresponds to **CRPIX**<sub>ja</sub>.

Likewise, because **TPV**, **TNX**, and **ZPX** are defined in terms of **CDi\_ja**, the independent variables of the polynomial are intermediate world coordinates rather than intermediate pixel coordinates. Because sequent distortions are always applied before **CDELT**<sub>ia</sub>, if **CDi\_ja** is translated to **PCi\_ja** plus **CDELT**<sub>ia</sub>, then either **CDELT**<sub>ia</sub> must be unity, or the distortion polynomial coefficients must be adjusted to account for the change of scale.

### Summary of the **dis** routines:

These routines apply the distortion functions defined by the extension to the FITS WCS standard proposed in Paper IV. They are based on the **disprm** struct which contains all information needed for the computations. The struct contains some members that must be set by the user, and others that are maintained by these routines, somewhat like a C++ class but with no encapsulation.

**dpfill()**, **dpkeyi()**, and **dpkeyd()** are provided to manage the **dpkey** struct.

**disndp()**, **disini()**, **disinit()**, **discpy()**, and **disfree()** are provided to manage the **disprm** struct, **dissize()** computes its total size including allocated memory, **disenq()** returns information about the state of the struct, and **disprt()** prints its contents.

**disperr()** prints the error message(s) (if any) stored in a **disprm** struct.

**wcshdo()** normally writes **SIP** and **TPV** headers in their native form if at all possible. However, **dishdo()** may be used to set a flag that tells it to write the header in the form of the **TPD** translation used internally.

A setup routine, **disset()**, computes intermediate values in the **disprm** struct from parameters in it that were supplied by the user. The struct always needs to be set up by **disset()**, though **disset()** need not be called explicitly - refer to the explanation of **disprm::flag**.

**disp2x()** and **disx2p()** implement the WCS distortion functions, **disp2x()** using separate functions, such as **dispoly()** and **tpd7()**, to do the computation.

An auxiliary routine, **diswarp()**, computes various measures of the distortion over a specified range of coordinates.

### PLEASE NOTE:

### 8.3.2 Macro Definition Documentation

#### DISP2X\_ARGS

```
#define DISP2X_ARGS
```

##### Value:

```
int inverse, const int iparm[], const double dparm[], \
int ncrd, const double rawcrd[], double *discrd
```

#### DISX2P\_ARGS

```
#define DISX2P_ARGS
```

##### Value:

```
int inverse, const int iparm[], const double dparm[], \
int ncrd, const double discrd[], double *rawcrd
```

#### DPLEN

```
#define DPLEN (sizeof(struct dpkey)/sizeof(int))
```

#### DISLEN

```
#define DISLEN (sizeof(struct disprm)/sizeof(int))
```

### 8.3.3 Enumeration Type Documentation

#### disenq\_enum

```
enum disenq_enum
```

##### Enumerator

DISENQ_MEM	
DISENQ_SET	
DISENQ_BYN	

#### dis\_errmsg\_enum

```
enum dis_errmsg_enum
```

##### Enumerator

---

DISERR_SUCCESS	
DISERR_NULL_POINTER	
DISERR_MEMORY	
DISERR_BAD_PARAM	
DISERR_DISTORT	
DISERR_DEDISTORT	

### 8.3.4 Function Documentation

#### disndp()

```
int disndp (
    int n)
```

Memory allocation for **DP<sub>ja</sub>** and **DQ<sub>ia</sub>**.

**disndp()** sets or gets the value of NDPMAX (default 256). This global variable controls the maximum number of dpkey structs, for holding **DP<sub>ja</sub>** or **DQ<sub>ia</sub>** keyvalues, that **disini()** should allocate space for. It is also used by **disinit()** as the default value of ndpmax.

**PLEASE NOTE:** This function is not thread-safe.

#### Parameters

in	<i>n</i>	Value of NDPMAX; ignored if < 0. Use a value less than zero to get the current value.
----	----------	---

#### Returns

Current value of NDPMAX.

#### dpfill()

```
int dpfill (
    struct dpkey * dp,
    const char * keyword,
    const char * field,
    int j,
    int type,
    int i,
    double f)
```

Fill the contents of a dpkey struct.

**dpfill()** is a utility routine to aid in filling the contents of the dpkey struct. No checks are done on the validity of the inputs.

WCS Paper IV specifies the syntax of a record-valued keyword as

```
keyword = '<field-specifier>: <float>'
```

However, some **DP<sub>ja</sub>** and **DQ<sub>ia</sub>** record values, such as those of **DP<sub>ja</sub>.NAXES** and **DP<sub>ja</sub>.AXIS.J**, are intrinsically integer-valued. While FITS header parsers are not expected to know in advance which of **DP<sub>ja</sub>** and **DQ<sub>ia</sub>** are integral and which are floating point, if the record's value parses as an integer (i.e. without decimal point or exponent), then preferably enter it into the dpkey struct as an integer. Either way, it doesn't matter as **diset()** accepts

**Parameters**

in, out	<i>dp</i>	Store for <b>DP</b> <sub>ja</sub> and <b>DQ</b> <sub>ia</sub> keyvalues.
in	<i>keyword</i>	
in	<i>field</i>	These arguments are concatenated with an intervening "." to construct the full record field name, i.e. including the keyword name, <b>DP</b> <sub>ja</sub> or <b>DQ</b> <sub>ia</sub> (but excluding the colon delimiter which is NOT part of the name). Either may be given as a NULL pointer. Set both NULL to omit setting this component of the struct.
in	<i>j</i>	Axis number (1-relative), i.e. the <i>j</i> in <b>DP</b> <sub>ja</sub> or <i>i</i> in <b>DQ</b> <sub>ia</sub> . Can be given as 0, in which case the axis number will be obtained from the keyword component of the field name which must either have been given or preset. If <i>j</i> is non-zero, and keyword was given, then the value of <i>j</i> will be used to fill in the axis number.
in	<i>type</i>	Data type of the record's value <ul style="list-style-type: none"> <li>• 0: Integer,</li> <li>• 1: Floating point.</li> </ul>
in	<i>i</i>	For type == 0, the integer value of the record.
in	<i>f</i>	For type == 1, the floating point value of the record.

**Returns**

Status return value:

- 0: Success.

**dpkeyi()**

```
int dpkeyi (
    const struct dpkey * dp)
```

Get the data value in a dpkey struct as int.

**dpkeyi()** returns the data value in a dpkey struct as an integer value.

**Parameters**

in, out	<i>dp</i>	Parsed contents of a <b>DP</b> <sub>ja</sub> or <b>DQ</b> <sub>ia</sub> keyrecord.
---------	-----------	--

**Returns**

The record's value as int.

**dpkeyd()**

```
double dpkeyd (
    const struct dpkey * dp)
```

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Get the data value in a dpkey struct as double.

**dpkeyd()** returns the data value in a dpkey struct as a floating point value.

### Parameters

<i>in, out</i>	<i>dp</i>	Parsed contents of a <b>DP</b> <sub>ja</sub> or <b>DQ</b> <sub>ia</sub> keyrecord.
----------------	-----------	--

### Returns

The record's value as double.

### disini()

```
int disini (
    int alloc,
    int naxis,
    struct disprm * dis)
```

Default constructor for the [disprm](#) struct.

**disini()** is a thin wrapper on **disinit()**. It invokes it with `ndpmax` set to -1 which causes it to use the value of the global variable `NDPMAX`. It is thereby potentially thread-unsafe if `NDPMAX` is altered dynamically via [disndp\(\)](#). Use **disinit()** for a thread-safe alternative in this case.

### disinit()

```
int disinit (
    int alloc,
    int naxis,
    struct disprm * dis,
    int ndpmax)
```

Default constructor for the [disprm](#) struct.

**disinit()** allocates memory for arrays in a [disprm](#) struct and sets all members of the struct to default values.

**PLEASE NOTE:** every [disprm](#) struct must be initialized by **disinit()**, possibly repeatedly. On the first invocation, and only the first invocation, [disprm::flag](#) must be set to -1 to initialize memory management, regardless of whether **disinit()** will actually be used to allocate memory.

### Parameters

<i>in</i>	<i>alloc</i>	If true, allocate memory unconditionally for arrays in the <a href="#">disprm</a> struct. If false, it is assumed that pointers to these arrays have been set by the user except if they are null pointers in which case memory will be allocated for them regardless. (In other words, setting <code>alloc</code> true saves having to initialize these pointers to zero.)
<i>in</i>	<i>naxis</i>	The number of world coordinate axes, used to determine array sizes.
<i>in, out</i>	<i>dis</i>	Distortion function parameters. Note that, in order to initialize memory management <a href="#">disprm::flag</a> must be set to -1 when <code>dis</code> is initialized for the first time (memory leaks may result if it had already been initialized).

<i>in</i>	<i>ndpmax</i>	The number of <b>DP</b> <sub>ja</sub> or <b>DQ</b> <sub>ia</sub> keywords to allocate space for. If set to -1, the value of the global variable NDPMAX will be used. This is potentially thread-unsafe if <a href="#">disndp()</a> is being used dynamically to alter its value.
-----------	---------------	--

### Returns

Status return value:

- 0: Success.
- 1: Null [disprm](#) pointer passed.
- 2: Memory allocation failed.

For returns > 1, a detailed error message is set in [disprm::err](#) if enabled, see [wcserr\\_enable\(\)](#).

### discpy()

```
int discpy (
    int alloc,
    const struct disprm * dissrc,
    struct disprm * disdst)
```

Copy routine for the [disprm](#) struct.

**discpy()** does a deep copy of one [disprm](#) struct to another, using [disinit\(\)](#) to allocate memory unconditionally for its arrays if required. Only the "information to be provided" part of the struct is copied; a call to [disset\(\)](#) is required to initialize the remainder.

### Parameters

<i>in</i>	<i>alloc</i>	If true, allocate memory unconditionally for arrays in the destination. Otherwise, it is assumed that pointers to these arrays have been set by the user except if they are null pointers in which case memory will be allocated for them regardless.
<i>in</i>	<i>dissrc</i>	Struct to copy from.
<i>in, out</i>	<i>disdst</i>	Struct to copy to. <a href="#">disprm::flag</a> should be set to -1 if disdst was not previously initialized (memory leaks may result if it was previously initialized).

### Returns

Status return value:

- 0: Success.
- 1: Null [disprm](#) pointer passed.
- 2: Memory allocation failed.

For returns > 1, a detailed error message is set in [disprm::err](#) if enabled, see [wcserr\\_enable\(\)](#).

### disfree()

```
int disfree (
    struct disprm * dis)
```

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Destructor for the [disprm](#) struct.

**disfree()** frees memory allocated for the [disprm](#) arrays by [disinit\(\)](#). [disinit\(\)](#) keeps a record of the memory it allocates

### Parameters

<code>in, out</code>	<code>dis</code>	Distortion function parameters.
----------------------	------------------	---------------------------------

### Returns

Status return value:

- 0: Success.
- 1: Null `disprm` pointer passed.

### `dissize()`

```
int dissize (
    const struct disprm * dis,
    int sizes[2])
```

Compute the size of a `disprm` struct.

`dissize()` computes the full size of a `disprm` struct, including allocated memory.

### Parameters

<code>in</code>	<code>dis</code>	Distortion function parameters. If NULL, the base size of the struct and the allocated size are both set to zero.
<code>out</code>	<code>sizes</code>	The first element is the base size of the struct as returned by <code>sizeof(struct <code>disprm</code>)</code> . The second element is the total allocated size, in bytes, assuming that the allocation was done by <code>disini()</code> . This figure includes memory allocated for members of constituent structs, such as <code>disprm::dp</code> . It is not an error for the struct not to have been set up via <code>tabset()</code> , which normally results in additional memory allocation.

### Returns

Status return value:

- 0: Success.

### `disenq()`

```
int disenq (
    const struct disprm * dis,
    int enquiry)
```

enquire about the state of a `disprm` struct.

`disenq()` may be used to obtain information about the state of a `disprm` struct. The function returns a true/false answer for the enquiry asked.

**Parameters**

in	<i>dis</i>	Distortion function parameters.
in	<i>enquiry</i>	<p>Enquiry according to the following parameters:</p> <ul style="list-style-type: none"> <li>• DISENQ_MEM: memory in the struct is being managed by WCSLIB (see <a href="#">disinit()</a>).</li> <li>• DISENQ_SET: the struct has been set up by <a href="#">disset()</a>.</li> <li>• DISENQ_BYP: the struct is in bypass mode (see <a href="#">disset()</a>).</li> </ul> <p>These may be combined by logical OR, e.g. DISENQ_MEM   DISENQ_SET. The enquiry result will be the logical AND of the individual results.</p>

**Returns**

Enquiry result:

- 0: No.
- 1: Yes.

**disprt()**

```
int disprt (
    const struct disprm * dis)
```

Print routine for the [disprm](#) struct.

**disprt()** prints the contents of a [disprm](#) struct using [wcsprintf\(\)](#). Mainly intended for diagnostic purposes.

**Parameters**

in	<i>dis</i>	Distortion function parameters.
----	------------	---------------------------------

**Returns**

Status return value:

- 0: Success.
- 1: Null [disprm](#) pointer passed.

**disperr()**

```
int disperr (
    const struct disprm * dis,
    const char * prefix)
```

Print error messages from a [disprm](#) struct.

**disperr()** prints the error message(s) (if any) stored in a [disprm](#) struct. If there are no errors then nothing is printed. It uses [wcserr\\_prt\(\)](#), q.v.

### Parameters

in	<i>dis</i>	Distortion function parameters.
in	<i>prefix</i>	If non-NULL, each output line will be prefixed with this string.

### Returns

Status return value:

- 0: Success.
- 1: Null [disprm](#) pointer passed.

### dishdo()

```
int dishdo (
    struct disprm * dis)
```

write FITS headers using **TPD**.

**dishdo()** sets a flag that tells [wushdo\(\)](#) to write FITS headers in the form of the **TPD** translation used internally. Normally **SIP** and **TPV** would be written in their native form if at all possible.

### Parameters

in, out	<i>dis</i>	Distortion function parameters.
---------	------------	---------------------------------

### Returns

Status return value:

- 0: Success.
- 1: Null [disprm](#) pointer passed.
- 3: No **TPD** translation.

### disset()

```
int disset (
    struct disprm * dis)
```

Setup routine for the [disprm](#) struct.

**disset()**, sets up the [disprm](#) struct according to information supplied within it - refer to the explanation of [disprm::flag](#).

Note that this routine need not be called directly; it will be invoked by [disp2x\(\)](#) and [disx2p\(\)](#) if the [disprm::flag](#) is anything other than a predefined magic value.

**disset()** normally operates regardless of the value of [disprm::flag](#); i.e. even if a struct was previously set up it will be reset unconditionally. However, a [disprm](#) struct may be put into "bypass" mode by invoking **disset()** initially with [disprm::flag](#) == 1 (rather than 0). **disset()** will return immediately if invoked on a struct in that state. To take a struct out of bypass mode, simply reset [disprm::flag](#) to zero. See also [diseng\(\)](#)

**Parameters**

<code>in, out</code>	<code>dis</code>	Distortion function parameters.
----------------------	------------------	---------------------------------

**Returns**

Status return value:

- 0: Success.
- 1: Null `disprm` pointer passed.
- 2: Memory allocation failed.
- 3: Invalid parameter.

For returns > 1, a detailed error message is set in `disprm::err` if enabled, see `wcserr_enable()`.

**`disp2x()`**

```
int disp2x (
    struct disprm * dis,
    const double rawcrd[],
    double discrd[])
```

Apply distortion function.

**`disp2x()`** applies the distortion functions. By definition, the distortion is in the pixel-to-world direction.

Depending on the point in the algorithm chain at which it is invoked, **`disp2x()`** may transform pixel coordinates to corrected pixel coordinates, or intermediate pixel coordinates to corrected intermediate pixel coordinates, or image coordinates to corrected image coordinates.

**`disx2p()`**

```
int disx2p (
    struct disprm * dis,
    const double discrd[],
    double rawcrd[])
```

Apply de-distortion function.

**`disx2p()`** applies the inverse of the distortion functions. By definition, the de-distortion is in the world-to-pixel direction.

Depending on the point in the algorithm chain at which it is invoked, **`disx2p()`** may transform corrected pixel coordinates to pixel coordinates, or corrected intermediate pixel coordinates to intermediate pixel coordinates, or corrected image coordinates to image coordinates.

**`disx2p()`** iteratively solves for the inverse using **`disp2x()`**. It assumes that the distortion is small and the functions are well-behaved, being continuous and with continuous derivatives. Also that, to first order in the neighbourhood of the solution,  $\text{discrd}[j] \approx a + b \cdot \text{rawcrd}[j]$ , i.e. independent of  $\text{rawcrd}[i]$ , where  $i \neq j$ . This is effectively equivalent to assuming that the distortion functions are separable to first order. Furthermore,  $a$  is assumed to be small, and  $b$  close to unity.

If `disprm::disx2p()` is defined, then **`disx2p()`** uses it to provide an initial estimate for its more precise iterative inversion.

### Parameters

<code>in, out</code>	<code>dis</code>	Distortion function parameters.
<code>in</code>	<code>discrd</code>	Array of coordinates.
<code>out</code>	<code>rawcrd</code>	Array of coordinates to which the inverse distortion functions have been applied.

### Returns

Status return value:

- 0: Success.
- 1: Null [disprm](#) pointer passed.
- 2: Memory allocation failed.
- 3: Invalid parameter.
- 5: De-distort error.

For returns > 1, a detailed error message is set in [disprm::err](#) if enabled, see [wcserr\\_enable\(\)](#).

### diswarp()

```
int diswarp (
    struct disprm * dis,
    const double pixblc[],
    const double pixtrc[],
    const double pixsamp[],
    int * nsamp,
    double maxdis[],
    double * maxtot,
    double avgdis[],
    double * avgtot,
    double rmsdis[],
    double * rmstot)
```

Compute measures of distortion.

**diswarp()** computes various measures of the distortion over a specified range of coordinates.

For prior distortions, the measures may be interpreted simply as an offset in pixel coordinates. For sequent distortions, the interpretation depends on the nature of the linear transformation matrix (**PCi\_ja** or **CDi\_ja**). If the latter introduces a scaling, then the measures will also be scaled. Note also that the image domain, which is rectangular in pixel coordinates, may be rotated, skewed, and/or stretched in intermediate pixel coordinates, and in general cannot be defined using `pixblc[]` and `pixtrc[]`.

**PLEASE NOTE:** the measures of total distortion may be essentially meaningless if there are multiple sequent distortions with different scaling.

See also [linwarp\(\)](#).

### Parameters

<code>in, out</code>	<code>dis</code>	Distortion function parameters.
----------------------	------------------	---------------------------------

in	<i>pixblc</i>	Start of the range of pixel coordinates (for prior distortions), or intermediate pixel coordinates (for sequent distortions). May be specified as a NULL pointer which is interpreted as (1,1,...).
in	<i>pixtrc</i>	End of the range of pixel coordinates (prior) or intermediate pixel coordinates (sequent).
in	<i>pixsamp</i>	If positive or zero, the increment on the particular axis, starting at <i>pixblc</i> []. Zero is interpreted as a unit increment. <i>pixsamp</i> may also be specified as a NULL pointer which is interpreted as all zeroes, i.e. unit increments on all axes. If negative, the grid size on the particular axis (the absolute value being rounded to the nearest integer). For example, if <i>pixsamp</i> is (-128.0,-128.0,...) then each axis will be sampled at 128 points between <i>pixblc</i> [] and <i>pixtrc</i> [] inclusive. Use caution when using this option on non-square images.
out	<i>nsamp</i>	The number of pixel coordinates sampled. Can be specified as a NULL pointer if not required.
out	<i>maxdis</i>	For each individual distortion function, the maximum absolute value of the distortion. Can be specified as a NULL pointer if not required.
out	<i>maxtot</i>	For the combination of all distortion functions, the maximum absolute value of the distortion. Can be specified as a NULL pointer if not required.
out	<i>avgdis</i>	For each individual distortion function, the mean value of the distortion. Can be specified as a NULL pointer if not required.
out	<i>avgtot</i>	For the combination of all distortion functions, the mean value of the distortion. Can be specified as a NULL pointer if not required.
out	<i>rmsdis</i>	For each individual distortion function, the root mean square deviation of the distortion. Can be specified as a NULL pointer if not required.
out	<i>rmstot</i>	For the combination of all distortion functions, the root mean square deviation of the distortion. Can be specified as a NULL pointer if not required.

## Returns

Status return value:

- 0: Success.
- 1: Null [disprm](#) pointer passed.
- 2: Memory allocation failed.
- 3: Invalid parameter.
- 4: Distort error.

### 8.3.5 Variable Documentation

#### dis\_errmsg

```
const char* dis_errmsg[] [extern]
```

Status return messages.

Error messages to match the status value returned from each function.

## 8.4 dis.h

[Go to the documentation of this file.](#)

```

00001 /*=====
00002 WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003 Copyright (C) 1995-2025, Mark Calabretta
00004
00005 This file is part of WCSLIB.
00006
00007 WCSLIB is free software: you can redistribute it and/or modify it under the
00008 terms of the GNU Lesser General Public License as published by the Free
00009 Software Foundation, either version 3 of the License, or (at your option)
00010 any later version.
00011
00012 WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013 WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
00014 FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015 more details.
00016
00017 You should have received a copy of the GNU Lesser General Public License
00018 along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020 Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021 http://www.atnf.csiro.au/people/Mark.Calabretta
00022 $Id: dis.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023 *=====
00024 *
00025 * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026 * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027 * overview of the library.
00028 *
00029 *
00030 * Summary of the dis routines
00031 * -----
00032 * Routines in this suite implement extensions to the FITS World Coordinate
00033 * System (WCS) standard proposed by
00034 *
00035 * "Representations of distortions in FITS world coordinate systems",
00036 * Calabretta, M.R. et al. (WCS Paper IV, draft dated 2004/04/22),
00037 * available from http://www.atnf.csiro.au/people/Mark.Calabretta
00038 *
00039 * In brief, a distortion function may occupy one of two positions in the WCS
00040 * algorithm chain. Prior distortions precede the linear transformation
00041 * matrix, whether it be PCi_ja or CDi_ja, and sequent distortions follow it.
00042 * WCS Paper IV defines FITS keywords used to specify parameters for predefined
00043 * distortion functions. The following are used for prior distortions:
00044 *
00045 * CPDISja ... (string-valued, identifies the distortion function)
00046 * DPja ... (record-valued, parameters)
00047 * CPERRja ... (floating-valued, maximum value)
00048 *
00049 * Their counterparts for sequent distortions are CQDISia, DQia, and CQERRia.
00050 * An additional floating-valued keyword, DVERRa, records the maximum value of
00051 * the combined distortions.
00052 *
00053 * DPja and DQia are "record-valued". Syntactically, the keyvalues are
00054 * standard FITS strings, but they are to be interpreted in a special way.
00055 * The general form is
00056 *
00057 * DPja = '<field-specifier>: <float>'
00058 *
00059 * where the field-specifier consists of a sequence of fields separated by
00060 * periods, and the ':' between the field-specifier and the floating-point
00061 * value is part of the record syntax. For example:
00062 *
00063 * DP1 = 'AXIS.1: 1'
00064 *
00065 * Certain field-specifiers are defined for all distortion functions, while
00066 * others are defined only for particular distortions. Refer to WCS Paper IV
00067 * for further details. wcsjih() parses all distortion keywords and loads them
00068 * into a disprm struct for analysis by disset() which knows (or possibly does
00069 * not know) how to interpret them. Of the Paper IV distortion functions, only
00070 * the general Polynomial distortion is currently implemented here.
00071 *
00072 * TPV - the TPV "projection":
00073 * -----
00074 * The distortion function component of the TPV celestial "projection" is also
00075 * supported. The TPV projection, originally proposed in a draft of WCS Paper
00076 * II, consists of a TAN projection with sequent polynomial distortion, the
00077 * coefficients of which are encoded in PVi_ma keyrecords. Full details may be
00078 * found at the registry of FITS conventions:
00079 *
00080 * http://fits.gsfc.nasa.gov/registry/tpvwcs/tpv.html
00081 *
00082 * Internally, wcsset() changes TPV to a TAN projection, translates the PVi_ma

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00083 * keywords to DQia and loads them into a disprm struct.  These DQia keyrecords
00084 * have the form
00085 *
00086 =   DQia = 'TPV.m: <value>'
00087 *
00088 * where i, a, m, and the value for each DQia match each PVi_ma.  Consequently,
00089 * WCSLIB would handle a FITS header containing these keywords, along with
00090 * CQDISia = 'TPV' and the required DQia.NAXES and DQia.AXIS.ihat keywords.
00091 *
00092 * Note that, as defined, TPV assumes that CDi_ja is used to define the linear
00093 * transformation.  The section on historical idiosyncrasies (below) cautions
00094 * about translating CDi_ja to PCi_ja plus CDELTia in this case.
00095 *
00096 * SIP - Simple Imaging Polynomial:
00097 * -----
00098 * These routines also support the Simple Imaging Polynomial (SIP), whose
00099 * design was influenced by early drafts of WCS Paper IV.  It is described in
00100 * detail in
00101 *
00102 =   http://fits.gsfc.nasa.gov/registry/sip.html
00103 *
00104 * SIP, which is defined only as a prior distortion for 2-D celestial images,
00105 * has the interesting feature that it records an approximation to the inverse
00106 * polynomial distortion function.  This is used by disx2p() to provide an
00107 * initial estimate for its more precise iterative inversion.  The
00108 * special-purpose keywords used by SIP are parsed and translated by wcspih()
00109 * as follows:
00110 *
00111 =   A_p_q = <value>    ->   DP1 = 'SIP.FWD.p_q: <value>'
00112 =   AP_p_q = <value>   ->   DP1 = 'SIP.REV.p_q: <value>'
00113 =   B_p_q = <value>    ->   DP2 = 'SIP.FWD.p_q: <value>'
00114 =   BP_p_q = <value>   ->   DP2 = 'SIP.REV.p_q: <value>'
00115 =   A_DMAX = <value>   ->   DPERR1 = <value>
00116 =   B_DMAX = <value>   ->   DPERR2 = <value>
00117 *
00118 * SIP's A_ORDER and B_ORDER keywords are not used.  WCSLIB would recognise a
00119 * FITS header containing the above keywords, along with CPDISja = 'SIP' and
00120 * the required DPja.NAXES keywords.
00121 *
00122 * DSS - Digitized Sky Survey:
00123 * -----
00124 * The Digitized Sky Survey resulted from the production of the Guide Star
00125 * Catalogue for the Hubble Space Telescope.  Plate solutions based on a
00126 * polynomial distortion function were encoded in FITS using non-standard
00127 * keywords.  Sect. 5.2 of WCS Paper IV describes how DSS coordinates may be
00128 * translated to a sequent Polynomial distortion using two auxiliary variables.
00129 * That translation is based on optimising the non-distortion component of the
00130 * plate solution.
00131 *
00132 * Following Paper IV, wcspih() translates the non-distortion component of DSS
00133 * coordinates to standard WCS keywords (CRPIXja, PCi_ja, CRVALia, etc), and
00134 * fills a wcsprm struct with their values.  It encodes the DSS polynomial
00135 * coefficients as
00136 *
00137 =   AMDXm = <value>    ->   DQ1 = 'AMD.m: <value>'
00138 =   AMDYm = <value>    ->   DQ2 = 'AMD.m: <value>'
00139 *
00140 * WCSLIB would recognise a FITS header containing the above keywords, along
00141 * with CQDISia = 'DSS' and the required DQia.NAXES keywords.
00142 *
00143 * WAT - the TNX and ZPX "projections":
00144 * -----
00145 * The TNX and ZPX "projections" add a polynomial distortion function to the
00146 * standard TAN and ZPN projections respectively.  Unusually, the polynomial
00147 * may be expressed as the sum of Chebyshev or Legendre polynomials, or as a
00148 * simple sum of monomials, as described in
00149 *
00150 =   http://fits.gsfc.nasa.gov/registry/tnx/tnx-doc.html
00151 =   http://fits.gsfc.nasa.gov/registry/zpxwcs/zpx.html
00152 *
00153 * The polynomial coefficients are encoded in special-purpose WATi_n keywords
00154 * as a set of continued strings, thus providing the name for this distortion
00155 * type.  WATi_n are parsed and translated by wcspih() into the following set:
00156 *
00157 =   DQi = 'WAT.POLY: <value>'
00158 =   DQi = 'WAT.XMIN: <value>'
00159 =   DQi = 'WAT.XMAX: <value>'
00160 =   DQi = 'WAT.YMIN: <value>'
00161 =   DQi = 'WAT.YMAX: <value>'
00162 =   DQi = 'WAT.CHBY.m_n: <value>' or
00163 =   DQi = 'WAT.LEGR.m_n: <value>' or
00164 =   DQi = 'WAT.MONO.m_n: <value>'
00165 *
00166 * along with CQDISia = 'WAT' and the required DPja.NAXES keywords.  For ZPX,
00167 * the ZPN projection parameters are also encoded in WATi_n, and wcspih()
00168 * translates these to standard PVi_ma.
00169 *

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00170 * Note that, as defined, TNX and ZPX assume that CDi_ja is used to define the
00171 * linear transformation. The section on historical idiosyncrasies (below)
00172 * cautions about translating CDi_ja to PCi_ja plus CDELTia in this case.
00173 *
00174 * TPD - Template Polynomial Distortion:
00175 * -----
00176 * The "Template Polynomial Distortion" (TPD) is a superset of the TPV, SIP,
00177 * DSS, and WAT (TNX & ZPX) polynomial distortions that also supports 1-D usage
00178 * and inversions. Like TPV, SIP, and DSS, the form of the polynomial is fixed
00179 * (the "template") and only the coefficients for the required terms are set
00180 * non-zero. TPD generalizes TPV in going to 9th degree, SIP by accomodating
00181 * TPV's linear and radial terms, and DSS in both respects. While in theory
00182 * the degree of the WAT polynomial distortion is unconstrained, in practice it
00183 * is limited to values that can be handled by TPD.
00184 *
00185 * Within WCSLIB, TPV, SIP, DSS, and WAT are all implemented as special cases
00186 * of TPD. Indeed, TPD was developed precisely for that purpose. WAT
00187 * distortions expressed as the sum of Chebyshev or Legendre polynomials are
00188 * expanded for TPD as a simple sum of monomials. Moreover, the general
00189 * Polynomial distortion is translated and implemented internally as TPD
00190 * whenever possible.
00191 *
00192 * However, WCSLIB also recognizes 'TPD' as a distortion function in its own
00193 * right (i.e. a recognized value of CPDISJa or CQDISJa), for use as both prior
00194 * and sequent distortions. Its DPja and DQja keyrecords have the form
00195 *
00196 *     DPja = 'TPD.FWD.m: <value>'
00197 *     DPja = 'TPD.REV.m: <value>'
00198 *
00199 * for the forward and reverse distortion functions. Moreover, like the
00200 * general Polynomial distortion, TPD supports auxiliary variables, though only
00201 * as a linear transformation of pixel coordinates (p1,p2):
00202 *
00203 *     x = a0 + a1*p1 + a2*p2
00204 *     y = b0 + b1*p1 + b2*p2
00205 *
00206 * where the coefficients of the auxiliary variables (x,y) are recorded as
00207 *
00208 *     DPja = 'AUX.1.COEFF.0: a0'      ...default 0.0
00209 *     DPja = 'AUX.1.COEFF.1: a1'      ...default 1.0
00210 *     DPja = 'AUX.1.COEFF.2: a2'      ...default 0.0
00211 *     DPja = 'AUX.2.COEFF.0: b0'      ...default 0.0
00212 *     DPja = 'AUX.2.COEFF.1: b1'      ...default 0.0
00213 *     DPja = 'AUX.2.COEFF.2: b2'      ...default 1.0
00214 *
00215 * Though nowhere near as powerful, in typical applications TPD is considerably
00216 * faster than the general Polynomial distortion. As TPD has a finite and not
00217 * too large number of possible terms (60), the coefficients for each can be
00218 * stored (by disset()) in a fixed location in the disprm:dparm[] array. A
00219 * large part of the speedup then arises from evaluating the polynomial using
00220 * Horner's scheme.
00221 *
00222 * Separate implementations for polynomials of each degree, and conditionals
00223 * for 1-D polynomials and 2-D polynomials with and without the radial
00224 * variable, ensure that unused terms mostly do not impose a significant
00225 * computational overhead.
00226 *
00227 * The TPD terms are as follows
00228 *
00229 *     0: 1      4: xx      12: xxxx      24: xxxxxx      40: xxxxxxxx
00230 *           5: xy      13: xxxy      25: xxxxyy      41: xxxxxxxxy
00231 *     1: x      6: yy      14: xxyy      26: xxxxyy      42: xxxxxxxyy
00232 *     2: y      15: yyyy      27: xxxyyy      43: xxxxxxxyy
00233 *     3: r      7: xxx      16: yyyy      28: xxyyyy      44: xxxxyyyy
00234 *           8: xxy      29: xyyyyy      45: xxxxyyyy
00235 *           9: xyy      17: xxxxx      30: yyyyyy      46: xxxyyyyy
00236 *          10: yyy      18: xxxxy      47: yyyyyyy      47: yyyyyyy
00237 *          11: rrr      19: xxxyy      31: xxxxxxx      48: yyyyyyy
00238 *          20: xyyy      32: xxxxyy
00239 *          21: yyyy      33: xxxxyy      49: xxxxxxxxx
00240 *          22: yyyyy      34: xxxxyy      50: xxxxxxxxy
00241 *          23: rrrrr      35: xxxyyy      51: xxxxxxxxy
00242 *          36: xxyyyy      52: xxxxyyy
00243 *          37: yyyyyy      53: xxxxyyy
00244 *          38: yyyyyy      54: xxxxyyy
00245 *          39: rrrrrr      55: xxxxyyy
00246 *          56: xxxxyyy
00247 *          57: xxyyyyyy
00248 *          58: yyyyyyyy
00249 *          59: rrrrrrrr
00250 *
00251 * where r = sqrt(xx + yy). Note that even powers of r are excluded since they
00252 * can be accomodated by powers of (xx + yy).
00253 *
00254 * Note here that "x" refers to the axis to which the distortion function is
00255 * attached, with "y" being the complementary axis. So, for example, with
00256 * longitude on axis 1 and latitude on axis 2, for TPD attached to axis 1, "x"

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00257 * refers to axis 1 and "y" to axis 2. For TPD attached to axis 2, "x" refers
00258 * to axis 2, and "y" to axis 1.
00259 *
00260 * TPV uses all terms up to 39. The m in its PVi_ma keywords translates
00261 * directly to the TPD coefficient number.
00262 *
00263 * SIP uses all terms except for 0, 3, 11, 23, 39, and 59, with terms 1 and 2
00264 * only used for the inverse. Its A_p_q, etc. keywords must be translated
00265 * using a map.
00266 *
00267 * DSS uses terms 0, 1, 2, 4, 5, 6, 7, 8, 9, 10, 17, 19, and 21. The presence
00268 * of a non-zero constant term arises through the use of auxiliary variables
00269 * with origin offset from the reference point of the TAN projection. However,
00270 * in the translation given by WCS Paper IV, the distortion polynomial is zero,
00271 * or very close to zero, at the reference pixel itself. The mapping between
00272 * DSS's AMDXm (or AMDYm) keyvalues and TPD coefficients, while still simple,
00273 * is not quite as straightforward as for TPV and SIP.
00274 *
00275 * WAT uses all but the radial terms, namely 3, 11, 23, 39, and 59. While the
00276 * mapping between WAT's monomial coefficients and TPD is fairly simple, for
00277 * its expression in terms of a sum of Chebyshev or Legendre polynomials it is
00278 * much less so.
00279 *
00280 * Historical idiosyncrasies:
00281 * -----
00282 * In addition to the above, some historical distortion functions have further
00283 * idiosyncrasies that must be taken into account when translating them to TPD.
00284 *
00285 * WCS Paper IV specifies that a distortion function returns a correction to be
00286 * added to pixel coordinates (prior distortion) or intermediate pixel
00287 * coordinates (sequent distortion). The correction is meant to be small so
00288 * that ignoring the distortion function, i.e. setting the correction to zero,
00289 * produces a commensurately small error.
00290 *
00291 * However, rather than an additive correction, some historical distortion
00292 * functions (TPV, DSS) define a polynomial that returns the corrected
00293 * coordinates directly.
00294 *
00295 * The difference between the two approaches is readily accounted for simply by
00296 * adding or subtracting 1 from the coefficient of the first degree term of the
00297 * polynomial. However, it opens the way for considerable confusion.
00298 *
00299 * Additional to the formalism of WCS Paper IV, both the Polynomial and TPD
00300 * distortion functions recognise a keyword
00301 *
00302 * = DPja = 'DOCORR: 0'
00303 *
00304 * which is meant to apply generally to indicate that the distortion function
00305 * returns the corrected coordinates directly. Any other value for DOCORR (or
00306 * its absence) indicates that the distortion function returns an additive
00307 * correction.
00308 *
00309 * WCS Paper IV also specifies that the independent variables of a distortion
00310 * function are pixel coordinates (prior distortion) or intermediate pixel
00311 * coordinates (sequent distortion).
00312 *
00313 * On the contrary, the independent variables of the SIP polynomial are pixel
00314 * coordinate offsets from the reference pixel. This is readily handled via
00315 * the renormalisation parameters
00316 *
00317 * = DPja = 'OFFSET.jhat: <value>'
00318 *
00319 * where the value corresponds to CRPIXja.
00320 *
00321 * Likewise, because TPV, TNX, and ZPX are defined in terms of CDi_ja, the
00322 * independent variables of the polynomial are intermediate world coordinates
00323 * rather than intermediate pixel coordinates. Because sequent distortions
00324 * are always applied before CDELTia, if CDi_ja is translated to PCi_ja plus
00325 * CDELTia, then either CDELTia must be unity, or the distortion polynomial
00326 * coefficients must be adjusted to account for the change of scale.
00327 *
00328 * Summary of the dis routines:
00329 * -----
00330 * These routines apply the distortion functions defined by the extension to
00331 * the FITS WCS standard proposed in Paper IV. They are based on the disprm
00332 * struct which contains all information needed for the computations. The
00333 * struct contains some members that must be set by the user, and others that
00334 * are maintained by these routines, somewhat like a C++ class but with no
00335 * encapsulation.
00336 *
00337 * dpfill(), dpkeyi(), and dpkeyd() are provided to manage the dpkey struct.
00338 *
00339 * disndp(), disini(), disinit(), discpy(), and disfree() are provided to
00340 * manage the disprm struct, dissize() computes its total size including
00341 * allocated memory, diseng() returns information about the state of the
00342 * struct, and disprt() prints its contents.
00343 *

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00344 * disperr() prints the error message(s) (if any) stored in a disprm struct.
00345 *
00346 * wcsldo() normally writes SIP and TPV headers in their native form if at all
00347 * possible. However, dishdo() may be used to set a flag that tells it to
00348 * write the header in the form of the TPD translation used internally.
00349 *
00350 * A setup routine, disset(), computes intermediate values in the disprm struct
00351 * from parameters in it that were supplied by the user. The struct always
00352 * needs to be set up by disset(), though disset() need not be called
00353 * explicitly - refer to the explanation of disprm::flag.
00354 *
00355 * disp2x() and disx2p() implement the WCS distortion functions, disp2x() using
00356 * separate functions, such as dispoly() and tpd7(), to do the computation.
00357 *
00358 * An auxiliary routine, diswarp(), computes various measures of the distortion
00359 * over a specified range of coordinates.
00360 *
00361 * PLEASE NOTE: Distortions are not yet handled by wcsbth(), or wcscompare().
00362 *
00363 *
00364 * disndp() - Memory allocation for DPja and DQia
00365 * -----
00366 * disndp() sets or gets the value of NDPMAX (default 256). This global
00367 * variable controls the maximum number of dpkey structs, for holding DPja or
00368 * DQia keyvalues, that disini() should allocate space for. It is also used by
00369 * disinit() as the default value of ndpmax.
00370 *
00371 * PLEASE NOTE: This function is not thread-safe.
00372 *
00373 * Given:
00374 *   n          int          Value of NDPMAX; ignored if < 0. Use a value less
00375 *                           than zero to get the current value.
00376 *
00377 * Function return value:
00378 *   int          Current value of NDPMAX.
00379 *
00380 *
00381 * dpfill() - Fill the contents of a dpkey struct
00382 * -----
00383 * dpfill() is a utility routine to aid in filling the contents of the dpkey
00384 * struct. No checks are done on the validity of the inputs.
00385 *
00386 * WCS Paper IV specifies the syntax of a record-valued keyword as
00387 *
00388 *   keyword = '<field-specifier>: <float>'
00389 *
00390 * However, some DPja and DQia record values, such as those of DPja.NAXES and
00391 * DPja.AXIS.j, are intrinsically integer-valued. While FITS header parsers
00392 * are not expected to know in advance which of DPja and DQia are integral and
00393 * which are floating point, if the record's value parses as an integer (i.e.
00394 * without decimal point or exponent), then preferably enter it into the dpkey
00395 * struct as an integer. Either way, it doesn't matter as disset() accepts
00396 * either data type for all record values.
00397 *
00398 * Given and returned:
00399 *   dp          struct dpkey*
00400 *                           Store for DPja and DQia keyvalues.
00401 *
00402 * Given:
00403 *   keyword      const char *
00404 *   field        const char *
00405 *
00406 *   These arguments are concatenated with an intervening
00407 *   "." to construct the full record field name, i.e.
00408 *   including the keyword name, DPja or DQia (but
00409 *   excluding the colon delimiter which is NOT part of the
00410 *   name). Either may be given as a NULL pointer. Set
00411 *   both NULL to omit setting this component of the
00412 *   struct.
00413 *
00414 *   j          int          Axis number (1-relative), i.e. the j in DPja or
00415 *                           i in DQia. Can be given as 0, in which case the axis
00416 *                           number will be obtained from the keyword component of
00417 *                           the field name which must either have been given or
00418 *                           preset.
00419 *
00420 *   If j is non-zero, and keyword was given, then the
00421 *   value of j will be used to fill in the axis number.
00422 *
00423 *   type        int          Data type of the record's value
00424 *                           0: Integer,
00425 *                           1: Floating point.
00426 *
00427 *   i          int          For type == 0, the integer value of the record.
00428 *
00429 *   f          double        For type == 1, the floating point value of the record.
00430 *
00431 * Function return value:

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00431 *          int          Status return value:
00432 *                      0: Success.
00433 *
00434 *
00435 * dpkeyi() - Get the data value in a dpkey struct as int
00436 * -----
00437 * dpkeyi() returns the data value in a dpkey struct as an integer value.
00438 *
00439 * Given and returned:
00440 *   dp          const struct dpkey *
00441 *               Parsed contents of a DPja or DQia keyrecord.
00442 *
00443 * Function return value:
00444 *   int          The record's value as int.
00445 *
00446 *
00447 * dpkeyd() - Get the data value in a dpkey struct as double
00448 * -----
00449 * dpkeyd() returns the data value in a dpkey struct as a floating point
00450 * value.
00451 *
00452 * Given and returned:
00453 *   dp          const struct dpkey *
00454 *               Parsed contents of a DPja or DQia keyrecord.
00455 *
00456 * Function return value:
00457 *   double       The record's value as double.
00458 *
00459 *
00460 * disini() - Default constructor for the disprm struct
00461 * -----
00462 * disini() is a thin wrapper on disinit(). It invokes it with ndpmax set
00463 * to -1 which causes it to use the value of the global variable NDPMAX. It
00464 * is thereby potentially thread-unsafe if NDPMAX is altered dynamically via
00465 * disndp(). Use disinit() for a thread-safe alternative in this case.
00466 *
00467 *
00468 * disinit() - Default constructor for the disprm struct
00469 * -----
00470 * disinit() allocates memory for arrays in a disprm struct and sets all
00471 * members of the struct to default values.
00472 *
00473 * PLEASE NOTE: every disprm struct must be initialized by disinit(), possibly
00474 * repeatedly. On the first invocation, and only the first invocation,
00475 * disprm::flag must be set to -1 to initialize memory management, regardless
00476 * of whether disinit() will actually be used to allocate memory.
00477 *
00478 * Given:
00479 *   alloc      int          If true, allocate memory unconditionally for arrays in
00480 *                           the disprm struct.
00481 *
00482 *                           If false, it is assumed that pointers to these arrays
00483 *                           have been set by the user except if they are null
00484 *                           pointers in which case memory will be allocated for
00485 *                           them regardless. (In other words, setting alloc true
00486 *                           saves having to initialize these pointers to zero.)
00487 *
00488 *   naxis      int          The number of world coordinate axes, used to determine
00489 *                           array sizes.
00490 *
00491 * Given and returned:
00492 *   dis        struct disprm*
00493 *               Distortion function parameters. Note that, in order
00494 *               to initialize memory management disprm::flag must be
00495 *               set to -1 when dis is initialized for the first time
00496 *               (memory leaks may result if it had already been
00497 *               initialized).
00498 *
00499 * Given:
00500 *   ndpmax     int          The number of DPja or DQia keywords to allocate space
00501 *                           for. If set to -1, the value of the global variable
00502 *                           NDPMAX will be used. This is potentially
00503 *                           thread-unsafe if disndp() is being used dynamically to
00504 *                           alter its value.
00505 *
00506 * Function return value:
00507 *   int          Status return value:
00508 *               0: Success.
00509 *               1: Null disprm pointer passed.
00510 *               2: Memory allocation failed.
00511 *
00512 *               For returns > 1, a detailed error message is set in
00513 *               disprm::err if enabled, see wcserr_enable().
00514 *
00515 *
00516 * discpy() - Copy routine for the disprm struct
00517 * -----

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00518 * discpy() does a deep copy of one disprm struct to another, using disinit()
00519 * to allocate memory unconditionally for its arrays if required. Only the
00520 * "information to be provided" part of the struct is copied; a call to
00521 * disset() is required to initialize the remainder.
00522 *
00523 * Given:
00524 *   alloc      int          If true, allocate memory unconditionally for arrays in
00525 *                           the destination. Otherwise, it is assumed that
00526 *                           pointers to these arrays have been set by the user
00527 *                           except if they are null pointers in which case memory
00528 *                           will be allocated for them regardless.
00529 *
00530 *   dissrc      const struct disprm*
00531 *                           Struct to copy from.
00532 *
00533 * Given and returned:
00534 *   disdst      struct disprm*
00535 *                           Struct to copy to. disprm::flag should be set to -1
00536 *                           if disdst was not previously initialized (memory leaks
00537 *                           may result if it was previously initialized).
00538 *
00539 * Function return value:
00540 *   int          Status return value:
00541 *               0: Success.
00542 *               1: Null disprm pointer passed.
00543 *               2: Memory allocation failed.
00544 *
00545 *               For returns > 1, a detailed error message is set in
00546 *               disprm::err if enabled, see wcserr_enable().
00547 *
00548 *
00549 * disfree() - Destructor for the disprm struct
00550 * -----
00551 * disfree() frees memory allocated for the disprm arrays by disinit().
00552 * disinit() keeps a record of the memory it allocates and disfree() will only
00553 * attempt to free this.
00554 *
00555 * PLEASE NOTE: disfree() must not be invoked on a disprm struct that was not
00556 * initialized by disinit().
00557 *
00558 * Given and returned:
00559 *   dis          struct disprm*
00560 *               Distortion function parameters.
00561 *
00562 * Function return value:
00563 *   int          Status return value:
00564 *               0: Success.
00565 *               1: Null disprm pointer passed.
00566 *
00567 *
00568 * dissize() - Compute the size of a disprm struct
00569 * -----
00570 * dissize() computes the full size of a disprm struct, including allocated
00571 * memory.
00572 *
00573 * Given:
00574 *   dis          const struct disprm*
00575 *               Distortion function parameters.
00576 *
00577 *               If NULL, the base size of the struct and the allocated
00578 *               size are both set to zero.
00579 *
00580 * Returned:
00581 *   sizes        int[2]      The first element is the base size of the struct as
00582 *                           returned by sizeof(struct disprm). The second element
00583 *                           is the total allocated size, in bytes, assuming that
00584 *                           the allocation was done by disini(). This figure
00585 *                           includes memory allocated for members of constituent
00586 *                           structs, such as disprm::dp.
00587 *
00588 *               It is not an error for the struct not to have been set
00589 *               up via tabset(), which normally results in additional
00590 *               memory allocation.
00591 *
00592 * Function return value:
00593 *   int          Status return value:
00594 *               0: Success.
00595 *
00596 *
00597 * disenq() - enquire about the state of a disprm struct
00598 * -----
00599 * disenq() may be used to obtain information about the state of a disprm
00600 * struct. The function returns a true/false answer for the enquiry asked.
00601 *
00602 * Given:
00603 *   dis          const struct disprm*
00604 *               Distortion function parameters.

```

```

00605 *
00606 *   enquiry   int           Enquiry according to the following parameters:
00607 *                       DISENQ_MEM: memory in the struct is being managed by
00608 *                               WCSLIB (see disinit()).
00609 *                       DISENQ_SET: the struct has been set up by disset().
00610 *                       DISENQ_BYP: the struct is in bypass mode (see
00611 *                               disset()).
00612 *                       These may be combined by logical OR, e.g.
00613 *                       DISENQ_MEM | DISENQ_SET. The enquiry result will be
00614 *                       the logical AND of the individual results.
00615 *
00616 * Function return value:
00617 *   int       Enquiry result:
00618 *       0: No.
00619 *       1: Yes.
00620 *
00621 *
00622 * disprmt() - Print routine for the disprm struct
00623 * -----
00624 * disprmt() prints the contents of a disprm struct using wcsprintf().  Mainly
00625 * intended for diagnostic purposes.
00626 *
00627 * Given:
00628 *   dis       const struct disprm*
00629 *               Distortion function parameters.
00630 *
00631 * Function return value:
00632 *   int       Status return value:
00633 *       0: Success.
00634 *       1: Null disprm pointer passed.
00635 *
00636 *
00637 * disperr() - Print error messages from a disprm struct
00638 * -----
00639 * disperr() prints the error message(s) (if any) stored in a disprm struct.
00640 * If there are no errors then nothing is printed.  It uses wcserr_prt(), q.v.
00641 *
00642 * Given:
00643 *   dis       const struct disprm*
00644 *               Distortion function parameters.
00645 *
00646 *   prefix    const char *
00647 *               If non-NULL, each output line will be prefixed with
00648 *               this string.
00649 *
00650 * Function return value:
00651 *   int       Status return value:
00652 *       0: Success.
00653 *       1: Null disprm pointer passed.
00654 *
00655 *
00656 * dishdo() - write FITS headers using TPD
00657 * -----
00658 * dishdo() sets a flag that tells wchshdo() to write FITS headers in the form
00659 * of the TPD translation used internally.  Normally SIP and TPV would be
00660 * written in their native form if at all possible.
00661 *
00662 * Given and returned:
00663 *   dis       struct disprm*
00664 *               Distortion function parameters.
00665 *
00666 * Function return value:
00667 *   int       Status return value:
00668 *       0: Success.
00669 *       1: Null disprm pointer passed.
00670 *       3: No TPD translation.
00671 *
00672 *
00673 * disset() - Setup routine for the disprm struct
00674 * -----
00675 * disset(), sets up the disprm struct according to information supplied within
00676 * it - refer to the explanation of disprm::flag.
00677 *
00678 * Note that this routine need not be called directly; it will be invoked by
00679 * disp2x() and disx2p() if the disprm::flag is anything other than a
00680 * predefined magic value.
00681 *
00682 * disset() normally operates regardless of the value of disprm::flag; i.e.
00683 * even if a struct was previously set up it will be reset unconditionally.
00684 * However, a disprm struct may be put into "bypass" mode by invoking disset()
00685 * initially with disprm::flag == 1 (rather than 0).  disset() will return
00686 * immediately if invoked on a struct in that state.  To take a struct out of
00687 * bypass mode, simply reset disprm::flag to zero.  See also disenq().
00688 *
00689 * Given and returned:
00690 *   dis       struct disprm*
00691 *               Distortion function parameters.

```

```

00692 *
00693 * Function return value:
00694 *     int          Status return value:
00695 *                 0: Success.
00696 *                 1: Null disprm pointer passed.
00697 *                 2: Memory allocation failed.
00698 *                 3: Invalid parameter.
00699 *
00700 *                 For returns > 1, a detailed error message is set in
00701 *                 disprm::err if enabled, see wcserr_enable().
00702 *
00703 *
00704 * disp2x() - Apply distortion function
00705 * -----
00706 * disp2x() applies the distortion functions. By definition, the distortion
00707 * is in the pixel-to-world direction.
00708 *
00709 * Depending on the point in the algorithm chain at which it is invoked,
00710 * disp2x() may transform pixel coordinates to corrected pixel coordinates, or
00711 * intermediate pixel coordinates to corrected intermediate pixel coordinates,
00712 * or image coordinates to corrected image coordinates.
00713 *
00714 *
00715 * Given and returned:
00716 *     dis          struct disprm*
00717 *                 Distortion function parameters.
00718 *
00719 * Given:
00720 *     rawcrd       const double[naxis]
00721 *                 Array of coordinates.
00722 *
00723 * Returned:
00724 *     disprd       double[naxis]
00725 *                 Array of coordinates to which the distortion functions
00726 *                 have been applied.
00727 *
00728 * Function return value:
00729 *     int          Status return value:
00730 *                 0: Success.
00731 *                 1: Null disprm pointer passed.
00732 *                 2: Memory allocation failed.
00733 *                 3: Invalid parameter.
00734 *                 4: Distort error.
00735 *
00736 *                 For returns > 1, a detailed error message is set in
00737 *                 disprm::err if enabled, see wcserr_enable().
00738 *
00739 *
00740 * disx2p() - Apply de-distortion function
00741 * -----
00742 * disx2p() applies the inverse of the distortion functions. By definition,
00743 * the de-distortion is in the world-to-pixel direction.
00744 *
00745 * Depending on the point in the algorithm chain at which it is invoked,
00746 * disx2p() may transform corrected pixel coordinates to pixel coordinates, or
00747 * corrected intermediate pixel coordinates to intermediate pixel coordinates,
00748 * or corrected image coordinates to image coordinates.
00749 *
00750 * disx2p() iteratively solves for the inverse using disp2x(). It assumes
00751 * that the distortion is small and the functions are well-behaved, being
00752 * continuous and with continuous derivatives. Also that, to first order
00753 * in the neighbourhood of the solution,  $disprd[j] \approx a + b \cdot rawcrd[j]$ , i.e.
00754 * independent of  $rawcrd[i]$ , where  $i \neq j$ . This is effectively equivalent to
00755 * assuming that the distortion functions are separable to first order.
00756 * Furthermore,  $a$  is assumed to be small, and  $b$  close to unity.
00757 *
00758 * If disprm::disx2p() is defined, then disx2p() uses it to provide an initial
00759 * estimate for its more precise iterative inversion.
00760 *
00761 * Given and returned:
00762 *     dis          struct disprm*
00763 *                 Distortion function parameters.
00764 *
00765 * Given:
00766 *     disprd       const double[naxis]
00767 *                 Array of coordinates.
00768 *
00769 * Returned:
00770 *     rawcrd       double[naxis]
00771 *                 Array of coordinates to which the inverse distortion
00772 *                 functions have been applied.
00773 *
00774 * Function return value:
00775 *     int          Status return value:
00776 *                 0: Success.
00777 *                 1: Null disprm pointer passed.
00778 *                 2: Memory allocation failed.

```

```

00779 *          3: Invalid parameter.
00780 *          5: De-distort error.
00781 *
00782 *          For returns > 1, a detailed error message is set in
00783 *          disprm::err if enabled, see wcserr_enable().
00784 *
00785 *
00786 * diswarp() - Compute measures of distortion
00787 * -----
00788 * diswarp() computes various measures of the distortion over a specified range
00789 * of coordinates.
00790 *
00791 * For prior distortions, the measures may be interpreted simply as an offset
00792 * in pixel coordinates. For sequent distortions, the interpretation depends
00793 * on the nature of the linear transformation matrix (PCi_ja or CDi_ja). If
00794 * the latter introduces a scaling, then the measures will also be scaled.
00795 * Note also that the image domain, which is rectangular in pixel coordinates,
00796 * may be rotated, skewed, and/or stretched in intermediate pixel coordinates,
00797 * and in general cannot be defined using pixblc[] and pixtrc[].
00798 *
00799 * PLEASE NOTE: the measures of total distortion may be essentially meaningless
00800 * if there are multiple sequent distortions with different scaling.
00801 *
00802 * See also linwarp().
00803 *
00804 * Given and returned:
00805 *   dis          struct disprm*
00806 *               Distortion function parameters.
00807 *
00808 * Given:
00809 *   pixblc       const double[naxis]
00810 *               Start of the range of pixel coordinates (for prior
00811 *               distortions), or intermediate pixel coordinates (for
00812 *               sequent distortions). May be specified as a NULL
00813 *               pointer which is interpreted as (1,1,...).
00814 *
00815 *   pixtrc       const double[naxis]
00816 *               End of the range of pixel coordinates (prior) or
00817 *               intermediate pixel coordinates (sequent).
00818 *
00819 *   pixsamp      const double[naxis]
00820 *               If positive or zero, the increment on the particular
00821 *               axis, starting at pixblc[]. Zero is interpreted as a
00822 *               unit increment. pixsamp may also be specified as a
00823 *               NULL pointer which is interpreted as all zeroes, i.e.
00824 *               unit increments on all axes.
00825 *
00826 *               If negative, the grid size on the particular axis (the
00827 *               absolute value being rounded to the nearest integer).
00828 *               For example, if pixsamp is (-128.0,-128.0,...) then
00829 *               each axis will be sampled at 128 points between
00830 *               pixblc[] and pixtrc[] inclusive. Use caution when
00831 *               using this option on non-square images.
00832 *
00833 * Returned:
00834 *   nsamp        int*      The number of pixel coordinates sampled.
00835 *
00836 *               Can be specified as a NULL pointer if not required.
00837 *
00838 *   maxdis       double[naxis]
00839 *               For each individual distortion function, the
00840 *               maximum absolute value of the distortion.
00841 *
00842 *               Can be specified as a NULL pointer if not required.
00843 *
00844 *   maxtot       double*   For the combination of all distortion functions, the
00845 *               maximum absolute value of the distortion.
00846 *
00847 *               Can be specified as a NULL pointer if not required.
00848 *
00849 *   avgdis       double[naxis]
00850 *               For each individual distortion function, the
00851 *               mean value of the distortion.
00852 *
00853 *               Can be specified as a NULL pointer if not required.
00854 *
00855 *   avgtot       double*   For the combination of all distortion functions, the
00856 *               mean value of the distortion.
00857 *
00858 *               Can be specified as a NULL pointer if not required.
00859 *
00860 *   rmsdis       double[naxis]
00861 *               For each individual distortion function, the
00862 *               root mean square deviation of the distortion.
00863 *
00864 *               Can be specified as a NULL pointer if not required.
00865 *

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00866 *   rmstot      double*   For the combination of all distortion functions, the
00867 *                       root mean square deviation of the distortion.
00868 *
00869 *                       Can be specified as a NULL pointer if not required.
00870 *
00871 * Function return value:
00872 *       int       Status return value:
00873 *               0: Success.
00874 *               1: Null disprm pointer passed.
00875 *               2: Memory allocation failed.
00876 *               3: Invalid parameter.
00877 *               4: Distort error.
00878 *
00879 *
00880 * disprm struct - Distortion parameters
00881 * -----
00882 * The disprm struct contains all of the information required to apply a set of
00883 * distortion functions. It consists of certain members that must be set by
00884 * the user ("given") and others that are set by the WCSLIB routines
00885 * ("returned"). While the addresses of the arrays themselves may be set by
00886 * disinit() if it (optionally) allocates memory, their contents must be set by
00887 * the user.
00888 *
00889 *   int flag
00890 *   (Given and returned) This flag must be set to zero (or 1, see disset())
00891 *   whenever any of the following disprm members are set or changed:
00892 *
00893 *       - disprm::naxis,
00894 *       - disprm::dtype,
00895 *       - disprm::ndp,
00896 *       - disprm::dp.
00897 *
00898 *   This signals the initialization routine, disset(), to recompute the
00899 *   returned members of the disprm struct. disset() will reset flag to
00900 *   indicate that this has been done.
00901 *
00902 *   PLEASE NOTE: flag must be set to -1 when disinit() is called for the
00903 *   first time for a particular disprm struct in order to initialize memory
00904 *   management. It must ONLY be used on the first initialization otherwise
00905 *   memory leaks may result.
00906 *
00907 *   int naxis
00908 *   (Given or returned) Number of pixel and world coordinate elements.
00909 *
00910 *   If disinit() is used to initialize the disprm struct (as would normally
00911 *   be the case) then it will set naxis from the value passed to it as a
00912 *   function argument. The user should not subsequently modify it.
00913 *
00914 *   char (*dtype)[72]
00915 *   (Given) Pointer to the first element of an array of char[72] containing
00916 *   the name of the distortion function for each axis.
00917 *
00918 *   int ndp
00919 *   (Given) The number of entries in the disprm::dp[] array.
00920 *
00921 *   int ndpmax
00922 *   (Given) The length of the disprm::dp[] array.
00923 *
00924 *   ndpmax will be set by disinit() if it allocates memory for disprm::dp[],
00925 *   otherwise it must be set by the user. See also disndp().
00926 *
00927 *   struct dpkey dp
00928 *   (Given) Address of the first element of an array of length ndpmax of
00929 *   dpkey structs.
00930 *
00931 *   As a FITS header parser encounters each DPja or DQia keyword it should
00932 *   load it into a dpkey struct in the array and increment ndp. However,
00933 *   note that a single disprm struct must hold only DPja or DQia keyvalues,
00934 *   not both. disset() interprets them as required by the particular
00935 *   distortion function.
00936 *
00937 *   double *maxdis
00938 *   (Given) Pointer to the first element of an array of double specifying
00939 *   the maximum absolute value of the distortion for each axis computed over
00940 *   the whole image.
00941 *
00942 *   It is not necessary to reset the disprm struct (via disset()) when
00943 *   disprm::maxdis is changed.
00944 *
00945 *   double totdis
00946 *   (Given) The maximum absolute value of the combination of all distortion
00947 *   functions specified as an offset in pixel coordinates computed over the
00948 *   whole image.
00949 *
00950 *   It is not necessary to reset the disprm struct (via disset()) when
00951 *   disprm::totdis is changed.
00952 *

```

```

00953 *   int *docorr
00954 *       (Returned) Pointer to the first element of an array of int containing
00955 *       flags that indicate the mode of correction for each axis.
00956 *
00957 *       If docorr is zero, the distortion function returns the corrected
00958 *       coordinates directly. Any other value indicates that the distortion
00959 *       function computes a correction to be added to pixel coordinates (prior
00960 *       distortion) or intermediate pixel coordinates (sequent distortion).
00961 *
00962 *   int *Nhat
00963 *       (Returned) Pointer to the first element of an array of int containing
00964 *       the number of coordinate axes that form the independent variables of the
00965 *       distortion function for each axis.
00966 *
00967 *   int **axmap
00968 *       (Returned) Pointer to the first element of an array of int* containing
00969 *       pointers to the first elements of the axis mapping arrays for each axis.
00970 *
00971 *       An axis mapping associates the independent variables of a distortion
00972 *       function with the 0-relative image axis number. For example, consider
00973 *       an image with a spectrum on the first axis (axis 0), followed by RA
00974 *       (axis 1), Dec (axis2), and time (axis 3) axes. For a distortion in
00975 *       (RA,Dec) and no distortion on the spectral or time axes, the axis
00976 *       mapping arrays, axmap[j][], would be
00977 *
00978 *       j=0: [-1, -1, -1, -1] ...no distortion on spectral axis,
00979 *       1: [ 1,  2, -1, -1] ...RA distortion depends on RA and Dec,
00980 *       2: [ 2,  1, -1, -1] ...Dec distortion depends on Dec and RA,
00981 *       3: [-1, -1, -1, -1] ...no distortion on time axis,
00982 *
00983 *       where -1 indicates that there is no corresponding independent
00984 *       variable.
00985 *
00986 *   double **offset
00987 *       (Returned) Pointer to the first element of an array of double*
00988 *       containing pointers to the first elements of arrays of offsets used to
00989 *       renormalize the independent variables of the distortion function for
00990 *       each axis.
00991 *
00992 *       The offsets are subtracted from the independent variables before
00993 *       scaling.
00994 *
00995 *   double **scale
00996 *       (Returned) Pointer to the first element of an array of double*
00997 *       containing pointers to the first elements of arrays of scales used to
00998 *       renormalize the independent variables of the distortion function for
00999 *       each axis.
01000 *
01001 *       The scale is applied to the independent variables after the offsets are
01002 *       subtracted.
01003 *
01004 *   int **iparm
01005 *       (Returned) Pointer to the first element of an array of int*
01006 *       containing pointers to the first elements of the arrays of integer
01007 *       distortion parameters for each axis.
01008 *
01009 *   double **dparm
01010 *       (Returned) Pointer to the first element of an array of double*
01011 *       containing pointers to the first elements of the arrays of floating
01012 *       point distortion parameters for each axis.
01013 *
01014 *   int i_naxis
01015 *       (Returned) Dimension of the internal arrays (normally equal to naxis).
01016 *
01017 *   int ndis
01018 *       (Returned) The number of distortion functions.
01019 *
01020 *   struct wcserr *err
01021 *       (Returned) If enabled, when an error status is returned, this struct
01022 *       contains detailed information about the error, see wcserr_enable().
01023 *
01024 *   int (**disp2x) (DISP2X_ARGS)
01025 *       (For internal use only.)
01026 *   int (**disx2p) (DISX2P_ARGS)
01027 *       (For internal use only.)
01028 *   int m_flag
01029 *       (For internal use only.)
01030 *   int m_naxis
01031 *       (For internal use only.)
01032 *   char (*m_dtype)[72]
01033 *       (For internal use only.)
01034 *   double **m_dp
01035 *       (For internal use only.)
01036 *   double *m_maxdis
01037 *       (For internal use only.)
01038 *
01039 *

```

```

01040 * dpkey struct - Store for DPja and DQia keyvalues
01041 * -----
01042 * The dpkey struct is used to pass the parsed contents of DPja or DQia
01043 * keyrecords to disset() via the disprm struct. A disprm struct must hold
01044 * only DPja or DQia keyvalues, not both.
01045 *
01046 * All members of this struct are to be set by the user.
01047 *
01048 *   char field[72]
01049 *       (Given) The full field name of the record, including the keyword name.
01050 *       Note that the colon delimiter separating the field name and the value in
01051 *       record-valued keyvalues is not part of the field name. For example, in
01052 *       the following:
01053 *
01054 *           DP3A = 'AXIS.1: 2'
01055 *
01056 *       the full record field name is "DP3A.AXIS.1", and the record's value
01057 *       is 2.
01058 *
01059 *   int j
01060 *       (Given) Axis number (1-relative), i.e. the j in DPja or i in DQia.
01061 *
01062 *   int type
01063 *       (Given) The data type of the record's value
01064 *       - 0: Integer (stored as an int),
01065 *       - 1: Floating point (stored as a double).
01066 *
01067 *   union value
01068 *       (Given) A union comprised of
01069 *       - dpkey::i,
01070 *       - dpkey::f,
01071 *
01072 *       the record's value.
01073 *
01074 *
01075 * Global variable: const char *dis_errmsg[] - Status return messages
01076 * -----
01077 * Error messages to match the status value returned from each function.
01078 *
01079 * =====*/
01080
01081 #ifndef WCSLIB_DIS
01082 #define WCSLIB_DIS
01083
01084 #ifdef __cplusplus
01085 extern "C" {
01086 #endif
01087
01088 enum disenq_enum {
01089     DISENQ_MEM = 1,           // disprm struct memory is managed by WCSLIB.
01090     DISENQ_SET = 2,           // disprm struct has been set up.
01091     DISENQ_BYN = 4,           // disprm struct is in bypass mode.
01092 };
01093
01094 extern const char *dis_errmsg[];
01095
01096 enum dis_errmsg_enum {
01097     DISERR_SUCCESS = 0,       // Success.
01098     DISERR_NULL_POINTER = 1,  // Null disprm pointer passed.
01099     DISERR_MEMORY = 2,        // Memory allocation failed.
01100     DISERR_BAD_PARAM = 3,     // Invalid parameter value.
01101     DISERR_DISTORT = 4,       // Distortion error.
01102     DISERR_DEDISTORT = 5,     // De-distortion error.
01103 };
01104
01105 // For use in declaring distortion function prototypes (= DISX2P_ARGS).
01106 #define DISP2X_ARGS int inverse, const int iparm[], const double dparm[], \
01107 int ncrd, const double rawcrd[], double *discrd
01108
01109 // For use in declaring de-distortion function prototypes (= DISP2X_ARGS).
01110 #define DISX2P_ARGS int inverse, const int iparm[], const double dparm[], \
01111 int ncrd, const double discrd[], double *rawcrd
01112
01113
01114 // Struct used for storing DPja and DQia keyvalues.
01115 struct dpkey {
01116     char field[72];           // Full record field name (no colon).
01117     int j;                    // Axis number, as in DPja (1-relative).
01118     int type;                  // Data type of value.
01119     union {
01120         int i;                // Integer record value.
01121         double f;             // Floating point record value.
01122     } value;                  // Record value.
01123 };
01124
01125 // Size of the dpkey struct in int units, used by the Fortran wrappers.
01126 #define DPLEN (sizeof(struct dpkey)/sizeof(int))

```

```

01127
01128
01129 struct disprm {
01130     // Initialization flag (see the prologue above).
01131     //-----
01132     int flag;                                // Set to zero to force initialization.
01133
01134     // Parameters to be provided (see the prologue above).
01135     //-----
01136     int naxis;                                // The number of pixel coordinate elements,
01137                                           // given by NAXIS.
01138     char (*dtype)[72];                       // For each axis, the distortion type.
01139     int ndp;                                  // Number of DPja or DQia keywords, and the
01140     int ndpmax;                               // number for which space was allocated.
01141     struct dpkey *dp;                         // DPja or DQia keyvalues (not both).
01142     double totdis;                           // The maximum combined distortion.
01143     double *maxdis;                          // For each axis, the maximum distortion.
01144
01145     // Information derived from the parameters supplied.
01146     //-----
01147     int *docorr;                             // For each axis, the mode of correction.
01148     int *Nhat;                               // For each axis, the number of coordinate
01149                                           // axes that form the independent variables
01150                                           // of the distortion function.
01151     int **axmap;                             // For each axis, the axis mapping array.
01152     double **offset;                        // For each axis, renormalization offsets.
01153     double **scale;                         // For each axis, renormalization scales.
01154     int **iparm;                            // For each axis, the array of integer
01155                                           // distortion parameters.
01156     double **dparm;                         // For each axis, the array of floating
01157                                           // point distortion parameters.
01158     int i_naxis;                            // Dimension of the internal arrays.
01159     int ndis;                               // The number of distortion functions.
01160
01161     // Error messaging, if enabled.
01162     //-----
01163     struct wcserr *err;
01164
01165     //-----
01166     // Private - the remainder are for internal use.
01167     //-----
01168     int (**disp2x)(DISP2X_ARGS); // For each axis, pointers to the
01169     int (**disx2p)(DISX2P_ARGS); // distortion function and its inverse.
01170
01171     int m_flag, m_naxis;                // The remainder are for memory management.
01172     char (*m_dtype)[72];
01173     struct dpkey *m_dp;
01174     double *m_maxdis;
01175 };
01176
01177 // Size of the disprm struct in int units, used by the Fortran wrappers.
01178 #define DISLEN (sizeof(struct disprm)/sizeof(int))
01179
01180
01181 int disndp(int n);
01182
01183 int dpfill(struct dpkey *dp, const char *keyword, const char *field, int j,
01184           int type, int i, double f);
01185
01186 int dpkeyi(const struct dpkey *dp);
01187
01188 double dpkeyd(const struct dpkey *dp);
01189
01190 int disini(int alloc, int naxis, struct disprm *dis);
01191
01192 int disinit(int alloc, int naxis, struct disprm *dis, int ndpmax);
01193
01194 int discpy(int alloc, const struct disprm *dissrc, struct disprm *disdst);
01195
01196 int disfree(struct disprm *dis);
01197
01198 int dissize(const struct disprm *dis, int sizes[2]);
01199
01200 int disenq(const struct disprm *dis, int enquiry);
01201
01202 int disprt(const struct disprm *dis);
01203
01204 int disperr(const struct disprm *dis, const char *prefix);
01205
01206 int dishdo(struct disprm *dis);
01207
01208 int disset(struct disprm *dis);
01209
01210 int disp2x(struct disprm *dis, const double rawcrd[], double discrd[]);
01211
01212 int disx2p(struct disprm *dis, const double discrd[], double rawcrd[]);
01213

```

```

01214 int diswarp(struct disprm *dis, const double pixblc[], const double pixtrc[],
01215             const double pixsamp[], int *nsamp,
01216             double maxdis[], double *maxtot,
01217             double avgdis[], double *avgtot,
01218             double rmsdis[], double *rmstot);
01219
01220 #ifdef __cplusplus
01221 }
01222 #endif
01223
01224 #endif // WCSLIB_DIS

```

## 8.5 fitshdr.h File Reference

```
#include "wcsconfig.h"
```

### Data Structures

- struct [fitskeyid](#)  
*Keyword indexing.*
- struct [fitskey](#)  
*Keyword/value information.*

### Macros

- #define [FITSHDR\\_KEYWORD](#) 0x01  
*Flag bit indicating illegal keyword syntax.*
- #define [FITSHDR\\_KEYVALUE](#) 0x02  
*Flag bit indicating illegal keyvalue syntax.*
- #define [FITSHDR\\_COMMENT](#) 0x04  
*Flag bit indicating illegal keycomment syntax.*
- #define [FITSHDR\\_KEYREC](#) 0x08  
*Flag bit indicating illegal keyrecord.*
- #define [FITSHDR\\_CARD](#) 0x08  
*Deprecated.*
- #define [FITSHDR\\_TRAILER](#) 0x10  
*Flag bit indicating keyrecord following a valid END keyrecord.*
- #define [KEYIDLEN](#) (sizeof(struct [fitskeyid](#))/sizeof(int))
- #define [KEYLEN](#) (sizeof(struct [fitskey](#))/sizeof(int))

### Typedefs

- typedef int [int64](#)[3]  
*64-bit signed integer data type.*

### Enumerations

- enum [fitshdr\\_errmsg\\_enum](#) {  
[FITSHDRERR\\_SUCCESS](#) = 0 , [FITSHDRERR\\_NULL\\_POINTER](#) = 1 , [FITSHDRERR\\_MEMORY](#) = 2 ,  
[FITSHDRERR\\_FLEX\\_PARSER](#) = 3 ,  
[FITSHDRERR\\_DATA\\_TYPE](#) = 4 }

## Functions

- int [fitshdr](#) (const char header[], int nkeyrec, int nkeyids, struct [fitskeyid](#) keyids[], int \*nreject, struct [fitskey](#) \*\*keys)  
*FITS header parser routine.*

## Variables

- const char \* [fitshdr\\_errmsg](#) []  
*Status return messages.*

### 8.5.1 Detailed Description

The Flexible Image Transport System (FITS), is a data format widely used in astronomy for data interchange and archive. It is described in

"Definition of the Flexible Image Transport System (FITS), version 3.0",  
Pence, W.D., Chiappetti, L., Page, C.G., Shaw, R.A., & Stobie, E. 2010,  
A&A, 524, A42 - <http://dx.doi.org/10.1051/0004-6361/201015362>

#### See also [http:](#)

[fitshdr\(\)](#) is a generic FITS header parser provided to handle keyrecords that are ignored by the WCS header parsers, [wcspih\(\)](#) and [wcsbth\(\)](#). Typically the latter may be set to remove WCS keyrecords from a header leaving [fitshdr\(\)](#) to handle the remainder.

### 8.5.2 Macro Definition Documentation

#### FITSHDR\_KEYWORD

```
#define FITSHDR_KEYWORD 0x01
```

Flag bit indicating illegal keyword syntax.

Bit mask for the status flag bit-vector returned by [fitshdr\(\)](#) indicating illegal keyword syntax.

#### FITSHDR\_KEYVALUE

```
#define FITSHDR_KEYVALUE 0x02
```

Flag bit indicating illegal keyvalue syntax.

Bit mask for the status flag bit-vector returned by [fitshdr\(\)](#) indicating illegal keyvalue syntax.

#### FITSHDR\_COMMENT

```
#define FITSHDR_COMMENT 0x04
```

Flag bit indicating illegal keycomment syntax.

Bit mask for the status flag bit-vector returned by [fitshdr\(\)](#) indicating illegal keycomment syntax.

## FITSHDR\_KEYREC

```
#define FITSHDR_KEYREC 0x08
```

Flag bit indicating illegal keyrecord.

Bit mask for the status flag bit-vector returned by `fits_hdr()` indicating an illegal keyrecord, e.g. an END keyrecord with trailing text.

## FITSHDR\_CARD

```
#define FITSHDR_CARD 0x08
```

Deprecated.

**Deprecated** Added for backwards compatibility, use `FITSHDR_KEYREC` instead.

## FITSHDR\_TRAILER

```
#define FITSHDR_TRAILER 0x10
```

Flag bit indicating keyrecord following a valid END keyrecord.

Bit mask for the status flag bit-vector returned by `fits_hdr()` indicating a keyrecord following a valid END keyrecord.

## KEYIDLEN

```
#define KEYIDLEN (sizeof(struct fitskeyid)/sizeof(int))
```

## KEYLEN

```
#define KEYLEN (sizeof(struct fitskey)/sizeof(int))
```

## 8.5.3 Typedef Documentation

### int64

```
typedef int int64[3]
```

64-bit signed integer data type.

64-bit signed integer data type defined via preprocessor macro `WCSLIB_INT64` which may be defined in `wcsconfig.h`. For example

```
#define WCSLIB_INT64 long long int
```

This is typedef'd in `fits_hdr.h` as

```
#ifndef WCSLIB_INT64
    typedef WCSLIB_INT64 int64;
#else
    typedef int int64[3];
#endif
```

**Enumerator**

FITSHDRERR_SUCCESS	
FITSHDRERR_NULL_POINTER	
FITSHDRERR_MEMORY	
FITSHDRERR_FLEX_PARSER	
FITSHDRERR_DATA_TYPE	

**8.5.5 Function Documentation****fitshdr()**

```
int fitshdr (
    const char header[],
    int nkeyrec,
    int nkeyids,
    struct fitskeyid keyids[],
    int * nreject,
    struct fitskey ** keys)
```

FITS header parser routine.

**fitshdr()** parses a character array containing a FITS header, extracting all keywords and their values into an array of [fitskey](#) structs.

**Parameters**

in	<i>header</i>	Character array containing the (entire) FITS header, for example, as might be obtained conveniently via the CFITSIO routine <code>fits_hdr2str()</code> . Each header "keyrecord" (formerly "card image") consists of exactly 80 7-bit ASCII printing characters in the range 0x20 to 0x7e (which excludes NUL, BS, TAB, LF, FF and CR) especially noting that the keyrecords are NOT null-terminated.
in	<i>nkeyrec</i>	Number of keyrecords in header[].
in	<i>nkeyids</i>	Number of entries in keyids[].
in, out	<i>keyids</i>	While all keywords are extracted from the header, keyids[] provides a convenient way of indexing them. The <a href="#">fitskeyid</a> struct contains three members; <a href="#">fitskeyid::name</a> must be set by the user while <a href="#">fitskeyid::count</a> and <a href="#">fitskeyid::idx</a> are returned by <b>fitshdr()</b> . All matched keywords will have their <a href="#">fitskey::keyno</a> member negated.
out	<i>nreject</i>	Number of header keyrecords rejected for syntax errors.
out	<i>keys</i>	Pointer to an array of nkeyrec <a href="#">fitskey</a> structs containing all keywords and keyvalues extracted from the header. Memory for the array is allocated by <b>fitshdr()</b> and this must be freed by the user. See <a href="#">wcsdealloc()</a> .

## Returns

Status return value:

- 0: Success.
- 1: Null `fitskey` pointer passed.
- 2: Memory allocation failed.
- 3: Fatal error returned by Flex parser.
- 4: Unrecognised data type.

## Notes:

1. Keyword parsing is done in accordance with the syntax defined by NOST 100-2.0, noting the following points in particular:
  - a Sect. 5.1.2.1 specifies that keywords be left-justified in columns 1-8, blank-filled with no embedded spaces, composed only of the ASCII characters **ABCDEFGHIJKLMNOPQRSTUVWXYZ0123456789-↵**  
**fitshdr()** accepts any characters in columns 1-8 but flags keywords that do not conform to standard syntax.
  - b Sect. 5.1.2.2 defines the "value indicator" as the characters "**=** " occurring in columns 9 and 10. If these are absent then the keyword has no value and columns 9-80 may contain any ASCII text (but see note 2 for **CONTINUE** keyrecords). This is copied to the comment member of the `fitskey` struct.
  - c Sect. 5.1.2.3 states that a keyword may have a null (undefined) value if the value/comment field, columns 11-80, consists entirely of spaces, possibly followed by a comment.
  - d Sect. 5.1.1 states that trailing blanks in a string keyvalue are not significant and the parser always removes them. A string containing nothing but blanks will be replaced with a single blank.  
 Sect. 5.2.1 also states that a quote character ( `'` ) in a string value is to be represented by two successive quote characters and the parser removes the repeated quote.
  - e The parser recognizes free-format character (NOST 100-2.0, Sect. 5.2.1), integer (Sect. 5.2.3), and floating-point values (Sect. 5.2.4) for all keywords.
  - f Sect. 5.2.3 offers no comment on the size of an integer keyvalue except indirectly in limiting it to 70 digits. The parser will translate an integer keyvalue to a 32-bit signed integer if it lies in the range -2147483648 to +2147483647, otherwise it interprets it as a 64-bit signed integer if possible, or else a "very long" integer (see `fitskey::type`).
  - g **END** not followed by 77 blanks is not considered to be a legitimate end keyrecord.
2. The parser supports a generalization of the OGIP Long String Keyvalue Convention (v1.0) whereby strings may be continued onto successive header keyrecords. A keyrecord contains a segment of a continued string if and only if
  - a it contains the pseudo-keyword **CONTINUE**,
  - b columns 9 and 10 are both blank,
  - c columns 11 to 80 contain what would be considered a valid string keyvalue, including optional key-comment, if column 9 had contained '**=**',
  - d the previous keyrecord contained either a valid string keyvalue or a valid **CONTINUE** keyrecord.

If any of these conditions is violated, the keyrecord is considered in isolation.

Syntax errors in keycomments in a continued string are treated more permissively than usual; the `'/'` delimiter may be omitted provided that parsing of the string keyvalue is not compromised. However, the `FITSHDR_↵COMMENT` status bit will be set for the keyrecord (see `fitskey::status`).

As for normal strings, trailing blanks in a continued string are not significant.

In the OGIP convention "the `'&'` character is used as the last non-blank character of the string to indicate that the string is (probably) continued on the following keyword". This additional syntax is not required by `fitshdr()`, but if `'&'` does occur as the last non-blank character of a continued string keyvalue then it will be removed, along with any trailing blanks. However, blanks that occur before the `'&'` will be preserved.

### 8.5.6 Variable Documentation

#### fitshdr\_errmsg

```
const char* fitshdr_errmsg[] [extern]
```

Status return messages.

Error messages to match the status value returned from each function.

## 8.6 fitshdr.h

[Go to the documentation of this file.](#)

```
00001 /*=====
00002  WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003  Copyright (C) 1995-2025, Mark Calabretta
00004
00005  This file is part of WCSLIB.
00006
00007  WCSLIB is free software: you can redistribute it and/or modify it under the
00008  terms of the GNU Lesser General Public License as published by the Free
00009  Software Foundation, either version 3 of the License, or (at your option)
00010  any later version.
00011
00012  WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013  WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
00014  FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015  more details.
00016
00017  You should have received a copy of the GNU Lesser General Public License
00018  along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020  Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021  http://www.atnf.csiro.au/people/Mark.Calabretta
00022  $Id: fitshdr.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023 *=====
00024 *
00025 * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026 * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027 * overview of the library.
00028 *
00029 *
00030 * Summary of the fitshdr routines
00031 * -----
00032 * The Flexible Image Transport System (FITS), is a data format widely used in
00033 * astronomy for data interchange and archive. It is described in
00034 *
00035 * "Definition of the Flexible Image Transport System (FITS), version 3.0",
00036 * Pence, W.D., Chiappetti, L., Page, C.G., Shaw, R.A., & Stobie, E. 2010,
00037 * A&A, 524, A42 - http://dx.doi.org/10.1051/0004-6361/201015362
00038 *
00039 * See also http://fits.gsfc.nasa.gov
00040 *
00041 * fitshdr() is a generic FITS header parser provided to handle keyrecords that
00042 * are ignored by the WCS header parsers, wcspih() and wcsbth(). Typically the
00043 * latter may be set to remove WCS keyrecords from a header leaving fitshdr()
00044 * to handle the remainder.
00045 *
00046 *
00047 * fitshdr() - FITS header parser routine
00048 * -----
00049 * fitshdr() parses a character array containing a FITS header, extracting
00050 * all keywords and their values into an array of fitskey structs.
00051 *
00052 * Given:
00053 *   header    const char []
00054 *
00055 *   Character array containing the (entire) FITS header,
00056 *   for example, as might be obtained conveniently via the
00057 *   CFITSIO routine fits_hdr2str().
00058 *
00059 *   Each header "keyrecord" (formerly "card image")
00060 *   consists of exactly 80 7-bit ASCII printing characters
00061 *   in the range 0x20 to 0x7e (which excludes NUL, BS,
00062 *   TAB, LF, FF and CR) especially noting that the
00063 *   keyrecords are NOT null-terminated.
```

```

00064 *   nkeyrec   int           Number of keyrecords in header[].
00065 *
00066 *   nkeyids   int           Number of entries in keyids[].
00067 *
00068 * Given and returned:
00069 *   keyids     struct fitskeyid []
00070 *           While all keywords are extracted from the header,
00071 *           keyids[] provides a convenient way of indexing them.
00072 *           The fitskeyid struct contains three members;
00073 *           fitskeyid::name must be set by the user while
00074 *           fitskeyid::count and fitskeyid::idx are returned by
00075 *           fitshdr(). All matched keywords will have their
00076 *           fitskey::keyno member negated.
00077 *
00078 * Returned:
00079 *   nreject    int*         Number of header keyrecords rejected for syntax
00080 *                           errors.
00081 *
00082 *   keys       struct fitskey**
00083 *           Pointer to an array of nkeyrec fitskey structs
00084 *           containing all keywords and keyvalues extracted from
00085 *           the header.
00086 *
00087 *           Memory for the array is allocated by fitshdr() and
00088 *           this must be freed by the user. See wcsdealloc().
00089 *
00090 * Function return value:
00091 *   int         Status return value:
00092 *           0: Success.
00093 *           1: Null fitskey pointer passed.
00094 *           2: Memory allocation failed.
00095 *           3: Fatal error returned by Flex parser.
00096 *           4: Unrecognised data type.
00097 *
00098 * Notes:
00099 *   1: Keyword parsing is done in accordance with the syntax defined by
00100 *      NOST 100-2.0, noting the following points in particular:
00101 *
00102 *      a: Sect. 5.1.2.1 specifies that keywords be left-justified in columns
00103 *         1-8, blank-filled with no embedded spaces, composed only of the
00104 *         ASCII characters ABCDEFGHJKLMNPOQRSTUVWXYZ0123456789-_
00105 *
00106 *         fitshdr() accepts any characters in columns 1-8 but flags keywords
00107 *         that do not conform to standard syntax.
00108 *
00109 *      b: Sect. 5.1.2.2 defines the "value indicator" as the characters "="
00110 *         occurring in columns 9 and 10. If these are absent then the
00111 *         keyword has no value and columns 9-80 may contain any ASCII text
00112 *         (but see note 2 for CONTINUE keyrecords). This is copied to the
00113 *         comment member of the fitskey struct.
00114 *
00115 *      c: Sect. 5.1.2.3 states that a keyword may have a null (undefined)
00116 *         value if the value/comment field, columns 11-80, consists entirely
00117 *         of spaces, possibly followed by a comment.
00118 *
00119 *      d: Sect. 5.1.1 states that trailing blanks in a string keyvalue are
00120 *         not significant and the parser always removes them. A string
00121 *         containing nothing but blanks will be replaced with a single
00122 *         blank.
00123 *
00124 *         Sect. 5.2.1 also states that a quote character (') in a string
00125 *         value is to be represented by two successive quote characters and
00126 *         the parser removes the repeated quote.
00127 *
00128 *      e: The parser recognizes free-format character (NOST 100-2.0,
00129 *         Sect. 5.2.1), integer (Sect. 5.2.3), and floating-point values
00130 *         (Sect. 5.2.4) for all keywords.
00131 *
00132 *      f: Sect. 5.2.3 offers no comment on the size of an integer keyvalue
00133 *         except indirectly in limiting it to 70 digits. The parser will
00134 *         translate an integer keyvalue to a 32-bit signed integer if it
00135 *         lies in the range -2147483648 to +2147483647, otherwise it
00136 *         interprets it as a 64-bit signed integer if possible, or else a
00137 *         "very long" integer (see fitskey::type).
00138 *
00139 *      g: END not followed by 77 blanks is not considered to be a legitimate
00140 *         end keyrecord.
00141 *
00142 *   2: The parser supports a generalization of the OGIP Long String Keyvalue
00143 *      Convention (v1.0) whereby strings may be continued onto successive
00144 *      header keyrecords. A keyrecord contains a segment of a continued
00145 *      string if and only if
00146 *
00147 *      a: it contains the pseudo-keyword CONTINUE,
00148 *
00149 *      b: columns 9 and 10 are both blank,
00150 *

```

```

00151 *      c: columns 11 to 80 contain what would be considered a valid string
00152 *      keyvalue, including optional keycomment, if column 9 had contained
00153 *      '=',
00154 *
00155 *      d: the previous keyrecord contained either a valid string keyvalue or
00156 *      a valid CONTINUE keyrecord.
00157 *
00158 *      If any of these conditions is violated, the keyrecord is considered in
00159 *      isolation.
00160 *
00161 *      Syntax errors in keycomments in a continued string are treated more
00162 *      permissively than usual; the '/' delimiter may be omitted provided that
00163 *      parsing of the string keyvalue is not compromised. However, the
00164 *      FITSHDR_COMMENT status bit will be set for the keyrecord (see
00165 *      fitskey::status).
00166 *
00167 *      As for normal strings, trailing blanks in a continued string are not
00168 *      significant.
00169 *
00170 *      In the OGIP convention "the '&' character is used as the last non-blank
00171 *      character of a string to indicate that the string is (probably)
00172 *      continued on the following keyword". This additional syntax is not
00173 *      required by fitshdr(), but if '&' does occur as the last non-blank
00174 *      character of a continued string keyvalue then it will be removed, along
00175 *      with any trailing blanks. However, blanks that occur before the '&'
00176 *      will be preserved.
00177 *
00178 *
00179 * fitskeyid struct - Keyword indexing
00180 * -----
00181 * fitshdr() uses the fitskeyid struct to return indexing information for
00182 * specified keywords. The struct contains three members, the first of which,
00183 * fitskeyid::name, must be set by the user with the remainder returned by
00184 * fitshdr().
00185 *
00186 *      char name[12]:
00187 *      (Given) Name of the required keyword. This is to be set by the user;
00188 *      the '.' character may be used for wildcarding. Trailing blanks will be
00189 *      replaced with nulls.
00190 *
00191 *      int count:
00192 *      (Returned) The number of matches found for the keyword.
00193 *
00194 *      int idx[2]:
00195 *      (Returned) Indices into keys[], the array of fitskey structs returned by
00196 *      fitshdr(). Note that these are 0-relative array indices, not keyrecord
00197 *      numbers.
00198 *
00199 *      If the keyword is found in the header the first index will be set to the
00200 *      array index of its first occurrence, otherwise it will be set to -1.
00201 *
00202 *      If multiples of the keyword are found, the second index will be set to
00203 *      the array index of its last occurrence, otherwise it will be set to -1.
00204 *
00205 *
00206 * fitskey struct - Keyword/value information
00207 * -----
00208 * fitshdr() returns an array of fitskey structs, each of which contains the
00209 * result of parsing one FITS header keyrecord. All members of the fitskey
00210 * struct are returned by fitshdr(), none are given by the user.
00211 *
00212 *      int keyno
00213 *      (Returned) Keyrecord number (1-relative) in the array passed as input to
00214 *      fitshdr(). This will be negated if the keyword matched any specified in
00215 *      the keyids[] index.
00216 *
00217 *      int keyid
00218 *      (Returned) Index into the first entry in keyids[] with which the
00219 *      keyrecord matches, else -1.
00220 *
00221 *      int status
00222 *      (Returned) Status flag bit-vector for the header keyrecord employing the
00223 *      following bit masks defined as preprocessor macros:
00224 *
00225 *      - FITSHDR_KEYWORD:      Illegal keyword syntax.
00226 *      - FITSHDR_KEYVALUE:     Illegal keyvalue syntax.
00227 *      - FITSHDR_COMMENT:      Illegal keycomment syntax.
00228 *      - FITSHDR_KEYREC:       Illegal keyrecord, e.g. an END keyrecord with
00229 *      trailing text.
00230 *      - FITSHDR_TRAILER:      Keyrecord following a valid END keyrecord.
00231 *
00232 *      The header keyrecord is syntactically correct if no bits are set.
00233 *
00234 *      char keyword[12]
00235 *      (Returned) Keyword name, null-filled for keywords of less than eight
00236 *      characters (trailing blanks replaced by nulls).
00237 *

```

```

00238 *      Use
00239 *
00240 =      sprintf(dst, "%.8s", keyword)
00241 *
00242 *      to copy it to a character array with null-termination, or
00243 *
00244 =      sprintf(dst, "%8.8s", keyword)
00245 *
00246 *      to blank-fill to eight characters followed by null-termination.
00247 *
00248 *  int type
00249 *      (Returned) Keyvalue data type:
00250 *      - 0: No keyvalue (both the value and type are undefined).
00251 *      - 1: Logical, represented as int.
00252 *      - 2: 32-bit signed integer.
00253 *      - 3: 64-bit signed integer (see below).
00254 *      - 4: Very long integer (see below).
00255 *      - 5: Floating point (stored as double).
00256 *      - 6: Integer complex (stored as double[2]).
00257 *      - 7: Floating point complex (stored as double[2]).
00258 *      - 8: String.
00259 *      - 8+10*n: Continued string (described below and in fitshdr() note 2).
00260 *
00261 *      A negative type indicates that a syntax error was encountered when
00262 *      attempting to parse a keyvalue of the particular type.
00263 *
00264 *      Comments on particular data types:
00265 *      - 64-bit signed integers lie in the range
00266 *
00267 =      (-9223372036854775808 <= int64 < -2147483648) ||
00268 =      (+2147483647 < int64 <= +9223372036854775807)
00269 *
00270 *      A native 64-bit data type may be defined via preprocessor macro
00271 *      WCSLIB_INT64 defined in wcsconfig.h, e.g. as 'long long int'; this
00272 *      will be typedef'd to 'int64' here. If WCSLIB_INT64 is not set, then
00273 *      int64 is typedef'd to int[3] instead and fitskey::keyvalue is to be
00274 *      computed as
00275 *
00276 =      ((keyvalue.k[2]) * 1000000000 +
00277 =      keyvalue.k[1]) * 1000000000 +
00278 =      keyvalue.k[0]
00279 *
00280 *      and may reported via
00281 *
00282 =      if (keyvalue.k[2]) {
00283 =          printf("%d%09d%09d", keyvalue.k[2], abs(keyvalue.k[1]),
00284 =                  abs(keyvalue.k[0]));
00285 =      } else {
00286 =          printf("%d%09d", keyvalue.k[1], abs(keyvalue.k[0]));
00287 =      }
00288 *
00289 *      where keyvalue.k[0] and keyvalue.k[1] range from -999999999 to
00290 *      +999999999.
00291 *
00292 *      - Very long integers, up to 70 decimal digits in length, are encoded
00293 *      in keyvalue.l as an array of int[8], each of which stores 9 decimal
00294 *      digits. fitskey::keyvalue is to be computed as
00295 *
00296 =      ((((((keyvalue.l[7]) * 1000000000 +
00297 =      keyvalue.l[6]) * 1000000000 +
00298 =      keyvalue.l[5]) * 1000000000 +
00299 =      keyvalue.l[4]) * 1000000000 +
00300 =      keyvalue.l[3]) * 1000000000 +
00301 =      keyvalue.l[2]) * 1000000000 +
00302 =      keyvalue.l[1]) * 1000000000 +
00303 =      keyvalue.l[0]
00304 *
00305 *      - Continued strings are not reconstructed, they remain split over
00306 *      successive fitskey structs in the keys[] array returned by
00307 *      fitshdr(). fitskey::keyvalue data type, 8 + 10n, indicates the
00308 *      segment number, n, in the continuation.
00309 *
00310 *  int padding
00311 *      (An unused variable inserted for alignment purposes only.)
00312 *
00313 *  union keyvalue
00314 *      (Returned) A union comprised of
00315 *
00316 *      - fitskey::i,
00317 *      - fitskey::k,
00318 *      - fitskey::l,
00319 *      - fitskey::f,
00320 *      - fitskey::c,
00321 *      - fitskey::s,
00322 *
00323 *      used by the fitskey struct to contain the value associated with a
00324 *      keyword.

```

```

00325 *
00326 *   int i
00327 *       (Returned) Logical (fitskey::type == 1) and 32-bit signed integer
00328 *       (fitskey::type == 2) data types in the fitskey::keyvalue union.
00329 *
00330 *   int64 k
00331 *       (Returned) 64-bit signed integer (fitskey::type == 3) data type in the
00332 *       fitskey::keyvalue union.
00333 *
00334 *   int l[8]
00335 *       (Returned) Very long integer (fitskey::type == 4) data type in the
00336 *       fitskey::keyvalue union.
00337 *
00338 *   double f
00339 *       (Returned) Floating point (fitskey::type == 5) data type in the
00340 *       fitskey::keyvalue union.
00341 *
00342 *   double c[2]
00343 *       (Returned) Integer and floating point complex (fitskey::type == 6 || 7)
00344 *       data types in the fitskey::keyvalue union.
00345 *
00346 *   char s[72]
00347 *       (Returned) Null-terminated string (fitskey::type == 8) data type in the
00348 *       fitskey::keyvalue union.
00349 *
00350 *   int ulen
00351 *       (Returned) Where a keycomment contains a units string in the standard
00352 *       form, e.g. [m/s], the ulen member indicates its length, inclusive of
00353 *       square brackets. Otherwise ulen is zero.
00354 *
00355 *   char comment[84]
00356 *       (Returned) Keycomment, i.e. comment associated with the keyword or, for
00357 *       keyrecords rejected because of syntax errors, the compete keyrecord
00358 *       itself with null-termination.
00359 *
00360 *       Comments are null-terminated with trailing spaces removed. Leading
00361 *       spaces are also removed from keycomments (i.e. those immediately
00362 *       following the '/' character), but not from COMMENT or HISTORY keyrecords
00363 *       or keyrecords without a value indicator ("= " in columns 9-80).
00364 *
00365 *
00366 * Global variable: const char *fitshdr_errmsg[] - Status return messages
00367 * -----
00368 * Error messages to match the status value returned from each function.
00369 *
00370 * =====*/
00371
00372 #ifndef WCSLIB_FITSHDR
00373 #define WCSLIB_FITSHDR
00374
00375 #include "wcsconfig.h"
00376
00377 #ifdef __cplusplus
00378 extern "C" {
00379 #endif
00380
00381 #define FITSHDR_KEYWORD 0x01
00382 #define FITSHDR_KEYVALUE 0x02
00383 #define FITSHDR_COMMENT 0x04
00384 #define FITSHDR_KEYREC 0x08
00385 #define FITSHDR_CARD 0x08 // Alias for backwards compatibility.
00386 #define FITSHDR_TRAILER 0x10
00387
00388
00389 extern const char *fitshdr_errmsg[];
00390
00391 enum fitshdr_errmsg_enum {
00392     FITSHDRERR_SUCCESS = 0, // Success.
00393     FITSHDRERR_NULL_POINTER = 1, // Null fitskey pointer passed.
00394     FITSHDRERR_MEMORY = 2, // Memory allocation failed.
00395     FITSHDRERR_FLEX_PARSER = 3, // Fatal error returned by Flex parser.
00396     FITSHDRERR_DATA_TYPE = 4 // Unrecognised data type.
00397 };
00398
00399 #ifdef WCSLIB_INT64
00400     typedef WCSLIB_INT64 int64;
00401 #else
00402     typedef int int64[3];
00403 #endif
00404
00405
00406 // Struct used for indexing the keywords.
00407 struct fitskeyid {
00408     char name[12]; // Keyword name, null-terminated.
00409     int count; // Number of occurrences of keyword.
00410     int idx[2]; // Indices into fitskey array.
00411 };

```

```

00412
00413 // Size of the fitskeyid struct in int units, used by the Fortran wrappers.
00414 #define KEYIDLEN (sizeof(struct fitskeyid)/sizeof(int))
00415
00416
00417 // Struct used for storing FITS keywords.
00418 struct fitskey {
00419     int keyno; // Header keyrecord sequence number (1-rel).
00420     int keyid; // Index into fitskeyid[].
00421     int status; // Header keyrecord status bit flags.
00422     char keyword[12]; // Keyword name, null-filled.
00423     int type; // Keyvalue type (see above).
00424     int padding; // (Dummy inserted for alignment purposes.)
00425     union {
00426         int i; // 32-bit integer and logical values.
00427         int64 k; // 64-bit integer values.
00428         int l[8]; // Very long signed integer values.
00429         double f; // Floating point values.
00430         double c[2]; // Complex values.
00431         char s[72]; // String values, null-terminated.
00432     } keyvalue; // Keyvalue.
00433     int ulen; // Length of units string.
00434     char comment[84]; // Comment (or keyrecord), null-terminated.
00435 };
00436
00437 // Size of the fitskey struct in int units, used by the Fortran wrappers.
00438 #define KEYLEN (sizeof(struct fitskey)/sizeof(int))
00439
00440
00441 int fitshdr(const char header[], int nkeyrec, int nkeyids,
00442            struct fitskeyid keyids[], int *nreject, struct fitskey **keys);
00443
00444
00445 #ifdef __cplusplus
00446 }
00447 #endif
00448
00449 #endif // WCSLIB_FITSHDR

```

## 8.7 getwcstab.h File Reference

```
#include <fitsio.h>
```

### Data Structures

- struct [wtbarr](#)

*Extraction of coordinate lookup tables from BINTABLE.*

### Functions

- int [fits\\_read\\_wcstab](#) (fitsfile \*fptr, int nwtb, [wtbarr](#) \*wtb, int \*status)

*FITS 'TAB' table reading routine.*

#### 8.7.1 Detailed Description

[fits\\_read\\_wcstab\(\)](#), an implementation of a FITS table reading routine for 'TAB' coordinates, is provided for CFITSIO programmers. It has been incorporated into CFITSIO as of v3.006 with the definitions in this file, [getwcstab.h](#), moved into fitsio.h.

[fits\\_read\\_wcstab\(\)](#) is not included in the WCSLIB object library but the source code is presented here as it may be useful for programmers using an older version of CFITSIO than 3.006, or as a programming template for non-↔ CFITSIO programmers.

## 8.7.2 Function Documentation

### `fits_read_wcstab()`

```
int fits_read_wcstab (
    fitsfile * fptr,
    int nwtb,
    wtbarr * wtb,
    int * status)
```

FITS '**TAB**' table reading routine.

`fits_read_wcstab()` extracts arrays from a binary table required in constructing '**TAB**' coordinates.

#### Parameters

in	<i>fptr</i>	Pointer to the file handle returned, for example, by the <code>fits_open_file()</code> routine in CFITSIO.
in	<i>nwtb</i>	Number of arrays to be read from the binary table(s).
in, out	<i>wtb</i>	Address of the first element of an array of <code>wtbarr</code> typedefs. This <code>wtbarr</code> typedef is defined to match the <code>wtbarr</code> struct defined in WCSLIB. An array of such structs returned by the WCSLIB function <code>wcstab()</code> as discussed in the notes below.
out	<i>status</i>	CFITSIO status value.

#### Returns

CFITSIO status value.

#### Notes:

1. In order to maintain WCSLIB and CFITSIO as independent libraries it is not permissible for any CFITSIO library code to include WCSLIB header files, or vice versa. However, the CFITSIO function `fits_read_wcstab()` accepts an array of `wtbarr` structs defined in `wcs.h` within WCSLIB.

The problem therefore is to define the `wtbarr` struct within `fitsio.h` without including `wcs.h`, especially noting that `wcs.h` will often (but not always) be included together with `fitsio.h` in an applications program that uses `fits_read_wcstab()`.

The solution adopted is for WCSLIB to define "struct `wtbarr`" while `fitsio.h` defines "typedef `wtbarr`" as an untagged struct with identical members. This allows both `wcs.h` and `fitsio.h` to define a `wtbarr` data type without conflict by virtue of the fact that structure tags and typedef names share different name spaces in C; Appendix A, Sect. A11.1 (p227) of the K&R ANSI edition states that:

```
Identifiers fall into several name spaces that do not interfere with
one another; the same identifier may be used for different purposes,
even in the same scope, if the uses are in different name spaces.
These classes are: objects, functions, typedef names, and enum
constants; labels; tags of structures, unions, and enumerations; and
members of each structure or union individually.
```

Therefore, declarations within WCSLIB look like

```
struct wtbarr *w;
```

while within CFITSIO they are simply

```
wtbarr *w;
```

As suggested by the commonality of the names, these are really the same aggregate data type. However, in passing a (struct `wtbarr` \*) to `fits_read_wcstab()` a cast to (`wtbarr` \*) is formally required.

When using WCSLIB and CFITSIO together in C++ the situation is complicated by the fact that typedefs and structs share the same namespace; C++ Annotated Reference Manual, Sect. 7.1.3 (p105). In that case the `wtbarr` struct in `wcs.h` is renamed by preprocessor macro substitution to `wtbarr_s` to distinguish it from the typedef defined in `fitsio.h`. However, the scope of this macro substitution is limited to `wcs.h` itself and CFITSIO programmer code, whether in C++ or C, should always use the `wtbarr` typedef.

## 8.8 getwcstab.h

[Go to the documentation of this file.](#)

```

00001 /*=====
00002 WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003 Copyright (C) 1995-2025, Mark Calabretta
00004
00005 This file is part of WCSLIB.
00006
00007 WCSLIB is free software: you can redistribute it and/or modify it under the
00008 terms of the GNU Lesser General Public License as published by the Free
00009 Software Foundation, either version 3 of the License, or (at your option)
00010 any later version.
00011
00012 WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013 WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
00014 FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015 more details.
00016
00017 You should have received a copy of the GNU Lesser General Public License
00018 along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020 Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021 http://www.atnf.csiro.au/people/Mark.Calabretta
00022 $Id: getwcstab.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023 *=====
00024 *
00025 * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026 * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027 * overview of the library.
00028 *
00029 * Summary of the getwcstab routines
00030 * -----
00031 * fits_read_wcstab(), an implementation of a FITS table reading routine for
00032 * 'TAB' coordinates, is provided for CFITSIO programmers. It has been
00033 * incorporated into CFITSIO as of v3.006 with the definitions in this file,
00034 * getwcstab.h, moved into fitsio.h.
00035 *
00036 * fits_read_wcstab() is not included in the WCSLIB object library but the
00037 * source code is presented here as it may be useful for programmers using an
00038 * older version of CFITSIO than 3.006, or as a programming template for
00039 * non-CFITSIO programmers.
00040 *
00041 *
00042 * fits_read_wcstab() - FITS 'TAB' table reading routine
00043 * -----
00044 * fits_read_wcstab() extracts arrays from a binary table required in
00045 * constructing 'TAB' coordinates.
00046 *
00047 * Given:
00048 *   fptr      fitsfile *
00049 *               Pointer to the file handle returned, for example, by
00050 *               the fits_open_file() routine in CFITSIO.
00051 *
00052 *   nwtb      int
00053 *               Number of arrays to be read from the binary table(s).
00054 *
00055 * Given and returned:
00056 *   wtb       wtbar *
00057 *               Address of the first element of an array of wtbar
00058 *               typedefs. This wtbar typedef is defined to match the
00059 *               wtbar struct defined in WCSLIB. An array of such
00060 *               structs returned by the WCSLIB function wcstab() as
00061 *               discussed in the notes below.
00062 *
00063 * Returned:
00064 *   status    int *
00065 *               CFITSIO status value.
00066 *
00067 * Function return value:
00068 *   int
00069 *               CFITSIO status value.
00070 *
00071 * Notes:
00072 *   1: In order to maintain WCSLIB and CFITSIO as independent libraries it is
00073 *      not permissible for any CFITSIO library code to include WCSLIB header
00074 *      files, or vice versa. However, the CFITSIO function fits_read_wcstab()
00075 *      accepts an array of wtbar structs defined in wcs.h within WCSLIB.
00076 *
00077 *      The problem therefore is to define the wtbar struct within fitsio.h
00078 *      without including wcs.h, especially noting that wcs.h will often (but
00079 *      not always) be included together with fitsio.h in an applications
00080 *      program that uses fits_read_wcstab().
00081 *
00082 *      The solution adopted is for WCSLIB to define "struct wtbar" while
00083 *      fitsio.h defines "typedef wtbar" as an untagged struct with identical
00084 *      members. This allows both wcs.h and fitsio.h to define a wtbar data
00085 *      type without conflict by virtue of the fact that structure tags and
00086 *      typedef names share different name spaces in C; Appendix A, Sect. A11.1

```

```

00083 *      (p227) of the K&R ANSI edition states that:
00084 *
00085 =      Identifiers fall into several name spaces that do not interfere with
00086 =      one another; the same identifier may be used for different purposes,
00087 =      even in the same scope, if the uses are in different name spaces.
00088 =      These classes are: objects, functions, typedef names, and enum
00089 =      constants; labels; tags of structures, unions, and enumerations; and
00090 =      members of each structure or union individually.
00091 *
00092 *      Therefore, declarations within WCSLIB look like
00093 *
00094 =      struct wt barr *w;
00095 *
00096 *      while within CFITSIO they are simply
00097 *
00098 =      wt barr *w;
00099 *
00100 *      As suggested by the commonality of the names, these are really the same
00101 *      aggregate data type. However, in passing a (struct wt barr *) to
00102 *      fits_read_wcstab() a cast to (wt barr *) is formally required.
00103 *
00104 *      When using WCSLIB and CFITSIO together in C++ the situation is
00105 *      complicated by the fact that typedefs and structs share the same
00106 *      namespace; C++ Annotated Reference Manual, Sect. 7.1.3 (p105). In that
00107 *      case the wt barr struct in wcs.h is renamed by preprocessor macro
00108 *      substitution to wt barr_s to distinguish it from the typedef defined in
00109 *      fitsio.h. However, the scope of this macro substitution is limited to
00110 *      wcs.h itself and CFITSIO programmer code, whether in C++ or C, should
00111 *      always use the wt barr typedef.
00112 *
00113 *
00114 * wt barr typedef
00115 * -----
00116 * The wt barr typedef is defined as a struct containing the following members:
00117 *
00118 *      int i
00119 *          Image axis number.
00120 *
00121 *      int m
00122 *          Array axis number for index vectors.
00123 *
00124 *      int kind
00125 *          Character identifying the array type:
00126 *              - c: coordinate array,
00127 *              - i: index vector.
00128 *
00129 *      char extnam[72]
00130 *          EXTNAME identifying the binary table extension.
00131 *
00132 *      int extver
00133 *          EXTVER identifying the binary table extension.
00134 *
00135 *      int extlev
00136 *          EXTLEV identifying the binary table extension.
00137 *
00138 *      char ttype[72]
00139 *          TYPEn identifying the column of the binary table that contains the
00140 *          array.
00141 *
00142 *      long row
00143 *          Table row number.
00144 *
00145 *      int ndim
00146 *          Expected dimensionality of the array.
00147 *
00148 *      int *dimlen
00149 *          Address of the first element of an array of int of length ndim into
00150 *          which the array axis lengths are to be written.
00151 *
00152 *      double **arrayp
00153 *          Pointer to an array of double which is to be allocated by the user
00154 *          and into which the array is to be written.
00155 *
00156 * =====*/
00157
00158 #ifndef WCSLIB_GETWCSTAB
00159 #define WCSLIB_GETWCSTAB
00160
00161 #ifdef __cplusplus
00162 extern "C" {
00163 #endif
00164
00165 #include <fitsio.h>
00166
00167 typedef struct {
00168     int i;                // Image axis number.
00169     int m;                // Array axis number for index vectors.

```

```

00170 int kind; // Array type, 'c' (coord) or 'i' (index).
00171 char extnam[72]; // EXTNAME of binary table extension.
00172 int extver; // EXTVER of binary table extension.
00173 int extlev; // EXTLEV of binary table extension.
00174 char ttype[72]; // TTYPEn of column containing the array.
00175 long row; // Table row number.
00176 int ndim; // Expected array dimensionality.
00177 int *dimlen; // Where to write the array axis lengths.
00178 double **arrayp; // Where to write the address of the array
00179 // allocated to store the array.
00180 } wtbarr;
00181
00182
00183 int fits_read_wcstab(fitsfile *fptr, int nwtb, wtbarr *wtb, int *status);
00184
00185
00186 #ifdef __cplusplus
00187 }
00188 #endif
00189
00190 #endif // WCSLIB_GETWCSTAB

```

## 8.9 lin.h File Reference

### Data Structures

- struct [linprm](#)  
*Linear transformation parameters.*

### Macros

- #define [LINLEN](#) (sizeof(struct [linprm](#))/sizeof(int))  
*Size of the [linprm](#) struct in int units.*
- #define [linini\\_errmsg](#) [lin\\_errmsg](#)  
*Deprecated.*
- #define [lincpy\\_errmsg](#) [lin\\_errmsg](#)  
*Deprecated.*
- #define [linfree\\_errmsg](#) [lin\\_errmsg](#)  
*Deprecated.*
- #define [linprt\\_errmsg](#) [lin\\_errmsg](#)  
*Deprecated.*
- #define [linset\\_errmsg](#) [lin\\_errmsg](#)  
*Deprecated.*
- #define [linp2x\\_errmsg](#) [lin\\_errmsg](#)  
*Deprecated.*
- #define [linx2p\\_errmsg](#) [lin\\_errmsg](#)  
*Deprecated.*

### Enumerations

- enum [linenq\\_enum](#) { [LINENQ\\_MEM](#) = 1 , [LINENQ\\_SET](#) = 2 , [LINENQ\\_BYP](#) = 4 }
- enum [lin\\_errmsg\\_enum](#) {  
[LINERR\\_SUCCESS](#) = 0 , [LINERR\\_NULL\\_POINTER](#) = 1 , [LINERR\\_MEMORY](#) = 2 , [LINERR\\_SINGULAR\\_MTX](#)  
= 3 ,  
[LINERR\\_DISTORT\\_INIT](#) = 4 , [LINERR\\_DISTORT](#) = 5 , [LINERR\\_DEDISTORT](#) = 6 }

## Functions

- int **linini** (int alloc, int naxis, struct **linprm** \*lin)  
*Default constructor for the **linprm** struct.*
- int **lininit** (int alloc, int naxis, struct **linprm** \*lin, int ndpmax)  
*Default constructor for the **linprm** struct.*
- int **lindis** (int sequence, struct **linprm** \*lin, struct **disprm** \*dis)  
*Assign a distortion to a **linprm** struct.*
- int **lindist** (int sequence, struct **linprm** \*lin, struct **disprm** \*dis, int ndpmax)  
*Assign a distortion to a **linprm** struct.*
- int **lincpy** (int alloc, const struct **linprm** \*linsrc, struct **linprm** \*lindst)  
*Copy routine for the **linprm** struct.*
- int **linfree** (struct **linprm** \*lin)  
*Destructor for the **linprm** struct.*
- int **linsize** (const struct **linprm** \*lin, int sizes[2])  
*Compute the size of a **linprm** struct.*
- int **linenq** (const struct **linprm** \*lin, int enquiry)  
*enquire about the state of a **linprm** struct.*
- int **linprt** (const struct **linprm** \*lin)  
*Print routine for the **linprm** struct.*
- int **linperr** (const struct **linprm** \*lin, const char \*prefix)  
*Print error messages from a **linprm** struct.*
- int **linset** (struct **linprm** \*lin)  
*Setup routine for the **linprm** struct.*
- int **linp2x** (struct **linprm** \*lin, int ncoord, int nelemt, const double pixcrd[], double imgcrd[])  
*Pixel-to-world linear transformation.*
- int **linx2p** (struct **linprm** \*lin, int ncoord, int nelemt, const double imgcrd[], double pixcrd[])  
*World-to-pixel linear transformation.*
- int **linwarp** (struct **linprm** \*lin, const double pixblc[], const double pixtrc[], const double pixsamp[], int \*nsamp, double maxdis[], double \*maxtot, double avgdis[], double \*avgtot, double rmsdis[], double \*rmstot)  
*Compute measures of distortion.*
- int **matinv** (int n, const double mat[], double inv[])  
*Matrix inversion.*

## Variables

- const char \* **lin\_errmsg** []  
*Status return messages.*

### 8.9.1 Detailed Description

Routines in this suite apply the linear transformation defined by the FITS World Coordinate System (WCS) standard, as described in

"Representations of world coordinates in FITS",  
Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)

These routines are based on the **linprm** struct which contains all information needed for the computations. The struct contains some members that must be set by the user, and others that are maintained by these routines, somewhat like a C++ class but with no encapsulation.

Six routines, `linini()`, `lininit()`, `lindis()`, `lindist()`, `lincpy()`, and `linfree()` are provided to manage the `linprm` struct, `linsize()` computes its total size including allocated memory, `linenq()` returns information about the state of the struct, and `linprt()` prints its contents.

`linperr()` prints the error message(s) (if any) stored in a `linprm` struct, and the `disprm` structs that it may contain.

A setup routine, `linset()`, computes intermediate values in the `linprm` struct from parameters in it that were supplied by the user. The struct always needs to be set up by `linset()` but need not be called explicitly - refer to the explanation of `linprm::flag`.

`linp2x()` and `linx2p()` implement the WCS linear transformations.

An auxiliary routine, `linwarp()`, computes various measures of the distortion over a specified range of pixel coordinates.

An auxiliary matrix inversion routine, `matinv()`, is included. It uses LU-triangular factorization with scaled partial pivoting.

## 8.9.2 Macro Definition Documentation

### LINLEN

```
#define LINLEN (sizeof(struct linprm)/sizeof(int))
```

Size of the `linprm` struct in *int* units.

Size of the `linprm` struct in *int* units, used by the Fortran wrappers.

### linini\_errmsg

```
#define linini_errmsg lin_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use `lin_errmsg` directly now instead.

### lincpy\_errmsg

```
#define lincpy_errmsg lin_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use `lin_errmsg` directly now instead.

**linfree\_errmsg**

```
#define linfree_errmsg lin\_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [lin\\_errmsg](#) directly now instead.

**linprt\_errmsg**

```
#define linprt_errmsg lin\_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [lin\\_errmsg](#) directly now instead.

**linset\_errmsg**

```
#define linset_errmsg lin\_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [lin\\_errmsg](#) directly now instead.

**linp2x\_errmsg**

```
#define linp2x_errmsg lin\_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [lin\\_errmsg](#) directly now instead.

**linx2p\_errmsg**

```
#define linx2p_errmsg lin\_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [lin\\_errmsg](#) directly now instead.

---

**8.9.3 Enumeration Type Documentation**

Generated on Sun Dec 7 2025 00:49:01 for WCSLIB by Doxygen

**linenq\_enum**

## Enumerator

LINENQ_MEM	
LINENQ_SET	
LINENQ_BYP	

## lin\_errmsg\_enum

```
enum lin_errmsg_enum
```

## Enumerator

LINERR_SUCCESS	
LINERR_NULL_POINTER	
LINERR_MEMORY	
LINERR_SINGULAR_MTX	
LINERR_DISTORT_INIT	
LINERR_DISTORT	
LINERR_DEDISTORT	

## 8.9.4 Function Documentation

### linini()

```
int linini (
    int alloc,
    int naxis,
    struct linprm * lin)
```

Default constructor for the [linprm](#) struct.

**linini()** is a thin wrapper on **lininit()**. It invokes it with ndpmax set to -1 which causes it to use the value of the global variable NDPMAX. It is thereby potentially thread-unsafe if NDPMAX is altered dynamically via [disndp\(\)](#). Use **lininit()** for a thread-safe alternative in this case.

### lininit()

```
int lininit (
    int alloc,
    int naxis,
    struct linprm * lin,
    int ndpmax)
```

Default constructor for the [linprm](#) struct.

**lininit()** allocates memory for arrays in a [linprm](#) struct and sets all members of the struct to default values.

---

**PLEASE NOTE:** every [linprm](#) struct must be initialized by **lininit()**, possibly repeatedly. On the first invocation, and only the first invocation, [linprm::flag](#) must be set to -1 to initialize memory management, regardless of whether **lininit()** will actually be used to allocate memory.

## Parameters

in	<i>alloc</i>	If true, allocate memory unconditionally for arrays in the <a href="#">linprm</a> struct. If false, it is assumed that pointers to these arrays have been set by the user except if they are null pointers in which case memory will be allocated for them regardless. (In other words, setting alloc true saves having to initialize these pointers to zero.)
in	<i>naxis</i>	The number of world coordinate axes, used to determine array sizes.
in, out	<i>lin</i>	Linear transformation parameters. Note that, in order to initialize memory management <a href="#">linprm::flag</a> should be set to -1 when lin is initialized for the first time (memory leaks may result if it had already been initialized).
in	<i>ndpmax</i>	The number of DPja or DQia keywords to allocate space for. If set to -1, the value of the global variable NDPMAX will be used. This is potentially thread-unsafe if <a href="#">disndp()</a> is being used dynamically to alter its value.

## Returns

Status return value:

- 0: Success.
- 1: Null [linprm](#) pointer passed.
- 2: Memory allocation failed.

For returns > 1, a detailed error message is set in [linprm::err](#) if enabled, see [wcserr\\_enable\(\)](#).

**lindis()**

```
int lindis (
    int sequence,
    struct linprm * lin,
    struct disprm * dis)
```

Assign a distortion to a [linprm](#) struct.

**lindis()** is a thin wrapper on **lindist()**. It invokes it with ndpmax set to -1 which causes the value of the global variable NDPMAX to be used (by [disinit\(\)](#)). It is thereby potentially thread-unsafe if NDPMAX is altered dynamically via [disndp\(\)](#). Use **lindist()** for a thread-safe alternative in this case.

**lindist()**

```
int lindist (
    int sequence,
    struct linprm * lin,
    struct disprm * dis,
    int ndpmax)
```

Assign a distortion to a [linprm](#) struct.

**lindist()** may be used to assign the address of a disprm struct to [linprm::dispre](#) or [linprm::disseq](#). The [linprm](#) struct must already have been initialized by [lininit\(\)](#).

The disprm struct must have been allocated from the heap (e.g. using malloc(), calloc(), etc.). **lindist()** will immediately initialize it via a call to [disini\(\)](#) using the value of [linprm::naxis](#). Subsequently, it will be reinitialized by calls to [disini\(\)](#) and freed by [disfree\(\)](#), neither of which would happen if the disprm struct was assigned directly.

If the disprm struct had previously been assigned via **lindist()**, it will be freed before reassignment. It is also permissible for a null disprm pointer to be assigned to disable the distortion correction.

### Parameters

<code>in</code>	<code>sequence</code>	Is it a prior or sequent distortion? <ul style="list-style-type: none"> <li>• 1: Prior, the assignment is to <code>linprm::dispre</code>.</li> <li>• 2: Sequent, the assignment is to <code>linprm::disseq</code>.</li> </ul> Anything else is an error.
<code>in, out</code>	<code>lin</code>	Linear transformation parameters.
<code>in, out</code>	<code>dis</code>	Distortion function parameters.
<code>in</code>	<code>ndpmax</code>	The number of DPja or DQia keywords to allocate space for. If set to -1, the value of the global variable NDPMAX will be used. This is potentially thread-unsafe if <code>disndp()</code> is being used dynamically to alter its value.

### Returns

Status return value:

- 0: Success.
- 1: Null `linprm` pointer passed.
- 4: Invalid sequence.

### lincpy()

```
int lincpy (
    int alloc,
    const struct linprm * linsrc,
    struct linprm * lindst)
```

Copy routine for the `linprm` struct.

**lincpy()** does a deep copy of one `linprm` struct to another, using `lininit()` to allocate memory for its arrays if required. Only the "information to be provided" part of the struct is copied; a call to `linset()` is required to initialize the remainder.

### Parameters

<code>in</code>	<code>alloc</code>	If true, allocate memory for the <code>crpix</code> , <code>pc</code> , and <code>cdelt</code> arrays in the destination. Otherwise, it is assumed that pointers to these arrays have been set by the user except if they are null pointers in which case memory will be allocated for them regardless.
<code>in</code>	<code>linsrc</code>	Struct to copy from.
<code>in, out</code>	<code>lindst</code>	Struct to copy to. <code>linprm::flag</code> should be set to -1 if <code>lindst</code> was not previously initialized (memory leaks may result if it was previously initialized).

### Returns

Status return value:

- 0: Success.
- 1: Null `linprm` pointer passed.
- 2: Memory allocation failed.

For returns > 1, a detailed error message is set in `linprm::err` if enabled, see `wcserr_enable()`.

**linfree()**

```
int linfree (  
    struct linprm * lin)
```

Destructor for the `linprm` struct.

**linfree()** frees memory allocated for the `linprm` arrays by `lininit()` and/or `linset()`. `lininit()` keeps a record of the memory it allocates and **linfree()** will only attempt to free this.

**PLEASE NOTE:** **linfree()** must not be invoked on a `linprm` struct that was not initialized by `lininit()`.

**Parameters**

<code>in, out</code>	<code>lin</code>	Linear transformation parameters.
----------------------	------------------	-----------------------------------

**Returns**

Status return value:

- 0: Success.
- 1: Null `linprm` pointer passed.

**linsize()**

```
int linsize (  
    const struct linprm * lin,  
    int sizes[2])
```

Compute the size of a `linprm` struct.

**linsize()** computes the full size of a `linprm` struct, including allocated memory.

**Parameters**

<code>in</code>	<code>lin</code>	Linear transformation parameters. If NULL, the base size of the struct and the allocated size are both set to zero.
<code>out</code>	<code>sizes</code>	The first element is the base size of the struct as returned by <code>sizeof(struct linprm)</code> . The second element is the total size of memory allocated in the struct, in bytes, assuming that the allocation was done by <code>lininit()</code> . This figure includes memory allocated for members of constituent structs, * such as <code>linprm::dispre</code> . It is not an error for the struct not to have been set up via <code>linset()</code> , which normally results in additional memory allocation.

**Returns**

Status return value:

- 0: Success.

## linenq()

```
int linenq (
    const struct linprm * lin,
    int enquiry)
```

enquire about the state of a [linprm](#) struct.

**linenq()** may be used to obtain information about the state of a [linprm](#) struct. The function returns a true/false answer for the enquiry asked.

### Parameters

in	<i>lin</i>	Linear transformation parameters.
in	<i>enquiry</i>	<div>Enquiry according to the following parameters:<ul style="list-style-type: none"><li>• LINENQ_MEM: memory in the struct is being managed by WCSLIB (see <a href="#">lininit()</a>).</li><li>• LINENQ_SET: the struct has been set up by <a href="#">linset()</a>.</li><li>• LINENQ_BYP: the struct is in bypass mode (see <a href="#">linset()</a>).</li></ul>These may be combined by logical OR, e.g. LINENQ_MEM   LINENQ_SET. The enquiry result will be the logical AND of the individual results.</div>

### Returns

Enquiry result:

- 0: No.
- 1: Yes.

## linprt()

```
int linprt (
    const struct linprm * lin)
```

Print routine for the [linprm](#) struct.

**linprt()** prints the contents of a [linprm](#) struct using [wcsprintf\(\)](#). Mainly intended for diagnostic purposes.

### Parameters

in	<i>lin</i>	Linear transformation parameters.
----	------------	-----------------------------------

### Returns

Status return value:

- 0: Success.
- 1: Null [linprm](#) pointer passed.

**linperr()**

```
int linperr (
    const struct linprm * lin,
    const char * prefix)
```

Print error messages from a [linprm](#) struct.

**linperr()** prints the error message(s) (if any) stored in a [linprm](#) struct, and the disprm structs that it may contain. If there are no errors then nothing is printed. It uses [wcserr\\_prt\(\)](#), q.v.

**Parameters**

in	<i>lin</i>	Coordinate transformation parameters.
in	<i>prefix</i>	If non-NULL, each output line will be prefixed with this string.

**Returns**

Status return value:

- 0: Success.
- 1: Null [linprm](#) pointer passed.

**linset()**

```
int linset (
    struct linprm * lin)
```

Setup routine for the [linprm](#) struct.

**linset()**, if necessary, allocates memory for the [linprm::piximg](#) and [linprm::imgpix](#) arrays and sets up the [linprm](#) struct according to information supplied within it - refer to the explanation of [linprm::flag](#).

Note that this routine need not be called directly; it will be invoked by [linp2x\(\)](#) and [linx2p\(\)](#) if the [linprm::flag](#) is anything other than a predefined magic value.

**linset()** normally operates regardless of the value of [linprm::flag](#); i.e. even if a struct was previously set up it will be reset unconditionally. However, a [linprm](#) struct may be put into "bypass" mode by invoking **linset()** initially with [linprm::flag](#) == 1 (rather than 0). **linset()** will return immediately if invoked on a struct in that state. To take a struct out of bypass mode, simply reset [linprm::flag](#) to zero. See also [linenq\(\)](#).

**Parameters**

in, out	<i>lin</i>	Linear transformation parameters.
---------	------------	-----------------------------------

**Returns**

Status return value:

- 0: Success.
- 1: Null [linprm](#) pointer passed.
- 2: Memory allocation failed.
- 3: **PCi\_ja** matrix is singular.
- 4: Failed to initialise distortions.

For returns > 1, a detailed error message is set in [linprm::err](#) if enabled, see [wcserr\\_enable\(\)](#).

**linp2x()**

```
int linp2x (
    struct linprm * lin,
    int ncoord,
    int nelem,
    const double pixcrd[],
    double imgcrd[])
```

Pixel-to-world linear transformation.

**linp2x()** transforms pixel coordinates to intermediate world coordinates.

**Parameters**

in, out	<i>lin</i>	Linear transformation parameters.
in	<i>ncoord, nelem</i>	The number of coordinates, each of vector length <i>nelem</i> but containing <i>lin.naxis</i> coordinate elements.
in	<i>pixcrd</i>	Array of pixel coordinates.
out	<i>imgcrd</i>	Array of intermediate world coordinates.

**Returns**

Status return value:

- 0: Success.
- 1: Null [linprm](#) pointer passed.
- 2: Memory allocation failed.
- 3: **PCi\_ja** matrix is singular.
- 4: Failed to initialise distortions.
- 5: Distort error.

For returns > 1, a detailed error message is set in [linprm::err](#) if enabled, see [wcserr\\_enable\(\)](#).

**Notes:**

1. Historically, the API to **linp2x()** did not have a *stat[]* vector because a valid linear transformation should always succeed. However, now that it invokes [disp2x\(\)](#) if distortions are present, it does have the potential to fail. Consequently, when distortions are present and a status return (*stat[]*) is required for each coordinate, then **linp2x()** should be invoked separately for each of them.

**linx2p()**

```
int linx2p (
    struct linprm * lin,
    int ncoord,
    int nelem,
    const double imgcrd[],
    double pixcrd[])
```

World-to-pixel linear transformation.

**linx2p()** transforms intermediate world coordinates to pixel coordinates.

## Parameters

in, out	<i>lin</i>	Linear transformation parameters.
in	<i>ncoord, nelelem</i>	The number of coordinates, each of vector length nelelem but containing lin.naxis coordinate elements.
in	<i>imgcrd</i>	Array of intermediate world coordinates.
out	<i>pixcrd</i>	<p>Array of pixel coordinates. Status return value:</p> <ul style="list-style-type: none"> <li>• 0: Success.</li> <li>• 1: Null <a href="#">linprm</a> pointer passed.</li> <li>• 2: Memory allocation failed.</li> <li>• 3: <b>PCi__ja</b> matrix is singular.</li> <li>• 4: Failed to initialise distortions.</li> <li>• 6: De-distort error.</li> </ul> <p>For returns &gt; 1, a detailed error message is set in <a href="#">linprm::err</a> if enabled, see <a href="#">wcserr_enable()</a>.</p>

## Notes:

1. Historically, the API to **linx2p()** did not have a stat[] vector because a valid linear transformation should always succeed. However, now that it invokes [disx2p\(\)](#) if distortions are present, it does have the potential to fail. Consequently, when distortions are present and a status return (stat[]) is required for each coordinate, then **linx2p()** should be invoked separately for each of them.

## linwarp()

```
int linwarp (
    struct linprm * lin,
    const double pixblc[],
    const double pixtrc[],
    const double pixsamp[],
    int * nsamp,
    double maxdis[],
    double * maxtot,
    double avgdis[],
    double * avgtot,
    double rmsdis[],
    double * rmstot)
```

Compute measures of distortion.

**linwarp()** computes various measures of the distortion over a specified range of pixel coordinates.

All distortion measures are specified as an offset in pixel coordinates, as given directly by prior distortions. The offset in intermediate pixel coordinates given by sequent distortions is translated back to pixel coordinates by applying the inverse of the linear transformation matrix (**PCi\_\_ja** or **CDi\_\_ja**). The difference may be significant if the matrix introduced a scaling.

If all distortions are prior, then **linwarp()** uses [diswarp\(\)](#), q.v.

## Parameters

in, out	<i>lin</i>	Linear transformation parameters plus distortions.
in	<i>pixblc</i>	Start of the range of pixel coordinates (i.e. "bottom left-hand corner" in the conventional FITS image display orientation). May be specified as a NULL pointer which is interpreted as (1,1,...).
in	<i>pixtrc</i>	End of the range of pixel coordinates (i.e. "top right-hand corner" in the conventional FITS image display orientation).
in	<i>pixsamp</i>	If positive or zero, the increment on the particular axis, starting at <i>pixblc</i> []. Zero is interpreted as a unit increment. <i>pixsamp</i> may also be specified as a NULL pointer which is interpreted as all zeroes, i.e. unit increments on all axes. If negative, the grid size on the particular axis (the absolute value being rounded to the nearest integer). For example, if <i>pixsamp</i> is (-128.0,-128.0,...) then each axis will be sampled at 128 points between <i>pixblc</i> [] and <i>pixtrc</i> [] inclusive. Use caution when using this option on non-square images.
out	<i>nsamp</i>	The number of pixel coordinates sampled. Can be specified as a NULL pointer if not required.
out	<i>maxdis</i>	For each individual distortion function, the maximum absolute value of the distortion. Can be specified as a NULL pointer if not required.
out	<i>maxtot</i>	For the combination of all distortion functions, the maximum absolute value of the distortion. Can be specified as a NULL pointer if not required.
out	<i>avgdis</i>	For each individual distortion function, the mean value of the distortion. Can be specified as a NULL pointer if not required.
out	<i>avgtot</i>	For the combination of all distortion functions, the mean value of the distortion. Can be specified as a NULL pointer if not required.
out	<i>rmsdis</i>	For each individual distortion function, the root mean square deviation of the distortion. Can be specified as a NULL pointer if not required.
out	<i>rmstot</i>	For the combination of all distortion functions, the root mean square deviation of the distortion. Can be specified as a NULL pointer if not required.

## Returns

Status return value:

- 0: Success.
- 1: Null [linprm](#) pointer passed.
- 2: Memory allocation failed.
- 3: Invalid parameter.
- 4: Distort error.

## matinv()

```
int matinv (
    int n,
    const double mat[],
    double inv[])
```

Matrix inversion.

**matinv()** performs matrix inversion using LU-triangular factorization with scaled partial pivoting.

**Parameters**

in	$n$	Order of the matrix ( $n \times n$ ).
in	$mat$	Matrix to be inverted, stored as $mat[in + j]$ where $i$ and $j$ are the row and column indices respectively.
out	$inv$	Inverse of $mat$ with the same storage convention.

**Returns**

Status return value:

- 0: Success.
- 2: Memory allocation failed.
- 3: Singular matrix.

**8.9.5 Variable Documentation****lin\_errmsg**

```
const char* lin_errmsg[] [extern]
```

Status return messages.

Error messages to match the status value returned from each function.

**8.10 lin.h**

[Go to the documentation of this file.](#)

```

00001 /*=====
00002  WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003  Copyright (C) 1995-2025, Mark Calabretta
00004
00005  This file is part of WCSLIB.
00006
00007  WCSLIB is free software: you can redistribute it and/or modify it under the
00008  terms of the GNU Lesser General Public License as published by the Free
00009  Software Foundation, either version 3 of the License, or (at your option)
00010  any later version.
00011
00012  WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013  WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
00014  FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015  more details.
00016
00017  You should have received a copy of the GNU Lesser General Public License
00018  along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020  Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021  http://www.atnf.csiro.au/people/Mark.Calabretta
00022  $Id: lin.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023  *=====
00024  *
00025  * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026  * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027  * overview of the library.
00028  *
00029  *
00030  * Summary of the lin routines
00031  * -----
00032  * Routines in this suite apply the linear transformation defined by the FITS
00033  * World Coordinate System (WCS) standard, as described in
00034  *

```

```

00035 = "Representations of world coordinates in FITS",
00036 = Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)
00037 *
00038 * These routines are based on the linprm struct which contains all information
00039 * needed for the computations. The struct contains some members that must be
00040 * set by the user, and others that are maintained by these routines, somewhat
00041 * like a C++ class but with no encapsulation.
00042 *
00043 * Six routines, linini(), lininit(), lindis(), lindist(), lincpy(), and
00044 * linfree() are provided to manage the linprm struct, linsize() computes its
00045 * total size including allocated memory, linenq() returns information about
00046 * the state of the struct, and linprt() prints its contents.
00047 *
00048 * linperr() prints the error message(s) (if any) stored in a linprm struct,
00049 * and the disprm structs that it may contain.
00050 *
00051 * A setup routine, linset(), computes intermediate values in the linprm struct
00052 * from parameters in it that were supplied by the user. The struct always
00053 * needs to be set up by linset() but need not be called explicitly - refer to
00054 * the explanation of linprm::flag.
00055 *
00056 * linp2x() and linx2p() implement the WCS linear transformations.
00057 *
00058 * An auxiliary routine, linwarp(), computes various measures of the distortion
00059 * over a specified range of pixel coordinates.
00060 *
00061 * An auxiliary matrix inversion routine, matinv(), is included. It uses
00062 * LU-triangular factorization with scaled partial pivoting.
00063 *
00064 *
00065 * linini() - Default constructor for the linprm struct
00066 * -----
00067 * linini() is a thin wrapper on lininit(). It invokes it with ndpmax set
00068 * to -1 which causes it to use the value of the global variable NDPMAX. It
00069 * is thereby potentially thread-unsafe if NDPMAX is altered dynamically via
00070 * disndp(). Use lininit() for a thread-safe alternative in this case.
00071 *
00072 *
00073 * lininit() - Default constructor for the linprm struct
00074 * -----
00075 * lininit() allocates memory for arrays in a linprm struct and sets all
00076 * members of the struct to default values.
00077 *
00078 * PLEASE NOTE: every linprm struct must be initialized by lininit(), possibly
00079 * repeatedly. On the first invocation, and only the first invocation,
00080 * linprm::flag must be set to -1 to initialize memory management, regardless
00081 * of whether lininit() will actually be used to allocate memory.
00082 *
00083 * Given:
00084 *   alloc      int      If true, allocate memory unconditionally for arrays in
00085 *                        the linprm struct.
00086 *
00087 *                        If false, it is assumed that pointers to these arrays
00088 *                        have been set by the user except if they are null
00089 *                        pointers in which case memory will be allocated for
00090 *                        them regardless. (In other words, setting alloc true
00091 *                        saves having to initialize these pointers to zero.)
00092 *
00093 *   naxis      int      The number of world coordinate axes, used to determine
00094 *                        array sizes.
00095 *
00096 * Given and returned:
00097 *   lin        struct linprm*
00098 *                        Linear transformation parameters. Note that, in order
00099 *                        to initialize memory management linprm::flag should be
00100 *                        set to -1 when lin is initialized for the first time
00101 *                        (memory leaks may result if it had already been
00102 *                        initialized).
00103 *
00104 * Given:
00105 *   ndpmax     int      The number of DPja or DQia keywords to allocate space
00106 *                        for. If set to -1, the value of the global variable
00107 *                        NDPMAX will be used. This is potentially
00108 *                        thread-unsafe if disndp() is being used dynamically to
00109 *                        alter its value.
00110 *
00111 * Function return value:
00112 *   int        Status return value:
00113 *                0: Success.
00114 *                1: Null linprm pointer passed.
00115 *                2: Memory allocation failed.
00116 *
00117 *                        For returns > 1, a detailed error message is set in
00118 *                        linprm::err if enabled, see wcserr_enable().
00119 *
00120 *
00121 * lindis() - Assign a distortion to a linprm struct

```

```

00122 * -----
00123 * lindist() is a thin wrapper on lindist(). It invokes it with ndpmax set
00124 * to -1 which causes the value of the global variable NDPMAX to be used (by
00125 * disinit()). It is thereby potentially thread-unsafe if NDPMAX is altered
00126 * dynamically via disndp(). Use lindist() for a thread-safe alternative in
00127 * this case.
00128 *
00129 *
00130 * lindist() - Assign a distortion to a linprm struct
00131 * -----
00132 * lindist() may be used to assign the address of a disprm struct to
00133 * linprm::dispre or linprm::disseq. The linprm struct must already have been
00134 * initialized by lininit().
00135 *
00136 * The disprm struct must have been allocated from the heap (e.g. using
00137 * malloc(), calloc(), etc.). lindist() will immediately initialize it via a
00138 * call to disini() using the value of linprm::naxis. Subsequently, it will be
00139 * reinitialized by calls to lininit(), and freed by linfree(), neither of
00140 * which would happen if the disprm struct was assigned directly.
00141 *
00142 * If the disprm struct had previously been assigned via lindist(), it will be
00143 * freed before reassignment. It is also permissible for a null disprm pointer
00144 * to be assigned to disable the distortion correction.
00145 *
00146 * Given:
00147 *     sequence  int           Is it a prior or sequent distortion?
00148 *                       1: Prior, the assignment is to linprm::dispre.
00149 *                       2: Sequent, the assignment is to linprm::disseq.
00150 *
00151 *                       Anything else is an error.
00152 *
00153 * Given and returned:
00154 *     lin       struct linprm*
00155 *               Linear transformation parameters.
00156 *
00157 *     dis       struct disprm*
00158 *               Distortion function parameters.
00159 *
00160 * Given:
00161 *     ndpmax    int           The number of DPja or DQia keywords to allocate space
00162 *                           for. If set to -1, the value of the global variable
00163 *                           NDPMAX will be used. This is potentially
00164 *                           thread-unsafe if disndp() is being used dynamically to
00165 *                           alter its value.
00166 *
00167 * Function return value:
00168 *     int       Status return value:
00169 *               0: Success.
00170 *               1: Null linprm pointer passed.
00171 *               4: Invalid sequence.
00172 *
00173 *
00174 * lincpy() - Copy routine for the linprm struct
00175 * -----
00176 * lincpy() does a deep copy of one linprm struct to another, using lininit()
00177 * to allocate memory for its arrays if required. Only the "information to be
00178 * provided" part of the struct is copied; a call to linset() is required to
00179 * initialize the remainder.
00180 *
00181 * Given:
00182 *     alloc     int           If true, allocate memory for the crpix, pc, and cdelt
00183 *                           arrays in the destination. Otherwise, it is assumed
00184 *                           that pointers to these arrays have been set by the
00185 *                           user except if they are null pointers in which case
00186 *                           memory will be allocated for them regardless.
00187 *
00188 *     linsrc    const struct linprm*
00189 *               Struct to copy from.
00190 *
00191 * Given and returned:
00192 *     lindst    struct linprm*
00193 *               Struct to copy to. linprm::flag should be set to -1
00194 *               if lindst was not previously initialized (memory leaks
00195 *               may result if it was previously initialized).
00196 *
00197 * Function return value:
00198 *     int       Status return value:
00199 *               0: Success.
00200 *               1: Null linprm pointer passed.
00201 *               2: Memory allocation failed.
00202 *
00203 *               For returns > 1, a detailed error message is set in
00204 *               linprm::err if enabled, see wcserr_enable().
00205 *
00206 *
00207 * linfree() - Destructor for the linprm struct
00208 * -----

```

```

00209 * linfree() frees memory allocated for the linprm arrays by lininit() and/or
00210 * linset().  lininit() keeps a record of the memory it allocates and linfree()
00211 * will only attempt to free this.
00212 *
00213 * PLEASE NOTE: linfree() must not be invoked on a linprm struct that was not
00214 * initialized by lininit().
00215 *
00216 * Given and returned:
00217 *   lin          struct linprm*
00218 *               Linear transformation parameters.
00219 *
00220 * Function return value:
00221 *   int          Status return value:
00222 *               0: Success.
00223 *               1: Null linprm pointer passed.
00224 *
00225 *
00226 * linsize() - Compute the size of a linprm struct
00227 * -----
00228 * linsize() computes the full size of a linprm struct, including allocated
00229 * memory.
00230 *
00231 * Given:
00232 *   lin          const struct linprm*
00233 *               Linear transformation parameters.
00234 *
00235 *               If NULL, the base size of the struct and the allocated
00236 *               size are both set to zero.
00237 *
00238 * Returned:
00239 *   sizes        int[2]   The first element is the base size of the struct as
00240 *                          returned by sizeof(struct linprm).
00241 *
00242 *               The second element is the total size of memory
00243 *               allocated in the struct, in bytes, assuming that the
00244 *               allocation was done by lininit().  This figure
00245 *               includes memory allocated for members of constituent
00246 *               structs, *               such as linprm::dispre.
00247 *
00248 *               It is not an error for the struct not to have been set
00249 *               up via linset(), which normally results in additional
00250 *               memory allocation.
00251 *
00252 * Function return value:
00253 *   int          Status return value:
00254 *               0: Success.
00255 *
00256 *
00257 * linenq() - enquire about the state of a linprm struct
00258 * -----
00259 * linenq() may be used to obtain information about the state of a linprm
00260 * struct.  The function returns a true/false answer for the enquiry asked.
00261 *
00262 * Given:
00263 *   lin          const struct linprm*
00264 *               Linear transformation parameters.
00265 *
00266 *   enquiry      int      Enquiry according to the following parameters:
00267 *                           LINENQ_MEM: memory in the struct is being managed by
00268 *                           WCSLIB (see lininit()).
00269 *                           LINENQ_SET: the struct has been set up by linset().
00270 *                           LINENQ_BYP: the struct is in bypass mode (see
00271 *                           linset()).
00272 *               These may be combined by logical OR, e.g.
00273 *               LINENQ_MEM | LINENQ_SET.  The enquiry result will be
00274 *               the logical AND of the individual results.
00275 *
00276 * Function return value:
00277 *   int          Enquiry result:
00278 *               0: No.
00279 *               1: Yes.
00280 *
00281 *
00282 * linprt() - Print routine for the linprm struct
00283 * -----
00284 * linprt() prints the contents of a linprm struct using wcsprintf().  Mainly
00285 * intended for diagnostic purposes.
00286 *
00287 * Given:
00288 *   lin          const struct linprm*
00289 *               Linear transformation parameters.
00290 *
00291 * Function return value:
00292 *   int          Status return value:
00293 *               0: Success.
00294 *               1: Null linprm pointer passed.
00295 *

```

```

00296 *
00297 * linperr() - Print error messages from a linprm struct
00298 * -----
00299 * linperr() prints the error message(s) (if any) stored in a linprm struct,
00300 * and the disprm structs that it may contain. If there are no errors then
00301 * nothing is printed. It uses wcserr_prt(), q.v.
00302 *
00303 * Given:
00304 *   lin      const struct linprm*
00305 *               Coordinate transformation parameters.
00306 *
00307 *   prefix   const char *
00308 *               If non-NULL, each output line will be prefixed with
00309 *               this string.
00310 *
00311 * Function return value:
00312 *   int      Status return value:
00313 *           0: Success.
00314 *           1: Null linprm pointer passed.
00315 *
00316 *
00317 * linset() - Setup routine for the linprm struct
00318 * -----
00319 * linset(), if necessary, allocates memory for the linprm::piximg and
00320 * linprm::imgpix arrays and sets up the linprm struct according to information
00321 * supplied within it - refer to the explanation of linprm::flag.
00322 *
00323 * Note that this routine need not be called directly; it will be invoked by
00324 * linp2x() and linx2p() if the linprm::flag is anything other than a
00325 * predefined magic value.
00326 *
00327 * linset() normally operates regardless of the value of linprm::flag; i.e.
00328 * even if a struct was previously set up it will be reset unconditionally.
00329 * However, a linprm struct may be put into "bypass" mode by invoking linset()
00330 * initially with linprm::flag == 1 (rather than 0). linset() will return
00331 * immediately if invoked on a struct in that state. To take a struct out of
00332 * bypass mode, simply reset linprm::flag to zero. See also linenq().
00333 *
00334 * Given and returned:
00335 *   lin      struct linprm*
00336 *               Linear transformation parameters.
00337 *
00338 * Function return value:
00339 *   int      Status return value:
00340 *           0: Success.
00341 *           1: Null linprm pointer passed.
00342 *           2: Memory allocation failed.
00343 *           3: PCi_ja matrix is singular.
00344 *           4: Failed to initialise distortions.
00345 *
00346 *           For returns > 1, a detailed error message is set in
00347 *           linprm::err if enabled, see wcserr_enable().
00348 *
00349 *
00350 * linp2x() - Pixel-to-world linear transformation
00351 * -----
00352 * linp2x() transforms pixel coordinates to intermediate world coordinates.
00353 *
00354 * Given and returned:
00355 *   lin      struct linprm*
00356 *               Linear transformation parameters.
00357 *
00358 * Given:
00359 *   ncoord,  int      The number of coordinates, each of vector length nelelem
00360 *   nelelem  but containing lin.naxis coordinate elements.
00361 *
00362 *
00363 *   pixcrd   const double[ncoord][nelelem]
00364 *               Array of pixel coordinates.
00365 *
00366 * Returned:
00367 *   imgcrd   double[ncoord][nelelem]
00368 *               Array of intermediate world coordinates.
00369 *
00370 * Function return value:
00371 *   int      Status return value:
00372 *           0: Success.
00373 *           1: Null linprm pointer passed.
00374 *           2: Memory allocation failed.
00375 *           3: PCi_ja matrix is singular.
00376 *           4: Failed to initialise distortions.
00377 *           5: Distort error.
00378 *
00379 *           For returns > 1, a detailed error message is set in
00380 *           linprm::err if enabled, see wcserr_enable().
00381 *
00382 * Notes:

```

```

00383 * 1. Historically, the API to linp2x() did not have a stat[] vector because
00384 * a valid linear transformation should always succeed. However, now that
00385 * it invokes disp2x() if distortions are present, it does have the
00386 * potential to fail. Consequently, when distortions are present and a
00387 * status return (stat[]) is required for each coordinate, then linp2x()
00388 * should be invoked separately for each of them.
00389 *
00390 *
00391 * linx2p() - World-to-pixel linear transformation
00392 * -----
00393 * linx2p() transforms intermediate world coordinates to pixel coordinates.
00394 *
00395 * Given and returned:
00396 *   lin      struct linprm*
00397 *           Linear transformation parameters.
00398 *
00399 * Given:
00400 *   ncoord,
00401 *   nelelem  int          The number of coordinates, each of vector length nelelem
00402 *                        but containing lin.naxis coordinate elements.
00403 *
00404 *   imgcrd   const double[ncoord][nelelem]
00405 *           Array of intermediate world coordinates.
00406 *
00407 * Returned:
00408 *   pixcrd   double[ncoord][nelelem]
00409 *           Array of pixel coordinates.
00410 *
00411 *           int          Status return value:
00412 *                   0: Success.
00413 *                   1: Null linprm pointer passed.
00414 *                   2: Memory allocation failed.
00415 *                   3: PCi_ja matrix is singular.
00416 *                   4: Failed to initialise distortions.
00417 *                   6: De-distort error.
00418 *
00419 *           For returns > 1, a detailed error message is set in
00420 *           linprm::err if enabled, see wcserr_enable().
00421 *
00422 * Notes:
00423 * 1. Historically, the API to linx2p() did not have a stat[] vector because
00424 * a valid linear transformation should always succeed. However, now that
00425 * it invokes disx2p() if distortions are present, it does have the
00426 * potential to fail. Consequently, when distortions are present and a
00427 * status return (stat[]) is required for each coordinate, then linx2p()
00428 * should be invoked separately for each of them.
00429 *
00430 *
00431 * linwarp() - Compute measures of distortion
00432 * -----
00433 * linwarp() computes various measures of the distortion over a specified range
00434 * of pixel coordinates.
00435 *
00436 * All distortion measures are specified as an offset in pixel coordinates,
00437 * as given directly by prior distortions. The offset in intermediate pixel
00438 * coordinates given by sequent distortions is translated back to pixel
00439 * coordinates by applying the inverse of the linear transformation matrix
00440 * (PCi_ja or CDi_ja). The difference may be significant if the matrix
00441 * introduced a scaling.
00442 *
00443 * If all distortions are prior, then linwarp() uses diswarp(), q.v.
00444 *
00445 * Given and returned:
00446 *   lin      struct linprm*
00447 *           Linear transformation parameters plus distortions.
00448 *
00449 * Given:
00450 *   pixblc   const double[naxis]
00451 *           Start of the range of pixel coordinates (i.e. "bottom
00452 * left-hand corner" in the conventional FITS image
00453 * display orientation). May be specified as a NULL
00454 * pointer which is interpreted as (1,1,...).
00455 *
00456 *   pixtrc   const double[naxis]
00457 *           End of the range of pixel coordinates (i.e. "top
00458 * right-hand corner" in the conventional FITS image
00459 * display orientation).
00460 *
00461 *   pixsamp  const double[naxis]
00462 *           If positive or zero, the increment on the particular
00463 * axis, starting at pixblc[]. Zero is interpreted as a
00464 * unit increment. pixsamp may also be specified as a
00465 * NULL pointer which is interpreted as all zeroes, i.e.
00466 * unit increments on all axes.
00467 *
00468 *           If negative, the grid size on the particular axis (the
00469 * absolute value being rounded to the nearest integer).

```

```

00470 *          For example, if pixsamp is (-128.0,-128.0,...) then
00471 *          each axis will be sampled at 128 points between
00472 *          pixblc[] and pixtrc[] inclusive. Use caution when
00473 *          using this option on non-square images.
00474 *
00475 * Returned:
00476 *   nsamp      int*      The number of pixel coordinates sampled.
00477 *
00478 *                  Can be specified as a NULL pointer if not required.
00479 *
00480 *   maxdis     double[naxis]
00481 *                  For each individual distortion function, the
00482 *                  maximum absolute value of the distortion.
00483 *
00484 *                  Can be specified as a NULL pointer if not required.
00485 *
00486 *   maxtot     double*   For the combination of all distortion functions, the
00487 *                  maximum absolute value of the distortion.
00488 *
00489 *                  Can be specified as a NULL pointer if not required.
00490 *
00491 *   avgdis     double[naxis]
00492 *                  For each individual distortion function, the
00493 *                  mean value of the distortion.
00494 *
00495 *                  Can be specified as a NULL pointer if not required.
00496 *
00497 *   avgtot     double*   For the combination of all distortion functions, the
00498 *                  mean value of the distortion.
00499 *
00500 *                  Can be specified as a NULL pointer if not required.
00501 *
00502 *   rmsdis     double[naxis]
00503 *                  For each individual distortion function, the
00504 *                  root mean square deviation of the distortion.
00505 *
00506 *                  Can be specified as a NULL pointer if not required.
00507 *
00508 *   rmstot     double*   For the combination of all distortion functions, the
00509 *                  root mean square deviation of the distortion.
00510 *
00511 *                  Can be specified as a NULL pointer if not required.
00512 *
00513 * Function return value:
00514 *   int          Status return value:
00515 *   0: Success.
00516 *   1: Null linprm pointer passed.
00517 *   2: Memory allocation failed.
00518 *   3: Invalid parameter.
00519 *   4: Distort error.
00520 *
00521 *
00522 * linprm struct - Linear transformation parameters
00523 * -----
00524 * The linprm struct contains all of the information required to perform a
00525 * linear transformation. It consists of certain members that must be set by
00526 * the user ("given") and others that are set by the WCSLIB routines
00527 * ("returned").
00528 *
00529 *   int flag
00530 *   (Given and returned) This flag must be set to zero (or 1, see linset())
00531 *   whenever any of the following linprm members are set or changed:
00532 *
00533 *       - linprm::naxis (q.v., not normally set by the user),
00534 *       - linprm::pc,
00535 *       - linprm::cdelt,
00536 *       - linprm::dispre.
00537 *       - linprm::disseq.
00538 *
00539 *   This signals the initialization routine, linset(), to recompute the
00540 *   returned members of the linprm struct. linset() will reset flag to
00541 *   indicate that this has been done.
00542 *
00543 *   PLEASE NOTE: flag should be set to -1 when lininit() is called for the
00544 *   first time for a particular linprm struct in order to initialize memory
00545 *   management. It must ONLY be used on the first initialization otherwise
00546 *   memory leaks may result.
00547 *
00548 *   int naxis
00549 *   (Given or returned) Number of pixel and world coordinate elements.
00550 *
00551 *   If lininit() is used to initialize the linprm struct (as would normally
00552 *   be the case) then it will set naxis from the value passed to it as a
00553 *   function argument. The user should not subsequently modify it.
00554 *
00555 *   double *crpix
00556 *   (Given) Pointer to the first element of an array of double containing

```

```

00557 *      the coordinate reference pixel, CRPIXja.
00558 *
00559 *      It is not necessary to reset the linprm struct (via linset()) when
00560 *      linprm::crpix is changed.
00561 *
00562 *      double *pc
00563 *      (Given) Pointer to the first element of the PCi_ja (pixel coordinate)
00564 *      transformation matrix. The expected order is
00565 *
00566 *      struct linprm lin;
00567 *      lin.pc = {PC1_1, PC1_2, PC2_1, PC2_2};
00568 *
00569 *      This may be constructed conveniently from a 2-D array via
00570 *
00571 *      double m[2][2] = {{PC1_1, PC1_2},
00572 *                        {PC2_1, PC2_2}};
00573 *
00574 *      which is equivalent to
00575 *
00576 *      double m[2][2];
00577 *      m[0][0] = PC1_1;
00578 *      m[0][1] = PC1_2;
00579 *      m[1][0] = PC2_1;
00580 *      m[1][1] = PC2_2;
00581 *
00582 *      The storage order for this 2-D array is the same as for the 1-D array,
00583 *      whence
00584 *
00585 *      lin.pc = *m;
00586 *
00587 *      would be legitimate.
00588 *
00589 *      double *cdelt
00590 *      (Given) Pointer to the first element of an array of double containing
00591 *      the coordinate increments, CDELTia.
00592 *
00593 *      struct disprm *dispre
00594 *      (Given) Pointer to a disprm struct holding parameters for prior
00595 *      distortion functions, or a null (0x0) pointer if there are none.
00596 *
00597 *      Function lindist() may be used to assign a disprm pointer to a linprm
00598 *      struct, allowing it to take control of any memory allocated for it, as
00599 *      in the following example:
00600 *
00601 *      void add_distortion(struct linprm *lin)
00602 *      {
00603 *          struct disprm *dispre;
00604 *
00605 *          dispre = malloc(sizeof(struct disprm));
00606 *          dispre->flag = -1;
00607 *          lindist(1, lin, dispre, ndpmax);
00608 *          :
00609 *          (Set up dispre.)
00610 *          :
00611 *          return;
00612 *      }
00613 *
00614 *      Here, after the distortion function parameters etc. are copied into
00615 *      dispre, dispre is assigned using lindist() which takes control of the
00616 *      allocated memory. It will be freed later when linfree() is invoked on
00617 *      the linprm struct.
00618 *
00619 *      Consider also the following erroneous code:
00620 *
00621 *      void bad_code(struct linprm *lin)
00622 *      {
00623 *          struct disprm dispre;
00624 *
00625 *          dispre.flag = -1;
00626 *          lindist(1, lin, &dispre, ndpmax);    // WRONG.
00627 *          :
00628 *          return;
00629 *      }
00630 *
00631 *      Here, dispre is declared as a struct, rather than a pointer. When the
00632 *      function returns, dispre will go out of scope and its memory will most
00633 *      likely be reused, thereby trashing its contents. Later, a segfault will
00634 *      occur when linfree() tries to free dispre's stale address.
00635 *
00636 *      struct disprm *disseq
00637 *      (Given) Pointer to a disprm struct holding parameters for sequent
00638 *      distortion functions, or a null (0x0) pointer if there are none.
00639 *
00640 *      Refer to the comments and examples given for disprm::dispre.
00641 *
00642 *
00643 *

```

```

00644 * double *piximg
00645 * (Returned) Pointer to the first element of the matrix containing the
00646 * product of the CDELTia diagonal matrix and the PCi_ja matrix.
00647 *
00648 * double *imgpix
00649 * (Returned) Pointer to the first element of the inverse of the
00650 * linprm::piximg matrix.
00651 *
00652 * int i_naxis
00653 * (Returned) The dimension of linprm::piximg and linprm::imgpix (normally
00654 * equal to naxis).
00655 *
00656 * int unity
00657 * (Returned) True if the linear transformation matrix is unity.
00658 *
00659 * int affine
00660 * (Returned) True if there are no distortions.
00661 *
00662 * int simple
00663 * (Returned) True if unity and no distortions.
00664 *
00665 * struct wcserr *err
00666 * (Returned) If enabled, when an error status is returned, this struct
00667 * contains detailed information about the error, see wcserr_enable().
00668 *
00669 * double *dummy
00670 * (For internal use only.)
00671 * int m_flag
00672 * (For internal use only.)
00673 * int m_naxis
00674 * (For internal use only.)
00675 * double *m_crpix
00676 * (For internal use only.)
00677 * double *m_pc
00678 * (For internal use only.)
00679 * double *m_cdelat
00680 * (For internal use only.)
00681 * struct disprm *m_dispre
00682 * (For internal use only.)
00683 * struct disprm *m_disseq
00684 * (For internal use only.)
00685 *
00686 *
00687 * Global variable: const char *lin_errmsg[] - Status return messages
00688 * -----
00689 * Error messages to match the status value returned from each function.
00690 *
00691 * =====*/
00692
00693 #ifndef WCSLIB_LIN
00694 #define WCSLIB_LIN
00695
00696 #ifdef __cplusplus
00697 extern "C" {
00698 #endif
00699
00700 enum lineng_enum {
00701     LINENG_MEM = 1,           // linprm struct memory is managed by WCSLIB.
00702     LINENG_SET = 2,          // linprm struct has been set up.
00703     LINENG_BYP = 4,          // linprm struct is in bypass mode.
00704 };
00705
00706 extern const char *lin_errmsg[];
00707
00708 enum lin_errmsg_enum {
00709     LINERR_SUCCESS = 0,      // Success.
00710     LINERR_NULL_POINTER = 1, // Null linprm pointer passed.
00711     LINERR_MEMORY = 2,       // Memory allocation failed.
00712     LINERR_SINGULAR_MTX = 3,  // PCi_ja matrix is singular.
00713     LINERR_DISTORT_INIT = 4,  // Failed to initialise distortions.
00714     LINERR_DISTORT = 5,       // Distort error.
00715     LINERR_DEDISTORT = 6,     // De-distort error.
00716 };
00717
00718 struct linprm {
00719     // Initialization flag (see the prologue above).
00720     //-----
00721     int flag;                // Set to zero to force initialization.
00722
00723     // Parameters to be provided (see the prologue above).
00724     //-----
00725     int naxis;                // The number of axes, given by NAXIS.
00726     double *crpix;            // CRPIXja keywords for each pixel axis.
00727     double *pc;               // PCi_ja linear transformation matrix.
00728     double *cdelt;            // CDELTia keywords for each coord axis.
00729     struct disprm *dispre;     // Prior distortion parameters, if any.
00730     struct disprm *disseq;     // Sequent distortion parameters, if any.

```

```

00731
00732 // Information derived from the parameters supplied.
00733 //-----
00734 double *piximg;           // Product of CDELTia and PCi_ja matrices.
00735 double *imgpix;           // Inverse of the piximg matrix.
00736 int i_naxis;              // Dimension of piximg and imgpix.
00737 int unity;                // True if the PCi_ja matrix is unity.
00738 int affine;               // True if there are no distortions.
00739 int simple;               // True if unity and no distortions.
00740
00741 // Error messaging, if enabled.
00742 //-----
00743 struct wcserr *err;
00744
00745 //-----
00746 // Private - the remainder are for internal use.
00747 //-----
00748 double *dummy;
00749
00750 // The remainder are for memory management.
00751 int m_flag, m_naxis;
00752 double *m_crpix, *m_pc, *m_cdelt;
00753 struct disprm *m_dispre, *m_disseq;
00754 };
00755
00756 // Size of the linprm struct in int units, used by the Fortran wrappers.
00757 #define LINLEN (sizeof(struct linprm)/sizeof(int))
00758
00759 int linini(int alloc, int naxis, struct linprm *lin);
00760
00761 int lininit(int alloc, int naxis, struct linprm *lin, int ndpmax);
00762
00763 int lindis(int sequence, struct linprm *lin, struct disprm *dis);
00764
00765 int lindist(int sequence, struct linprm *lin, struct disprm *dis, int ndpmax);
00766
00767 int lincpy(int alloc, const struct linprm *linsrc, struct linprm *lindst);
00768
00769 int linfree(struct linprm *lin);
00770
00771 int linsize(const struct linprm *lin, int sizes[2]);
00772
00773 int linenq(const struct linprm *lin, int enquiry);
00774
00775 int linprt(const struct linprm *lin);
00776
00777 int linperr(const struct linprm *lin, const char *prefix);
00778
00779 int linset(struct linprm *lin);
00780
00781 int linp2x(struct linprm *lin, int ncoord, int nele, const double pixcrd[],
00782           double imgcrd[]);
00783
00784 int linx2p(struct linprm *lin, int ncoord, int nele, const double imgcrd[],
00785           double pixcrd[]);
00786
00787 int linwarp(struct linprm *lin, const double pixblc[], const double pixtrc[],
00788           const double pixsamp[], int nsamp,
00789           double maxdis[], double maxtot,
00790           double avgdis[], double avgtot,
00791           double rmsdis[], double rmstot);
00792
00793 int matinv(int n, const double mat[], double inv[]);
00794
00795
00796 // Deprecated.
00797 #define linini_errmsg lin_errmsg
00798 #define lincpy_errmsg lin_errmsg
00799 #define linfree_errmsg lin_errmsg
00800 #define linprt_errmsg lin_errmsg
00801 #define linset_errmsg lin_errmsg
00802 #define linp2x_errmsg lin_errmsg
00803 #define linx2p_errmsg lin_errmsg
00804
00805 #ifdef __cplusplus
00806 }
00807 #endif
00808 #endif
00809
00810 #endif // WCSLIB_LIN

```

## 8.11 log.h File Reference

### Enumerations

- enum [log\\_errmsg\\_enum](#) {  
[LOGERR\\_SUCCESS](#) = 0 , [LOGERR\\_NULL\\_POINTER](#) = 1 , [LOGERR\\_BAD\\_LOG\\_REF\\_VAL](#) = 2 ,  
[LOGERR\\_BAD\\_X](#) = 3 ,  
[LOGERR\\_BAD\\_WORLD](#) = 4 }

### Functions

- int [logx2s](#) (double crval, int nx, int sx, int slogc, const double x[], double logc[], int stat[])  
*Transform to logarithmic coordinates.*
- int [logs2x](#) (double crval, int nlogc, int slogc, int sx, const double logc[], double x[], int stat[])  
*Transform logarithmic coordinates.*

### Variables

- const char \* [log\\_errmsg](#) []  
*Status return messages.*

#### 8.11.1 Detailed Description

Routines in this suite implement the part of the FITS World Coordinate System (WCS) standard that deals with logarithmic coordinates, as described in

"Representations of world coordinates in FITS", Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)

"Representations of spectral coordinates in FITS", Greisen, E.W., Calabretta, M.R., Valdes, F.G., & Allen, S.L. 2006, A&A, 446, 747 (WCS Paper III)

These routines define methods to be used for computing logarithmic world coordinates from intermediate world coordinates (a linear transformation of image pixel coordinates), and vice versa.

[logx2s\(\)](#) and [logs2x\(\)](#) implement the WCS logarithmic coordinate transformations.

#### Argument checking:

The input log-coordinate values are only checked for values that would result in floating point exceptions and the same is true for the log-coordinate reference value.

#### Accuracy:

No warranty is given for the accuracy of these routines (refer to the copyright notice); intending users must satisfy for themselves their adequacy for the intended purpose. However, closure effectively to within double precision rounding error was demonstrated by test routine tlog.c which accompanies this software.

#### 8.11.2 Enumeration Type Documentation

##### log\_errmsg\_enum

## Enumerator

LOGERR_SUCCESS	
LOGERR_NULL_POINTER	
LOGERR_BAD_LOG_REF_VAL	
LOGERR_BAD_X	
LOGERR_BAD_WORLD	

## 8.11.3 Function Documentation

### logx2s()

```
int logx2s (  
    double crval,  
    int nx,  
    int sx,  
    int slogc,  
    const double x[],  
    double logc[],  
    int stat[])
```

Transform to logarithmic coordinates.

**logx2s()** transforms intermediate world coordinates to logarithmic coordinates.

### Parameters

in, out	<i>crval</i>	Log-coordinate reference value ( <b>CRVAL</b> <sub>ia</sub> ).
in	<i>nx</i>	Vector length.
in	<i>sx</i>	Vector stride.
in	<i>slogc</i>	Vector stride.
in	<i>x</i>	Intermediate world coordinates, in SI units.
out	<i>logc</i>	Logarithmic coordinates, in SI units.
out	<i>stat</i>	Status return value status for each vector element: <ul style="list-style-type: none"><li>• 0: Success.</li></ul>

### Returns

Status return value:

- 0: Success.
- 2: Invalid log-coordinate reference value.

**logs2x()**

```
int logs2x (
    double crval,
    int nlogc,
    int slogc,
    int sx,
    const double logc[],
    double x[],
    int stat[])
```

Transform logarithmic coordinates.

**logs2x()** transforms logarithmic world coordinates to intermediate world coordinates.

**Parameters**

in, out	<i>crval</i>	Log-coordinate reference value ( <b>CRVAL</b> <sub>ia</sub> ).
in	<i>nlogc</i>	Vector length.
in	<i>slogc</i>	Vector stride.
in	<i>sx</i>	Vector stride.
in	<i>logc</i>	Logarithmic coordinates, in SI units.
out	<i>x</i>	Intermediate world coordinates, in SI units.
out	<i>stat</i>	Status return value status for each vector element: <ul style="list-style-type: none"> <li>• 0: Success.</li> <li>• 1: Invalid value of logc.</li> </ul>

**Returns**

Status return value:

- 0: Success.
- 2: Invalid log-coordinate reference value.
- 4: One or more of the world-coordinate values are incorrect, as indicated by the stat vector.

**8.11.4 Variable Documentation****log\_errmsg**

```
const char* log_errmsg[] [extern]
```

Status return messages.

Error messages to match the status value returned from each function.

## 8.12 log.h

[Go to the documentation of this file.](#)

```

00001 /*=====
00002 WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003 Copyright (C) 1995-2025, Mark Calabretta
00004
00005 This file is part of WCSLIB.
00006
00007 WCSLIB is free software: you can redistribute it and/or modify it under the
00008 terms of the GNU Lesser General Public License as published by the Free
00009 Software Foundation, either version 3 of the License, or (at your option)
00010 any later version.
00011
00012 WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013 WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
00014 FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015 more details.
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00017 You should have received a copy of the GNU Lesser General Public License
00018 along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020 Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021 http://www.atnf.csiro.au/people/Mark.Calabretta
00022 $Id: log.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023 *=====
00024 *
00025 * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026 * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027 * overview of the library.
00028 *
00029 *
00030 * Summary of the log routines
00031 * -----
00032 * Routines in this suite implement the part of the FITS World Coordinate
00033 * System (WCS) standard that deals with logarithmic coordinates, as described
00034 * in
00035 *
00036 * "Representations of world coordinates in FITS",
00037 * Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)
00038 *
00039 * "Representations of spectral coordinates in FITS",
00040 * Greisen, E.W., Calabretta, M.R., Valdes, F.G., & Allen, S.L.
00041 * 2006, A&A, 446, 747 (WCS Paper III)
00042 *
00043 * These routines define methods to be used for computing logarithmic world
00044 * coordinates from intermediate world coordinates (a linear transformation of
00045 * image pixel coordinates), and vice versa.
00046 *
00047 * logx2s() and logs2x() implement the WCS logarithmic coordinate
00048 * transformations.
00049 *
00050 * Argument checking:
00051 * -----
00052 * The input log-coordinate values are only checked for values that would
00053 * result in floating point exceptions and the same is true for the
00054 * log-coordinate reference value.
00055 *
00056 * Accuracy:
00057 * -----
00058 * No warranty is given for the accuracy of these routines (refer to the
00059 * copyright notice); intending users must satisfy for themselves their
00060 * adequacy for the intended purpose. However, closure effectively to within
00061 * double precision rounding error was demonstrated by test routine tlog.c
00062 * which accompanies this software.
00063 *
00064 *
00065 * logx2s() - Transform to logarithmic coordinates
00066 * -----
00067 * logx2s() transforms intermediate world coordinates to logarithmic
00068 * coordinates.
00069 *
00070 * Given and returned:
00071 * crval double Log-coordinate reference value (CRVALia).
00072 *
00073 * Given:
00074 * nx int Vector length.
00075 *
00076 * sx int Vector stride.
00077 *
00078 * slogc int Vector stride.
00079 *
00080 * x const double[]
00081 * Intermediate world coordinates, in SI units.
00082 *

```

```

00083 * Returned:
00084 *   logc      double[]   Logarithmic coordinates, in SI units.
00085 *
00086 *   stat      int[]      Status return value status for each vector element:
00087 *                       0: Success.
00088 *
00089 * Function return value:
00090 *   int        Status return value:
00091 *               0: Success.
00092 *               2: Invalid log-coordinate reference value.
00093 *
00094 *
00095 * logs2x() - Transform logarithmic coordinates
00096 * -----
00097 * logs2x() transforms logarithmic world coordinates to intermediate world
00098 * coordinates.
00099 *
00100 * Given and returned:
00101 *   crval      double     Log-coordinate reference value (CRVALia).
00102 *
00103 * Given:
00104 *   nlogc      int        Vector length.
00105 *
00106 *   slogc      int        Vector stride.
00107 *
00108 *   sx         int        Vector stride.
00109 *
00110 *   logc       const double[]
00111 *               Logarithmic coordinates, in SI units.
00112 *
00113 * Returned:
00114 *   x          double[]   Intermediate world coordinates, in SI units.
00115 *
00116 *   stat       int[]      Status return value status for each vector element:
00117 *                       0: Success.
00118 *                       1: Invalid value of logc.
00119 *
00120 * Function return value:
00121 *   int        Status return value:
00122 *               0: Success.
00123 *               2: Invalid log-coordinate reference value.
00124 *               4: One or more of the world-coordinate values
00125 *                   are incorrect, as indicated by the stat vector.
00126 *
00127 *
00128 * Global variable: const char *log_errmsg[] - Status return messages
00129 * -----
00130 * Error messages to match the status value returned from each function.
00131 *
00132 * =====*/
00133
00134 #ifndef WCSLIB_LOG
00135 #define WCSLIB_LOG
00136
00137 #ifdef __cplusplus
00138 extern "C" {
00139 #endif
00140
00141 extern const char *log_errmsg[];
00142
00143 enum log_errmsg_enum {
00144     LOGERR_SUCCESS      = 0,    // Success.
00145     LOGERR_NULL_POINTER = 1,    // Null pointer passed.
00146     LOGERR_BAD_LOG_REF_VAL = 2, // Invalid log-coordinate reference value.
00147     LOGERR_BAD_X        = 3,    // One or more of the x coordinates were
00148                               // invalid.
00149     LOGERR_BAD_WORLD    = 4,    // One or more of the world coordinates were
00150                               // invalid.
00151 };
00152
00153 int logx2s(double crval, int nx, int sx, int slogc, const double x[],
00154           double logc[], int stat[]);
00155
00156 int logs2x(double crval, int nlogc, int slogc, int sx, const double logc[],
00157           double x[], int stat[]);
00158
00159
00160 #ifdef __cplusplus
00161 }
00162 #endif
00163
00164 #endif // WCSLIB_LOG

```

## 8.13 prj.h File Reference

### Data Structures

- struct [prjprm](#)  
*Projection parameters.*

### Macros

- #define [PVN](#) 30  
*Total number of projection parameters.*
- #define [PRJX2S\\_ARGS](#)  
*For use in declaring deprojection function prototypes.*
- #define [PRJS2X\\_ARGS](#)  
*For use in declaring projection function prototypes.*
- #define [PRJLEN](#) (sizeof(struct [prjprm](#))/sizeof(int))  
*Size of the [prjprm](#) struct in int units.*
- #define [prjini\\_errmsg](#) [prj\\_errmsg](#)  
*Deprecated.*
- #define [prjprt\\_errmsg](#) [prj\\_errmsg](#)  
*Deprecated.*
- #define [prjset\\_errmsg](#) [prj\\_errmsg](#)  
*Deprecated.*
- #define [prjx2s\\_errmsg](#) [prj\\_errmsg](#)  
*Deprecated.*
- #define [prjs2x\\_errmsg](#) [prj\\_errmsg](#)  
*Deprecated.*

### Enumerations

- enum [prjenq\\_enum](#) { [PRJENQ\\_SET](#) = 2 , [PRJENQ\\_BYP](#) = 4 }
- enum [prj\\_errmsg\\_enum](#) {  
  [PRJERR\\_SUCCESS](#) = 0 , [PRJERR\\_NULL\\_POINTER](#) = 1 , [PRJERR\\_BAD\\_PARAM](#) = 2 , [PRJERR\\_BAD\\_PIX](#)  
  = 3 ,  
  [PRJERR\\_BAD\\_WORLD](#) = 4 }

### Functions

- int [prjini](#) (struct [prjprm](#) \*prj)  
*Default constructor for the [prjprm](#) struct.*
- int [prjfree](#) (struct [prjprm](#) \*prj)  
*Destructor for the [prjprm](#) struct.*
- int [prjsize](#) (const struct [prjprm](#) \*prj, int sizes[2])  
*Compute the size of a [prjprm](#) struct.*
- int [prjenq](#) (const struct [prjprm](#) \*prj, int enquiry)  
*enquire about the state of a [prjprm](#) struct.*
- int [prjprt](#) (const struct [prjprm](#) \*prj)  
*Print routine for the [prjprm](#) struct.*
- int [prjperr](#) (const struct [prjprm](#) \*prj, const char \*prefix)

- *Print error messages from a [prjprm](#) struct.*
- [prjbchk](#) (double tol, int nphi, int ntheta, int spt, double phi[], double theta[], int stat[])  
*Bounds checking on native coordinates.*
- [prjset](#) (struct [prjprm](#) \*prj)  
*Generic setup routine for the [prjprm](#) struct.*
- [prjx2s](#) ([PRJX2S\\_ARGS](#))  
*Generic Cartesian-to-spherical deprojection.*
- [prjs2x](#) ([PRJS2X\\_ARGS](#))  
*Generic spherical-to-Cartesian projection.*
- [azpset](#) (struct [prjprm](#) \*prj)  
*Set up a [prjprm](#) struct for the **zenithal/azimuthal perspective (AZP)** projection.*
- [azpx2s](#) ([PRJX2S\\_ARGS](#))  
*Cartesian-to-spherical transformation for the **zenithal/azimuthal perspective (AZP)** projection.*
- [azps2x](#) ([PRJS2X\\_ARGS](#))  
*Spherical-to-Cartesian transformation for the **zenithal/azimuthal perspective (AZP)** projection.*
- [szpset](#) (struct [prjprm](#) \*prj)  
*Set up a [prjprm](#) struct for the **slant zenithal perspective (SZP)** projection.*
- [szpx2s](#) ([PRJX2S\\_ARGS](#))  
*Cartesian-to-spherical transformation for the **slant zenithal perspective (SZP)** projection.*
- [szps2x](#) ([PRJS2X\\_ARGS](#))  
*Spherical-to-Cartesian transformation for the **slant zenithal perspective (SZP)** projection.*
- [tanset](#) (struct [prjprm](#) \*prj)  
*Set up a [prjprm](#) struct for the **gnomonic (TAN)** projection.*
- [tanx2s](#) ([PRJX2S\\_ARGS](#))  
*Cartesian-to-spherical transformation for the **gnomonic (TAN)** projection.*
- [tans2x](#) ([PRJS2X\\_ARGS](#))  
*Spherical-to-Cartesian transformation for the **gnomonic (TAN)** projection.*
- [stgset](#) (struct [prjprm](#) \*prj)  
*Set up a [prjprm](#) struct for the **stereographic (STG)** projection.*
- [stgx2s](#) ([PRJX2S\\_ARGS](#))  
*Cartesian-to-spherical transformation for the **stereographic (STG)** projection.*
- [stgs2x](#) ([PRJS2X\\_ARGS](#))  
*Spherical-to-Cartesian transformation for the **stereographic (STG)** projection.*
- [sinset](#) (struct [prjprm](#) \*prj)  
*Set up a [prjprm](#) struct for the **orthographic/synthesis (SIN)** projection.*
- [sinx2s](#) ([PRJX2S\\_ARGS](#))  
*Cartesian-to-spherical transformation for the **orthographic/synthesis (SIN)** projection.*
- [sins2x](#) ([PRJS2X\\_ARGS](#))  
*Spherical-to-Cartesian transformation for the **orthographic/synthesis (SIN)** projection.*
- [arcset](#) (struct [prjprm](#) \*prj)  
*Set up a [prjprm](#) struct for the **zenithal/azimuthal equidistant (ARC)** projection.*
- [arcx2s](#) ([PRJX2S\\_ARGS](#))  
*Cartesian-to-spherical transformation for the **zenithal/azimuthal equidistant (ARC)** projection.*
- [arcs2x](#) ([PRJS2X\\_ARGS](#))  
*Spherical-to-Cartesian transformation for the **zenithal/azimuthal equidistant (ARC)** projection.*
- [zpnset](#) (struct [prjprm](#) \*prj)  
*Set up a [prjprm](#) struct for the **zenithal/azimuthal polynomial (ZPN)** projection.*
- [zpnx2s](#) ([PRJX2S\\_ARGS](#))  
*Cartesian-to-spherical transformation for the **zenithal/azimuthal polynomial (ZPN)** projection.*
- [zpns2x](#) ([PRJS2X\\_ARGS](#))  
*Spherical-to-Cartesian transformation for the **zenithal/azimuthal polynomial (ZPN)** projection.*

- int `zeaset` (struct `prjprm` \*prj)  
Set up a `prjprm` struct for the **zenithal/azimuthal equal area (ZEA)** projection.
- int `zeax2s` (`PRJX2S_ARGS`)  
Cartesian-to-spherical transformation for the **zenithal/azimuthal equal area (ZEA)** projection.
- int `zeas2x` (`PRJS2X_ARGS`)  
Spherical-to-Cartesian transformation for the **zenithal/azimuthal equal area (ZEA)** projection.
- int `airset` (struct `prjprm` \*prj)  
Set up a `prjprm` struct for **Airy's (AIR)** projection.
- int `airx2s` (`PRJX2S_ARGS`)  
Cartesian-to-spherical transformation for **Airy's (AIR)** projection.
- int `airs2x` (`PRJS2X_ARGS`)  
Spherical-to-Cartesian transformation for **Airy's (AIR)** projection.
- int `cypset` (struct `prjprm` \*prj)  
Set up a `prjprm` struct for the **cylindrical perspective (CYP)** projection.
- int `cypx2s` (`PRJX2S_ARGS`)  
Cartesian-to-spherical transformation for the **cylindrical perspective (CYP)** projection.
- int `cyps2x` (`PRJS2X_ARGS`)  
Spherical-to-Cartesian transformation for the **cylindrical perspective (CYP)** projection.
- int `ceaset` (struct `prjprm` \*prj)  
Set up a `prjprm` struct for the **cylindrical equal area (CEA)** projection.
- int `ceax2s` (`PRJX2S_ARGS`)  
Cartesian-to-spherical transformation for the **cylindrical equal area (CEA)** projection.
- int `ceas2x` (`PRJS2X_ARGS`)  
Spherical-to-Cartesian transformation for the **cylindrical equal area (CEA)** projection.
- int `carset` (struct `prjprm` \*prj)  
Set up a `prjprm` struct for the **plate carrée (CAR)** projection.
- int `carx2s` (`PRJX2S_ARGS`)  
Cartesian-to-spherical transformation for the **plate carrée (CAR)** projection.
- int `cars2x` (`PRJS2X_ARGS`)  
Spherical-to-Cartesian transformation for the **plate carrée (CAR)** projection.
- int `meraset` (struct `prjprm` \*prj)  
Set up a `prjprm` struct for **Mercator's (MER)** projection.
- int `merx2s` (`PRJX2S_ARGS`)  
Cartesian-to-spherical transformation for **Mercator's (MER)** projection.
- int `mers2x` (`PRJS2X_ARGS`)  
Spherical-to-Cartesian transformation for **Mercator's (MER)** projection.
- int `sflset` (struct `prjprm` \*prj)  
Set up a `prjprm` struct for the **Sanson-Flamsteed (SFL)** projection.
- int `sflx2s` (`PRJX2S_ARGS`)  
Cartesian-to-spherical transformation for the **Sanson-Flamsteed (SFL)** projection.
- int `sfls2x` (`PRJS2X_ARGS`)  
Spherical-to-Cartesian transformation for the **Sanson-Flamsteed (SFL)** projection.
- int `paraset` (struct `prjprm` \*prj)  
Set up a `prjprm` struct for the **parabolic (PAR)** projection.
- int `parx2s` (`PRJX2S_ARGS`)  
Cartesian-to-spherical transformation for the **parabolic (PAR)** projection.
- int `pars2x` (`PRJS2X_ARGS`)  
Spherical-to-Cartesian transformation for the **parabolic (PAR)** projection.
- int `molset` (struct `prjprm` \*prj)  
Set up a `prjprm` struct for **Mollweide's (MOL)** projection.
- int `molx2s` (`PRJX2S_ARGS`)

- Cartesian-to-spherical transformation for **Mollweide's (MOL)** projection.
- int [mols2x](#) ([PRJS2X\\_ARGS](#))
- Spherical-to-Cartesian transformation for **Mollweide's (MOL)** projection.
- int [aitset](#) (struct [prjprm](#) \*prj)
- Set up a [prjprm](#) struct for the **Hammer-Aitoff (AIT)** projection.
- int [aitx2s](#) ([PRJX2S\\_ARGS](#))
- Cartesian-to-spherical transformation for the **Hammer-Aitoff (AIT)** projection.
- int [aits2x](#) ([PRJS2X\\_ARGS](#))
- Spherical-to-Cartesian transformation for the **Hammer-Aitoff (AIT)** projection.
- int [copset](#) (struct [prjprm](#) \*prj)
- Set up a [prjprm](#) struct for the **conic perspective (COP)** projection.
- int [copx2s](#) ([PRJX2S\\_ARGS](#))
- Cartesian-to-spherical transformation for the **conic perspective (COP)** projection.
- int [cops2x](#) ([PRJS2X\\_ARGS](#))
- Spherical-to-Cartesian transformation for the **conic perspective (COP)** projection.
- int [coeset](#) (struct [prjprm](#) \*prj)
- Set up a [prjprm](#) struct for the **conic equal area (COE)** projection.
- int [coex2s](#) ([PRJX2S\\_ARGS](#))
- Cartesian-to-spherical transformation for the **conic equal area (COE)** projection.
- int [coes2x](#) ([PRJS2X\\_ARGS](#))
- Spherical-to-Cartesian transformation for the **conic equal area (COE)** projection.
- int [codset](#) (struct [prjprm](#) \*prj)
- Set up a [prjprm](#) struct for the **conic equidistant (COD)** projection.
- int [codx2s](#) ([PRJX2S\\_ARGS](#))
- Cartesian-to-spherical transformation for the **conic equidistant (COD)** projection.
- int [cods2x](#) ([PRJS2X\\_ARGS](#))
- Spherical-to-Cartesian transformation for the **conic equidistant (COD)** projection.
- int [cooset](#) (struct [prjprm](#) \*prj)
- Set up a [prjprm](#) struct for the **conic orthomorphic (COO)** projection.
- int [coox2s](#) ([PRJX2S\\_ARGS](#))
- Cartesian-to-spherical transformation for the **conic orthomorphic (COO)** projection.
- int [coos2x](#) ([PRJS2X\\_ARGS](#))
- Spherical-to-Cartesian transformation for the **conic orthomorphic (COO)** projection.
- int [bonset](#) (struct [prjprm](#) \*prj)
- Set up a [prjprm](#) struct for **Bonne's (BON)** projection.
- int [bonx2s](#) ([PRJX2S\\_ARGS](#))
- Cartesian-to-spherical transformation for **Bonne's (BON)** projection.
- int [bons2x](#) ([PRJS2X\\_ARGS](#))
- Spherical-to-Cartesian transformation for **Bonne's (BON)** projection.
- int [pcoset](#) (struct [prjprm](#) \*prj)
- Set up a [prjprm](#) struct for the **polyconic (PCO)** projection.
- int [pcox2s](#) ([PRJX2S\\_ARGS](#))
- Cartesian-to-spherical transformation for the **polyconic (PCO)** projection.
- int [pcos2x](#) ([PRJS2X\\_ARGS](#))
- Spherical-to-Cartesian transformation for the **polyconic (PCO)** projection.
- int [tscset](#) (struct [prjprm](#) \*prj)
- Set up a [prjprm](#) struct for the **tangential spherical cube (TSC)** projection.
- int [tsctx2s](#) ([PRJX2S\\_ARGS](#))
- Cartesian-to-spherical transformation for the **tangential spherical cube (TSC)** projection.
- int [tscs2x](#) ([PRJS2X\\_ARGS](#))
- Spherical-to-Cartesian transformation for the **tangential spherical cube (TSC)** projection.

- int `cscset` (struct `prjprm` \*prj)  
*Set up a `prjprm` struct for the **COBE spherical cube (CSC)** projection.*
- int `cscx2s` (`PRJX2S_ARGS`)  
*Cartesian-to-spherical transformation for the **COBE spherical cube (CSC)** projection.*
- int `cscs2x` (`PRJS2X_ARGS`)  
*Spherical-to-Cartesian transformation for the **COBE spherical cube (CSC)** projection.*
- int `qscset` (struct `prjprm` \*prj)  
*Set up a `prjprm` struct for the **quadrilateralized spherical cube (QSC)** projection.*
- int `qscx2s` (`PRJX2S_ARGS`)  
*Cartesian-to-spherical transformation for the **quadrilateralized spherical cube (QSC)** projection.*
- int `qscs2x` (`PRJS2X_ARGS`)  
*Spherical-to-Cartesian transformation for the **quadrilateralized spherical cube (QSC)** projection.*
- int `hpxset` (struct `prjprm` \*prj)  
*Set up a `prjprm` struct for the **HEALPix (HPX)** projection.*
- int `hpxx2s` (`PRJX2S_ARGS`)  
*Cartesian-to-spherical transformation for the **HEALPix (HPX)** projection.*
- int `hpxs2x` (`PRJS2X_ARGS`)  
*Spherical-to-Cartesian transformation for the **HEALPix (HPX)** projection.*
- int `xphset` (struct `prjprm` \*prj)
- int `xphx2s` (`PRJX2S_ARGS`)
- int `xphs2x` (`PRJS2X_ARGS`)

## Variables

- const char \* `prj_errmsg` []  
*Status return messages.*
- const int `CONIC`  
*Identifier for conic projections.*
- const int `CONVENTIONAL`  
*Identifier for conventional projections.*
- const int `CYLINDRICAL`  
*Identifier for cylindrical projections.*
- const int `POLYCONIC`  
*Identifier for polyconic projections.*
- const int `PSEUDOCYLINDRICAL`  
*Identifier for pseudocylindrical projections.*
- const int `QUADCUBE`  
*Identifier for quadcube projections.*
- const int `ZENITHAL`  
*Identifier for zenithal/azimuthal projections.*
- const int `HEALPIX`  
*Identifier for the HEALPix projection.*
- const char `prj_categories` [9][32]  
*Projection categories.*
- const int `prj_ncode`  
*The number of recognized three-letter projection codes.*
- const char `prj_codes` [28][4]  
*Recognized three-letter projection codes.*

### 8.13.1 Detailed Description

Routines in this suite implement the spherical map projections defined by the FITS World Coordinate System (WCS) standard, as described in

"Representations of world coordinates in FITS",  
Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)

"Representations of celestial coordinates in FITS",  
Calabretta, M.R., & Greisen, E.W. 2002, A&A, 395, 1077 (WCS Paper II)

"Mapping on the HEALPix grid",  
Calabretta, M.R., & Roukema, B.F. 2007, MNRAS, 381, 865 (WCS Paper V)

"Representing the 'Butterfly' Projection in FITS -- Projection Code XPH",  
Calabretta, M.R., & Lowe, S.R. 2013, PASA, 30, e050 (WCS Paper VI)

These routines are based on the `prjprm` struct which contains all information needed for the computations. The struct contains some members that must be set by the user, and others that are maintained by these routines, somewhat like a C++ class but with no encapsulation.

Routine `prjini()` is provided to initialize the `prjprm` struct with default values, `prjfree()` reclaims any memory that may have been allocated to store an error message, `prjsize()` computes its total size including allocated memory, `prjenq()` returns information about the state of the struct, and `prjpri()` prints its contents.

`prjperr()` prints the error message(s) (if any) stored in a `prjprm` struct. `prjbchk()` performs bounds checking on native spherical coordinates.

Setup routines for each projection with names of the form `???set()`, where "???" is the down-cased three-letter projection code, compute intermediate values in the `prjprm` struct from parameters in it that were supplied by the user. The struct always needs to be set by the projection's setup routine but that need not be called explicitly - refer to the explanation of `prjprm::flag`.

Each map projection is implemented via separate functions for the spherical projection, `???s2x()`, and deprojection, `???x2s()`.

A set of driver routines, `prjset()`, `prjx2s()`, and `prjs2x()`, provides a generic interface to the specific projection routines which they invoke via pointers-to-functions stored in the `prjprm` struct.

**In summary, the routines are:**

- `prjini()` Initialization routine for the `prjprm` struct.
- `prjfree()` Reclaim memory allocated for error messages.
- `prjsize()` Compute total size of a `prjprm` struct.
- `prjpri()` Print a `prjprm` struct.
- `prjperr()` Print error message (if any).
- `prjbchk()` Bounds checking on native coordinates.
- `prjset()`, `prjx2s()`, `prjs2x()`: Generic driver routines
- `azpset()`, `azpx2s()`, `azps2x()`: **AZP** (zenithal/azimuthal perspective)
- `szpset()`, `szpx2s()`, `szps2x()`: **SZP** (slant zenithal perspective)
- `tanset()`, `tanx2s()`, `tans2x()`: **TAN** (gnomonic)
- `stgset()`, `stgx2s()`, `stgs2x()`: **STG** (stereographic)
- `sinset()`, `sinox2s()`, `sins2x()`: **SIN** (orthographic/synthesis)

- `arcset()`, `arcx2s()`, `arcs2x()`: **ARC** (zenithal/azimuthal equidistant)
- `zpnset()`, `zpnx2s()`, `zpns2x()`: **ZPN** (zenithal/azimuthal polynomial)
- `zeaset()`, `zeax2s()`, `zeas2x()`: **ZEA** (zenithal/azimuthal equal area)
- `airset()`, `airx2s()`, `airs2x()`: **AIR** (Airy)
- `cypset()`, `cypx2s()`, `cyps2x()`: **CYP** (cylindrical perspective)
- `ceaset()`, `ceax2s()`, `ceas2x()`: **CEA** (cylindrical equal area)
- `carset()`, `carx2s()`, `cars2x()`: **CAR** (Plate carée)
- `meraset()`, `merx2s()`, `mers2x()`: **MER** (Mercator)
- `sflset()`, `sflx2s()`, `sfls2x()`: **SFL** (Sanson-Flamsteed)
- `paraset()`, `parx2s()`, `pars2x()`: **PAR** (parabolic)
- `molset()`, `molx2s()`, `mols2x()`: **MOL** (Mollweide)
- `aitset()`, `aitx2s()`, `aits2x()`: **AIT** (Hammer-Aitoff)
- `copset()`, `copx2s()`, `cops2x()`: **COP** (conic perspective)
- `coaset()`, `coex2s()`, `coes2x()`: **COE** (conic equal area)
- `codset()`, `codx2s()`, `cods2x()`: **COD** (conic equidistant)
- `cooset()`, `coox2s()`, `coos2x()`: **COO** (conic orthomorphic)
- `bonset()`, `bonx2s()`, `bons2x()`: **BON** (Bonne)
- `pcoset()`, `pcox2s()`, `pcos2x()`: **PCO** (polyconic)
- `tscset()`, `tscx2s()`, `tscs2x()`: **TSC** (tangential spherical cube)
- `cscset()`, `cscx2s()`, `cscs2x()`: **CSC** (COBE spherical cube)
- `qscset()`, `qscx2s()`, `qscs2x()`: **QSC** (quadrilateralized spherical cube)
- `hpxset()`, `hpxx2s()`, `hpxs2x()`: **HPX** (HEALPix)
- `xphset()`, `xphx2s()`, `xphs2x()`: **XPH** (HEALPix polar, aka "butterfly")

#### Argument checking (projection routines):

The values of  $\phi$  and  $\theta$  (the native longitude and latitude) normally lie in the range  $[-180^\circ, 180^\circ]$  for  $\phi$ , and  $[-90^\circ, 90^\circ]$  for  $\theta$ . However, all projection routines will accept any value of  $\phi$  and will not normalize it.

The projection routines do not explicitly check that  $\theta$  lies within the range  $[-90^\circ, 90^\circ]$ . They do check for any value of  $\theta$  that produces an invalid argument to the projection equations (e.g. leading to division by zero). The projection routines for **AZP**, **SZP**, **TAN**, **SIN**, **ZPN**, and **COP** also return error 2 if  $(\phi, \theta)$  corresponds to the overlapped (far) side of the projection but also return the corresponding value of  $(x, y)$ . This strict bounds checking may be relaxed at any time by setting `prjprm::bounds%2` to 0 (rather than 1); the projections need not be reinitialized.

#### Argument checking (deprojection routines):

Error checking on the projected coordinates  $(x, y)$  is limited to that required to ascertain whether a solution exists. Where a solution does exist, an optional check is made that the value of  $\phi$  and  $\theta$  obtained lie within the ranges  $[-180^\circ, 180^\circ]$  for  $\phi$ , and  $[-90^\circ, 90^\circ]$  for  $\theta$ . This check, performed by `prjbchk()`, is enabled by default. It may be disabled by setting `prjprm::bounds%4` to 0 (rather than 1); the projections need not be reinitialized.

#### Accuracy:

No warranty is given for the accuracy of these routines (refer to the copyright notice); intending users must satisfy for themselves their adequacy for the intended purpose. However, closure to a precision of at least  $0^\circ.0000000001$  of longitude and latitude has been verified for typical projection parameters on the  $1^\circ$  degree graticule of native longitude and latitude (to within  $5^\circ$  of any latitude where the projection may diverge). Refer to the `tpj1.c` and `tpj2.c` test routines that accompany this software.

### 8.13.2 Macro Definition Documentation

#### PVN

```
#define PVN 30
```

Total number of projection parameters.

The total number of projection parameters numbered 0 to **PVN**-1.

#### PRJX2S\_ARGS

```
#define PRJX2S_ARGS
```

##### Value:

```
struct prjprm *prj, int nx, int ny, int sxy, int spt, \
const double x[], const double y[], double phi[], double theta[], int stat[]
```

For use in declaring deprojection function prototypes.

Preprocessor macro used for declaring deprojection function prototypes.

#### PRJS2X\_ARGS

```
#define PRJS2X_ARGS
```

##### Value:

```
struct prjprm *prj, int nx, int ny, int sxy, int spt, \
const double phi[], const double theta[], double x[], double y[], int stat[]
```

For use in declaring projection function prototypes.

Preprocessor macro used for declaring projection function prototypes.

#### PRJLEN

```
#define PRJLEN (sizeof(struct prjprm)/sizeof(int))
```

Size of the `prjprm` struct in *int* units.

Size of the `prjprm` struct in *int* units, used by the Fortran wrappers.

#### prjini\_errmsg

```
#define prjini_errmsg prj_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use `prj_errmsg` directly now instead.

**prjpri\_errmsg**

```
#define prjpri_errmsg prj_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [prj\\_errmsg](#) directly now instead.

**prjset\_errmsg**

```
#define prjset_errmsg prj_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [prj\\_errmsg](#) directly now instead.

**prjx2s\_errmsg**

```
#define prjx2s_errmsg prj_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [prj\\_errmsg](#) directly now instead.

**prjs2x\_errmsg**

```
#define prjs2x_errmsg prj_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [prj\\_errmsg](#) directly now instead.

### 8.13.3 Enumeration Type Documentation

**prjenq\_enum**

```
enum prjenq_enum
```

**Enumerator**

PRJENQ_SET	
------------	--

PRJENQ_BYP	
------------	--

## prj\_errmsg\_enum

enum [prj\\_errmsg\\_enum](#)

### Enumerator

PRJERR_SUCCESS	
PRJERR_NULL_POINTER	
PRJERR_BAD_PARAM	
PRJERR_BAD_PIX	
PRJERR_BAD_WORLD	

## 8.13.4 Function Documentation

### prjini()

```
int prjini (  
    struct prjprm * prj)
```

Default constructor for the [prjprm](#) struct.

**prjini()** sets all members of a [prjprm](#) struct to default values. It should be used to initialize every [prjprm](#) struct.

**PLEASE NOTE:** If the [prjprm](#) struct has already been initialized, then before reinitializing, it [prjfree\(\)](#) should be used to free any memory that may have been allocated to store an error message. A memory leak may otherwise result.

### Parameters

out	<i>prj</i>	Projection parameters.
-----	------------	------------------------

### Returns

Status return value:

- 0: Success.
- 1: Null [prjprm](#) pointer passed.

### prjfree()

```
int prjfree (  
    struct prjprm * prj)
```

Destructor for the [prjprm](#) struct.

### Parameters

in, out	<i>prj</i>	Projection parameters.
---------	------------	------------------------

### Returns

Status return value:

- 0: Success.
- 1: Null [prjprm](#) pointer passed.

### **prjsize()**

```
int prjsize (  
    const struct prjprm * prj,  
    int sizes[2])
```

Compute the size of a [prjprm](#) struct.

**prjsize()** computes the full size of a [prjprm](#) struct, including allocated memory.

### Parameters

in	<i>prj</i>	Projection parameters. If NULL, the base size of the struct and the allocated size are both set to zero.
out	<i>sizes</i>	The first element is the base size of the struct as returned by <code>sizeof(struct <a href="#">prjprm</a>)</code> . The second element is the total allocated size, in bytes. This figure includes memory allocated for the constituent struct, <a href="#">prjprm::err</a> . It is not an error for the struct not to have been set up via <a href="#">prjset()</a> .

### Returns

Status return value:

- 0: Success.

### **prjenq()**

```
int prjenq (  
    const struct prjprm * prj,  
    int enquiry)
```

enquire about the state of a [prjprm](#) struct.

**prjenq()** may be used to obtain information about the state of a [prjprm](#) struct. The function returns a true/false answer for the enquiry asked.

**Parameters**

in	<i>prj</i>	Projection parameters.
in	<i>enquiry</i>	Enquiry according to the following parameters: <ul style="list-style-type: none"> <li>• PRJENQ_SET: the struct has been set up by <a href="#">prjset()</a>.</li> <li>• PRJENQ_BYP: the struct is in bypass mode (see <a href="#">prjset()</a>).</li> </ul>

**Returns**

Enquiry result:

- 0: No.
- 1: Yes.

**prjprt()**

```
int prjprt (
    const struct prjprm * prj)
```

Print routine for the [prjprm](#) struct.

**prjprt()** prints the contents of a [prjprm](#) struct using [wcsprintf\(\)](#). Mainly intended for diagnostic purposes.

**Parameters**

in	<i>prj</i>	Projection parameters.
----	------------	------------------------

**Returns**

Status return value:

- 0: Success.
- 1: Null [prjprm](#) pointer passed.

**prjperr()**

```
int prjperr (
    const struct prjprm * prj,
    const char * prefix)
```

Print error messages from a [prjprm](#) struct.

**prjperr()** prints the error message(s) (if any) stored in a [prjprm](#) struct. If there are no errors then nothing is printed. It uses [wcserr\\_prt\(\)](#), q.v.

### Parameters

in	<i>prj</i>	Projection parameters.
in	<i>prefix</i>	If non-NULL, each output line will be prefixed with this string.

### Returns

Status return value:

- 0: Success.
- 1: Null [prjprm](#) pointer passed.

### prjbchk()

```
int prjbchk (
    double tol,
    int nphi,
    int ntheta,
    int spt,
    double phi[],
    double theta[],
    int stat[])
```

Bounds checking on native coordinates.

**prjbchk()** performs bounds checking on native spherical coordinates. As returned by the deprojection (x2s) routines, native longitude is expected to lie in the closed interval  $[-180^\circ, 180^\circ]$ , with latitude in  $[-90^\circ, 90^\circ]$ .

A tolerance may be specified to provide a small allowance for numerical imprecision. Values that lie outside the allowed range by not more than the specified tolerance will be adjusted back into range.

If [prjprm::bounds](#) is set, as it is by [prjini\(\)](#), then **prjbchk()** will be invoked automatically by the Cartesian-to-spherical deprojection (x2s) routines with an appropriate tolerance set for each projection.

### Parameters

in	<i>tol</i>	Tolerance for the bounds check [deg].
in	<i>nphi, ntheta</i>	Vector lengths.
in	<i>spt</i>	Vector stride.
in, out	<i>phi, theta</i>	Native longitude and latitude $(\phi, \theta)$ [deg].
out	<i>stat</i>	Status value for each vector element: <ul style="list-style-type: none"> <li>• 0: Valid value of <math>(\phi, \theta)</math>.</li> <li>• 1: Invalid value.</li> </ul>

### Returns

Status return value:

- 0: Success.
- 1: One or more of the  $(\phi, \theta)$  coordinates were, invalid, as indicated by the stat vector.

**prjset()**

```
int prjset (
    struct prjprm * prj)
```

Generic setup routine for the `prjprm` struct.

**prjset()** sets up a `prjprm` struct according to information supplied within it.

The one important distinction between **prjset()** and the setup routines for the specific projections is that the projection code must be defined in the `prjprm` struct in order for **prjset()** to identify the required projection. Once **prjset()** has initialized the `prjprm` struct, `prjx2s()` and `prjs2x()` use the pointers to the specific projection and deprojection routines contained therein.

Note that this routine need not be called directly; it will be invoked by `prjx2s()` and `prjs2x()` if `prj.flag` is anything other than a predefined magic value.

**prjset()** normally operates regardless of the value of `prjprm::flag`; i.e. even if a struct was previously set up it will be reset unconditionally. However, a `prjprm` struct may be put into "bypass" mode by invoking **prjset()** initially with `prjprm::flag == 1` (rather than 0). **prjset()** will return immediately if invoked on a struct in that state. To take a struct out of bypass mode, simply reset `prjprm::flag` to zero. See also `prjenq()`.

**Parameters**

<code>in, out</code>	<code>prj</code>	Projection parameters.
----------------------	------------------	------------------------

**Returns**

Status return value:

- 0: Success.
- 1: Null `prjprm` pointer passed.
- 2: Invalid projection parameters.

For returns > 1, a detailed error message is set in `prjprm::err` if enabled, see `wcserr_enable()`.

**prjx2s()**

```
int prjx2s (
    PRJX2S_ARGS )
```

Generic Cartesian-to-spherical deprojection.

Deproject Cartesian  $(x, y)$  coordinates in the plane of projection to native spherical coordinates  $(\phi, \theta)$ .

The projection is that specified by `prjprm::code`.

**Parameters**

<code>in, out</code>	<code>prj</code>	Projection parameters.
<code>in</code>	<code>nx, ny</code>	Vector lengths.

in	<i>sxy,spt</i>	Vector strides.
in	<i>x,y</i>	Projected coordinates.
out	<i>phi,theta</i>	Longitude and latitude ( $\phi, \theta$ ) of the projected point in native spherical coordinates [deg].
out	<i>stat</i>	Status value for each vector element: <ul style="list-style-type: none"> <li>• 0: Success.</li> <li>• 1: Invalid value of <math>(x, y)</math>.</li> </ul>

## Returns

Status return value:

- 0: Success.
- 1: Null [prjprm](#) pointer passed.
- 2: Invalid projection parameters.
- 3: One or more of the  $(x, y)$  coordinates were invalid, as indicated by the stat vector.

For returns  $> 1$ , a detailed error message is set in [prjprm::err](#) if enabled, see [wcserr\\_enable\(\)](#).

## prjs2x()

```
int prjs2x (
    PRJS2X\_ARGS )
```

Generic spherical-to-Cartesian projection.

Project native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of projection.

The projection is that specified by [prjprm::code](#).

## Parameters

in, out	<i>prj</i>	Projection parameters.
in	<i>nphi,ntheta</i>	Vector lengths.
in	<i>spt,sxy</i>	Vector strides.
in	<i>phi,theta</i>	Longitude and latitude ( $\phi, \theta$ ) of the projected point in native spherical coordinates [deg].
out	<i>x,y</i>	Projected coordinates.
out	<i>stat</i>	Status value for each vector element: <ul style="list-style-type: none"> <li>• 0: Success.</li> <li>• 1: Invalid value of <math>(\phi, \theta)</math>.</li> </ul>

## Returns

Status return value:

- 0: Success.
- 1: Null [prjprm](#) pointer passed.
- 2: Invalid projection parameters.
- 4: One or more of the  $(\phi, \theta)$  coordinates were, invalid, as indicated by the stat vector.

For returns  $> 1$ , a detailed error message is set in [prjprm::err](#) if enabled, see [wcserr\\_enable\(\)](#).

**azpset()**

```
int azpset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **zenithal/azimuthal perspective (AZP)** projection.

**azpset()** sets up a [prjprm](#) struct for a **zenithal/azimuthal perspective (AZP)** projection.

See [prjset\(\)](#) for a description of the API.

**azpx2s()**

```
int azpx2s (
    PRJX2S\_ARGS )
```

Cartesian-to-spherical transformation for the **zenithal/azimuthal perspective (AZP)** projection.

**azpx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **zenithal/azimuthal perspective (AZP)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**azps2x()**

```
int azps2x (
    PRJS2X\_ARGS )
```

Spherical-to-Cartesian transformation for the **zenithal/azimuthal perspective (AZP)** projection.

**azps2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **zenithal/azimuthal perspective (AZP)** projection.

See [prjs2x\(\)](#) for a description of the API.

**szpset()**

```
int szpset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **slant zenithal perspective (SZP)** projection.

**szpset()** sets up a [prjprm](#) struct for a **slant zenithal perspective (SZP)** projection.

See [prjset\(\)](#) for a description of the API.

**szpx2s()**

```
int szpx2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for the **slant zenithal perspective (SZP)** projection.

**szpx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **slant zenithal perspective (SZP)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**szps2x()**

```
int szps2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for the **slant zenithal perspective (SZP)** projection.

**szps2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **slant zenithal perspective (SZP)** projection.

See [prjs2x\(\)](#) for a description of the API.

**tanset()**

```
int tanset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **gnomonic (TAN)** projection.

**tanset()** sets up a [prjprm](#) struct for a **gnomonic (TAN)** projection.

See [prjset\(\)](#) for a description of the API.

**tanx2s()**

```
int tanx2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for the **gnomonic (TAN)** projection.

**tanx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **gnomonic (TAN)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**tans2x()**

```
int tans2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for the **gnomonic (TAN)** projection.

**tans2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **gnomonic (TAN)** projection.

See [prjs2x\(\)](#) for a description of the API.

**stgset()**

```
int stgset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **stereographic (STG)** projection.

**stgset()** sets up a [prjprm](#) struct for a **stereographic (STG)** projection.

See [prjset\(\)](#) for a description of the API.

**stgx2s()**

```
int stgx2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for the **stereographic (STG)** projection.

**stgx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **stereographic (STG)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**stgs2x()**

```
int stgs2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for the **stereographic (STG)** projection.

**stgs2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **stereographic (STG)** projection.

See [prjs2x\(\)](#) for a description of the API.

**sinset()**

```
int sinset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **orthographic/synthesis (SIN)** projection.

**stgset()** sets up a [prjprm](#) struct for an **orthographic/synthesis (SIN)** projection.

See [prjset\(\)](#) for a description of the API.

**sinx2s()**

```
int sinx2s (
    PRJX2S\_ARGS )
```

Cartesian-to-spherical transformation for the **orthographic/synthesis (SIN)** projection.

**sinx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of an **orthographic/synthesis (SIN)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**sins2x()**

```
int sins2x (
    PRJS2X\_ARGS )
```

Spherical-to-Cartesian transformation for the **orthographic/synthesis (SIN)** projection.

**sins2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of an **orthographic/synthesis (SIN)** projection.

See [prjs2x\(\)](#) for a description of the API.

**arcset()**

```
int arcset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **zenithal/azimuthal equidistant (ARC)** projection.

**arcset()** sets up a [prjprm](#) struct for a **zenithal/azimuthal equidistant (ARC)** projection.

See [prjset\(\)](#) for a description of the API.

**arcx2s()**

```
int arcx2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for the **zenithal/azimuthal equidistant (ARC)** projection.

**arcx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **zenithal/azimuthal equidistant (ARC)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**arcs2x()**

```
int arcs2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for the **zenithal/azimuthal equidistant (ARC)** projection.

**arcs2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **zenithal/azimuthal equidistant (ARC)** projection.

See [prjs2x\(\)](#) for a description of the API.

**zpnset()**

```
int zpnset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **zenithal/azimuthal polynomial (ZPN)** projection.

**zpnset()** sets up a [prjprm](#) struct for a **zenithal/azimuthal polynomial (ZPN)** projection.

See [prjset\(\)](#) for a description of the API.

**zpnx2s()**

```
int zpnx2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for the **zenithal/azimuthal polynomial (ZPN)** projection.

**zpnx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **zenithal/azimuthal polynomial (ZPN)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**zpns2x()**

```
int zpns2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for the **zenithal/azimuthal polynomial (ZPN)** projection.

**zpns2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **zenithal/azimuthal polynomial (ZPN)** projection.

See [prjs2x\(\)](#) for a description of the API.

**zeaset()**

```
int zeaset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **zenithal/azimuthal equal area (ZEA)** projection.

**zeaset()** sets up a [prjprm](#) struct for a **zenithal/azimuthal equal area (ZEA)** projection.

See [prjset\(\)](#) for a description of the API.

**zeax2s()**

```
int zeax2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for the **zenithal/azimuthal equal area (ZEA)** projection.

**zeax2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **zenithal/azimuthal equal area (ZEA)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**zeas2x()**

```
int zeas2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for the **zenithal/azimuthal equal area (ZEA)** projection.

**zeas2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **zenithal/azimuthal equal area (ZEA)** projection.

See [prjs2x\(\)](#) for a description of the API.

**airset()**

```
int airset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for **Airy's (AIR)** projection.

**airset()** sets up a [prjprm](#) struct for an **Airy (AIR)** projection.

See [prjset\(\)](#) for a description of the API.

**airx2s()**

```
int airx2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for **Airy's (AIR)** projection.

**airx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of an **Airy (AIR)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**airs2x()**

```
int airs2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for **Airy's (AIR)** projection.

**airs2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of an **Airy (AIR)** projection.

See [prjs2x\(\)](#) for a description of the API.

**cypset()**

```
int cypset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **cylindrical perspective (CYP)** projection.

**cypset()** sets up a [prjprm](#) struct for a **cylindrical perspective (CYP)** projection.

See [prjset\(\)](#) for a description of the API.

**cypx2s()**

```
int cypx2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for the **cylindrical perspective (CYP)** projection.

**cypx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **cylindrical perspective (CYP)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**cyps2x()**

```
int cyps2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for the **cylindrical perspective (CYP)** projection.

**cyps2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **cylindrical perspective (CYP)** projection.

See [prjs2x\(\)](#) for a description of the API.

**ceaset()**

```
int ceaset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **cylindrical equal area (CEA)** projection.

**ceaset()** sets up a [prjprm](#) struct for a **cylindrical equal area (CEA)** projection.

See [prjset\(\)](#) for a description of the API.

**ceax2s()**

```
int ceax2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for the **cylindrical equal area (CEA)** projection.

**ceax2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **cylindrical equal area (CEA)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**ceas2x()**

```
int ceas2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for the **cylindrical equal area (CEA)** projection.

**ceas2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **cylindrical equal area (CEA)** projection.

See [prjs2x\(\)](#) for a description of the API.

**carset()**

```
int carset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **plate carrée (CAR)** projection.

**carset()** sets up a [prjprm](#) struct for a **plate carrée (CAR)** projection.

See [prjset\(\)](#) for a description of the API.

**carx2s()**

```
int carx2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for the **plate carrée (CAR)** projection.

**carx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **plate carrée (CAR)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**cars2x()**

```
int cars2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for the **plate carrée (CAR)** projection.

**cars2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **plate carrée (CAR)** projection.

See [prjs2x\(\)](#) for a description of the API.

**meraset()**

```
int meraset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for **Mercator's (MER)** projection.

**meraset()** sets up a [prjprm](#) struct for a **Mercator (MER)** projection.

See [prjset\(\)](#) for a description of the API.

**merx2s()**

```
int merx2s (
    PRJX2S\_ARGS )
```

Cartesian-to-spherical transformation for **Mercator's (MER)** projection.

**merx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **Mercator (MER)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**mers2x()**

```
int mers2x (
    PRJS2X\_ARGS )
```

Spherical-to-Cartesian transformation for **Mercator's (MER)** projection.

**mers2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **Mercator (MER)** projection.

See [prjs2x\(\)](#) for a description of the API.

**sflset()**

```
int sflset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **Sanson-Flamsteed (SFL)** projection.

**sflset()** sets up a [prjprm](#) struct for a **Sanson-Flamsteed (SFL)** projection.

See [prjset\(\)](#) for a description of the API.

**sflx2s()**

```
int sflx2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for the **Sanson-Flamsteed (SFL)** projection.

**sflx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **Sanson-Flamsteed (SFL)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**sfls2x()**

```
int sfls2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for the **Sanson-Flamsteed (SFL)** projection.

**sfls2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **Sanson-Flamsteed (SFL)** projection.

See [prjs2x\(\)](#) for a description of the API.

**parset()**

```
int parset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **parabolic (PAR)** projection.

**parset()** sets up a [prjprm](#) struct for a **parabolic (PAR)** projection.

See [prjset\(\)](#) for a description of the API.

**parx2s()**

```
int parx2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for the **parabolic (PAR)** projection.

**parx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **parabolic (PAR)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**pars2x()**

```
int pars2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for the **parabolic (PAR)** projection.

**pars2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **parabolic (PAR)** projection.

See [prjs2x\(\)](#) for a description of the API.

**molset()**

```
int molset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for **Mollweide's (MOL)** projection.

**molset()** sets up a [prjprm](#) struct for a **Mollweide (MOL)** projection.

See [prjset\(\)](#) for a description of the API.

**molx2s()**

```
int molx2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for **Mollweide's (MOL)** projection.

**molx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **Mollweide (MOL)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**mols2x()**

```
int mols2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for **Mollweide's (MOL)** projection.

**mols2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **Mollweide (MOL)** projection.

See [prjs2x\(\)](#) for a description of the API.

**aitset()**

```
int aitset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **Hammer-Aitoff (AIT)** projection.

**aitset()** sets up a [prjprm](#) struct for a **Hammer-Aitoff (AIT)** projection.

See [prjset\(\)](#) for a description of the API.

**aitx2s()**

```
int aitx2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for the **Hammer-Aitoff (AIT)** projection.

**aitx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **Hammer-Aitoff (AIT)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**aits2x()**

```
int aits2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for the **Hammer-Aitoff (AIT)** projection.

**aits2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **Hammer-Aitoff (AIT)** projection.

See [prjs2x\(\)](#) for a description of the API.

**copset()**

```
int copset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **conic perspective (COP)** projection.

**copset()** sets up a [prjprm](#) struct for a **conic perspective (COP)** projection.

See [prjset\(\)](#) for a description of the API.

**copx2s()**

```
int copx2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for the **conic perspective (COP)** projection.

**copx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **conic perspective (COP)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**cops2x()**

```
int cops2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for the **conic perspective (COP)** projection.

**cops2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **conic perspective (COP)** projection.

See [prjs2x\(\)](#) for a description of the API.

**coeset()**

```
int coeset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **conic equal area (COE)** projection.

**coeset()** sets up a [prjprm](#) struct for a **conic equal area (COE)** projection.

See [prjset\(\)](#) for a description of the API.

**coex2s()**

```
int coex2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for the **conic equal area (COE)** projection.

**coex2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **conic equal area (COE)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**coes2x()**

```
int coes2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for the **conic equal area (COE)** projection.

**coes2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **conic equal area (COE)** projection.

See [prjs2x\(\)](#) for a description of the API.

**codset()**

```
int codset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **conic equidistant (COD)** projection.

**codset()** sets up a [prjprm](#) struct for a **conic equidistant (COD)** projection.

See [prjset\(\)](#) for a description of the API.

**codx2s()**

```
int codx2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for the **conic equidistant (COD)** projection.

**codx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **conic equidistant (COD)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**cods2x()**

```
int cods2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for the **conic equidistant (COD)** projection.

**cods2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **conic equidistant (COD)** projection.

See [prjs2x\(\)](#) for a description of the API.

**cooset()**

```
int cooset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **conic orthomorphic (COO)** projection.

**cooset()** sets up a [prjprm](#) struct for a **conic orthomorphic (COO)** projection.

See [prjset\(\)](#) for a description of the API.

**coox2s()**

```
int coox2s (
    PRJX2S\_ARGS )
```

Cartesian-to-spherical transformation for the **conic orthomorphic (COO)** projection.

**coox2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **conic orthomorphic (COO)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**coos2x()**

```
int coos2x (
    PRJS2X\_ARGS )
```

Spherical-to-Cartesian transformation for the **conic orthomorphic (COO)** projection.

**coos2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **conic orthomorphic (COO)** projection.

See [prjs2x\(\)](#) for a description of the API.

**bonset()**

```
int bonset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for **Bonne's (BON)** projection.

**bonset()** sets up a [prjprm](#) struct for a **Bonne (BON)** projection.

See [prjset\(\)](#) for a description of the API.

**bonx2s()**

```
int bonx2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for **Bonne's (BON)** projection.

**bonx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **Bonne (BON)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**bons2x()**

```
int bons2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for **Bonne's (BON)** projection.

**bons2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **Bonne (BON)** projection.

See [prjs2x\(\)](#) for a description of the API.

**pcoset()**

```
int pcoset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **polyconic (PCO)** projection.

**pcoset()** sets up a [prjprm](#) struct for a **polyconic (PCO)** projection.

See [prjset\(\)](#) for a description of the API.

**pcox2s()**

```
int pcox2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for the **polyconic (PCO)** projection.

**pcox2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **polyconic (PCO)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**pcos2x()**

```
int pcos2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for the **polyconic (PCO)** projection.

**pcos2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **polyconic (PCO)** projection.

See [prjs2x\(\)](#) for a description of the API.

**tscset()**

```
int tscset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **tangential spherical cube (TSC)** projection.

**tscset()** sets up a [prjprm](#) struct for a **tangential spherical cube (TSC)** projection.

See [prjset\(\)](#) for a description of the API.

**tscx2s()**

```
int tscx2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for the **tangential spherical cube (TSC)** projection.

**tscx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **tangential spherical cube (TSC)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**tscs2x()**

```
int tscs2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for the **tangential spherical cube (TSC)** projection.

**tscs2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **tangential spherical cube (TSC)** projection.

See [prjs2x\(\)](#) for a description of the API.

**cscset()**

```
int cscset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **COBE spherical cube (CSC)** projection.

**cscset()** sets up a [prjprm](#) struct for a **COBE spherical cube (CSC)** projection.

See [prjset\(\)](#) for a description of the API.

**cscx2s()**

```
int cscx2s (
    PRJX2S\_ARGS )
```

Cartesian-to-spherical transformation for the **COBE spherical cube (CSC)** projection.

**cscx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **COBE spherical cube (CSC)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**cscs2x()**

```
int cscs2x (
    PRJS2X\_ARGS )
```

Spherical-to-Cartesian transformation for the **COBE spherical cube (CSC)** projection.

**cscs2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **COBE spherical cube (CSC)** projection.

See [prjs2x\(\)](#) for a description of the API.

**qscset()**

```
int qscset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **quadrilateralized spherical cube (QSC)** projection.

**qscset()** sets up a [prjprm](#) struct for a **quadrilateralized spherical cube (QSC)** projection.

See [prjset\(\)](#) for a description of the API.

**qscx2s()**

```
int qscx2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for the **quadrilateralized spherical cube (QSC)** projection.

**qscx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **quadrilateralized spherical cube (QSC)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**qscs2x()**

```
int qscs2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for the **quadrilateralized spherical cube (QSC)** projection.

**qscs2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **quadrilateralized spherical cube (QSC)** projection.

See [prjs2x\(\)](#) for a description of the API.

**hpxset()**

```
int hpxset (
    struct prjprm * prj)
```

Set up a [prjprm](#) struct for the **HEALPix (HPX)** projection.

**hpxset()** sets up a [prjprm](#) struct for a **HEALPix (HPX)** projection.

See [prjset\(\)](#) for a description of the API.

**hpxx2s()**

```
int hpxx2s (
    PRJX2S_ARGS )
```

Cartesian-to-spherical transformation for the **HEALPix (HPX)** projection.

**hpxx2s()** deprojects Cartesian  $(x, y)$  coordinates in the plane of a **HEALPix (HPX)** projection to native spherical coordinates  $(\phi, \theta)$ .

See [prjx2s\(\)](#) for a description of the API.

**hpxs2x()**

```
int hpxs2x (
    PRJS2X_ARGS )
```

Spherical-to-Cartesian transformation for the **HEALPix (HPX)** projection.

**hpxs2x()** projects native spherical coordinates  $(\phi, \theta)$  to Cartesian  $(x, y)$  coordinates in the plane of a **HEALPix (HPX)** projection.

See [prjs2x\(\)](#) for a description of the API.

**xphset()**

```
int xphset (
    struct prjprm * prj)
```

**xphx2s()**

```
int xphx2s (
    PRJX2S_ARGS )
```

**xphs2x()**

```
int xphs2x (
    PRJS2X_ARGS )
```

**8.13.5 Variable Documentation****prj\_errmsg**

```
const char* prj_errmsg[] [extern]
```

Status return messages.

Error messages to match the status value returned from each function.

**CONIC**

```
const int CONIC [extern]
```

Identifier for conic projections.

Identifier for conic projections, see [prjprm::category](#).

## CONVENTIONAL

```
const int CONVENTIONAL
```

Identifier for conventional projections.

Identifier for conventional projections, see [prjprm::category](#).

## CYLINDRICAL

```
const int CYLINDRICAL
```

Identifier for cylindrical projections.

Identifier for cylindrical projections, see [prjprm::category](#).

## POLYCONIC

```
const int POLYCONIC
```

Identifier for polyconic projections.

Identifier for polyconic projections, see [prjprm::category](#).

## PSEUDOCYLINDRICAL

```
const int PSEUDOCYLINDRICAL
```

Identifier for pseudocylindrical projections.

Identifier for pseudocylindrical projections, see [prjprm::category](#).

## QUADCUBE

```
const int QUADCUBE
```

Identifier for quadcube projections.

Identifier for quadcube projections, see [prjprm::category](#).

## ZENITHAL

```
const int ZENITHAL
```

Identifier for zenithal/azimuthal projections.

Identifier for zenithal/azimuthal projections, see [prjprm::category](#).

## HEALPIX

```
const int HEALPIX
```

Identifier for the HEALPix projection.

Identifier for the HEALPix projection, see [prjprm::category](#).

## prj\_categories

```
const char prj_categories[9][32] [extern]
```

Projection categories.

Names of the projection categories, all in lower-case except for "HEALPix".

Provided for information only, not used by the projection routines.

## prj\_ncode

```
const int prj_ncode [extern]
```

The number of recognized three-letter projection codes.

The number of recognized three-letter projection codes (currently 27), see [prj\\_codes](#).

## prj\_codes

```
const char prj_codes[28][4] [extern]
```

Recognized three-letter projection codes.

List of all recognized three-letter projection codes (currently 27), e.g. **SIN**, **TAN**, etc.

## 8.14 prj.h

[Go to the documentation of this file.](#)

```

00001 /*=====
00002 WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003 Copyright (C) 1995-2025, Mark Calabretta
00004
00005 This file is part of WCSLIB.
00006
00007 WCSLIB is free software: you can redistribute it and/or modify it under the
00008 terms of the GNU Lesser General Public License as published by the Free
00009 Software Foundation, either version 3 of the License, or (at your option)
00010 any later version.
00011
00012 WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
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00014 FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
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00017 You should have received a copy of the GNU Lesser General Public License
00018 along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020 Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021 http://www.atnf.csiro.au/people/Mark.Calabretta
00022 $Id: prj.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023 *=====
00024 *
00025 * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026 * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027 * overview of the library.
00028 *
00029 *
00030 * Summary of the prj routines
00031 * -----
00032 * Routines in this suite implement the spherical map projections defined by
00033 * the FITS World Coordinate System (WCS) standard, as described in
00034 *
00035 * "Representations of world coordinates in FITS",
00036 * Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)
00037 *
00038 * "Representations of celestial coordinates in FITS",
00039 * Calabretta, M.R., & Greisen, E.W. 2002, A&A, 395, 1077 (WCS Paper II)
00040 *
00041 * "Mapping on the HEALPix grid",
00042 * Calabretta, M.R., & Roukema, B.F. 2007, MNRAS, 381, 865 (WCS Paper V)
00043 *
00044 * "Representing the 'Butterfly' Projection in FITS -- Projection Code XPH",
00045 * Calabretta, M.R., & Lowe, S.R. 2013, PASA, 30, e050 (WCS Paper VI)
00046 *
00047 * These routines are based on the prjprm struct which contains all information
00048 * needed for the computations. The struct contains some members that must be
00049 * set by the user, and others that are maintained by these routines, somewhat
00050 * like a C++ class but with no encapsulation.
00051 *
00052 * Routine prjini() is provided to initialize the prjprm struct with default
00053 * values, prjfree() reclaims any memory that may have been allocated to store
00054 * an error message, prjsize() computes its total size including allocated
00055 * memory, prjenc() returns information about the state of the struct, and
00056 * prjpri() prints its contents.
00057 *
00058 * prjperr() prints the error message(s) (if any) stored in a prjprm struct.
00059 * prjbchk() performs bounds checking on native spherical coordinates.
00060 *
00061 * Setup routines for each projection with names of the form ???set(), where
00062 * "???" is the down-cased three-letter projection code, compute intermediate
00063 * values in the prjprm struct from parameters in it that were supplied by the
00064 * user. The struct always needs to be set by the projection's setup routine
00065 * but that need not be called explicitly - refer to the explanation of
00066 * prjprm::flag.
00067 *
00068 * Each map projection is implemented via separate functions for the spherical
00069 * projection, ???s2x(), and deprojection, ???x2s().
00070 *
00071 * A set of driver routines, prjset(), prjx2s(), and prjs2x(), provides a
00072 * generic interface to the specific projection routines which they invoke
00073 * via pointers-to-functions stored in the prjprm struct.
00074 *
00075 * In summary, the routines are:
00076 * - prjini() Initialization routine for the prjprm struct.
00077 * - prjfree() Reclaim memory allocated for error messages.
00078 * - prjsize() Compute total size of a prjprm struct.
00079 * - prjpri() Print a prjprm struct.
00080 * - prjperr() Print error message (if any).
00081 * - prjbchk() Bounds checking on native coordinates.
00082 *

```

```

00083 * - prjset(), prjx2s(), prjs2x(): Generic driver routines
00084 *
00085 * - azpset(), azpx2s(), azps2x(): AZP (zenithal/azimuthal perspective)
00086 * - szpset(), szpx2s(), szps2x(): SZP (slant zenithal perspective)
00087 * - tanset(), tanx2s(), tans2x(): TAN (gnomonic)
00088 * - stgset(), stgx2s(), stgs2x(): STG (stereographic)
00089 * - sinset(), sinx2s(), sins2x(): SIN (orthographic/synthesis)
00090 * - arcset(), arcx2s(), arcs2x(): ARC (zenithal/azimuthal equidistant)
00091 * - zpnset(), zpnx2s(), zpns2x(): ZPN (zenithal/azimuthal polynomial)
00092 * - zeaset(), zeax2s(), zeas2x(): ZEA (zenithal/azimuthal equal area)
00093 * - airset(), airx2s(), airs2x(): AIR (Airy)
00094 * - cypset(), cypx2s(), cyps2x(): CYP (cylindrical perspective)
00095 * - ceaset(), ceax2s(), ceas2x(): CEA (cylindrical equal area)
00096 * - carset(), carx2s(), cars2x(): CAR (Plate carree)
00097 * - merset(), merx2s(), mers2x(): MER (Mercator)
00098 * - sflset(), sflx2s(), sfls2x(): SFL (Sanson-Flamsteed)
00099 * - parset(), parx2s(), pars2x(): PAR (parabolic)
00100 * - molset(), molx2s(), mols2x(): MOL (Mollweide)
00101 * - aitset(), aitx2s(), aits2x(): AIT (Hammer-Aitoff)
00102 * - copset(), copx2s(), cops2x(): COP (conic perspective)
00103 * - coeset(), coex2s(), coes2x(): COE (conic equal area)
00104 * - codset(), codx2s(), cods2x(): COD (conic equidistant)
00105 * - cooset(), coox2s(), coos2x(): COO (conic orthomorphic)
00106 * - bonset(), bonx2s(), bons2x(): BON (Bonne)
00107 * - pcoset(), pcox2s(), pcos2x(): PCO (polyconic)
00108 * - tscset(), tscx2s(), tscs2x(): TSC (tangential spherical cube)
00109 * - cscset(), cscx2s(), cscs2x(): CSC (COBE spherical cube)
00110 * - qscset(), qscx2s(), qscs2x(): QSC (quadrilateralized spherical cube)
00111 * - hpxset(), hpvx2s(), hpxs2x(): HPX (HEALPix)
00112 * - xphset(), xphx2s(), xphs2x(): XPH (HEALPix polar, aka "butterfly")
00113 *
00114 * Argument checking (projection routines):
00115 * -----
00116 * The values of phi and theta (the native longitude and latitude) normally lie
00117 * in the range [-180,180] for phi, and [-90,90] for theta. However, all
00118 * projection routines will accept any value of phi and will not normalize it.
00119 *
00120 * The projection routines do not explicitly check that theta lies within the
00121 * range [-90,90]. They do check for any value of theta that produces an
00122 * invalid argument to the projection equations (e.g. leading to division by
00123 * zero). The projection routines for AZP, SZP, TAN, SIN, ZPN, and COP also
00124 * return error 2 if (phi,theta) corresponds to the overlapped (far) side of
00125 * the projection but also return the corresponding value of (x,y). This
00126 * strict bounds checking may be relaxed at any time by setting
00127 * prjprm::bounds%2 to 0 (rather than 1); the projections need not be
00128 * reinitialized.
00129 *
00130 * Argument checking (deprojection routines):
00131 * -----
00132 * Error checking on the projected coordinates (x,y) is limited to that
00133 * required to ascertain whether a solution exists. Where a solution does
00134 * exist, an optional check is made that the value of phi and theta obtained
00135 * lie within the ranges [-180,180] for phi, and [-90,90] for theta. This
00136 * check, performed by prjbchk(), is enabled by default. It may be disabled by
00137 * setting prjprm::bounds%4 to 0 (rather than 1); the projections need not be
00138 * reinitialized.
00139 *
00140 * Accuracy:
00141 * -----
00142 * No warranty is given for the accuracy of these routines (refer to the
00143 * copyright notice); intending users must satisfy for themselves their
00144 * adequacy for the intended purpose. However, closure to a precision of at
00145 * least 1E-10 degree of longitude and latitude has been verified for typical
00146 * projection parameters on the 1 degree graticule of native longitude and
00147 * latitude (to within 5 degrees of any latitude where the projection may
00148 * diverge). Refer to the tprj1.c and tprj2.c test routines that accompany
00149 * this software.
00150 *
00151 *
00152 * prjini() - Default constructor for the prjprm struct
00153 * -----
00154 * prjini() sets all members of a prjprm struct to default values. It should
00155 * be used to initialize every prjprm struct.
00156 *
00157 * PLEASE NOTE: If the prjprm struct has already been initialized, then before
00158 * reinitializing, it prjfree() should be used to free any memory that may have
00159 * been allocated to store an error message. A memory leak may otherwise
00160 * result.
00161 *
00162 * Returned:
00163 * prj struct prjprm*
00164 * Projection parameters.
00165 *
00166 * Function return value:
00167 * int Status return value:
00168 * 0: Success.
00169 * 1: Null prjprm pointer passed.

```

```

00170 *
00171 *
00172 * prjfree() - Destructor for the prjprm struct
00173 * -----
00174 * prjfree() frees any memory that may have been allocated to store an error
00175 * message in the prjprm struct.
00176 *
00177 * Given and returned:
00178 *   prj          struct prjprm*
00179 *               Projection parameters.
00180 *
00181 * Function return value:
00182 *   int          Status return value:
00183 *               0: Success.
00184 *               1: Null prjprm pointer passed.
00185 *
00186 *
00187 * prjsize() - Compute the size of a prjprm struct
00188 * -----
00189 * prjsize() computes the full size of a prjprm struct, including allocated
00190 * memory.
00191 *
00192 * Given:
00193 *   prj          const struct prjprm*
00194 *               Projection parameters.
00195 *
00196 *               If NULL, the base size of the struct and the allocated
00197 *               size are both set to zero.
00198 *
00199 * Returned:
00200 *   sizes        int[2]   The first element is the base size of the struct as
00201 *                          returned by sizeof(struct prjprm). The second element
00202 *                          is the total allocated size, in bytes. This figure
00203 *                          includes memory allocated for the constituent struct,
00204 *                          prjprm::err.
00205 *
00206 *               It is not an error for the struct not to have been set
00207 *               up via prjset().
00208 *
00209 * Function return value:
00210 *   int          Status return value:
00211 *               0: Success.
00212 *
00213 *
00214 * prjenvq() - enquire about the state of a prjprm struct
00215 * -----
00216 * prjenvq() may be used to obtain information about the state of a prjprm
00217 * struct. The function returns a true/false answer for the enquiry asked.
00218 *
00219 * Given:
00220 *   prj          const struct prjprm*
00221 *               Projection parameters.
00222 *
00223 *   enquiry      int       Enquiry according to the following parameters:
00224 *                           PRJENQ_SET: the struct has been set up by prjset().
00225 *                           PRJENQ_BYP: the struct is in bypass mode (see
00226 *                           prjset()).
00227 *
00228 * Function return value:
00229 *   int          Enquiry result:
00230 *               0: No.
00231 *               1: Yes.
00232 *
00233 *
00234 * prjprt() - Print routine for the prjprm struct
00235 * -----
00236 * prjprt() prints the contents of a prjprm struct using wcsprintf(). Mainly
00237 * intended for diagnostic purposes.
00238 *
00239 * Given:
00240 *   prj          const struct prjprm*
00241 *               Projection parameters.
00242 *
00243 * Function return value:
00244 *   int          Status return value:
00245 *               0: Success.
00246 *               1: Null prjprm pointer passed.
00247 *
00248 *
00249 * prjperr() - Print error messages from a prjprm struct
00250 * -----
00251 * prjperr() prints the error message(s) (if any) stored in a prjprm struct.
00252 * If there are no errors then nothing is printed. It uses wcserr_prt(), q.v.
00253 *
00254 * Given:
00255 *   prj          const struct prjprm*
00256 *               Projection parameters.

```

```

00257 *
00258 *   prefix      const char *
00259 *               If non-NULL, each output line will be prefixed with
00260 *               this string.
00261 *
00262 * Function return value:
00263 *       int      Status return value:
00264 *               0: Success.
00265 *               1: Null prjprm pointer passed.
00266 *
00267 *
00268 * prjbchk() - Bounds checking on native coordinates
00269 * -----
00270 * prjbchk() performs bounds checking on native spherical coordinates. As
00271 * returned by the deprojection (x2s) routines, native longitude is expected
00272 * to lie in the closed interval [-180,180], with latitude in [-90,90].
00273 *
00274 * A tolerance may be specified to provide a small allowance for numerical
00275 * imprecision. Values that lie outside the allowed range by not more than
00276 * the specified tolerance will be adjusted back into range.
00277 *
00278 * If prjprm::bounds&4 is set, as it is by prjini(), then prjbchk() will be
00279 * invoked automatically by the Cartesian-to-spherical deprojection (x2s)
00280 * routines with an appropriate tolerance set for each projection.
00281 *
00282 * Given:
00283 *   tol      double      Tolerance for the bounds check [deg].
00284 *
00285 *   nphi,
00286 *   ntheta   int         Vector lengths.
00287 *
00288 *   spt      int         Vector stride.
00289 *
00290 * Given and returned:
00291 *   phi,theta double[]   Native longitude and latitude (phi,theta) [deg].
00292 *
00293 * Returned:
00294 *   stat      int[]      Status value for each vector element:
00295 *                   0: Valid value of (phi,theta).
00296 *                   1: Invalid value.
00297 *
00298 * Function return value:
00299 *       int      Status return value:
00300 *               0: Success.
00301 *               1: One or more of the (phi,theta) coordinates
00302 *                   were, invalid, as indicated by the stat vector.
00303 *
00304 *
00305 * prjset() - Generic setup routine for the prjprm struct
00306 * -----
00307 * prjset() sets up a prjprm struct according to information supplied within
00308 * it.
00309 *
00310 * The one important distinction between prjset() and the setup routines for
00311 * the specific projections is that the projection code must be defined in the
00312 * prjprm struct in order for prjset() to identify the required projection.
00313 * Once prjset() has initialized the prjprm struct, prjx2s() and prjs2x() use
00314 * the pointers to the specific projection and deprojection routines contained
00315 * therein.
00316 *
00317 * Note that this routine need not be called directly; it will be invoked by
00318 * prjx2s() and prjs2x() if prj.flag is anything other than a predefined magic
00319 * value.
00320 *
00321 * prjset() normally operates regardless of the value of prjprm::flag; i.e.
00322 * even if a struct was previously set up it will be reset unconditionally.
00323 * However, a prjprm struct may be put into "bypass" mode by invoking prjset()
00324 * initially with prjprm::flag == 1 (rather than 0). prjset() will return
00325 * immediately if invoked on a struct in that state. To take a struct out of
00326 * bypass mode, simply reset prjprm::flag to zero. See also prjenq().
00327 *
00328 * Given and returned:
00329 *   prj      struct prjprm*
00330 *               Projection parameters.
00331 *
00332 * Function return value:
00333 *       int      Status return value:
00334 *               0: Success.
00335 *               1: Null prjprm pointer passed.
00336 *               2: Invalid projection parameters.
00337 *
00338 *               For returns > 1, a detailed error message is set in
00339 *               prjprm::err if enabled, see wcserr_enable().
00340 *
00341 *
00342 * prjx2s() - Generic Cartesian-to-spherical deprojection
00343 * -----

```

```

00344 * Deproject Cartesian (x,y) coordinates in the plane of projection to native
00345 * spherical coordinates (phi,theta).
00346 *
00347 * The projection is that specified by prjprm::code.
00348 *
00349 * Given and returned:
00350 *   prj          struct prjprm*
00351 *               Projection parameters.
00352 *
00353 * Given:
00354 *   nx,ny        int           Vector lengths.
00355 *
00356 *   sxy,spt      int           Vector strides.
00357 *
00358 *   x,y          const double[]
00359 *               Projected coordinates.
00360 *
00361 * Returned:
00362 *   phi,theta double[] Longitude and latitude (phi,theta) of the projected
00363 *                       point in native spherical coordinates [deg].
00364 *
00365 *   stat         int[]        Status value for each vector element:
00366 *                               0: Success.
00367 *                               1: Invalid value of (x,y).
00368 *
00369 * Function return value:
00370 *   int           Status return value:
00371 *               0: Success.
00372 *               1: Null prjprm pointer passed.
00373 *               2: Invalid projection parameters.
00374 *               3: One or more of the (x,y) coordinates were
00375 *                   invalid, as indicated by the stat vector.
00376 *
00377 *               For returns > 1, a detailed error message is set in
00378 *               prjprm::err if enabled, see wcserr_enable().
00379 *
00380 *
00381 * prjs2x() - Generic spherical-to-Cartesian projection
00382 * -----
00383 * Project native spherical coordinates (phi,theta) to Cartesian (x,y)
00384 * coordinates in the plane of projection.
00385 *
00386 * The projection is that specified by prjprm::code.
00387 *
00388 * Given and returned:
00389 *   prj          struct prjprm*
00390 *               Projection parameters.
00391 *
00392 * Given:
00393 *   nphi,
00394 *   ntheta      int           Vector lengths.
00395 *
00396 *   spt,sxy     int           Vector strides.
00397 *
00398 *   phi,theta const double[]
00399 *               Longitude and latitude (phi,theta) of the projected
00400 *               point in native spherical coordinates [deg].
00401 *
00402 * Returned:
00403 *   x,y         double[]      Projected coordinates.
00404 *
00405 *   stat        int[]         Status value for each vector element:
00406 *                               0: Success.
00407 *                               1: Invalid value of (phi,theta).
00408 *
00409 * Function return value:
00410 *   int          Status return value:
00411 *               0: Success.
00412 *               1: Null prjprm pointer passed.
00413 *               2: Invalid projection parameters.
00414 *               4: One or more of the (phi,theta) coordinates
00415 *                   were, invalid, as indicated by the stat vector.
00416 *
00417 *               For returns > 1, a detailed error message is set in
00418 *               prjprm::err if enabled, see wcserr_enable().
00419 *
00420 *
00421 * ???set() - Specific setup routines for the prjprm struct
00422 * -----
00423 * Set up a prjprm struct for a particular projection according to information
00424 * supplied within it.
00425 *
00426 * Given and returned:
00427 *   prj          struct prjprm*
00428 *               Projection parameters.
00429 *
00430 * Function return value:

```

```

00431 *          int          Status return value:
00432 *                      0: Success.
00433 *                      1: Null prjprm pointer passed.
00434 *                      2: Invalid projection parameters.
00435 *
00436 *                      For returns > 1, a detailed error message is set in
00437 *                      prjprm::err if enabled, see wcserr_enable().
00438 *
00439 *
00440 * ???x2s() - Specific Cartesian-to-spherical deprojection routines
00441 * -----
00442 * Transform (x,y) coordinates in the plane of projection to native spherical
00443 * coordinates (phi,theta).
00444 *
00445 * Given and returned:
00446 *   prj          struct prjprm*
00447 *                Projection parameters.
00448 *
00449 * Given:
00450 *   nx,ny        int          Vector lengths.
00451 *
00452 *   sxy,spt      int          Vector strides.
00453 *
00454 *   x,y          const double[]
00455 *                Projected coordinates.
00456 *
00457 * Returned:
00458 *   phi,theta double[] Longitude and latitude of the projected point in
00459 *                       native spherical coordinates [deg].
00460 *
00461 *   stat          int[]       Status value for each vector element:
00462 *                       0: Success.
00463 *                       1: Invalid value of (x,y).
00464 *
00465 * Function return value:
00466 *          int          Status return value:
00467 *                      0: Success.
00468 *                      1: Null prjprm pointer passed.
00469 *                      2: Invalid projection parameters.
00470 *                      3: One or more of the (x,y) coordinates were
00471 *                      invalid, as indicated by the stat vector.
00472 *
00473 *                      For returns > 1, a detailed error message is set in
00474 *                      prjprm::err if enabled, see wcserr_enable().
00475 *
00476 *
00477 * ???s2x() - Specific spherical-to-Cartesian projection routines
00478 * -----
00479 * Transform native spherical coordinates (phi,theta) to (x,y) coordinates in
00480 * the plane of projection.
00481 *
00482 * Given and returned:
00483 *   prj          struct prjprm*
00484 *                Projection parameters.
00485 *
00486 * Given:
00487 *   nphi,
00488 *   ntheta      int          Vector lengths.
00489 *
00490 *   spt,sxy     int          Vector strides.
00491 *
00492 *   phi,theta const double[]
00493 *                       Longitude and latitude of the projected point in
00494 *                       native spherical coordinates [deg].
00495 *
00496 * Returned:
00497 *   x,y          double[]    Projected coordinates.
00498 *
00499 *   stat          int[]       Status value for each vector element:
00500 *                       0: Success.
00501 *                       1: Invalid value of (phi,theta).
00502 *
00503 * Function return value:
00504 *          int          Status return value:
00505 *                      0: Success.
00506 *                      1: Null prjprm pointer passed.
00507 *                      2: Invalid projection parameters.
00508 *                      4: One or more of the (phi,theta) coordinates
00509 *                      were, invalid, as indicated by the stat vector.
00510 *
00511 *                      For returns > 1, a detailed error message is set in
00512 *                      prjprm::err if enabled, see wcserr_enable().
00513 *
00514 *
00515 * prjprm struct - Projection parameters
00516 * -----
00517 * The prjprm struct contains all information needed to project or deproject

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00518 * native spherical coordinates. It consists of certain members that must be
00519 * set by the user ("given") and others that are set by the WCSLIB routines
00520 * ("returned"). Some of the latter are supplied for informational purposes
00521 * while others are for internal use only.
00522 *
00523 *   int flag
00524 *       (Given and returned) This flag must be set to zero (or 1, see prjset())
00525 *       whenever any of the following prjprm members are set or changed:
00526 *
00527 *       - prjprm::code,
00528 *       - prjprm::r0,
00529 *       - prjprm::pv[],
00530 *       - prjprm::phi0,
00531 *       - prjprm::theta0.
00532 *
00533 *       This signals the initialization routine (prjset() or ???set()) to
00534 *       recompute the returned members of the prjprm struct. flag will then be
00535 *       reset to indicate that this has been done.
00536 *
00537 *       Note that flag need not be reset when prjprm::bounds is changed.
00538 *
00539 *   char code[4]
00540 *       (Given) Three-letter projection code defined by the FITS standard.
00541 *
00542 *   double r0
00543 *       (Given) The radius of the generating sphere for the projection, a linear
00544 *       scaling parameter. If this is zero, it will be reset to its default
00545 *       value of 180/pi (the value for FITS WCS).
00546 *
00547 *   double pv[30]
00548 *       (Given) Projection parameters. These correspond to the PVi_ma keywords
00549 *       in FITS, so pv[0] is PVi_0a, pv[1] is PVi_1a, etc., where i denotes the
00550 *       latitude-like axis. Many projections use pv[1] (PVi_1a), some also use
00551 *       pv[2] (PVi_2a) and SZP uses pv[3] (PVi_3a). ZPN is currently the only
00552 *       projection that uses any of the others.
00553 *
00554 *       Usage of the pv[] array as it applies to each projection is described in
00555 *       the prologue to each trio of projection routines in prj.c.
00556 *
00557 *   double phi0
00558 *       (Given) The native longitude, phi_0 [deg], and ...
00559 *   double theta0
00560 *       (Given) ... the native latitude, theta_0 [deg], of the reference point,
00561 *       i.e. the point (x,y) = (0,0). If undefined (set to a magic value by
00562 *       prjini()) the initialization routine will set this to a
00563 *       projection-specific default.
00564 *
00565 *   int bounds
00566 *       (Given) Controls bounds checking. If bounds&1 then enable strict bounds
00567 *       checking for the spherical-to-Cartesian (s2x) transformation for the
00568 *       AZP, SZP, TAN, SIN, ZPN, and COP projections. If bounds&2 then enable
00569 *       strict bounds checking for the Cartesian-to-spherical transformation
00570 *       (x2s) for the HPX and XPH projections. If bounds&4 then the Cartesian-
00571 *       to-spherical transformations (x2s) will invoke prjbchk() to perform
00572 *       bounds checking on the computed native coordinates, with a tolerance set
00573 *       to suit each projection. bounds is set to 7 by prjini() by default
00574 *       which enables all checks. Zero it to disable all checking.
00575 *
00576 *       It is not necessary to reset the prjprm struct (via prjset() or
00577 *       ???set()) when prjprm::bounds is changed.
00578 *
00579 * The remaining members of the prjprm struct are maintained by the setup
00580 * routines and must not be modified elsewhere:
00581 *
00582 *   char name[40]
00583 *       (Returned) Long name of the projection.
00584 *
00585 *       Provided for information only, not used by the projection routines.
00586 *
00587 *   int category
00588 *       (Returned) Projection category matching the value of the relevant global
00589 *       variable:
00590 *
00591 *       - ZENITHAL,
00592 *       - CYLINDRICAL,
00593 *       - PSEUDOCYLINDRICAL,
00594 *       - CONVENTIONAL,
00595 *       - CONIC,
00596 *       - POLYCONIC,
00597 *       - QUADCUBE, and
00598 *       - HEALPIX.
00599 *
00600 *       The category name may be identified via the prj_categories character
00601 *       array, e.g.
00602 *
00603 *       struct prjprm prj;
00604 *       ...

```

```

00605 =      printf("%s\n", prj_categories[prj.category]);
00606 *
00607 *      Provided for information only, not used by the projection routines.
00608 *
00609 *      int pvrage
00610 *      (Returned) Range of projection parameter indices: 100 times the first
00611 *      allowed index plus the number of parameters, e.g. TAN is 0 (no
00612 *      parameters), SZP is 103 (1 to 3), and ZPN is 30 (0 to 29).
00613 *
00614 *      Provided for information only, not used by the projection routines.
00615 *
00616 *      int simplezen
00617 *      (Returned) True if the projection is a radially-symmetric zenithal
00618 *      projection.
00619 *
00620 *      Provided for information only, not used by the projection routines.
00621 *
00622 *      int equiareal
00623 *      (Returned) True if the projection is equal area.
00624 *
00625 *      Provided for information only, not used by the projection routines.
00626 *
00627 *      int conformal
00628 *      (Returned) True if the projection is conformal.
00629 *
00630 *      Provided for information only, not used by the projection routines.
00631 *
00632 *      int global
00633 *      (Returned) True if the projection can represent the whole sphere in a
00634 *      finite, non-overlapped mapping.
00635 *
00636 *      Provided for information only, not used by the projection routines.
00637 *
00638 *      int divergent
00639 *      (Returned) True if the projection diverges in latitude.
00640 *
00641 *      Provided for information only, not used by the projection routines.
00642 *
00643 *      double x0
00644 *      (Returned) The offset in x, and ...
00645 *      double y0
00646 *      (Returned) ... the offset in y used to force (x,y) = (0,0) at
00647 *      (phi_0,theta_0).
00648 *
00649 *      struct wcserr *err
00650 *      (Returned) If enabled, when an error status is returned, this struct
00651 *      contains detailed information about the error, see wcserr_enable().
00652 *
00653 *      void *padding
00654 *      (An unused variable inserted for alignment purposes only.)
00655 *
00656 *      double w[10]
00657 *      (For internal use only.) Intermediate floating-point values derived from
00658 *      the projection parameters by prjset(), cached here to save recomputation.
00659 *
00660 *      Usage of the w[] array as it applies to each projection is described in
00661 *      the prologue to each trio of projection routines in prj.c.
00662 *
00663 *      int m, n
00664 *      (For internal use only.) Intermediate integer values set by prjset()
00665 *      (used only for the ZPN and HPX projections).
00666 *
00667 *      int (*prjx2s)(PRJX2S_ARGS)
00668 *      (For internal use only.) Pointer to the spherical projection ...
00669 *      int (*prjs2x)(PRJ_ARGS)
00670 *      (For internal use only.) ... and deprojection routines.
00671 *
00672 *
00673 * Global variable: const char *prj_errmsg[] - Status return messages
00674 * -----
00675 * Error messages to match the status value returned from each function.
00676 *
00677 * =====*/
00678
00679 #ifndef WCSLIB_PROJ
00680 #define WCSLIB_PROJ
00681
00682 #ifdef __cplusplus
00683 extern "C" {
00684 #endif
00685
00686 enum prjenc_enum {
00687     PRJENQ_SET = 2,          // prjprm struct has been set up.
00688     PRJENQ_BYP = 4,          // prjprm struct is in bypass mode.
00689 };
00690
00691 // Total number of projection parameters; 0 to PVN-1.

```

```

00692 #define PVN 30
00693
00694 extern const char *prj_errmsg[];
00695
00696 enum prj_errmsg_enum {
00697     PRJERR_SUCCESS = 0,          // Success.
00698     PRJERR_NULL_POINTER = 1,     // Null prjprm pointer passed.
00699     PRJERR_BAD_PARAM = 2,        // Invalid projection parameters.
00700     PRJERR_BAD_PIX = 3,          // One or more of the (x, y) coordinates were
00701                                   // invalid.
00702     PRJERR_BAD_WORLD = 4         // One or more of the (phi, theta) coordinates
00703                                   // were invalid.
00704 };
00705
00706 extern const int CONIC, CONVENTIONAL, CYLINDRICAL, POLYCONIC,
00707                 PSEUDOCYLINDRICAL, QUADCUBE, ZENITHAL, HEALPIX;
00708 extern const char prj_categories[9][32];
00709
00710 extern const int prj_ncode;
00711 extern const char prj_codes[28][4];
00712
00713 #ifdef PRJX2S_ARGS
00714 #undef PRJX2S_ARGS
00715 #endif
00716
00717 #ifdef PRJS2X_ARGS
00718 #undef PRJS2X_ARGS
00719 #endif
00720
00721 // For use in declaring deprojection function prototypes.
00722 #define PRJX2S_ARGS struct prjprm *prj, int nx, int ny, int sxy, int spt, \
00723 const double x[], const double y[], double phi[], double theta[], int stat[]
00724
00725 // For use in declaring projection function prototypes.
00726 #define PRJS2X_ARGS struct prjprm *prj, int nx, int ny, int sxy, int spt, \
00727 const double phi[], const double theta[], double x[], double y[], int stat[]
00728
00729
00730 struct prjprm {
00731     // Initialization flag (see the prologue above).
00732     //-----
00733     int flag;                      // Set to zero to force initialization.
00734
00735     // Parameters to be provided (see the prologue above).
00736     //-----
00737     char code[4];                  // Three-letter projection code.
00738     double r0;                     // Radius of the generating sphere.
00739     double pv[PVN];                // Projection parameters.
00740     double phi0, theta0;           // Fiducial native coordinates.
00741     int bounds;                    // Controls bounds checking.
00742
00743     // Information derived from the parameters supplied.
00744     //-----
00745     char name[40];                 // Projection name.
00746     int category;                  // Projection category.
00747     int pvrang;                     // Range of projection parameter indices.
00748     int simplezen;                  // Is it a simple zenithal projection?
00749     int equiareal;                  // Is it an equal area projection?
00750     int conformal;                  // Is it a conformal projection?
00751     int global;                     // Can it map the whole sphere?
00752     int divergent;                  // Does the projection diverge in latitude?
00753     double x0, y0;                 // Fiducial offsets.
00754
00755     // Error messaging, if enabled.
00756     //-----
00757     struct wcserr *err;
00758
00759     //-----
00760     // Private - the remainder are for internal use.
00761     //-----
00762     void *padding;                  // (Dummy inserted for alignment purposes.)
00763
00764     double w[10];                  // Intermediate values set by prjset().
00765     int m, n;                       // Intermediate values set by prjset().
00766
00767     int (*prjx2s)(PRJX2S_ARGS);    // Pointers to the spherical projection and
00768     int (*prjs2x)(PRJS2X_ARGS);    // deprojection functions.
00769 };
00770
00771 // Size of the prjprm struct in int units, used by the Fortran wrappers.
00772 #define PRJLEN (sizeof(struct prjprm)/sizeof(int))
00773
00774
00775 int prjini(struct prjprm *prj);
00776
00777 int prjfree(struct prjprm *prj);
00778

```

```

00779 int prjsize(const struct prjprm *prj, int sizes[2]);
00780
00781 int prjenq(const struct prjprm *prj, int enquiry);
00782
00783 int prjpri(const struct prjprm *prj);
00784
00785 int prjperr(const struct prjprm *prj, const char *prefix);
00786
00787 int prjbchk(double tol, int nphi, int ntheta, int spt, double phi[],
00788             double theta[], int stat[]);
00789
00790 // Use the preprocessor to help declare function prototypes (see above).
00791 int prjset(struct prjprm *prj);
00792 int prjx2s(PRJX2S_ARGS);
00793 int prjs2x(PRJS2X_ARGS);
00794
00795 int azpset(struct prjprm *prj);
00796 int azpx2s(PRJX2S_ARGS);
00797 int azps2x(PRJS2X_ARGS);
00798
00799 int szpset(struct prjprm *prj);
00800 int szpx2s(PRJX2S_ARGS);
00801 int szps2x(PRJS2X_ARGS);
00802
00803 int tanset(struct prjprm *prj);
00804 int tanx2s(PRJX2S_ARGS);
00805 int tans2x(PRJS2X_ARGS);
00806
00807 int stgset(struct prjprm *prj);
00808 int stgx2s(PRJX2S_ARGS);
00809 int stgs2x(PRJS2X_ARGS);
00810
00811 int sinset(struct prjprm *prj);
00812 int sinx2s(PRJX2S_ARGS);
00813 int sins2x(PRJS2X_ARGS);
00814
00815 int arcset(struct prjprm *prj);
00816 int arcx2s(PRJX2S_ARGS);
00817 int arcs2x(PRJS2X_ARGS);
00818
00819 int zpnset(struct prjprm *prj);
00820 int zpnx2s(PRJX2S_ARGS);
00821 int zpns2x(PRJS2X_ARGS);
00822
00823 int zeaset(struct prjprm *prj);
00824 int zeax2s(PRJX2S_ARGS);
00825 int zeas2x(PRJS2X_ARGS);
00826
00827 int airset(struct prjprm *prj);
00828 int airx2s(PRJX2S_ARGS);
00829 int airs2x(PRJS2X_ARGS);
00830
00831 int cypset(struct prjprm *prj);
00832 int cypx2s(PRJX2S_ARGS);
00833 int cyps2x(PRJS2X_ARGS);
00834
00835 int ceaset(struct prjprm *prj);
00836 int ceax2s(PRJX2S_ARGS);
00837 int ceas2x(PRJS2X_ARGS);
00838
00839 int carset(struct prjprm *prj);
00840 int carx2s(PRJX2S_ARGS);
00841 int cars2x(PRJS2X_ARGS);
00842
00843 int merset(struct prjprm *prj);
00844 int merx2s(PRJX2S_ARGS);
00845 int mers2x(PRJS2X_ARGS);
00846
00847 int sflset(struct prjprm *prj);
00848 int sflx2s(PRJX2S_ARGS);
00849 int sfls2x(PRJS2X_ARGS);
00850
00851 int parset(struct prjprm *prj);
00852 int parx2s(PRJX2S_ARGS);
00853 int pars2x(PRJS2X_ARGS);
00854
00855 int molset(struct prjprm *prj);
00856 int molx2s(PRJX2S_ARGS);
00857 int mols2x(PRJS2X_ARGS);
00858
00859 int aitset(struct prjprm *prj);
00860 int aitx2s(PRJX2S_ARGS);
00861 int aits2x(PRJS2X_ARGS);
00862
00863 int copset(struct prjprm *prj);
00864 int copx2s(PRJX2S_ARGS);
00865 int cops2x(PRJS2X_ARGS);

```

```

00866
00867 int coeset(struct prjprm *prj);
00868 int coex2s(PRJX2S_ARGS);
00869 int coes2x(PRJS2X_ARGS);
00870
00871 int codset(struct prjprm *prj);
00872 int codx2s(PRJX2S_ARGS);
00873 int cods2x(PRJS2X_ARGS);
00874
00875 int cooset(struct prjprm *prj);
00876 int coox2s(PRJX2S_ARGS);
00877 int coos2x(PRJS2X_ARGS);
00878
00879 int bonset(struct prjprm *prj);
00880 int bonx2s(PRJX2S_ARGS);
00881 int bons2x(PRJS2X_ARGS);
00882
00883 int pcset(struct prjprm *prj);
00884 int pcx2s(PRJX2S_ARGS);
00885 int pcs2x(PRJS2X_ARGS);
00886
00887 int tscset(struct prjprm *prj);
00888 int tscx2s(PRJX2S_ARGS);
00889 int tscs2x(PRJS2X_ARGS);
00890
00891 int cscset(struct prjprm *prj);
00892 int cscx2s(PRJX2S_ARGS);
00893 int cscs2x(PRJS2X_ARGS);
00894
00895 int qscset(struct prjprm *prj);
00896 int qscx2s(PRJX2S_ARGS);
00897 int qscs2x(PRJS2X_ARGS);
00898
00899 int hpxset(struct prjprm *prj);
00900 int hpvx2s(PRJX2S_ARGS);
00901 int hpvs2x(PRJS2X_ARGS);
00902
00903 int xphset(struct prjprm *prj);
00904 int xphx2s(PRJX2S_ARGS);
00905 int xphs2x(PRJS2X_ARGS);
00906
00907
00908 // Deprecated.
00909 #define prjini_errmsg prj_errmsg
00910 #define prjpvt_errmsg prj_errmsg
00911 #define prjset_errmsg prj_errmsg
00912 #define prjx2s_errmsg prj_errmsg
00913 #define prjs2x_errmsg prj_errmsg
00914
00915 #ifdef __cplusplus
00916 }
00917 #endif
00918
00919 #endif // WCSLIB_PROJ

```

## 8.15 spc.h File Reference

```
#include "spc.h"
```

### Data Structures

- struct [spcprm](#)  
*Spectral transformation parameters.*

### Macros

- #define [SPCLEN](#) (sizeof(struct [spcprm](#))/sizeof(int))  
*Size of the [spcprm](#) struct in int units.*
- #define [spcini\\_errmsg](#) [spc\\_errmsg](#)  
*Deprecated.*

- `#define spcpri_errmsg spc_errmsg`  
*Deprecated.*
- `#define spcset_errmsg spc_errmsg`  
*Deprecated.*
- `#define spcx2s_errmsg spc_errmsg`  
*Deprecated.*
- `#define spcs2x_errmsg spc_errmsg`  
*Deprecated.*

## Enumerations

- enum `spcenq_enum` { `SPCENQ_SET` = 2 , `SPCENQ_BYP` = 4 }
- enum `spc_errmsg_enum` {  
  `SPCERR_NO_CHANGE` = -1 , `SPCERR_SUCCESS` = 0 , `SPCERR_NULL_POINTER` = 1 , `SPCERR_BAD_SPEC_PARAMS`  
  = 2 ,  
  `SPCERR_BAD_X` = 3 , `SPCERR_BAD_SPEC` = 4 }

## Functions

- int `spcini` (struct `spcprm` \*`spc`)  
*Default constructor for the spcprm struct.*
- int `spcfree` (struct `spcprm` \*`spc`)  
*Destructor for the spcprm struct.*
- int `spcsiz` (const struct `spcprm` \*`spc`, int `sizes`[2])  
*Compute the size of a spcprm struct.*
- int `spcenq` (const struct `spcprm` \*`spc`, int `enquiry`)  
*enquire about the state of a spcprm struct.*
- int `spcpri` (const struct `spcprm` \*`spc`)  
*Print routine for the spcprm struct.*
- int `spcperr` (const struct `spcprm` \*`spc`, const char \*`prefix`)  
*Print error messages from a spcprm struct.*
- int `spcset` (struct `spcprm` \*`spc`)  
*Setup routine for the spcprm struct.*
- int `spcx2s` (struct `spcprm` \*`spc`, int `nx`, int `sx`, int `sspec`, const double `x`[], double `spec`[], int `stat`[])  
*Transform to spectral coordinates.*
- int `spcs2x` (struct `spcprm` \*`spc`, int `nspec`, int `sspec`, int `sx`, const double `spec`[], double `x`[], int `stat`[])  
*Transform spectral coordinates.*
- int `spctype` (const char `ctype`[9], char `stype`[], char `scode`[], char `sname`[], char `units`[], char \*`ptype`, char \*`xtype`, int \*`restreq`, struct `wcserr` \*\*`err`)  
*Spectral **CTYPE**<sub>i</sub> keyword analysis.*
- int `spcspxe` (const char `ctypeS`[9], double `crvalS`, double `restfrq`, double `restwav`, char \*`ptype`, char \*`xtype`, int \*`restreq`, double \*`crvalX`, double \*`dXdS`, struct `wcserr` \*\*`err`)  
*Spectral keyword analysis.*
- int `spcxpse` (const char `ctypeS`[9], double `crvalX`, double `restfrq`, double `restwav`, char \*`ptype`, char \*`xtype`, int \*`restreq`, double \*`crvalS`, double \*`dSdX`, struct `wcserr` \*\*`err`)  
*Spectral keyword synthesis.*
- int `spctrne` (const char `ctypeS1`[9], double `crvalS1`, double `cdeltS1`, double `restfrq`, double `restwav`, char `ctypeS2`[9], double \*`crvalS2`, double \*`cdeltS2`, struct `wcserr` \*\*`err`)  
*Spectral keyword translation.*
- int `spcaips` (const char `ctypeA`[9], int `velref`, char `ctype`[9], char `specsys`[9])

*Translate AIPS-convention spectral keywords.*

- int [spctyp](#) (const char ctype[9], char stype[], char scode[], char sname[], char units[], char \*ptype, char \*xtype, int \*restreq)
- int [spcspx](#) (const char ctypeS[9], double crvalS, double restfrq, double restwav, char \*ptype, char \*xtype, int \*restreq, double \*crvalX, double \*dXdS)
- int [spcxps](#) (const char ctypeS[9], double crvalX, double restfrq, double restwav, char \*ptype, char \*xtype, int \*restreq, double \*crvalS, double \*dSdX)
- int [spctrn](#) (const char ctypeS1[9], double crvalS1, double cdeltS1, double restfrq, double restwav, char ctypeS2[9], double \*crvalS2, double \*cdeltS2)

## Variables

- const char \* [spc\\_errmsg](#) []

*Status return messages.*

### 8.15.1 Detailed Description

Routines in this suite implement the part of the FITS World Coordinate System (WCS) standard that deals with spectral coordinates, as described in

"Representations of world coordinates in FITS",  
Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)

"Representations of spectral coordinates in FITS",  
Greisen, E.W., Calabretta, M.R., Valdes, F.G., & Allen, S.L.  
2006, A&A, 446, 747 (WCS Paper III)

These routines define methods to be used for computing spectral world coordinates from intermediate world coordinates (a linear transformation of image pixel coordinates), and vice versa. They are based on the `spcprm` struct which contains all information needed for the computations. The struct contains some members that must be set by the user, and others that are maintained by these routines, somewhat like a C++ class but with no encapsulation.

Routine [spcini\(\)](#) is provided to initialize the `spcprm` struct with default values, [spcfree\(\)](#) reclaims any memory that may have been allocated to store an error message, [spcsz\(\)](#) computes its total size including allocated memory, [spcnq\(\)](#) returns information about the state of the struct, and [spcpri\(\)](#) prints its contents.

[spcperr\(\)](#) prints the error message(s) (if any) stored in a `spcprm` struct.

A setup routine, [spcset\(\)](#), computes intermediate values in the `spcprm` struct from parameters in it that were supplied by the user. The struct always needs to be set up by [spcset\(\)](#) but it need not be called explicitly - refer to the explanation of `spcprm::flag`.

[spcx2s\(\)](#) and [spcs2x\(\)](#) implement the WCS spectral coordinate transformations. In fact, they are high level driver routines for the lower level spectral coordinate transformation routines described in [spx.h](#).

A number of routines are provided to aid in analysing or synthesising sets of FITS spectral axis keywords:

- [spctype\(\)](#) checks a spectral **CTYPE**<sub>ia</sub> keyword for validity and returns information derived from it.
- Spectral keyword analysis routine [spcspxe\(\)](#) computes the values of the *X*-type spectral variables for the *S*-type variables supplied.
- Spectral keyword synthesis routine, [spcxpse\(\)](#), computes the *S*-type variables for the *X*-types supplied.
- Given a set of spectral keywords, a translation routine, [spctrne\(\)](#), produces the corresponding set for the specified spectral **CTYPE**<sub>ia</sub>.
- [spcaips\(\)](#) translates AIPS-convention spectral **CTYPE**<sub>ia</sub> and **VELREF** keyvalues.

**Spectral variable types -  $S$ ,  $P$ , and  $X$ :**

A few words of explanation are necessary regarding spectral variable types in FITS.

Every FITS spectral axis has three associated spectral variables:

$S$ -type: the spectral variable in which coordinates are to be expressed. Each  $S$ -type is encoded as four characters and is linearly related to one of four basic types as follows:

F (Frequency):

- **'FREQ'**: frequency
- **'AFRQ'**: angular frequency
- **'ENER'**: photon energy
- **'WAVN'**: wave number
- **'VRAD'**: radio velocity

W (Wavelength in vacuo):

- **'WAVE'**: wavelength
- **'VOPT'**: optical velocity
- **'ZOPT'**: redshift

A (wavelength in Air):

- **'AWAV'**: wavelength in air

V (Velocity):

- **'VELO'**: relativistic velocity
- **'BETA'**: relativistic beta factor

The  $S$ -type forms the first four characters of the **CTYPE**<sub>ia</sub> keyvalue, and **CRVAL**<sub>ia</sub> and **CDEL**<sub>ia</sub> are expressed as  $S$ -type quantities so that they provide a first-order approximation to the  $S$ -type variable at the reference point.

Note that **'AFRQ'**, angular frequency, is additional to the variables defined in WCS Paper III.

$P$ -type: the basic spectral variable (F, W, A, or V) with which the  $S$ -type variable is associated (see list above).

For non-grism axes, the  $P$ -type is encoded as the eighth character of **CTYPE**<sub>ia</sub>.

$X$ -type: the basic spectral variable (F, W, A, or V) for which the spectral axis is linear, grisms excluded (see below).

For non-grism axes, the  $X$ -type is encoded as the sixth character of **CTYPE**<sub>ia</sub>.

Grisms: Grism axes have normal  $S$ -, and  $P$ -types but the axis is linear, not in any spectral variable, but in a special "grism parameter". The  $X$ -type spectral variable is either W or A for grisms in vacuo or air respectively, but is encoded as 'w' or 'a' to indicate that an additional transformation is required to convert to or from the grism parameter. The spectral algorithm code for grisms also has a special encoding in **CTYPE**<sub>ia</sub>, either **'GRI'** (in vacuo) or **'GRA'** (in air).

In the algorithm chain, the non-linear transformation occurs between the  $X$ -type and the  $P$ -type variables; the transformation between  $P$ -type and  $S$ -type variables is always linear.

When the  $P$ -type and  $X$ -type variables are the same, the spectral axis is linear in the  $S$ -type variable and the second four characters of `CTYPEia` are blank. This can never happen for grism axes.

As an example, correlating radio spectrometers always produce spectra that are regularly gridded in frequency; a redshift scale on such a spectrum is non-linear. The required value of `CTYPEia` would be '`ZOPT-F2W`', where the desired  $S$ -type is '`ZOPT`' (redshift), the  $P$ -type is necessarily '`W`' (wavelength), and the  $X$ -type is '`F`' (frequency) by the nature of the instrument.

#### Air-to-vacuum wavelength conversion:

Please refer to the prologue of [spx.h](#) for important comments relating to the air-to-vacuum wavelength conversion.

#### Argument checking:

The input spectral values are only checked for values that would result in floating point exceptions. In particular, negative frequencies and wavelengths are allowed, as are velocities greater than the speed of light. The same is true for the spectral parameters - rest frequency and wavelength.

#### Accuracy:

No warranty is given for the accuracy of these routines (refer to the copyright notice); intending users must satisfy for themselves their adequacy for the intended purpose. However, closure effectively to within double precision rounding error was demonstrated by test routine `tspc.c` which accompanies this software.

## 8.15.2 Macro Definition Documentation

### SPCLEN

```
#define SPCLEN (sizeof(struct spcprm)/sizeof(int))
```

Size of the `spcprm` struct in *int* units.

Size of the `spcprm` struct in *int* units, used by the Fortran wrappers.

### spcini\_errmsg

```
#define spcini_errmsg spc_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [spc\\_errmsg](#) directly now instead.

### spcpert\_errmsg

```
#define spcpert_errmsg spc_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [spc\\_errmsg](#) directly now instead.

**spcset\_errmsg**

```
#define spcset_errmsg spc_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [spc\\_errmsg](#) directly now instead.

**spcx2s\_errmsg**

```
#define spcx2s_errmsg spc_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [spc\\_errmsg](#) directly now instead.

**spcs2x\_errmsg**

```
#define spcs2x_errmsg spc_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [spc\\_errmsg](#) directly now instead.

### 8.15.3 Enumeration Type Documentation

**spcenq\_enum**

```
enum spcenq_enum
```

**Enumerator**

SPCENQ_SET	
SPCENQ_BYD	

**spc\_errmsg\_enum**

```
enum spc_errmsg_enum
```

**Enumerator**

---

SPCERR_NO_CHANGE	
SPCERR_SUCCESS	
SPCERR_NULL_POINTER	
SPCERR_BAD_SPEC_PARAMS	
SPCERR_BAD_X	
SPCERR_BAD_SPEC	

#### 8.15.4 Function Documentation

##### **spcini()**

```
int spcini (
    struct spcprm * spc)
```

Default constructor for the spcprm struct.

**spcini()** sets all members of a spcprm struct to default values. It should be used to initialize every spcprm struct.

**PLEASE NOTE:** If the spcprm struct has already been initialized then, before reinitializing it, [spcfree\(\)](#) should be used to free any memory that may have been allocated to store an error message. Else a memory leak may result.

##### **Parameters**

in, out	spc	Spectral transformation parameters.
---------	-----	-------------------------------------

##### **Returns**

Status return value:

- 0: Success.
- 1: Null spcprm pointer passed.

##### **spcfree()**

```
int spcfree (
    struct spcprm * spc)
```

Destructor for the spcprm struct.

**spcfree()** frees any memory that may have been allocated to store an error message in the spcprm struct.

##### **Parameters**

in, out	spc	Spectral transformation parameters.
---------	-----	-------------------------------------

##### **Returns**

Status return value:

- 0: Success.
- 1: Null spcprm pointer passed.

**spcsize()**

```
int spcsize (
    const struct spcprm * spc,
    int sizes[2])
```

Compute the size of a `spcprm` struct.

**spcsize()** computes the full size of a `spcprm` struct, including allocated memory.

**Parameters**

in	<i>spc</i>	Spectral transformation parameters. If NULL, the base size of the struct and the allocated size are both set to zero.
out	<i>sizes</i>	The first element is the base size of the struct as returned by <code>sizeof(struct spcprm)</code> . The second element is the total allocated size, in bytes. This figure includes memory allocated for the constituent struct, <a href="#">spcprm::err</a> . It is not an error for the struct not to have been set up via <a href="#">spcset()</a> .

**Returns**

Status return value:

- 0: Success.

**spcenq()**

```
int spcenq (
    const struct spcprm * spc,
    int enquiry)
```

enquire about the state of a `spcprm` struct.

**spcenq()** may be used to obtain information about the state of a `spcprm` struct. The function returns a true/false answer for the enquiry asked.

**Parameters**

in	<i>spc</i>	Spectral transformation parameters.
in	<i>enquiry</i>	Enquiry according to the following parameters: <ul style="list-style-type: none"> <li>• <code>SPCENQ_MEM</code>: memory in the struct is being managed by WCSLIB (see <a href="#">spcini()</a>).</li> <li>• <code>SPCENQ_SET</code>: the struct has been set up by <a href="#">spcset()</a>.</li> <li>• <code>SPCENQ_BYP</code>: the struct is in bypass mode (see <a href="#">spcset()</a>).</li> </ul> <p>These may be combined by logical OR, e.g. <code>SPCENQ_MEM   SPCENQ_SET</code>. The enquiry result will be the logical AND of the individual results.</p>

**Returns**

Enquiry result:

- 0: No.
- 1: Yes.

**spcpert()**

```
int spcpert (
    const struct spcprm * spc)
```

Print routine for the `spcprm` struct.

**spcpert()** prints the contents of a `spcprm` struct using [wcsprintf\(\)](#). Mainly intended for diagnostic purposes.

**Parameters**

in	<i>spc</i>	Spectral transformation parameters.
----	------------	-------------------------------------

**Returns**

Status return value:

- 0: Success.
- 1: Null `spcprm` pointer passed.

**spcperr()**

```
int spcperr (
    const struct spcprm * spc,
    const char * prefix)
```

Print error messages from a `spcprm` struct.

**spcperr()** prints the error message(s) (if any) stored in a `spcprm` struct. If there are no errors then nothing is printed. It uses [wcserr\\_prt\(\)](#), q.v.

**Parameters**

in	<i>spc</i>	Spectral transformation parameters.
in	<i>prefix</i>	If non-NULL, each output line will be prefixed with this string.

**Returns**

Status return value:

- 0: Success.
- 1: Null `spcprm` pointer passed.

**spcset()**

```
int spcset (
    struct spcprm * spc)
```

Setup routine for the `spcprm` struct.

**spcset()** sets up a `spcprm` struct according to information supplied within it.

Note that this routine need not be called directly: it will be invoked by [spcx2s\(\)](#) and [spcs2x\(\)](#) if `spcprm::flag` is

**Parameters**

in, out	<i>spc</i>	Spectral transformation parameters.
---------	------------	-------------------------------------

**Returns**

Status return value:

- 0: Success.
- 1: Null `spcprm` pointer passed.
- 2: Invalid spectral parameters.

For returns > 1, a detailed error message is set in `spcprm::err` if enabled, see `wcserr_enable()`.

**spcx2s()**

```
int spcx2s (
    struct spcprm * spc,
    int nx,
    int sx,
    int sspec,
    const double x[],
    double spec[],
    int stat[])
```

Transform to spectral coordinates.

**spcx2s()** transforms intermediate world coordinates to spectral coordinates.

**Parameters**

in, out	<i>spc</i>	Spectral transformation parameters.
in	<i>nx</i>	Vector length.
in	<i>sx</i>	Vector stride.
in	<i>sspec</i>	Vector stride.
in	<i>x</i>	Intermediate world coordinates, in SI units.
out	<i>spec</i>	Spectral coordinates, in SI units.
out	<i>stat</i>	Status return value status for each vector element: <ul style="list-style-type: none"> <li>• 0: Success.</li> <li>• 1: Invalid value of x.</li> </ul>

**Returns**

Status return value:

- 0: Success.
- 1: Null `spcprm` pointer passed.
- 2: Invalid spectral parameters.
- 3: One or more of the x coordinates were invalid, as indicated by the `stat` vector.

For returns > 1, a detailed error message is set in `spcprm::err` if enabled, see `wcserr_enable()`.

**spcs2x()**

```
int spcs2x (
    struct spcprm * spc,
    int nspec,
    int sspec,
    int sx,
    const double spec[],
    double x[],
    int stat[])
```

Transform spectral coordinates.

**spcs2x()** transforms spectral world coordinates to intermediate world coordinates.

**Parameters**

in, out	<i>spc</i>	Spectral transformation parameters.
in	<i>nspec</i>	Vector length.
in	<i>sspec</i>	Vector stride.
in	<i>sx</i>	Vector stride.
in	<i>spec</i>	Spectral coordinates, in SI units.
out	<i>x</i>	Intermediate world coordinates, in SI units.
out	<i>stat</i>	Status return value status for each vector element: <ul style="list-style-type: none"> <li>• 0: Success.</li> <li>• 1: Invalid value of spec.</li> </ul>

**Returns**

Status return value:

- 0: Success.
- 1: Null [spcprm](#) pointer passed.
- 2: Invalid spectral parameters.
- 4: One or more of the spec coordinates were invalid, as indicated by the stat vector.

For returns > 1, a detailed error message is set in [spcprm::err](#) if enabled, see [wcserr\\_enable\(\)](#).

**spctype()**

```
int spctype (
    const char ctype[9],
    char stype[],
    char scode[],
    char sname[],
    char units[],
    char * ptype,
    char * xtype,
```

```
int * restreq,
struct wcserr ** err)
```

Spectral **CTYPE**<sub>ia</sub> keyword analysis.

**spctype()** checks whether a **CTYPE**<sub>ia</sub> keyvalue is a valid spectral axis type and if so returns information derived from it relating to the associated *S*-, *P*-, and *X*-type spectral variables (see explanation above).

The return arguments are guaranteed not be modified if **CTYPE**<sub>ia</sub> is not a valid spectral type; zero-pointers may be specified for any that are not of interest.

A deprecated form of this function, **spctyp()**, lacks the `wcserr**` parameter.

### Parameters

in	<i>ctype</i>	The <b>CTYPE</b> <sub>ia</sub> keyvalue, (eight characters with null termination).
out	<i>stype</i>	The four-letter name of the <i>S</i> -type spectral variable copied or translated from <i>ctype</i> . If a non-zero pointer is given, the array must accomodate a null-terminated string of length 5.
out	<i>scode</i>	The three-letter spectral algorithm code copied or translated from <i>ctype</i> . Logarithmic (' <b>LOG</b> ') and tabular (' <b>TAB</b> ') codes are also recognized. If a non-zero pointer is given, the array must accomodate a null-terminated string of length 4.
out	<i>sname</i>	Descriptive name of the <i>S</i> -type spectral variable. If a non-zero pointer is given, the array must accomodate a null-terminated string of length 22.
out	<i>units</i>	SI units of the <i>S</i> -type spectral variable. If a non-zero pointer is given, the array must accomodate a null-terminated string of length 8.
out	<i>pctype</i>	Character code for the <i>P</i> -type spectral variable derived from <i>ctype</i> , one of 'F', 'W', 'A', or 'V'.
out	<i>xctype</i>	Character code for the <i>X</i> -type spectral variable derived from <i>ctype</i> , one of 'F', 'W', 'A', or 'V'. Also, 'w' and 'a' are synonymous to 'W' and 'A' for grisms in vacuo and air respectively. Set to 'L' or 'T' for logarithmic (' <b>LOG</b> ') and tabular (' <b>TAB</b> ') axes.
out	<i>restreq</i>	Multivalued flag that indicates whether rest frequency or wavelength is required to compute spectral variables for this <b>CTYPE</b> <sub>ia</sub> : <ul style="list-style-type: none"> <li>• 0: Not required.</li> <li>• 1: Required for the conversion between <i>S</i>- and <i>P</i>-types (e.g. '<b>ZOPT-F2W</b>').</li> <li>• 2: Required for the conversion between <i>P</i>- and <i>X</i>-types (e.g. '<b>BETA-W2V</b>').</li> <li>• 3: Required for the conversion between <i>S</i>- and <i>P</i>-types, and between <i>P</i>- and <i>X</i>-types, but not between <i>S</i>- and <i>X</i>-types (this applies only for '<b>VRAD-V2F</b>', '<b>VOPT-V2W</b>', and '<b>ZOPT-V2W</b>').</li> </ul> <p>Thus the rest frequency or wavelength is required for spectral coordinate computations (i.e. between <i>S</i>- and <i>X</i>-types) only if <code>restreq%3 != 0</code>.</p>
out	<i>err</i>	If enabled, for function return values > 1, this struct will contain a detailed error message, see <a href="#">wcserr_enable()</a> . May be NULL if an error message is not desired. Otherwise, the user is responsible for deleting the memory allocated for the <code>wcserr</code> struct.

### Returns

Status return value:

- 0: Success.
- 2: Invalid spectral parameters (not a spectral **CTYPE**<sub>ia</sub>).

**spcspxe()**

```
int spcspxe (
    const char ctypeS[9],
    double crvalS,
    double restfrq,
    double restwav,
    char * ptype,
    char * xtype,
    int * restreq,
    double * crvalX,
    double * dXdS,
    struct wcserr ** err)
```

Spectral keyword analysis.

**spcspxe()** analyses the **CTYPEia** and **CRVALia** FITS spectral axis keyword values and returns information about the associated *X*-type spectral variable.

A deprecated form of this function, [spcspx\(\)](#), lacks the `wcserr**` parameter.

**Parameters**

in	<i>ctypeS</i>	Spectral axis type, i.e. the <b>CTYPEia</b> keyvalue, (eight characters with null termination). For non-grism axes, the character code for the <i>P</i> -type spectral variable in the algorithm code (i.e. the eighth character of <b>CTYPEia</b> ) may be set to '?' (it will not be reset).
in	<i>crvalS</i>	Value of the <i>S</i> -type spectral variable at the reference point, i.e. the <b>CRVALia</b> keyvalue, SI units.
in	<i>restfrq, restwav</i>	Rest frequency [Hz] and rest wavelength in vacuo [m], only one of which need be given, the other should be set to zero.
out	<i>ptype</i>	Character code for the <i>P</i> -type spectral variable derived from <i>ctypeS</i> , one of 'F', 'W', 'A', or 'V'.
out	<i>xtype</i>	Character code for the <i>X</i> -type spectral variable derived from <i>ctypeS</i> , one of 'F', 'W', 'A', or 'V'. Also, 'w' and 'a' are synonymous to 'W' and 'A' for grisms in vacuo and air respectively; <i>crvalX</i> and <i>dXdS</i> (see below) will conform to these.
out	<i>restreq</i>	Multivalued flag that indicates whether rest frequency or wavelength is required to compute spectral variables for this <b>CTYPEia</b> , as for <a href="#">spctype()</a> .
out	<i>crvalX</i>	Value of the <i>X</i> -type spectral variable at the reference point, SI units.
out	<i>dXdS</i>	The derivative, $dX/dS$ , evaluated at the reference point, SI units. Multiply the <b>CDELTia</b> keyvalue by this to get the pixel spacing in the <i>X</i> -type spectral coordinate.
out	<i>err</i>	If enabled, for function return values $> 1$ , this struct will contain a detailed error message, see <a href="#">wcserr_enable()</a> . May be NULL if an error message is not desired. Otherwise, the user is responsible for deleting the memory allocated for the <code>wcserr</code> struct.

**Returns**

Status return value:

- 0: Success.
- 2: Invalid spectral parameters.

**spcxpse()**

```
int spcxpse (
    const char ctypeS[9],
    double crvalX,
    double restfrq,
    double restwav,
    char * ptype,
    char * xtype,
    int * restreq,
    double * crvalS,
    double * dSdX,
    struct wcserr ** err)
```

Spectral keyword synthesis.

**spcxpse()**, for the spectral axis type specified and the value provided for the  $X$ -type spectral variable at the reference point, deduces the value of the FITS spectral axis keyword **CRVAL**<sub>ia</sub> and also the derivative  $dS/dX$  which may be used to compute **CDEL**<sub>ia</sub>. See above for an explanation of the  $S$ -,  $P$ -, and  $X$ -type spectral variables.

A deprecated form of this function, **spcxps()**, lacks the `wcserr**` parameter.

**Parameters**

in	<i>ctypeS</i>	The required spectral axis type, i.e. the <b>CTYPE</b> <sub>ia</sub> keyvalue, (eight characters with null termination). For non-grism axes, the character code for the $P$ -type spectral variable in the algorithm code (i.e. the eighth character of <b>CTYPE</b> <sub>ia</sub> ) may be set to '?' (it will not be reset).
in	<i>crvalX</i>	Value of the $X$ -type spectral variable at the reference point (N.B. NOT the <b>CRVAL</b> <sub>ia</sub> keyvalue), SI units.
in	<i>restfrq, restwav</i>	Rest frequency [Hz] and rest wavelength in vacuo [m], only one of which need be given, the other should be set to zero.
out	<i>ptype</i>	Character code for the $P$ -type spectral variable derived from <i>ctypeS</i> , one of 'F', 'W', 'A', or 'V'.
out	<i>xtype</i>	Character code for the $X$ -type spectral variable derived from <i>ctypeS</i> , one of 'F', 'W', 'A', or 'V'. Also, 'w' and 'a' are synonymous to 'W' and 'A' for grisms; <i>crvalX</i> and <i>cdeltX</i> must conform to these.
out	<i>restreq</i>	Multivalued flag that indicates whether rest frequency or wavelength is required to compute spectral variables for this <b>CTYPE</b> <sub>ia</sub> , as for <a href="#">spctype()</a> .
out	<i>crvalS</i>	Value of the $S$ -type spectral variable at the reference point (i.e. the appropriate <b>CRVAL</b> <sub>ia</sub> keyvalue), SI units.
out	<i>dSdX</i>	The derivative, $dS/dX$ , evaluated at the reference point, SI units. Multiply this by the pixel spacing in the $X$ -type spectral coordinate to get the <b>CDEL</b> <sub>ia</sub> keyvalue.
out	<i>err</i>	If enabled, for function return values $> 1$ , this struct will contain a detailed error message, see <a href="#">wcserr_enable()</a> . May be NULL if an error message is not desired. Otherwise, the user is responsible for deleting the memory allocated for the <code>wcserr</code> struct.

**Returns**

Status return value:

- 0: Success.
- 2: Invalid spectral parameters.

**spctrne()**

```
int spctrne (
    const char ctypeS1[9],
    double crvalS1,
    double cdeltS1,
    double restfrq,
    double restwav,
    char ctypeS2[9],
    double * crvalS2,
    double * cdeltS2,
    struct wcserr ** err)
```

Spectral keyword translation.

**spctrne()** translates a set of FITS spectral axis keywords into the corresponding set for the specified spectral axis type. For example, a **'FREQ'** axis may be translated into **'ZOPT-F2W'** and vice versa.

A deprecated form of this function, [spctrn\(\)](#), lacks the `wcserr**` parameter.

**Parameters**

in	<i>ctypeS1</i>	Spectral axis type, i.e. the <b>CTYPE</b> <sub>ia</sub> keyvalue, (eight characters with null termination). For non-grism axes, the character code for the <i>P</i> -type spectral variable in the algorithm code (i.e. the eighth character of <b>CTYPE</b> <sub>ia</sub> ) may be set to '?' (it will not be reset).
in	<i>crvalS1</i>	Value of the <i>S</i> -type spectral variable at the reference point, i.e. the <b>CRVAL</b> <sub>ia</sub> keyvalue, SI units.
in	<i>cdeltS1</i>	Increment of the <i>S</i> -type spectral variable at the reference point, SI units.
in	<i>restfrq,restwav</i>	Rest frequency [Hz] and rest wavelength in vacuo [m], only one of which need be given, the other should be set to zero. Neither are required if the translation is between wave-characteristic types, or between velocity-characteristic types. E.g., required for <b>'FREQ'</b> -> <b>'ZOPT-F2W'</b> , but not required for <b>'VELO-F2V'</b> -> <b>'ZOPT-F2W'</b> .
in, out	<i>ctypeS2</i>	Required spectral axis type (eight characters with null termination). The first four characters are required to be given and are never modified. The remaining four, the algorithm code, are completely determined by, and must be consistent with, <i>ctypeS1</i> and the first four characters of <i>ctypeS2</i> . A non-zero status value will be returned if they are inconsistent (see below). However, if the final three characters are specified as "???", or if just the eighth character is specified as '?', the correct algorithm code will be substituted (applies for grism axes as well as non-grism).
out	<i>crvalS2</i>	Value of the new <i>S</i> -type spectral variable at the reference point, i.e. the new <b>CRVAL</b> <sub>ia</sub> keyvalue, SI units.
out	<i>cdeltS2</i>	Increment of the new <i>S</i> -type spectral variable at the reference point, i.e. the new <b>CDELTA</b> <sub>ia</sub> keyvalue, SI units.
out	<i>err</i>	If enabled, for function return values > 1, this struct will contain a detailed error message, see <a href="#">wcserr_enable()</a> . May be NULL if an error message is not desired. Otherwise, the user is responsible for deleting the memory allocated for the <code>wcserr</code> struct.

## Returns

Status return value:

- 0: Success.
- 2: Invalid spectral parameters.

A status value of 2 will be returned if `restfrq` or `restwav` are not specified when required, or if `ctypeS1` or `ctypeS2` are self-inconsistent, or have different spectral *X*-type variables.

**spcaips()**

```
int spcaips (
    const char ctypeA[9],
    int velref,
    char ctype[9],
    char specsyst[9])
```

Translate AIPS-convention spectral keywords.

**spcaips()** translates AIPS-convention spectral **CTYPE**<sub>ia</sub> and **VELREF** keyvalues.

## Parameters

in	<i>ctypeA</i>	<b>CTYPE</b> <sub>ia</sub> keyvalue possibly containing an AIPS-convention spectral code (eight characters, need not be null-terminated).
in	<i>velref</i>	<p>AIPS-convention <b>VELREF</b> code. It has the following integer values:</p> <ul style="list-style-type: none"> <li>• 1: LSR kinematic, originally described simply as "LSR" without distinction between the kinematic and dynamic definitions.</li> <li>• 2: Barycentric, originally described as "HEL" meaning heliocentric.</li> <li>• 3: Topocentric, originally described as "OBS" meaning geocentric but widely interpreted as topocentric.</li> </ul> <p>AIPS++ extensions to <b>VELREF</b> are also recognized:</p> <ul style="list-style-type: none"> <li>• 4: LSR dynamic.</li> <li>• 5: Geocentric.</li> <li>• 6: Source rest frame.</li> <li>• 7: Galactocentric.</li> </ul> <p>For an AIPS <b>'VELO'</b> axis, a radio convention velocity (VRAD) is denoted by adding 256 to <b>VELREF</b>, otherwise an optical velocity (VOPT) is indicated (this is not applicable to <b>'FREQ'</b> or <b>'VELO'</b> axes). Setting <code>velref</code> to 0 or 256 chooses between optical and radio velocity without specifying a Doppler frame, provided that a frame is encoded in <code>ctypeA</code>. If not, i.e. for <code>ctypeA</code> = <b>'VELO'</b>, <code>ctype</code> will be returned as <b>'VELO'</b>.</p> <p><b>VELREF</b> takes precedence over <b>CTYPE</b><sub>ia</sub> in defining the Doppler frame, e.g.</p> <pre>ctypeA = 'VELO-HEL'; velref = 1;</pre> <p>returns <code>ctype</code> = <b>'VOPT'</b> with <code>specsyst</code> set to <b>'LSRK'</b>.</p> <p>If omitted from the header, the default value of <b>VELREF</b> is 0.</p>

out	<i>ctype</i>	Translated <b>CTYPE</b> <sub>ia</sub> keyvalue, or a copy of ctypeA if no translation was performed (in which case any trailing blanks in ctypeA will be replaced with nulls).
out	<i>specsys</i>	Doppler reference frame indicated by <b>VELREF</b> or else by <b>CTYPE</b> <sub>ia</sub> with value corresponding to the SPECSYS keyvalue in the FITS WCS standard. May be returned blank if neither specifies a Doppler frame, e.g. ctypeA = ' <b>FELO</b> ' and velref%256 == 0.

## Returns

Status return value:

- -1: No translation required (not an error).
- 0: Success.
- 2: Invalid value of **VELREF**.

## spctyp()

```
int spctyp (
    const char ctype[9],
    char stype[],
    char scode[],
    char sname[],
    char units[],
    char * ptype,
    char * xtype,
    int * restreq)
```

## spcspx()

```
int spcspx (
    const char ctypeS[9],
    double crvalS,
    double restfrq,
    double restwav,
    char * ptype,
    char * xtype,
    int * restreq,
    double * crvalX,
    double * dXdS)
```

## spcxps()

```
int spcxps (
    const char ctypeS[9],
    double crvalX,
    double restfrq,
    double restwav,
    char * ptype,
    char * xtype,
    int * restreq,
    double * crvalS,
    double * dSdX)
```

**spctrn()**

```
int spctrn (
    const char ctypeS1[9],
    double crvalS1,
    double cdelts1,
    double restfrq,
    double restwav,
    char ctypeS2[9],
    double * crvalS2,
    double * cdelts2)
```

**8.15.5 Variable Documentation****spc\_errmsg**

```
const char* spc_errmsg[] [extern]
```

Status return messages.

Error messages to match the status value returned from each function.

**8.16 spc.h**

[Go to the documentation of this file.](#)

```
00001 /*=====
00002 WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003 Copyright (C) 1995-2025, Mark Calabretta
00004
00005 This file is part of WCSLIB.
00006
00007 WCSLIB is free software: you can redistribute it and/or modify it under the
00008 terms of the GNU Lesser General Public License as published by the Free
00009 Software Foundation, either version 3 of the License, or (at your option)
00010 any later version.
00011
00012 WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013 WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
00014 FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015 more details.
00016
00017 You should have received a copy of the GNU Lesser General Public License
00018 along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020 Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021 http://www.atnf.csiro.au/people/Mark.Calabretta
00022 $Id: spc.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023 *=====
00024 *
00025 * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026 * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027 * overview of the library.
00028 *
00029 *
00030 * Summary of the spc routines
00031 * -----
00032 * Routines in this suite implement the part of the FITS World Coordinate
00033 * System (WCS) standard that deals with spectral coordinates, as described in
00034 *
00035 * "Representations of world coordinates in FITS",
00036 * Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)
00037 *
00038 * "Representations of spectral coordinates in FITS",
00039 * Greisen, E.W., Calabretta, M.R., Valdes, F.G., & Allen, S.L.
00040 * 2006, A&A, 446, 747 (WCS Paper III)
00041 *
00042 * These routines define methods to be used for computing spectral world
00043 * coordinates from intermediate world coordinates (a linear transformation
```

```

00044 * of image pixel coordinates), and vice versa. They are based on the spcprm
00045 * struct which contains all information needed for the computations. The
00046 * struct contains some members that must be set by the user, and others that
00047 * are maintained by these routines, somewhat like a C++ class but with no
00048 * encapsulation.
00049 *
00050 * Routine spcini() is provided to initialize the spcprm struct with default
00051 * values, spcfree() reclaims any memory that may have been allocated to store
00052 * an error message, spcsize() computes its total size including allocated
00053 * memory, spcenq() returns information about the state of the struct, and
00054 * spcprrt() prints its contents.
00055 *
00056 * spcperr() prints the error message(s) (if any) stored in a spcprm struct.
00057 *
00058 * A setup routine, spcset(), computes intermediate values in the spcprm struct
00059 * from parameters in it that were supplied by the user. The struct always
00060 * needs to be set up by spcset() but it need not be called explicitly - refer
00061 * to the explanation of spcprm::flag.
00062 *
00063 * spcx2s() and spcs2x() implement the WCS spectral coordinate transformations.
00064 * In fact, they are high level driver routines for the lower level spectral
00065 * coordinate transformation routines described in spx.h.
00066 *
00067 * A number of routines are provided to aid in analysing or synthesising sets
00068 * of FITS spectral axis keywords:
00069 *
00070 * - spctype() checks a spectral CTYPEx keyword for validity and returns
00071 *   information derived from it.
00072 *
00073 * - Spectral keyword analysis routine spcspxe() computes the values of the
00074 *   X-type spectral variables for the S-type variables supplied.
00075 *
00076 * - Spectral keyword synthesis routine, spcxpse(), computes the S-type
00077 *   variables for the X-types supplied.
00078 *
00079 * - Given a set of spectral keywords, a translation routine, spctrne(),
00080 *   produces the corresponding set for the specified spectral CTYPEx.
00081 *
00082 * - spcaips() translates AIPS-convention spectral CTYPEx and VELREF
00083 *   keyvalues.
00084 *
00085 * Spectral variable types - S, P, and X:
00086 * -----
00087 * A few words of explanation are necessary regarding spectral variable types
00088 * in FITS.
00089 *
00090 * Every FITS spectral axis has three associated spectral variables:
00091 *
00092 * S-type: the spectral variable in which coordinates are to be
00093 * expressed. Each S-type is encoded as four characters and is
00094 * linearly related to one of four basic types as follows:
00095 *
00096 * F (Frequency):
00097 *   - 'FREQ': frequency
00098 *   - 'AFRQ': angular frequency
00099 *   - 'ENER': photon energy
00100 *   - 'WAVN': wave number
00101 *   - 'VRAD': radio velocity
00102 *
00103 * W (Wavelength in vacuo):
00104 *   - 'WAVE': wavelength
00105 *   - 'VOPT': optical velocity
00106 *   - 'ZOPT': redshift
00107 *
00108 * A (wavelength in Air):
00109 *   - 'AWAV': wavelength in air
00110 *
00111 * V (Velocity):
00112 *   - 'VELO': relativistic velocity
00113 *   - 'BETA': relativistic beta factor
00114 *
00115 * The S-type forms the first four characters of the CTYPEx keyvalue,
00116 * and CRVALx and CDELTx are expressed as S-type quantities so that
00117 * they provide a first-order approximation to the S-type variable at
00118 * the reference point.
00119 *
00120 * Note that 'AFRQ', angular frequency, is additional to the variables
00121 * defined in WCS Paper III.
00122 *
00123 * P-type: the basic spectral variable (F, W, A, or V) with which the
00124 * S-type variable is associated (see list above).
00125 *
00126 * For non-grism axes, the P-type is encoded as the eighth character of
00127 * CTYPEx.
00128 *
00129 * X-type: the basic spectral variable (F, W, A, or V) for which the
00130 * spectral axis is linear, grisms excluded (see below).

```

```

00131 *
00132 *   For non-grism axes, the X-type is encoded as the sixth character of
00133 *   CTYPEia.
00134 *
00135 *   Grisms: Grism axes have normal S-, and P-types but the axis is linear,
00136 *   not in any spectral variable, but in a special "grism parameter".
00137 *   The X-type spectral variable is either W or A for grisms in vacuo or
00138 *   air respectively, but is encoded as 'w' or 'a' to indicate that an
00139 *   additional transformation is required to convert to or from the
00140 *   grism parameter. The spectral algorithm code for grisms also has a
00141 *   special encoding in CTYPEia, either 'GRI' (in vacuo) or 'GRA' (in air).
00142 *
00143 *   In the algorithm chain, the non-linear transformation occurs between the
00144 *   X-type and the P-type variables; the transformation between P-type and
00145 *   S-type variables is always linear.
00146 *
00147 *   When the P-type and X-type variables are the same, the spectral axis is
00148 *   linear in the S-type variable and the second four characters of CTYPEia
00149 *   are blank. This can never happen for grism axes.
00150 *
00151 *   As an example, correlating radio spectrometers always produce spectra that
00152 *   are regularly gridded in frequency; a redshift scale on such a spectrum is
00153 *   non-linear. The required value of CTYPEia would be 'ZOPT-F2W', where the
00154 *   desired S-type is 'ZOPT' (redshift), the P-type is necessarily 'W'
00155 *   (wavelength), and the X-type is 'F' (frequency) by the nature of the
00156 *   instrument.
00157 *
00158 *   Air-to-vacuum wavelength conversion:
00159 *   -----
00160 *   Please refer to the prologue of spx.h for important comments relating to the
00161 *   air-to-vacuum wavelength conversion.
00162 *
00163 *   Argument checking:
00164 *   -----
00165 *   The input spectral values are only checked for values that would result in
00166 *   floating point exceptions. In particular, negative frequencies and
00167 *   wavelengths are allowed, as are velocities greater than the speed of
00168 *   light. The same is true for the spectral parameters - rest frequency and
00169 *   wavelength.
00170 *
00171 *   Accuracy:
00172 *   -----
00173 *   No warranty is given for the accuracy of these routines (refer to the
00174 *   copyright notice); intending users must satisfy for themselves their
00175 *   adequacy for the intended purpose. However, closure effectively to within
00176 *   double precision rounding error was demonstrated by test routine tspec.c
00177 *   which accompanies this software.
00178 *
00179 *
00180 *   spcini() - Default constructor for the spcprm struct
00181 *   -----
00182 *   spcini() sets all members of a spcprm struct to default values. It should
00183 *   be used to initialize every spcprm struct.
00184 *
00185 *   PLEASE NOTE: If the spcprm struct has already been initialized then, before
00186 *   reinitializing it, spcfree() should be used to free any memory that may have
00187 *   been allocated to store an error message. Else a memory leak may result.
00188 *
00189 *   Given and returned:
00190 *   spc          struct spcprm*
00191 *               Spectral transformation parameters.
00192 *
00193 *   Function return value:
00194 *   int          Status return value:
00195 *               0: Success.
00196 *               1: Null spcprm pointer passed.
00197 *
00198 *
00199 *   spcfree() - Destructor for the spcprm struct
00200 *   -----
00201 *   spcfree() frees any memory that may have been allocated to store an error
00202 *   message in the spcprm struct.
00203 *
00204 *   Given and returned:
00205 *   spc          struct spcprm*
00206 *               Spectral transformation parameters.
00207 *
00208 *   Function return value:
00209 *   int          Status return value:
00210 *               0: Success.
00211 *               1: Null spcprm pointer passed.
00212 *
00213 *
00214 *   spcsize() - Compute the size of a spcprm struct
00215 *   -----
00216 *   spcsize() computes the full size of a spcprm struct, including allocated
00217 *   memory.

```

```

00218 *
00219 * Given:
00220 *   spc          const struct spcprm*
00221 *               Spectral transformation parameters.
00222 *
00223 *               If NULL, the base size of the struct and the allocated
00224 *               size are both set to zero.
00225 *
00226 * Returned:
00227 *   sizes      int[2]   The first element is the base size of the struct as
00228 *                       returned by sizeof(struct spcprm). The second element
00229 *                       is the total allocated size, in bytes. This figure
00230 *                       includes memory allocated for the constituent struct,
00231 *                       spcprm::err.
00232 *
00233 *               It is not an error for the struct not to have been set
00234 *               up via spcset().
00235 *
00236 * Function return value:
00237 *   int         Status return value:
00238 *               0: Success.
00239 *
00240 *
00241 * spcenq() - enquire about the state of a spcprm struct
00242 * -----
00243 * spcenq() may be used to obtain information about the state of a spcprm
00244 * struct. The function returns a true/false answer for the enquiry asked.
00245 *
00246 * Given:
00247 *   spc          const struct spcprm*
00248 *               Spectral transformation parameters.
00249 *
00250 *   enquiry      int      Enquiry according to the following parameters:
00251 *                       SPCEMQ_MEM: memory in the struct is being managed by
00252 *                       WCSLIB (see spcini()).
00253 *                       SPCEMQ_SET: the struct has been set up by spcset().
00254 *                       SPCEMQ_BY: the struct is in bypass mode (see
00255 *                       spcset()).
00256 *                       These may be combined by logical OR, e.g.
00257 *                       SPCEMQ_MEM | SPCEMQ_SET. The enquiry result will be
00258 *                       the logical AND of the individual results.
00259 *
00260 * Function return value:
00261 *   int          Enquiry result:
00262 *               0: No.
00263 *               1: Yes.
00264 *
00265 *
00266 * spcprr() - Print routine for the spcprm struct
00267 * -----
00268 * spcprr() prints the contents of a spcprm struct using wcsprintf(). Mainly
00269 * intended for diagnostic purposes.
00270 *
00271 * Given:
00272 *   spc          const struct spcprm*
00273 *               Spectral transformation parameters.
00274 *
00275 * Function return value:
00276 *   int          Status return value:
00277 *               0: Success.
00278 *               1: Null spcprm pointer passed.
00279 *
00280 *
00281 * spcperr() - Print error messages from a spcprm struct
00282 * -----
00283 * spcperr() prints the error message(s) (if any) stored in a spcprm struct.
00284 * If there are no errors then nothing is printed. It uses wcserr_prt(), q.v.
00285 *
00286 * Given:
00287 *   spc          const struct spcprm*
00288 *               Spectral transformation parameters.
00289 *
00290 *   prefix      const char *
00291 *               If non-NULL, each output line will be prefixed with
00292 *               this string.
00293 *
00294 * Function return value:
00295 *   int          Status return value:
00296 *               0: Success.
00297 *               1: Null spcprm pointer passed.
00298 *
00299 *
00300 * spcset() - Setup routine for the spcprm struct
00301 * -----
00302 * spcset() sets up a spcprm struct according to information supplied within
00303 * it.
00304 *

```

```

00305 * Note that this routine need not be called directly; it will be invoked by
00306 * spcx2s() and spcs2x() if spcprm::flag is anything other than a predefined
00307 * magic value.
00308 *
00309 * spcset() normally operates regardless of the value of spcprm::flag; i.e.
00310 * even if a struct was previously set up it will be reset unconditionally.
00311 * However, a spcprm struct may be put into "bypass" mode by invoking spcset()
00312 * initially with spcprm::flag == 1 (rather than 0). spcset() will return
00313 * immediately if invoked on a struct in that state. To take a struct out of
00314 * bypass mode, simply reset spcprm::flag to zero. See also spcenq().
00315 *
00316 * Given and returned:
00317 *   spc      struct spcprm*
00318 *           Spectral transformation parameters.
00319 *
00320 * Function return value:
00321 *   int      Status return value:
00322 *           0: Success.
00323 *           1: Null spcprm pointer passed.
00324 *           2: Invalid spectral parameters.
00325 *
00326 *           For returns > 1, a detailed error message is set in
00327 *           spcprm::err if enabled, see wcserr_enable().
00328 *
00329 *
00330 * spcx2s() - Transform to spectral coordinates
00331 * -----
00332 * spcx2s() transforms intermediate world coordinates to spectral coordinates.
00333 *
00334 * Given and returned:
00335 *   spc      struct spcprm*
00336 *           Spectral transformation parameters.
00337 *
00338 * Given:
00339 *   nx      int      Vector length.
00340 *
00341 *   sx      int      Vector stride.
00342 *
00343 *   sspec   int      Vector stride.
00344 *
00345 *   x       const double[]
00346 *           Intermediate world coordinates, in SI units.
00347 *
00348 * Returned:
00349 *   spec    double[] Spectral coordinates, in SI units.
00350 *
00351 *   stat    int[]    Status return value status for each vector element:
00352 *           0: Success.
00353 *           1: Invalid value of x.
00354 *
00355 * Function return value:
00356 *   int      Status return value:
00357 *           0: Success.
00358 *           1: Null spcprm pointer passed.
00359 *           2: Invalid spectral parameters.
00360 *           3: One or more of the x coordinates were invalid,
00361 *           as indicated by the stat vector.
00362 *
00363 *           For returns > 1, a detailed error message is set in
00364 *           spcprm::err if enabled, see wcserr_enable().
00365 *
00366 *
00367 * spcs2x() - Transform spectral coordinates
00368 * -----
00369 * spcs2x() transforms spectral world coordinates to intermediate world
00370 * coordinates.
00371 *
00372 * Given and returned:
00373 *   spc      struct spcprm*
00374 *           Spectral transformation parameters.
00375 *
00376 * Given:
00377 *   nspec   int      Vector length.
00378 *
00379 *   sspec   int      Vector stride.
00380 *
00381 *   sx      int      Vector stride.
00382 *
00383 *   spec    const double[]
00384 *           Spectral coordinates, in SI units.
00385 *
00386 * Returned:
00387 *   x       double[] Intermediate world coordinates, in SI units.
00388 *
00389 *   stat    int[]    Status return value status for each vector element:
00390 *           0: Success.
00391 *           1: Invalid value of spec.

```

```

00392 *
00393 * Function return value:
00394 *      int      Status return value:
00395 *              0: Success.
00396 *              1: Null spcprm pointer passed.
00397 *              2: Invalid spectral parameters.
00398 *              4: One or more of the spec coordinates were
00399 *                  invalid, as indicated by the stat vector.
00400 *
00401 *              For returns > 1, a detailed error message is set in
00402 *              spcprm::err if enabled, see wcserr_enable().
00403 *
00404 *
00405 * spctype() - Spectral CTYPEia keyword analysis
00406 * -----
00407 * spctype() checks whether a CTYPEia keyvalue is a valid spectral axis type
00408 * and if so returns information derived from it relating to the associated S-,
00409 * P-, and X-type spectral variables (see explanation above).
00410 *
00411 * The return arguments are guaranteed not be modified if CTYPEia is not a
00412 * valid spectral type; zero-pointers may be specified for any that are not of
00413 * interest.
00414 *
00415 * A deprecated form of this function, spctyp(), lacks the wcserr** parameter.
00416 *
00417 * Given:
00418 *      ctype      const char[9]
00419 *                  The CTYPEia keyvalue, (eight characters with null
00420 *                  termination).
00421 *
00422 * Returned:
00423 *      stype      char[]      The four-letter name of the S-type spectral variable
00424 *                              copied or translated from ctype.  If a non-zero
00425 *                              pointer is given, the array must accomodate a null-
00426 *                              terminated string of length 5.
00427 *
00428 *      scode      char[]      The three-letter spectral algorithm code copied or
00429 *                              translated from ctype.  Logarithmic ('LOG') and
00430 *                              tabular ('TAB') codes are also recognized.  If a
00431 *                              non-zero pointer is given, the array must accomodate a
00432 *                              null-terminated string of length 4.
00433 *
00434 *      sname      char[]      Descriptive name of the S-type spectral variable.
00435 *                              If a non-zero pointer is given, the array must
00436 *                              accomodate a null-terminated string of length 22.
00437 *
00438 *      units      char[]      SI units of the S-type spectral variable.  If a
00439 *                              non-zero pointer is given, the array must accomodate a
00440 *                              null-terminated string of length 8.
00441 *
00442 *      ptype      char*       Character code for the P-type spectral variable
00443 *                              derived from ctype, one of 'F', 'W', 'A', or 'V'.
00444 *
00445 *      xtype      char*       Character code for the X-type spectral variable
00446 *                              derived from ctype, one of 'F', 'W', 'A', or 'V'.
00447 *                              Also, 'w' and 'a' are synonymous to 'W' and 'A' for
00448 *                              grisms in vacuo and air respectively.  Set to 'L' or
00449 *                              'T' for logarithmic ('LOG') and tabular ('TAB') axes.
00450 *
00451 *      restreq    int*        Multivalued flag that indicates whether rest
00452 *                              frequency or wavelength is required to compute
00453 *                              spectral variables for this CTYPEia:
00454 *                              0: Not required.
00455 *                              1: Required for the conversion between S- and
00456 *                              P-types (e.g. 'ZOPT-F2W').
00457 *                              2: Required for the conversion between P- and
00458 *                              X-types (e.g. 'BETA-W2V').
00459 *                              3: Required for the conversion between S- and
00460 *                              P-types, and between P- and X-types, but not
00461 *                              between S- and X-types (this applies only for
00462 *                              'VRAD-V2F', 'VOPT-V2W', and 'ZOPT-V2W').
00463 *                              Thus the rest frequency or wavelength is required for
00464 *                              spectral coordinate computations (i.e. between S- and
00465 *                              X-types) only if restreq%3 != 0.
00466 *
00467 *      err        struct wcserr **
00468 *                  If enabled, for function return values > 1, this
00469 *                  struct will contain a detailed error message, see
00470 *                  wcserr_enable().  May be NULL if an error message is
00471 *                  not desired.  Otherwise, the user is responsible for
00472 *                  deleting the memory allocated for the wcserr struct.
00473 *
00474 * Function return value:
00475 *      int      Status return value:
00476 *              0: Success.
00477 *              2: Invalid spectral parameters (not a spectral
00478 *                  CTYPEia).

```

```

00479 *
00480 *
00481 * spcspxe() - Spectral keyword analysis
00482 * -----
00483 * spcspxe() analyses the CTYPExia and CRVALia FITS spectral axis keyword values
00484 * and returns information about the associated X-type spectral variable.
00485 *
00486 * A deprecated form of this function, spcspX(), lacks the wcserr** parameter.
00487 *
00488 * Given:
00489 *   ctypeS      const char[9]
00490 *               Spectral axis type, i.e. the CTYPExia keyvalue, (eight
00491 *               characters with null termination). For non-grism
00492 *               axes, the character code for the P-type spectral
00493 *               variable in the algorithm code (i.e. the eighth
00494 *               character of CTYPExia) may be set to '?' (it will not
00495 *               be reset).
00496 *
00497 *   crvalS      double      Value of the S-type spectral variable at the reference
00498 *                           point, i.e. the CRVALia keyvalue, SI units.
00499 *
00500 *   restfrq,
00501 *   restwav     double      Rest frequency [Hz] and rest wavelength in vacuo [m],
00502 *                           only one of which need be given, the other should be
00503 *                           set to zero.
00504 *
00505 * Returned:
00506 *   ptype       char*       Character code for the P-type spectral variable
00507 *                           derived from ctypeS, one of 'F', 'W', 'A', or 'V'.
00508 *
00509 *   xtype       char*       Character code for the X-type spectral variable
00510 *                           derived from ctypeS, one of 'F', 'W', 'A', or 'V'.
00511 *                           Also, 'w' and 'a' are synonymous to 'W' and 'A' for
00512 *                           grisms in vacuo and air respectively; crvalX and dXdS
00513 *                           (see below) will conform to these.
00514 *
00515 *   restreq     int*        Multivalued flag that indicates whether rest frequency
00516 *                           or wavelength is required to compute spectral
00517 *                           variables for this CTYPExia, as for spctype().
00518 *
00519 *   crvalX      double*     Value of the X-type spectral variable at the reference
00520 *                           point, SI units.
00521 *
00522 *   dXdS        double*     The derivative, dX/dS, evaluated at the reference
00523 *                           point, SI units. Multiply the CDELTia keyvalue by
00524 *                           this to get the pixel spacing in the X-type spectral
00525 *                           coordinate.
00526 *
00527 *   err         struct wcserr **
00528 *                           If enabled, for function return values > 1, this
00529 *                           struct will contain a detailed error message, see
00530 *                           wcserr_enable(). May be NULL if an error message is
00531 *                           not desired. Otherwise, the user is responsible for
00532 *                           deleting the memory allocated for the wcserr struct.
00533 *
00534 * Function return value:
00535 *   int          Status return value:
00536 *               0: Success.
00537 *               2: Invalid spectral parameters.
00538 *
00539 *
00540 * spcxpse() - Spectral keyword synthesis
00541 * -----
00542 * spcxpse(), for the spectral axis type specified and the value provided for
00543 * the X-type spectral variable at the reference point, deduces the value of
00544 * the FITS spectral axis keyword CRVALia and also the derivative dS/dX which
00545 * may be used to compute CDELTia. See above for an explanation of the S-,
00546 * P-, and X-type spectral variables.
00547 *
00548 * A deprecated form of this function, spcxps(), lacks the wcserr** parameter.
00549 *
00550 * Given:
00551 *   ctypeS      const char[9]
00552 *               The required spectral axis type, i.e. the CTYPExia
00553 *               keyvalue, (eight characters with null termination).
00554 *               For non-grism axes, the character code for the P-type
00555 *               spectral variable in the algorithm code (i.e. the
00556 *               eighth character of CTYPExia) may be set to '?' (it
00557 *               will not be reset).
00558 *
00559 *   crvalX      double      Value of the X-type spectral variable at the reference
00560 *                           point (N.B. NOT the CRVALia keyvalue), SI units.
00561 *
00562 *   restfrq,
00563 *   restwav     double      Rest frequency [Hz] and rest wavelength in vacuo [m],
00564 *                           only one of which need be given, the other should be
00565 *                           set to zero.

```

```

00566 *
00567 * Returned:
00568 *   ptype      char*      Character code for the P-type spectral variable
00569 *                      derived from ctypeS, one of 'F', 'W', 'A', or 'V'.
00570 *
00571 *   xtype      char*      Character code for the X-type spectral variable
00572 *                      derived from ctypeS, one of 'F', 'W', 'A', or 'V'.
00573 *                      Also, 'w' and 'a' are synonymous to 'W' and 'A' for
00574 *                      grisms; crvalX and cdeltX must conform to these.
00575 *
00576 *   restreq    int*       Multivalued flag that indicates whether rest frequency
00577 *                      or wavelength is required to compute spectral
00578 *                      variables for this CTYPeIa, as for spctype().
00579 *
00580 *   crvalS     double*    Value of the S-type spectral variable at the reference
00581 *                      point (i.e. the appropriate CRVALia keyvalue), SI
00582 *                      units.
00583 *
00584 *   dSdX       double*    The derivative, dS/dX, evaluated at the reference
00585 *                      point, SI units. Multiply this by the pixel spacing
00586 *                      in the X-type spectral coordinate to get the CDELtia
00587 *                      keyvalue.
00588 *
00589 *   err        struct wcserr **
00590 *                      If enabled, for function return values > 1, this
00591 *                      struct will contain a detailed error message, see
00592 *                      wcserr_enable(). May be NULL if an error message is
00593 *                      not desired. Otherwise, the user is responsible for
00594 *                      deleting the memory allocated for the wcserr struct.
00595 *
00596 * Function return value:
00597 *   int        Status return value:
00598 *             0: Success.
00599 *             2: Invalid spectral parameters.
00600 *
00601 *
00602 * spctrne() - Spectral keyword translation
00603 * -----
00604 * spctrne() translates a set of FITS spectral axis keywords into the
00605 * corresponding set for the specified spectral axis type. For example, a
00606 * 'FREQ' axis may be translated into 'ZOPT-F2W' and vice versa.
00607 *
00608 * A deprecated form of this function, spctrn(), lacks the wcserr** parameter.
00609 *
00610 * Given:
00611 *   ctypeS1    const char[9]
00612 *                      Spectral axis type, i.e. the CTYPeIa keyvalue, (eight
00613 *                      characters with null termination). For non-grism
00614 *                      axes, the character code for the P-type spectral
00615 *                      variable in the algorithm code (i.e. the eighth
00616 *                      character of CTYPeIa) may be set to '?' (it will not
00617 *                      be reset).
00618 *
00619 *   crvalS1    double     Value of the S-type spectral variable at the reference
00620 *                      point, i.e. the CRVALia keyvalue, SI units.
00621 *
00622 *   cdeltS1    double     Increment of the S-type spectral variable at the
00623 *                      reference point, SI units.
00624 *
00625 *   restfrq,   double     Rest frequency [Hz] and rest wavelength in vacuo [m],
00626 *   restwav    double     only one of which need be given, the other should be
00627 *                      set to zero. Neither are required if the translation
00628 *                      is between wave-characteristic types, or between
00629 *                      velocity-characteristic types. E.g., required for
00630 *                      'FREQ' -> 'ZOPT-F2W', but not required for
00631 *                      'VELO-F2V' -> 'ZOPT-F2W'.
00632 *
00633 *
00634 * Given and returned:
00635 *   ctypeS2    char[9]    Required spectral axis type (eight characters with
00636 *                      null termination). The first four characters are
00637 *                      required to be given and are never modified. The
00638 *                      remaining four, the algorithm code, are completely
00639 *                      determined by, and must be consistent with, ctypeS1
00640 *                      and the first four characters of ctypeS2. A non-zero
00641 *                      status value will be returned if they are inconsistent
00642 *                      (see below). However, if the final three characters
00643 *                      are specified as "???", or if just the eighth
00644 *                      character is specified as '?', the correct algorithm
00645 *                      code will be substituted (applies for grism axes as
00646 *                      well as non-grism).
00647 *
00648 * Returned:
00649 *   crvalS2    double*    Value of the new S-type spectral variable at the
00650 *                      reference point, i.e. the new CRVALia keyvalue, SI
00651 *                      units.
00652 *

```

```

00653 *   cdelts2    double*   Increment of the new S-type spectral variable at the
00654 *                   reference point, i.e. the new CDELTia keyvalue, SI
00655 *                   units.
00656 *
00657 *   err        struct wcserr **
00658 *                   If enabled, for function return values > 1, this
00659 *                   struct will contain a detailed error message, see
00660 *                   wcserr_enable(). May be NULL if an error message is
00661 *                   not desired. Otherwise, the user is responsible for
00662 *                   deleting the memory allocated for the wcserr struct.
00663 *
00664 * Function return value:
00665 *   int         Status return value:
00666 *               0: Success.
00667 *               2: Invalid spectral parameters.
00668 *
00669 *               A status value of 2 will be returned if restfrq or
00670 *               restwav are not specified when required, or if ctypeS1
00671 *               or ctypeS2 are self-inconsistent, or have different
00672 *               spectral X-type variables.
00673 *
00674 *
00675 * spcaips() - Translate AIPS-convention spectral keywords
00676 * -----
00677 * spcaips() translates AIPS-convention spectral CTYPIa and VELREF keyvalues.
00678 *
00679 * Given:
00680 *   ctypeA     const char[9]
00681 *               CTYPIa keyvalue possibly containing an
00682 *               AIPS-convention spectral code (eight characters, need
00683 *               not be null-terminated).
00684 *
00685 *   velref     int         AIPS-convention VELREF code. It has the following
00686 *               integer values:
00687 *               1: LSR kinematic, originally described simply as
00688 *                  "LSR" without distinction between the kinematic
00689 *                  and dynamic definitions.
00690 *               2: Barycentric, originally described as "HEL"
00691 *                  meaning heliocentric.
00692 *               3: Topocentric, originally described as "OBS"
00693 *                  meaning geocentric but widely interpreted as
00694 *                  topocentric.
00695 *               AIPS++ extensions to VELREF are also recognized:
00696 *               4: LSR dynamic.
00697 *               5: Geocentric.
00698 *               6: Source rest frame.
00699 *               7: Galactocentric.
00700 *
00701 *               For an AIPS 'VELO' axis, a radio convention velocity
00702 *               (VRAD) is denoted by adding 256 to VELREF, otherwise
00703 *               an optical velocity (VOPT) is indicated (this is not
00704 *               applicable to 'FREQ' or 'FELO' axes). Setting velref
00705 *               to 0 or 256 chooses between optical and radio velocity
00706 *               without specifying a Doppler frame, provided that a
00707 *               frame is encoded in ctypeA. If not, i.e. for
00708 *               ctypeA = 'VELO', ctype will be returned as 'VELO'.
00709 *
00710 *               VELREF takes precedence over CTYPIa in defining the
00711 *               Doppler frame, e.g.
00712 *
00713 *               ctypeA = 'VELO-HEL';
00714 *               velref = 1;
00715 *
00716 *               returns ctype = 'VOPT' with specsyz set to 'LSRK'.
00717 *
00718 *               If omitted from the header, the default value of
00719 *               VELREF is 0.
00720 *
00721 * Returned:
00722 *   ctype       char[9]   Translated CTYPIa keyvalue, or a copy of ctypeA if no
00723 *                   translation was performed (in which case any trailing
00724 *                   blanks in ctypeA will be replaced with nulls).
00725 *
00726 *   specsyz     char[9]   Doppler reference frame indicated by VELREF or else
00727 *                   by CTYPIa with value corresponding to the SPECSYS
00728 *                   keyvalue in the FITS WCS standard. May be returned
00729 *                   blank if neither specifies a Doppler frame, e.g.
00730 *                   ctypeA = 'FELO' and velref%256 == 0.
00731 *
00732 * Function return value:
00733 *   int         Status return value:
00734 *               -1: No translation required (not an error).
00735 *               0: Success.
00736 *               2: Invalid value of VELREF.
00737 *
00738 *
00739 * spcprm struct - Spectral transformation parameters

```

```

00740 * -----
00741 * The spcprm struct contains information required to transform spectral
00742 * coordinates. It consists of certain members that must be set by the user
00743 * ("given") and others that are set by the WCSLIB routines ("returned"). Some
00744 * of the latter are supplied for informational purposes while others are for
00745 * internal use only.
00746 *
00747 *   int flag
00748 *       (Given and returned) This flag must be set to zero (or 1, see spcset())
00749 *       whenever any of the following spcprm members are set or changed:
00750 *
00751 *       - spcprm::type,
00752 *       - spcprm::code,
00753 *       - spcprm::crval,
00754 *       - spcprm::restfrq,
00755 *       - spcprm::restwav,
00756 *       - spcprm::pv[].
00757 *
00758 *       This signals the initialization routine, spcset(), to recompute the
00759 *       returned members of the spcprm struct. spcset() will reset flag to
00760 *       indicate that this has been done.
00761 *
00762 *   char type[8]
00763 *       (Given) Four-letter spectral variable type, e.g "ZOPT" for
00764 *       CTYPEia = 'ZOPT-F2W'. (Declared as char[8] for alignment reasons.)
00765 *
00766 *   char code[4]
00767 *       (Given) Three-letter spectral algorithm code, e.g "F2W" for
00768 *       CTYPEia = 'ZOPT-F2W'.
00769 *
00770 *   double crval
00771 *       (Given) Reference value (CRVALia), SI units.
00772 *
00773 *   double restfrq
00774 *       (Given) The rest frequency [Hz], and ...
00775 *
00776 *   double restwav
00777 *       (Given) ... the rest wavelength in vacuo [m], only one of which need be
00778 *       given, the other should be set to zero. Neither are required if the
00779 *       X and S spectral variables are both wave-characteristic, or both
00780 *       velocity-characteristic, types.
00781 *
00782 *   double pv[7]
00783 *       (Given) Grism parameters for 'GRI' and 'GRA' algorithm codes:
00784 *       - 0: G, grating ruling density.
00785 *       - 1: m, interference order.
00786 *       - 2: alpha, angle of incidence [deg].
00787 *       - 3: n_r, refractive index at the reference wavelength, lambda_r.
00788 *       - 4: n'_r, dn/dlambda at the reference wavelength, lambda_r (/m).
00789 *       - 5: epsilon, grating tilt angle [deg].
00790 *       - 6: theta, detector tilt angle [deg].
00791 *
00792 * The remaining members of the spcprm struct are maintained by spcset() and
00793 * must not be modified elsewhere:
00794 *
00795 *   double w[6]
00796 *       (Returned) Intermediate values:
00797 *       - 0: Rest frequency or wavelength (SI).
00798 *       - 1: The value of the X-type spectral variable at the reference point
00799 *         (SI units).
00800 *       - 2: dX/dS at the reference point (SI units).
00801 *       The remainder are grism intermediates.
00802 *
00803 *   int isGrism
00804 *       (Returned) Grism coordinates?
00805 *       - 0: no,
00806 *       - 1: in vacuum,
00807 *       - 2: in air.
00808 *
00809 *   int padding1
00810 *       (An unused variable inserted for alignment purposes only.)
00811 *
00812 *   struct wcserr *err
00813 *       (Returned) If enabled, when an error status is returned, this struct
00814 *       contains detailed information about the error, see wcserr_enable().
00815 *
00816 *   void *padding2
00817 *       (An unused variable inserted for alignment purposes only.)
00818 *   int (*spxX2P) (SPX_ARGS)
00819 *       (For internal use only) The first and ...
00820 *   int (*spxP2S) (SPX_ARGS)
00821 *       (For internal use only) ... the second of the pointers to the
00822 *       transformation functions in the two-step algorithm chain X -> P -> S in
00823 *       the pixel-to-spectral direction where the non-linear transformation is
00824 *       from X to P. The argument list, SPX_ARGS, is defined in spx.h.
00825 *
00826 *   int (*spxS2P) (SPX_ARGS)

```

```

00827 *      (For internal use only) The first and ...
00828 *      int (*spXP2X)(SPX_ARGS)
00829 *      (For internal use only) ... the second of the pointers to the
00830 *      transformation functions in the two-step algorithm chain S -> P -> X in
00831 *      the spectral-to-pixel direction where the non-linear transformation is
00832 *      from P to X. The argument list, SPX_ARGS, is defined in spx.h.
00833 *
00834 *
00835 * Global variable: const char *spc_errmsg[] - Status return messages
00836 * -----
00837 * Error messages to match the status value returned from each function.
00838 *
00839 *=====*/
00840
00841 #ifndef WCSLIB_SPC
00842 #define WCSLIB_SPC
00843
00844 #include "spx.h"
00845
00846 #ifdef __cplusplus
00847 extern "C" {
00848 #endif
00849
00850 enum spceng_enum {
00851     SPCENQ_SET = 2,           // spcprm struct has been set up.
00852     SPCENQ_BYP = 4,          // spcprm struct is in bypass mode.
00853 };
00854
00855 extern const char *spc_errmsg[];
00856
00857 enum spc_errmsg_enum {
00858     SPCERR_NO_CHANGE      = -1, // No change.
00859     SPCERR_SUCCESS        = 0,  // Success.
00860     SPCERR_NULL_POINTER   = 1,  // Null spcprm pointer passed.
00861     SPCERR_BAD_SPEC_PARAMS = 2,  // Invalid spectral parameters.
00862     SPCERR_BAD_X          = 3,  // One or more of x coordinates were
00863                                // invalid.
00864     SPCERR_BAD_SPEC       = 4   // One or more of the spec coordinates were
00865                                // invalid.
00866 };
00867
00868 struct spcprm {
00869     // Initialization flag (see the prologue above).
00870     //-----
00871     int    flag;                // Set to zero to force initialization.
00872
00873     // Parameters to be provided (see the prologue above).
00874     //-----
00875     char    type[8];            // Four-letter spectral variable type.
00876     char    code[4];           // Three-letter spectral algorithm code.
00877
00878     double  crval;              // Reference value (CRVALia), SI units.
00879     double  restfrq;            // Rest frequency, Hz.
00880     double  restwav;           // Rest wavelength, m.
00881
00882     double  pv[7];             // Grism parameters:
00883                                // 0: G, grating ruling density.
00884                                // 1: m, interference order.
00885                                // 2: alpha, angle of incidence.
00886                                // 3: n_r, refractive index at lambda_r.
00887                                // 4: n'_r, dn/dlambda at lambda_r.
00888                                // 5: epsilon, grating tilt angle.
00889                                // 6: theta, detector tilt angle.
00890
00891     // Information derived from the parameters supplied.
00892     //-----
00893     double  w[6];              // Intermediate values.
00894                                // 0: Rest frequency or wavelength (SI).
00895                                // 1: CRVALX (SI units).
00896                                // 2: CDELTX/CDELTia = dX/dS (SI units).
00897                                // The remainder are grism intermediates.
00898
00899     int     isGrism;            // Grism coordinates? 1: vacuum, 2: air.
00900     int     padding1;          // (Dummy inserted for alignment purposes.)
00901
00902     // Error messaging, if enabled.
00903     //-----
00904     struct wcserr *err;
00905
00906     //-----
00907     // Private - the remainder are for internal use.
00908     //-----
00909     void *padding2;            // (Dummy inserted for alignment purposes.)
00910
00911     int (*spXP2P)(SPX_ARGS);   // Pointers to the transformation functions
00912     int (*spXP2S)(SPX_ARGS);   // in the two-step algorithm chain in the
00913                                // pixel-to-spectral direction.

```

```

00914
00915     int (*spxs2P)(SPX_ARGS);          // Pointers to the transformation functions
00916     int (*spxp2X)(SPX_ARGS);          // in the two-step algorithm chain in the
00917                                         // spectral-to-pixel direction.
00918 };
00919
00920 // Size of the spcprm struct in int units, used by the Fortran wrappers.
00921 #define SPCLEN (sizeof(struct spcprm)/sizeof(int))
00922
00923
00924 int spcini(struct spcprm *spc);
00925
00926 int spcfree(struct spcprm *spc);
00927
00928 int spcsize(const struct spcprm *spc, int sizes[2]);
00929
00930 int spcenq(const struct spcprm *spc, int enquiry);
00931
00932 int spcprt(const struct spcprm *spc);
00933
00934 int spcperr(const struct spcprm *spc, const char *prefix);
00935
00936 int spcset(struct spcprm *spc);
00937
00938 int spcx2s(struct spcprm *spc, int nx, int sx, int sspec,
00939           const double x[], double spec[], int stat[]);
00940
00941 int spcs2x(struct spcprm *spc, int nspec, int sspec, int sx,
00942           const double spec[], double x[], int stat[]);
00943
00944 int spctype(const char ctype[9], char stype[], char scode[], char sname[],
00945            char units[], char *ptype, char *xtype, int *restreq,
00946            struct wcserr **err);
00947
00948 int spcspxe(const char ctypeS[9], double crvalS, double restfrq,
00949            double restwav, char *ptype, char *xtype, int *restreq,
00950            double *crvalX, double *dXdS, struct wcserr **err);
00951
00952 int spcxpse(const char ctypeS[9], double crvalX, double restfrq,
00953            double restwav, char *ptype, char *xtype, int *restreq,
00954            double *crvalS, double *dSdX, struct wcserr **err);
00955
00956 int spctrne(const char ctypeS1[9], double crvalS1, double cdeltS1,
00957            double restfrq, double restwav, char ctypeS2[9], double *crvalS2,
00958            double *cdeltS2, struct wcserr **err);
00959
00960 int spcaips(const char ctypeA[9], int velref, char ctype[9], char specs[9]);
00961
00962
00963 // Deprecated.
00964 #define spcini_errmsg spc_errmsg
00965 #define spcprt_errmsg spc_errmsg
00966 #define spcset_errmsg spc_errmsg
00967 #define spcx2s_errmsg spc_errmsg
00968 #define spcs2x_errmsg spc_errmsg
00969
00970 int spctype(const char ctype[9], char stype[], char scode[], char sname[],
00971            char units[], char *ptype, char *xtype, int *restreq);
00972 int spcspx(const char ctypeS[9], double crvalS, double restfrq,
00973            double restwav, char *ptype, char *xtype, int *restreq,
00974            double *crvalX, double *dXdS);
00975 int spcxps(const char ctypeS[9], double crvalX, double restfrq,
00976            double restwav, char *ptype, char *xtype, int *restreq,
00977            double *crvalS, double *dSdX);
00978 int spctrn(const char ctypeS1[9], double crvalS1, double cdeltS1,
00979            double restfrq, double restwav, char ctypeS2[9], double *crvalS2,
00980            double *cdeltS2);
00981
00982 #ifdef __cplusplus
00983 }
00984 #endif
00985
00986 #endif // WCSLIB_SPC

```

## 8.17 sph.h File Reference

### Functions

- int [sphx2s](#) (const double eul[5], int nphi, int ntheta, int spt, int sxy, const double phi[], const double theta[], double lng[], double lat[])

*Rotation in the pixel-to-world direction.*

- int [sphs2x](#) (const double eul[5], int nlng, int nlat, int sll, int spt, const double lng[], const double lat[], double phi[], double theta[])

*Rotation in the world-to-pixel direction.*

- int [sphdpa](#) (int nfield, double lng0, double lat0, const double lng[], const double lat[], double dist[], double pa[])

*Compute angular distance and position angle.*

- int [sphpad](#) (int nfield, double lng0, double lat0, const double dist[], const double pa[], double lng[], double lat[])

*Compute field points offset from a given point.*

### 8.17.1 Detailed Description

Routines in this suite implement the spherical coordinate transformations defined by the FITS World Coordinate System (WCS) standard

"Representations of world coordinates in FITS",  
Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)

"Representations of celestial coordinates in FITS",  
Calabretta, M.R., & Greisen, E.W. 2002, A&A, 395, 1077 (WCS Paper II)

The transformations are implemented via separate functions, [sphx2s\(\)](#) and [sphs2x\(\)](#), for the spherical rotation in each direction.

A utility function, [sphdpa\(\)](#), computes the angular distances and position angles from a given point on the sky to a number of other points. [sphpad\(\)](#) does the complementary operation - computes the coordinates of points offset by the given angular distances and position angles from a given point on the sky.

### 8.17.2 Function Documentation

#### [sphx2s\(\)](#)

```
int sphx2s (
    const double eul[5],
    int nphi,
    int ntheta,
    int spt,
    int sxy,
    const double phi[],
    const double theta[],
    double lng[],
    double lat[])
```

Rotation in the pixel-to-world direction.

[sphx2s\(\)](#) transforms native coordinates of a projection to celestial coordinates.

#### Parameters

---

in	<i>eul</i>	Euler angles for the transformation: <ul style="list-style-type: none"> <li>• 0: Celestial longitude of the native pole [deg].</li> <li>• 1: Celestial colatitude of the native pole, or native colatitude of the celestial pole [deg].</li> <li>• 2: Native longitude of the celestial pole [deg].</li> <li>• 3: <math>\cos(\text{eul}[1])</math></li> <li>• 4: <math>\sin(\text{eul}[1])</math></li> </ul>
in	<i>nphi,ntheta</i>	Vector lengths.
in	<i>spt,sxy</i>	Vector strides.
in	<i>phi,theta</i>	Longitude and latitude in the native coordinate system of the projection [deg].
out	<i>lng,lat</i>	Celestial longitude and latitude [deg]. These may refer to the same storage as <i>phi</i> and <i>theta</i> respectively.

### Returns

Status return value:

- 0: Success.

### sphs2x()

```
int sphs2x (
    const double eul[5],
    int nlng,
    int nlat,
    int sll,
    int spt,
    const double lng[],
    const double lat[],
    double phi[],
    double theta[])
```

Rotation in the world-to-pixel direction.

**sphs2x()** transforms celestial coordinates to the native coordinates of a projection.

### Parameters

in	<i>eul</i>	Euler angles for the transformation: <ul style="list-style-type: none"> <li>• 0: Celestial longitude of the native pole [deg].</li> <li>• 1: Celestial colatitude of the native pole, or native colatitude of the celestial pole [deg].</li> <li>• 2: Native longitude of the celestial pole [deg].</li> <li>• 3: <math>\cos(\text{eul}[1])</math></li> <li>• 4: <math>\sin(\text{eul}[1])</math></li> </ul>
in	<i>nlng,nlat</i>	Vector lengths.
in	<i>sll,spt</i>	Vector strides.
in	<i>lng,lat</i>	Celestial longitude and latitude [deg].
out	<i>phi,theta</i>	Longitude and latitude in the native coordinate system of the projection [deg]. These may refer to the same storage as <i>lng</i> and <i>lat</i> respectively.

### Returns

Status return value:

- 0: Success.

### sphdpa()

```
int sphdpa (
    int nfield,
    double lng0,
    double lat0,
    const double lng[],
    const double lat[],
    double dist[],
    double pa[])
```

Compute angular distance and position angle.

**sphdpa()** computes the angular distance and generalized position angle (see notes) from a "reference" point to a number of "field" points on the sphere. The points must be specified consistently in any spherical coordinate system.

**sphdpa()** is complementary to [sphpad\(\)](#).

### Parameters

in	<i>nfield</i>	The number of field points.
in	<i>lng0,lat0</i>	Spherical coordinates of the reference point [deg].
in	<i>lng,lat</i>	Spherical coordinates of the field points [deg].
out	<i>dist,pa</i>	Angular distances and position angles [deg]. These may refer to the same storage as <i>lng</i> and <i>lat</i> respectively.

## Returns

Status return value:

- 0: Success.

## Notes:

1. **sphdpa()** uses **sphs2x()** to rotate coordinates so that the reference point is at the north pole of the new system with the north pole of the old system at zero longitude in the new. The Euler angles required by **sphs2x()** for this rotation are

```
eul[0] = lng0;
eul[1] = 90.0 - lat0;
eul[2] = 0.0;
```

The angular distance and generalized position angle are readily obtained from the longitude and latitude of the field point in the new system. This applies even if the reference point is at one of the poles, in which case the "position angle" returned is as would be computed for a reference point at  $(\alpha_0, +90^\circ - \epsilon)$  or  $(\alpha_0, -90^\circ + \epsilon)$ , in the limit as  $\epsilon$  goes to zero.

It is evident that the coordinate system in which the two points are expressed is irrelevant to the determination of the angular separation between the points. However, this is not true of the generalized position angle.

The generalized position angle is here defined as the angle of intersection of the great circle containing the reference and field points with that containing the reference point and the pole. It has its normal meaning when the reference and field points are specified in equatorial coordinates (right ascension and declination).

Interchanging the reference and field points changes the position angle in a non-intuitive way (because the sum of the angles of a spherical triangle normally exceeds  $180^\circ$ ).

The position angle is undefined if the reference and field points are coincident or antipodal. This may be detected by checking for a distance of  $0^\circ$  or  $180^\circ$  (within rounding tolerance). **sphdpa()** will return an arbitrary position angle in such circumstances.

## sphpad()

```
int sphpad (
    int nfield,
    double lng0,
    double lat0,
    const double dist[],
    const double pa[],
    double lng[],
    double lat[])
```

Compute field points offset from a given point.

**sphpad()** computes the coordinates of a set of points that are offset by the specified angular distances and position angles from a given "reference" point on the sky. The distances and position angles must be specified consistently in any spherical coordinate system.

**sphpad()** is complementary to **sphdpa()**.

## Parameters

in	nfield	The number of field points.
----	--------	-----------------------------

in	<i>lng0,lat0</i>	Spherical coordinates of the reference point [deg].
in	<i>dist,pa</i>	Angular distances and position angles [deg].
out	<i>lng,lat</i>	Spherical coordinates of the field points [deg]. These may refer to the same storage as <i>dist</i> and <i>pa</i> respectively.

### Returns

Status return value:

- 0: Success.

### Notes:

1. **sphpad()** is implemented analogously to **sphdpa()** although using **sphx2s()** for the inverse transformation. In particular, when the reference point is at one of the poles, "position angle" is interpreted as though the reference point was at  $(\alpha_0, +90^\circ - \epsilon)$  or  $(\alpha_0, -90^\circ + \epsilon)$ , in the limit as  $\epsilon$  goes to zero.

Applying **sphpad()** with the distances and position angles computed by **sphdpa()** should return the original field points.

## 8.18 sph.h

[Go to the documentation of this file.](#)

```

00001 /*=====
00002  WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003  Copyright (C) 1995-2025, Mark Calabretta
00004
00005  This file is part of WCSLIB.
00006
00007  WCSLIB is free software: you can redistribute it and/or modify it under the
00008  terms of the GNU Lesser General Public License as published by the Free
00009  Software Foundation, either version 3 of the License, or (at your option)
00010  any later version.
00011
00012  WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013  WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
00014  FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015  more details.
00016
00017  You should have received a copy of the GNU Lesser General Public License
00018  along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020  Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021  http://www.atnf.csiro.au/people/Mark.Calabretta
00022  $Id: sph.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023 *=====
00024 *
00025 * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026 * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027 * overview of the library.
00028 *
00029 *
00030 * Summary of the sph routines
00031 * -----
00032 * Routines in this suite implement the spherical coordinate transformations
00033 * defined by the FITS World Coordinate System (WCS) standard
00034 *
00035 * "Representations of world coordinates in FITS",
00036 * Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)
00037 *
00038 * "Representations of celestial coordinates in FITS",
00039 * Calabretta, M.R., & Greisen, E.W. 2002, A&A, 395, 1077 (WCS Paper II)
00040 *
00041 * The transformations are implemented via separate functions, sphx2s() and
00042 * sphs2x(), for the spherical rotation in each direction.

```

```

00043 *
00044 * A utility function, sphdpa(), computes the angular distances and position
00045 * angles from a given point on the sky to a number of other points. sphpad()
00046 * does the complementary operation - computes the coordinates of points offset
00047 * by the given angular distances and position angles from a given point on the
00048 * sky.
00049 *
00050 *
00051 * sphx2s() - Rotation in the pixel-to-world direction
00052 * -----
00053 * sphx2s() transforms native coordinates of a projection to celestial
00054 * coordinates.
00055 *
00056 * Given:
00057 *     eul          const double[5]
00058 *                      Euler angles for the transformation:
00059 *                      0: Celestial longitude of the native pole [deg].
00060 *                      1: Celestial colatitude of the native pole, or
00061 *                         native colatitude of the celestial pole [deg].
00062 *                      2: Native longitude of the celestial pole [deg].
00063 *                      3: cos(eul[1])
00064 *                      4: sin(eul[1])
00065 *
00066 *     nphi,
00067 *     ntheta      int          Vector lengths.
00068 *
00069 *     spt,sxy     int          Vector strides.
00070 *
00071 *     phi,theta   const double[]
00072 *                      Longitude and latitude in the native coordinate
00073 *                      system of the projection [deg].
00074 *
00075 * Returned:
00076 *     lng,lat     double[]     Celestial longitude and latitude [deg]. These may
00077 *                               refer to the same storage as phi and theta
00078 *                               respectively.
00079 *
00080 * Function return value:
00081 *     int          Status return value:
00082 *     0: Success.
00083 *
00084 *
00085 * sphs2x() - Rotation in the world-to-pixel direction
00086 * -----
00087 * sphs2x() transforms celestial coordinates to the native coordinates of a
00088 * projection.
00089 *
00090 * Given:
00091 *     eul          const double[5]
00092 *                      Euler angles for the transformation:
00093 *                      0: Celestial longitude of the native pole [deg].
00094 *                      1: Celestial colatitude of the native pole, or
00095 *                         native colatitude of the celestial pole [deg].
00096 *                      2: Native longitude of the celestial pole [deg].
00097 *                      3: cos(eul[1])
00098 *                      4: sin(eul[1])
00099 *
00100 *     nlng,nlat   int          Vector lengths.
00101 *
00102 *     sll,spt     int          Vector strides.
00103 *
00104 *     lng,lat     const double[]
00105 *                      Celestial longitude and latitude [deg].
00106 *
00107 * Returned:
00108 *     phi,theta   double[]     Longitude and latitude in the native coordinate system
00109 *                               of the projection [deg]. These may refer to the same
00110 *                               storage as lng and lat respectively.
00111 *
00112 * Function return value:
00113 *     int          Status return value:
00114 *     0: Success.
00115 *
00116 *
00117 * sphdpa() - Compute angular distance and position angle
00118 * -----
00119 * sphdpa() computes the angular distance and generalized position angle (see
00120 * notes) from a "reference" point to a number of "field" points on the sphere.
00121 * The points must be specified consistently in any spherical coordinate
00122 * system.
00123 *
00124 * sphdpa() is complementary to sphpad().
00125 *
00126 * Given:
00127 *     nfield      int          The number of field points.
00128 *
00129 *     lng0,lat0   double       Spherical coordinates of the reference point [deg].

```

```

00130 *
00131 *   lng,lat   const double[]
00132 *           Spherical coordinates of the field points [deg].
00133 *
00134 * Returned:
00135 *   dist,pa   double[]   Angular distances and position angles [deg].  These
00136 *                       may refer to the same storage as lng and lat
00137 *                       respectively.
00138 *
00139 * Function return value:
00140 *           int           Status return value:
00141 *                       0: Success.
00142 *
00143 * Notes:
00144 *   1. sphdpa() uses sphs2x() to rotate coordinates so that the reference
00145 *      point is at the north pole of the new system with the north pole of the
00146 *      old system at zero longitude in the new.  The Euler angles required by
00147 *      sphs2x() for this rotation are
00148 *
00149 *      eul[0] = lng0;
00150 *      eul[1] = 90.0 - lat0;
00151 *      eul[2] = 0.0;
00152 *
00153 *      The angular distance and generalized position angle are readily
00154 *      obtained from the longitude and latitude of the field point in the new
00155 *      system.  This applies even if the reference point is at one of the
00156 *      poles, in which case the "position angle" returned is as would be
00157 *      computed for a reference point at (lng0,+90-epsilon) or
00158 *      (lng0,-90+epsilon), in the limit as epsilon goes to zero.
00159 *
00160 *      It is evident that the coordinate system in which the two points are
00161 *      expressed is irrelevant to the determination of the angular separation
00162 *      between the points.  However, this is not true of the generalized
00163 *      position angle.
00164 *
00165 *      The generalized position angle is here defined as the angle of
00166 *      intersection of the great circle containing the reference and field
00167 *      points with that containing the reference point and the pole.  It has
00168 *      its normal meaning when the reference and field points are
00169 *      specified in equatorial coordinates (right ascension and declination).
00170 *
00171 *      Interchanging the reference and field points changes the position angle
00172 *      in a non-intuitive way (because the sum of the angles of a spherical
00173 *      triangle normally exceeds 180 degrees).
00174 *
00175 *      The position angle is undefined if the reference and field points are
00176 *      coincident or antipodal.  This may be detected by checking for a
00177 *      distance of 0 or 180 degrees (within rounding tolerance).  sphdpa()
00178 *      will return an arbitrary position angle in such circumstances.
00179 *
00180 *
00181 * sphpad() - Compute field points offset from a given point
00182 * -----
00183 * sphpad() computes the coordinates of a set of points that are offset by the
00184 * specified angular distances and position angles from a given "reference"
00185 * point on the sky.  The distances and position angles must be specified
00186 * consistently in any spherical coordinate system.
00187 *
00188 * sphpad() is complementary to sphdpa().
00189 *
00190 * Given:
00191 *   nfield   int           The number of field points.
00192 *
00193 *   lng0,lat0 double       Spherical coordinates of the reference point [deg].
00194 *
00195 *   dist,pa   const double[]
00196 *           Angular distances and position angles [deg].
00197 *
00198 * Returned:
00199 *   lng,lat   double[]   Spherical coordinates of the field points [deg].
00200 *                       These may refer to the same storage as dist and pa
00201 *                       respectively.
00202 *
00203 * Function return value:
00204 *           int           Status return value:
00205 *                       0: Success.
00206 *
00207 * Notes:
00208 *   1: sphpad() is implemented analogously to sphdpa() although using sphx2s()
00209 *      for the inverse transformation.  In particular, when the reference
00210 *      point is at one of the poles, "position angle" is interpreted as though
00211 *      the reference point was at (lng0,+90-epsilon) or (lng0,-90+epsilon), in
00212 *      the limit as epsilon goes to zero.
00213 *
00214 *      Applying sphpad() with the distances and position angles computed by
00215 *      sphdpa() should return the original field points.
00216 *

```

```

00217 *=====*/
00218
00219 #ifndef WCSLIB_SPH
00220 #define WCSLIB_SPH
00221
00222 #ifdef __cplusplus
00223 extern "C" {
00224 #endif
00225
00226
00227 int sphx2s(const double eul[5], int nphi, int ntheta, int spt, int sxy,
00228           const double phi[], const double theta[],
00229           double lng[], double lat[]);
00230
00231 int sphs2x(const double eul[5], int nlng, int nlat, int sll, int spt,
00232           const double lng[], const double lat[],
00233           double phi[], double theta[]);
00234
00235 int sphdpa(int nfield, double lng0, double lat0,
00236           const double lng[], const double lat[],
00237           double dist[], double pa[]);
00238
00239 int sphpad(int nfield, double lng0, double lat0,
00240           const double dist[], const double pa[],
00241           double lng[], double lat[]);
00242
00243
00244 #ifdef __cplusplus
00245 }
00246 #endif
00247
00248 #endif // WCSLIB_SPH

```

## 8.19 spx.h File Reference

### Data Structures

- struct [spxprm](#)  
*Spectral variables and their derivatives.*

### Macros

- #define [SPXLEN](#) (sizeof(struct [spxprm](#))/sizeof(int))  
*Size of the `spxprm` struct in int units.*
- #define [SPX\\_ARGS](#)  
*For use in declaring spectral conversion function prototypes.*

### Enumerations

- enum [spx\\_errmsg](#) {  
[SPXERR\\_SUCCESS](#) = 0 , [SPXERR\\_NULL\\_POINTER](#) = 1 , [SPXERR\\_BAD\\_SPEC\\_PARAMS](#) = 2 ,  
[SPXERR\\_BAD\\_SPEC\\_VAR](#) = 3 ,  
[SPXERR\\_BAD\\_INSPEC\\_COORD](#) = 4 }  
*Status return messages.*

## Functions

- int [specx](#) (const char \*type, double spec, double restfrq, double restwav, struct [spxprm](#) \*specs)  
*Spectral cross conversions (scalar).*
- int [spxperr](#) (const struct [spxprm](#) \*spx, const char \*prefix)  
*Print error messages from a spxprm struct.*
- int [freqafrq](#) ([SPX\\_ARGS](#))  
*Convert frequency to angular frequency (vector).*
- int [afrqfreq](#) ([SPX\\_ARGS](#))  
*Convert angular frequency to frequency (vector).*
- int [freqener](#) ([SPX\\_ARGS](#))  
*Convert frequency to photon energy (vector).*
- int [enerfreq](#) ([SPX\\_ARGS](#))  
*Convert photon energy to frequency (vector).*
- int [freqwavn](#) ([SPX\\_ARGS](#))  
*Convert frequency to wave number (vector).*
- int [wavnfreq](#) ([SPX\\_ARGS](#))  
*Convert wave number to frequency (vector).*
- int [freqwave](#) ([SPX\\_ARGS](#))  
*Convert frequency to vacuum wavelength (vector).*
- int [wavefreq](#) ([SPX\\_ARGS](#))  
*Convert vacuum wavelength to frequency (vector).*
- int [freqawav](#) ([SPX\\_ARGS](#))  
*Convert frequency to air wavelength (vector).*
- int [awavfreq](#) ([SPX\\_ARGS](#))  
*Convert air wavelength to frequency (vector).*
- int [waveawav](#) ([SPX\\_ARGS](#))  
*Convert vacuum wavelength to air wavelength (vector).*
- int [awavwave](#) ([SPX\\_ARGS](#))  
*Convert air wavelength to vacuum wavelength (vector).*
- int [velobeta](#) ([SPX\\_ARGS](#))  
*Convert relativistic velocity to relativistic beta (vector).*
- int [betavelo](#) ([SPX\\_ARGS](#))  
*Convert relativistic beta to relativistic velocity (vector).*
- int [freqvelo](#) ([SPX\\_ARGS](#))  
*Convert frequency to relativistic velocity (vector).*
- int [velofreq](#) ([SPX\\_ARGS](#))  
*Convert relativistic velocity to frequency (vector).*
- int [freqvrad](#) ([SPX\\_ARGS](#))  
*Convert frequency to radio velocity (vector).*
- int [vradfreq](#) ([SPX\\_ARGS](#))  
*Convert radio velocity to frequency (vector).*
- int [wavevelo](#) ([SPX\\_ARGS](#))  
*Conversions between wavelength and velocity types (vector).*
- int [velowave](#) ([SPX\\_ARGS](#))  
*Convert relativistic velocity to vacuum wavelength (vector).*
- int [awavvelo](#) ([SPX\\_ARGS](#))  
*Convert air wavelength to relativistic velocity (vector).*
- int [veloawav](#) ([SPX\\_ARGS](#))  
*Convert relativistic velocity to air wavelength (vector).*
- int [wavevopt](#) ([SPX\\_ARGS](#))

- *Convert vacuum wavelength to optical velocity (vector).*  
• int [voptwave](#) ([SPX\\_ARGS](#))  
*Convert optical velocity to vacuum wavelength (vector).*
- int [wavezopt](#) ([SPX\\_ARGS](#))  
*Convert vacuum wavelength to redshift (vector).*
- int [zoptwave](#) ([SPX\\_ARGS](#))  
*Convert redshift to vacuum wavelength (vector).*

## Variables

- const char \* [spx\\_errmsg](#) []

### 8.19.1 Detailed Description

Routines in this suite implement the spectral coordinate systems recognized by the FITS World Coordinate System (WCS) standard, as described in

"Representations of world coordinates in FITS",  
Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)

"Representations of spectral coordinates in FITS",  
Greisen, E.W., Calabretta, M.R., Valdes, F.G., & Allen, S.L.  
2006, A&A, 446, 747 (WCS Paper III)

[specx\(\)](#) is a scalar routine that, given one spectral variable (e.g. frequency), computes all the others (e.g. wavelength, velocity, etc.) plus the required derivatives of each with respect to the others. The results are returned in the `spxprm` struct.

[spxperr\(\)](#) prints the error message(s) (if any) stored in a `spxprm` struct.

The remaining routines are all vector conversions from one spectral variable to another. The API of these functions only differ in whether the rest frequency or wavelength need be supplied.

#### Non-linear:

- [freqwave\(\)](#) frequency -> vacuum wavelength
- [wavefreq\(\)](#) vacuum wavelength -> frequency
- [freqawav\(\)](#) frequency -> air wavelength
- [awavfreq\(\)](#) air wavelength -> frequency
- [freqvelo\(\)](#) frequency -> relativistic velocity
- [velofreq\(\)](#) relativistic velocity -> frequency
- [waveawav\(\)](#) vacuum wavelength -> air wavelength
- [awavwave\(\)](#) air wavelength -> vacuum wavelength
- [wavevelo\(\)](#) vacuum wavelength -> relativistic velocity
- [velowave\(\)](#) relativistic velocity -> vacuum wavelength
- [awavvelo\(\)](#) air wavelength -> relativistic velocity
- [veloawav\(\)](#) relativistic velocity -> air wavelength

**Linear:**

- `freqafrq()` frequency -> angular frequency
- `afrqfreq()` angular frequency -> frequency
- `freqener()` frequency -> energy
- `enerfreq()` energy -> frequency
- `freqwavn()` frequency -> wave number
- `wavnfreq()` wave number -> frequency
- `freqvrad()` frequency -> radio velocity
- `vradfreq()` radio velocity -> frequency
- `wavevopt()` vacuum wavelength -> optical velocity
- `voptwave()` optical velocity -> vacuum wavelength
- `wavezopt()` vacuum wavelength -> redshift
- `zoptwave()` redshift -> vacuum wavelength
- `velobeta()` relativistic velocity -> beta ( $\beta = v/c$ )
- `betavelo()` beta ( $\beta = v/c$ ) -> relativistic velocity

These are the workhorse routines, to be used for fast transformations. Conversions may be done "in place" by calling the routine with the output vector set to the input.

**Air-to-vacuum wavelength conversion:**

The air-to-vacuum wavelength conversion in early drafts of WCS Paper III cites Cox (ed., 2000, Allen's Astrophysical Quantities, AIP Press, Springer-Verlag, New York), which itself derives from Edlén (1953, Journal of the Optical Society of America, 43, 339). This is the IAU standard, adopted in 1957 and again in 1991. No more recent IAU resolution replaces this relation, and it is the one used by WCSLIB.

However, the Cox relation was replaced in later drafts of Paper III, and as eventually published, by the IUGG relation (1999, International Union of Geodesy and Geophysics, comptes rendus of the 22nd General Assembly, Birmingham UK, p111). There is a nearly constant ratio between the two, with IUGG/Cox = 1.000015 over most of the range between 200nm and 10,000nm.

The IUGG relation itself is derived from the work of Ciddor (1996, Applied Optics, 35, 1566), which is used directly by the Sloan Digital Sky Survey. It agrees closely with Cox; longwards of 2500nm, the ratio Ciddor/Cox is fixed at 1.000000021, decreasing only slightly, to 1.000000018, at 1000nm.

The Cox, IUGG, and Ciddor relations all accurately provide the wavelength dependence of the air-to-vacuum wavelength conversion. However, for full accuracy, the atmospheric temperature, pressure, and partial pressure of water vapour must be taken into account. These will determine a small, wavelength-independent scale factor and offset, which is not considered by WCS Paper III.

WCS Paper III is also silent on the question of the range of validity of the air-to-vacuum wavelength conversion. Cox's relation would appear to be valid in the range 200nm to 10,000nm. Both the Cox and the Ciddor relations have singularities below 200nm, with Cox's at 156nm and 83nm. WCSLIB checks neither the range of validity, nor for these singularities.

**Argument checking:**

The input spectral values are only checked for values that would result in floating point exceptions. In particular, negative frequencies and wavelengths are allowed, as are velocities greater than the speed of light. The same is true for the spectral parameters - rest frequency and wavelength.

**Accuracy:**

No warranty is given for the accuracy of these routines (refer to the copyright notice); intending users must satisfy for themselves their adequacy for the intended purpose. However, closure effectively to within double precision rounding error was demonstrated by test routine `tspec.c` which accompanies this software.

### 8.19.2 Macro Definition Documentation

#### SPXLEN

```
#define SPXLEN (sizeof(struct spxprm)/sizeof(int))
```

Size of the `spxprm` struct in *int* units.

Size of the `spxprm` struct in *int* units, used by the Fortran wrappers.

#### SPX\_ARGS

```
#define SPX_ARGS
```

##### Value:

```
double param, int nspec, int instep, int outstep, \
const double inspec[], double outspec[], int stat[]
```

For use in declaring spectral conversion function prototypes.

Preprocessor macro used for declaring spectral conversion function prototypes.

### 8.19.3 Enumeration Type Documentation

#### spx\_errmsg

```
enum spx_errmsg
```

Status return messages.

Error messages to match the status value returned from each function.

##### Enumerator

SPXERR_SUCCESS	
SPXERR_NULL_POINTER	
SPXERR_BAD_SPEC_PARAMS	
SPXERR_BAD_SPEC_VAR	
SPXERR_BAD_INSPEC_COORD	

### 8.19.4 Function Documentation

#### specx()

```
int specx (
    const char * type,
    double spec,
    double restfrq,
    double restwav,
    struct spxprm * specs)
```

Spectral cross conversions (scalar).

## Parameters

in	<i>type</i>	The type of spectral variable given by spec, <b>FREQ</b> , <b>AFRQ</b> , <b>ENER</b> , <b>WAVN</b> , <b>VRAD</b> , <b>WAVE</b> , <b>VOPT</b> , <b>ZOPT</b> , <b>AWAV</b> , <b>VELO</b> , or <b>BETA</b> (case sensitive).
in	<i>spec</i>	The spectral variable given, in SI units.
in	<i>restfrq,restwav</i>	Rest frequency [Hz] or rest wavelength in vacuo [m], only one of which need be given. The other should be set to zero. If both are zero, only a subset of the spectral variables can be computed, the remainder are set to zero. Specifically, given one of <b>FREQ</b> , <b>AFRQ</b> , <b>ENER</b> , <b>WAVN</b> , <b>WAVE</b> , or <b>AWAV</b> the others can be computed without knowledge of the rest frequency. Likewise, <b>VRAD</b> , <b>VOPT</b> , <b>ZOPT</b> , <b>VELO</b> , and <b>BETA</b> .
in, out	<i>specs</i>	Data structure containing all spectral variables and their derivatives, in SI units.

## Returns

Status return value:

- 0: Success.
- 1: Null `spxprm` pointer passed.
- 2: Invalid spectral parameters.
- 3: Invalid spectral variable.

For returns > 1, a detailed error message is set in `spxprm::err` if enabled, see `wcserr_enable()`.

`freqafreq()`, `afreqfreq()`, `freqener()`, `enerfreq()`, `freqwavn()`, `wavnfreq()`, `freqwave()`, `wavefreq()`, `freqawav()`, `awavfreq()`, `waveawav()`, `awavwave()`, `velobeta()`, and `betavelo()` implement vector conversions between wave-like or velocity-like spectral types (i.e. conversions that do not need the rest frequency or wavelength). They all have the same API.

**spxperr()**

```
int spxperr (
    const struct spxprm * spx,
    const char * prefix)
```

Print error messages from a `spxprm` struct.

**spxperr()** prints the error message(s) (if any) stored in a `spxprm` struct. If there are no errors then nothing is printed. It uses `wcserr_prt()`, q.v.

## Parameters

in	<i>spx</i>	Spectral variables and their derivatives.
in	<i>prefix</i>	If non-NULL, each output line will be prefixed with this string.

## Returns

Status return value:

- 0: Success.
- 1: Null `spxprm` pointer passed.

**freqafreq()**

```
int freqafreq (
    SPX_ARGS )
```

Convert frequency to angular frequency (vector).

**freqafreq()** converts frequency to angular frequency.

**Parameters**

in	<i>param</i>	Ignored.
in	<i>nspec</i>	Vector length.
in	<i>instep, outstep</i>	Vector strides.
in	<i>inspec</i>	Input spectral variables, in SI units.
out	<i>outspec</i>	Output spectral variables, in SI units.
out	<i>stat</i>	Status return value for each vector element: <ul style="list-style-type: none"> <li>• 0: Success.</li> <li>• 1: Invalid value of inspec.</li> </ul>

**Returns**

Status return value:

- 0: Success.
- 2: Invalid spectral parameters.
- 4: One or more of the inspec coordinates were invalid, as indicated by the stat vector.

**afrqfreq()**

```
int afrqfreq (
    SPX_ARGS )
```

Convert angular frequency to frequency (vector).

**afrqfreq()** converts angular frequency to frequency.

See [freqafreq\(\)](#) for a description of the API.

**freqener()**

```
int freqener (
    SPX_ARGS )
```

Convert frequency to photon energy (vector).

**freqener()** converts frequency to photon energy.

See [freqafreq\(\)](#) for a description of the API.

**enerfreq()**

```
int enerfreq (
    SPX_ARGS )
```

Convert photon energy to frequency (vector).

**enerfreq()** converts photon energy to frequency.

See [freqafrq\(\)](#) for a description of the API.

**freqwavn()**

```
int freqwavn (
    SPX_ARGS )
```

Convert frequency to wave number (vector).

**freqwavn()** converts frequency to wave number.

See [freqafrq\(\)](#) for a description of the API.

**wavnfreq()**

```
int wavnfreq (
    SPX_ARGS )
```

Convert wave number to frequency (vector).

**wavnfreq()** converts wave number to frequency.

See [freqafrq\(\)](#) for a description of the API.

**freqwave()**

```
int freqwave (
    SPX_ARGS )
```

Convert frequency to vacuum wavelength (vector).

**freqwave()** converts frequency to vacuum wavelength.

See [freqafrq\(\)](#) for a description of the API.

**wavefreq()**

```
int wavefreq (
    SPX_ARGS )
```

Convert vacuum wavelength to frequency (vector).

**wavefreq()** converts vacuum wavelength to frequency.

See [freqafrq\(\)](#) for a description of the API.

**freqawav()**

```
int freqawav (
    SPX_ARGS )
```

Convert frequency to air wavelength (vector).

**freqawav()** converts frequency to air wavelength.

See [freqafrq\(\)](#) for a description of the API.

**awavfreq()**

```
int awavfreq (
    SPX_ARGS )
```

Convert air wavelength to frequency (vector).

**awavfreq()** converts air wavelength to frequency.

See [freqafrq\(\)](#) for a description of the API.

**waveawav()**

```
int waveawav (
    SPX_ARGS )
```

Convert vacuum wavelength to air wavelength (vector).

**waveawav()** converts vacuum wavelength to air wavelength.

See [freqafrq\(\)](#) for a description of the API.

**awavwave()**

```
int awavwave (
    SPX_ARGS )
```

Convert air wavelength to vacuum wavelength (vector).

**awavwave()** converts air wavelength to vacuum wavelength.

See [freqafrq\(\)](#) for a description of the API.

**velobeta()**

```
int velobeta (
    SPX_ARGS )
```

Convert relativistic velocity to relativistic beta (vector).

**velobeta()** converts relativistic velocity to relativistic beta.

See [freqafrq\(\)](#) for a description of the API.

**betavelo()**

```
int betavelo (
    SPX_ARGS )
```

Convert relativistic beta to relativistic velocity (vector).

**betavelo()** converts relativistic beta to relativistic velocity.

See [freqafrq\(\)](#) for a description of the API.

**freqvelo()**

```
int freqvelo (
    SPX_ARGS )
```

Convert frequency to relativistic velocity (vector).

**freqvelo()** converts frequency to relativistic velocity.

**Parameters**

in	<i>param</i>	Rest frequency [Hz].
in	<i>nspec</i>	Vector length.
in	<i>instep,outstep</i>	Vector strides.
in	<i>inspec</i>	Input spectral variables, in SI units.
out	<i>outspec</i>	Output spectral variables, in SI units.
out	<i>stat</i>	Status return value for each vector element: <ul style="list-style-type: none"> <li>• 0: Success.</li> <li>• 1: Invalid value of inspec.</li> </ul>

**Returns**

Status return value:

- 0: Success.
- 2: Invalid spectral parameters.
- 4: One or more of the inspec coordinates were invalid, as indicated by the stat vector.

**velofreq()**

```
int velofreq (
    SPX_ARGS )
```

Convert relativistic velocity to frequency (vector).

**velofreq()** converts relativistic velocity to frequency.

See [freqvelo\(\)](#) for a description of the API.

**freqvrad()**

```
int freqvrad (
    SPX_ARGS )
```

Convert frequency to radio velocity (vector).

**freqvrad()** converts frequency to radio velocity.

See [freqvelo\(\)](#) for a description of the API.

**vradfreq()**

```
int vradfreq (
    SPX_ARGS )
```

Convert radio velocity to frequency (vector).

**vradfreq()** converts radio velocity to frequency.

See [freqvelo\(\)](#) for a description of the API.

**wavevelo()**

```
int wavevelo (
    SPX_ARGS )
```

Conversions between wavelength and velocity types (vector).

**wavevelo()** converts vacuum wavelength to relativistic velocity.

**Parameters**

in	<i>param</i>	Rest wavelength in vacuo [m].
in	<i>nspec</i>	Vector length.
in	<i>instep,outstep</i>	Vector strides.
in	<i>inspec</i>	Input spectral variables, in SI units.
out	<i>outspec</i>	Output spectral variables, in SI units.
out	<i>stat</i>	Status return value for each vector element: <ul style="list-style-type: none"> <li>• 0: Success.</li> <li>• 1: Invalid value of inspec.</li> </ul>

**Returns**

Status return value:

- 0: Success.
- 2: Invalid spectral parameters.
- 4: One or more of the inspec coordinates were invalid, as indicated by the stat vector.

**velowave()**

```
int velowave (
    SPX_ARGS )
```

Convert relativistic velocity to vacuum wavelength (vector).

**velowave()** converts relativistic velocity to vacuum wavelength.

See [freqvelo\(\)](#) for a description of the API.

**awavvelo()**

```
int awavvelo (
    SPX_ARGS )
```

Convert air wavelength to relativistic velocity (vector).

**awavvelo()** converts air wavelength to relativistic velocity.

See [freqvelo\(\)](#) for a description of the API.

**veloawav()**

```
int veloawav (
    SPX_ARGS )
```

Convert relativistic velocity to air wavelength (vector).

**veloawav()** converts relativistic velocity to air wavelength.

See [freqvelo\(\)](#) for a description of the API.

**wavevopt()**

```
int wavevopt (
    SPX_ARGS )
```

Convert vacuum wavelength to optical velocity (vector).

**wavevopt()** converts vacuum wavelength to optical velocity.

See [freqvelo\(\)](#) for a description of the API.

**voptwave()**

```
int voptwave (
    SPX_ARGS )
```

Convert optical velocity to vacuum wavelength (vector).

**voptwave()** converts optical velocity to vacuum wavelength.

See [freqvelo\(\)](#) for a description of the API.

**wavezopt()**

```
int wavezopt (
    SPX_ARGS )
```

Convert vacuum wavelength to redshift (vector).

**wavevopt()** converts vacuum wavelength to redshift.

See [freqvelo\(\)](#) for a description of the API.

**zoptwave()**

```
int zoptwave (
    SPX_ARGS )
```

Convert redshift to vacuum wavelength (vector).

**zoptwave()** converts redshift to vacuum wavelength.

See [freqvelo\(\)](#) for a description of the API.

**8.19.5 Variable Documentation****spx\_errmsg**

```
const char* spx_errmsg[] [extern]
```

**8.20 spx.h**

[Go to the documentation of this file.](#)

```
00001 /*=====
00002  WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003  Copyright (C) 1995-2025, Mark Calabretta
00004
00005  This file is part of WCSLIB.
00006
00007  WCSLIB is free software: you can redistribute it and/or modify it under the
00008  terms of the GNU Lesser General Public License as published by the Free
00009  Software Foundation, either version 3 of the License, or (at your option)
00010  any later version.
00011
00012  WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013  WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
00014  FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015  more details.
00016
00017  You should have received a copy of the GNU Lesser General Public License
00018  along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020  Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021  http://www.atnf.csiro.au/people/Mark.Calabretta
00022  $Id: spx.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023 *=====
00024 *
00025 * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026 * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027 * overview of the library.
00028 *
00029 *
00030 * Summary of the spx routines
00031 * -----
```

```

00032 * Routines in this suite implement the spectral coordinate systems recognized
00033 * by the FITS World Coordinate System (WCS) standard, as described in
00034 *
00035 = "Representations of world coordinates in FITS",
00036 = Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)
00037 =
00038 = "Representations of spectral coordinates in FITS",
00039 = Greisen, E.W., Calabretta, M.R., Valdes, F.G., & Allen, S.L.
00040 = 2006, A&A, 446, 747 (WCS Paper III)
00041 *
00042 * specx() is a scalar routine that, given one spectral variable (e.g.
00043 * frequency), computes all the others (e.g. wavelength, velocity, etc.) plus
00044 * the required derivatives of each with respect to the others. The results
00045 * are returned in the spxprm struct.
00046 *
00047 * spxperr() prints the error message(s) (if any) stored in a spxprm struct.
00048 *
00049 * The remaining routines are all vector conversions from one spectral
00050 * variable to another. The API of these functions only differ in whether the
00051 * rest frequency or wavelength need be supplied.
00052 *
00053 * Non-linear:
00054 *   - freqwave()      frequency          -> vacuum wavelength
00055 *   - wavefreq()      vacuum wavelength   -> frequency
00056 *
00057 *   - freqawav()      frequency          -> air wavelength
00058 *   - awavfreq()      air wavelength      -> frequency
00059 *
00060 *   - freqvelo()      frequency          -> relativistic velocity
00061 *   - velofreq()      relativistic velocity -> frequency
00062 *
00063 *   - waveawav()      vacuum wavelength   -> air wavelength
00064 *   - awavwave()      air wavelength      -> vacuum wavelength
00065 *
00066 *   - wavevelo()      vacuum wavelength   -> relativistic velocity
00067 *   - velowave()      relativistic velocity -> vacuum wavelength
00068 *
00069 *   - awavvelo()      air wavelength      -> relativistic velocity
00070 *   - veloawav()      relativistic velocity -> air wavelength
00071 *
00072 * Linear:
00073 *   - freqafreq()     frequency          -> angular frequency
00074 *   - afrqfreq()      angular frequency   -> frequency
00075 *
00076 *   - freqener()      frequency          -> energy
00077 *   - enerfreq()      energy             -> frequency
00078 *
00079 *   - freqwavn()      frequency          -> wave number
00080 *   - wavnfreq()      wave number         -> frequency
00081 *
00082 *   - freqvrad()      frequency          -> radio velocity
00083 *   - vradfreq()      radio velocity      -> frequency
00084 *
00085 *   - wavevopt()      vacuum wavelength   -> optical velocity
00086 *   - voptwave()      optical velocity     -> vacuum wavelength
00087 *
00088 *   - wavezopt()      vacuum wavelength   -> redshift
00089 *   - zoptwave()      redshift            -> vacuum wavelength
00090 *
00091 *   - velobeta()      relativistic velocity -> beta (= v/c)
00092 *   - betavelo()      beta (= v/c)        -> relativistic velocity
00093 *
00094 * These are the workhorse routines, to be used for fast transformations.
00095 * Conversions may be done "in place" by calling the routine with the output
00096 * vector set to the input.
00097 *
00098 * Air-to-vacuum wavelength conversion:
00099 * -----
00100 * The air-to-vacuum wavelength conversion in early drafts of WCS Paper III
00101 * cites Cox (ed., 2000, Allen's Astrophysical Quantities, AIP Press,
00102 * Springer-Verlag, New York), which itself derives from Edlén (1953, Journal
00103 * of the Optical Society of America, 43, 339). This is the IAU standard,
00104 * adopted in 1957 and again in 1991. No more recent IAU resolution replaces
00105 * this relation, and it is the one used by WCSLIB.
00106 *
00107 * However, the Cox relation was replaced in later drafts of Paper III, and as
00108 * eventually published, by the IUGG relation (1999, International Union of
00109 * Geodesy and Geophysics, comptes rendus of the 22nd General Assembly,
00110 * Birmingham UK, p111). There is a nearly constant ratio between the two,
00111 * with IUGG/Cox = 1.000015 over most of the range between 200nm and 10,000nm.
00112 *
00113 * The IUGG relation itself is derived from the work of Ciddor (1996, Applied
00114 * Optics, 35, 1566), which is used directly by the Sloan Digital Sky Survey.
00115 * It agrees closely with Cox; longwards of 2500nm, the ratio Ciddor/Cox is
00116 * fixed at 1.000000021, decreasing only slightly, to 1.000000018, at 1000nm.
00117 *
00118 * The Cox, IUGG, and Ciddor relations all accurately provide the wavelength

```

```

00119 * dependence of the air-to-vacuum wavelength conversion. However, for full
00120 * accuracy, the atmospheric temperature, pressure, and partial pressure of
00121 * water vapour must be taken into account. These will determine a small,
00122 * wavelength-independent scale factor and offset, which is not considered by
00123 * WCS Paper III.
00124 *
00125 * WCS Paper III is also silent on the question of the range of validity of the
00126 * air-to-vacuum wavelength conversion. Cox's relation would appear to be
00127 * valid in the range 200nm to 10,000nm. Both the Cox and the Ciddor relations
00128 * have singularities below 200nm, with Cox's at 156nm and 83nm. WCSLIB checks
00129 * neither the range of validity, nor for these singularities.
00130 *
00131 * Argument checking:
00132 * -----
00133 * The input spectral values are only checked for values that would result
00134 * in floating point exceptions. In particular, negative frequencies and
00135 * wavelengths are allowed, as are velocities greater than the speed of
00136 * light. The same is true for the spectral parameters - rest frequency and
00137 * wavelength.
00138 *
00139 * Accuracy:
00140 * -----
00141 * No warranty is given for the accuracy of these routines (refer to the
00142 * copyright notice); intending users must satisfy for themselves their
00143 * adequacy for the intended purpose. However, closure effectively to within
00144 * double precision rounding error was demonstrated by test routine tspec.c
00145 * which accompanies this software.
00146 *
00147 *
00148 * specx() - Spectral cross conversions (scalar)
00149 * -----
00150 * Given one spectral variable specx() computes all the others, plus the
00151 * required derivatives of each with respect to the others.
00152 *
00153 * Given:
00154 *   type          const char*
00155 *               The type of spectral variable given by spec, FREQ,
00156 *               AFRQ, ENER, WAVN, VRAD, WAVE, VOPT, ZOPT, AWAV, VELO,
00157 *               or BETA (case sensitive).
00158 *
00159 *   spec          double      The spectral variable given, in SI units.
00160 *
00161 *   restfrq,
00162 *   restwav      double      Rest frequency [Hz] or rest wavelength in vacuo [m],
00163 *                           only one of which need be given. The other should be
00164 *                           set to zero. If both are zero, only a subset of the
00165 *                           spectral variables can be computed, the remainder are
00166 *                           set to zero. Specifically, given one of FREQ, AFRQ,
00167 *                           ENER, WAVN, WAVE, or AWAV the others can be computed
00168 *                           without knowledge of the rest frequency. Likewise,
00169 *                           VRAD, VOPT, ZOPT, VELO, and BETA.
00170 *
00171 * Given and returned:
00172 *   specs          struct spxprm*
00173 *               Data structure containing all spectral variables and
00174 *               their derivatives, in SI units.
00175 *
00176 * Function return value:
00177 *   int            Status return value:
00178 *               0: Success.
00179 *               1: Null spxprm pointer passed.
00180 *               2: Invalid spectral parameters.
00181 *               3: Invalid spectral variable.
00182 *
00183 *               For returns > 1, a detailed error message is set in
00184 *               spxprm::err if enabled, see wcserr_enable().
00185 *
00186 * freqafrq(), afrqfreq(), freqener(), enerfreq(), freqwavn(), wavnfreq(),
00187 * freqwave(), wavefreq(), freqawav(), awavfreq(), waveawav(), awavwave(),
00188 * velobeta(), and betavelo() implement vector conversions between wave-like
00189 * or velocity-like spectral types (i.e. conversions that do not need the rest
00190 * frequency or wavelength). They all have the same API.
00191 *
00192 *
00193 * spxperr() - Print error messages from a spxprm struct
00194 * -----
00195 * spxperr() prints the error message(s) (if any) stored in a spxprm struct.
00196 * If there are no errors then nothing is printed. It uses wcserr_prt(), q.v.
00197 *
00198 * Given:
00199 *   spx            const struct spxprm*
00200 *               Spectral variables and their derivatives.
00201 *
00202 *   prefix         const char *
00203 *               If non-NULL, each output line will be prefixed with
00204 *               this string.
00205 *

```

```

00206 * Function return value:
00207 *         int          Status return value:
00208 *                 0: Success.
00209 *                 1: Null spxprm pointer passed.
00210 *
00211 *
00212 * freqafreq() - Convert frequency to angular frequency (vector)
00213 * -----
00214 * freqafreq() converts frequency to angular frequency.
00215 *
00216 * Given:
00217 *   param    double    Ignored.
00218 *
00219 *   nspec    int       Vector length.
00220 *
00221 *   instep,
00222 *   outstep  int       Vector strides.
00223 *
00224 *   inspec   const double[]
00225 *               Input spectral variables, in SI units.
00226 *
00227 * Returned:
00228 *   outspec  double[]  Output spectral variables, in SI units.
00229 *
00230 *   stat     int[]     Status return value for each vector element:
00231 *               0: Success.
00232 *               1: Invalid value of inspec.
00233 *
00234 * Function return value:
00235 *         int          Status return value:
00236 *                 0: Success.
00237 *                 2: Invalid spectral parameters.
00238 *                 4: One or more of the inspec coordinates were
00239 *                     invalid, as indicated by the stat vector.
00240 *
00241 *
00242 * freqvelo(), velofreq(), freqvrad(), and vradfreq() implement vector
00243 * conversions between frequency and velocity spectral types. They all have
00244 * the same API.
00245 *
00246 *
00247 * freqvelo() - Convert frequency to relativistic velocity (vector)
00248 * -----
00249 * freqvelo() converts frequency to relativistic velocity.
00250 *
00251 * Given:
00252 *   param    double    Rest frequency [Hz].
00253 *
00254 *   nspec    int       Vector length.
00255 *
00256 *   instep,
00257 *   outstep  int       Vector strides.
00258 *
00259 *   inspec   const double[]
00260 *               Input spectral variables, in SI units.
00261 *
00262 * Returned:
00263 *   outspec  double[]  Output spectral variables, in SI units.
00264 *
00265 *   stat     int[]     Status return value for each vector element:
00266 *               0: Success.
00267 *               1: Invalid value of inspec.
00268 *
00269 * Function return value:
00270 *         int          Status return value:
00271 *                 0: Success.
00272 *                 2: Invalid spectral parameters.
00273 *                 4: One or more of the inspec coordinates were
00274 *                     invalid, as indicated by the stat vector.
00275 *
00276 *
00277 * wavevelo(), velowave(), awavvelo(), veloawav(), wavevopt(), voptwave(),
00278 * wavezopt(), and zoptwave() implement vector conversions between wavelength
00279 * and velocity spectral types. They all have the same API.
00280 *
00281 *
00282 * wavevelo() - Conversions between wavelength and velocity types (vector)
00283 * -----
00284 * wavevelo() converts vacuum wavelength to relativistic velocity.
00285 *
00286 * Given:
00287 *   param    double    Rest wavelength in vacuo [m].
00288 *
00289 *   nspec    int       Vector length.
00290 *
00291 *   instep,
00292 *   outstep  int       Vector strides.

```

```

00293 *
00294 *   inspec      const double[]
00295 *               Input spectral variables, in SI units.
00296 *
00297 * Returned:
00298 *   outspec     double[]   Output spectral variables, in SI units.
00299 *
00300 *   stat        int[]      Status return value for each vector element:
00301 *                       0: Success.
00302 *                       1: Invalid value of inspec.
00303 *
00304 * Function return value:
00305 *   int         Status return value:
00306 *               0: Success.
00307 *               2: Invalid spectral parameters.
00308 *               4: One or more of the inspec coordinates were
00309 *                   invalid, as indicated by the stat vector.
00310 *
00311 *
00312 * spxprm struct - Spectral variables and their derivatives
00313 * -----
00314 * The spxprm struct contains the value of all spectral variables and their
00315 * derivatives. It is used solely by specx() which constructs it from
00316 * information provided via its function arguments.
00317 *
00318 * This struct should be considered read-only, no members need ever be set nor
00319 * should ever be modified by the user.
00320 *
00321 *   double restfrq
00322 *       (Returned) Rest frequency [Hz].
00323 *
00324 *   double restwav
00325 *       (Returned) Rest wavelength [m].
00326 *
00327 *   int wavetype
00328 *       (Returned) True if wave types have been computed, and ...
00329 *
00330 *   int velotype
00331 *       (Returned) ... true if velocity types have been computed; types are
00332 *       defined below.
00333 *
00334 *       If one or other of spxprm::restfrq and spxprm::restwav is given
00335 *       (non-zero) then all spectral variables may be computed. If both are
00336 *       given, restfrq is used. If restfrq and restwav are both zero, only wave
00337 *       characteristic xor velocity type spectral variables may be computed
00338 *       depending on the variable given. These flags indicate what is
00339 *       available.
00340 *
00341 *   double freq
00342 *       (Returned) Frequency [Hz] (wavetype).
00343 *
00344 *   double afrq
00345 *       (Returned) Angular frequency [rad/s] (wavetype).
00346 *
00347 *   double ener
00348 *       (Returned) Photon energy [J] (wavetype).
00349 *
00350 *   double wavn
00351 *       (Returned) Wave number [/m] (wavetype).
00352 *
00353 *   double vrad
00354 *       (Returned) Radio velocity [m/s] (velotype).
00355 *
00356 *   double wave
00357 *       (Returned) Vacuum wavelength [m] (wavetype).
00358 *
00359 *   double vopt
00360 *       (Returned) Optical velocity [m/s] (velotype).
00361 *
00362 *   double zopt
00363 *       (Returned) Redshift [dimensionless] (velotype).
00364 *
00365 *   double awav
00366 *       (Returned) Air wavelength [m] (wavetype).
00367 *
00368 *   double velo
00369 *       (Returned) Relativistic velocity [m/s] (velotype).
00370 *
00371 *   double beta
00372 *       (Returned) Relativistic beta [dimensionless] (velotype).
00373 *
00374 *   double dfreqafrq
00375 *       (Returned) Derivative of frequency with respect to angular frequency
00376 *       [/rad] (constant, = 1 / 2*pi), and ...
00377 *   double dafrqfreq
00378 *       (Returned) ... vice versa [rad] (constant, = 2*pi, always available).
00379 *

```

```

00380 * double dfreqener
00381 *     (Returned) Derivative of frequency with respect to photon energy
00382 *     [/J/s] (constant, = 1/h), and ...
00383 * double denerfreq
00384 *     (Returned) ... vice versa [Js] (constant, = h, Planck's constant,
00385 *     always available).
00386 *
00387 * double dfreqwavn
00388 *     (Returned) Derivative of frequency with respect to wave number [m/s]
00389 *     (constant, = c, the speed of light in vacuo), and ...
00390 * double dwavnfreq
00391 *     (Returned) ... vice versa [s/m] (constant, = 1/c, always available).
00392 *
00393 * double dfreqvrad
00394 *     (Returned) Derivative of frequency with respect to radio velocity [/m],
00395 *     and ...
00396 * double dvradfrefreq
00397 *     (Returned) ... vice versa [m] (wavetype && velotype).
00398 *
00399 * double dfreqwave
00400 *     (Returned) Derivative of frequency with respect to vacuum wavelength
00401 *     [/m/s], and ...
00402 * double dwavefreq
00403 *     (Returned) ... vice versa [m s] (wavetype).
00404 *
00405 * double dfreqawav
00406 *     (Returned) Derivative of frequency with respect to air wavelength,
00407 *     [/m/s], and ...
00408 * double dawavfreq
00409 *     (Returned) ... vice versa [m s] (wavetype).
00410 *
00411 * double dfreqvelo
00412 *     (Returned) Derivative of frequency with respect to relativistic
00413 *     velocity [/m], and ...
00414 * double dvelofreq
00415 *     (Returned) ... vice versa [m] (wavetype && velotype).
00416 *
00417 * double dwavevopt
00418 *     (Returned) Derivative of vacuum wavelength with respect to optical
00419 *     velocity [s], and ...
00420 * double dvoptwave
00421 *     (Returned) ... vice versa [/s] (wavetype && velotype).
00422 *
00423 * double dwavezopt
00424 *     (Returned) Derivative of vacuum wavelength with respect to redshift [m],
00425 *     and ...
00426 * double dzoptwave
00427 *     (Returned) ... vice versa [/m] (wavetype && velotype).
00428 *
00429 * double dwaveawav
00430 *     (Returned) Derivative of vacuum wavelength with respect to air
00431 *     wavelength [dimensionless], and ...
00432 * double dawavwave
00433 *     (Returned) ... vice versa [dimensionless] (wavetype).
00434 *
00435 * double dwavevelo
00436 *     (Returned) Derivative of vacuum wavelength with respect to relativistic
00437 *     velocity [s], and ...
00438 * double dvelowave
00439 *     (Returned) ... vice versa [/s] (wavetype && velotype).
00440 *
00441 * double dawavvelo
00442 *     (Returned) Derivative of air wavelength with respect to relativistic
00443 *     velocity [s], and ...
00444 * double dveloawav
00445 *     (Returned) ... vice versa [/s] (wavetype && velotype).
00446 *
00447 * double dvelobeta
00448 *     (Returned) Derivative of relativistic velocity with respect to
00449 *     relativistic beta [m/s] (constant, = c, the speed of light in vacuo),
00450 *     and ...
00451 * double dbetavelo
00452 *     (Returned) ... vice versa [s/m] (constant, = 1/c, always available).
00453 *
00454 * struct wcserr *err
00455 *     (Returned) If enabled, when an error status is returned, this struct
00456 *     contains detailed information about the error, see wcserr_enable().
00457 *
00458 * void *padding
00459 *     (An unused variable inserted for alignment purposes only.)
00460 *
00461 *
00462 * Global variable: const char *spx_errmsg[] - Status return messages
00463 * -----
00464 * Error messages to match the status value returned from each function.
00465 *
00466 * =====*/

```

```

00467
00468 #ifndef WCSLIB_SPEC
00469 #define WCSLIB_SPEC
00470
00471 #ifdef __cplusplus
00472 extern "C" {
00473 #endif
00474
00475 extern const char *spx_errmsg[];
00476
00477 enum spx_errmsg {
00478     SPXERR_SUCCESS           = 0, // Success.
00479     SPXERR_NULL_POINTER     = 1, // Null spxprm pointer passed.
00480     SPXERR_BAD_SPEC_PARAMS  = 2, // Invalid spectral parameters.
00481     SPXERR_BAD_SPEC_VAR     = 3, // Invalid spectral variable.
00482     SPXERR_BAD_INSPEC_COORD = 4, // One or more of the inspec coordinates were
00483                                   // invalid.
00484 };
00485
00486 struct spxprm {
00487     double restfrq, restwav; // Rest frequency [Hz] and wavelength [m].
00488
00489     int wavetype, velotype; // True if wave/velocity types have been
00490                             // computed; types are defined below.
00491
00492     // Spectral variables computed by specx().
00493     //-----
00494     double freq, // wavetype: Frequency [Hz].
00495            afrq, // wavetype: Angular frequency [rad/s].
00496            ener, // wavetype: Photon energy [J].
00497            wavn, // wavetype: Wave number [/m].
00498            vrad, // velotype: Radio velocity [m/s].
00499            wave, // wavetype: Vacuum wavelength [m].
00500            vopt, // velotype: Optical velocity [m/s].
00501            zopt, // velotype: Redshift.
00502            awav, // wavetype: Air wavelength [m].
00503            velo, // velotype: Relativistic velocity [m/s].
00504            beta; // velotype: Relativistic beta.
00505
00506     // Derivatives of spectral variables computed by specx().
00507     //-----
00508     double dfreqafrq, dafrqfreq, // Constant, always available.
00509            dfregener, denerfreq, // Constant, always available.
00510            dfreqwavn, dwavnfreq, // Constant, always available.
00511            dfreqvrad, dvradfreg, // wavetype && velotype.
00512            dfreqwave, dwavefreq, // wavetype.
00513            dfreqawav, dawavfreq, // wavetype.
00514            dfreqvelo, dvelofreg, // wavetype && velotype.
00515            dwavevopt, dvoptwave, // wavetype && velotype.
00516            dwavezopt, dzoptwave, // wavetype && velotype.
00517            dwaveawav, dawavwave, // wavetype.
00518            dwavevelo, dvelowave, // wavetype && velotype.
00519            dawavvelo, dveloawav, // wavetype && velotype.
00520            dvelobeta, dbetavelo; // Constant, always available.
00521
00522     // Error handling
00523     //-----
00524     struct wcserr *err;
00525
00526     // Private
00527     //-----
00528     void *padding; // (Dummy inserted for alignment purposes.)
00529 };
00530
00531 // Size of the spxprm struct in int units, used by the Fortran wrappers.
00532 #define SPXLEN (sizeof(struct spxprm)/sizeof(int))
00533
00534
00535 int specx(const char *type, double spec, double restfrq, double restwav,
00536          struct spxprm *specs);
00537
00538 int spxperr(const struct spxprm *spx, const char *prefix);
00539
00540 // For use in declaring function prototypes, e.g. in spcprm.
00541 #define SPX_ARGS double param, int nspec, int instep, int outstep, \
00542     const double inspec[], double outspec[], int stat[]
00543
00544 int freqafrq(SPX_ARGS);
00545 int afrqfreq(SPX_ARGS);
00546
00547 int freqener(SPX_ARGS);
00548 int enerfreq(SPX_ARGS);
00549
00550 int freqwavn(SPX_ARGS);
00551 int wavnfreq(SPX_ARGS);
00552
00553 int freqwave(SPX_ARGS);

```

```

00554 int wavefreq(SPX_ARGS);
00555
00556 int freqawav(SPX_ARGS);
00557 int awavfreq(SPX_ARGS);
00558
00559 int waveawav(SPX_ARGS);
00560 int awavwave(SPX_ARGS);
00561
00562 int velobeta(SPX_ARGS);
00563 int betavelo(SPX_ARGS);
00564
00565
00566 int freqvelo(SPX_ARGS);
00567 int velofreq(SPX_ARGS);
00568
00569 int freqvrad(SPX_ARGS);
00570 int vradfreq(SPX_ARGS);
00571
00572
00573 int wavevelo(SPX_ARGS);
00574 int velowave(SPX_ARGS);
00575
00576 int awavvelo(SPX_ARGS);
00577 int veloawav(SPX_ARGS);
00578
00579 int wavevopt(SPX_ARGS);
00580 int voptwave(SPX_ARGS);
00581
00582 int wavezopt(SPX_ARGS);
00583 int zoptwave(SPX_ARGS);
00584
00585
00586 #ifdef __cplusplus
00587 }
00588 #endif
00589
00590 #endif // WCSLIB_SPEC

```

## 8.21 tab.h File Reference

### Data Structures

- struct [tabprm](#)  
*Tabular transformation parameters.*

### Macros

- #define [TABLEN](#) (sizeof(struct [tabprm](#))/sizeof(int))  
*Size of the tabprm struct in int units.*
- #define [tabini\\_errmsg](#) [tab\\_errmsg](#)  
*Deprecated.*
- #define [tabcpy\\_errmsg](#) [tab\\_errmsg](#)  
*Deprecated.*
- #define [tabfree\\_errmsg](#) [tab\\_errmsg](#)  
*Deprecated.*
- #define [tabprt\\_errmsg](#) [tab\\_errmsg](#)  
*Deprecated.*
- #define [tabset\\_errmsg](#) [tab\\_errmsg](#)  
*Deprecated.*
- #define [tabx2s\\_errmsg](#) [tab\\_errmsg](#)  
*Deprecated.*
- #define [tabs2x\\_errmsg](#) [tab\\_errmsg](#)  
*Deprecated.*

## Enumerations

- enum `tabenq_enum` { `TABENQ_MEM` = 1 , `TABENQ_SET` = 2 , `TABENQ_BYE` = 4 }
- enum `tab_errmsg_enum` {  
`TABERR_SUCCESS` = 0 , `TABERR_NULL_POINTER` = 1 , `TABERR_MEMORY` = 2 , `TABERR_BAD_PARAMS`  
= 3 ,  
`TABERR_BAD_X` = 4 , `TABERR_BAD_WORLD` = 5 }

## Functions

- int `tabini` (int alloc, int M, const int K[], struct `tabprm` \*tab)  
*Default constructor for the tabprm struct.*
- int `tabmem` (struct `tabprm` \*tab)  
*Acquire tabular memory.*
- int `tabcpy` (int alloc, const struct `tabprm` \*tabsrc, struct `tabprm` \*tabdst)  
*Copy routine for the tabprm struct.*
- int `tabcmp` (int cmp, double tol, const struct `tabprm` \*tab1, const struct `tabprm` \*tab2, int \*equal)  
*Compare two tabprm structs for equality.*
- int `tabfree` (struct `tabprm` \*tab)  
*Destructor for the tabprm struct.*
- int `tabsize` (const struct `tabprm` \*tab, int size[2])  
*Compute the size of a tabprm struct.*
- int `tabenq` (const struct `tabprm` \*tab, int enquiry)  
*enquire about the state of a tabprm struct.*
- int `tabprt` (const struct `tabprm` \*tab)  
*Print routine for the tabprm struct.*
- int `taberr` (const struct `tabprm` \*tab, const char \*prefix)  
*Print error messages from a tabprm struct.*
- int `tabset` (struct `tabprm` \*tab)  
*Setup routine for the tabprm struct.*
- int `tabx2s` (struct `tabprm` \*tab, int ncoord, int nelelem, const double x[], double world[], int stat[])  
*Pixel-to-world transformation.*
- int `tabs2x` (struct `tabprm` \*tab, int ncoord, int nelelem, const double world[], double x[], int stat[])  
*World-to-pixel transformation.*

## Variables

- const char \* `tab_errmsg` []  
*Status return messages.*

### 8.21.1 Detailed Description

Routines in this suite implement the part of the FITS World Coordinate System (WCS) standard that deals with tabular coordinates, i.e. coordinates that are defined via a lookup table, as described in

"Representations of world coordinates in FITS",  
Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)

"Representations of spectral coordinates in FITS",  
Greisen, E.W., Calabretta, M.R., Valdes, F.G., & Allen, S.L.  
2006, A&A, 446, 747 (WCS Paper III)

These routines define methods to be used for computing tabular world coordinates from intermediate world coordinates (a linear transformation of image pixel coordinates), and vice versa. They are based on the `tabprm` struct which contains all information needed for the computations. The struct contains some members that must be set by the user, and others that are maintained by these routines, somewhat like a C++ class but with no encapsulation.

`tabini()`, `tabmem()`, `tabcpy()`, and `tabfree()` are provided to manage the `tabprm` struct, `tabsize()` computes its total size including allocated memory, `tabenq()` returns information about the state of the struct, and `tabprt()` prints its contents.

`tabperr()` prints the error message(s) (if any) stored in a `tabprm` struct.

A setup routine, `tabset()`, computes intermediate values in the `tabprm` struct from parameters in it that were supplied by the user. The struct always needs to be set up by `tabset()` but it need not be called explicitly - refer to the explanation of `tabprm::flag`.

`tabx2s()` and `tabs2x()` implement the WCS tabular coordinate transformations.

#### Accuracy:

No warranty is given for the accuracy of these routines (refer to the copyright notice); intending users must satisfy for themselves their adequacy for the intended purpose. However, closure effectively to within double precision rounding error was demonstrated by test routine `ttab.c` which accompanies this software.

### 8.21.2 Macro Definition Documentation

#### TABLEN

```
#define TABLEN (sizeof(struct tabprm)/sizeof(int))
```

Size of the `tabprm` struct in *int* units.

Size of the `tabprm` struct in *int* units, used by the Fortran wrappers.

#### tabini\_errmsg

```
#define tabini_errmsg tab_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use `tab_errmsg` directly now instead.

#### tabcpy\_errmsg

```
#define tabcpy_errmsg tab_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use `tab_errmsg` directly now instead.

**tabfree\_errmsg**

```
#define tabfree_errmsg tab_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [tab\\_errmsg](#) directly now instead.

**tabprt\_errmsg**

```
#define tabprt_errmsg tab_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [tab\\_errmsg](#) directly now instead.

**tabset\_errmsg**

```
#define tabset_errmsg tab_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [tab\\_errmsg](#) directly now instead.

**tabx2s\_errmsg**

```
#define tabx2s_errmsg tab_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [tab\\_errmsg](#) directly now instead.

**tabs2x\_errmsg**

```
#define tabs2x_errmsg tab_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [tab\\_errmsg](#) directly now instead.

---

**8.21.3 Enumeration Type Documentation****tabenq\_enum**

**Enumerator**

TABENQ_MEM	
TABENQ_SET	
TABENQ_BYP	

**tab\_errmsg\_enum**

```
enum tab_errmsg_enum
```

**Enumerator**

TABERR_SUCCESS	
TABERR_NULL_POINTER	
TABERR_MEMORY	
TABERR_BAD_PARAMS	
TABERR_BAD_X	
TABERR_BAD_WORLD	

**8.21.4 Function Documentation****tabini()**

```
int tabini (
    int alloc,
    int M,
    const int K[],
    struct tabprm * tab)
```

Default constructor for the tabprm struct.

**tabini()** allocates memory for arrays in a tabprm struct and sets all members of the struct to default values.

**PLEASE NOTE:** every tabprm struct should be initialized by **tabini()**, possibly repeatedly. On the first invocation, and only the first invocation, the flag member of the tabprm struct must be set to -1 to initialize memory management, regardless of whether **tabini()** will actually be used to allocate memory.

**Parameters**

in	<i>alloc</i>	If true, allocate memory unconditionally for arrays in the tabprm struct. If false, it is assumed that pointers to these arrays have been set by the user except if they are null pointers in which case memory will be allocated for them regardless. (In other words, setting alloc true saves having to initialize these pointers to zero.)
in	<i>M</i>	The number of tabular coordinate axes.

<code>in</code>	<code>K</code>	Vector of length $M$ whose elements $(K_1, K_2, \dots, K_M)$ record the lengths of the axes of the coordinate array and of each indexing vector. $M$ and $K[]$ are used to determine the length of the various <code>tabprm</code> arrays and therefore the amount of memory to allocate for them. Their values are copied into the <code>tabprm</code> struct. It is permissible to set $K$ (i.e. the address of the array) to zero which has the same effect as setting each element of $K[]$ to zero. In this case no memory will be allocated for the index vectors or coordinate array in the <code>tabprm</code> struct. These together with the $K$ vector must be set separately before calling <code>tabset()</code> .
<code>in, out</code>	<code>tab</code>	Tabular transformation parameters. Note that, in order to initialize memory management <code>tabprm::flag</code> should be set to -1 when <code>tab</code> is initialized for the first time (memory leaks may result if it had already been initialized).

### Returns

Status return value:

- 0: Success.
- 1: Null `tabprm` pointer passed.
- 2: Memory allocation failed.
- 3: Invalid tabular parameters.

For returns  $> 1$ , a detailed error message is set in `tabprm::err` if enabled, see `wcserr_enable()`.

### tabmem()

```
int tabmem (
    struct tabprm * tab)
```

Acquire tabular memory.

**tabmem()** takes control of memory allocated by the user for arrays in the `tabprm` struct.

### Parameters

<code>in, out</code>	<code>tab</code>	Tabular transformation parameters.
----------------------	------------------	------------------------------------

### Returns

Status return value:

- 0: Success.
- 1: Null `tabprm` pointer passed.
- 2: Memory allocation failed.

For returns  $> 1$ , a detailed error message is set in `tabprm::err` if enabled, see `wcserr_enable()`.

### tabcpy()

```
int tabcpy (
    int alloc,
    const struct tabprm * tabsrc,
    struct tabprm * tabdst)
```

Copy routine for the `tabprm` struct

**Parameters**

in	<i>alloc</i>	If true, allocate memory unconditionally for arrays in the <code>tabprm</code> struct. If false, it is assumed that pointers to these arrays have been set by the user except if they are null pointers in which case memory will be allocated for them regardless. (In other words, setting <code>alloc</code> true saves having to initialize these pointers to zero.)
in	<i>tabsrc</i>	Struct to copy from.
in, out	<i>tabdst</i>	Struct to copy to. <code>tabprm::flag</code> should be set to -1 if <code>tabdst</code> was not previously initialized (memory leaks may result if it was previously initialized).

**Returns**

Status return value:

- 0: Success.
- 1: Null `tabprm` pointer passed.
- 2: Memory allocation failed.

For returns > 1, a detailed error message is set in `tabprm::err` (associated with `tabdst`) if enabled, see `wcserr_enable()`.

**tabcmp()**

```
int tabcmp (
    int cmp,
    double tol,
    const struct tabprm * tab1,
    const struct tabprm * tab2,
    int * equal)
```

Compare two `tabprm` structs for equality.

**tabcmp()** compares two `tabprm` structs for equality.

**Parameters**

in	<i>cmp</i>	A bit field controlling the strictness of the comparison. At present, this value must always be 0, indicating a strict comparison. In the future, other options may be added.
in	<i>tol</i>	Tolerance for comparison of floating-point values. For example, for <code>tol == 1e-6</code> , all floating-point values in the structs must be equal to the first 6 decimal places. A value of 0 implies exact equality.
in	<i>tab1</i>	The first <code>tabprm</code> struct to compare.
in	<i>tab2</i>	The second <code>tabprm</code> struct to compare.
out	<i>equal</i>	Non-zero when the given structs are equal.

**Returns**

Status return value:

- 0: Success.
- 1: Null pointer passed.

**tabfree()**

```
int tabfree (
    struct tabprm * tab)
```

Destructor for the tabprm struct.

**tabfree()** frees memory allocated for the tabprm arrays by **tabini()**. **tabini()** records the memory it allocates and **tabfree()** will only attempt to free this.

**PLEASE NOTE:** **tabfree()** must not be invoked on a tabprm struct that was not initialized by **tabini()**.

**Parameters**

in, out	tab	Coordinate transformation parameters.
---------	-----	---------------------------------------

**Returns**

- Status return value:
- 0: Success.
  - 1: Null tabprm pointer passed.

**tabsize()**

```
int tabsize (
    const struct tabprm * tab,
    int size[2])
```

Compute the size of a tabprm struct.

**tabsize()** computes the full size of a tabprm struct, including allocated memory.

**Parameters**

in	tab	Tabular transformation parameters. If NULL, the base size of the struct and the allocated size are both set to zero.
out	sizes	The first element is the base size of the struct as returned by sizeof(struct tabprm). The second element is the total allocated size, in bytes, assuming that the allocation was done by <b>tabini()</b> . This figure includes memory allocated for the constituent struct, <b>tabprm::err</b> . It is not an error for the struct not to have been set up via <b>tabset()</b> , which normally results in additional memory allocation.

**Returns**

- Status return value:
- 0: Success.

**tabenq()**

```
int tabenq (
    const struct tabprm * tab,
```

Parameters

in	<i>tab</i>	Tabular transformation parameters.
in	<i>enquiry</i>	<div>Enquiry according to the following parameters:<ul style="list-style-type: none"><li>TABENQ_MEM: memory in the struct is being managed by WCSLIB (see <a href="#">tabini()</a>).</li><li>TABENQ_SET: the struct has been set up by <a href="#">tabset()</a>.</li><li>TABENQ_BYP: the struct is in bypass mode (see <a href="#">tabset()</a>).</li></ul><div>These may be combined by logical OR, e.g. TABENQ_MEM   TABENQ_SET. The enquiry result will be the logical AND of the individual results.</div></div>

Returns

Enquiry result:

- 0: No.
- 1: Yes.

tabprt()

```
int tabprt (  
    const struct tabprm * tab)
```

Print routine for the tabprm struct.

**tabprt()** prints the contents of a tabprm struct using [wcsprintf\(\)](#). Mainly intended for diagnostic purposes.

Parameters

in	<i>tab</i>	Tabular transformation parameters.
----	------------	------------------------------------

Returns

Status return value:

- 0: Success.
- 1: Null tabprm pointer passed.

tabperr()

```
int tabperr (  
    const struct tabprm * tab,  
    const char * prefix)
```

Print error messages from a tabprm struct.

**tabperr()** prints the error message(s) (if any) stored in a tabprm struct. If there are no errors then nothing is printed. It uses [wcserr\\_prt\(\)](#), q.v.

## Parameters

in	<i>tab</i>	Tabular transformation parameters.
in	<i>prefix</i>	If non-NULL, each output line will be prefixed with this string.

## Returns

Status return value:

- 0: Success.
- 1: Null tabprm pointer passed.

## tabset()

```
int tabset (
    struct tabprm * tab)
```

Setup routine for the tabprm struct.

**tabset()** allocates memory for work arrays in the tabprm struct and sets up the struct according to information supplied within it.

Note that this routine need not be called directly; it will be invoked by [tabx2s\(\)](#) and [tabs2x\(\)](#) if [tabprm::flag](#) is anything other than a predefined magic value.

**tabset()** normally operates regardless of the value of [tabprm::flag](#); i.e. even if a struct was previously set up it will be reset unconditionally. However, a tabprm struct may be put into "bypass" mode by invoking **tabset()** initially with [tabprm::flag](#) == 1 (rather than 0). **tabset()** will return immediately if invoked on a struct in that state. To take a struct out of bypass mode, simply reset [tabprm::flag](#) to zero. See also [tabenq\(\)](#).

## Parameters

in, out	<i>tab</i>	Tabular transformation parameters.
---------	------------	------------------------------------

## Returns

Status return value:

- 0: Success.
- 1: Null tabprm pointer passed.
- 3: Invalid tabular parameters.

For returns > 1, a detailed error message is set in [tabprm::err](#) if enabled, see [wcserr\\_enable\(\)](#).

## tabx2s()

```
int tabx2s (
    struct tabprm * tab,
    int ncoord,
    int nelelem,
    const double x[],
    double world[],
    int stat[])
```

**Parameters**

in, out	<i>tab</i>	Tabular transformation parameters.
in	<i>ncoord, nelem</i>	The number of coordinates, each of vector length nelem.
in	<i>x</i>	Array of intermediate world coordinates, SI units.
out	<i>world</i>	Array of world coordinates, in SI units.
out	<i>stat</i>	Status return value status for each coordinate: <ul style="list-style-type: none"> <li>• 0: Success.</li> <li>• 1: Invalid intermediate world coordinate.</li> </ul>

**Returns**

Status return value:

- 0: Success.
- 1: Null tabprm pointer passed.
- 3: Invalid tabular parameters.
- 4: One or more of the x coordinates were invalid, as indicated by the stat vector.

For returns > 1, a detailed error message is set in [tabprm::err](#) if enabled, see [wcserr\\_enable\(\)](#).

**tabs2x()**

```
int tabs2x (
    struct tabprm * tab,
    int ncoord,
    int nelem,
    const double world[],
    double x[],
    int stat[])
```

World-to-pixel transformation.

**tabs2x()** transforms world coordinates to intermediate world coordinates.

**Parameters**

in, out	<i>tab</i>	Tabular transformation parameters.
in	<i>ncoord, nelem</i>	The number of coordinates, each of vector length nelem.
in	<i>world</i>	Array of world coordinates, in SI units.
out	<i>x</i>	Array of intermediate world coordinates, SI units.

out	stat	Status return value status for each vector element: <ul style="list-style-type: none"> <li>• 0: Success.</li> <li>• 1: Invalid world coordinate.</li> </ul>
-----	------	---

## Returns

Status return value:

- 0: Success.
- 1: Null tabprm pointer passed.
- 3: Invalid tabular parameters.
- 5: One or more of the world coordinates were invalid, as indicated by the stat vector.

For returns > 1, a detailed error message is set in `tabprm::err` if enabled, see `wcserr_enable()`.

## 8.21.5 Variable Documentation

### tab\_errmsg

```
const char* tab_errmsg[] [extern]
```

Status return messages.

Error messages to match the status value returned from each function.

## 8.22 tab.h

[Go to the documentation of this file.](#)

```

00001 /*=====
00002  WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003  Copyright (C) 1995-2025, Mark Calabretta
00004
00005  This file is part of WCSLIB.
00006
00007  WCSLIB is free software: you can redistribute it and/or modify it under the
00008  terms of the GNU Lesser General Public License as published by the Free
00009  Software Foundation, either version 3 of the License, or (at your option)
00010  any later version.
00011
00012  WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013  WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
00014  FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015  more details.
00016
00017  You should have received a copy of the GNU Lesser General Public License
00018  along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020  Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021  http://www.atnf.csiro.au/people/Mark.Calabretta
00022  $Id: tab.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023 *=====
00024 *
00025 * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026 * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027 * overview of the library.
00028 *
00029 *
00030 * Summary of the tab routines

```

```

00031 * -----
00032 * Routines in this suite implement the part of the FITS World Coordinate
00033 * System (WCS) standard that deals with tabular coordinates, i.e. coordinates
00034 * that are defined via a lookup table, as described in
00035 *
00036 * "Representations of world coordinates in FITS",
00037 * Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)
00038 *
00039 * "Representations of spectral coordinates in FITS",
00040 * Greisen, E.W., Calabretta, M.R., Valdes, F.G., & Allen, S.L.
00041 * 2006, A&A, 446, 747 (WCS Paper III)
00042 *
00043 * These routines define methods to be used for computing tabular world
00044 * coordinates from intermediate world coordinates (a linear transformation
00045 * of image pixel coordinates), and vice versa. They are based on the tabprm
00046 * struct which contains all information needed for the computations. The
00047 * struct contains some members that must be set by the user, and others that
00048 * are maintained by these routines, somewhat like a C++ class but with no
00049 * encapsulation.
00050 *
00051 * tabini(), tabmem(), tabcpy(), and tabfree() are provided to manage the
00052 * tabprm struct, tabsize() computes its total size including allocated memory,
00053 * tabenq() returns information about the state of the struct, and tabprt()
00054 * prints its contents.
00055 *
00056 * tabperr() prints the error message(s) (if any) stored in a tabprm struct.
00057 *
00058 * A setup routine, tabset(), computes intermediate values in the tabprm struct
00059 * from parameters in it that were supplied by the user. The struct always
00060 * needs to be set up by tabset() but it need not be called explicitly - refer
00061 * to the explanation of tabprm::flag.
00062 *
00063 * tabx2s() and tabs2x() implement the WCS tabular coordinate transformations.
00064 *
00065 * Accuracy:
00066 * -----
00067 * No warranty is given for the accuracy of these routines (refer to the
00068 * copyright notice); intending users must satisfy for themselves their
00069 * adequacy for the intended purpose. However, closure effectively to within
00070 * double precision rounding error was demonstrated by test routine ttab.c
00071 * which accompanies this software.
00072 *
00073 *
00074 * tabini() - Default constructor for the tabprm struct
00075 * -----
00076 * tabini() allocates memory for arrays in a tabprm struct and sets all members
00077 * of the struct to default values.
00078 *
00079 * PLEASE NOTE: every tabprm struct should be initialized by tabini(), possibly
00080 * repeatedly. On the first invocation, and only the first invocation, the
00081 * flag member of the tabprm struct must be set to -1 to initialize memory
00082 * management, regardless of whether tabini() will actually be used to allocate
00083 * memory.
00084 *
00085 * Given:
00086 *   alloc      int      If true, allocate memory unconditionally for arrays in
00087 *                        the tabprm struct.
00088 *
00089 *                        If false, it is assumed that pointers to these arrays
00090 *                        have been set by the user except if they are null
00091 *                        pointers in which case memory will be allocated for
00092 *                        them regardless. (In other words, setting alloc true
00093 *                        saves having to initialize these pointers to zero.)
00094 *
00095 *   M           int      The number of tabular coordinate axes.
00096 *
00097 *   K           const int[]
00098 *                        Vector of length M whose elements (K_1, K_2,... K_M)
00099 *                        record the lengths of the axes of the coordinate array
00100 *                        and of each indexing vector. M and K[] are used to
00101 *                        determine the length of the various tabprm arrays and
00102 *                        therefore the amount of memory to allocate for them.
00103 *                        Their values are copied into the tabprm struct.
00104 *
00105 *                        It is permissible to set K (i.e. the address of the
00106 *                        array) to zero which has the same effect as setting
00107 *                        each element of K[] to zero. In this case no memory
00108 *                        will be allocated for the index vectors or coordinate
00109 *                        array in the tabprm struct. These together with the
00110 *                        K vector must be set separately before calling
00111 *                        tabset().
00112 *
00113 * Given and returned:
00114 *   tab         struct tabprm*
00115 *                        Tabular transformation parameters. Note that, in
00116 *                        order to initialize memory management tabprm::flag
00117 *                        should be set to -1 when tab is initialized for the

```

```

00118 *                first time (memory leaks may result if it had already
00119 *                been initialized).
00120 *
00121 * Function return value:
00122 *         int          Status return value:
00123 *                     0: Success.
00124 *                     1: Null tabprm pointer passed.
00125 *                     2: Memory allocation failed.
00126 *                     3: Invalid tabular parameters.
00127 *
00128 *                For returns > 1, a detailed error message is set in
00129 *                tabprm::err if enabled, see wcserr_enable().
00130 *
00131 *
00132 * tabmem() - Acquire tabular memory
00133 * -----
00134 * tabmem() takes control of memory allocated by the user for arrays in the
00135 * tabprm struct.
00136 *
00137 * Given and returned:
00138 *         tab          struct tabprm*
00139 *                     Tabular transformation parameters.
00140 *
00141 * Function return value:
00142 *         int          Status return value:
00143 *                     0: Success.
00144 *                     1: Null tabprm pointer passed.
00145 *                     2: Memory allocation failed.
00146 *
00147 *                For returns > 1, a detailed error message is set in
00148 *                tabprm::err if enabled, see wcserr_enable().
00149 *
00150 *
00151 * tabcpy() - Copy routine for the tabprm struct
00152 * -----
00153 * tabcpy() does a deep copy of one tabprm struct to another, using tabini() to
00154 * allocate memory for its arrays if required. Only the "information to be
00155 * provided" part of the struct is copied; a call to tabset() is required to
00156 * set up the remainder.
00157 *
00158 * Given:
00159 *         alloc        int          If true, allocate memory unconditionally for arrays in
00160 *                                     the tabprm struct.
00161 *
00162 *                                     If false, it is assumed that pointers to these arrays
00163 *                                     have been set by the user except if they are null
00164 *                                     pointers in which case memory will be allocated for
00165 *                                     them regardless. (In other words, setting alloc true
00166 *                                     saves having to initialize these pointers to zero.)
00167 *
00168 *         tabsrc       const struct tabprm*
00169 *                                     Struct to copy from.
00170 *
00171 * Given and returned:
00172 *         tabdst       struct tabprm*
00173 *                                     Struct to copy to. tabprm::flag should be set to -1
00174 *                                     if tabdst was not previously initialized (memory leaks
00175 *                                     may result if it was previously initialized).
00176 *
00177 * Function return value:
00178 *         int          Status return value:
00179 *                     0: Success.
00180 *                     1: Null tabprm pointer passed.
00181 *                     2: Memory allocation failed.
00182 *
00183 *                For returns > 1, a detailed error message is set in
00184 *                tabprm::err (associated with tabdst) if enabled, see
00185 *                wcserr_enable().
00186 *
00187 *
00188 * tabcmp() - Compare two tabprm structs for equality
00189 * -----
00190 * tabcmp() compares two tabprm structs for equality.
00191 *
00192 * Given:
00193 *         cmp          int          A bit field controlling the strictness of the
00194 *                                     comparison. At present, this value must always be 0,
00195 *                                     indicating a strict comparison. In the future, other
00196 *                                     options may be added.
00197 *
00198 *         tol          double       Tolerance for comparison of floating-point values.
00199 *                                     For example, for tol == 1e-6, all floating-point
00200 *                                     values in the structs must be equal to the first 6
00201 *                                     decimal places. A value of 0 implies exact equality.
00202 *
00203 *         tab1         const struct tabprm*
00204 *                                     The first tabprm struct to compare.

```

```

00205 *
00206 *   tab2      const struct tabprm*
00207 *           The second tabprm struct to compare.
00208 *
00209 * Returned:
00210 *   equal     int*      Non-zero when the given structs are equal.
00211 *
00212 * Function return value:
00213 *           int          Status return value:
00214 *               0: Success.
00215 *               1: Null pointer passed.
00216 *
00217 *
00218 * tabfree() - Destructor for the tabprm struct
00219 * -----
00220 * tabfree() frees memory allocated for the tabprm arrays by tabini().
00221 * tabini() records the memory it allocates and tabfree() will only attempt to
00222 * free this.
00223 *
00224 * PLEASE NOTE: tabfree() must not be invoked on a tabprm struct that was not
00225 * initialized by tabini().
00226 *
00227 * Given and returned:
00228 *   tab      struct tabprm*
00229 *           Coordinate transformation parameters.
00230 *
00231 * Function return value:
00232 *           int          Status return value:
00233 *               0: Success.
00234 *               1: Null tabprm pointer passed.
00235 *
00236 *
00237 * tabsize() - Compute the size of a tabprm struct
00238 * -----
00239 * tabsize() computes the full size of a tabprm struct, including allocated
00240 * memory.
00241 *
00242 * Given:
00243 *   tab      const struct tabprm*
00244 *           Tabular transformation parameters.
00245 *
00246 *           If NULL, the base size of the struct and the allocated
00247 *           size are both set to zero.
00248 *
00249 * Returned:
00250 *   sizes    int[2]      The first element is the base size of the struct as
00251 *                       returned by sizeof(struct tabprm). The second element
00252 *                       is the total allocated size, in bytes, assuming that
00253 *                       the allocation was done by tabini(). This figure
00254 *                       includes memory allocated for the constituent struct,
00255 *                       tabprm::err.
00256 *
00257 *           It is not an error for the struct not to have been set
00258 *           up via tabset(), which normally results in additional
00259 *           memory allocation.
00260 *
00261 * Function return value:
00262 *           int          Status return value:
00263 *               0: Success.
00264 *
00265 *
00266 * tabenq() - enquire about the state of a tabprm struct
00267 * -----
00268 * tabenq() may be used to obtain information about the state of a tabprm
00269 * struct. The function returns a true/false answer for the enquiry asked.
00270 *
00271 * Given:
00272 *   tab      const struct tabprm*
00273 *           Tabular transformation parameters.
00274 *
00275 *   enquiry  int          Enquiry according to the following parameters:
00276 *                       TABENQ_MEM: memory in the struct is being managed by
00277 *                       WCSLIB (see tabini()).
00278 *                       TABENQ_SET: the struct has been set up by tabset().
00279 *                       TABENQ_BYB: the struct is in bypass mode (see
00280 *                       tabset()).
00281 *                       These may be combined by logical OR, e.g.
00282 *                       TABENQ_MEM | TABENQ_SET. The enquiry result will be
00283 *                       the logical AND of the individual results.
00284 *
00285 * Function return value:
00286 *           int          Enquiry result:
00287 *               0: No.
00288 *               1: Yes.
00289 *
00290 *
00291 * tabprt() - Print routine for the tabprm struct

```

```

00292 * -----
00293 * tabprt() prints the contents of a tabprm struct using wcsprintf().  Mainly
00294 * intended for diagnostic purposes.
00295 *
00296 * Given:
00297 *   tab      const struct tabprm*
00298 *              Tabular transformation parameters.
00299 *
00300 * Function return value:
00301 *   int      Status return value:
00302 *             0: Success.
00303 *             1: Null tabprm pointer passed.
00304 *
00305 *
00306 * tabperr() - Print error messages from a tabprm struct
00307 * -----
00308 * tabperr() prints the error message(s) (if any) stored in a tabprm struct.
00309 * If there are no errors then nothing is printed.  It uses wcserr_prt(), q.v.
00310 *
00311 * Given:
00312 *   tab      const struct tabprm*
00313 *              Tabular transformation parameters.
00314 *
00315 *   prefix   const char *
00316 *              If non-NULL, each output line will be prefixed with
00317 *              this string.
00318 *
00319 * Function return value:
00320 *   int      Status return value:
00321 *             0: Success.
00322 *             1: Null tabprm pointer passed.
00323 *
00324 *
00325 * tabset() - Setup routine for the tabprm struct
00326 * -----
00327 * tabset() allocates memory for work arrays in the tabprm struct and sets up
00328 * the struct according to information supplied within it.
00329 *
00330 * Note that this routine need not be called directly; it will be invoked by
00331 * tabx2s() and tabs2x() if tabprm::flag is anything other than a predefined
00332 * magic value.
00333 *
00334 * tabset() normally operates regardless of the value of tabprm::flag; i.e.
00335 * even if a struct was previously set up it will be reset unconditionally.
00336 * However, a tabprm struct may be put into "bypass" mode by invoking tabset()
00337 * initially with tabprm::flag == 1 (rather than 0).  tabset() will return
00338 * immediately if invoked on a struct in that state.  To take a struct out of
00339 * bypass mode, simply reset tabprm::flag to zero.  See also tabenq().
00340 *
00341 * Given and returned:
00342 *   tab      struct tabprm*
00343 *              Tabular transformation parameters.
00344 *
00345 * Function return value:
00346 *   int      Status return value:
00347 *             0: Success.
00348 *             1: Null tabprm pointer passed.
00349 *             3: Invalid tabular parameters.
00350 *
00351 * For returns > 1, a detailed error message is set in
00352 * tabprm::err if enabled, see wcserr_enable().
00353 *
00354 *
00355 * tabx2s() - Pixel-to-world transformation
00356 * -----
00357 * tabx2s() transforms intermediate world coordinates to world coordinates
00358 * using coordinate lookup.
00359 *
00360 * Given and returned:
00361 *   tab      struct tabprm*
00362 *              Tabular transformation parameters.
00363 *
00364 * Given:
00365 *   ncoord,  int      The number of coordinates, each of vector length
00366 *   nelelem  nelelem  nelelem.
00367 *
00368 *
00369 *   x        const double[ncoord][nelelem]
00370 *              Array of intermediate world coordinates, SI units.
00371 *
00372 * Returned:
00373 *   world    double[ncoord][nelelem]
00374 *              Array of world coordinates, in SI units.
00375 *
00376 *   stat     int[ncoord]
00377 *              Status return value status for each coordinate:
00378 *             0: Success.

```

```

00379 *          1: Invalid intermediate world coordinate.
00380 *
00381 * Function return value:
00382 *      int      Status return value:
00383 *          0: Success.
00384 *          1: Null tabprm pointer passed.
00385 *          3: Invalid tabular parameters.
00386 *          4: One or more of the x coordinates were invalid,
00387 *             as indicated by the stat vector.
00388 *
00389 *          For returns > 1, a detailed error message is set in
00390 *          tabprm::err if enabled, see wcserr_enable().
00391 *
00392 *
00393 * tabs2x() - World-to-pixel transformation
00394 * -----
00395 * tabs2x() transforms world coordinates to intermediate world coordinates.
00396 *
00397 * Given and returned:
00398 *      tab      struct tabprm*
00399 *          Tabular transformation parameters.
00400 *
00401 * Given:
00402 *      ncoord,
00403 *      nelelem      int      The number of coordinates, each of vector length
00404 *                          nelelem.
00405 *      world      const double[ncoord][nelelem]
00406 *          Array of world coordinates, in SI units.
00407 *
00408 * Returned:
00409 *      x      double[ncoord][nelelem]
00410 *          Array of intermediate world coordinates, SI units.
00411 *      stat      int[ncoord]
00412 *          Status return value status for each vector element:
00413 *          0: Success.
00414 *          1: Invalid world coordinate.
00415 *
00416 * Function return value:
00417 *      int      Status return value:
00418 *          0: Success.
00419 *          1: Null tabprm pointer passed.
00420 *          3: Invalid tabular parameters.
00421 *          5: One or more of the world coordinates were
00422 *             invalid, as indicated by the stat vector.
00423 *
00424 *          For returns > 1, a detailed error message is set in
00425 *          tabprm::err if enabled, see wcserr_enable().
00426 *
00427 *
00428 * tabprm struct - Tabular transformation parameters
00429 * -----
00430 * The tabprm struct contains information required to transform tabular
00431 * coordinates. It consists of certain members that must be set by the user
00432 * ("given") and others that are set by the WCSLIB routines ("returned"). Some
00433 * of the latter are supplied for informational purposes while others are for
00434 * internal use only.
00435 *
00436 *      int flag
00437 *          (Given and returned) This flag must be set to zero (or 1, see tabset())
00438 *          whenever any of the following tabprm members are set or changed:
00439 *
00440 *          - tabprm::M (q.v., not normally set by the user),
00441 *          - tabprm::K (q.v., not normally set by the user),
00442 *          - tabprm::map,
00443 *          - tabprm::crval,
00444 *          - tabprm::index,
00445 *          - tabprm::coord.
00446 *
00447 *          This signals the initialization routine, tabset(), to recompute the
00448 *          returned members of the tabprm struct. tabset() will reset flag to
00449 *          indicate that this has been done.
00450 *
00451 *          PLEASE NOTE: flag should be set to -1 when tabini() is called for the
00452 *          first time for a particular tabprm struct in order to initialize memory
00453 *          management. It must ONLY be used on the first initialization otherwise
00454 *          memory leaks may result.
00455 *
00456 *      int M
00457 *          (Given or returned) Number of tabular coordinate axes.
00458 *
00459 *          If tabini() is used to initialize the tabprm struct (as would normally
00460 *          be the case) then it will set M from the value passed to it as a
00461 *          function argument. The user should not subsequently modify it.
00462 *
00463 *      int *K
00464 *          (Given or returned) Pointer to the first element of a vector of length
00465 *          tabprm::M whose elements (K_1, K_2, ... K_M) record the lengths of the

```

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00466 *      axes of the coordinate array and of each indexing vector.
00467 *
00468 *      If tabini() is used to initialize the tabprm struct (as would normally
00469 *      be the case) then it will set K from the array passed to it as a
00470 *      function argument. The user should not subsequently modify it.
00471 *
00472 *      int *map
00473 *      (Given) Pointer to the first element of a vector of length tabprm::M
00474 *      that defines the association between axis m in the M-dimensional
00475 *      coordinate array (1 <= m <= M) and the indices of the intermediate world
00476 *      coordinate and world coordinate arrays, x[] and world[], in the argument
00477 *      lists for tabx2s() and tabs2x().
00478 *
00479 *      When x[] and world[] contain the full complement of coordinate elements
00480 *      in image-order, as will usually be the case, then map[m-1] == i-1 for
00481 *      axis i in the N-dimensional image (1 <= i <= N). In terms of the FITS
00482 *      keywords
00483 *
00484 *      map[PVi_3a - 1] == i - 1.
00485 *
00486 *      However, a different association may result if x[], for example, only
00487 *      contains a (relevant) subset of intermediate world coordinate elements.
00488 *      For example, if M == 1 for an image with N > 1, it is possible to fill
00489 *      x[] with the relevant coordinate element with nelem set to 1. In this
00490 *      case map[0] = 0 regardless of the value of i.
00491 *
00492 *      double *crval
00493 *      (Given) Pointer to the first element of a vector of length tabprm::M
00494 *      whose elements contain the index value for the reference pixel for each
00495 *      of the tabular coordinate axes.
00496 *
00497 *      double **index
00498 *      (Given) Pointer to the first element of a vector of length tabprm::M of
00499 *      pointers to vectors of lengths (K_1, K_2,... K_M) of 0-relative indexes
00500 *      (see tabprm::K).
00501 *
00502 *      The address of any or all of these index vectors may be set to zero,
00503 *      i.e.
00504 *
00505 *      index[m] == 0;
00506 *
00507 *      this is interpreted as default indexing, i.e.
00508 *
00509 *      index[m][k] = k;
00510 *
00511 *      double *coord
00512 *      (Given) Pointer to the first element of the tabular coordinate array,
00513 *      treated as though it were defined as
00514 *
00515 *      double coord[K_M]...[K_2][K_1][M];
00516 *
00517 *      (see tabprm::K) i.e. with the M dimension varying fastest so that the
00518 *      M elements of a coordinate vector are stored contiguously in memory.
00519 *
00520 *      int nc
00521 *      (Returned) Total number of coordinate vectors in the coordinate array
00522 *      being the product K_1 * K_2 * ... * K_M (see tabprm::K).
00523 *
00524 *      int padding
00525 *      (An unused variable inserted for alignment purposes only.)
00526 *
00527 *      int *sense
00528 *      (Returned) Pointer to the first element of a vector of length tabprm::M
00529 *      whose elements indicate whether the corresponding indexing vector is
00530 *      monotonic increasing (+1), or decreasing (-1).
00531 *
00532 *      int *p0
00533 *      (Returned) Pointer to the first element of a vector of length tabprm::M
00534 *      of interpolated indices into the coordinate array such that Upsilon_m,
00535 *      as defined in Paper III, is equal to (p0[m] + 1) + tabprm::delta[m].
00536 *
00537 *      double *delta
00538 *      (Returned) Pointer to the first element of a vector of length tabprm::M
00539 *      of interpolated indices into the coordinate array such that Upsilon_m,
00540 *      as defined in Paper III, is equal to (tabprm::p0[m] + 1) + delta[m].
00541 *
00542 *      double *extrema
00543 *      (Returned) Pointer to the first element of an array that records the
00544 *      minimum and maximum value of each element of the coordinate vector in
00545 *      each row of the coordinate array, treated as though it were defined as
00546 *
00547 *      double extrema[K_M]...[K_2][2][M]
00548 *
00549 *      (see tabprm::K). The minimum is recorded in the first element of the
00550 *      compressed K_1 dimension, then the maximum. This array is used by the
00551 *      inverse table lookup function, tabs2x(), to speed up table searches.
00552 *

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00553 * struct wcserr *err
00554 * (Returned) If enabled, when an error status is returned, this struct
00555 * contains detailed information about the error, see wcserr_enable().
00556 *
00557 * int m_flag
00558 * (For internal use only.)
00559 * int m_M
00560 * (For internal use only.)
00561 * int m_N
00562 * (For internal use only.)
00563 * int set_M
00564 * (For internal use only.)
00565 * int m_K
00566 * (For internal use only.)
00567 * int m_map
00568 * (For internal use only.)
00569 * int m_crval
00570 * (For internal use only.)
00571 * int m_index
00572 * (For internal use only.)
00573 * int m_indxs
00574 * (For internal use only.)
00575 * int m_coord
00576 * (For internal use only.)
00577 *
00578 *
00579 * Global variable: const char *tab_errmsg[] - Status return messages
00580 * -----
00581 * Error messages to match the status value returned from each function.
00582 *
00583 *=====*/
00584
00585 #ifndef WCSLIB_TAB
00586 #define WCSLIB_TAB
00587
00588 #ifdef __cplusplus
00589 extern "C" {
00590 #endif
00591
00592 enum tabenq_enum {
00593     TABENQ_MEM = 1,           // tabprm struct memory is managed by WCSLIB.
00594     TABENQ_SET = 2,           // tabprm struct has been set up.
00595     TABENQ_BYP = 4,           // tabprm struct is in bypass mode.
00596 };
00597
00598 extern const char *tab_errmsg[];
00599
00600 enum tab_errmsg_enum {
00601     TABERR_SUCCESS = 0,       // Success.
00602     TABERR_NULL_POINTER = 1,  // Null tabprm pointer passed.
00603     TABERR_MEMORY = 2,        // Memory allocation failed.
00604     TABERR_BAD_PARAMS = 3,    // Invalid tabular parameters.
00605     TABERR_BAD_X = 4,         // One or more of the x coordinates were
00606                               // invalid.
00607     TABERR_BAD_WORLD = 5     // One or more of the world coordinates were
00608                               // invalid.
00609 };
00610
00611 struct tabprm {
00612     // Initialization flag (see the prologue above).
00613     //-----
00614     int flag;                  // Set to zero to force initialization.
00615
00616     // Parameters to be provided (see the prologue above).
00617     //-----
00618     int M;                    // Number of tabular coordinate axes.
00619     int *K;                   // Vector of length M whose elements
00620                               // (K_1, K_2, ... K_M) record the lengths of
00621                               // the axes of the coordinate array and of
00622                               // each indexing vector.
00623     int *map;                 // Vector of length M usually such that
00624                               // map[m-1] == i-1 for coordinate array
00625                               // axis m and image axis i (see above).
00626     double *crval;            // Vector of length M containing the index
00627                               // value for the reference pixel for each
00628                               // of the tabular coordinate axes.
00629     double **index;           // Vector of pointers to M indexing vectors
00630                               // of lengths (K_1, K_2, ... K_M).
00631     double *coord;            // (1+M)-dimensional tabular coordinate
00632                               // array (see above).
00633
00634     // Information derived from the parameters supplied.
00635     //-----
00636     int nc;                   // Number of coordinate vectors (of length
00637                               // M) in the coordinate array.
00638     int padding;              // (Dummy inserted for alignment purposes.)
00639     int *sense;               // Vector of M flags that indicate whether

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00640                                     // the Mth indexing vector is monotonic
00641                                     // increasing, or else decreasing.
00642     int      *p0;                      // Vector of M indices.
00643     double   *delta;                  // Vector of M increments.
00644     double   *extrema;                // (1+M)-dimensional array of coordinate
00645                                     // extrema.
00646
00647     // Error messaging, if enabled.
00648     //-----
00649     struct wcserr *err;
00650
00651     //-----
00652     // Private - the remainder are for internal use.
00653     //-----
00654                                     // Memory management.
00655     int      m_flag, m_M, m_N;
00656     int      set_M;
00657     int      *m_K, *m_map;
00658     double   *m_crval, **m_index, **m_indxs, *m_coord;
00659 };
00660
00661 // Size of the tabprm struct in int units, used by the Fortran wrappers.
00662 #define TABLEN (sizeof(struct tabprm)/sizeof(int))
00663
00664
00665 int tabini(int alloc, int M, const int K[], struct tabprm *tab);
00666
00667 int tabmem(struct tabprm *tab);
00668
00669 int tabcpy(int alloc, const struct tabprm *tabsrc, struct tabprm *tabdst);
00670
00671 int tabcmp(int cmp, double tol, const struct tabprm *tab1,
00672            const struct tabprm *tab2, int *equal);
00673
00674 int tabfree(struct tabprm *tab);
00675
00676 int tabsize(const struct tabprm *tab, int size[2]);
00677
00678 int tabenq(const struct tabprm *tab, int enquiry);
00679
00680 int tabprt(const struct tabprm *tab);
00681
00682 int tabperr(const struct tabprm *tab, const char *prefix);
00683
00684 int tabset(struct tabprm *tab);
00685
00686 int tabx2s(struct tabprm *tab, int ncoord, int nele, const double x[],
00687            double world[], int stat[]);
00688
00689 int tabs2x(struct tabprm *tab, int ncoord, int nele, const double world[],
00690            double x[], int stat[]);
00691
00692
00693 // Deprecated.
00694 #define tabini_errmsg tab_errmsg
00695 #define tabcpy_errmsg tab_errmsg
00696 #define tabfree_errmsg tab_errmsg
00697 #define tabprt_errmsg tab_errmsg
00698 #define tabset_errmsg tab_errmsg
00699 #define tabx2s_errmsg tab_errmsg
00700 #define tabs2x_errmsg tab_errmsg
00701
00702 #ifdef __cplusplus
00703 }
00704 #endif
00705
00706 #endif // WCSLIB_TAB

```

## 8.23 wcs.h File Reference

```

#include "lin.h"
#include "cel.h"
#include "spc.h"

```

### Data Structures

- struct [pvcards](#)

- *Store for **PV**<sub>i</sub><sub>ma</sub> keyrecords.*
- struct [pscard](#)
  - *Store for **PS**<sub>i</sub><sub>ma</sub> keyrecords.*
- struct [auxprm](#)
  - *Additional auxiliary parameters.*
- struct [wcsprm](#)
  - *Coordinate transformation parameters.*

## Macros

- #define [WCSSUB\\_LONGITUDE](#) 0x1001
  - *Mask for extraction of longitude axis by [wcsub\(\)](#).*
- #define [WCSSUB\\_LATITUDE](#) 0x1002
  - *Mask for extraction of latitude axis by [wcsub\(\)](#).*
- #define [WCSSUB\\_CUBEFACE](#) 0x1004
  - *Mask for extraction of **CUBEFACE** axis by [wcsub\(\)](#).*
- #define [WCSSUB\\_CELESTIAL](#) 0x1007
  - *Mask for extraction of celestial axes by [wcsub\(\)](#).*
- #define [WCSSUB\\_SPECTRAL](#) 0x1008
  - *Mask for extraction of spectral axis by [wcsub\(\)](#).*
- #define [WCSSUB\\_STOKES](#) 0x1010
  - *Mask for extraction of **STOKES** axis by [wcsub\(\)](#).*
- #define [WCSSUB\\_TIME](#) 0x1020
- #define [WCSCOMPARE Ancillary](#) 0x0001
- #define [WCSCOMPARE\\_TILING](#) 0x0002
- #define [WCSCOMPARE\\_CRPIX](#) 0x0004
- #define [PVLEN](#) (sizeof(struct [pvcard](#))/sizeof(int))
- #define [PSLEN](#) (sizeof(struct [pscard](#))/sizeof(int))
- #define [AUXLEN](#) (sizeof(struct [auxprm](#))/sizeof(int))
- #define [WCSLEN](#) (sizeof(struct [wcsprm](#))/sizeof(int))
  - *Size of the [wcsprm](#) struct in int units.*
- #define [wcscopy](#)(alloc, wcssrc, wcsdst)
  - *Copy routine for the [wcsprm](#) struct.*
- #define [wcsini\\_errmsg](#) [wcs\\_errmsg](#)
  - *Deprecated.*
- #define [wcsub\\_errmsg](#) [wcs\\_errmsg](#)
  - *Deprecated.*
- #define [wcscopy\\_errmsg](#) [wcs\\_errmsg](#)
  - *Deprecated.*
- #define [wcsfree\\_errmsg](#) [wcs\\_errmsg](#)
  - *Deprecated.*
- #define [wcsprt\\_errmsg](#) [wcs\\_errmsg](#)
  - *Deprecated.*
- #define [wcsset\\_errmsg](#) [wcs\\_errmsg](#)
  - *Deprecated.*
- #define [wcsp2s\\_errmsg](#) [wcs\\_errmsg](#)
  - *Deprecated.*
- #define [wcsp2p\\_errmsg](#) [wcs\\_errmsg](#)
  - *Deprecated.*
- #define [wcmix\\_errmsg](#) [wcs\\_errmsg](#)
  - *Deprecated.*

## Enumerations

- enum `wcsenq_enum` { `WCSENQ_MEM` = 1 , `WCSENQ_SET` = 2 , `WCSENQ_BYE` = 4 , `WCSENQ_CHK` = 8 }
- enum `wcs_errmsg_enum` {  
`WCSERR_SUCCESS` = 0 , `WCSERR_NULL_POINTER` = 1 , `WCSERR_MEMORY` = 2 , `WCSERR_SINGULAR_MTX` = 3 ,  
`WCSERR_BAD_CTYPE` = 4 , `WCSERR_BAD_PARAM` = 5 , `WCSERR_BAD_COORD_TRANS` = 6 ,  
`WCSERR_ILL_COORD_TRANS` = 7 ,  
`WCSERR_BAD_PIX` = 8 , `WCSERR_BAD_WORLD` = 9 , `WCSERR_BAD_WORLD_COORD` = 10 ,  
`WCSERR_NO_SOLUTION` = 11 ,  
`WCSERR_BAD_SUBIMAGE` = 12 , `WCSERR_NON_SEPARABLE` = 13 , `WCSERR_UNSET` = 14 }

## Functions

- int `wcsnpv` (int n)  
*Memory allocation for **PV**<sub>i</sub>\_**ma**.*
- int `wcsnps` (int n)  
*Memory allocation for **PS**<sub>i</sub>\_**ma**.*
- int `wcsini` (int alloc, int naxis, struct `wcsprm` \*wcs)  
*Default constructor for the `wcsprm` struct.*
- int `wcsinit` (int alloc, int naxis, struct `wcsprm` \*wcs, int npvmax, int npsmax, int ndpmax)  
*Default constructor for the `wcsprm` struct.*
- int `wcsauxi` (int alloc, struct `wcsprm` \*wcs)  
*Default constructor for the `auxprm` struct.*
- int `wcssub` (int alloc, const struct `wcsprm` \*wcsrc, int \*nsub, int axes[], struct `wcsprm` \*wcstdst)  
*Subimage extraction routine for the `wcsprm` struct.*
- int `wcscompare` (int cmp, double tol, const struct `wcsprm` \*wcs1, const struct `wcsprm` \*wcs2, int \*equal)  
*Compare two `wcsprm` structs for equality.*
- int `wcsfree` (struct `wcsprm` \*wcs)  
*Destructor for the `wcsprm` struct.*
- int `wcstrim` (struct `wcsprm` \*wcs)  
*Free unused arrays in the `wcsprm` struct.*
- int `wcssize` (const struct `wcsprm` \*wcs, int sizes[2])  
*Compute the size of a `wcsprm` struct.*
- int `auxsize` (const struct `auxprm` \*aux, int sizes[2])  
*Compute the size of a `auxprm` struct.*
- int `wcsenq` (const struct `wcsprm` \*wcs, int enquiry)  
*enquire about the state of a `wcsprm` struct.*
- int `wcsprt` (const struct `wcsprm` \*wcs)  
*Print routine for the `wcsprm` struct.*
- int `wcsperr` (const struct `wcsprm` \*wcs, const char \*prefix)  
*Print error messages from a `wcsprm` struct.*
- int `wcsbchk` (struct `wcsprm` \*wcs, int bounds)  
*Enable/disable bounds checking.*
- int `wcsset` (struct `wcsprm` \*wcs)  
*Setup routine for the `wcsprm` struct.*
- int `wcsp2s` (struct `wcsprm` \*wcs, int ncoord, int nele, const double pixcrd[], double imgcrd[], double phi[], double theta[], double world[], int stat[])  
*Pixel-to-world transformation.*
- int `wcss2p` (struct `wcsprm` \*wcs, int ncoord, int nele, const double world[], double phi[], double theta[], double imgcrd[], double pixcrd[], int stat[])

*World-to-pixel transformation.*

- int `wcsmix` (struct `wcsprm` \*wcs, int mixpix, int mixcel, const double vspan[2], double vstep, int viter, double world[], double phi[], double theta[], double imgcrd[], double pixcrd[])

*Hybrid coordinate transformation.*

- int `wscsccs` (struct `wcsprm` \*wcs, double lng2p1, double lat2p1, double lng1p2, const char \*clng, const char \*clat, const char \*radesys, double equinox, const char \*alt)

*Change celestial coordinate system.*

- int `wcssptr` (struct `wcsprm` \*wcs, int \*i, char ctype[9])

*Spectral axis translation.*

- const char \* `wcslib_version` (int vers[3])

## Variables

- const char \* `wcs_errmsg` []

*Status return messages.*

### 8.23.1 Detailed Description

Routines in this suite implement the FITS World Coordinate System (WCS) standard which defines methods to be used for computing world coordinates from image pixel coordinates, and vice versa. The standard, and proposed extensions for handling distortions, are described in

"Representations of world coordinates in FITS",  
Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)

"Representations of celestial coordinates in FITS",  
Calabretta, M.R., & Greisen, E.W. 2002, A&A, 395, 1077 (WCS Paper II)

"Representations of spectral coordinates in FITS",  
Greisen, E.W., Calabretta, M.R., Valdes, F.G., & Allen, S.L.  
2006, A&A, 446, 747 (WCS Paper III)

"Representations of distortions in FITS world coordinate systems",  
Calabretta, M.R. et al. (WCS Paper IV, draft dated 2004/04/22),  
available from <http://www.atnf.csiro.au/people/Mark.Calabretta>

"Mapping on the HEALPix grid",  
Calabretta, M.R., & Roukema, B.F. 2007, MNRAS, 381, 865 (WCS Paper V)

"Representing the 'Butterfly' Projection in FITS -- Projection Code XPH",  
Calabretta, M.R., & Lowe, S.R. 2013, PASA, 30, e050 (WCS Paper VI)

"Representations of time coordinates in FITS -  
Time and relative dimension in space",  
Rots, A.H., Bunclark, P.S., Calabretta, M.R., Allen, S.L.,  
Manchester, R.N., & Thompson, W.T. 2015, A&A, 574, A36 (WCS Paper VII)

These routines are based on the `wcsprm` struct which contains all information needed for the computations. The struct contains some members that must be set by the user, and others that are maintained by these routines, somewhat like a C++ class but with no encapsulation.

`wcsnpv()`, `wcsnps()`, `wcsini()`, `wcsinit()`, `wcssub()`, `wcsfree()`, and `wcstrim()`, are provided to manage the `wcsprm` struct, `wcssize()` computes its total size including allocated memory, `wcsenq()` returns information about the state of the struct, and `wcsprt()` prints its contents. `wcscopy()`, which does a deep copy of one `wcsprm` struct to another, is defined as a preprocessor macro function that invokes `wcssub()`.

`wcsper()` prints the error message(s) (if any) stored in a `wcsprm` struct, and the `linprm`, `celprm`, `priprm`, `spcprm`, and `tabprm` structs that it contains.

A setup routine, `wcsset()`, computes intermediate values in the `wcsprm` struct from parameters in it that were supplied by the user. The struct always needs to be set up by `wcsset()` but this need not be called explicitly - refer to the explanation of `wcsprm::flag`.

[wcsp2s\(\)](#) and [wcsp2p\(\)](#) implement the WCS world coordinate transformations. In fact, they are high level driver routines for the WCS linear, logarithmic, celestial, spectral and tabular transformation routines described in [lin.h](#), [log.h](#), [cel.h](#), [spc.h](#) and [tab.h](#).

Given either the celestial longitude or latitude plus an element of the pixel coordinate a hybrid routine, [wcmix\(\)](#), iteratively solves for the unknown elements.

[wcscs\(\)](#) changes the celestial coordinate system of a `wcsprm` struct, for example, from equatorial to galactic, and [wcsptr\(\)](#) translates the spectral axis. For example, a '**FREQ**' axis may be translated into '**ZOPT-F2W**' and vice versa.

[wcslib\\_version\(\)](#) returns the WCSLIB version number.

#### Quadcube projections:

The quadcube projections (**TSC**, **CSC**, **QSC**) may be represented in FITS in either of two ways:

a: The six faces may be laid out in one plane and numbered as follows:

```

      0
    4 3 2 1 4 3 2
      5

```

Faces 2, 3 and 4 may appear on one side or the other (or both). The world-to-pixel routines map faces 2, 3 and 4 to the left but the pixel-to-world routines accept them on either side.

b: The "COBE" convention in which the six faces are stored in a three-dimensional structure using a **CUBEFACE** axis indexed from 0 to 5 as above.

These routines support both methods; [wcsset\(\)](#) determines which is being used by the presence or absence of a **CUBEFACE** axis in `ctype[]`. [wcsp2s\(\)](#) and [wcsp2p\(\)](#) translate the **CUBEFACE** axis representation to the single plane representation understood by the lower-level WCSLIB projection routines.

### 8.23.2 Macro Definition Documentation

#### WCSSUB\_LONGITUDE

```
#define WCSSUB_LONGITUDE 0x1001
```

Mask for extraction of longitude axis by [wcsub\(\)](#).

Mask to use for extracting the longitude axis when sub-imaging, refer to the *axes* argument of [wcsub\(\)](#).

#### WCSSUB\_LATITUDE

```
#define WCSSUB_LATITUDE 0x1002
```

Mask for extraction of latitude axis by [wcsub\(\)](#).

Mask to use for extracting the latitude axis when sub-imaging, refer to the *axes* argument of [wcsub\(\)](#).

## WCSSUB\_CUBEFACE

```
#define WCSSUB_CUBEFACE 0x1004
```

Mask for extraction of **CUBEFACE** axis by [wcsub\(\)](#).

Mask to use for extracting the **CUBEFACE** axis when sub-imaging, refer to the *axes* argument of [wcsub\(\)](#).

## WCSSUB\_CELESTIAL

```
#define WCSSUB_CELESTIAL 0x1007
```

Mask for extraction of celestial axes by [wcsub\(\)](#).

Mask to use for extracting the celestial axes (longitude, latitude and cubeface) when sub-imaging, refer to the *axes* argument of [wcsub\(\)](#).

## WCSSUB\_SPECTRAL

```
#define WCSSUB_SPECTRAL 0x1008
```

Mask for extraction of spectral axis by [wcsub\(\)](#).

Mask to use for extracting the spectral axis when sub-imaging, refer to the *axes* argument of [wcsub\(\)](#).

## WCSSUB\_STOKES

```
#define WCSSUB_STOKES 0x1010
```

Mask for extraction of **STOKES** axis by [wcsub\(\)](#).

Mask to use for extracting the **STOKES** axis when sub-imaging, refer to the *axes* argument of [wcsub\(\)](#).

## WCSSUB\_TIME

```
#define WCSSUB_TIME 0x1020
```

## WCSCOMPARE Ancillary

```
#define WCSCOMPARE Ancillary 0x0001
```

## WCSCOMPARE\_TILING

```
#define WCSCOMPARE_TILING 0x0002
```

## WCSCOMPARE\_CRPIX

```
#define WCSCOMPARE_CRPIX 0x0004
```

## PVLEN

```
#define PVLEN (sizeof(struct pvcards)/sizeof(int))
```

## PSLEN

```
#define PSLEN (sizeof(struct pscards)/sizeof(int))
```

## AUXLEN

```
#define AUXLEN (sizeof(struct auxprm)/sizeof(int))
```

## WCSLEN

```
#define WCSLEN (sizeof(struct wcsprm)/sizeof(int))
```

Size of the `wcsprm` struct in int units.

Size of the `wcsprm` struct in *int* units, used by the Fortran wrappers.

## wscopy

```
#define wscopy(  
    alloc,  
    wcssrc,  
    wcsdst)
```

### Value:

```
wcssub(alloc, wcssrc, 0x0, 0x0, wcsdst)
```

Copy routine for the `wcsprm` struct.

**wscopy()** does a deep copy of one `wcsprm` struct to another. As of WCSLIB 3.6, it is implemented as a preprocessor macro that invokes `wcssub()` with the `nsub` and `axes` pointers both set to zero.

## wcsini\_errmsg

```
#define wcsini_errmsg wcs_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use `wcs_errmsg` directly now instead.

**wcssub\_errmsg**

```
#define wcssub_errmsg wcs\_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [wcs\\_errmsg](#) directly now instead.

**wscopy\_errmsg**

```
#define wscopy_errmsg wcs\_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [wcs\\_errmsg](#) directly now instead.

**wcsfree\_errmsg**

```
#define wcsfree_errmsg wcs\_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [wcs\\_errmsg](#) directly now instead.

**wcsprt\_errmsg**

```
#define wcsprt_errmsg wcs\_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [wcs\\_errmsg](#) directly now instead.

**wcsset\_errmsg**

```
#define wcsset_errmsg wcs\_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [wcs\\_errmsg](#) directly now instead.

**wcsp2s\_errmsg**

```
#define wcsp2s_errmsg wcs_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [wcs\\_errmsg](#) directly now instead.

**wcss2p\_errmsg**

```
#define wcss2p_errmsg wcs_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [wcs\\_errmsg](#) directly now instead.

**wcsmix\_errmsg**

```
#define wcsmix_errmsg wcs_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [wcs\\_errmsg](#) directly now instead.

### 8.23.3 Enumeration Type Documentation

**wcsenq\_enum**

```
enum wcsenq_enum
```

**Enumerator**

WCSENQ_MEM	
WCSENQ_SET	
WCSENQ_BYP	
WCSENQ_CHK	

**wcs\_errmsg\_enum**

```
enum wcs_errmsg_enum
```

**Enumerator**

WCSERR_SUCCESS	
WCSERR_NULL_POINTER	
WCSERR_MEMORY	
WCSERR_SINGULAR_MTX	
WCSERR_BAD_CTYPE	
WCSERR_BAD_PARAM	
WCSERR_BAD_COORD_TRANS	
WCSERR_ILL_COORD_TRANS	
WCSERR_BAD_PIX	
WCSERR_BAD_WORLD	
WCSERR_BAD_WORLD_COORD	
WCSERR_NO_SOLUTION	
WCSERR_BAD_SUBIMAGE	
WCSERR_NON_SEPARABLE	
WCSERR_UNSET	

**8.23.4 Function Documentation****wcsnpv()**

```
int wcsnpv (
    int n)
```

Memory allocation for **PV**<sub>i</sub>\_ma.

**wcsnpv()** sets or gets the value of NPVMAX (default 64). This global variable controls the number of pvcards structs, for holding **PV**<sub>i</sub>\_ma keyvalues, that [wcsini\(\)](#) should allocate space for. It is also used by [wcsinit\(\)](#) as the default value of npvmax.

**PLEASE NOTE:** This function is not thread-safe.

**Parameters**

in	<i>n</i>	Value of NPVMAX; ignored if < 0. Use a value less than zero to get the current value.
----	----------	---

**Returns**

Current value of NPVMAX.

**wcsnps()**

```
int wcsnps (
    int n)
```

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**wcsnps()** sets or gets the value of NPSMAX (default 8). This global variable controls the number of pscard structs, for holding **PS**<sub>i</sub>\_ma keyvalues, that [wcsini\(\)](#) should allocate space for. It is also used by [wcsinit\(\)](#) as the default

## Parameters

in	<i>n</i>	Value of NPSMAX; ignored if < 0. Use a value less than zero to get the current value.
----	----------	---

## Returns

Current value of NPSMAX.

## wcsini()

```
int wcsini (
    int alloc,
    int naxis,
    struct wcsprm * wcs)
```

Default constructor for the wcsprm struct.

**wcsini()** is a thin wrapper on **wcsinit()**. It invokes it with npvmax, npsmax, and ndpmax set to -1 which causes it to use the values of the global variables NDPMAX, NPSMAX, and NDPMAX. It is thereby potentially thread-unsafe if these variables are altered dynamically via [wcsnpv\(\)](#), [wcsnps\(\)](#), and [disndp\(\)](#). Use **wcsinit()** for a thread-safe alternative in this case.

## wcsinit()

```
int wcsinit (
    int alloc,
    int naxis,
    struct wcsprm * wcs,
    int npvmax,
    int npsmax,
    int ndpmax)
```

Default constructor for the wcsprm struct.

**wcsinit()** optionally allocates memory for arrays in a wcsprm struct and sets all members of the struct to default values.

**PLEASE NOTE:** every wcsprm struct should be initialized by **wcsinit()**, possibly repeatedly. On the first invocation, and only the first invocation, [wcsprm::flag](#) must be set to -1 to initialize memory management, regardless of whether **wcsinit()** will actually be used to allocate memory.

## Parameters

in	<i>alloc</i>	If true, allocate memory unconditionally for the crpix, etc. arrays. Please note that memory is never allocated by <b>wcsinit()</b> for the auxprm, tabprm, nor wtarr structs. If false, it is assumed that pointers to these arrays have been set by the user except if they are null pointers in which case memory will be allocated for them regardless. (In other words, setting alloc true saves having to initialize these pointers to zero.)
in	<i>naxis</i>	The number of world coordinate axes. This is used to determine the length of the various wcsprm vectors and matrices and therefore the amount of memory to allocate for them.

<i>in, out</i>	<i>wcs</i>	Coordinate transformation parameters. Note that, in order to initialize memory management, <a href="#">wcsprm::flag</a> should be set to -1 when wcs is initialized for the first time (memory leaks may result if it had already been initialized).
<i>in</i>	<i>npvmax</i>	The number of <b>PV</b> i_ma keywords to allocate space for. If set to -1, the value of the global variable NPVMAX will be used. This is potentially thread-unsafe if <a href="#">wcsnpv()</a> is being used dynamically to alter its value.
<i>in</i>	<i>npsmax</i>	The number of <b>PS</b> i_ma keywords to allocate space for. If set to -1, the value of the global variable NPSMAX will be used. This is potentially thread-unsafe if <a href="#">wcsnps()</a> is being used dynamically to alter its value.
<i>in</i>	<i>ndpmax</i>	The number of DPja or DQia keywords to allocate space for. If set to -1, the value of the global variable NDPMAX will be used. This is potentially thread-unsafe if <a href="#">disndp()</a> is being used dynamically to alter its value.

### Returns

Status return value:

- 0: Success.
- 1: Null wcsprm pointer passed.
- 2: Memory allocation failed.

For returns > 1, a detailed error message is set in [wcsprm::err](#) if enabled, see [wcserr\\_enable\(\)](#).

### wcsauxi()

```
int wcsauxi (
    int alloc,
    struct wcsprm * wcs)
```

Default constructor for the auxprm struct.

**wcsauxi()** optionally allocates memory for an auxprm struct, attaches it to wcsprm, and sets all members of the struct to default values.

### Parameters

<i>in</i>	<i>alloc</i>	If true, allocate memory unconditionally for the auxprm struct. If false, it is assumed that <a href="#">wcsprm::aux</a> has already been set to point to an auxprm struct, in which case the user is responsible for managing that memory. However, if <a href="#">wcsprm::aux</a> is a null pointer, memory will be allocated regardless. (In other words, setting alloc true saves having to initialize the pointer to zero.)
<i>in, out</i>	<i>wcs</i>	Coordinate transformation parameters.

### Returns

Status return value:

- 0: Success.
- 1: Null wcsprm pointer passed.
- 2: Memory allocation failed.

**wcssub()**

```
int wcssub (
    int alloc,
    const struct wcsprm * wcssrc,
    int * nsub,
    int axes[],
    struct wcsprm * wcsdst)
```

Subimage extraction routine for the wcsprm struct.

**wcssub()** extracts the coordinate description for a subimage from a wcsprm struct. It does a deep copy, using [wcsinit\(\)](#) to allocate memory for its arrays if required. Only the "information to be provided" part of the struct is extracted. Consequently, [wcsset\(\)](#) need not have been, and won't be invoked on the struct from which the subimage is extracted. A call to [wcsset\(\)](#) is required to set up the subimage struct.

The world coordinate system of the subimage must be separable in the sense that the world coordinates at any point in the subimage must depend only on the pixel coordinates of the axes extracted. In practice, this means that the linear transformation matrix of the original image must not contain non-zero off-diagonal terms that associate any of the subimage axes with any of the non-subimage axes. Likewise, if any distortions are associated with the subimage axes, they must not depend on any of the axes that are not being extracted.

Note that while the required elements of the tabprm array are extracted, the wtarr array is not. (Thus it is not appropriate to call **wcssub()** after [wcstab\(\)](#) but before filling the tabprm structs - refer to [wcschr.h](#).)

**wcssub()** can also add axes to a wcsprm struct. The new axes will be created using the defaults set by [wcsinit\(\)](#) which produce a simple, unnamed, linear axis with world coordinate equal to the pixel coordinate. These default values can be changed afterwards, before invoking [wcsset\(\)](#).

**Parameters**

in	<i>alloc</i>	If true, allocate memory for the crpix, etc. arrays in the destination. Otherwise, it is assumed that pointers to these arrays have been set by the user except if they are null pointers in which case memory will be allocated for them regardless.
in	<i>wcssrc</i>	Struct to extract from.
in, out	<i>nsub</i>	

<code>in, out</code>	<code>axes</code>	<p>Vector of length <code>*nsub</code> containing the image axis numbers (1-relative) to extract. Order is significant; <code>axes[0]</code> is the axis number of the input image that corresponds to the first axis in the subimage, etc.</p> <p>Use an axis number of 0 to create a new axis using the defaults set by <code>wcsinit()</code>. They can be changed later.</p> <p><code>nsub</code> (the pointer) may be set to zero, and so also may <code>*nsub</code>, which is interpreted to mean all axes in the input image; the number of axes will be returned if <code>nsub != 0x0</code>. <code>axes</code> itself (the pointer) may be set to zero to indicate the first <code>*nsub</code> axes in their original order.</p> <p>Set both <code>nsub</code> (or <code>*nsub</code>) and <code>axes</code> to zero to do a deep copy of one <code>wcsprm</code> struct to another.</p> <p>Subimage extraction by coordinate axis type may be done by setting the elements of <code>axes[]</code> to the following special preprocessor macro values:</p> <ul style="list-style-type: none"> <li>• <code>WCSSUB_LONGITUDE</code>: Celestial longitude.</li> <li>• <code>WCSSUB_LATITUDE</code>: Celestial latitude.</li> <li>• <code>WCSSUB_CUBEFACE</code>: Quadcube <b>CUBEFACE</b> axis.</li> <li>• <code>WCSSUB_SPECTRAL</code>: Spectral axis.</li> <li>• <code>WCSSUB_STOKES</code>: Stokes axis.</li> <li>• <code>WCSSUB_TIME</code>: Time axis.</li> </ul> <p>Refer to the notes (below) for further usage examples.</p> <p>On return, <code>*nsub</code> will be set to the number of axes in the subimage; this may be zero if there were no axes of the required type(s) (in which case no memory will be allocated). <code>axes[]</code> will contain the axis numbers that were extracted, or 0 for newly created axes. The vector length must be sufficient to contain all axis numbers. No checks are performed to verify that the coordinate axes are consistent, this is done by <code>wcsset()</code>.</p>
<code>in, out</code>	<code>wcsdst</code>	<p>Struct describing the subimage. <code>wcsprm::flag</code> should be set to -1 if <code>wcsdst</code> was not previously initialized (memory leaks may result if it was previously initialized).</p>

## Returns

Status return value:

- 0: Success.
- 1: Null `wcsprm` pointer passed.
- 2: Memory allocation failed.
- 12: Invalid subimage specification.
- 13: Non-separable subimage coordinate system.

For returns  $> 1$ , a detailed error message is set in `wcsprm::err` if enabled, see `wcserr_enable()`.

## Notes:

1. Combinations of subimage axes of particular types may be extracted in the same order as they occur in the input image by combining preprocessor codes, for example

```
*nsub = 1;
axes[0] = WCSSUB_LONGITUDE | WCSSUB_LATITUDE | WCSSUB_SPECTRAL;
```

would extract the longitude, latitude, and spectral axes in the same order as the input image. If one of each were present, `*nsub = 3` would be returned.

For convenience, `WCSSUB_CELESTIAL` is defined as the combination `WCSSUB_LONGITUDE | WCSSUB_LATITUDE | WCSSUB_CUBEFACE`.

The codes may also be negated to extract all but the types specified, for example

```
*nsub = 4;
axes[0] = WCSSUB_LONGITUDE;
axes[1] = WCSSUB_LATITUDE;
axes[2] = WCSSUB_CUBEFACE;
axes[3] = -(WCSSUB_SPECTRAL | WCSSUB_STOKES);
```

The last of these specifies all axis types other than spectral or Stokes. Extraction is done in the order specified by `axes[]` a longitude axis (if present) would be extracted first (via `axes[0]`) and not subsequently (via `axes[3]`). Likewise for the latitude and cube face axes in this example.

From the foregoing, it is apparent that the value of `*nsub` returned may be less than or greater than that given. However, it will never exceed the number of axes in the input image (plus the number of newly-created axes if any were specified on input).

## wcscompare()

```
int wcscompare (
    int cmp,
    double tol,
    const struct wcsprm * wcs1,
    const struct wcsprm * wcs2,
    int * equal)
```

Compare two `wcsprm` structs for equality.

**wcscompare()** compares two `wcsprm` structs for equality.

## Parameters

in	<i>cmp</i>	A bit field controlling the strictness of the comparison. When 0, all fields must be identical. The following constants may be or'ed together to relax the comparison: <ul style="list-style-type: none"> <li><b>WCSCOMPARE_ANCILLARY</b>: Ignore ancillary keywords that don't change the WCS transformation, such as <b>DATE-OBS</b> or <b>EQUINOX</b>.</li> <li><b>WCSCOMPARE_TILING</b>: Ignore integral differences in <b>CRPIX</b><sub>j</sub><sup>a</sup>. This is the 'tiling' condition, where two WCSes cover different regions of the same map projection and align on the same map grid.</li> <li><b>WCSCOMPARE_CRPIX</b>: Ignore any differences at all in <b>CRPIX</b><sub>j</sub><sup>a</sup>. The two WCSes cover different regions of the same map projection but may not align on the same map grid. Overrides <b>WCSCOMPARE_TILING</b>.</li> </ul>
in	<i>tol</i>	Tolerance for comparison of floating-point values. For example, for <code>tol == 1e-6</code> , all floating-point values in the structs must be equal to the first 6 decimal places. A value of 0 implies exact equality.
in	<i>wcs1</i>	The first <code>wcsprm</code> struct to compare.
in	<i>wcs2</i>	The second <code>wcsprm</code> struct to compare.
out	<i>equal</i>	Non-zero when the given structs are equal.

## Returns

Status return value:

- 0: Success.
- 1: Null pointer passed.

**wcsfree()**

```
int wcsfree (
    struct wcsprm * wcs)
```

Destructor for the [wcsprm](#) struct.

**wcsfree()** frees memory allocated for the [wcsprm](#) arrays by [wcsinit\(\)](#) and/or [wcsset\(\)](#). [wcsinit\(\)](#) records the memory it allocates and **wcsfree()** will only attempt to free this.

**PLEASE NOTE:** **wcsfree()** must not be invoked on a [wcsprm](#) struct that was not initialized by [wcsinit\(\)](#).

**Parameters**

in, out	<a href="#">wcs</a>	Coordinate transformation parameters.
---------	---------------------	---------------------------------------

**Returns**

Status return value:

- 0: Success.
- 1: Null [wcsprm](#) pointer passed.

**wcstrim()**

```
int wcstrim (
    struct wcsprm * wcs)
```

Free unused arrays in the [wcsprm](#) struct.

**wcstrim()** frees memory allocated by [wcsinit\(\)](#) for arrays in the [wcsprm](#) struct that remains unused after it has been set up by [wcsset\(\)](#).

The free'd array members are associated with FITS WCS keyrecords that are rarely used and usually just bloat the struct: [wcsprm::crota](#), [wcsprm::colax](#), [wcsprm::cname](#), [wcsprm::crder](#), [wcsprm::csyer](#), [wcsprm::czphs](#), and [wcsprm::cperi](#). If unused, [wcsprm::pv](#), [wcsprm::ps](#), and [wcsprm::cd](#) are also freed.

Once these arrays have been freed, a test such as

```
if (!undefined(wcs->cname[i])) {...}
```

must be protected as follows

```
if (wcs->cname && !undefined(wcs->cname[i])) {...}
```

In addition, if [wcsprm::npv](#) is non-zero but less than [wcsprm::npvmax](#), then the unused space in [wcsprm::pv](#) will be recovered (using [realloc\(\)](#)). Likewise for [wcsprm::ps](#).

**Parameters**

in, out	<a href="#">wcs</a>	Coordinate transformation parameters.
---------	---------------------	---------------------------------------

**Returns**

Status return value:

- 0: Success.
- 1: Null [wcsprm](#) pointer passed.
- 14: [wcsprm](#) struct is unset.

**wcssize()**

```
int wcssize (
    const struct wcsprm * wcs,
    int sizes[2])
```

Compute the size of a wcsprm struct.

**wcssize()** computes the full size of a wcsprm struct, including allocated memory.

**Parameters**

in	<i>wcs</i>	Coordinate transformation parameters. If NULL, the base size of the struct and the allocated size are both set to zero.
out	<i>sizes</i>	The first element is the base size of the struct as returned by sizeof(struct wcsprm). The second element is the total allocated size, in bytes, assuming that the allocation was done by <a href="#">wcsini()</a> . This figure includes memory allocated for members of constituent structs, such as <a href="#">wcsprm::lin</a> . It is not an error for the struct not to have been set up via <a href="#">wcsset()</a> , which normally results in additional memory allocation.

**Returns**

Status return value:

- 0: Success.

**auxsize()**

```
int auxsize (
    const struct auxprm * aux,
    int sizes[2])
```

Compute the size of a auxprm struct.

**auxsize()** computes the full size of an auxprm struct, including allocated memory.

**Parameters**

in	<i>aux</i>	Auxiliary coordinate information. If NULL, the base size of the struct and the allocated size are both set to zero.
out	<i>sizes</i>	The first element is the base size of the struct as returned by sizeof(struct auxprm). The second element is the total allocated size, in bytes, currently zero.

**Returns**

Status return value:

- 0: Success.

wcsenq()

```
int wcsenq (
    const struct wcsprm * wcs,
    int enquiry)
```

enquire about the state of a wcsprm struct.

**wcsenq()** may be used to obtain information about the state of a wcsprm struct. The function returns a true/false answer for the enquiry asked.

Parameters

in	wcs	Coordinate transformation parameters.
in	enquiry	Enquiry according to the following parameters: <ul style="list-style-type: none"><li>• WCSNQ_MEM: memory in the struct is being managed by WCSLIB (see <a href="#">wcsini()</a>).</li><li>• WCSNQ_SET: the struct has been set up by <a href="#">wcsset()</a>.</li><li>• WCSNQ_BYB: the struct is in bypass mode (see <a href="#">wcsset()</a>).</li><li>• WCSNQ_CHK: the struct is self-consistent in that no changes have been made to any of the "parameters to be given" since the last call to <a href="#">wcsset()</a>.</li></ul> These may be combined by logical OR, e.g. WCSNQ_MEM   WCSNQ_SET. The enquiry result will be the logical AND of the individual results.

Returns

Enquiry result:

- 0: False.
- 1: True.

wcsprt()

```
int wcsprt (
    const struct wcsprm * wcs)
```

Print routine for the wcsprm struct.

**wcsprt()** prints the contents of a wcsprm struct using [wcsprintf\(\)](#). Mainly intended for diagnostic purposes.

Parameters

in	wcs	Coordinate transformation parameters.
----	-----	---------------------------------------

Returns

Status return value:

- 0: Success.
- 1: Null wcsprm pointer passed.

**wcsperr()**

```
int wcsperr (
    const struct wcsprm * wcs,
    const char * prefix)
```

Print error messages from a [wcsprm](#) struct.

**wcsperr()** prints the error message(s), if any, stored in a [wcsprm](#) struct, and the [linprm](#), [celprm](#), [prjprm](#), [spcprm](#), and [tabprm](#) structs that it contains. If there are no errors then nothing is printed. It uses [wcserr\\_prt\(\)](#), [q.v.](#)

**Parameters**

in	<i>wcs</i>	Coordinate transformation parameters.
in	<i>prefix</i>	If non-NULL, each output line will be prefixed with this string.

**Returns**

Status return value:

- 0: Success.
- 1: Null [wcsprm](#) pointer passed.

**wcsbchk()**

```
int wcsbchk (
    struct wcsprm * wcs,
    int bounds)
```

Enable/disable bounds checking.

**wcsbchk()** is used to control bounds checking in the projection routines. Note that [wcsset\(\)](#) always enables bounds checking. **wcsbchk()** will invoke [wcsset\(\)](#) on the [wcsprm](#) struct beforehand if necessary.

**Parameters**

in, out	<i>wcs</i>	Coordinate transformation parameters.
in	<i>bounds</i>	<p>If <code>bounds&amp;1</code> then enable strict bounds checking for the spherical-to-Cartesian (s2x) transformation for the AZP, SZP, TAN, <b>SIN</b>, ZPN, and COP projections.</p> <p>If <code>bounds&amp;2</code> then enable strict bounds checking for the Cartesian-to-spherical (x2s) transformation for the HPX and XPH projections.</p> <p>If <code>bounds&amp;4</code> then enable bounds checking on the native coordinates returned by the Cartesian-to-spherical (x2s) transformations using <a href="#">prjchk()</a>.</p> <p>Zero it to disable all checking.</p>

**Returns**

Status return value:

- 0: Success.
- 1: Null [wcsprm](#) pointer passed.

**wcsset()**

```
int wcsset (
    struct wcsprm * wcs)
```

Setup routine for the [wcsprm](#) struct.

**wcsset()** sets up a [wcsprm](#) struct according to information supplied within it (refer to the description of the [wcsprm](#) struct).

**wcsset()** recognizes the **NCP** projection and converts it to the equivalent **SIN** projection and likewise translates **GLS** into **SFL**. It also translates the AIPS spectral types ('**FREQ-LSR**', '**FELO-HEL**', etc.), possibly changing the input header keywords [wcsprm::ctype](#) and/or [wcsprm::specsys](#) if necessary.

Note that this routine need not be called directly; it will be invoked by [wcsp2s\(\)](#) and [wcsp2p\(\)](#) if the [wcsprm::flag](#) is anything other than a predefined magic value.

**wcsset()** normally operates regardless of the value of [wcsprm::flag](#); i.e. even if a struct was previously set up it will be reset unconditionally. However, a [wcsprm](#) struct may be put into "bypass" mode by invoking **wcsset()** initially with [wcsprm::flag](#) == 1 (rather than 0). **wcsset()** will return immediately if invoked on a struct in that state. To take a struct out of bypass mode, simply reset [wcsprm::flag](#) to zero. See also [wcseqnq\(\)](#).

**Parameters**

<a href="#">in, out</a>	<a href="#">wcs</a>	Coordinate transformation parameters.
-------------------------	---------------------	---------------------------------------

**Returns**

Status return value:

- 0: Success.
- 1: Null [wcsprm](#) pointer passed.
- 2: Memory allocation failed.
- 3: Linear transformation matrix is singular.
- 4: Inconsistent or unrecognized coordinate axis types.
- 5: Invalid parameter value.
- 6: Invalid coordinate transformation parameters.
- 7: Ill-conditioned coordinate transformation parameters.

For returns > 1, a detailed error message is set in [wcsprm::err](#) if enabled, see [wcsero\\_enable\(\)](#).

**Notes:**

1. **wcsset()** always enables strict bounds checking in the projection routines (via a call to [prjini\(\)](#)). Use [wscbchk\(\)](#) to modify bounds-checking after **wcsset()** is invoked.

**wcsp2s()**

```
int wcsp2s (
    struct wcsprm * wcs,
    int ncoord,
    int nelem,
    const double pixcrd[],
    double imgcrd[],
    double phi[],
    double theta[],
    double world[],
    int stat[])
```

Pixel-to-world transformation.

**wcsp2s()** transforms pixel coordinates to world coordinates.

**Parameters**

in, out	<i>wcs</i>	Coordinate transformation parameters.
in	<i>ncoord, nelem</i>	The number of coordinates, each of vector length nelem but containing wcs.naxis coordinate elements. Thus nelem must equal or exceed the value of the <b>NAXIS</b> keyword unless ncoord == 1, in which case nelem is not used.
in	<i>pixcrd</i>	Array of pixel coordinates.
out	<i>imgcrd</i>	Array of intermediate world coordinates. For celestial axes, imgcrd[][wcs.lng] and imgcrd[][wcs.lat] are the projected <i>x</i> -, and <i>y</i> -coordinates in pseudo "degrees". For spectral axes, imgcrd[][wcs.spec] is the intermediate spectral coordinate, in SI units. For time axes, imgcrd[][wcs.time] is the intermediate time coordinate.
out	<i>phi, theta</i>	Longitude and latitude in the native coordinate system of the projection [deg].
out	<i>world</i>	Array of world coordinates. For celestial axes, world[][wcs.lng] and world[][wcs.lat] are the celestial longitude and latitude [deg]. For spectral axes, world[][wcs.spec] is the spectral coordinate, in SI units. For time axes, world[][wcs.time] is the time coordinate.
out	<i>stat</i>	Status return value for each coordinate: <ul style="list-style-type: none"> <li>• 0: Success.</li> </ul> 1+: A bit mask indicating invalid pixel coordinate element(s).

**Returns**

Status return value:

- 0: Success.
- 1: Null wcsprm pointer passed.
- 2: Memory allocation failed.
- 3: Linear transformation matrix is singular.
- 4: Inconsistent or unrecognized coordinate axis types.
- 5: Invalid parameter value.
- 6: Invalid coordinate transformation parameters.
- 7: Ill-conditioned coordinate transformation parameters.
- 8: One or more of the pixel coordinates were invalid, as indicated by the stat vector.

For returns > 1, a detailed error message is set in [wcsprm::err](#) if enabled, see [wcserr\\_enable\(\)](#).

**wcss2p()**

```
int wcss2p (
    struct wcsprm * wcs,
    int ncoord,
    int nelelem,
    const double world[],
    double phi[],
    double theta[],
    double imgcrd[],
    double pixcrd[],
    int stat[])
```

World-to-pixel transformation.

**wcss2p()** transforms world coordinates to pixel coordinates.

**Parameters**

in, out	<i>wcs</i>	Coordinate transformation parameters.
in	<i>ncoord, nelelem</i>	The number of coordinates, each of vector length nelelem but containing wcs.naxis coordinate elements. Thus nelelem must equal or exceed the value of the <b>NAXIS</b> keyword unless ncoord == 1, in which case nelelem is not used.
in	<i>world</i>	Array of world coordinates. For celestial axes, world[][wcs.lng] and world[][wcs.lat] are the celestial longitude and latitude [deg]. For spectral axes, world[][wcs.spec] is the spectral coordinate, in SI units. For time axes, world[][wcs.time] is the time coordinate.
out	<i>phi, theta</i>	Longitude and latitude in the native coordinate system of the projection [deg].
out	<i>imgcrd</i>	Array of intermediate world coordinates. For celestial axes, imgcrd[][wcs.lng] and imgcrd[][wcs.lat] are the projected <i>x</i> -, and <i>y</i> -coordinates in pseudo "degrees". For quadcube projections with a <b>CUBEFACE</b> axis the face number is also returned in imgcrd[][wcs.cubeface]. For spectral axes, imgcrd[][wcs.spec] is the intermediate spectral coordinate, in SI units. For time axes, imgcrd[][wcs.time] is the intermediate time coordinate.
out	<i>pixcrd</i>	Array of pixel coordinates.
out	<i>stat</i>	Status return value for each coordinate: <ul style="list-style-type: none"> <li>• 0: Success.</li> </ul> 1+: A bit mask indicating invalid world coordinate element(s).

**Returns**

Status return value:

- 0: Success.
- 1: Null wcsprm pointer passed.
- 2: Memory allocation failed.
- 3: Linear transformation matrix is singular.
- 4: Inconsistent or unrecognized coordinate axis types.
- 5: Invalid parameter value.
- 6: Invalid coordinate transformation parameters.
- 7: Ill-conditioned coordinate transformation parameters.
- 9: One or more of the world coordinates were invalid, as indicated by the stat vector.

For returns > 1, a detailed error message is set in **wcsprm::err** if enabled, see **wcserr\_enable()**.

**wcsmix()**

```
int wcsmix (
    struct wcsprm * wcs,
    int mixpix,
    int mixcel,
    const double vspan[2],
    double vstep,
    int viter,
    double world[],
    double phi[],
    double theta[],
    double imgcrd[],
    double pixcrd[])
```

Hybrid coordinate transformation.

**wcsmix()**, given either the celestial longitude or latitude plus an element of the pixel coordinate, solves for the remaining elements by iterating on the unknown celestial coordinate element using **wcss2p()**. Refer also to the notes below.

**Parameters**

in, out	<i>wcs</i>	Indices for the celestial coordinates obtained by parsing the <b>wcsprm::ctype[]</b> .
in	<i>mixpix</i>	Which element of the pixel coordinate is given.
in	<i>mixcel</i>	Which element of the celestial coordinate is given: <ul style="list-style-type: none"> <li>• 1: Celestial longitude is given in world[wcs.lng], latitude returned in world[wcs.lat].</li> <li>• 2: Celestial latitude is given in world[wcs.lat], longitude returned in world[wcs.lng].</li> </ul>
in	<i>vspan</i>	Solution interval for the celestial coordinate [deg]. The ordering of the two limits is irrelevant. Longitude ranges may be specified with any convenient normalization, for example [-120,+120] is the same as [240,480], except that the solution will be returned with the same normalization, i.e. lie within the interval specified.
in	<i>vstep</i>	Step size for solution search [deg]. If zero, a sensible, although perhaps non-optimal default will be used.
in	<i>viter</i>	If a solution is not found then the step size will be halved and the search recommenced. viter controls how many times the step size is halved. The allowed range is 5 - 10.
in, out	<i>world</i>	World coordinate elements. world[wcs.lng] and world[wcs.lat] are the celestial longitude and latitude [deg]. Which is given and which returned depends on the value of mixcel. All other elements are given.
out	<i>phi,theta</i>	Longitude and latitude in the native coordinate system of the projection [deg].
out	<i>imgcrd</i>	Image coordinate elements. imgcrd[wcs.lng] and imgcrd[wcs.lat] are the projected <i>x</i> -, and <i>y</i> -coordinates in pseudo "degrees".
in, out	<i>pixcrd</i>	Pixel coordinate. The element indicated by mixpix is given and the remaining elements are returned.

**Returns**

Status return value:

- 0: Success.
- 1: Null wcsprm pointer passed.

- 2: Memory allocation failed.
- 3: Linear transformation matrix is singular.
- 4: Inconsistent or unrecognized coordinate axis types.
- 5: Invalid parameter value.
- 6: Invalid coordinate transformation parameters.
- 7: Ill-conditioned coordinate transformation parameters.
- 10: Invalid world coordinate.
- 11: No solution found in the specified interval.

For returns  $> 1$ , a detailed error message is set in `wcsprm::err` if enabled, see `wcserr_enable()`.

#### Notes:

1. Initially the specified solution interval is checked to see if it's a "crossing" interval. If it isn't, a search is made for a crossing solution by iterating on the unknown celestial coordinate starting at the upper limit of the solution interval and decrementing by the specified step size. A crossing is indicated if the trial value of the pixel coordinate steps through the value specified. If a crossing interval is found then the solution is determined by a modified form of "regula falsi" division of the crossing interval. If no crossing interval was found within the specified solution interval then a search is made for a "non-crossing" solution as may arise from a point of tangency. The process is complicated by having to make allowance for the discontinuities that occur in all map projections.

Once one solution has been determined others may be found by subsequent invocations of `wcsmix()` with suitably restricted solution intervals.

Note the circumstance that arises when the solution point lies at a native pole of a projection in which the pole is represented as a finite curve, for example the zenithals and conics. In such cases two or more valid solutions may exist but `wcsmix()` only ever returns one.

Because of its generality `wcsmix()` is very compute-intensive. For compute-limited applications more efficient special-case solvers could be written for simple projections, for example non-oblique cylindrical projections.

#### **wcscs()**

```
int wcscs (
    struct wcsprm * wcs,
    double lng2p1,
    double lat2p1,
    double lng1p2,
    const char * clng,
    const char * clat,
    const char * radesys,
    double equinox,
    const char * alt)
```

Change celestial coordinate system.

**wcscs()** changes the celestial coordinate system of a `wcsprm` struct. For example, from equatorial to galactic coordinates.

Parameters that define the spherical coordinate transformation, essentially being three Euler angles, must be provided. Thereby **wcscs()** does not need prior knowledge of specific celestial coordinate systems. It also has the advantage of making it completely general.

Auxiliary members of the `wcsprm` struct relating to equatorial celestial coordinate systems may also be changed.

Only orthodox spherical coordinate systems are supported. That is, they must be right-handed, with latitude increasing from zero at the equator to +90 degrees at the pole. This precludes systems such as azimuth and zenith distance, which, however, could be handled as negative azimuth and elevation.

**PLEASE NOTE:** Information in the `wcsprm` struct relating to the original coordinate system will be overwritten and therefore lost. If this is undesirable, invoke `wcsccs()` on a copy of the struct made with `wcssub()`. The `wcsprm` struct is reset on return with an explicit call to `wcsset()`.

### Parameters

in, out	<i>wcs</i>	Coordinate transformation parameters. Particular "values to be given" elements of the <code>wcsprm</code> struct are modified.
in	<i>lng2p1,lat2p1</i>	Longitude and latitude in the new celestial coordinate system of the pole (i.e. latitude +90) of the original system [deg]. See notes 1 and 2 below.
in	<i>lng1p2</i>	Longitude in the original celestial coordinate system of the pole (i.e. latitude +90) of the new system [deg]. See note 1 below.
in	<i>clng,clat</i>	Longitude and latitude identifiers of the new <b>CTYPE<sub>ia</sub></b> celestial axis codes, without trailing dashes. For example, "RA" and "DEC" or "GLON" and "GLAT". Up to four characters are used, longer strings need not be null-terminated.
in	<i>radesys</i>	Used when transforming to equatorial coordinates, identified by <code>clng == "RA"</code> and <code>clat == "DEC"</code> . May be set to the null pointer to preserve the current value. Up to 71 characters are used, longer strings need not be null-terminated. If the new coordinate system is anything other than equatorial, then <code>wcsprm::radesys</code> will be cleared.
in	<i>equinox</i>	Used when transforming to equatorial coordinates. May be set to zero to preserve the current value. If the new coordinate system is not equatorial, then <code>wcsprm::equinox</code> will be marked as undefined.
in	<i>alt</i>	Character code for alternate coordinate descriptions (i.e. the 'a' in keyword names such as <b>CTYPE<sub>ia</sub></b> ). This is blank for the primary coordinate description, or one of the 26 upper-case letters, A-Z. May be set to the null pointer, or null string if no change is required.

### Returns

Status return value:

- 0: Success.
- 1: Null `wcsprm` pointer passed.
- 12: Invalid subimage specification (no celestial axes).

### Notes:

1. Follows the prescription given in WCS Paper II, Sect. 2.7 for changing celestial coordinates.

The implementation takes account of indeterminacies that arise in that prescription in the particular cases where one of the poles of the new system is at the fiducial point, or one of them is at the native pole.

2. If  $\text{lat2p1} == +90$ , i.e. where the poles of the two coordinate systems coincide, then the spherical coordinate transformation becomes a simple change in origin of longitude given by  $\text{lng2} = \text{lng1} + (\text{lng2p1} - \text{lng1p2} - 180)$ , and  $\text{lat2} = \text{lat1}$ , where  $(\text{lng2}, \text{lat2})$  are coordinates in the new system, and  $(\text{lng1}, \text{lat1})$  are coordinates in the original system.

Likewise, if  $\text{lat2p1} == -90$ , then  $\text{lng2} = -\text{lng1} + (\text{lng2p1} + \text{lng1p2})$ , and  $\text{lat2} = -\text{lat1}$ .

3. For example, if the original coordinate system is B1950 equatorial and the desired new coordinate system is galactic, then

- $(\text{lng2p1}, \text{lat2p1})$  are the galactic coordinates of the B1950 celestial pole, defined by the IAU to be  $(123.456, 0, +27.4)$ , and  $\text{lng1p2}$  is the B1950 right ascension of the galactic pole, defined as 192.25. Clearly these coordinates are fixed for a particular coordinate transformation.
- $(\text{c}(\text{lng}), \text{c}(\text{lat}))$  would be 'GLON' and 'GLAT', these being the FITS standard identifiers for galactic coordinates.
- Since the new coordinate system is not equatorial, `wcsprm::radesys` and `wcsprm::equinox` will be cleared.

4. The coordinates required for some common transformations (obtained from [https://ned.ipac.caltech.edu/coordinate\\_calculator](https://ned.ipac.caltech.edu/coordinate_calculator)) are as follows:

```
(123.0000,+27.4000) galactic coordinates of B1950 celestial pole,
(192.2500,+27.4000) B1950 equatorial coordinates of galactic pole.

(122.9319,+27.1283) galactic coordinates of J2000 celestial pole,
(192.8595,+27.1283) J2000 equatorial coordinates of galactic pole.

(359.6774,+89.7217) B1950 equatorial coordinates of J2000 pole,
(180.3162,+89.7217) J2000 equatorial coordinates of B1950 pole.

(270.0000,+66.5542) B1950 equatorial coordinates of B1950 ecliptic pole,
( 90.0000,+66.5542) B1950 ecliptic coordinates of B1950 celestial pole.

(270.0000,+66.5607) J2000 equatorial coordinates of J2000 ecliptic pole,
( 90.0000,+66.5607) J2000 ecliptic coordinates of J2000 celestial pole.

( 26.7315,+15.6441) supergalactic coordinates of B1950 celestial pole,
(283.1894,+15.6441) B1950 equatorial coordinates of supergalactic pole.

( 26.4505,+15.7089) supergalactic coordinates of J2000 celestial pole,
(283.7542,+15.7089) J2000 equatorial coordinates of supergalactic pole.
```

## wcssptr()

```
int wcssptr (
    struct wcsprm * wcs,
    int * i,
    char ctype[9])
```

Spectral axis translation.

**wcssptr()** translates the spectral axis in a `wcsprm` struct. For example, a 'FREQ' axis may be translated into 'ZOPT-F2W' and vice versa.

**PLEASE NOTE:** Information in the `wcsprm` struct relating to the original coordinate system will be overwritten and therefore lost. If this is undesirable, invoke **wcssptr()** on a copy of the struct made with `wcssub()`. The `wcsprm` struct is reset on return with an explicit call to `wcsset()`.

## Parameters

in, out	<i>wcs</i>	Coordinate transformation parameters.
in, out	<i>i</i>	Index of the spectral axis (0-relative). If given $< 0$ it will be set to the first spectral axis identified from the <code>ctype[]</code> keyvalues in the <code>wcsprm</code> struct.

<i>in, out</i>	<i>ctype</i>	Desired spectral <b>CTYPE</b> <sub>ia</sub> . Wildcarding may be used as for the ctypeS2 argument to <a href="#">spctrn()</a> as described in the prologue of <a href="#">spc.h</a> , i.e. if the final three characters are specified as "???", or if just the eighth character is specified as '?', the correct algorithm code will be substituted and returned.
----------------	--------------	--

## Returns

Status return value:

- 0: Success.
- 1: Null wcsprm pointer passed.
- 2: Memory allocation failed.
- 3: Linear transformation matrix is singular.
- 4: Inconsistent or unrecognized coordinate axis types.
- 5: Invalid parameter value.
- 6: Invalid coordinate transformation parameters.
- 7: Ill-conditioned coordinate transformation parameters.
- 12: Invalid subimage specification (no spectral axis).

For returns > 1, a detailed error message is set in [wcsprm::err](#) if enabled, see [wcserr\\_enable\(\)](#).

## wcslib\_version()

```
const char * wcslib_version (
    int vers[3])
```

## 8.23.5 Variable Documentation

### wcs\_errmsg

```
const char* wcs_errmsg[] [extern]
```

Status return messages.

Error messages to match the status value returned from each function.

## 8.24 wcs.h

[Go to the documentation of this file.](#)

```
00001 /*=====
00002 WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003 Copyright (C) 1995-2025, Mark Calabretta
00004
00005 This file is part of WCSLIB.
00006
00007 WCSLIB is free software: you can redistribute it and/or modify it under the
00008 terms of the GNU Lesser General Public License as published by the Free
00009 Software Foundation, either version 3 of the License, or (at your option)
00010 any later version.
00011
00012 WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013 WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
```

```

00014 FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015 more details.
00016
00017 You should have received a copy of the GNU Lesser General Public License
00018 along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020 Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021 http://www.atnf.csiro.au/people/Mark.Calabretta
00022 $Id: wcs.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023 *=====
00024 *
00025 * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026 * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027 * overview of the library.
00028 *
00029 *
00030 * Summary of the wcs routines
00031 * -----
00032 * Routines in this suite implement the FITS World Coordinate System (WCS)
00033 * standard which defines methods to be used for computing world coordinates
00034 * from image pixel coordinates, and vice versa. The standard, and proposed
00035 * extensions for handling distortions, are described in
00036 *
00037 * "Representations of world coordinates in FITS",
00038 * Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)
00039 *
00040 * "Representations of celestial coordinates in FITS",
00041 * Calabretta, M.R., & Greisen, E.W. 2002, A&A, 395, 1077 (WCS Paper II)
00042 *
00043 * "Representations of spectral coordinates in FITS",
00044 * Greisen, E.W., Calabretta, M.R., Valdes, F.G., & Allen, S.L.
00045 * 2006, A&A, 446, 747 (WCS Paper III)
00046 *
00047 * "Representations of distortions in FITS world coordinate systems",
00048 * Calabretta, M.R. et al. (WCS Paper IV, draft dated 2004/04/22),
00049 * available from http://www.atnf.csiro.au/people/Mark.Calabretta
00050 *
00051 * "Mapping on the HEALPix grid",
00052 * Calabretta, M.R., & Roukema, B.F. 2007, MNRAS, 381, 865 (WCS Paper V)
00053 *
00054 * "Representing the 'Butterfly' Projection in FITS -- Projection Code XPH",
00055 * Calabretta, M.R., & Lowe, S.R. 2013, PASA, 30, e050 (WCS Paper VI)
00056 *
00057 * "Representations of time coordinates in FITS -
00058 * Time and relative dimension in space",
00059 * Rots, A.H., Bunclark, P.S., Calabretta, M.R., Allen, S.L.,
00060 * Manchester, R.N., & Thompson, W.T. 2015, A&A, 574, A36 (WCS Paper VII)
00061 *
00062 * These routines are based on the wcsprm struct which contains all information
00063 * needed for the computations. The struct contains some members that must be
00064 * set by the user, and others that are maintained by these routines, somewhat
00065 * like a C++ class but with no encapsulation.
00066 *
00067 * wcsnpv(), wcsnps(), wcsini(), wcsinit(), wcsub(), wcsfree(), and wcsstrim(),
00068 * are provided to manage the wcsprm struct, wcssize() computes its total size
00069 * including allocated memory, wcsenq() returns information about the state of
00070 * the struct, and wcsprt() prints its contents. wcscopy(), which does a deep
00071 * copy of one wcsprm struct to another, is defined as a preprocessor macro
00072 * function that invokes wcsub().
00073 *
00074 * wcperr() prints the error message(s) (if any) stored in a wcsprm struct,
00075 * and the linprm, celprm, prjprm, spcprm, and tabprm structs that it contains.
00076 *
00077 * A setup routine, wcsset(), computes intermediate values in the wcsprm struct
00078 * from parameters in it that were supplied by the user. The struct always
00079 * needs to be set up by wcsset() but this need not be called explicitly -
00080 * refer to the explanation of wcsprm::flag.
00081 *
00082 * wcsp2s() and wcsp2p() implement the WCS world coordinate transformations.
00083 * In fact, they are high level driver routines for the WCS linear,
00084 * logarithmic, celestial, spectral and tabular transformation routines
00085 * described in lin.h, log.h, cel.h, spc.h and tab.h.
00086 *
00087 * Given either the celestial longitude or latitude plus an element of the
00088 * pixel coordinate a hybrid routine, wcmix(), iteratively solves for the
00089 * unknown elements.
00090 *
00091 * wscscs() changes the celestial coordinate system of a wcsprm struct, for
00092 * example, from equatorial to galactic, and wcsptr() translates the spectral
00093 * axis. For example, a 'FREQ' axis may be translated into 'ZOPT-F2W' and vice
00094 * versa.
00095 *
00096 * wcslib_version() returns the WCSLIB version number.
00097 *
00098 * Quadcube projections:
00099 * -----
00100 * The quadcube projections (TSC, CSC, QSC) may be represented in FITS in

```

```

00101 *   either of two ways:
00102 *
00103 *       a: The six faces may be laid out in one plane and numbered as follows:
00104 *
00105 *           0
00106 *
00107 *           4 3 2 1 4 3 2
00108 *
00109 *           5
00110 *
00111 *       Faces 2, 3 and 4 may appear on one side or the other (or both). The
00112 *       world-to-pixel routines map faces 2, 3 and 4 to the left but the
00113 *       pixel-to-world routines accept them on either side.
00114 *
00115 *       b: The "COBE" convention in which the six faces are stored in a
00116 *       three-dimensional structure using a CUBEFACE axis indexed from
00117 *       0 to 5 as above.
00118 *
00119 *       These routines support both methods; wcsset() determines which is being
00120 *       used by the presence or absence of a CUBEFACE axis in ctype[]. wcssp2s()
00121 *       and wcss2p() translate the CUBEFACE axis representation to the single
00122 *       plane representation understood by the lower-level WCSLIB projection
00123 *       routines.
00124 *
00125 *
00126 * wcsnpv() - Memory allocation for PVi_ma
00127 * -----
00128 * wcsnpv() sets or gets the value of NPVMAX (default 64). This global
00129 * variable controls the number of pvcards structs, for holding PVi_ma
00130 * keyvalues, that wcsini() should allocate space for. It is also used by
00131 * wcsinit() as the default value of npvmax.
00132 *
00133 * PLEASE NOTE: This function is not thread-safe.
00134 *
00135 * Given:
00136 *     n      int      Value of NPVMAX; ignored if < 0. Use a value less
00137 *                    than zero to get the current value.
00138 *
00139 * Function return value:
00140 *     int      Current value of NPVMAX.
00141 *
00142 *
00143 * wcsnps() - Memory allocation for PSi_ma
00144 * -----
00145 * wcsnps() sets or gets the value of NPSMAX (default 8). This global variable
00146 * controls the number of pscard structs, for holding PSi_ma keyvalues, that
00147 * wcsini() should allocate space for. It is also used by wcsinit() as the
00148 * default value of npsmax.
00149 *
00150 * PLEASE NOTE: This function is not thread-safe.
00151 *
00152 * Given:
00153 *     n      int      Value of NPSMAX; ignored if < 0. Use a value less
00154 *                    than zero to get the current value.
00155 *
00156 * Function return value:
00157 *     int      Current value of NPSMAX.
00158 *
00159 *
00160 * wcsini() - Default constructor for the wcsprm struct
00161 * -----
00162 * wcsini() is a thin wrapper on wcsinit(). It invokes it with npvmax,
00163 * npsmax, and ndpmax set to -1 which causes it to use the values of the
00164 * global variables NDPMAX, NPSMAX, and NPVMAX. It is thereby potentially
00165 * thread-unsafe if these variables are altered dynamically via wcsnpv(),
00166 * wcsnps(), and disndp(). Use wcsinit() for a thread-safe alternative in
00167 * this case.
00168 *
00169 *
00170 * wcsinit() - Default constructor for the wcsprm struct
00171 * -----
00172 * wcsinit() optionally allocates memory for arrays in a wcsprm struct and sets
00173 * all members of the struct to default values.
00174 *
00175 * PLEASE NOTE: every wcsprm struct should be initialized by wcsinit(),
00176 * possibly repeatedly. On the first invocation, and only the first
00177 * invocation, wcsprm::flag must be set to -1 to initialize memory management,
00178 * regardless of whether wcsinit() will actually be used to allocate memory.
00179 *
00180 * Given:
00181 *     alloc   int      If true, allocate memory unconditionally for the
00182 *                    crpix, etc. arrays. Please note that memory is never
00183 *                    allocated by wcsinit() for the auxprm, tabprm, nor
00184 *                    wtbarrr structs.
00185 *
00186 *                    If false, it is assumed that pointers to these arrays
00187 *                    have been set by the user except if they are null

```

```

00188 *           pointers in which case memory will be allocated for
00189 *           them regardless. (In other words, setting alloc true
00190 *           saves having to initialize these pointers to zero.)
00191 *
00192 *   naxis      int      The number of world coordinate axes. This is used to
00193 *                       determine the length of the various wcsprm vectors and
00194 *                       matrices and therefore the amount of memory to
00195 *                       allocate for them.
00196 *
00197 * Given and returned:
00198 *   wcs         struct wcsprm*
00199 *               Coordinate transformation parameters.
00200 *
00201 *               Note that, in order to initialize memory management,
00202 *               wcsprm::flag should be set to -1 when wcs is
00203 *               initialized for the first time (memory leaks may
00204 *               result if it had already been initialized).
00205 *
00206 * Given:
00207 *   npvmax      int      The number of PVi_ma keywords to allocate space for.
00208 *                       If set to -1, the value of the global variable NPVMAX
00209 *                       will be used. This is potentially thread-unsafe if
00210 *                       wcsnpv() is being used dynamically to alter its value.
00211 *
00212 *   npsmax      int      The number of PSi_ma keywords to allocate space for.
00213 *                       If set to -1, the value of the global variable NPSMAX
00214 *                       will be used. This is potentially thread-unsafe if
00215 *                       wcsnps() is being used dynamically to alter its value.
00216 *
00217 *   ndpmax      int      The number of DPja or DQia keywords to allocate space
00218 *                       for. If set to -1, the value of the global variable
00219 *                       NDPMAX will be used. This is potentially
00220 *                       thread-unsafe if disndp() is being used dynamically to
00221 *                       alter its value.
00222 *
00223 * Function return value:
00224 *   int          Status return value:
00225 *               0: Success.
00226 *               1: Null wcsprm pointer passed.
00227 *               2: Memory allocation failed.
00228 *
00229 *               For returns > 1, a detailed error message is set in
00230 *               wcsprm::err if enabled, see wcserr_enable().
00231 *
00232 *
00233 * wcsauxi() - Default constructor for the auxprm struct
00234 * -----
00235 * wcsauxi() optionally allocates memory for an auxprm struct, attaches it to
00236 * wcsprm, and sets all members of the struct to default values.
00237 *
00238 * Given:
00239 *   alloc      int      If true, allocate memory unconditionally for the
00240 *                       auxprm struct.
00241 *
00242 *               If false, it is assumed that wcsprm::aux has already
00243 *               been set to point to an auxprm struct, in which case
00244 *               the user is responsible for managing that memory.
00245 *               However, if wcsprm::aux is a null pointer, memory will
00246 *               be allocated regardless. (In other words, setting
00247 *               alloc true saves having to initialize the pointer to
00248 *               zero.)
00249 *
00250 * Given and returned:
00251 *   wcs         struct wcsprm*
00252 *               Coordinate transformation parameters.
00253 *
00254 * Function return value:
00255 *   int          Status return value:
00256 *               0: Success.
00257 *               1: Null wcsprm pointer passed.
00258 *               2: Memory allocation failed.
00259 *
00260 *
00261 * wcsub() - Subimage extraction routine for the wcsprm struct
00262 * -----
00263 * wcsub() extracts the coordinate description for a subimage from a wcsprm
00264 * struct. It does a deep copy, using wcsinit() to allocate memory for its
00265 * arrays if required. Only the "information to be provided" part of the
00266 * struct is extracted. Consequently, wcsset() need not have been, and won't
00267 * be invoked on the struct from which the subimage is extracted. A call to
00268 * wcsset() is required to set up the subimage struct.
00269 *
00270 * The world coordinate system of the subimage must be separable in the sense
00271 * that the world coordinates at any point in the subimage must depend only on
00272 * the pixel coordinates of the axes extracted. In practice, this means that
00273 * the linear transformation matrix of the original image must not contain
00274 * non-zero off-diagonal terms that associate any of the subimage axes with any

```

```

00275 * of the non-subimage axes. Likewise, if any distortions are associated with
00276 * the subimage axes, they must not depend on any of the axes that are not
00277 * being extracted.
00278 *
00279 * Note that while the required elements of the tabprm array are extracted, the
00280 * wtbar array is not. (Thus it is not appropriate to call wcsub() after
00281 * wcstab() but before filling the tabprm structs - refer to wshdr.h.)
00282 *
00283 * wcsub() can also add axes to a wcsprm struct. The new axes will be created
00284 * using the defaults set by wcsinit() which produce a simple, unnamed, linear
00285 * axis with world coordinate equal to the pixel coordinate. These default
00286 * values can be changed afterwards, before invoking wcsset().
00287 *
00288 * Given:
00289 *   alloc      int           If true, allocate memory for the crpix, etc. arrays in
00290 *                             the destination. Otherwise, it is assumed that
00291 *                             pointers to these arrays have been set by the user
00292 *                             except if they are null pointers in which case memory
00293 *                             will be allocated for them regardless.
00294 *
00295 *   wcssrc     const struct wcsprm*
00296 *                             Struct to extract from.
00297 *
00298 * Given and returned:
00299 *   nsub       int*
00300 *   axes       int[]         Vector of length *nsub containing the image axis
00301 *                             numbers (1-relative) to extract. Order is
00302 *                             significant; axes[0] is the axis number of the input
00303 *                             image that corresponds to the first axis in the
00304 *                             subimage, etc.
00305 *
00306 *                             Use an axis number of 0 to create a new axis using
00307 *                             the defaults set by wcsinit(). They can be changed
00308 *                             later.
00309 *
00310 *                             nsub (the pointer) may be set to zero, and so also may
00311 *                             *nsub, which is interpreted to mean all axes in the
00312 *                             input image; the number of axes will be returned if
00313 *                             nsub != 0x0. axes itself (the pointer) may be set to
00314 *                             zero to indicate the first *nsub axes in their
00315 *                             original order.
00316 *
00317 *                             Set both nsub (or *nsub) and axes to zero to do a deep
00318 *                             copy of one wcsprm struct to another.
00319 *
00320 *                             Subimage extraction by coordinate axis type may be
00321 *                             done by setting the elements of axes[] to the
00322 *                             following special preprocessor macro values:
00323 *
00324 *                             WCSSUB_LONGITUDE: Celestial longitude.
00325 *                             WCSSUB_LATITUDE:   Celestial latitude.
00326 *                             WCSSUB_CUBEFACE:   Quadcube CUBEFACE axis.
00327 *                             WCSSUB_SPECTRAL:    Spectral axis.
00328 *                             WCSSUB_STOKES:     Stokes axis.
00329 *                             WCSSUB_TIME:       Time axis.
00330 *
00331 *                             Refer to the notes (below) for further usage examples.
00332 *
00333 *                             On return, *nsub will be set to the number of axes in
00334 *                             the subimage; this may be zero if there were no axes
00335 *                             of the required type(s) (in which case no memory will
00336 *                             be allocated). axes[] will contain the axis numbers
00337 *                             that were extracted, or 0 for newly created axes. The
00338 *                             vector length must be sufficient to contain all axis
00339 *                             numbers. No checks are performed to verify that the
00340 *                             coordinate axes are consistent, this is done by
00341 *                             wcsset().
00342 *
00343 *   wcdst      struct wcsprm*
00344 *                             Struct describing the subimage. wcsprm::flag should
00345 *                             be set to -1 if wcdst was not previously initialized
00346 *                             (memory leaks may result if it was previously
00347 *                             initialized).
00348 *
00349 * Function return value:
00350 *   int        Status return value:
00351 *               0: Success.
00352 *               1: Null wcsprm pointer passed.
00353 *               2: Memory allocation failed.
00354 *               12: Invalid subimage specification.
00355 *               13: Non-separable subimage coordinate system.
00356 *
00357 *               For returns > 1, a detailed error message is set in
00358 *               wcsprm::err if enabled, see wcserr_enable().
00359 *
00360 * Notes:
00361 *   1: Combinations of subimage axes of particular types may be extracted in

```

```

00362 *      the same order as they occur in the input image by combining
00363 *      preprocessor codes, for example
00364 *
00365 *      *nsub = 1;
00366 *      axes[0] = WCSSUB_LONGITUDE | WCSSUB_LATITUDE | WCSSUB_SPECTRAL;
00367 *
00368 *      would extract the longitude, latitude, and spectral axes in the same
00369 *      order as the input image. If one of each were present, *nsub = 3 would
00370 *      be returned.
00371 *
00372 *      For convenience, WCSSUB_CELESTIAL is defined as the combination
00373 *      WCSSUB_LONGITUDE | WCSSUB_LATITUDE | WCSSUB_CUBEFACE.
00374 *
00375 *      The codes may also be negated to extract all but the types specified,
00376 *      for example
00377 *
00378 *      *nsub = 4;
00379 *      axes[0] = WCSSUB_LONGITUDE;
00380 *      axes[1] = WCSSUB_LATITUDE;
00381 *      axes[2] = WCSSUB_CUBEFACE;
00382 *      axes[3] = -(WCSSUB_SPECTRAL | WCSSUB_STOKES);
00383 *
00384 *      The last of these specifies all axis types other than spectral or
00385 *      Stokes. Extraction is done in the order specified by axes[] a
00386 *      longitude axis (if present) would be extracted first (via axes[0]) and
00387 *      not subsequently (via axes[3]). Likewise for the latitude and cube face
00388 *      axes in this example.
00389 *
00390 *      From the foregoing, it is apparent that the value of *nsub returned may
00391 *      be less than or greater than that given. However, it will never exceed
00392 *      the number of axes in the input image (plus the number of newly-created
00393 *      axes if any were specified on input).
00394 *
00395 *
00396 * wscscompare() - Compare two wcsprm structs for equality
00397 * -----
00398 * wscscompare() compares two wcsprm structs for equality.
00399 *
00400 * Given:
00401 *   cmp      int      A bit field controlling the strictness of the
00402 *                     comparison. When 0, all fields must be identical.
00403 *
00404 *                     The following constants may be or'ed together to
00405 *                     relax the comparison:
00406 *                     WSCOMPARE_ANCILLARY: Ignore ancillary keywords
00407 *                     that don't change the WCS transformation, such
00408 *                     as DATE-OBS or EQUINOX.
00409 *                     WSCOMPARE_TILING: Ignore integral differences in
00410 *                     CRPIXja. This is the 'tiling' condition, where
00411 *                     two WCSes cover different regions of the same
00412 *                     map projection and align on the same map grid.
00413 *                     WSCOMPARE_CRPIX: Ignore any differences at all in
00414 *                     CRPIXja. The two WCSes cover different regions
00415 *                     of the same map projection but may not align on
00416 *                     the same map grid. Overrides WSCOMPARE_TILING.
00417 *
00418 *   tol      double   Tolerance for comparison of floating-point values.
00419 *                     For example, for tol == 1e-6, all floating-point
00420 *                     values in the structs must be equal to the first 6
00421 *                     decimal places. A value of 0 implies exact equality.
00422 *
00423 *   wcs1     const struct wcsprm*
00424 *                     The first wcsprm struct to compare.
00425 *
00426 *   wcs2     const struct wcsprm*
00427 *                     The second wcsprm struct to compare.
00428 *
00429 * Returned:
00430 *   equal    int*      Non-zero when the given structs are equal.
00431 *
00432 * Function return value:
00433 *   int      Status return value:
00434 *             0: Success.
00435 *             1: Null pointer passed.
00436 *
00437 *
00438 * wscsncpy() macro - Copy routine for the wcsprm struct
00439 * -----
00440 * wscsncpy() does a deep copy of one wcsprm struct to another. As of
00441 * WCSLIB 3.6, it is implemented as a preprocessor macro that invokes
00442 * wcsncpy() with the nsub and axes pointers both set to zero.
00443 *
00444 *
00445 * wcsfree() - Destructor for the wcsprm struct
00446 * -----
00447 * wcsfree() frees memory allocated for the wcsprm arrays by wcsinit() and/or
00448 * wcsset(). wcsinit() records the memory it allocates and wcsfree() will only

```

```

00449 * attempt to free this.
00450 *
00451 * PLEASE NOTE: wcsfree() must not be invoked on a wcsprm struct that was not
00452 * initialized by wcsinit().
00453 *
00454 * Given and returned:
00455 *   wcs          struct wcsprm*
00456 *               Coordinate transformation parameters.
00457 *
00458 * Function return value:
00459 *   int          Status return value:
00460 *               0: Success.
00461 *               1: Null wcsprm pointer passed.
00462 *
00463 *
00464 * wcsstrim() - Free unused arrays in the wcsprm struct
00465 * -----
00466 * wcsstrim() frees memory allocated by wcsinit() for arrays in the wcsprm
00467 * struct that remains unused after it has been set up by wcsset().
00468 *
00469 * The free'd array members are associated with FITS WCS keyrecords that are
00470 * rarely used and usually just bloat the struct: wcsprm::crota, wcsprm::colax,
00471 * wcsprm::cname, wcsprm::crder, wcsprm::csyer, wcsprm::czphs, and
00472 * wcsprm::cperi. If unused, wcsprm::pv, wcsprm::ps, and wcsprm::cd are also
00473 * freed.
00474 *
00475 * Once these arrays have been freed, a test such as
00476 * =
00477 * =         if (!undefined(wcs->cname[i])) {...}
00478 * =
00479 * must be protected as follows
00480 * =
00481 * =         if (wcs->cname && !undefined(wcs->cname[i])) {...}
00482 * =
00483 * In addition, if wcsprm::npv is non-zero but less than wcsprm::npvmax, then
00484 * the unused space in wcsprm::pv will be recovered (using realloc()).
00485 * Likewise for wcsprm::ps.
00486 *
00487 * Given and returned:
00488 *   wcs          struct wcsprm*
00489 *               Coordinate transformation parameters.
00490 *
00491 * Function return value:
00492 *   int          Status return value:
00493 *               0: Success.
00494 *               1: Null wcsprm pointer passed.
00495 *               14: wcsprm struct is unset.
00496 *
00497 *
00498 * wcszsize() - Compute the size of a wcsprm struct
00499 * -----
00500 * wcszsize() computes the full size of a wcsprm struct, including allocated
00501 * memory.
00502 *
00503 * Given:
00504 *   wcs          const struct wcsprm*
00505 *               Coordinate transformation parameters.
00506 *
00507 *               If NULL, the base size of the struct and the allocated
00508 *               size are both set to zero.
00509 *
00510 * Returned:
00511 *   sizes        int[2]   The first element is the base size of the struct as
00512 *                         returned by sizeof(struct wcsprm). The second element
00513 *                         is the total allocated size, in bytes, assuming that
00514 *                         the allocation was done by wcsini(). This figure
00515 *                         includes memory allocated for members of constituent
00516 *                         structs, such as wcsprm::lin.
00517 *
00518 *               It is not an error for the struct not to have been set
00519 *               up via wcsset(), which normally results in additional
00520 *               memory allocation.
00521 *
00522 * Function return value:
00523 *   int          Status return value:
00524 *               0: Success.
00525 *
00526 *
00527 * auxsize() - Compute the size of a auxprm struct
00528 * -----
00529 * auxsize() computes the full size of an auxprm struct, including allocated
00530 * memory.
00531 *
00532 * Given:
00533 *   aux          const struct auxprm*
00534 *               Auxiliary coordinate information.
00535 *

```

```

00536 *                               If NULL, the base size of the struct and the allocated
00537 *                               size are both set to zero.
00538 *
00539 * Returned:
00540 *   sizes      int[2]      The first element is the base size of the struct as
00541 *                           returned by sizeof(struct auxprm). The second element
00542 *                           is the total allocated size, in bytes, currently zero.
00543 *
00544 * Function return value:
00545 *   int        Status return value:
00546 *               0: Success.
00547 *
00548 *
00549 * wcsenq() - enquire about the state of a wcsprm struct
00550 * -----
00551 * wcsenq() may be used to obtain information about the state of a wcsprm
00552 * struct. The function returns a true/false answer for the enquiry asked.
00553 *
00554 * Given:
00555 *   wcs        const struct wcsprm*
00556 *               Coordinate transformation parameters.
00557 *
00558 *   enquiry    int          Enquiry according to the following parameters:
00559 *                           WCsENQ_MEM: memory in the struct is being managed by
00560 *                           WCsLIB (see wcsini()).
00561 *                           WCsENQ_SET: the struct has been set up by wcsset().
00562 *                           WCsENQ_BY: the struct is in bypass mode (see
00563 *                           wcsset()).
00564 *                           WCsENQ_CHK: the struct is self-consistent in that
00565 *                           no changes have been made to any of the
00566 *                           "parameters to be given" since the last
00567 *                           call to wcsset().
00568 *                           These may be combined by logical OR, e.g.
00569 *                           WCsENQ_MEM | WCsENQ_SET. The enquiry result will be
00570 *                           the logical AND of the individual results.
00571 *
00572 * Function return value:
00573 *   int        Enquiry result:
00574 *               0: False.
00575 *               1: True.
00576 *
00577 *
00578 * wcsprt() - Print routine for the wcsprm struct
00579 * -----
00580 * wcsprt() prints the contents of a wcsprm struct using wcsprintf(). Mainly
00581 * intended for diagnostic purposes.
00582 *
00583 * Given:
00584 *   wcs        const struct wcsprm*
00585 *               Coordinate transformation parameters.
00586 *
00587 * Function return value:
00588 *   int        Status return value:
00589 *               0: Success.
00590 *               1: Null wcsprm pointer passed.
00591 *
00592 *
00593 * wcsprerr() - Print error messages from a wcsprm struct
00594 * -----
00595 * wcsprerr() prints the error message(s), if any, stored in a wcsprm struct,
00596 * and the linprm, celprm, prjprm, spcprm, and tabprm structs that it contains.
00597 * If there are no errors then nothing is printed. It uses wcserr_prt(), q.v.
00598 *
00599 * Given:
00600 *   wcs        const struct wcsprm*
00601 *               Coordinate transformation parameters.
00602 *
00603 *   prefix     const char *
00604 *               If non-NULL, each output line will be prefixed with
00605 *               this string.
00606 *
00607 * Function return value:
00608 *   int        Status return value:
00609 *               0: Success.
00610 *               1: Null wcsprm pointer passed.
00611 *
00612 *
00613 * wcsbchk() - Enable/disable bounds checking
00614 * -----
00615 * wcsbchk() is used to control bounds checking in the projection routines.
00616 * Note that wcsset() always enables bounds checking. wcsbchk() will invoke
00617 * wcsset() on the wcsprm struct beforehand if necessary.
00618 *
00619 * Given and returned:
00620 *   wcs        struct wcsprm*
00621 *               Coordinate transformation parameters.
00622 *

```

```

00623 * Given:
00624 *   bounds      int      If bounds&1 then enable strict bounds checking for the
00625 *                        spherical-to-Cartesian (s2x) transformation for the
00626 *                        AZP, SZP, TAN, SIN, ZPN, and COP projections.
00627 *
00628 *                        If bounds&2 then enable strict bounds checking for the
00629 *                        Cartesian-to-spherical (x2s) transformation for the
00630 *                        HPX and XPH projections.
00631 *
00632 *                        If bounds&4 then enable bounds checking on the native
00633 *                        coordinates returned by the Cartesian-to-spherical
00634 *                        (x2s) transformations using prjchk().
00635 *
00636 *                        Zero it to disable all checking.
00637 *
00638 * Function return value:
00639 *           int          Status return value:
00640 *                        0: Success.
00641 *                        1: Null wcsprm pointer passed.
00642 *
00643 *
00644 * wcsset() - Setup routine for the wcsprm struct
00645 * -----
00646 * wcsset() sets up a wcsprm struct according to information supplied within
00647 * it (refer to the description of the wcsprm struct).
00648 *
00649 * wcsset() recognizes the NCP projection and converts it to the equivalent SIN
00650 * projection and likewise translates GLS into SFL. It also translates the
00651 * AIPS spectral types ('FREQ-LSR', 'FELO-HEL', etc.), possibly changing the
00652 * input header keywords wcsprm::ctype and/or wcsprm::specsys if necessary.
00653 *
00654 * Note that this routine need not be called directly; it will be invoked by
00655 * wcp2s() and wcsp2p() if the wcsprm::flag is anything other than a
00656 * predefined magic value.
00657 *
00658 * wcsset() normally operates regardless of the value of wcsprm::flag; i.e.
00659 * even if a struct was previously set up it will be reset unconditionally.
00660 * However, a wcsprm struct may be put into "bypass" mode by invoking wcsset()
00661 * initially with wcsprm::flag == 1 (rather than 0). wcsset() will return
00662 * immediately if invoked on a struct in that state. To take a struct out of
00663 * bypass mode, simply reset wcsprm::flag to zero. See also wcsenq().
00664 *
00665 * Given and returned:
00666 *   wcs          struct wcsprm*
00667 *                Coordinate transformation parameters.
00668 *
00669 * Function return value:
00670 *           int          Status return value:
00671 *                        0: Success.
00672 *                        1: Null wcsprm pointer passed.
00673 *                        2: Memory allocation failed.
00674 *                        3: Linear transformation matrix is singular.
00675 *                        4: Inconsistent or unrecognized coordinate axis
00676 *                           types.
00677 *                        5: Invalid parameter value.
00678 *                        6: Invalid coordinate transformation parameters.
00679 *                        7: Ill-conditioned coordinate transformation
00680 *                           parameters.
00681 *
00682 * For returns > 1, a detailed error message is set in
00683 * wcsprm::err if enabled, see wcserr_enable().
00684 *
00685 * Notes:
00686 * 1: wcsset() always enables strict bounds checking in the projection
00687 *    routines (via a call to prjini()). Use wcsbchk() to modify
00688 *    bounds-checking after wcsset() is invoked.
00689 *
00690 *
00691 * wcp2s() - Pixel-to-world transformation
00692 * -----
00693 * wcp2s() transforms pixel coordinates to world coordinates.
00694 *
00695 * Given and returned:
00696 *   wcs          struct wcsprm*
00697 *                Coordinate transformation parameters.
00698 *
00699 * Given:
00700 *   ncoord,
00701 *   nelelem      int      The number of coordinates, each of vector length
00702 *                        nelelem but containing wcs.naxis coordinate elements.
00703 *                        Thus nelelem must equal or exceed the value of the
00704 *                        NAXIS keyword unless ncoord == 1, in which case nelelem
00705 *                        is not used.
00706 *
00707 *   pixcrd       const double[ncoord][nelelem]
00708 *                Array of pixel coordinates.
00709 *

```

```

00710 * Returned:
00711 *   imgcrd      double[ncoord][nelem]
00712 *               Array of intermediate world coordinates. For
00713 *               celestial axes, imgcrd[][wcs.lng] and
00714 *               imgcrd[][wcs.lat] are the projected x-, and
00715 *               y-coordinates in pseudo "degrees". For spectral
00716 *               axes, imgcrd[][wcs.spec] is the intermediate spectral
00717 *               coordinate, in SI units. For time axes,
00718 *               imgcrd[][wcs.time] is the intermediate time
00719 *               coordinate.
00720 *
00721 *   phi,theta double[ncoord]
00722 *               Longitude and latitude in the native coordinate system
00723 *               of the projection [deg].
00724 *
00725 *   world        double[ncoord][nelem]
00726 *               Array of world coordinates. For celestial axes,
00727 *               world[][wcs.lng] and world[][wcs.lat] are the
00728 *               celestial longitude and latitude [deg]. For spectral
00729 *               axes, world[][wcs.spec] is the spectral coordinate, in
00730 *               SI units. For time axes, world[][wcs.time] is the
00731 *               time coordinate.
00732 *
00733 *   stat          int[ncoord]
00734 *               Status return value for each coordinate:
00735 *               0: Success.
00736 *               1+: A bit mask indicating invalid pixel coordinate
00737 *                  element(s).
00738 *
00739 * Function return value:
00740 *   int           Status return value:
00741 *               0: Success.
00742 *               1: Null wcsprm pointer passed.
00743 *               2: Memory allocation failed.
00744 *               3: Linear transformation matrix is singular.
00745 *               4: Inconsistent or unrecognized coordinate axis
00746 *                  types.
00747 *               5: Invalid parameter value.
00748 *               6: Invalid coordinate transformation parameters.
00749 *               7: Ill-conditioned coordinate transformation
00750 *                  parameters.
00751 *               8: One or more of the pixel coordinates were
00752 *                  invalid, as indicated by the stat vector.
00753 *
00754 *               For returns > 1, a detailed error message is set in
00755 *               wcsprm::err if enabled, see wcserr_enable().
00756 *
00757 *
00758 * wcss2p() - World-to-pixel transformation
00759 * -----
00760 * wcss2p() transforms world coordinates to pixel coordinates.
00761 *
00762 * Given and returned:
00763 *   wcs           struct wcsprm*
00764 *               Coordinate transformation parameters.
00765 *
00766 * Given:
00767 *   ncoord,
00768 *   nelelem      int
00769 *               The number of coordinates, each of vector length nelelem
00770 *               but containing wcs.naxis coordinate elements. Thus
00771 *               nelelem must equal or exceed the value of the NAXIS
00772 *               keyword unless ncoord == 1, in which case nelelem is not
00773 *               used.
00774 *
00775 *   world         const double[ncoord][nelem]
00776 *               Array of world coordinates. For celestial axes,
00777 *               world[][wcs.lng] and world[][wcs.lat] are the
00778 *               celestial longitude and latitude [deg]. For spectral
00779 *               axes, world[][wcs.spec] is the spectral coordinate, in
00780 *               SI units. For time axes, world[][wcs.time] is the
00781 *               time coordinate.
00782 *
00783 * Returned:
00784 *   phi,theta double[ncoord]
00785 *               Longitude and latitude in the native coordinate
00786 *               system of the projection [deg].
00787 *
00788 *   imgcrd        double[ncoord][nelem]
00789 *               Array of intermediate world coordinates. For
00790 *               celestial axes, imgcrd[][wcs.lng] and
00791 *               imgcrd[][wcs.lat] are the projected x-, and
00792 *               y-coordinates in pseudo "degrees". For quadcube
00793 *               projections with a CUBEFACE axis the face number is
00794 *               also returned in imgcrd[][wcs.cubeface]. For
00795 *               spectral axes, imgcrd[][wcs.spec] is the intermediate
00796 *               spectral coordinate, in SI units. For time axes,
00797 *               imgcrd[][wcs.time] is the intermediate time

```

```

00797 *                      coordinate.
00798 *
00799 *   pixcrd      double[ncoord][nelem]
00800 *              Array of pixel coordinates.
00801 *
00802 *   stat        int[ncoord]
00803 *              Status return value for each coordinate:
00804 *              0: Success.
00805 *              1+: A bit mask indicating invalid world coordinate
00806 *                  element(s).
00807 *
00808 * Function return value:
00809 *   int         Status return value:
00810 *   0: Success.
00811 *   1: Null wcsprm pointer passed.
00812 *   2: Memory allocation failed.
00813 *   3: Linear transformation matrix is singular.
00814 *   4: Inconsistent or unrecognized coordinate axis
00815 *       types.
00816 *   5: Invalid parameter value.
00817 *   6: Invalid coordinate transformation parameters.
00818 *   7: Ill-conditioned coordinate transformation
00819 *       parameters.
00820 *   9: One or more of the world coordinates were
00821 *       invalid, as indicated by the stat vector.
00822 *
00823 * For returns > 1, a detailed error message is set in
00824 * wcsprm::err if enabled, see wcserr_enable().
00825 *
00826 *
00827 * wcmix() - Hybrid coordinate transformation
00828 * -----
00829 * wcmix(), given either the celestial longitude or latitude plus an element
00830 * of the pixel coordinate, solves for the remaining elements by iterating on
00831 * the unknown celestial coordinate element using wcsc2p(). Refer also to the
00832 * notes below.
00833 *
00834 * Given and returned:
00835 *   wcs          struct wcsprm*
00836 *               Indices for the celestial coordinates obtained
00837 *               by parsing the wcsprm::ctype[].
00838 *
00839 * Given:
00840 *   mixpix       int          Which element of the pixel coordinate is given.
00841 *
00842 *   mixcel       int          Which element of the celestial coordinate is given:
00843 *   1: Celestial longitude is given in
00844 *       world[wcs.lng], latitude returned in
00845 *       world[wcs.lat].
00846 *   2: Celestial latitude is given in
00847 *       world[wcs.lat], longitude returned in
00848 *       world[wcs.lng].
00849 *
00850 *   vspan        const double[2]
00851 *               Solution interval for the celestial coordinate [deg].
00852 *               The ordering of the two limits is irrelevant.
00853 *               Longitude ranges may be specified with any convenient
00854 *               normalization, for example [-120,+120] is the same as
00855 *               [240,480], except that the solution will be returned
00856 *               with the same normalization, i.e. lie within the
00857 *               interval specified.
00858 *
00859 *   vstep        const double
00860 *               Step size for solution search [deg]. If zero, a
00861 *               sensible, although perhaps non-optimal default will be
00862 *               used.
00863 *
00864 *   viter        int          If a solution is not found then the step size will be
00865 *                               halved and the search recommenced. viter controls how
00866 *                               many times the step size is halved. The allowed range
00867 *                               is 5 - 10.
00868 *
00869 * Given and returned:
00870 *   world         double[naxis]
00871 *               World coordinate elements. world[wcs.lng] and
00872 *               world[wcs.lat] are the celestial longitude and
00873 *               latitude [deg]. Which is given and which returned
00874 *               depends on the value of mixcel. All other elements
00875 *               are given.
00876 *
00877 * Returned:
00878 *   phi,theta     double[naxis]
00879 *               Longitude and latitude in the native coordinate
00880 *               system of the projection [deg].
00881 *
00882 *   imgcrd        double[naxis]
00883 *               Image coordinate elements. imgcrd[wcs.lng] and

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00884 *          imgcrd[wcs.lat] are the projected x-, and
00885 *          y-coordinates in pseudo "degrees".
00886 *
00887 * Given and returned:
00888 *   pixcrd      double[naxis]
00889 *          Pixel coordinate. The element indicated by mixpix is
00890 *          given and the remaining elements are returned.
00891 *
00892 * Function return value:
00893 *   int          Status return value:
00894 *       0: Success.
00895 *       1: Null wcsprm pointer passed.
00896 *       2: Memory allocation failed.
00897 *       3: Linear transformation matrix is singular.
00898 *       4: Inconsistent or unrecognized coordinate axis
00899 *          types.
00900 *       5: Invalid parameter value.
00901 *       6: Invalid coordinate transformation parameters.
00902 *       7: Ill-conditioned coordinate transformation
00903 *          parameters.
00904 *      10: Invalid world coordinate.
00905 *      11: No solution found in the specified interval.
00906 *
00907 * For returns > 1, a detailed error message is set in
00908 * wcsprm::err if enabled, see wcserr_enable().
00909 *
00910 * Notes:
00911 *   1: Initially the specified solution interval is checked to see if it's a
00912 *      "crossing" interval. If it isn't, a search is made for a crossing
00913 *      solution by iterating on the unknown celestial coordinate starting at
00914 *      the upper limit of the solution interval and decrementing by the
00915 *      specified step size. A crossing is indicated if the trial value of the
00916 *      pixel coordinate steps through the value specified. If a crossing
00917 *      interval is found then the solution is determined by a modified form of
00918 *      "regula falsi" division of the crossing interval. If no crossing
00919 *      interval was found within the specified solution interval then a search
00920 *      is made for a "non-crossing" solution as may arise from a point of
00921 *      tangency. The process is complicated by having to make allowance for
00922 *      the discontinuities that occur in all map projections.
00923 *
00924 *      Once one solution has been determined others may be found by subsequent
00925 *      invocations of wcsmix() with suitably restricted solution intervals.
00926 *
00927 *      Note the circumstance that arises when the solution point lies at a
00928 *      native pole of a projection in which the pole is represented as a
00929 *      finite curve, for example the zenithals and conics. In such cases two
00930 *      or more valid solutions may exist but wcsmix() only ever returns one.
00931 *
00932 *      Because of its generality wcsmix() is very compute-intensive. For
00933 *      compute-limited applications more efficient special-case solvers could
00934 *      be written for simple projections, for example non-oblique cylindrical
00935 *      projections.
00936 *
00937 *
00938 * wscscs() - Change celestial coordinate system
00939 * -----
00940 * wscscs() changes the celestial coordinate system of a wcsprm struct. For
00941 * example, from equatorial to galactic coordinates.
00942 *
00943 * Parameters that define the spherical coordinate transformation, essentially
00944 * being three Euler angles, must be provided. Thereby wscscs() does not need
00945 * prior knowledge of specific celestial coordinate systems. It also has the
00946 * advantage of making it completely general.
00947 *
00948 * Auxiliary members of the wcsprm struct relating to equatorial celestial
00949 * coordinate systems may also be changed.
00950 *
00951 * Only orthodox spherical coordinate systems are supported. That is, they
00952 * must be right-handed, with latitude increasing from zero at the equator to
00953 * +90 degrees at the pole. This precludes systems such as azimuth and zenith
00954 * distance, which, however, could be handled as negative azimuth and
00955 * elevation.
00956 *
00957 * PLEASE NOTE: Information in the wcsprm struct relating to the original
00958 * coordinate system will be overwritten and therefore lost. If this is
00959 * undesirable, invoke wscscs() on a copy of the struct made with wcsub().
00960 * The wcsprm struct is reset on return with an explicit call to wcsset().
00961 *
00962 * Given and returned:
00963 *   wcs          struct wcsprm*
00964 *          Coordinate transformation parameters. Particular
00965 *          "values to be given" elements of the wcsprm struct
00966 *          are modified.
00967 *
00968 * Given:
00969 *   lng2pl,
00970 *   lat2pl      double      Longitude and latitude in the new celestial coordinate

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```

00971 *          system of the pole (i.e. latitude +90) of the original
00972 *          system [deg]. See notes 1 and 2 below.
00973 *
00974 *   lng1p2    double   Longitude in the original celestial coordinate system
00975 *                  of the pole (i.e. latitude +90) of the new system
00976 *                  [deg]. See note 1 below.
00977 *
00978 *   clng,clat const char*
00979 *                  Longitude and latitude identifiers of the new CTYPEia
00980 *                  celestial axis codes, without trailing dashes. For
00981 *                  example, "RA" and "DEC" or "GLON" and "GLAT". Up to
00982 *                  four characters are used, longer strings need not be
00983 *                  null-terminated.
00984 *
00985 *   radesys   const char*
00986 *                  Used when transforming to equatorial coordinates,
00987 *                  identified by clng == "RA" and clat = "DEC". May be
00988 *                  set to the null pointer to preserve the current value.
00989 *                  Up to 71 characters are used, longer strings need not
00990 *                  be null-terminated.
00991 *
00992 *                  If the new coordinate system is anything other than
00993 *                  equatorial, then wcsprm::radesys will be cleared.
00994 *
00995 *   equinox   double   Used when transforming to equatorial coordinates. May
00996 *                  be set to zero to preserve the current value.
00997 *
00998 *                  If the new coordinate system is not equatorial, then
00999 *                  wcsprm::equinox will be marked as undefined.
01000 *
01001 *   alt       const char*
01002 *                  Character code for alternate coordinate descriptions
01003 *                  (i.e. the 'a' in keyword names such as CTYPEia). This
01004 *                  is blank for the primary coordinate description, or
01005 *                  one of the 26 upper-case letters, A-Z. May be set to
01006 *                  the null pointer, or null string if no change is
01007 *                  required.
01008 *
01009 * Function return value:
01010 *   int       Status return value:
01011 *             0: Success.
01012 *             1: Null wcsprm pointer passed.
01013 *             12: Invalid subimage specification (no celestial
01014 *                 axes).
01015 *
01016 * Notes:
01017 *   1: Follows the prescription given in WCS Paper II, Sect. 2.7 for changing
01018 *       celestial coordinates.
01019 *
01020 *       The implementation takes account of indeterminacies that arise in that
01021 *       prescription in the particular cases where one of the poles of the new
01022 *       system is at the fiducial point, or one of them is at the native pole.
01023 *
01024 *   2: If lat2p1 == +90, i.e. where the poles of the two coordinate systems
01025 *       coincide, then the spherical coordinate transformation becomes a simple
01026 *       change in origin of longitude given by
01027 *       lng2 = lng1 + (lng2p1 - lng1p2 - 180), and lat2 = lat1, where
01028 *       (lng2,lat2) are coordinates in the new system, and (lng1,lat1) are
01029 *       coordinates in the original system.
01030 *
01031 *       Likewise, if lat2p1 == -90, then lng2 = -lng1 + (lng2p1 + lng1p2), and
01032 *       lat2 = -lat1.
01033 *
01034 *   3: For example, if the original coordinate system is B1950 equatorial and
01035 *       the desired new coordinate system is galactic, then
01036 *
01037 *       - (lng2p1,lat2p1) are the galactic coordinates of the B1950 celestial
01038 *         pole, defined by the IAU to be (123.0,+27.4), and lng1p2 is the B1950
01039 *         right ascension of the galactic pole, defined as 192.25. Clearly
01040 *         these coordinates are fixed for a particular coordinate
01041 *         transformation.
01042 *
01043 *       - (clng,clat) would be 'GLON' and 'GLAT', these being the FITS standard
01044 *         identifiers for galactic coordinates.
01045 *
01046 *       - Since the new coordinate system is not equatorial, wcsprm::radesys
01047 *         and wcsprm::equinox will be cleared.
01048 *
01049 *   4. The coordinates required for some common transformations (obtained from
01050 *       https://ned.ipac.caltech.edu/coordinate\_calculator) are as follows:
01051 *
01052 *   (123.0000,+27.4000) galactic coordinates of B1950 celestial pole,
01053 *   (192.2500,+27.4000) B1950 equatorial coordinates of galactic pole.
01054 *
01055 *   (122.9319,+27.1283) galactic coordinates of J2000 celestial pole,
01056 *   (192.8595,+27.1283) J2000 equatorial coordinates of galactic pole.
01057 *

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01058 =      (359.6774,+89.7217) B1950 equatorial coordinates of J2000 pole,
01059 =      (180.3162,+89.7217) J2000 equatorial coordinates of B1950 pole.
01060 *
01061 =      (270.0000,+66.5542) B1950 equatorial coordinates of B1950 ecliptic pole,
01062 =      ( 90.0000,+66.5542) B1950 ecliptic coordinates of B1950 celestial pole.
01063 *
01064 =      (270.0000,+66.5607) J2000 equatorial coordinates of J2000 ecliptic pole,
01065 =      ( 90.0000,+66.5607) J2000 ecliptic coordinates of J2000 celestial pole.
01066 *
01067 =      ( 26.7315,+15.6441) supergalactic coordinates of B1950 celestial pole,
01068 =      (283.1894,+15.6441) B1950 equatorial coordinates of supergalactic pole.
01069 *
01070 =      ( 26.4505,+15.7089) supergalactic coordinates of J2000 celestial pole,
01071 =      (283.7542,+15.7089) J2000 equatorial coordinates of supergalactic pole.
01072 *
01073 *
01074 * wcssptr() - Spectral axis translation
01075 * -----
01076 * wcssptr() translates the spectral axis in a wcsprm struct. For example, a
01077 * 'FREQ' axis may be translated into 'ZOPT-F2W' and vice versa.
01078 *
01079 * PLEASE NOTE: Information in the wcsprm struct relating to the original
01080 * coordinate system will be overwritten and therefore lost. If this is
01081 * undesirable, invoke wcssptr() on a copy of the struct made with wcssub().
01082 * The wcsprm struct is reset on return with an explicit call to wcsset().
01083 *
01084 * Given and returned:
01085 *   wcs      struct wcsprm*
01086 *           Coordinate transformation parameters.
01087 *
01088 *   i        int*      Index of the spectral axis (0-relative). If given < 0
01089 *           it will be set to the first spectral axis identified
01090 *           from the ctype[] keyvalues in the wcsprm struct.
01091 *
01092 *   ctype    char[9]   Desired spectral CTYpeia. Wildcarding may be used as
01093 *           for the ctypeS2 argument to spctrn() as described in
01094 *           the prologue of spc.h, i.e. if the final three
01095 *           characters are specified as "???", or if just the
01096 *           eighth character is specified as '?', the correct
01097 *           algorithm code will be substituted and returned.
01098 *
01099 * Function return value:
01100 *   int      Status return value:
01101 *           0: Success.
01102 *           1: Null wcsprm pointer passed.
01103 *           2: Memory allocation failed.
01104 *           3: Linear transformation matrix is singular.
01105 *           4: Inconsistent or unrecognized coordinate axis
01106 *           types.
01107 *           5: Invalid parameter value.
01108 *           6: Invalid coordinate transformation parameters.
01109 *           7: Ill-conditioned coordinate transformation
01110 *           parameters.
01111 *           12: Invalid subimage specification (no spectral
01112 *           axis).
01113 *
01114 *           For returns > 1, a detailed error message is set in
01115 *           wcsprm::err if enabled, see wcserr_enable().
01116 *
01117 *
01118 * wcslib_version() - WCSLIB version number
01119 * -----
01120 * wcslib_version() returns the WCSLIB version number.
01121 *
01122 * The major version number changes when the ABI changes or when the license
01123 * conditions change. ABI changes typically result from a change to the
01124 * contents of one of the structs. The major version number is used to
01125 * distinguish between incompatible versions of the sharable library.
01126 *
01127 * The minor version number changes with new functionality or bug fixes that do
01128 * not involve a change in the ABI.
01129 *
01130 * The auxiliary version number (which is often absent) signals changes to the
01131 * documentation, test suite, build procedures, or any other change that does
01132 * not affect the compiled library.
01133 *
01134 * Returned:
01135 *   vers[3]  int[3]     The broken-down version number:
01136 *           0: Major version number.
01137 *           1: Minor version number.
01138 *           2: Auxiliary version number (zero if absent).
01139 *           May be given as a null pointer if not required.
01140 *
01141 * Function return value:
01142 *   char*     A null-terminated, statically allocated string
01143 *           containing the version number in the usual form, i.e.
01144 *           "<major>.<minor>.<auxiliary>".

```

```

01145 *
01146 *
01147 * wcsprm struct - Coordinate transformation parameters
01148 * -----
01149 * The wcsprm struct contains information required to transform world
01150 * coordinates. It consists of certain members that must be set by the user
01151 * ("given") and others that are set by the WCSLIB routines ("returned").
01152 * While the addresses of the arrays themselves may be set by wcsinit() if it
01153 * (optionally) allocates memory, their contents must be set by the user.
01154 *
01155 * Some parameters that are given are not actually required for transforming
01156 * coordinates. These are described as "auxiliary"; the struct simply provides
01157 * a place to store them, though they may be used by wcshdr() in constructing a
01158 * FITS header from a wcsprm struct. Some of the returned values are supplied
01159 * for informational purposes and others are for internal use only as
01160 * indicated.
01161 *
01162 * In practice, it is expected that a WCS parser would scan the FITS header to
01163 * determine the number of coordinate axes. It would then use wcsinit() to
01164 * allocate memory for arrays in the wcsprm struct and set default values.
01165 * Then as it reread the header and identified each WCS keyrecord it would load
01166 * the value into the relevant wcsprm array element. This is essentially what
01167 * wcsprh() does - refer to the prologue of wcshdr.h. As the final step,
01168 * wcsset() is invoked, either directly or indirectly, to set the derived
01169 * members of the wcsprm struct. wcsset() strips off trailing blanks in all
01170 * string members and null-fills the character array.
01171 *
01172 *   int flag
01173 *       (Given and returned) This flag must be set to zero (or 1, see wcsset())
01174 *       whenever any of the following wcsprm members are set or changed:
01175 *
01176 *       - wcsprm::naxis (q.v., not normally set by the user),
01177 *       - wcsprm::crpix,
01178 *       - wcsprm::pc,
01179 *       - wcsprm::cdelt,
01180 *       - wcsprm::crval,
01181 *       - wcsprm::cunit,
01182 *       - wcsprm::ctype,
01183 *       - wcsprm::lonpole,
01184 *       - wcsprm::latpole,
01185 *       - wcsprm::restfrq,
01186 *       - wcsprm::restwav,
01187 *       - wcsprm::npv,
01188 *       - wcsprm::pv,
01189 *       - wcsprm::nps,
01190 *       - wcsprm::ps,
01191 *       - wcsprm::cd,
01192 *       - wcsprm::crota,
01193 *       - wcsprm::altlin,
01194 *       - wcsprm::ntab,
01195 *       - wcsprm::nwtb,
01196 *       - wcsprm::tab,
01197 *       - wcsprm::wtb.
01198 *
01199 *   This signals the initialization routine, wcsset(), to recompute the
01200 *   returned members of the linprm, celprm, spcprm, and tabprm structs.
01201 *   wcsset() will reset flag to indicate that this has been done.
01202 *
01203 *   PLEASE NOTE: flag should be set to -1 when wcsinit() is called for the
01204 *   first time for a particular wcsprm struct in order to initialize memory
01205 *   management. It must ONLY be used on the first initialization otherwise
01206 *   memory leaks may result.
01207 *
01208 *   int naxis
01209 *       (Given or returned) Number of pixel and world coordinate elements.
01210 *
01211 *   If wcsinit() is used to initialize the linprm struct (as would normally
01212 *   be the case) then it will set naxis from the value passed to it as a
01213 *   function argument. The user should not subsequently modify it.
01214 *
01215 *   double *crpix
01216 *       (Given) Address of the first element of an array of double containing
01217 *       the coordinate reference pixel, CRPIXja.
01218 *
01219 *   double *pc
01220 *       (Given) Address of the first element of the PCi_ja (pixel coordinate)
01221 *       transformation matrix. The expected order is
01222 *
01223 *       struct wcsprm wcs;
01224 *       wcs.pc = {PC1_1, PC1_2, PC2_1, PC2_2};
01225 *
01226 *       This may be constructed conveniently from a 2-D array via
01227 *
01228 *       double m[2][2] = {{PC1_1, PC1_2},
01229 *                          {PC2_1, PC2_2}};
01230 *
01231 *       which is equivalent to

```

```

01232 *
01233 =     double m[2][2];
01234 =     m[0][0] = PC1_1;
01235 =     m[0][1] = PC1_2;
01236 =     m[1][0] = PC2_1;
01237 =     m[1][1] = PC2_2;
01238 *
01239 *     The storage order for this 2-D array is the same as for the 1-D array,
01240 *     whence
01241 *
01242 =     wcs.pc = *m;
01243 *
01244 *     would be legitimate.
01245 *
01246 *     double *cdelt
01247 *     (Given) Address of the first element of an array of double containing
01248 *     the coordinate increments, CDELTia.
01249 *
01250 *     double *crval
01251 *     (Given) Address of the first element of an array of double containing
01252 *     the coordinate reference values, CRVALia.
01253 *
01254 *     char (*cunit)[72]
01255 *     (Given) Address of the first element of an array of char[72] containing
01256 *     the CUNITia keyvalues which define the units of measurement of the
01257 *     CRVALia, CDELTia, and CDi_ja keywords.
01258 *
01259 *     As CUNITia is an optional header keyword, cunit[][72] may be left blank
01260 *     but otherwise is expected to contain a standard units specification as
01261 *     defined by WCS Paper I. Utility function wcsutrn(), described in
01262 *     wcsunits.h, is available to translate commonly used non-standard units
01263 *     specifications but this must be done as a separate step before invoking
01264 *     wcsset().
01265 *
01266 *     For celestial axes, if cunit[][72] is not blank, wcsset() uses
01267 *     wcsunits() to parse it and scale cdelt[], crval[], and cd[][*] to
01268 *     degrees. It then resets cunit[][72] to "deg".
01269 *
01270 *     For spectral axes, if cunit[][72] is not blank, wcsset() uses wcsunits()
01271 *     to parse it and scale cdelt[], crval[], and cd[][*] to SI units. It
01272 *     then resets cunit[][72] accordingly.
01273 *
01274 *     wcsset() ignores cunit[][72] for other coordinate types; cunit[][72] may
01275 *     be used to label coordinate values.
01276 *
01277 *     These variables accomodate the longest allowed string-valued FITS
01278 *     keyword, being limited to 68 characters, plus the null-terminating
01279 *     character.
01280 *
01281 *     char (*ctype)[72]
01282 *     (Given) Address of the first element of an array of char[72] containing
01283 *     the coordinate axis types, CTYPiEia.
01284 *
01285 *     The ctype[][72] keyword values must be in upper case and there must be
01286 *     zero or one pair of matched celestial axis types, and zero or one
01287 *     spectral axis. The ctype[][72] strings should be padded with blanks on
01288 *     the right and null-terminated so that they are at least eight characters
01289 *     in length.
01290 *
01291 *     These variables accomodate the longest allowed string-valued FITS
01292 *     keyword, being limited to 68 characters, plus the null-terminating
01293 *     character.
01294 *
01295 *     double lonpole
01296 *     (Given and returned) The native longitude of the celestial pole, phi_p,
01297 *     given by LONPOLEa [deg] or by PVi_2a [deg] attached to the longitude
01298 *     axis which takes precedence if defined, and ...
01299 *     double latpole
01300 *     (Given and returned) ... the native latitude of the celestial pole,
01301 *     theta_p, given by LATPOLEa [deg] or by PVi_3a [deg] attached to the
01302 *     longitude axis which takes precedence if defined.
01303 *
01304 *     lonpole and latpole may be left to default to values set by wcsinit()
01305 *     (see celpm::ref), but in any case they will be reset by wcsset() to
01306 *     the values actually used. Note therefore that if the wcsprm struct is
01307 *     reused without resetting them, whether directly or via wcsinit(), they
01308 *     will no longer have their default values.
01309 *
01310 *     double restfrq
01311 *     (Given) The rest frequency [Hz], and/or ...
01312 *     double restwav
01313 *     (Given) ... the rest wavelength in vacuo [m], only one of which need be
01314 *     given, the other should be set to zero.
01315 *
01316 *     int npv
01317 *     (Given) The number of entries in the wcsprm::pv[] array.
01318 *

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01319 * int npvmax
01320 *     (Given or returned) The length of the wcsprm::pv[] array.
01321 *
01322 *     npvmax will be set by wcsinit() if it allocates memory for wcsprm::pv[],
01323 *     otherwise it must be set by the user. See also wcsnpv().
01324 *
01325 * struct pvcards *pv
01326 *     (Given) Address of the first element of an array of length npvmax of
01327 *     pvcards structs.
01328 *
01329 *     As a FITS header parser encounters each PVi_ma keyword it should load it
01330 *     into a pvcards struct in the array and increment npv. wcsset()
01331 *     interprets these as required.
01332 *
01333 *     Note that, if they were not given, wcsset() resets the entries for
01334 *     PVi_1a, PVi_2a, PVi_3a, and PVi_4a for longitude axis i to match
01335 *     phi_0 and theta_0 (the native longitude and latitude of the reference
01336 *     point), LONPOLEa and LATPOLEa respectively.
01337 *
01338 * int nps
01339 *     (Given) The number of entries in the wcsprm::ps[] array.
01340 *
01341 * int npsmax
01342 *     (Given or returned) The length of the wcsprm::ps[] array.
01343 *
01344 *     npsmax will be set by wcsinit() if it allocates memory for wcsprm::ps[],
01345 *     otherwise it must be set by the user. See also wcsnps().
01346 *
01347 * struct pscards *ps
01348 *     (Given) Address of the first element of an array of length npsmax of
01349 *     pscards structs.
01350 *
01351 *     As a FITS header parser encounters each PSi_ma keyword it should load it
01352 *     into a pscards struct in the array and increment nps. wcsset()
01353 *     interprets these as required (currently no PSi_ma keyvalues are
01354 *     recognized).
01355 *
01356 * double *cd
01357 *     (Given) For historical compatibility, the wcsprm struct supports two
01358 *     alternate specifications of the linear transformation matrix, those
01359 *     associated with the CDi_ja keywords, and ...
01360 * double *crota
01361 *     (Given) ... those associated with the CROTAi keywords. Although these
01362 *     may not formally co-exist with PCi_ja, the approach taken here is simply
01363 *     to ignore them if given in conjunction with PCi_ja.
01364 *
01365 * int altlin
01366 *     (Given) altlin is a bit flag that denotes which of the PCi_ja, CDi_ja
01367 *     and CROTAi keywords are present in the header:
01368 *
01369 *     - Bit 0: PCi_ja is present.
01370 *
01371 *     - Bit 1: CDi_ja is present.
01372 *
01373 *     Matrix elements in the IRAF convention are equivalent to the product
01374 *     CDi_ja = CDELTia * PCi_ja, but the defaults differ from that of the
01375 *     PCi_ja matrix. If one or more CDi_ja keywords are present then all
01376 *     unspecified CDi_ja default to zero. If no CDi_ja (or CROTAi) keywords
01377 *     are present, then the header is assumed to be in PCi_ja form whether
01378 *     or not any PCi_ja keywords are present since this results in an
01379 *     interpretation of CDELTia consistent with the original FITS
01380 *     specification.
01381 *
01382 *     While CDi_ja may not formally co-exist with PCi_ja, it may co-exist
01383 *     with CDELTia and CROTAi which are to be ignored.
01384 *
01385 *     - Bit 2: CROTAi is present.
01386 *
01387 *     In the AIPS convention, CROTAi may only be associated with the
01388 *     latitude axis of a celestial axis pair. It specifies a rotation in
01389 *     the image plane that is applied AFTER the CDELTia; any other CROTAi
01390 *     keywords are ignored.
01391 *
01392 *     CROTAi may not formally co-exist with PCi_ja.
01393 *
01394 *     CROTAi and CDELTia may formally co-exist with CDi_ja but if so are to
01395 *     be ignored.
01396 *
01397 *     - Bit 3: PCi_ja + CDELTia was derived from CDi_ja by wcspx().
01398 *
01399 *     This bit is set by wcspx() when it derives PCi_ja and CDELTia from
01400 *     CDi_ja via an orthonormal decomposition. In particular, it signals
01401 *     wcsset() not to replace PCi_ja by a copy of CDi_ja with CDELTia set
01402 *     to unity.
01403 *
01404 *     CDi_ja and CROTAi keywords, if found, are to be stored in the wcsprm::cd
01405 *     and wcsprm::crota arrays which are dimensioned similarly to wcsprm::pc

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01406 *      and wcsprm::cdelt.  FITS header parsers should use the following
01407 *      procedure:
01408 *
01409 *      - Whenever a PCi_ja keyword is encountered: altlin |= 1;
01410 *
01411 *      - Whenever a CDi_ja keyword is encountered: altlin |= 2;
01412 *
01413 *      - Whenever a CROTAi keyword is encountered: altlin |= 4;
01414 *
01415 *      If none of these bits are set the PCi_ja representation results, i.e.
01416 *      wcsprm::pc and wcsprm::cdelt will be used as given.
01417 *
01418 *      These alternate specifications of the linear transformation matrix are
01419 *      translated immediately to PCi_ja by wcsset() and are invisible to the
01420 *      lower-level WCSLIB routines.  In particular, unless bit 3 is also set,
01421 *      wcsset() resets wcsprm::cdelt to unity if CDi_ja is present (and no
01422 *      PCi_ja).
01423 *
01424 *      If CROTAi are present but none is associated with the latitude axis
01425 *      (and no PCi_ja or CDi_ja), then wcsset() reverts to a unity PCi_ja
01426 *      matrix.
01427 *
01428 *      int velref
01429 *      (Given) AIPS velocity code VELREF, refer to spcaips().
01430 *
01431 *      It is not necessary to reset the wcsprm struct (via wcsset()) when
01432 *      wcsprm::velref is changed.
01433 *
01434 *      char alt[4]
01435 *      (Given, auxiliary) Character code for alternate coordinate descriptions
01436 *      (i.e. the 'a' in keyword names such as CTYPEia).  This is blank for the
01437 *      primary coordinate description, or one of the 26 upper-case letters,
01438 *      A-Z.
01439 *
01440 *      An array of four characters is provided for alignment purposes, only the
01441 *      first is used.
01442 *
01443 *      It is not necessary to reset the wcsprm struct (via wcsset()) when
01444 *      wcsprm::alt is changed.
01445 *
01446 *      int colnum
01447 *      (Given, auxiliary) Where the coordinate representation is associated
01448 *      with an image-array column in a FITS binary table, this variable may be
01449 *      used to record the relevant column number.
01450 *
01451 *      It should be set to zero for an image header or pixel list.
01452 *
01453 *      It is not necessary to reset the wcsprm struct (via wcsset()) when
01454 *      wcsprm::colnum is changed.
01455 *
01456 *      int *colax
01457 *      (Given, auxiliary) Address of the first element of an array of int
01458 *      recording the column numbers for each axis in a pixel list.
01459 *
01460 *      The array elements should be set to zero for an image header or image
01461 *      array in a binary table.
01462 *
01463 *      It is not necessary to reset the wcsprm struct (via wcsset()) when
01464 *      wcsprm::colax is changed.
01465 *
01466 *      char (*cname)[72]
01467 *      (Given, auxiliary) The address of the first element of an array of
01468 *      char[72] containing the coordinate axis names, CNAMEia.
01469 *
01470 *      These variables accomodate the longest allowed string-valued FITS
01471 *      keyword, being limited to 68 characters, plus the null-terminating
01472 *      character.
01473 *
01474 *      It is not necessary to reset the wcsprm struct (via wcsset()) when
01475 *      wcsprm::cname is changed.
01476 *
01477 *      double *crder
01478 *      (Given, auxiliary) Address of the first element of an array of double
01479 *      recording the random error in the coordinate value, CRDERia.
01480 *
01481 *      It is not necessary to reset the wcsprm struct (via wcsset()) when
01482 *      wcsprm::crder is changed.
01483 *
01484 *      double *csyer
01485 *      (Given, auxiliary) Address of the first element of an array of double
01486 *      recording the systematic error in the coordinate value, CSYERia.
01487 *
01488 *      It is not necessary to reset the wcsprm struct (via wcsset()) when
01489 *      wcsprm::csyer is changed.
01490 *
01491 *      double *czpshs
01492 *      (Given, auxiliary) Address of the first element of an array of double

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01493 *      recording the time at the zero point of a phase axis, CZPHSia.
01494 *
01495 *      It is not necessary to reset the wcsprm struct (via wcsset()) when
01496 *      wcsprm::czphs is changed.
01497 *
01498 *      double *cperi
01499 *      (Given, auxiliary) Address of the first element of an array of double
01500 *      recording the period of a phase axis, CPERIia.
01501 *
01502 *      It is not necessary to reset the wcsprm struct (via wcsset()) when
01503 *      wcsprm::cperi is changed.
01504 *
01505 *      char wcsname[72]
01506 *      (Given, auxiliary) The name given to the coordinate representation,
01507 *      WCSNAMEa. This variable accomodates the longest allowed string-valued
01508 *      FITS keyword, being limited to 68 characters, plus the null-terminating
01509 *      character.
01510 *
01511 *      It is not necessary to reset the wcsprm struct (via wcsset()) when
01512 *      wcsprm::wcsname is changed.
01513 *
01514 *      char timesys[72]
01515 *      (Given, auxiliary) TIMESYS keyvalue, being the time scale (UTC, TAI,
01516 *      etc.) in which all other time-related auxiliary header values are
01517 *      recorded. Also defines the time scale for an image axis with CTYPEna
01518 *      set to 'TIME'.
01519 *
01520 *      It is not necessary to reset the wcsprm struct (via wcsset()) when
01521 *      wcsprm::timesys is changed.
01522 *
01523 *      char trefpos[72]
01524 *      (Given, auxiliary) TREFPOS keyvalue, being the location in space where
01525 *      the recorded time is valid.
01526 *
01527 *      It is not necessary to reset the wcsprm struct (via wcsset()) when
01528 *      wcsprm::trefpos is changed.
01529 *
01530 *      char trefdir[72]
01531 *      (Given, auxiliary) TREFDIR keyvalue, being the reference direction used
01532 *      in calculating a pathlength delay.
01533 *
01534 *      It is not necessary to reset the wcsprm struct (via wcsset()) when
01535 *      wcsprm::trefdir is changed.
01536 *
01537 *      char plephem[72]
01538 *      (Given, auxiliary) PLEPHEM keyvalue, being the Solar System ephemeris
01539 *      used for calculating a pathlength delay.
01540 *
01541 *      It is not necessary to reset the wcsprm struct (via wcsset()) when
01542 *      wcsprm::plephem is changed.
01543 *
01544 *      char timeunit[72]
01545 *      (Given, auxiliary) TIMEUNIT keyvalue, being the time units in which
01546 *      the following header values are expressed: TSTART, TSTOP, TIMEOFFS,
01547 *      TIMSYER, TIMRDER, TIMEDEL. It also provides the default value for
01548 *      CUNITia for time axes.
01549 *
01550 *      It is not necessary to reset the wcsprm struct (via wcsset()) when
01551 *      wcsprm::timeunit is changed.
01552 *
01553 *      char dateref[72]
01554 *      (Given, auxiliary) DATEREf keyvalue, being the date of a reference epoch
01555 *      relative to which other time measurements refer.
01556 *
01557 *      It is not necessary to reset the wcsprm struct (via wcsset()) when
01558 *      wcsprm::dateref is changed.
01559 *
01560 *      double mjdref[2]
01561 *      (Given, auxiliary) MJDREF keyvalue, equivalent to DATEREf expressed as
01562 *      a Modified Julian Date (MJD = JD - 2400000.5). The value is given as
01563 *      the sum of the two-element vector, allowing increased precision.
01564 *
01565 *      It is not necessary to reset the wcsprm struct (via wcsset()) when
01566 *      wcsprm::mjdref is changed.
01567 *
01568 *      double timeoffs
01569 *      (Given, auxiliary) TIMEOFFS keyvalue, being a time offset, which may be
01570 *      used, for example, to provide a uniform clock correction for times
01571 *      referenced to DATEREf.
01572 *
01573 *      It is not necessary to reset the wcsprm struct (via wcsset()) when
01574 *      wcsprm::timeoffs is changed.
01575 *
01576 *      char dateobs[72]
01577 *      (Given, auxiliary) DATE-OBS keyvalue, being the date at the start of the
01578 *      observation unless otherwise explained in the DATE-OBS keycomment, in
01579 *      ISO format, yyyy-mm-ddThh:mm:ss.

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01580 *
01581 *   It is not necessary to reset the wcsprm struct (via wcsset()) when
01582 *   wcsprm::dateobs is changed.
01583 *
01584 *   char datebeg[72]
01585 *   (Given, auxiliary) DATE-BEG keyvalue, being the date at the start of the
01586 *   observation in ISO format, yyyy-mm-ddThh:mm:ss.
01587 *
01588 *   It is not necessary to reset the wcsprm struct (via wcsset()) when
01589 *   wcsprm::datebeg is changed.
01590 *
01591 *   char dateavg[72]
01592 *   (Given, auxiliary) DATE-AVG keyvalue, being the date at a representative
01593 *   mid-point of the observation in ISO format, yyyy-mm-ddThh:mm:ss.
01594 *
01595 *   It is not necessary to reset the wcsprm struct (via wcsset()) when
01596 *   wcsprm::dateavg is changed.
01597 *
01598 *   char dateend[72]
01599 *   (Given, auxiliary) DATE-END keyvalue, baing the date at the end of the
01600 *   observation in ISO format, yyyy-mm-ddThh:mm:ss.
01601 *
01602 *   It is not necessary to reset the wcsprm struct (via wcsset()) when
01603 *   wcsprm::dateend is changed.
01604 *
01605 *   double mjdobs
01606 *   (Given, auxiliary) MJD-OBS keyvalue, equivalent to DATE-OBS expressed
01607 *   as a Modified Julian Date (MJD = JD - 2400000.5).
01608 *
01609 *   It is not necessary to reset the wcsprm struct (via wcsset()) when
01610 *   wcsprm::mjdobs is changed.
01611 *
01612 *   double mjdbeg
01613 *   (Given, auxiliary) MJD-BEG keyvalue, equivalent to DATE-BEG expressed
01614 *   as a Modified Julian Date (MJD = JD - 2400000.5).
01615 *
01616 *   It is not necessary to reset the wcsprm struct (via wcsset()) when
01617 *   wcsprm::mjdbeg is changed.
01618 *
01619 *   double mjdavg
01620 *   (Given, auxiliary) MJD-AVG keyvalue, equivalent to DATE-AVG expressed
01621 *   as a Modified Julian Date (MJD = JD - 2400000.5).
01622 *
01623 *   It is not necessary to reset the wcsprm struct (via wcsset()) when
01624 *   wcsprm::mjdavg is changed.
01625 *
01626 *   double mjdend
01627 *   (Given, auxiliary) MJD-END keyvalue, equivalent to DATE-END expressed
01628 *   as a Modified Julian Date (MJD = JD - 2400000.5).
01629 *
01630 *   It is not necessary to reset the wcsprm struct (via wcsset()) when
01631 *   wcsprm::mjdend is changed.
01632 *
01633 *   double jepoch
01634 *   (Given, auxiliary) JEPOCH keyvalue, equivalent to DATE-OBS expressed
01635 *   as a Julian epoch.
01636 *
01637 *   It is not necessary to reset the wcsprm struct (via wcsset()) when
01638 *   wcsprm::jepoch is changed.
01639 *
01640 *   double bepoch
01641 *   (Given, auxiliary) BEPOCH keyvalue, equivalent to DATE-OBS expressed
01642 *   as a Besselian epoch
01643 *
01644 *   It is not necessary to reset the wcsprm struct (via wcsset()) when
01645 *   wcsprm::bepoch is changed.
01646 *
01647 *   double tstart
01648 *   (Given, auxiliary) TSTART keyvalue, equivalent to DATE-BEG expressed
01649 *   as a time in units of TIMEUNIT relative to DATEREF+TIMEOFFS.
01650 *
01651 *   It is not necessary to reset the wcsprm struct (via wcsset()) when
01652 *   wcsprm::tstart is changed.
01653 *
01654 *   double tstop
01655 *   (Given, auxiliary) TSTOP keyvalue, equivalent to DATE-END expressed
01656 *   as a time in units of TIMEUNIT relative to DATEREF+TIMEOFFS.
01657 *
01658 *   It is not necessary to reset the wcsprm struct (via wcsset()) when
01659 *   wcsprm::tstop is changed.
01660 *
01661 *   double xposure
01662 *   (Given, auxiliary) XPOSURE keyvalue, being the effective exposure time
01663 *   in units of TIMEUNIT.
01664 *
01665 *   It is not necessary to reset the wcsprm struct (via wcsset()) when
01666 *   wcsprm::xposure is changed.

```

```

01667 *
01668 * double telapse
01669 *     (Given, auxiliary) TELAPSE keyvalue, equivalent to the elapsed time
01670 *     between DATE-BEG and DATE-END, in units of TIMEUNIT.
01671 *
01672 *     It is not necessary to reset the wcsprm struct (via wcsset()) when
01673 *     wcsprm::telapse is changed.
01674 *
01675 * double timsyer
01676 *     (Given, auxiliary) TIMSYER keyvalue, being the absolute error of the
01677 *     time values, in units of TIMEUNIT.
01678 *
01679 *     It is not necessary to reset the wcsprm struct (via wcsset()) when
01680 *     wcsprm::timsyer is changed.
01681 *
01682 * double timrder
01683 *     (Given, auxiliary) TIMRDER keyvalue, being the accuracy of time stamps
01684 *     relative to each other, in units of TIMEUNIT.
01685 *
01686 *     It is not necessary to reset the wcsprm struct (via wcsset()) when
01687 *     wcsprm::timrder is changed.
01688 *
01689 * double timedel
01690 *     (Given, auxiliary) TIMEDEL keyvalue, being the resolution of the time
01691 *     stamps.
01692 *
01693 *     It is not necessary to reset the wcsprm struct (via wcsset()) when
01694 *     wcsprm::timedel is changed.
01695 *
01696 * double timepixr
01697 *     (Given, auxiliary) TIMEPIXR keyvalue, being the relative position of the
01698 *     time stamps in binned time intervals, a value between 0.0 and 1.0.
01699 *
01700 *     It is not necessary to reset the wcsprm struct (via wcsset()) when
01701 *     wcsprm::timepixr is changed.
01702 *
01703 * double obsgeo[6]
01704 *     (Given, auxiliary) Location of the observer in a standard terrestrial
01705 *     reference frame. The first three give ITRS Cartesian coordinates
01706 *     OBSGEO-X [m], OBSGEO-Y [m], OBSGEO-Z [m], and the second three give
01707 *     OBSGEO-L [deg], OBSGEO-B [deg], OBSGEO-H [m], which are related through
01708 *     a standard transformation.
01709 *
01710 *     It is not necessary to reset the wcsprm struct (via wcsset()) when
01711 *     wcsprm::obsgeo is changed.
01712 *
01713 * char obsorbit[72]
01714 *     (Given, auxiliary) OBSORBIT keyvalue, being the URI, URL, or name of an
01715 *     orbit ephemeris file giving spacecraft coordinates relating to TREFPOS.
01716 *
01717 *     It is not necessary to reset the wcsprm struct (via wcsset()) when
01718 *     wcsprm::obsorbit is changed.
01719 *
01720 * char radesys[72]
01721 *     (Given, auxiliary) The equatorial or ecliptic coordinate system type,
01722 *     RADESYSa.
01723 *
01724 *     It is not necessary to reset the wcsprm struct (via wcsset()) when
01725 *     wcsprm::radesys is changed.
01726 *
01727 * double equinox
01728 *     (Given, auxiliary) The equinox associated with dynamical equatorial or
01729 *     ecliptic coordinate systems, EQUINOXa (or EPOCH in older headers). Not
01730 *     applicable to ICRS equatorial or ecliptic coordinates.
01731 *
01732 *     It is not necessary to reset the wcsprm struct (via wcsset()) when
01733 *     wcsprm::equinox is changed.
01734 *
01735 * char specsyst[72]
01736 *     (Given, auxiliary) Spectral reference frame (standard of rest),
01737 *     SPECSYSTa.
01738 *
01739 *     It is not necessary to reset the wcsprm struct (via wcsset()) when
01740 *     wcsprm::specsyst is changed.
01741 *
01742 * char ssysobs[72]
01743 *     (Given, auxiliary) The spectral reference frame in which there is no
01744 *     differential variation in the spectral coordinate across the
01745 *     field-of-view, SSYSOBSa.
01746 *
01747 *     It is not necessary to reset the wcsprm struct (via wcsset()) when
01748 *     wcsprm::ssysobs is changed.
01749 *
01750 * double velosys
01751 *     (Given, auxiliary) The relative radial velocity [m/s] between the
01752 *     observer and the selected standard of rest in the direction of the
01753 *     celestial reference coordinate, VELOSYSa.

```

```

01754 *
01755 *     It is not necessary to reset the wcsprm struct (via wcsset()) when
01756 *     wcsprm::velosys is changed.
01757 *
01758 *     double zsource
01759 *         (Given, auxiliary) The redshift, ZSOURCEa, of the source.
01760 *
01761 *     It is not necessary to reset the wcsprm struct (via wcsset()) when
01762 *     wcsprm::zsource is changed.
01763 *
01764 *     char ssyssrc[72]
01765 *         (Given, auxiliary) The spectral reference frame (standard of rest),
01766 *         SSYSSRCa, in which wcsprm::zsource was measured.
01767 *
01768 *     It is not necessary to reset the wcsprm struct (via wcsset()) when
01769 *     wcsprm::ssyssrc is changed.
01770 *
01771 *     double velangl
01772 *         (Given, auxiliary) The angle [deg] that should be used to decompose an
01773 *         observed velocity into radial and transverse components.
01774 *
01775 *     It is not necessary to reset the wcsprm struct (via wcsset()) when
01776 *     wcsprm::velangl is changed.
01777 *
01778 *     struct auxprm *aux
01779 *         (Given, auxiliary) This struct holds auxiliary coordinate system
01780 *         information of a specialist nature. While these parameters may be
01781 *         widely recognized within particular fields of astronomy, they differ
01782 *         from the above auxiliary parameters in not being defined by any of the
01783 *         FITS WCS standards. Collecting them together in a separate struct that
01784 *         is allocated only when required helps to control bloat in the size of
01785 *         the wcsprm struct.
01786 *
01787 *     int ntab
01788 *         (Given) See wcsprm::tab.
01789 *
01790 *     int nwtb
01791 *         (Given) See wcsprm::wtb.
01792 *
01793 *     struct tabprm *tab
01794 *         (Given) Address of the first element of an array of ntab tabprm structs
01795 *         for which memory has been allocated. These are used to store tabular
01796 *         transformation parameters.
01797 *
01798 *         Although technically wcsprm::ntab and tab are "given", they will
01799 *         normally be set by invoking wcstab(), whether directly or indirectly.
01800 *
01801 *         The tabprm structs contain some members that must be supplied and others
01802 *         that are derived. The information to be supplied comes primarily from
01803 *         arrays stored in one or more FITS binary table extensions. These
01804 *         arrays, referred to here as "wcstab arrays", are themselves located by
01805 *         parameters stored in the FITS image header.
01806 *
01807 *     struct wt barr *wtb
01808 *         (Given) Address of the first element of an array of nwtb wt barr structs
01809 *         for which memory has been allocated. These are used in extracting
01810 *         wcstab arrays from a FITS binary table.
01811 *
01812 *         Although technically wcsprm::nwtb and wtb are "given", they will
01813 *         normally be set by invoking wcstab(), whether directly or indirectly.
01814 *
01815 *     char lngtyp[8]
01816 *         (Returned) Four-character WCS celestial longitude and ...
01817 *     char lattyp[8]
01818 *         (Returned) ... latitude axis types. e.g. "RA", "DEC", "GLON", "GLAT",
01819 *         etc. extracted from 'RA--', 'DEC-', 'GLON', 'GLAT', etc. in the first
01820 *         four characters of CTYPEna but with trailing dashes removed. (Declared
01821 *         as char[8] for alignment reasons.)
01822 *
01823 *     int lng
01824 *         (Returned) Index for the longitude coordinate, and ...
01825 *     int lat
01826 *         (Returned) ... index for the latitude coordinate, and ...
01827 *     int spec
01828 *         (Returned) ... index for the spectral coordinate, and ...
01829 *     int time
01830 *         (Returned) ... index for the time coordinate in the imgcrd[][] and
01831 *         world[][] arrays in the API of wcs2s(), wc2s2p() and wcmix().
01832 *
01833 *         These may also serve as indices into the pixcrd[][] array provided that
01834 *         the PCi_ja matrix does not transpose axes.
01835 *
01836 *     int cubeface
01837 *         (Returned) Index into the pixcrd[][] array for the CUBEFACE axis. This
01838 *         is used for quadcube projections where the cube faces are stored on a
01839 *         separate axis (see wcs.h).
01840 *

```

```

01841 * int chksum
01842 * (Returned) Checksum of keyvalues provided (see wcsprm::flag). Used by
01843 * wcsenq() to validate the self-consistency of the struct. Note that
01844 * the checksum incorporates addresses and is therefore highly specific to
01845 * the instance of the wcsprm struct.
01846 *
01847 * int *types
01848 * (Returned) Address of the first element of an array of int containing a
01849 * four-digit type code for each axis.
01850 *
01851 * - First digit (i.e. 1000s):
01852 *   - 0: Non-specific coordinate type.
01853 *   - 1: Stokes coordinate.
01854 *   - 2: Celestial coordinate (including CUBEFACE).
01855 *   - 3: Spectral coordinate.
01856 *   - 4: Time coordinate.
01857 *
01858 * - Second digit (i.e. 100s):
01859 *   - 0: Linear axis.
01860 *   - 1: Quantized axis (STOKES, CUBEFACE).
01861 *   - 2: Non-linear celestial axis.
01862 *   - 3: Non-linear spectral axis.
01863 *   - 4: Logarithmic axis.
01864 *   - 5: Tabular axis.
01865 *
01866 * - Third digit (i.e. 10s):
01867 *   - 0: Group number, e.g. lookup table number, being an index into the
01868 *     tabprm array (see above).
01869 *
01870 * - The fourth digit is used as a qualifier depending on the axis type.
01871 *
01872 *   - For celestial axes:
01873 *     - 0: Longitude coordinate.
01874 *     - 1: Latitude coordinate.
01875 *     - 2: CUBEFACE number.
01876 *
01877 *   - For lookup tables: the axis number in a multidimensional table.
01878 *
01879 * CTYPEia in "4-3" form with unrecognized algorithm code will have its
01880 * type set to -1 and generate an error.
01881 *
01882 * struct linprm lin
01883 * (Returned) Linear transformation parameters (usage is described in the
01884 * prologue to lin.h).
01885 *
01886 * struct celprm cel
01887 * (Returned) Celestial transformation parameters (usage is described in
01888 * the prologue to cel.h).
01889 *
01890 * struct spcprm spc
01891 * (Returned) Spectral transformation parameters (usage is described in the
01892 * prologue to spc.h).
01893 *
01894 * struct wcserr *err
01895 * (Returned) If enabled, when an error status is returned, this struct
01896 * contains detailed information about the error, see wcserr_enable().
01897 *
01898 * int m_flag
01899 * (For internal use only.)
01900 * int m_naxis
01901 * (For internal use only.)
01902 * double *m_crpix
01903 * (For internal use only.)
01904 * double *m_pc
01905 * (For internal use only.)
01906 * double *m_cdelt
01907 * (For internal use only.)
01908 * double *m_crval
01909 * (For internal use only.)
01910 * char (*m_cunit)[72]
01911 * (For internal use only.)
01912 * char (*m_ctype)[72]
01913 * (For internal use only.)
01914 * struct pvc card *m_pv
01915 * (For internal use only.)
01916 * struct pscard *m_ps
01917 * (For internal use only.)
01918 * double *m_cd
01919 * (For internal use only.)
01920 * double *m_crota
01921 * (For internal use only.)
01922 * int *m_colax
01923 * (For internal use only.)
01924 * char (*m_cname)[72]
01925 * (For internal use only.)
01926 * double *m_crder
01927 * (For internal use only.)

```

```

01928 *   double *m_csyer
01929 *       (For internal use only.)
01930 *   double *m_czphs
01931 *       (For internal use only.)
01932 *   double *m_cperi
01933 *       (For internal use only.)
01934 *   struct tabprm *m_tab
01935 *       (For internal use only.)
01936 *   struct wt barr *m_wtb
01937 *       (For internal use only.)
01938 *
01939 *
01940 *   pvc card struct - Store for PVi_ma keyrecords
01941 *   -----
01942 *   The pvc card struct is used to pass the parsed contents of PVi_ma keyrecords
01943 *   to wcsset() via the wcsprm struct.
01944 *
01945 *   All members of this struct are to be set by the user.
01946 *
01947 *   int i
01948 *       (Given) Axis number (1-relative), as in the FITS PVi_ma keyword.  If
01949 *       i == 0, wcsset() will replace it with the latitude axis number.
01950 *
01951 *   int m
01952 *       (Given) Parameter number (non-negative), as in the FITS PVi_ma keyword.
01953 *
01954 *   double value
01955 *       (Given) Parameter value.
01956 *
01957 *
01958 *   pscard struct - Store for PSi_ma keyrecords
01959 *   -----
01960 *   The pscard struct is used to pass the parsed contents of PSi_ma keyrecords
01961 *   to wcsset() via the wcsprm struct.
01962 *
01963 *   All members of this struct are to be set by the user.
01964 *
01965 *   int i
01966 *       (Given) Axis number (1-relative), as in the FITS PSi_ma keyword.
01967 *
01968 *   int m
01969 *       (Given) Parameter number (non-negative), as in the FITS PSi_ma keyword.
01970 *
01971 *   char value[72]
01972 *       (Given) Parameter value.
01973 *
01974 *
01975 *   auxprm struct - Additional auxiliary parameters
01976 *   -----
01977 *   The auxprm struct holds auxiliary coordinate system information of a
01978 *   specialist nature.  It is anticipated that this struct will expand in future
01979 *   to accomodate additional parameters.
01980 *
01981 *   All members of this struct are to be set by the user.
01982 *
01983 *   double rsun_ref
01984 *       (Given, auxiliary) Reference radius of the Sun used in coordinate
01985 *       calculations (m).
01986 *
01987 *   double dsun_obs
01988 *       (Given, auxiliary) Distance between the centre of the Sun and the
01989 *       observer (m).
01990 *
01991 *   double crln_obs
01992 *       (Given, auxiliary) Carrington heliographic longitude of the observer
01993 *       (deg).
01994 *
01995 *   double hgln_obs
01996 *       (Given, auxiliary) Stonyhurst heliographic longitude of the observer
01997 *       (deg).
01998 *
01999 *   double hglt_obs
02000 *       (Given, auxiliary) Heliographic latitude (Carrington or Stonyhurst) of
02001 *       the observer (deg).
02002 *
02003 *   double a_radius
02004 *       Length of the semi-major axis of a triaxial ellipsoid approximating the
02005 *       shape of a body (e.g. planet) in the solar system (m).
02006 *
02007 *   double b_radius
02008 *       Length of the intermediate axis, normal to the semi-major and semi-minor
02009 *       axes, of a triaxial ellipsoid approximating the shape of a body (m).
02010 *
02011 *   double c_radius
02012 *       Length of the semi-minor axis, normal to the semi-major axis, of a
02013 *       triaxial ellipsoid approximating the shape of a body (m).
02014 *

```

```

02015 *   double blon_obs
02016 *       Bodycentric longitude of the observer in the coordinate system fixed to
02017 *       the planet or other solar system body (deg, in range 0 to 360).
02018 *
02019 *   double blat_obs
02020 *       Bodycentric latitude of the observer in the coordinate system fixed to
02021 *       the planet or other solar system body (deg).
02022 *
02023 *   double bdis_obs
02024 *       Bodycentric distance of the observer (m).
02025 *
02026 *
02027 * Global variable: const char *wcs_errmsg[] - Status return messages
02028 * -----
02029 * Error messages to match the status value returned from each function.
02030 *
02031 * =====*/
02032
02033 #ifndef WCSLIB_WCS
02034 #define WCSLIB_WCS
02035
02036 #include "lin.h"
02037 #include "cel.h"
02038 #include "spc.h"
02039
02040 #ifdef __cplusplus
02041 extern "C" {
02042 #define wt barr wt barr_s           // See prologue of wt barr.h.
02043 #endif
02044
02045 enum wcsenq_enum {
02046     WCSENQ_MEM = 1,               // wcsprm struct memory is managed by WCSLIB.
02047     WCSENQ_SET = 2,               // wcsprm struct has been set up.
02048     WCSENQ_BYP = 4,               // wcsprm struct is in bypass mode.
02049     WCSENQ_CHK = 8,               // wcsprm struct is self-consistent.
02050 };
02051
02052 #define WCSSUB_LONGITUDE 0x1001
02053 #define WCSSUB_LATITUDE 0x1002
02054 #define WCSSUB_CUBEFACE 0x1004
02055 #define WCSSUB_CELESTIAL 0x1007
02056 #define WCSSUB_SPECTRAL 0x1008
02057 #define WCSSUB_STOKES 0x1010
02058 #define WCSSUB_TIME 0x1020
02059
02060
02061 #define WSCOMPARE Ancillary 0x0001
02062 #define WSCOMPARE Tiling 0x0002
02063 #define WSCOMPARE CRPIX 0x0004
02064
02065
02066 extern const char *wcs_errmsg[];
02067
02068 enum wcs_errmsg_enum {
02069     WCSERR_SUCCESS = 0, // Success.
02070     WCSERR_NULL_POINTER = 1, // Null wcsprm pointer passed.
02071     WCSERR_MEMORY = 2, // Memory allocation failed.
02072     WCSERR_SINGULAR_MTX = 3, // Linear transformation matrix is singular.
02073     WCSERR_BAD_CTYPE = 4, // Inconsistent or unrecognized coordinate
02074     // axis type.
02075     WCSERR_BAD_PARAM = 5, // Invalid parameter value.
02076     WCSERR_BAD_COORD_TRANS = 6, // Unrecognized coordinate transformation
02077     // parameter.
02078     WCSERR_ILL_COORD_TRANS = 7, // Ill-conditioned coordinate transformation
02079     // parameter.
02080     WCSERR_BAD_PIX = 8, // One or more of the pixel coordinates were
02081     // invalid.
02082     WCSERR_BAD_WORLD = 9, // One or more of the world coordinates were
02083     // invalid.
02084     WCSERR_BAD_WORLD_COORD = 10, // Invalid world coordinate.
02085     WCSERR_NO_SOLUTION = 11, // No solution found in the specified
02086     // interval.
02087     WCSERR_BAD_SUBIMAGE = 12, // Invalid subimage specification.
02088     WCSERR_NON_SEPARABLE = 13, // Non-separable subimage coordinate system.
02089     WCSERR_UNSET = 14, // wcsprm struct is unset.
02090 };
02091
02092
02093 // Struct used for storing PVi_ma keywords.
02094 struct pvcard {
02095     int i; // Axis number, as in PVi_ma (1-relative).
02096     int m; // Parameter number, ditto (0-relative).
02097     double value; // Parameter value.
02098 };
02099
02100 // Size of the pvcard struct in int units, used by the Fortran wrappers.
02101 #define PVLEN (sizeof(struct pvcard)/sizeof(int))

```

```

02102
02103 // Struct used for storing PSi_ma keywords.
02104 struct pscard {
02105     int i;                // Axis number, as in PSi_ma (1-relative).
02106     int m;                // Parameter number, ditto (0-relative).
02107     char value[72];       // Parameter value.
02108 };
02109
02110 // Size of the pscard struct in int units, used by the Fortran wrappers.
02111 #define PSLEN (sizeof(struct pscard)/sizeof(int))
02112
02113 // Struct used to hold additional auxiliary parameters.
02114 struct auxprm {
02115     double rsun_ref;       // Solar radius.
02116     double dsun_obs;       // Distance from Sun centre to observer.
02117     double crln_obs;       // Carrington heliographic lng of observer.
02118     double hgln_obs;       // Stonyhurst heliographic lng of observer.
02119     double hgltn_obs;      // Heliographic latitude of observer.
02120
02121     double a_radius;       // Semi-major axis of solar system body.
02122     double b_radius;       // Semi-intermediate axis of solar system body.
02123     double c_radius;       // Semi-minor axis of solar system body.
02124     double blon_obs;       // Bodycentric longitude of observer.
02125     double blat_obs;       // Bodycentric latitude of observer.
02126     double bdis_obs;       // Bodycentric distance of observer.
02127     double dummy[2];       // Reserved for future use.
02128 };
02129
02130 // Size of the auxprm struct in int units, used by the Fortran wrappers.
02131 #define AUXLEN (sizeof(struct auxprm)/sizeof(int))
02132
02133 struct wcsprm {
02134     // Initialization flag (see the prologue above).
02135     //-----
02136     int flag;              // Set to zero to force initialization.
02137
02138     // FITS header keyvalues to be provided (see the prologue above).
02139     //-----
02140     int naxis;             // Number of axes (pixel and coordinate).
02141     double *crpix;         // CRPIXja keyvalues for each pixel axis.
02142     double *pc;            // PCi_ja linear transformation matrix.
02143     double *cdelt;         // CDELTia keyvalues for each coord axis.
02144     double *crval;         // CRVALia keyvalues for each coord axis.
02145
02146     char (*cunit)[72];     // CUNITia keyvalues for each coord axis.
02147     char (*ctype)[72];     // CTYPEia keyvalues for each coord axis.
02148
02149     double lonpole;        // LONPOLEa keyvalue.
02150     double latpole;        // LATPOLEa keyvalue.
02151
02152     double restfrq;        // RESTFRQa keyvalue.
02153     double restwav;        // RESTWAVa keyvalue.
02154
02155     int npv;               // Number of PVi_ma keywords, and the
02156     int npvmax;            // number for which space was allocated.
02157     struct pvcord *pv;     // PVi_ma keywords for each i and m.
02158
02159     int nps;               // Number of PSi_ma keywords, and the
02160     int npsmax;            // number for which space was allocated.
02161     struct pscard *ps;     // PSi_ma keywords for each i and m.
02162
02163     // Alternative header keyvalues (see the prologue above).
02164     //-----
02165     double *cd;            // CDi_ja linear transformation matrix.
02166     double *crota;         // CROTAi keyvalues for each coord axis.
02167     int altlin;            // Alternative representations
02168                             // Bit 0: PCi_ja is present,
02169                             // Bit 1: CDi_ja is present,
02170                             // Bit 2: CROTAi is present.
02171     int velref;            // AIPS velocity code, VELREF.
02172
02173     // Auxiliary coordinate system information of a general nature. Not
02174     // used by WCSLIB. Refer to the prologue comments above for a brief
02175     // explanation of these values.
02176     char alt[4];
02177     int colnum;
02178     int *colax;            // Auxiliary coordinate axis information.
02179
02180     char (*cname)[72];
02181     double *corder;
02182     double *csyer;
02183     double *czphs;
02184     double *cperi;
02185
02186     char wcsname[72];
02187
02188     // Time reference system and measurement.

```

```

02189 char    timesys[72], trefpos[72], trefdir[72], plephem[72];
02190 char    timeunit[72];
02191 char    dateref[72];
02192 double  mjdref[2];
02193 double  timeoffs;
02194                                     // Data timestamps and durations.
02195 char    dateobs[72], datebeg[72], dateavg[72], dateend[72];
02196 double  mjdobs, mjdbeg, mjdavg, mjdend;
02197 double  jepoch, beepoch;
02198 double  tstart, tstop;
02199 double  xposure, telapse;
02200                                     // Timing accuracy.
02201 double  timsyer, timrder;
02202 double  timedel, timepixr;
02203                                     // Spatial & celestial reference frame.
02204 double  obsgeo[6];
02205 char    obsorbit[72];
02206 char    radesys[72];
02207 double  equinox;
02208 char    specsyst[72];
02209 char    ssysobs[72];
02210 double  velosys;
02211 double  zsource;
02212 char    ssyssrc[72];
02213 double  velangl;
02214
02215 // Additional auxiliary coordinate system information of a specialist
02216 // nature. Not used by WCSLIB. Refer to the prologue comments above.
02217 struct auxprm *aux;
02218
02219 // Coordinate lookup tables (see the prologue above).
02220 //-----
02221 int      ntab;                      // Number of separate tables.
02222 int      nwtab;                    // Number of wtbar structs.
02223 struct tabprm *tab;                // Tabular transformation parameters.
02224 struct wtbar *wtb;                 // Array of wtbar structs.
02225
02226 //-----
02227 // Information derived from the FITS header keyvalues by wcsset().
02228 //-----
02229 char     lngtyp[8], lattyp[8];     // Celestial axis types, e.g. RA, DEC.
02230 int      lng, lat, spec, time;     // Longitude, latitude, spectral, and time
02231                                     // axis indices (0-relative).
02232 int      cubeface;                 // True if there is a CUBEFACE axis.
02233 int      chksum;                   // Checksum of keyvalues provided.
02234 int      *types;                   // Coordinate type codes for each axis.
02235
02236 struct linprm lin;                 // Linear transformation parameters.
02237 struct celprm cel;                 // Celestial transformation parameters.
02238 struct spcprm spc;                 // Spectral transformation parameters.
02239
02240 // Error messaging, if enabled.
02241 //-----
02242 struct wcserr *err;
02243
02244 //-----
02245 // Private - the remainder are for internal use.
02246 //-----
02247                                     // Memory management.
02248 int      m_flag, m_naxis;
02249 double  *m_crpix, *m_pc, *m_cdelt, *m_crval;
02250 char    (*m_cunit)[72], (*m_ctype)[72];
02251 struct pvcard *m_pv;
02252 struct pscard *m_ps;
02253 double  *m_cd, *m_crota;
02254 int      *m_colax;
02255 char    (*m_cname)[72];
02256 double  *m_order, *m_csyer, *m_czphs, *m_cperi;
02257 struct auxprm *m_aux;
02258 struct tabprm *m_tab;
02259 struct wtbar *m_wtb;
02260 };
02261
02262 // Size of the wcsprm struct in int units, used by the Fortran wrappers.
02263 #define WCSLEN (sizeof(struct wcsprm)/sizeof(int))
02264
02265
02266 int wcsnpv(int n);
02267
02268 int wcsnps(int n);
02269
02270 int wcsini(int alloc, int naxis, struct wcsprm *wcs);
02271
02272 int wcsinit(int alloc, int naxis, struct wcsprm *wcs, int npvmax, int npsmax,
02273             int ndpmax);
02274
02275 int wcsauxi(int alloc, struct wcsprm *wcs);

```

```

02276
02277 int wcssub(int alloc, const struct wcsprm *wcsrc, int *nsub, int axes[],
02278           struct wcsprm *wcstdst);
02279
02280 int wcscompare(int cmp, double tol, const struct wcsprm *wcs1,
02281              const struct wcsprm *wcs2, int *equal);
02282
02283 int wcsfree(struct wcsprm *wcs);
02284
02285 int wcstrim(struct wcsprm *wcs);
02286
02287 int wcssize(const struct wcsprm *wcs, int sizes[2]);
02288
02289 int auxsize(const struct auxprm *aux, int sizes[2]);
02290
02291 int wcsengq(const struct wcsprm *wcs, int enquiry);
02292
02293 int wcsprt(const struct wcsprm *wcs);
02294
02295 int wcssperr(const struct wcsprm *wcs, const char *prefix);
02296
02297 int wcsbchk(struct wcsprm *wcs, int bounds);
02298
02299 int wcsset(struct wcsprm *wcs);
02300
02301 int wcssp2s(struct wcsprm *wcs, int ncoord, int nele, const double pixcrd[],
02302            double imgcrd[], double phi[], double theta[], double world[],
02303            int stat[]);
02304
02305 int wcss2p(struct wcsprm *wcs, int ncoord, int nele, const double world[],
02306            double phi[], double theta[], double imgcrd[], double pixcrd[],
02307            int stat[]);
02308
02309 int wcmix(struct wcsprm *wcs, int mixpix, int mixcel, const double vspan[2],
02310           double vstep, int viter, double world[], double phi[],
02311           double theta[], double imgcrd[], double pixcrd[]);
02312
02313 int wscsccs(struct wcsprm *wcs, double lng2p1, double lat2p1, double lng1p2,
02314            const char *clng, const char *clat, const char *radesys,
02315            double equinox, const char *alt);
02316
02317 int wcssptr(struct wcsprm *wcs, int *i, char ctype[9]);
02318
02319 const char* wcslib_version(int vers[3]);
02320
02321 // Defined mainly for backwards compatibility, use wcssub() instead.
02322 #define wccopy(alloc, wcsrc, wcstdst) wcssub(alloc, wcsrc, 0x0, 0x0, wcstdst)
02323
02324
02325 // Deprecated.
02326 #define wcsini_errmsg wcs_errmsg
02327 #define wcssub_errmsg wcs_errmsg
02328 #define wccopy_errmsg wcs_errmsg
02329 #define wcsfree_errmsg wcs_errmsg
02330 #define wcsprt_errmsg wcs_errmsg
02331 #define wcsset_errmsg wcs_errmsg
02332 #define wcssp2s_errmsg wcs_errmsg
02333 #define wcss2p_errmsg wcs_errmsg
02334 #define wcmix_errmsg wcs_errmsg
02335
02336 #ifdef __cplusplus
02337 #undef wt barr
02338 }
02339 #endif
02340
02341 #endif // WCSLIB_WCS

```

## 8.25 wcserr.h File Reference

### Data Structures

- struct [wcserr](#)  
*Error message handling.*

### Macros

- #define [ERRLEN](#) (sizeof(struct [wcserr](#))/sizeof(int))
- #define [WCSERR\\_SET](#)(status)  
*Fill in the contents of an error object.*

## Functions

- int `wcserr_enable` (int enable)  
*Enable/disable error messaging.*
- int `wcserr_size` (const struct `wcserr` \*err, int sizes[2])  
*Compute the size of a `wcserr` struct.*
- int `wcserr_prt` (const struct `wcserr` \*err, const char \*prefix)  
*Print a `wcserr` struct.*
- int `wcserr_clear` (struct `wcserr` \*\*err)  
*Clear a `wcserr` struct.*
- int `wcserr_set` (struct `wcserr` \*\*err, int status, const char \*function, const char \*file, int line\_no, const char \*format,...)  
*Fill in the contents of an error object.*
- int `wcserr_copy` (const struct `wcserr` \*src, struct `wcserr` \*dst)  
*Copy an error object.*

### 8.25.1 Detailed Description

Most of the structs in WCSLIB contain a pointer to a `wcserr` struct as a member. Functions in WCSLIB that return an error status code can also allocate and set a detailed error message in this struct, which also identifies the function, source file, and line number where the error occurred.

#### For example:

```
struct prjprm prj;
wcserr_enable(1);
if (prjini(&prj)) {
    // Print the error message to stderr.
    wcsprintf_set(stderr);
    wcserr_prt(prj.err, 0x0);
}
```

A number of utility functions used in managing the `wcserr` struct are for **internal use only**. They are documented here solely as an aid to understanding the code. They are not intended for external use - the API may change without notice!

### 8.25.2 Macro Definition Documentation

#### ERRLEN

```
#define ERRLEN (sizeof(struct wcserr)/sizeof(int))
```

#### WCSErr\_SET

```
#define WCSErr_SET(
    status)
```

#### Value:

```
err, status, function, __FILE__, __LINE__
```

Fill in the contents of an error object.

#### INTERNAL USE ONLY.

`WCSErr_SET()` is a preprocessor macro that helps to fill in the argument list of `wcserr_set()`. It takes status as an argument of its own and provides the name of the source file and the line number at the point where invoked. It assumes that the err and function arguments of `wcserr_set()` will be provided by variables of the same names.

### 8.25.3 Function Documentation

#### wcserr\_enable()

```
int wcserr_enable (
    int enable)
```

Enable/disable error messaging.

**wcserr\_enable()** enables or disables [wcserr](#) error messaging. By default it is disabled.

**PLEASE NOTE:** This function is not thread-safe.

#### Parameters

in	<i>enable</i>	If true (non-zero), enable error messaging, else disable it.
----	---------------	--

#### Returns

Status return value:

- 0: Error messaging is disabled.
- 1: Error messaging is enabled.

#### wcserr\_size()

```
int wcserr_size (
    const struct wcserr * err,
    int sizes[2])
```

Compute the size of a [wcserr](#) struct.

**wcserr\_size()** computes the full size of a [wcserr](#) struct, including allocated memory.

#### Parameters

in	<i>err</i>	The error object. If NULL, the base size of the struct and the allocated size are both set to zero.
out	<i>sizes</i>	The first element is the base size of the struct as returned by <code>sizeof(struct <a href="#">wcserr</a>)</code> . The second element is the total allocated size of the message buffer, in bytes.

#### Returns

Status return value:

- 0: Success.

#### wcserr\_prt()

---

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```
int wcserr_prt (
    const struct wcserr * err,
    const char * prefix)
```

**Parameters**

in	<i>err</i>	The error object. If NULL, nothing is printed.
in	<i>prefix</i>	If non-NULL, each output line will be prefixed with this string.

**Returns**

Status return value:

- 0: Success.
- 2: Error messaging is not enabled.

**wcserr\_clear()**

```
int wcserr_clear (  
    struct wcserr ** err)
```

Clear a **wcserr** struct.

**wcserr\_clear()** clears (deletes) a **wcserr** struct.

**Parameters**

in, out	<i>err</i>	The error object. If NULL, nothing is done. Set to NULL on return.
---------	------------	--

**Returns**

Status return value:

- 0: Success.

**wcserr\_set()**

```
int wcserr_set (  
    struct wcserr ** err,  
    int status,  
    const char * function,  
    const char * file,  
    int line_no,  
    const char * format,  
    ...)
```

Fill in the contents of an error object.

**INTERNAL USE ONLY.**

**wcserr\_set()** fills a **wcserr** struct with information about an error.

A convenience macro, **WCSERR\_SET**, provides the source file and line number information automatically.

**Parameters**

<i>in, out</i>	<i>err</i>	Error object. If <i>err</i> is NULL, returns the status code given without setting an error message. If <i>*err</i> is NULL, allocates memory for a <a href="#">wcserr</a> struct (provided that status is non-zero).
<i>in</i>	<i>status</i>	Numeric status code to set. If 0, then <i>*err</i> will be deleted and <i>*err</i> will be returned as NULL.
<i>in</i>	<i>function</i>	Name of the function generating the error. This must point to a constant string, i.e. in the initialized read-only data section ("data") of the executable.
<i>in</i>	<i>file</i>	Name of the source file generating the error. This must point to a constant string, i.e. in the initialized read-only data section ("data") of the executable such as given by the <code>__FILE__</code> preprocessor macro.
<i>in</i>	<i>line_no</i>	Line number in the source file generating the error such as given by the <code>__LINE__</code> ↵ preprocessor macro.
<i>in</i>	<i>format</i>	Format string of the error message. May contain printf-style %-formatting codes.
<i>in</i>	<i>...</i>	The remaining variable arguments are applied (like printf) to the format string to generate the error message.

**Returns**

The status return code passed in.

**wcserr\_copy()**

```
int wcserr_copy (
    const struct wcserr * src,
    struct wcserr * dst)
```

Copy an error object.

**INTERNAL USE ONLY.**

**wcserr\_copy()** copies one error object to another. Use of this function should be avoided in general since the function, source file, and line number information copied to the destination may lose its context.

**Parameters**

<i>in</i>	<i>src</i>	Source error object. If <i>src</i> is NULL, <i>dst</i> is cleared.
<i>out</i>	<i>dst</i>	Destination error object. If NULL, no copy is made.

**Returns**

Numeric status code of the source error object.

## 8.26 wcserr.h

[Go to the documentation of this file.](#)

```

00001 /*=====
00002 WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003 Copyright (C) 1995-2025, Mark Calabretta
00004
00005 This file is part of WCSLIB.
00006
00007 WCSLIB is free software: you can redistribute it and/or modify it under the
00008 terms of the GNU Lesser General Public License as published by the Free
00009 Software Foundation, either version 3 of the License, or (at your option)
00010 any later version.
00011
00012 WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013 WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
00014 FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015 more details.
00016
00017 You should have received a copy of the GNU Lesser General Public License
00018 along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020 Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021 Module author: Michael Droettboom
00022 http://www.atnf.csiro.au/people/Mark.Calabretta
00023 $Id: wcserr.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00024 *=====
00025 *
00026 * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00027 * (WCS) standard. Refer to the README file provided with WCSLIB for an
00028 * overview of the library.
00029 *
00030 * Summary of the wcserr routines
00031 * -----
00032 * Most of the structs in WCSLIB contain a pointer to a wcserr struct as a
00033 * member. Functions in WCSLIB that return an error status code can also
00034 * allocate and set a detailed error message in this struct, which also
00035 * identifies the function, source file, and line number where the error
00036 * occurred.
00037 *
00038 * For example:
00039 *
00040 *     struct prjprm prj;
00041 *     wcserr_enable(1);
00042 *     if (prjini(&prj)) {
00043 *         // Print the error message to stderr.
00044 *         wcsprintf_set(stderr);
00045 *         wcserr_prt(prj.err, 0x0);
00046 *     }
00047 *
00048 * A number of utility functions used in managing the wcserr struct are for
00049 * internal use only. They are documented here solely as an aid to
00050 * understanding the code. They are not intended for external use - the API
00051 * may change without notice!
00052 *
00053 *
00054 * wcserr struct - Error message handling
00055 * -----
00056 * The wcserr struct contains the numeric error code, a textual description of
00057 * the error, and information about the function, source file, and line number
00058 * where the error was generated.
00059 *
00060 *     int status
00061 *         Numeric status code associated with the error, the meaning of which
00062 *         depends on the function that generated it. See the documentation for
00063 *         the particular function.
00064 *
00065 *     int line_no
00066 *         Line number where the error occurred as given by the __LINE__
00067 *         preprocessor macro.
00068 *
00069 *     const char *function
00070 *         Name of the function where the error occurred.
00071 *
00072 *     const char *file
00073 *         Name of the source file where the error occurred as given by the
00074 *         __FILE__ preprocessor macro.
00075 *
00076 *     char *msg
00077 *         Informative error message.
00078 *
00079 *
00080 * wcserr_enable() - Enable/disable error messaging
00081 * -----
00082 * wcserr_enable() enables or disables wcserr error messaging. By default it

```

```

00083 * is disabled.
00084 *
00085 * PLEASE NOTE: This function is not thread-safe.
00086 *
00087 * Given:
00088 *     enable    int           If true (non-zero), enable error messaging, else
00089 *                             disable it.
00090 *
00091 * Function return value:
00092 *     int       Status return value:
00093 *               0: Error messaging is disabled.
00094 *               1: Error messaging is enabled.
00095 *
00096 *
00097 * wcserr_size() - Compute the size of a wcserr struct
00098 * -----
00099 * wcserr_size() computes the full size of a wcserr struct, including allocated
00100 * memory.
00101 *
00102 * Given:
00103 *     err        const struct wcserr*
00104 *               The error object.
00105 *
00106 *               If NULL, the base size of the struct and the allocated
00107 *               size are both set to zero.
00108 *
00109 * Returned:
00110 *     sizes     int[2]        The first element is the base size of the struct as
00111 *                             returned by sizeof(struct wcserr). The second element
00112 *                             is the total allocated size of the message buffer, in
00113 *                             bytes.
00114 *
00115 * Function return value:
00116 *     int       Status return value:
00117 *               0: Success.
00118 *
00119 *
00120 * wcserr_prt() - Print a wcserr struct
00121 * -----
00122 * wcserr_prt() prints the error message (if any) contained in a wcserr struct.
00123 * It uses the wcsprintf() functions.
00124 *
00125 * Given:
00126 *     err        const struct wcserr*
00127 *               The error object. If NULL, nothing is printed.
00128 *
00129 *     prefix     const char *
00130 *               If non-NULL, each output line will be prefixed with
00131 *               this string.
00132 *
00133 * Function return value:
00134 *     int       Status return value:
00135 *               0: Success.
00136 *               2: Error messaging is not enabled.
00137 *
00138 *
00139 * wcserr_clear() - Clear a wcserr struct
00140 * -----
00141 * wcserr_clear() clears (deletes) a wcserr struct.
00142 *
00143 * Given and returned:
00144 *     err        struct wcserr**
00145 *               The error object. If NULL, nothing is done. Set to
00146 *               NULL on return.
00147 *
00148 * Function return value:
00149 *     int       Status return value:
00150 *               0: Success.
00151 *
00152 *
00153 * wcserr_set() - Fill in the contents of an error object
00154 * -----
00155 * INTERNAL USE ONLY.
00156 *
00157 * wcserr_set() fills a wcserr struct with information about an error.
00158 *
00159 * A convenience macro, WCSERR_SET, provides the source file and line number
00160 * information automatically.
00161 *
00162 * Given and returned:
00163 *     err        struct wcserr**
00164 *               Error object.
00165 *
00166 *               If err is NULL, returns the status code given without
00167 *               setting an error message.
00168 *
00169 *               If *err is NULL, allocates memory for a wcserr struct

```

```

00170 *                                     (provided that status is non-zero).
00171 *
00172 * Given:
00173 *   status      int          Numeric status code to set.  If 0, then *err will be
00174 *                           deleted and *err will be returned as NULL.
00175 *
00176 *   function     const char *
00177 *                           Name of the function generating the error.  This
00178 *                           must point to a constant string, i.e. in the
00179 *                           initialized read-only data section ("data") of the
00180 *                           executable.
00181 *
00182 *   file         const char *
00183 *                           Name of the source file generating the error.  This
00184 *                           must point to a constant string, i.e. in the
00185 *                           initialized read-only data section ("data") of the
00186 *                           executable such as given by the __FILE__ preprocessor
00187 *                           macro.
00188 *
00189 *   line_no      int          Line number in the source file generating the error
00190 *                           such as given by the __LINE__ preprocessor macro.
00191 *
00192 *   format       const char *
00193 *                           Format string of the error message.  May contain
00194 *                           printf-style %-formatting codes.
00195 *
00196 *   ...          mixed        The remaining variable arguments are applied (like
00197 *                           printf) to the format string to generate the error
00198 *                           message.
00199 *
00200 * Function return value:
00201 *   int          The status return code passed in.
00202 *
00203 *
00204 * wcserr_copy() - Copy an error object
00205 * -----
00206 * INTERNAL USE ONLY.
00207 *
00208 * wcserr_copy() copies one error object to another.  Use of this function
00209 * should be avoided in general since the function, source file, and line
00210 * number information copied to the destination may lose its context.
00211 *
00212 * Given:
00213 *   src          const struct wcserr*
00214 *                           Source error object.  If src is NULL, dst is cleared.
00215 *
00216 * Returned:
00217 *   dst          struct wcserr*
00218 *                           Destination error object.  If NULL, no copy is made.
00219 *
00220 * Function return value:
00221 *   int          Numeric status code of the source error object.
00222 *
00223 *
00224 * WCSERR_SET() macro - Fill in the contents of an error object
00225 * -----
00226 * INTERNAL USE ONLY.
00227 *
00228 * WCSERR_SET() is a preprocessor macro that helps to fill in the argument list
00229 * of wcserr_set().  It takes status as an argument of its own and provides the
00230 * name of the source file and the line number at the point where invoked.  It
00231 * assumes that the err and function arguments of wcserr_set() will be provided
00232 * by variables of the same names.
00233 *
00234 * =====*/
00235
00236 #ifndef WCSLIB_WCSERR
00237 #define WCSLIB_WCSERR
00238
00239 #ifdef __cplusplus
00240 extern "C" {
00241 #endif
00242
00243 struct wcserr {
00244     int     status;           // Status code for the error.
00245     int     line_no;         // Line number where the error occurred.
00246     const char *function;    // Function name.
00247     const char *file;        // Source file name.
00248     char *msg;               // Informative error message.
00249 };
00250
00251 // Size of the wcserr struct in int units, used by the Fortran wrappers.
00252 #define ERRLEN (sizeof(struct wcserr)/sizeof(int))
00253
00254 int wcserr_enable(int enable);
00255
00256 int wcserr_size(const struct wcserr *err, int sizes[2]);

```

```

00257
00258 int wcserr_prt(const struct wcserr *err, const char *prefix);
00259
00260 int wcserr_clear(struct wcserr **err);
00261
00262
00263 // INTERNAL USE ONLY -----
00264
00265 int wcserr_set(struct wcserr **err, int status, const char *function,
00266     const char *file, int line_no, const char *format, ...);
00267
00268 int wcserr_copy(const struct wcserr *src, struct wcserr *dst);
00269
00270 // Convenience macro for invoking wcserr_set().
00271 #define WCSERR_SET(status) err, status, function, __FILE__, __LINE__
00272
00273 #ifdef __cplusplus
00274 }
00275 #endif
00276
00277 #endif // WSCLIB_WCSERR

```

## 8.27 wcsfix.h File Reference

```

#include "wcs.h"
#include "wcserr.h"

```

### Macros

- `#define CDFIX 0`  
*Index of `cdfix()` status value in vector returned by `wcsfix()`.*
- `#define DATFIX 1`  
*Index of `datfix()` status value in vector returned by `wcsfix()`.*
- `#define OBSFIX 2`
- `#define UNITFIX 3`  
*Index of `unitfix()` status value in vector returned by `wcsfix()`.*
- `#define SPCFIX 4`  
*Index of `spcfix()` status value in vector returned by `wcsfix()`.*
- `#define CELFIX 5`  
*Index of `celfix()` status value in vector returned by `wcsfix()`.*
- `#define CYLFIX 6`  
*Index of `cylfix()` status value in vector returned by `wcsfix()`.*
- `#define NWCSFIX 7`  
*Number of elements in the status vector returned by `wcsfix()`.*
- `#define cylfix_errmsg wcsfix_errmsg`  
*Deprecated.*

### Enumerations

- enum `wcsfix_errmsg_enum` {  
`FIXERR_OBSGEO_FIX = -5`, `FIXERR_DATE_FIX = -4`, `FIXERR_SPC_UPDATE = -3`, `FIXERR_UNITS_ALIAS`  
`= -2`,  
`FIXERR_NO_CHANGE = -1`, `FIXERR_SUCCESS = 0`, `FIXERR_NULL_POINTER = 1`, `FIXERR_MEMORY`  
`= 2`,  
`FIXERR_SINGULAR_MTX = 3`, `FIXERR_BAD_CTYPE = 4`, `FIXERR_BAD_PARAM = 5`, `FIXERR_BAD_COORD_TRANS`  
`= 6`,  
`FIXERR_ILL_COORD_TRANS = 7`, `FIXERR_BAD_CORNER_PIX = 8`, `FIXERR_NO_REF_PIX_COORD =`  
`9`, `FIXERR_NO_REF_PIX_VAL = 10` }

## Functions

- int `wcsfix` (int ctrl, const int naxis[], struct `wcsprm` \*wcs, int stat[])  
*Translate a non-standard WCS struct.*
- int `wcsfixi` (int ctrl, const int naxis[], struct `wcsprm` \*wcs, int stat[], struct `wcserr` info[])  
*Translate a non-standard WCS struct.*
- int `cdfix` (struct `wcsprm` \*wcs)  
*Fix erroneously omitted `CDi_ja` keywords.*
- int `datfix` (struct `wcsprm` \*wcs)  
*Translate **DATE-OBS** and derive **MJD-OBS** or vice versa.*
- int `obsfix` (int ctrl, struct `wcsprm` \*wcs)  
*complete the **OBSGEO-[XYZLBH]** vector of observatory coordinates.*
- int `unitfix` (int ctrl, struct `wcsprm` \*wcs)  
*Correct aberrant **CUNITia** keyvalues.*
- int `spcfix` (struct `wcsprm` \*wcs)  
*Translate AIPS-convention spectral types.*
- int `celfix` (struct `wcsprm` \*wcs)  
*Translate AIPS-convention celestial projection types.*
- int `cylfix` (const int naxis[], struct `wcsprm` \*wcs)  
*Fix malformed cylindrical projections.*
- int `wcspcx` (struct `wcsprm` \*wcs, int dopc, int permute, double rotn[2])  
*regularize `PCi_j`.*

## Variables

- const char \* `wcsfix_errmsg` []  
*Status return messages.*

### 8.27.1 Detailed Description

Routines in this suite identify and translate various forms of construct known to occur in FITS headers that violate the FITS World Coordinate System (WCS) standard described in

"Representations of world coordinates in FITS",  
Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)

"Representations of celestial coordinates in FITS",  
Calabretta, M.R., & Greisen, E.W. 2002, A&A, 395, 1077 (WCS Paper II)

"Representations of spectral coordinates in FITS",  
Greisen, E.W., Calabretta, M.R., Valdes, F.G., & Allen, S.L.  
2006, A&A, 446, 747 (WCS Paper III)

"Representations of time coordinates in FITS -  
Time and relative dimension in space",  
Rots, A.H., Bunclark, P.S., Calabretta, M.R., Allen, S.L.,  
Manchester, R.N., & Thompson, W.T. 2015, A&A, 574, A36 (WCS Paper VII)

Repairs effected by these routines range from the translation of non-standard values for standard WCS keywords, to the repair of malformed coordinate representations. Some routines are also provided to check the consistency of pairs of keyvalues that define the same measure in two different ways, for example, as a date and an MJD.

A separate routine, `wcspcx()`, "regularizes" the linear transformation matrix component (`PCi_j`) of the coordinate transformation to make it more human- readable. Where a coordinate description was constructed from `CDi_j`, it decomposes it into `PCi_j` + `CDELTi` in a meaningful way. Optionally, it can also diagonalize the `PCi_j` matrix (as far as possible), i.e. undo a transposition of axes in the intermediate pixel coordinate system.

**Non-standard keyvalues:**

AIPS-convention celestial projection types, **NCP** and **GLS**, and spectral types, '**FREQ-LSR**', '**FELO-HEL**', etc., set in **CTYPEia** are translated on-the-fly by [wcsset\(\)](#) but without modifying the relevant `ctype[]`, `pv[]` or `specsys` members of the `wcsprm` struct. That is, only the information extracted from `ctype[]` is translated when [wcsset\(\)](#) fills in [wcsprm::cel](#) (`celprm` struct) or [wcsprm::spc](#) (`spcprm` struct).

On the other hand, these routines do change the values of [wcsprm::ctype\[\]](#), [wcsprm::pv\[\]](#), [wcsprm::specsys](#) and other `wcsprm` struct members as appropriate to produce the same result as if the FITS header itself had been translated.

Auxiliary WCS header information not used directly by WCSLIB may also be translated. For example, the older **DATE-OBS** date format ([wcsprm::dateobs](#)) is recast to year-2000 standard form, and **MJD-OBS** ([wcsprm::mjdobs](#)) will be deduced from it if not already set.

Certain combinations of keyvalues that result in malformed coordinate systems, as described in Sect. 7.3.4 of Paper I, may also be repaired. These are handled by [cylfix\(\)](#).

**Non-standard keywords:**

The AIPS-convention CROTAn keywords are recognized as quasi-standard and as such are accommodated by [wcsprm::crota\[\]](#) and translated to [wcsprm::pc\[\]\[\]](#) by [wcsset\(\)](#). These are not dealt with here, nor are any other non-standard keywords since these routines work only on the contents of a `wcsprm` struct and do not deal with FITS headers per se. In particular, they do not identify or translate **CD00i00j**, **PC00i00j**, **PROJPN**, **EPOCH**, **VELREF** or **VSOURCEa** keywords; this may be done by the FITS WCS header parser supplied with WCSLIB, refer to [wcs\\_hdr.h](#).

[wcsfix\(\)](#) and [wcsfixi\(\)](#) apply all of the corrections handled by the following specific functions, which may also be invoked separately:

- [cdfix\(\)](#): Sets the diagonal element of the **CDi\_ja** matrix to 1.0 if all **CDi\_ja** keywords associated with a particular axis are omitted.
- [datfix\(\)](#): recast an older **DATE-OBS** date format in `dateobs` to year-2000 standard form. Derive `dateref` from `mjdref` if not already set. Alternatively, if `dateref` is set and `mjdref` isn't, then derive `mjdref` from it. If both are set, then check consistency. Likewise for `dateobs` and `mjdobs`; `datebeg` and `mjdbeg`; `dateavg` and `mjdavg`; and `dateend` and `mjdend`.
- [obsfix\(\)](#): if only one half of `obsgeo[]` is set, then derive the other half from it. If both halves are set, then check consistency.
- [unitfix\(\)](#): translate some commonly used but non-standard unit strings in the **CUNITia** keyvalues, e.g. '**DEG**' -> '**deg**'.
- [spcfix\(\)](#): translate AIPS-convention spectral types, '**FREQ-LSR**', '**FELO-HEL**', etc., in `ctype[]` as set from **CTYPEia**.
- [celfix\(\)](#): translate AIPS-convention celestial projection types, **NCP** and **GLS**, in `ctype[]` as set from **CTYPEia**.
- [cylfix\(\)](#): fixes WCS keyvalues for malformed cylindrical projections that suffer from the problem described in Sect. 7.3.4 of Paper I.

**8.27.2 Macro Definition Documentation****CDFIX**

```
#define CDFIX 0
```

Index of [cdfix\(\)](#) status value in vector returned by [wcsfix\(\)](#).

Index of the status value returned by [cdfix\(\)](#) in the status vector returned by [wcsfix\(\)](#).

**DATFIX**

```
#define DATFIX 1
```

Index of [datfix\(\)](#) status value in vector returned by [wcsfix\(\)](#).

Index of the status value returned by [datfix\(\)](#) in the status vector returned by [wcsfix\(\)](#).

**OBSFIX**

```
#define OBSFIX 2
```

**UNITFIX**

```
#define UNITFIX 3
```

Index of [unitfix\(\)](#) status value in vector returned by [wcsfix\(\)](#).

Index of the status value returned by [unitfix\(\)](#) in the status vector returned by [wcsfix\(\)](#).

**SPCFIX**

```
#define SPCFIX 4
```

Index of [spcfix\(\)](#) status value in vector returned by [wcsfix\(\)](#).

Index of the status value returned by [spcfix\(\)](#) in the status vector returned by [wcsfix\(\)](#).

**CELFIX**

```
#define CELFIX 5
```

Index of [celfix\(\)](#) status value in vector returned by [wcsfix\(\)](#).

Index of the status value returned by [celfix\(\)](#) in the status vector returned by [wcsfix\(\)](#).

**CYLFIX**

```
#define CYLFIX 6
```

Index of [cylfix\(\)](#) status value in vector returned by [wcsfix\(\)](#).

Index of the status value returned by [cylfix\(\)](#) in the status vector returned by [wcsfix\(\)](#).

## NWCSFIX

```
#define NWCSFIX 7
```

Number of elements in the status vector returned by [wcsfix\(\)](#).

Number of elements in the status vector returned by [wcsfix\(\)](#).

## cylfix\_errmsg

```
#define cylfix_errmsg wcsfix_errmsg
```

Deprecated.

**Deprecated** Added for backwards compatibility, use [wcsfix\\_errmsg](#) directly now instead.

### 8.27.3 Enumeration Type Documentation

#### wcsfix\_errmsg\_enum

```
enum wcsfix_errmsg_enum
```

#### Enumerator

FIXERR_OBSGEO_FIX	
FIXERR_DATE_FIX	
FIXERR_SPC_UPDATE	
FIXERR_UNITS_ALIAS	
FIXERR_NO_CHANGE	
FIXERR_SUCCESS	
FIXERR_NULL_POINTER	
FIXERR_MEMORY	
FIXERR_SINGULAR_MTX	
FIXERR_BAD_CTYPE	
FIXERR_BAD_PARAM	
FIXERR_BAD_COORD_TRANS	
FIXERR_ILL_COORD_TRANS	
FIXERR_BAD_CORNER_PIX	
FIXERR_NO_REF_PIX_COORD	
FIXERR_NO_REF_PIX_VAL	

## 8.27.4 Function Documentation

### wcsfix()

```
int wcsfix (
    int ctrl,
    const int naxis[],
    struct wcsprm * wcs,
    int stat[])
```

Translate a non-standard WCS struct.

**wcsfix()** is identical to **wcsfixi()**, but lacks the info argument.

### wcsfixi()

```
int wcsfixi (
    int ctrl,
    const int naxis[],
    struct wcsprm * wcs,
    int stat[],
    struct wcserr info[])
```

Translate a non-standard WCS struct.

**wcsfixi()** applies all of the corrections handled separately by [cdfix\(\)](#), [datfix\(\)](#), [obsfix\(\)](#), [unitfix\(\)](#), [spcfix\(\)](#), [celfix\(\)](#), and [cylfix\(\)](#).

### Parameters

in	<i>ctrl</i>	Do potentially unsafe translations of non-standard unit strings as described in the usage notes to <a href="#">wcsutrn()</a> .
in	<i>naxis</i>	Image axis lengths. If this array pointer is set to zero then <a href="#">cylfix()</a> will not be invoked.
in, out	<i>wcs</i>	Coordinate transformation parameters.
out	<i>stat</i>	Status returns from each of the functions. Use the preprocessor macros NWCSFIX to dimension this vector and CDFIX, DATFIX, <b>OBSFIX</b> , UNITFIX, SPCFIX, CELFIX, and CYLFIX to access its elements. A status value of -2 is set for functions that were not invoked.
out	<i>info</i>	Status messages from each of the functions. Use the preprocessor macros NWCSFIX to dimension this vector and CDFIX, DATFIX, <b>OBSFIX</b> , UNITFIX, SPCFIX, CELFIX, and CYLFIX to access its elements. Note that the memory allocated by <b>wcsfixi()</b> for the message in each wcserr struct ( <a href="#">wcserr::msg</a> , if non-zero) must be freed by the user. See <a href="#">wcsdealloc()</a> .

### Returns

Status return value:

- 0: Success.
- 1: One or more of the translation functions returned an error.

**cdfix()**

```
int cdfix (
    struct wcsprm * wcs)
```

Fix erroneously omitted **CDi\_ja** keywords.

**cdfix()** sets the diagonal element of the **CDi\_ja** matrix to unity if all **CDi\_ja** keywords associated with a given axis were omitted. According to WCS Paper I, if any **CDi\_ja** keywords at all are given in a FITS header then those not given default to zero. This results in a singular matrix with an intersecting row and column of zeros.

**cdfix()** is expected to be invoked before **wcsset()**, which will fail if these errors have not been corrected.

**Parameters**

in, out	wcs	Coordinate transformation parameters.
---------	-----	---------------------------------------

**Returns**

Status return value:

- -1: No change required (not an error).
- 0: Success.
- 1: Null wcsprm pointer passed.

**datfix()**

```
int datfix (
    struct wcsprm * wcs)
```

Translate **DATE—OBS** and derive **MJD—OBS** or vice versa.

**datfix()** translates the old **DATE—OBS** date format set in **wcsprm::dateobs** to year-2000 standard form (*yyyy-mm-ddThh:mm:ss*). It derives **wcsprm::dateref** from **wcsprm::mjdfref** if not already set. Alternatively, if **dateref** is set and **mjdref** isn't, then it derives **mjdref** from it. If both are set but disagree by more than 0.001 day (86.4 seconds) then an error status is returned. Likewise for **wcsprm::dateobs** and **wcsprm::mjdoobs**; **wcsprm::datebeg** and **wcsprm::mjdbeg**; **wcsprm::dateavg** and **wcsprm::mjdagv**; and **wcsprm::dateend** and **wcsprm::mj dend**.

If neither **dateobs** nor **mjdoobs** are set, but **wcsprm::jepoch** (primarily) or **wcsprm::bepoch** is, then both are derived from it. If **jepoch** and/or **bepoch** are set but disagree with **dateobs** or **mjdoobs** by more than 0.000002 year (63.2 seconds), an informative message is produced.

The translations done by **datfix()** do not affect and are not affected by **wcsset()**.

**Parameters**

in, out	wcs	Coordinate transformation parameters. <b>wcsprm::dateref</b> and/or <b>wcsprm::mjdfref</b> may be changed. <b>wcsprm::dateobs</b> and/or <b>wcsprm::mjdoobs</b> may be changed. <b>wcsprm::datebeg</b> and/or <b>wcsprm::mjdbeg</b> may be changed. <b>wcsprm::dateavg</b> and/or <b>wcsprm::mjdagv</b> may be changed. <b>wcsprm::dateend</b> and/or <b>wcsprm::mj dend</b> may be changed.
---------	-----	--

## Returns

Status return value:

- -1: No change required (not an error).
- 0: Success.
- 1: Null `wcsprm` pointer passed.
- 5: Invalid parameter value.

For returns  $\geq 0$ , a detailed message, whether informative or an error message, may be set in `wcsprm::err` if enabled, see `wcserr_enable()`, with `wcsprm::err.status` set to `FIXERR_DATE_FIX`.

## Notes:

1. The MJD algorithms used by `datfix()` are from D.A. Hatcher, 1984, QJRAS, 25, 53-55, as modified by P.T. Wallace for use in SLALIB subroutines *CLDJ* and *DJCL*.

## obsfix()

```
int obsfix (
    int ctrl,
    struct wcsprm * wcs)
```

complete the **OBSGEO**-[XYZLBH] vector of observatory coordinates.

**obsfix()** completes the `wcsprm::obsgeo` vector of observatory coordinates. That is, if only the (x,y,z) Cartesian coordinate triplet or the (l,b,h) geodetic coordinate triplet are set, then it derives the other triplet from it. If both triplets are set, then it checks for consistency at the level of 1 metre.

The operations done by **obsfix()** do not affect and are not affected by `wcsset()`.

## Parameters

in	ctrl	Flag that controls behaviour if one triplet is defined and the other is only partially defined: <ul style="list-style-type: none"> <li>• 0: Reset only the undefined elements of an incomplete coordinate triplet.</li> <li>• 1: Reset all elements of an incomplete triplet.</li> <li>• 2: Don't make any changes, check for consistency only. Returns an error if either of the two triplets is incomplete.</li> </ul>
in, out	wcs	Coordinate transformation parameters. <code>wcsprm::obsgeo</code> may be changed.

## Returns

Status return value:

- -1: No change required (not an error).
- 0: Success.
- 1: Null wcsprm pointer passed.
- 5: Invalid parameter value.

For returns  $\geq 0$ , a detailed message, whether informative or an error message, may be set in `wcsprm::err` if enabled, see `wcserr_enable()`, with `wcsprm::err.status` set to `FIXERR_OBS_FIX`.

## Notes:

1. While the International Terrestrial Reference System (ITRS) is based solely on Cartesian coordinates, it recommends the use of the GRS80 ellipsoid in converting to geodetic coordinates. However, while WCS Paper III recommends ITRS Cartesian coordinates, Paper VII prescribes the use of the IAU(1976) ellipsoid for geodetic coordinates, and consequently that is what is used here.

2. For reference, parameters of commonly used global reference ellipsoids:

a (m)	1/f	Standard
6378140	298.2577	IAU (1976)
6378137	298.257222101	GRS80
6378137	298.257223563	WGS84
6378136	298.257	IERS (1989)
6378136.6	298.25642	IERS (2003, 2010), IAU (2009/2012)

where  $f = (a - b) / a$  is the flattening, and  $a$  and  $b$  are the semi-major and semi-minor radii in metres.

3. The transformation from geodetic (lng,lat, hgt) to Cartesian (x,y,z) is

```
x = (n + hgt)*coslng*coslat,
y = (n + hgt)*sinlng*coslat,
z = (n*(1.0 - e^2) + hgt)*sinlat,
```

where the "prime vertical radius",  $n$ , is a function of latitude

```
n = a / sqrt(1 - (e*sinlat)^2),
```

and  $a$ , the equatorial radius, and  $e^2 = (2 - f)*f$ , the (first) eccentricity of the ellipsoid, are constants. **obsfix()** inverts these iteratively by writing

```
x = rho*coslng*coslat,
y = rho*sinlng*coslat,
zeta = rho*sinlat,
```

where

```
rho = n + hgt,
     = sqrt(x^2 + y^2 + zeta^2),
zeta = z / (1 - n*e^2/rho),
```

and iterating over the value of  $zeta$ . Since  $e$  is small, a good first approximation is given by  $zeta = z$ .

## unitfix()

```
int unitfix (
    int ctrl,
    struct wcsprm * wcs)
```

Correct aberrant **CUNITia** keyvalues.

**unitfix()** applies `wcsutrn()` to translate non-standard **CUNITia** keyvalues, e.g. **'DEG'** -> **'deg'**, also stripping off unnecessary whitespace.

**unitfix()** is expected to be invoked before `wcsset()`, which will fail if non-standard **CUNITia** keyvalues have not been translated.

## Parameters

in	<i>ctrl</i>	Do potentially unsafe translations described in the usage notes to <a href="#">wcsutrn()</a> .
in, out	<i>wcs</i>	Coordinate transformation parameters.

## Returns

Status return value:

- -1: No change required (not an error).
- 0: Success (an alias was applied).
- 1: Null wcsprm pointer passed.

When units are translated (i.e. 0 is returned), an informative message is set in [wcsprm::err](#) if enabled, see [wcserr\\_enable\(\)](#), with [wcsprm::err.status](#) set to `FIXERR_UNITS_ALIAS`.

## spcfix()

```
int spcfix (
    struct wcsprm * wcs)
```

Translate AIPS-convention spectral types.

**spcfix()** translates AIPS-convention spectral coordinate types, '**FREQ,FELO,VELO**'-'**LSR,HEL,OBS**' (e.g. 'FREQ-OBS', '**FELO-HEL**', 'VELO-LSR') set in [wcsprm::ctype](#)[], subject to **VELREF** set in [wcsprm::velref](#).

Note that if [wcs::specsys](#) is already set then it will not be overridden.

AIPS-convention spectral types set in **CTYPE**<sub>ia</sub> are translated on-the-fly by [wcsset\(\)](#) but without modifying [wcsprm::ctype](#) or [wcsprm::specsys](#). That is, only the information extracted from [wcsprm::ctype](#) is translated when [wcsset\(\)](#) fills in [wcsprm::spc](#) (spcprm struct). **spcfix()** modifies [wcsprm::ctype](#) so that if the header is subsequently written out, e.g. by [wcsldo\(\)](#), then it will contain translated **CTYPE**<sub>ia</sub> keyvalues.

The operations done by **spcfix()** do not affect and are not affected by [wcsset\(\)](#).

## Parameters

in, out	<i>wcs</i>	Coordinate transformation parameters. <a href="#">wcsprm::ctype</a> and/or <a href="#">wcsprm::specsys</a> may be changed.
---------	------------	--

## Returns

Status return value:

- -1: No change required (not an error).
- 0: Success.
- 1: Null wcsprm pointer passed.
- 2: Memory allocation failed.
- 3: Linear transformation matrix is singular.
- 4: Inconsistent or unrecognized coordinate axis types.
- 5: Invalid parameter value.
- 6: Invalid coordinate transformation parameters.
- 7: Ill-conditioned coordinate transformation parameters.

For returns  $\geq 0$ , a detailed message, whether informative or an error message, may be set in [wcsprm::err](#) if enabled, see [wcserr\\_enable\(\)](#), with [wcsprm::err.status](#) set to `FIXERR_SPC_UPDTE`.

**celfix()**

```
int celfix (
    struct wcsprm * wcs)
```

Translate AIPS-convention celestial projection types.

**celfix()** translates AIPS-convention celestial projection types, **NCP** and **GLS**, set in the `ctype[]` member of the `wcsprm` struct.

Two additional `pv[]` keyvalues are created when translating **NCP**, and three are created when translating **GLS** with non-zero reference point. If the `pv[]` array was initially allocated by `wcsini()` then the array will be expanded if necessary. Otherwise, error 2 will be returned if sufficient empty slots are not already available for use.

AIPS-convention celestial projection types set in **CTYPE**<sub>ia</sub> are translated on-the-fly by `wcsset()` but without modifying `wcsprm::ctype[]`, `wcsprm::pv[]`, or `wcsprm::npv`. That is, only the information extracted from `wcsprm::ctype[]` is translated when `wcsset()` fills in `wcsprm::cel` (`celprm` struct). **celfix()** modifies `wcsprm::ctype[]`, `wcsprm::pv[]`, and `wcsprm::npv` so that if the header is subsequently written out, e.g. by `wcshdo()`, then it will contain translated **CTYPE**<sub>ia</sub> keyvalues and the relevant **PV**<sub>i\_ma</sub>.

The operations done by **celfix()** do not affect and are not affected by `wcsset()`. However, it uses information in the `wcsprm` struct provided by `wcsset()`, and will invoke it if necessary.

**Parameters**

<code>in, out</code>	<code>wcs</code>	Coordinate transformation parameters. <code>wcsprm::ctype[]</code> and/or <code>wcsprm::pv[]</code> may be changed.
----------------------	------------------	---

**Returns**

Status return value:

- -1: No change required (not an error).
- 0: Success.
- 1: Null `wcsprm` pointer passed.
- 2: Memory allocation failed.
- 3: Linear transformation matrix is singular.
- 4: Inconsistent or unrecognized coordinate axis types.
- 5: Invalid parameter value.
- 6: Invalid coordinate transformation parameters.
- 7: Ill-conditioned coordinate transformation parameters.

For returns > 1, a detailed error message is set in `wcsprm::err` if enabled, see `wcserr_enable()`.

**cylfix()**

```
int cylfix (
    const int naxis[],
    struct wcsprm * wcs)
```

Fix malformed cylindrical projections.

**cylfix()** fixes WCS keyvalues for malformed cylindrical projections that suffer from the problem described in Sect. 7.3.4 of Paper I.

**cylfix()** requires the `wcsprm` struct to have been set up by `wcsset()`, and will invoke it if necessary. After modification,

## Parameters

<code>in</code>	<code>naxis</code>	Image axis lengths.
<code>in, out</code>	<code>wcs</code>	Coordinate transformation parameters.

## Returns

Status return value:

- -1: No change required (not an error).
- 0: Success.
- 1: Null `wcsprm` pointer passed.
- 2: Memory allocation failed.
- 3: Linear transformation matrix is singular.
- 4: Inconsistent or unrecognized coordinate axis types.
- 5: Invalid parameter value.
- 6: Invalid coordinate transformation parameters.
- 7: Ill-conditioned coordinate transformation parameters.
- 8: All of the corner pixel coordinates are invalid.
- 9: Could not determine reference pixel coordinate.
- 10: Could not determine reference pixel value.

For returns  $> 1$ , a detailed error message is set in `wcsprm::err` if enabled, see `wcserr_enable()`.

## wcspcx()

```
int wcspcx (
    struct wcsprm * wcs,
    int dopc,
    int permute,
    double rotn[2])
```

regularize  $\mathbf{PCi\_j}$ .

**wcspcx()** "regularizes" the linear transformation matrix component of the coordinate transformation ( $\mathbf{PCi\_ja}$ ) to make it more human-readable.

Normally, upon encountering a FITS header containing a  $\mathbf{CDi\_ja}$  matrix, `wcsset()` simply treats it as  $\mathbf{PCi\_ja}$  and sets  $\mathbf{CDELTia}$  to unity. However, **wcspcx()** decomposes  $\mathbf{CDi\_ja}$  into  $\mathbf{PCi\_ja}$  and  $\mathbf{CDELTia}$  in such a way that  $\mathbf{CDELTia}$  form meaningful scaling parameters. In practice, the residual  $\mathbf{PCi\_ja}$  matrix will often then be orthogonal, i.e. unity, or describing a pure rotation, axis permutation, or reflection, or a combination thereof.

The decomposition is based on normalizing the length in the transformed system (i.e. intermediate pixel coordinates) of the orthonormal basis vectors of the pixel coordinate system. This deviates slightly from the prescription given by Eq. (4) of WCS Paper I, namely  $\text{Sum}(j=1,N)(\mathbf{PCi\_ja})^2 = 1$ , in replacing the sum over  $j$  with the sum over  $i$ . Consequently, the columns of  $\mathbf{PCi\_ja}$  will consist of unit vectors. In practice, especially in cubes and higher dimensional images, at least some pairs of these unit vectors, if not all, will often be orthogonal or close to orthogonal.

The sign of  $\mathbf{CDELTia}$  is chosen to make the  $\mathbf{PCi\_ja}$  matrix as close to the, possibly permuted, unit matrix as possible, except that where the coordinate description contains a pair of celestial axes, the sign of  $\mathbf{CDELTia}$  is set negative for the longitude axis and positive for the latitude axis.

Optionally, rows of the **PCi\_ja** matrix may also be permuted to diagonalize it as far as possible, thus undoing any transposition of axes in the intermediate pixel coordinate system.

If the coordinate description contains a celestial plane, then the angle of rotation of each of the basis vectors associated with the celestial axes is returned. For a pure rotation the two angles should be identical. Any difference between them is a measure of axis skewness.

The decomposition is not performed for axes involving a sequent distortion function that is defined in terms of **CDi\_ja**, such as TPV, TNX, or ZPX, which always are. The independent variables of the polynomial are therefore intermediate world coordinates rather than intermediate pixel coordinates. Because sequent distortions are always applied before **CDELTia**, if **CDi\_ja** was translated to **PCi\_ja** plus **CDELTia**, then the distortion would be altered unless the polynomial coefficients were also adjusted to account for the change of scale.

**wcspx()** requires the **wcsprm** struct to have been set up by **wcsset()**, and will invoke it if necessary. The **wcsprm** struct is reset on return with an explicit call to **wcsset()**.

### Parameters

in, out	<i>wcs</i>	Coordinate transformation parameters.
in	<i>dopc</i>	If 1, then <b>PCi_ja</b> and <b>CDELTia</b> , as given, will be recomposed according to the above prescription. If 0, the operation is restricted to decomposing <b>CDi_ja</b> .
in	<i>permute</i>	If 1, then after decomposition (or recomposition), permute rows of <b>PCi_ja</b> to make the axes of the intermediate pixel coordinate system match as closely as possible those of the pixel coordinates. That is, make it as close to a diagonal matrix as possible. However, celestial axes are special in always being paired, with the longitude axis preceding the latitude axis. All WCS entities indexed by i, such as <b>CTYPEia</b> , <b>CRVALia</b> , <b>CDELTia</b> , etc., including coordinate lookup tables, will also be permuted as necessary to account for the change to <b>PCi_ja</b> . This does not apply to <b>CRPIXja</b> , nor prior distortion functions. These operate on pixel coordinates, which are not affected by the permutation.
out	<i>rotn</i>	with the celestial axes. For a pure rotation the two angles should be identical. Any difference between them is a measure of axis skewness. May be set to the NULL pointer if this information is not required.

### Returns

Status return value:

- 0: Success.
- 1: Null **wcsprm** pointer passed.
- 2: Memory allocation failed.
- 5: **CDi\_j** matrix not used.
- 6: Sequent distortion function present.

### 8.27.5 Variable Documentation

#### wcsfix\_errmsg

```
const char* wcsfix_errmsg[] [extern]
```

Status return messages.

Error messages to match the status value returned from each function.

## 8.28 wcsfix.h

[Go to the documentation of this file.](#)

```

00001 /*=====
00002 WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003 Copyright (C) 1995-2025, Mark Calabretta
00004
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00006
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00019
00020 Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021 http://www.atnf.csiro.au/people/Mark.Calabretta
00022 $Id: wcsfix.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023 *=====
00024 *
00025 * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026 * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027 * overview of the library.
00028 *
00029 *
00030 * Summary of the wcsfix routines
00031 * -----
00032 * Routines in this suite identify and translate various forms of construct
00033 * known to occur in FITS headers that violate the FITS World Coordinate System
00034 * (WCS) standard described in
00035 *
00036 * "Representations of world coordinates in FITS",
00037 * Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)
00038 *
00039 * "Representations of celestial coordinates in FITS",
00040 * Calabretta, M.R., & Greisen, E.W. 2002, A&A, 395, 1077 (WCS Paper II)
00041 *
00042 * "Representations of spectral coordinates in FITS",
00043 * Greisen, E.W., Calabretta, M.R., Valdes, F.G., & Allen, S.L.
00044 * 2006, A&A, 446, 747 (WCS Paper III)
00045 *
00046 * "Representations of time coordinates in FITS -
00047 * Time and relative dimension in space",
00048 * Rots, A.H., Bunclark, P.S., Calabretta, M.R., Allen, S.L.,
00049 * Manchester, R.N., & Thompson, W.T. 2015, A&A, 574, A36 (WCS Paper VII)
00050 *
00051 * Repairs effected by these routines range from the translation of
00052 * non-standard values for standard WCS keywords, to the repair of malformed
00053 * coordinate representations. Some routines are also provided to check the
00054 * consistency of pairs of keyvalues that define the same measure in two
00055 * different ways, for example, as a date and an MJD.
00056 *
00057 * A separate routine, wcpsex(), "regularizes" the linear transformation matrix
00058 * component (PCi_j) of the coordinate transformation to make it more human-
00059 * readable. Where a coordinate description was constructed from CDi_j, it
00060 * decomposes it into PCi_j + CDELTi in a meaningful way. Optionally, it can
00061 * also diagonalize the PCi_j matrix (as far as possible), i.e. undo a
00062 * transposition of axes in the intermediate pixel coordinate system.
00063 *
00064 * Non-standard keyvalues:
00065 * -----
00066 * AIPS-convention celestial projection types, NCP and GLS, and spectral
00067 * types, 'FREQ-LSR', 'FELO-HEL', etc., set in CTYPEn are translated
00068 * on-the-fly by wcsset() but without modifying the relevant ctype[], pv[] or
00069 * specs members of the wcsprm struct. That is, only the information
00070 * extracted from ctype[] is translated when wcsset() fills in wcsprm::cel
00071 * (celprm struct) or wcsprm::spc (spcprm struct).
00072 *
00073 * On the other hand, these routines do change the values of wcsprm::ctype[],
00074 * wcsprm::pv[], wcsprm::specsys and other wcsprm struct members as
00075 * appropriate to produce the same result as if the FITS header itself had
00076 * been translated.
00077 *
00078 * Auxiliary WCS header information not used directly by WCSLIB may also be
00079 * translated. For example, the older DATE-OBS date format (wcsprm::dateobs)
00080 * is recast to year-2000 standard form, and MJD-OBS (wcsprm::mjdobs) will be
00081 * deduced from it if not already set.
00082 *

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00083 *   Certain combinations of keyvalues that result in malformed coordinate
00084 *   systems, as described in Sect. 7.3.4 of Paper I, may also be repaired.
00085 *   These are handled by cylfix().
00086 *
00087 * Non-standard keywords:
00088 * -----
00089 *   The AIPS-convention CROTA keywords are recognized as quasi-standard
00090 *   and as such are accommodated by wcsprm::crota[] and translated to
00091 *   wcsprm::pc[][] by wcsset(). These are not dealt with here, nor are any
00092 *   other non-standard keywords since these routines work only on the contents
00093 *   of a wcsprm struct and do not deal with FITS headers per se. In
00094 *   particular, they do not identify or translate CD00i00j, PC00i00j, PROJPN,
00095 *   EPOCH, VELREF or VSOURCEa keywords; this may be done by the FITS WCS
00096 *   header parser supplied with WCSLIB, refer to wcsshr.h.
00097 *
00098 *   wcsfix() and wcsfixi() apply all of the corrections handled by the following
00099 *   specific functions, which may also be invoked separately:
00100 *
00101 *   - cdfix(): Sets the diagonal element of the CDi_ja matrix to 1.0 if all
00102 *     CDi_ja keywords associated with a particular axis are omitted.
00103 *
00104 *   - datfix(): recast an older DATE-OBS date format in dateobs to year-2000
00105 *     standard form. Derive dateref from mjdrref if not already set.
00106 *     Alternatively, if dateref is set and mjdrref isn't, then derive mjdrref
00107 *     from it. If both are set, then check consistency. Likewise for dateobs
00108 *     and mjdobs; datebeg and mjddeg; dateavg and mjdavg; and dateend and
00109 *     mjdend.
00110 *
00111 *   - obsfix(): if only one half of obsgeo[] is set, then derive the other
00112 *     half from it. If both halves are set, then check consistency.
00113 *
00114 *   - unitfix(): translate some commonly used but non-standard unit strings in
00115 *     the CUNITia keyvalues, e.g. 'DEG' -> 'deg'.
00116 *
00117 *   - spcfix(): translate AIPS-convention spectral types, 'FREQ-LSR',
00118 *     'FEL0-HEL', etc., in ctype[] as set from CTYPEia.
00119 *
00120 *   - celfix(): translate AIPS-convention celestial projection types, NCP and
00121 *     GLS, in ctype[] as set from CTYPEia.
00122 *
00123 *   - cylfix(): fixes WCS keyvalues for malformed cylindrical projections that
00124 *     suffer from the problem described in Sect. 7.3.4 of Paper I.
00125 *
00126 *
00127 *   wcsfix() - Translate a non-standard WCS struct
00128 *   -----
00129 *   wcsfix() is identical to wcsfixi(), but lacks the info argument.
00130 *
00131 *
00132 *   wcsfixi() - Translate a non-standard WCS struct
00133 *   -----
00134 *   wcsfixi() applies all of the corrections handled separately by cdfix(),
00135 *   datfix(), obsfix(), unitfix(), spcfix(), celfix(), and cylfix().
00136 *
00137 *   Given:
00138 *   ctrl      int          Do potentially unsafe translations of non-standard
00139 *   unit strings as described in the usage notes to
00140 *   wcsutrn().
00141 *
00142 *   naxis      const int []
00143 *   Image axis lengths. If this array pointer is set to
00144 *   zero then cylfix() will not be invoked.
00145 *
00146 *   Given and returned:
00147 *   wcs        struct wcsprm*
00148 *   Coordinate transformation parameters.
00149 *
00150 *   Returned:
00151 *   stat       int [NWCSFIX]
00152 *   Status returns from each of the functions. Use the
00153 *   preprocessor macros NWCSFIX to dimension this vector
00154 *   and CDFIX, DATFIX, OBSFIX, UNITFIX, SPCFIX, CELFIX,
00155 *   and CYLFIX to access its elements. A status value
00156 *   of -2 is set for functions that were not invoked.
00157 *
00158 *   info       struct wcserr [NWCSFIX]
00159 *   Status messages from each of the functions. Use the
00160 *   preprocessor macros NWCSFIX to dimension this vector
00161 *   and CDFIX, DATFIX, OBSFIX, UNITFIX, SPCFIX, CELFIX,
00162 *   and CYLFIX to access its elements.
00163 *
00164 *   Note that the memory allocated by wcsfixi() for the
00165 *   message in each wcserr struct (wcserr::msg, if
00166 *   non-zero) must be freed by the user. See
00167 *   wcsdealloc().
00168 *
00169 *   Function return value:

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```

00170 *          int          Status return value:
00171 *                      0: Success.
00172 *                      1: One or more of the translation functions
00173 *                          returned an error.
00174 *
00175 *
00176 * cdfix() - Fix erroneously omitted CDi_ja keywords
00177 * -----
00178 * cdfix() sets the diagonal element of the CDi_ja matrix to unity if all
00179 * CDi_ja keywords associated with a given axis were omitted. According to WCS
00180 * Paper I, if any CDi_ja keywords at all are given in a FITS header then those
00181 * not given default to zero. This results in a singular matrix with an
00182 * intersecting row and column of zeros.
00183 *
00184 * cdfix() is expected to be invoked before wcsset(), which will fail if these
00185 * errors have not been corrected.
00186 *
00187 * Given and returned:
00188 *   wcs          struct wcsprm*
00189 *               Coordinate transformation parameters.
00190 *
00191 * Function return value:
00192 *   int          Status return value:
00193 *               -1: No change required (not an error).
00194 *               0: Success.
00195 *               1: Null wcsprm pointer passed.
00196 *
00197 *
00198 * datfix() - Translate DATE-OBS and derive MJD-OBS or vice versa
00199 * -----
00200 * datfix() translates the old DATE-OBS date format set in wcsprm::dateobs to
00201 * year-2000 standard form (yyyy-mm-ddThh:mm:ss). It derives wcsprm::dateref
00202 * from wcsprm::mjdref if not already set. Alternatively, if dateref is set
00203 * and mjdref isn't, then it derives mjdref from it. If both are set but
00204 * disagree by more than 0.001 day (86.4 seconds) then an error status is
00205 * returned. Likewise for wcsprm::dateobs and wcsprm::mjdobs; wcsprm::datebeg
00206 * and wcsprm::mjdbeg; wcsprm::dateavg and wcsprm::mjdavg; and wcsprm::dateend
00207 * and wcsprm::mjdend.
00208 *
00209 * If neither dateobs nor mjdobs are set, but wcsprm::jepoch (primarily) or
00210 * wcsprm::bepoch is, then both are derived from it. If jepoch and/or bepoch
00211 * are set but disagree with dateobs or mjdobs by more than 0.000002 year
00212 * (63.2 seconds), an informative message is produced.
00213 *
00214 * The translations done by datfix() do not affect and are not affected by
00215 * wcsset().
00216 *
00217 * Given and returned:
00218 *   wcs          struct wcsprm*
00219 *               Coordinate transformation parameters.
00220 *               wcsprm::dateref and/or wcsprm::mjdref may be changed.
00221 *               wcsprm::dateobs and/or wcsprm::mjdobs may be changed.
00222 *               wcsprm::datebeg and/or wcsprm::mjdbeg may be changed.
00223 *               wcsprm::dateavg and/or wcsprm::mjdavg may be changed.
00224 *               wcsprm::dateend and/or wcsprm::mjdend may be changed.
00225 *
00226 * Function return value:
00227 *   int          Status return value:
00228 *               -1: No change required (not an error).
00229 *               0: Success.
00230 *               1: Null wcsprm pointer passed.
00231 *               5: Invalid parameter value.
00232 *
00233 *               For returns >= 0, a detailed message, whether
00234 *               informative or an error message, may be set in
00235 *               wcsprm::err if enabled, see wcserr_enable(), with
00236 *               wcsprm::err.status set to FIXERR_DATE_FIX.
00237 *
00238 * Notes:
00239 *   1: The MJD algorithms used by datfix() are from D.A. Hatcher, 1984, QJRAS,
00240 *      25, 53-55, as modified by P.T. Wallace for use in SLALIB subroutines
00241 *      CLDJ and DJCL.
00242 *
00243 *
00244 * obsfix() - complete the OBSGEO-[XYZLBH] vector of observatory coordinates
00245 * -----
00246 * obsfix() completes the wcsprm::obsgeo vector of observatory coordinates.
00247 * That is, if only the (x,y,z) Cartesian coordinate triplet or the (l,b,h)
00248 * geodetic coordinate triplet are set, then it derives the other triplet from
00249 * it. If both triplets are set, then it checks for consistency at the level
00250 * of 1 metre.
00251 *
00252 * The operations done by obsfix() do not affect and are not affected by
00253 * wcsset().
00254 *
00255 * Given:
00256 *   ctrl      int          Flag that controls behaviour if one triplet is

```

```

00257 *          defined and the other is only partially defined:
00258 *          0: Reset only the undefined elements of an
00259 *             incomplete coordinate triplet.
00260 *          1: Reset all elements of an incomplete triplet.
00261 *          2: Don't make any changes, check for consistency
00262 *             only. Returns an error if either of the two
00263 *             triplets is incomplete.
00264 *
00265 * Given and returned:
00266 *   wcs      struct wcsprm*
00267 *             Coordinate transformation parameters.
00268 *             wcsprm::obsgeo may be changed.
00269 *
00270 * Function return value:
00271 *   int      Status return value:
00272 *             -1: No change required (not an error).
00273 *             0: Success.
00274 *             1: Null wcsprm pointer passed.
00275 *             5: Invalid parameter value.
00276 *
00277 *             For returns >= 0, a detailed message, whether
00278 *             informative or an error message, may be set in
00279 *             wcsprm::err if enabled, see wcserr_enable(), with
00280 *             wcsprm::err.status set to FIXERR_OBS_FIX.
00281 *
00282 * Notes:
00283 *   1: While the International Terrestrial Reference System (ITRS) is based
00284 *       solely on Cartesian coordinates, it recommends the use of the GRS80
00285 *       ellipsoid in converting to geodetic coordinates. However, while WCS
00286 *       Paper III recommends ITRS Cartesian coordinates, Paper VII prescribes
00287 *       the use of the IAU(1976) ellipsoid for geodetic coordinates, and
00288 *       consequently that is what is used here.
00289 *
00290 *   2: For reference, parameters of commonly used global reference ellipsoids:
00291 *
00292 *       a (m)          1/f          Standard
00293 *       -----
00294 *       6378140        298.2577      IAU(1976)
00295 *       6378137        298.257222101 GRS80
00296 *       6378137        298.257223563 WGS84
00297 *       6378136        298.257        IERS(1989)
00298 *       6378136.6      298.25642      IERS(2003,2010), IAU(2009/2012)
00299 *
00300 *       where  $f = (a - b) / a$  is the flattening, and  $a$  and  $b$  are the semi-major
00301 *       and semi-minor radii in metres.
00302 *
00303 *   3: The transformation from geodetic (lng,lat,htg) to Cartesian (x,y,z) is
00304 *
00305 *        $x = (n + hgt) * \cos lng * \cos lat,$ 
00306 *        $y = (n + hgt) * \sin lng * \cos lat,$ 
00307 *        $z = (n * (1.0 - e^2) + hgt) * \sin lat,$ 
00308 *
00309 *       where the "prime vertical radius",  $n$ , is a function of latitude
00310 *
00311 *        $n = a / \sqrt{1 - (e * \sin lat)^2},$ 
00312 *
00313 *       and  $a$ , the equatorial radius, and  $e^2 = (2 - f) * f$ , the (first)
00314 *       eccentricity of the ellipsoid, are constants. obsfix() inverts these
00315 *       iteratively by writing
00316 *
00317 *        $x = \rho * \cos lng * \cos lat,$ 
00318 *        $y = \rho * \sin lng * \cos lat,$ 
00319 *        $zeta = \rho * \sin lat,$ 
00320 *
00321 *       where
00322 *
00323 *        $\rho = n + hgt,$ 
00324 *        $= \sqrt{x^2 + y^2 + zeta^2},$ 
00325 *        $zeta = z / (1 - n * e^2 / \rho),$ 
00326 *
00327 *       and iterating over the value of  $zeta$ . Since  $e$  is small, a good first
00328 *       approximation is given by  $zeta = z$ .
00329 *
00330 *
00331 * unitfix() - Correct aberrant CUNITia keyvalues
00332 * -----
00333 * unitfix() applies wcsutrn() to translate non-standard CUNITia keyvalues,
00334 * e.g. 'DEG' -> 'deg', also stripping off unnecessary whitespace.
00335 *
00336 * unitfix() is expected to be invoked before wcsset(), which will fail if
00337 * non-standard CUNITia keyvalues have not been translated.
00338 *
00339 * Given:
00340 *   ctrl      int      Do potentially unsafe translations described in the
00341 *                       usage notes to wcsutrn().
00342 *
00343 * Given and returned:

```

```

00344 *   wcs          struct wcsprm*
00345 *               Coordinate transformation parameters.
00346 *
00347 * Function return value:
00348 *   int          Status return value:
00349 *               -1: No change required (not an error).
00350 *               0: Success (an alias was applied).
00351 *               1: Null wcsprm pointer passed.
00352 *
00353 *               When units are translated (i.e. 0 is returned), an
00354 *               informative message is set in wcsprm::err if enabled,
00355 *               see wcserr_enable(), with wcsprm::err.status set to
00356 *               FIXERR_UNITS_ALIAS.
00357 *
00358 *
00359 * spcfix() - Translate AIPS-convention spectral types
00360 * -----
00361 * spcfix() translates AIPS-convention spectral coordinate types,
00362 * '{FREQ,FELO,VELO}-{LSR,HEL,OBS}' (e.g. 'FREQ-OBS', 'FELO-HEL', 'VELO-LSR')
00363 * set in wcsprm::ctype[], subject to VELREF set in wcsprm::velref.
00364 *
00365 * Note that if wcs::specsys is already set then it will not be overridden.
00366 *
00367 * AIPS-convention spectral types set in CTYPEDia are translated on-the-fly by
00368 * wcsset() but without modifying wcsprm::ctype[] or wcsprm::specsys. That is,
00369 * only the information extracted from wcsprm::ctype[] is translated when
00370 * wcsset() fills in wcsprm::spc (spcprm struct). spcfix() modifies
00371 * wcsprm::ctype[] so that if the header is subsequently written out, e.g. by
00372 * wcshdo(), then it will contain translated CTYPEDia keyvalues.
00373 *
00374 * The operations done by spcfix() do not affect and are not affected by
00375 * wcsset().
00376 *
00377 * Given and returned:
00378 *   wcs          struct wcsprm*
00379 *               Coordinate transformation parameters.  wcsprm::ctype[]
00380 *               and/or wcsprm::specsys may be changed.
00381 *
00382 * Function return value:
00383 *   int          Status return value:
00384 *               -1: No change required (not an error).
00385 *               0: Success.
00386 *               1: Null wcsprm pointer passed.
00387 *               2: Memory allocation failed.
00388 *               3: Linear transformation matrix is singular.
00389 *               4: Inconsistent or unrecognized coordinate axis
00390 *               types.
00391 *               5: Invalid parameter value.
00392 *               6: Invalid coordinate transformation parameters.
00393 *               7: Ill-conditioned coordinate transformation
00394 *               parameters.
00395 *
00396 *               For returns >= 0, a detailed message, whether
00397 *               informative or an error message, may be set in
00398 *               wcsprm::err if enabled, see wcserr_enable(), with
00399 *               wcsprm::err.status set to FIXERR_SPC_UPDTE.
00400 *
00401 *
00402 * celfix() - Translate AIPS-convention celestial projection types
00403 * -----
00404 * celfix() translates AIPS-convention celestial projection types, NCP and
00405 * GLS, set in the ctype[] member of the wcsprm struct.
00406 *
00407 * Two additional pv[] keyvalues are created when translating NCP, and three
00408 * are created when translating GLS with non-zero reference point. If the pv[]
00409 * array was initially allocated by wcsini() then the array will be expanded if
00410 * necessary. Otherwise, error 2 will be returned if sufficient empty slots
00411 * are not already available for use.
00412 *
00413 * AIPS-convention celestial projection types set in CTYPEDia are translated
00414 * on-the-fly by wcsset() but without modifying wcsprm::ctype[], wcsprm::pv[],
00415 * or wcsprm::npv. That is, only the information extracted from
00416 * wcsprm::ctype[] is translated when wcsset() fills in wcsprm::cel (celprm
00417 * struct). celfix() modifies wcsprm::ctype[], wcsprm::pv[], and wcsprm::npv
00418 * so that if the header is subsequently written out, e.g. by wcshdo(), then it
00419 * will contain translated CTYPEDia keyvalues and the relevant PVi_ma.
00420 *
00421 * The operations done by celfix() do not affect and are not affected by
00422 * wcsset(). However, it uses information in the wcsprm struct provided by
00423 * wcsset(), and will invoke it if necessary.
00424 *
00425 * Given and returned:
00426 *   wcs          struct wcsprm*
00427 *               Coordinate transformation parameters.  wcsprm::ctype[]
00428 *               and/or wcsprm::pv[] may be changed.
00429 *
00430 * Function return value:

```

```

00431 *          int          Status return value:
00432 *                  -1: No change required (not an error).
00433 *                  0: Success.
00434 *                  1: Null wcsprm pointer passed.
00435 *                  2: Memory allocation failed.
00436 *                  3: Linear transformation matrix is singular.
00437 *                  4: Inconsistent or unrecognized coordinate axis
00438 *                     types.
00439 *                  5: Invalid parameter value.
00440 *                  6: Invalid coordinate transformation parameters.
00441 *                  7: Ill-conditioned coordinate transformation
00442 *                     parameters.
00443 *
00444 *                  For returns > 1, a detailed error message is set in
00445 *                  wcsprm::err if enabled, see wcserr_enable().
00446 *
00447 *
00448 * cylfix() - Fix malformed cylindrical projections
00449 * -----
00450 * cylfix() fixes WCS keyvalues for malformed cylindrical projections that
00451 * suffer from the problem described in Sect. 7.3.4 of Paper I.
00452 *
00453 * cylfix() requires the wcsprm struct to have been set up by wcsset(), and
00454 * will invoke it if necessary. After modification, the struct is reset on
00455 * return with an explicit call to wcsset().
00456 *
00457 * Given:
00458 *   naxis      const int []
00459 *               Image axis lengths.
00460 *
00461 * Given and returned:
00462 *   wcs        struct wcsprm*
00463 *               Coordinate transformation parameters.
00464 *
00465 * Function return value:
00466 *   int          Status return value:
00467 *                  -1: No change required (not an error).
00468 *                  0: Success.
00469 *                  1: Null wcsprm pointer passed.
00470 *                  2: Memory allocation failed.
00471 *                  3: Linear transformation matrix is singular.
00472 *                  4: Inconsistent or unrecognized coordinate axis
00473 *                     types.
00474 *                  5: Invalid parameter value.
00475 *                  6: Invalid coordinate transformation parameters.
00476 *                  7: Ill-conditioned coordinate transformation
00477 *                     parameters.
00478 *                  8: All of the corner pixel coordinates are invalid.
00479 *                  9: Could not determine reference pixel coordinate.
00480 *                  10: Could not determine reference pixel value.
00481 *
00482 *                  For returns > 1, a detailed error message is set in
00483 *                  wcsprm::err if enabled, see wcserr_enable().
00484 *
00485 *
00486 * wpcspcx() - regularize PCi_j
00487 * -----
00488 * wpcspcx() "regularizes" the linear transformation matrix component of the
00489 * coordinate transformation (PCi_ja) to make it more human-readable.
00490 *
00491 * Normally, upon encountering a FITS header containing a Cdi_ja matrix,
00492 * wcsset() simply treats it as PCi_ja and sets CDELTia to unity. However,
00493 * wpcspcx() decomposes Cdi_ja into PCi_ja and CDELTia in such a way that
00494 * CDELTia form meaningful scaling parameters. In practice, the residual
00495 * PCi_ja matrix will often then be orthogonal, i.e. unity, or describing a
00496 * pure rotation, axis permutation, or reflection, or a combination thereof.
00497 *
00498 * The decomposition is based on normalizing the length in the transformed
00499 * system (i.e. intermediate pixel coordinates) of the orthonormal basis
00500 * vectors of the pixel coordinate system. This deviates slightly from the
00501 * prescription given by Eq. (4) of WCS Paper I, namely  $\sum_{j=1,N} (PCi\_ja)^2 = 1$ ,
00502 * in replacing the sum over j with the sum over i. Consequently, the columns
00503 * of PCi_ja will consist of unit vectors. In practice, especially in cubes
00504 * and higher dimensional images, at least some pairs of these unit vectors, if
00505 * not all, will often be orthogonal or close to orthogonal.
00506 *
00507 * The sign of CDELTia is chosen to make the PCi_ja matrix as close to the,
00508 * possibly permuted, unit matrix as possible, except that where the coordinate
00509 * description contains a pair of celestial axes, the sign of CDELTia is set
00510 * negative for the longitude axis and positive for the latitude axis.
00511 *
00512 * Optionally, rows of the PCi_ja matrix may also be permuted to diagonalize
00513 * it as far as possible, thus undoing any transposition of axes in the
00514 * intermediate pixel coordinate system.
00515 *
00516 * If the coordinate description contains a celestial plane, then the angle of
00517 * rotation of each of the basis vectors associated with the celestial axes is

```

```

00518 * returned. For a pure rotation the two angles should be identical. Any
00519 * difference between them is a measure of axis skewness.
00520 *
00521 * The decomposition is not performed for axes involving a sequent distortion
00522 * function that is defined in terms of CDi_ja, such as TPV, TNX, or ZPX, which
00523 * always are. The independent variables of the polynomial are therefore
00524 * intermediate world coordinates rather than intermediate pixel coordinates.
00525 * Because sequent distortions are always applied before CDELTia, if CDi_ja was
00526 * translated to PCi_ja plus CDELTia, then the distortion would be altered
00527 * unless the polynomial coefficients were also adjusted to account for the
00528 * change of scale.
00529 *
00530 * wcspx() requires the wcsprm struct to have been set up by wcsset(), and
00531 * will invoke it if necessary. The wcsprm struct is reset on return with an
00532 * explicit call to wcsset().
00533 *
00534 * Given and returned:
00535 *   wcs           struct wcsprm*
00536 *               Coordinate transformation parameters.
00537 *
00538 * Given:
00539 *   dopc          int           If 1, then PCi_ja and CDELTia, as given, will be
00540 *                               recomposed according to the above prescription. If 0,
00541 *                               the operation is restricted to decomposing CDi_ja.
00542 *
00543 *   permute       int           If 1, then after decomposition (or recomposition),
00544 *                               permute rows of PCi_ja to make the axes of the
00545 *                               intermediate pixel coordinate system match as closely
00546 *                               as possible those of the pixel coordinates. That is,
00547 *                               make it as close to a diagonal matrix as possible.
00548 *                               However, celestial axes are special in always being
00549 *                               paired, with the longitude axis preceding the latitude
00550 *                               axis.
00551 *
00552 *                               All WCS entities indexed by i, such as CTYPiEia,
00553 *                               CRVALiA, CDELTia, etc., including coordinate lookup
00554 *                               tables, will also be permuted as necessary to account
00555 *                               for the change to PCi_ja. This does not apply to
00556 *                               CRPIXja, nor prior distortion functions. These
00557 *                               operate on pixel coordinates, which are not affected
00558 *                               by the permutation.
00559 *
00560 * Returned:
00561 *   rotn          double[2]      Rotation angle [deg] of each basis vector associated
00562 *                               with the celestial axes. For a pure rotation the two
00563 *                               angles should be identical. Any difference between
00564 *                               them is a measure of axis skewness.
00565 *
00566 *                               May be set to the NULL pointer if this information is
00567 *                               not required.
00568 *
00569 * Function return value:
00570 *   int           Status return value:
00571 *   0: Success.
00572 *   1: Null wcsprm pointer passed.
00573 *   2: Memory allocation failed.
00574 *   5: CDi_j matrix not used.
00575 *   6: Sequent distortion function present.
00576 *
00577 *
00578 * Global variable: const char *wcsfix_errmsg[] - Status return messages
00579 * -----
00580 * Error messages to match the status value returned from each function.
00581 *
00582 * =====*/
00583
00584 #ifndef WCSLIB_WCSFIX
00585 #define WCSLIB_WCSFIX
00586
00587 #include "wcs.h"
00588 #include "wcserr.h"
00589
00590 #ifdef __cplusplus
00591 extern "C" {
00592 #endif
00593
00594 #define CDFIX      0
00595 #define DATFIX     1
00596 #define OBSFIX     2
00597 #define UNITFIX    3
00598 #define SPCFIX     4
00599 #define CELFIX     5
00600 #define CYLFIX     6
00601 #define NWCSFIX    7
00602
00603 extern const char *wcsfix_errmsg[];
00604 #define cylfix_errmsg wcsfix_errmsg

```

```

00605
00606 enum wcsfix_errmsg_enum {
00607     FIXERR_OBSGEO_FIX      = -5, // Observatory coordinates amended.
00608     FIXERR_DATE_FIX        = -4, // Date string reformatted.
00609     FIXERR_SPC_UPDATE      = -3, // Spectral axis type modified.
00610     FIXERR_UNITS_ALIAS     = -2, // Units alias translation.
00611     FIXERR_NO_CHANGE       = -1, // No change.
00612     FIXERR_SUCCESS         =  0, // Success.
00613     FIXERR_NULL_POINTER    =  1, // Null wcsprm pointer passed.
00614     FIXERR_MEMORY          =  2, // Memory allocation failed.
00615     FIXERR_SINGULAR_MTX    =  3, // Linear transformation matrix is singular.
00616     FIXERR_BAD_CTYPE       =  4, // Inconsistent or unrecognized coordinate
00617                                // axis types.
00618     FIXERR_BAD_PARAM       =  5, // Invalid parameter value.
00619     FIXERR_BAD_COORD_TRANS =  6, // Invalid coordinate transformation
00620                                // parameters.
00621     FIXERR_ILL_COORD_TRANS =  7, // Ill-conditioned coordinate transformation
00622                                // parameters.
00623     FIXERR_BAD_CORNER_PIX  =  8, // All of the corner pixel coordinates are
00624                                // invalid.
00625     FIXERR_NO_REF_PIX_COORD =  9, // Could not determine reference pixel
00626                                // coordinate.
00627     FIXERR_NO_REF_PIX_VAL  = 10, // Could not determine reference pixel value.
00628 };
00629
00630 int wcsfix(int ctrl, const int naxis[], struct wcsprm *wcs, int stat[]);
00631
00632 int wcsfixi(int ctrl, const int naxis[], struct wcsprm *wcs, int stat[],
00633             struct wcserr info[]);
00634
00635 int cdfix(struct wcsprm *wcs);
00636
00637 int datfix(struct wcsprm *wcs);
00638
00639 int obsfix(int ctrl, struct wcsprm *wcs);
00640
00641 int unitfix(int ctrl, struct wcsprm *wcs);
00642
00643 int spcfix(struct wcsprm *wcs);
00644
00645 int celfix(struct wcsprm *wcs);
00646
00647 int cylfix(const int naxis[], struct wcsprm *wcs);
00648
00649 int wscpcx(struct wcsprm *wcs, int dopc, int permute, double rotn[2]);
00650
00651
00652 #ifdef __cplusplus
00653 }
00654 #endif
00655
00656 #endif // WCSLIB_WCSFIX

```

## 8.29 wcshdr.h File Reference

```
#include "wcs.h"
```

### Macros

- **#define WCSHDR\_none** 0x00000000  
*Bit mask for `wcspih()` and `wcsbth()` - reject all extensions.*
- **#define WCSHDR\_all** 0x000FFFFF  
*Bit mask for `wcspih()` and `wcsbth()` - accept all extensions.*
- **#define WCSHDR\_reject** 0x10000000  
*Bit mask for `wcspih()` and `wcsbth()` - reject non-standard keywords.*
- **#define WCSHDR\_strict** 0x20000000
- **#define WCSHDR\_CROTAia** 0x00000001  
*Bit mask for `wcspih()` and `wcsbth()` - accept **CROTAia**, **iCROTna**, **TCROTna**.*
- **#define WCSHDR\_VELREFa** 0x00000002  
*Bit mask for `wcspih()` and `wcsbth()` - accept **VELREFa**.*

- #define `WCSHDR_CD00i00j` 0x00000004  
*Bit mask for `wcspih()` and `wcsbth()` - accept `CD00i00j`.*
- #define `WCSHDR_PC00i00j` 0x00000008  
*Bit mask for `wcspih()` and `wcsbth()` - accept `PC00i00j`.*
- #define `WCSHDR_PROJPn` 0x00000010  
*Bit mask for `wcspih()` and `wcsbth()` - accept `PROJPn`.*
- #define `WCSHDR_CD0i_0ja` 0x00000020
- #define `WCSHDR_PC0i_0ja` 0x00000040
- #define `WCSHDR_PV0i_0ma` 0x00000080
- #define `WCSHDR_PS0i_0ma` 0x00000100
- #define `WCSHDR_DOBSn` 0x00000200  
*Bit mask for `wcspih()` and `wcsbth()` - accept `DOBSn`.*
- #define `WCSHDR_OBSGLBhn` 0x00000400
- #define `WCSHDR_RADECSYS` 0x00000800  
*Bit mask for `wcspih()` and `wcsbth()` - accept `RADECSYS`.*
- #define `WCSHDR_EPOCHa` 0x00001000  
*Bit mask for `wcspih()` and `wcsbth()` - accept `EPOCHa`.*
- #define `WCSHDR_VSOURCE` 0x00002000  
*Bit mask for `wcspih()` and `wcsbth()` - accept `VSOURCEa`.*
- #define `WCSHDR_DATEREF` 0x00004000
- #define `WCSHDR_LONGKEY` 0x00008000  
*Bit mask for `wcspih()` and `wcsbth()` - accept long forms of the alternate binary table and pixel list WCS keywords.*
- #define `WCSHDR_CNAMn` 0x00010000  
*Bit mask for `wcspih()` and `wcsbth()` - accept `iCNAMn`, `TCNAMn`, `iCRDEn`, `TCRDEn`, `iCSYE`, `TCSYE`.*
- #define `WCSHDR_AUXIMG` 0x00020000  
*Bit mask for `wcspih()` and `wcsbth()` - allow the image-header form of an auxiliary WCS keyword to provide a default value for all images.*
- #define `WCSHDR_ALLIMG` 0x00040000  
*Bit mask for `wcspih()` and `wcsbth()` - allow the image-header form of all image header WCS keywords to provide a default value for all images.*
- #define `WCSHDR_IMGHEAD` 0x00100000  
*Bit mask for `wcsbth()` - restrict to image header keywords only.*
- #define `WCSHDR_BIMGARR` 0x00200000  
*Bit mask for `wcsbth()` - restrict to binary table image array keywords only.*
- #define `WCSHDR_PIXLIST` 0x00400000  
*Bit mask for `wcsbth()` - restrict to pixel list keywords only.*
- #define `WCSHDO_none` 0x000000  
*Bit mask for `wcshdo()` - don't write any extensions.*
- #define `WCSHDO_all` 0x0000FF  
*Bit mask for `wcshdo()` - write all extensions.*
- #define `WCSHDO_safe` 0x0000F  
*Bit mask for `wcshdo()` - write safe extensions only.*
- #define `WCSHDO_DOBSn` 0x00001  
*Bit mask for `wcshdo()` - write `DOBSn`.*
- #define `WCSHDO_TPCn_ka` 0x00002  
*Bit mask for `wcshdo()` - write `TPCn_ka`.*
- #define `WCSHDO_PVn_ma` 0x00004  
*Bit mask for `wcshdo()` - write `iPVn_ma`, `TPVn_ma`, `iPSn_ma`, `TPSn_ma`.*
- #define `WCSHDO_CRPXna` 0x00008  
*Bit mask for `wcshdo()` - write `jCRPXna`, `TCRPXna`, `iCDLTna`, `TCDLTna`, `iCUNIna`, `TCUNIna`, `iCTYPna`, `TCTYPna`, `iCRVLna`, `TCRVLna`.*
- #define `WCSHDO_CNAMna` 0x00010

- Bit mask for `wcshdo()` - write `iCNAMna`, `TCNAMna`, `iCRDEna`, `TCRDEna`, `iCSYEna`, `TCSYEna`.
  - #define `WCSHDO_WCSNna` 0x00020
- Bit mask for `wcshdo()` - write `WCSNna` instead of `TWCSna`.
  - #define `WCSHDO_P12` 0x01000
  - #define `WCSHDO_P13` 0x02000
  - #define `WCSHDO_P14` 0x04000
  - #define `WCSHDO_P15` 0x08000
  - #define `WCSHDO_P16` 0x10000
  - #define `WCSHDO_P17` 0x20000
  - #define `WCSHDO_EFMT` 0x40000

## Enumerations

- enum `wcshdr_errmsg_enum` {  
`WCSHDRERR_SUCCESS` = 0 , `WCSHDRERR_NULL_POINTER` = 1 , `WCSHDRERR_MEMORY` = 2 ,  
`WCSHDRERR_BAD_COLUMN` = 3 ,  
`WCSHDRERR_PARSER` = 4 , `WCSHDRERR_BAD_TABULAR_PARAMS` = 5 }

## Functions

- int `wcspih` (char \*header, int nkeyrec, int relax, int ctrl, int \*nreject, int \*nwcs, struct `wcsprm` \*\*wcs)  
*FITS WCS parser routine for image headers.*
- int `wcsbth` (char \*header, int nkeyrec, int relax, int ctrl, int keysel, int \*colsel, int \*nreject, int \*nwcs, struct `wcsprm` \*\*wcs)  
*FITS WCS parser routine for binary table and image headers.*
- int `wcstab` (struct `wcsprm` \*wcs)  
*Tabular construction routine.*
- int `wcsidx` (int nwcs, struct `wcsprm` \*\*wcs, int alts[27])  
*Index alternate coordinate representations.*
- int `wcsbdx` (int nwcs, struct `wcsprm` \*\*wcs, int type, short alts[1000][28])  
*Index alternate coordinate representations.*
- int `wcsvfree` (int \*nwcs, struct `wcsprm` \*\*wcs)  
*Free the array of `wcsprm` structs.*
- int `wcshdo` (int ctrl, struct `wcsprm` \*wcs, int \*nkeyrec, char \*\*header)  
*Write out a `wcsprm` struct as a FITS header.*

## Variables

- const char \* `wcshdr_errmsg` []  
*Status return messages.*

### 8.29.1 Detailed Description

Routines in this suite are aimed at extracting WCS information from a FITS file. The information is encoded via keywords defined in

"Representations of world coordinates in FITS",  
Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)

"Representations of celestial coordinates in FITS",  
Calabretta, M.R., & Greisen, E.W. 2002, A&A, 395, 1077 (WCS Paper II)

"Representations of spectral coordinates in FITS",  
Greisen, E.W., Calabretta, M.R., Valdes, F.G., & Allen, S.L.  
2006, A&A, 446, 747 (WCS Paper III)

"Representations of distortions in FITS world coordinate systems",  
Calabretta, M.R. et al. (WCS Paper IV, draft dated 2004/04/22),  
available from <http://www.atnf.csiro.au/people/Mark.Calabretta>

"Representations of time coordinates in FITS -  
Time and relative dimension in space",  
Rots, A.H., Bunclark, P.S., Calabretta, M.R., Allen, S.L.,  
Manchester, R.N., & Thompson, W.T. 2015, A&A, 574, A36 (WCS Paper VII)

These routines provide the high-level interface between the FITS file and the WCS coordinate transformation routines.

Additionally, function `wcshdo()` is provided to write out the contents of a `wcsprm` struct as a FITS header.

Briefly, the anticipated sequence of operations is as follows:

- 1: Open the FITS file and read the image or binary table header, e.g. using CFITSIO routine `fits_hdr2str()`.
- 2: Parse the header using `wcspih()` or `wcsbth()`; they will automatically interpret 'TAB' header keywords using `wcstab()`.
- 3: Allocate memory for, and read 'TAB' arrays from the binary table extension, e.g. using CFITSIO routine `fits_read_wcstab()` - refer to the prologue of `getwcstab.h`. `wcsset()` will automatically take control of this allocated memory, in particular causing it to be freed by `wcsfree()`.
- 4: Translate non-standard WCS usage using `wcsfix()`, see `wcsfix.h`.
- 5: Initialize `wcsprm` struct(s) using `wcsset()` and calculate coordinates using `wcsp2s()` and/or `wcss2p()`. Refer to the prologue of `wcs.h` for a description of these and other high-level WCS coordinate transformation routines.
- 6: Clean up by freeing memory with `wcsvfree()`.

In detail:

- `wcspih()` is a high-level FITS WCS routine that parses an image header. It returns an array of up to 27 `wcsprm` structs on each of which it invokes `wcstab()`.
- `wcsbth()` is the analogue of `wcspih()` for use with binary tables; it handles image array and pixel list keywords. As an extension of the FITS WCS standard, it also recognizes image header keywords which may be used to provide default values via an inheritance mechanism.
- `wcstab()` assists in filling in members of the `wcsprm` struct associated with coordinate lookup tables ('TAB'). These are based on arrays stored in a FITS binary table extension (BINTABLE) that are located by `PVi_ma` keywords in the image header.
- `wcsidx()` and `wcsbidx()` are utility routines that return the index for a specified alternate coordinate descriptor in the array of `wcsprm` structs returned by `wcspih()` or `wcsbth()`.
- `wcsvfree()` deallocates memory for an array of `wcsprm` structs, such as returned by `wcspih()` or `wcsbth()`.
- `wcshdo()` writes out a `wcsprm` struct as a FITS header.

## 8.29.2 Macro Definition Documentation

### WCSHDR\_none

```
#define WCSHDR_none 0x00000000
```

Bit mask for [wcspih\(\)](#) and [wcsbth\(\)](#) - reject all extensions.

Bit mask for the *relax* argument of [wcspih\(\)](#) and [wcsbth\(\)](#) - reject all extensions.

Refer to [wcsbth\(\)](#) note 5.

### WCSHDR\_all

```
#define WCSHDR_all 0x000FFFFF
```

Bit mask for [wcspih\(\)](#) and [wcsbth\(\)](#) - accept all extensions.

Bit mask for the *relax* argument of [wcspih\(\)](#) and [wcsbth\(\)](#) - accept all extensions.

Refer to [wcsbth\(\)](#) note 5.

### WCSHDR\_reject

```
#define WCSHDR_reject 0x10000000
```

Bit mask for [wcspih\(\)](#) and [wcsbth\(\)](#) - reject non-standard keywords.

Bit mask for the *relax* argument of [wcspih\(\)](#) and [wcsbth\(\)](#) - reject non-standard keywords.

Refer to [wcsbth\(\)](#) note 5.

### WCSHDR\_strict

```
#define WCSHDR_strict 0x20000000
```

### WCSHDR\_CROTAia

```
#define WCSHDR_CROTAia 0x00000001
```

Bit mask for [wcspih\(\)](#) and [wcsbth\(\)](#) - accept **CROTA**<sub>ia</sub>, **iCROT**<sub>na</sub>, **TCROT**<sub>na</sub>.

Bit mask for the *relax* argument of [wcspih\(\)](#) and [wcsbth\(\)](#) - accept **CROTA**<sub>ia</sub>, **iCROT**<sub>na</sub>, **TCROT**<sub>na</sub>.

Refer to [wcsbth\(\)](#) note 5.

**WCSHDR\_VELREFa**

```
#define WCSHDR_VELREFa 0x00000002
```

Bit mask for [wcspih\(\)](#) and [wcsbth\(\)](#) - accept **VELREF**a.

Bit mask for the *relax* argument of [wcspih\(\)](#) and [wcsbth\(\)](#) - accept **VELREF**a.

Refer to [wcsbth\(\)](#) note 5.

**WCSHDR\_CD00i00j**

```
#define WCSHDR_CD00i00j 0x00000004
```

Bit mask for [wcspih\(\)](#) and [wcsbth\(\)](#) - accept **CD00i00j**.

Bit mask for the *relax* argument of [wcspih\(\)](#) and [wcsbth\(\)](#) - accept **CD00i00j**.

Refer to [wcsbth\(\)](#) note 5.

**WCSHDR\_PC00i00j**

```
#define WCSHDR_PC00i00j 0x00000008
```

Bit mask for [wcspih\(\)](#) and [wcsbth\(\)](#) - accept **PC00i00j**.

Bit mask for the *relax* argument of [wcspih\(\)](#) and [wcsbth\(\)](#) - accept **PC00i00j**.

Refer to [wcsbth\(\)](#) note 5.

**WCSHDR\_PROJPN**

```
#define WCSHDR_PROJPN 0x00000010
```

Bit mask for [wcspih\(\)](#) and [wcsbth\(\)](#) - accept **PROJPN**.

Bit mask for the *relax* argument of [wcspih\(\)](#) and [wcsbth\(\)](#) - accept **PROJPN**.

Refer to [wcsbth\(\)](#) note 5.

**WCSHDR\_CD0i\_0ja**

```
#define WCSHDR_CD0i_0ja 0x00000020
```

**WCSHDR\_PC0i\_0ja**

```
#define WCSHDR_PC0i_0ja 0x00000040
```

**WCSHDR\_PV0i\_0ma**

```
#define WCSHDR_PV0i_0ma 0x00000080
```

**WCSHDR\_PS0i\_0ma**

```
#define WCSHDR_PS0i_0ma 0x00000100
```

**WCSHDR\_DOBSn**

```
#define WCSHDR_DOBSn 0x00000200
```

Bit mask for [wvspih\(\)](#) and [wvsbth\(\)](#) - accept **DOBSn**.

Bit mask for the *relax* argument of [wvspih\(\)](#) and [wvsbth\(\)](#) - accept **DOBSn**.

Refer to [wvsbth\(\)](#) note 5.

**WCSHDR\_OBSGLBHn**

```
#define WCSHDR_OBSGLBHn 0x00000400
```

**WCSHDR\_RADECSYS**

```
#define WCSHDR_RADECSYS 0x00000800
```

Bit mask for [wvspih\(\)](#) and [wvsbth\(\)](#) - accept **RADECSYS**.

Bit mask for the *relax* argument of [wvspih\(\)](#) and [wvsbth\(\)](#) - accept **RADECSYS**.

Refer to [wvsbth\(\)](#) note 5.

**WCSHDR\_EPOCHa**

```
#define WCSHDR_EPOCHa 0x00001000
```

Bit mask for [wvspih\(\)](#) and [wvsbth\(\)](#) - accept **EPOCHa**.

Bit mask for the *relax* argument of [wvspih\(\)](#) and [wvsbth\(\)](#) - accept **EPOCHa**.

Refer to [wvsbth\(\)](#) note 5.

**WCSHDR\_VSOURCE**

```
#define WCSHDR_VSOURCE 0x00002000
```

Bit mask for [wvspih\(\)](#) and [wvsbth\(\)](#) - accept **VSOURCEa**.

Bit mask for the *relax* argument of [wvspih\(\)](#) and [wvsbth\(\)](#) - accept **VSOURCEa**.

Refer to [wvsbth\(\)](#) note 5.

**WCSHDR\_DATEREF**

```
#define WCSHDR_DATEREF 0x00004000
```

**WCSHDR\_LONGKEY**

```
#define WCSHDR_LONGKEY 0x00008000
```

Bit mask for [wcspih\(\)](#) and [wcsbth\(\)](#) - accept long forms of the alternate binary table and pixel list WCS keywords.

Bit mask for the *relax* argument of [wcspih\(\)](#) and [wcsbth\(\)](#) - accept long forms of the alternate binary table and pixel list WCS keywords.

Refer to [wcsbth\(\)](#) note 5.

**WCSHDR\_CNAMn**

```
#define WCSHDR_CNAMn 0x00010000
```

Bit mask for [wcspih\(\)](#) and [wcsbth\(\)](#) - accept **iCNAM<sub>n</sub>**, **TCNAM<sub>n</sub>**, **iCRDE<sub>n</sub>**, **TCRDE<sub>n</sub>**, **iCSYE<sub>n</sub>**, **TCSYE<sub>n</sub>**.

Bit mask for the *relax* argument of [wcspih\(\)](#) and [wcsbth\(\)](#) - accept **iCNAM<sub>n</sub>**, **TCNAM<sub>n</sub>**, **iCRDE<sub>n</sub>**, **TCRDE<sub>n</sub>**, **iCSYE<sub>n</sub>**, **TCSYE<sub>n</sub>**.

Refer to [wcsbth\(\)](#) note 5.

**WCSHDR\_AUXIMG**

```
#define WCSHDR_AUXIMG 0x00020000
```

Bit mask for [wcspih\(\)](#) and [wcsbth\(\)](#) - allow the image-header form of an auxiliary WCS keyword to provide a default value for all images.

Bit mask for the *relax* argument of [wcspih\(\)](#) and [wcsbth\(\)](#) - allow the image-header form of an auxiliary WCS keyword with representation-wide scope to provide a default value for all images.

Refer to [wcsbth\(\)](#) note 5.

**WCSHDR\_ALLIMG**

```
#define WCSHDR_ALLIMG 0x00040000
```

Bit mask for [wcspih\(\)](#) and [wcsbth\(\)](#) - allow the image-header form of *all* image header WCS keywords to provide a default value for all images.

Bit mask for the *relax* argument of [wcspih\(\)](#) and [wcsbth\(\)](#) - allow the image-header form of *all* image header WCS keywords to provide a default value for all image arrays in a binary table (n.b. not pixel list).

Refer to [wcsbth\(\)](#) note 5.

## WCSHDR\_IMGHEAD

```
#define WCSHDR_IMGHEAD 0x00100000
```

Bit mask for [wcsbth\(\)](#) - restrict to image header keywords only.

Bit mask for the *keysel* argument of [wcsbth\(\)](#) - restrict keyword types considered to image header keywords only.

## WCSHDR\_BIMGARR

```
#define WCSHDR_BIMGARR 0x00200000
```

Bit mask for [wcsbth\(\)](#) - restrict to binary table image array keywords only.

Bit mask for the *keysel* argument of [wcsbth\(\)](#) - restrict keyword types considered to binary table image array keywords only.

## WCSHDR\_PIXLIST

```
#define WCSHDR_PIXLIST 0x00400000
```

Bit mask for [wcsbth\(\)](#) - restrict to pixel list keywords only.

Bit mask for the *keysel* argument of [wcsbth\(\)](#) - restrict keyword types considered to pixel list keywords only.

## WCSHDO\_none

```
#define WCSHDO_none 0x00000
```

Bit mask for [wcsbthdo\(\)](#) - don't write any extensions.

Bit mask for the *relax* argument of [wcsbthdo\(\)](#) - don't write any extensions.

Refer to the notes for [wcsbthdo\(\)](#).

## WCSHDO\_all

```
#define WCSHDO_all 0x000FF
```

Bit mask for [wcsbthdo\(\)](#) - write all extensions.

Bit mask for the *relax* argument of [wcsbthdo\(\)](#) - write all extensions.

Refer to the notes for [wcsbthdo\(\)](#).

**WCSHDO\_safe**

```
#define WCSHDO_safe 0x0000F
```

Bit mask for [wcsldo\(\)](#) - write safe extensions only.

Bit mask for the *relax* argument of [wcsldo\(\)](#) - write only extensions that are considered safe.

Refer to the notes for [wcsldo\(\)](#).

**WCSHDO\_DOBSn**

```
#define WCSHDO_DOBSn 0x00001
```

Bit mask for [wcsldo\(\)](#) - write **DOBSn**.

Bit mask for the *relax* argument of [wcsldo\(\)](#) - write **DOBSn**, the column-specific analogue of DATE-OBS for use in binary tables and pixel lists.

Refer to the notes for [wcsldo\(\)](#).

**WCSHDO\_TPCn\_ka**

```
#define WCSHDO_TPCn_ka 0x00002
```

Bit mask for [wcsldo\(\)](#) - write **TPCn\_ka**.

Bit mask for the *relax* argument of [wcsldo\(\)](#) - write **TPCn\_ka** if less than eight characters instead of **TPn\_ka**.

Refer to the notes for [wcsldo\(\)](#).

**WCSHDO\_PVn\_ma**

```
#define WCSHDO_PVn_ma 0x00004
```

Bit mask for [wcsldo\(\)](#) - write **iPVn\_ma**, **TPVn\_ma**, **iPSn\_ma**, **TPSn\_ma**.

Bit mask for the *relax* argument of [wcsldo\(\)](#) - write **iPVn\_ma**, **TPVn\_ma**, **iPSn\_ma**, **TPSn\_ma**, if less than eight characters instead of **iVn\_ma**, **TVn\_ma**, **iSn\_ma**, **TSn\_ma**.

Refer to the notes for [wcsldo\(\)](#).

**WCSHDO\_CRPXna**

```
#define WCSHDO_CRPXna 0x00008
```

Bit mask for [wcsldo\(\)](#) - write **jCRPXna**, **TCRPXna**, **iCDLTna**, **TCDLTna**, **iCUNIna**, **TCUNIna**, **iCTYPna**, **TCTYPna**, **iCRVLna**, **TCRVLna**.

Bit mask for the *relax* argument of [wcsldo\(\)](#) - write **jCRPXna**, **TCRPXna**, **iCDLTna**, **TCDLTna**, **iCUNIna**, **TCUNIna**, **iCTYPna**, **TCTYPna**, **iCRVLna**, **TCRVLna**, if less than eight characters instead of **jCRPna**, **TCRPna**, **iCDEna**, **TCDEna**, **iCUNna**, **TCUNna**, **iCTYna**, **TCTYna**, **iCRVna**, **TCRVna**.

Refer to the notes for [wcsldo\(\)](#).

**WCSHDO\_CNAMna**

```
#define WCSHDO_CNAMna 0x00010
```

Bit mask for [wshdo\(\)](#) - write **iCNAMna**, **TCNAMna**, **iCRDEna**, **TCRDEna**, **iCSYEna**, **TCSYEna**.

Bit mask for the *relax* argument of [wshdo\(\)](#) - write **iCNAMna**, **TCNAMna**, **iCRDEna**, **TCRDEna**, **iCSYEna**, **TCSYEna**, if less than eight characters instead of **iCNAa**, **TCNAa**, **iCRDna**, **TCRDna**, **iCSYna**, **TCSYna**.

Refer to the notes for [wshdo\(\)](#).

**WCSHDO\_WCSNna**

```
#define WCSHDO_WCSNna 0x00020
```

Bit mask for [wshdo\(\)](#) - write **WCSNna** instead of **TWCSna**.

Bit mask for the *relax* argument of [wshdo\(\)](#) - write **WCSNna** instead of **TWCSna**.

Refer to the notes for [wshdo\(\)](#).

**WCSHDO\_P12**

```
#define WCSHDO_P12 0x01000
```

**WCSHDO\_P13**

```
#define WCSHDO_P13 0x02000
```

**WCSHDO\_P14**

```
#define WCSHDO_P14 0x04000
```

**WCSHDO\_P15**

```
#define WCSHDO_P15 0x08000
```

**WCSHDO\_P16**

```
#define WCSHDO_P16 0x10000
```

**WCSHDO\_P17**

```
#define WCSHDO_P17 0x20000
```

## Enumerator

WCSHDRERR_SUCCESS	
WCSHDRERR_NULL_POINTER	
WCSHDRERR_MEMORY	
WCSHDRERR_BAD_COLUMN	
WCSHDRERR_PARSER	
WCSHDRERR_BAD_TABULAR_PARAMS	

## 8.29.4 Function Documentation

### wcspih()

```
int wcspih (
    char * header,
    int nkeyrec,
    int relax,
    int ctrl,
    int * nreject,
    int * nwcs,
    struct wcsprm ** wcs)
```

FITS WCS parser routine for image headers.

**wcspih()** is a high-level FITS WCS routine that parses an image header, either that of a primary HDU or of an image extension. All WCS keywords defined in Papers I, II, III, IV, and VII are recognized, and also those used by the AIPS convention and certain other keywords that existed in early drafts of the WCS papers as explained in [wcsbth\(\)](#) note 5. **wcspih()** also handles keywords associated with non-standard distortion functions described in the prologue of [dis.h](#).

Given a character array containing a FITS image header, **wcspih()** identifies and reads all WCS keywords for the primary coordinate representation and up to 26 alternate representations. It returns this information as an array of [wcsprm](#) structs.

**wcspih()** invokes [wcstab\(\)](#) on each of the [wcsprm](#) structs that it returns.

Use [wcsbth\(\)](#) in preference to **wcspih()** for FITS headers of unknown type; [wcsbth\(\)](#) can parse image headers as well as binary table and pixel list headers, although it cannot handle keywords relating to distortion functions, which may only exist in an image header (primary or extension).

### Parameters

in, out	<i>header</i>	Character array containing the (entire) FITS image header from which to identify and construct the coordinate representations, for example, as might be obtained conveniently via the CFITSIO routine <i>fits_hdr2str()</i> . Each header "keyrecord" (formerly "card image") consists of exactly 80 7-bit ASCII printing characters in the range 0x20 to 0x7e (which excludes NUL, BS, TAB, LF, FF and CR) especially noting that the keyrecords are NOT null-terminated. For negative values of ctrl (see below), header[] is modified so that WCS keyrecords processed by <b>wcspih()</b> are removed from it.
in	<i>nkeyrec</i>	Number of keyrecords in header[].

in	<i>relax</i>	<p>Degree of permissiveness:</p> <ul style="list-style-type: none"> <li>• 0: Recognize only FITS keywords defined by the published WCS standard.</li> <li>• <a href="#">WCSHDR_all</a>: Admit all recognized informal extensions of the WCS standard.</li> </ul> <p>Fine-grained control of the degree of permissiveness is also possible as explained in <a href="#">wcsbth()</a> note 5.</p>
in	<i>ctrl</i>	<p>Error reporting and other control options for invalid WCS and other header keyrecords:</p> <ul style="list-style-type: none"> <li>• 0: Do not report any rejected header keyrecords.</li> <li>• 1: Produce a one-line message stating the number of WCS keyrecords rejected (nreject).</li> <li>• 2: Report each rejected keyrecord and the reason why it was rejected.</li> <li>• 3: As above, but also report all non-WCS keyrecords that were discarded, and the number of coordinate representations (nwcs) found.</li> <li>• 4: As above, but also report the accepted WCS keyrecords, with a summary of the number accepted as well as rejected.</li> </ul> <p>The report is written to stderr by default, or the stream set by <a href="#">wcsprintf_set()</a>. For ctrl &lt; 0, WCS keyrecords processed by <a href="#">wcspih()</a> are removed from header[]:</p> <ul style="list-style-type: none"> <li>• -1: Remove only valid WCS keyrecords whose values were successfully extracted, nothing is reported.</li> <li>• -2: As above, but also remove WCS keyrecords that were rejected, reporting each one and the reason that it was rejected.</li> <li>• -3: As above, and also report the number of coordinate representations (nwcs) found.</li> <li>• -11: Same as -1 but preserving global WCS-related keywords such as ' { <b>DATE,MJD</b> } - { <b>OBS, BEG, AVG, END</b> } ' and the other basic time-related keywords, and ' <b>OBSGEO</b> - { <b>X, Y, Z, L, B, H</b> } '.</li> </ul> <p>If any keyrecords are removed from header[] it will be null-terminated (NUL not being a legal FITS header character), otherwise it will contain its original complement of nkeyrec keyrecords and possibly not be null-terminated.</p>
out	<i>nreject</i>	Number of WCS keywords rejected for syntax errors, illegal values, etc. Keywords not recognized as WCS keywords are simply ignored. Refer also to <a href="#">wcsbth()</a> note 5.
out	<i>nwcs</i>	Number of coordinate representations found.
out	<i>wcs</i>	<p>Pointer to an array of <a href="#">wcsprm</a> structs containing up to 27 coordinate representations. Memory for the array is allocated by <a href="#">wcspih()</a> which also invokes <a href="#">wcsini()</a> for each struct to allocate memory for internal arrays and initialize their members to default values. Refer also to <a href="#">wcsbth()</a> note 8. Note that <a href="#">wcsset()</a> is not invoked on these structs.</p> <p>This allocated memory must be freed by the user, first by invoking <a href="#">wcsfree()</a> for each struct, and then by freeing the array itself. A routine, <a href="#">wcsvfree()</a>, is provided to do this (see below).</p>

## Returns

Status return value:

- 0: Success.
- 1: Null [wcsprm](#) pointer passed.
- 2: Memory allocation failed.

- 4: Fatal error returned by Flex parser.

**Notes:**

1. Refer to [wcsbth\(\)](#) notes 1, 2, 3, 5, 7, and 8.

**wcsbth()**

```
int wcsbth (
    char * header,
    int nkeyrec,
    int relax,
    int ctrl,
    int keysel,
    int * colsel,
    int * nreject,
    int * nwcs,
    struct wcsprm ** wcs)
```

FITS WCS parser routine for binary table and image headers.

**wcsbth()** is a high-level FITS WCS routine that parses a binary table header. It handles image array and pixel list WCS keywords which may be present together in one header.

As an extension of the FITS WCS standard, **wcsbth()** also recognizes image header keywords in a binary table header. These may be used to provide default values via an inheritance mechanism discussed in note 5 (c.f. [WCSHDR\\_AUXIMG](#) and [WCSHDR\\_ALLIMG](#)), or may instead result in [wcsprm](#) structs that are not associated with any particular column. Thus **wcsbth()** can handle primary image and image extension headers in addition to binary table headers (it ignores **NAXIS** and does not rely on the presence of the **TFIELDS** keyword).

All WCS keywords defined in Papers I, II, III, and VII are recognized, and also those used by the AIPS convention and certain other keywords that existed in early drafts of the WCS papers as explained in note 5 below.

**wcsbth()** sets the `colnum` or `colax[]` members of the [wcsprm](#) structs that it returns with the column number of an image array or the column numbers associated with each pixel coordinate element in a pixel list. [wcsprm](#) structs that are not associated with any particular column, as may be derived from image header keywords, have `colnum == 0`.

Note 6 below discusses the number of [wcsprm](#) structs returned by **wcsbth()**, and the circumstances in which image header keywords cause a struct to be created. See also note 9 concerning the number of separate images that may be stored in a pixel list.

The API to **wcsbth()** is similar to that of [wcspih\(\)](#) except for the addition of extra arguments that may be used to restrict its operation. Like [wcspih\(\)](#), **wcsbth()** invokes [wcstab\(\)](#) on each of the [wcsprm](#) structs that it returns.

**Parameters**

---

in, out	<i>header</i>	<p>Character array containing the (entire) FITS binary table, primary image, or image extension header from which to identify and construct the coordinate representations, for example, as might be obtained conveniently via the CFITSIO routine <code>fits_hdr2str()</code>. Each header "keyrecord" (formerly "card image") consists of exactly 80 7-bit ASCII printing characters in the range 0x20 to 0x7e (which excludes NUL, BS, TAB, LF, FF and CR) especially noting that the keyrecords are NOT null-terminated.</p> <p>For negative values of <code>ctrl</code> (see below), <code>header[]</code> is modified so that WCS keyrecords processed by <code>wcsbth()</code> are removed from it.</p>
in	<i>nkeyrec</i>	Number of keyrecords in <code>header[]</code> .
in	<i>relax</i>	<p>Degree of permissiveness:</p> <ul style="list-style-type: none"> <li>• 0: Recognize only FITS keywords defined by the published WCS standard.</li> <li>• <a href="#">WCSDR_all</a>: Admit all recognized informal extensions of the WCS standard.</li> </ul> <p>Fine-grained control of the degree of permissiveness is also possible, as explained in note 5 below.</p>
in	<i>ctrl</i>	<p>Error reporting and other control options for invalid WCS and other header keyrecords:</p> <ul style="list-style-type: none"> <li>• 0: Do not report any rejected header keyrecords.</li> <li>• 1: Produce a one-line message stating the number of WCS keyrecords rejected (<code>nreject</code>).</li> <li>• 2: Report each rejected keyrecord and the reason why it was rejected.</li> <li>• 3: As above, but also report all non-WCS keyrecords that were discarded, and the number of coordinate representations (<code>nwcs</code>) found.</li> <li>• 4: As above, but also report the accepted WCS keyrecords, with a summary of the number accepted as well as rejected.</li> </ul> <p>The report is written to <code>stderr</code> by default, or the stream set by <code>wcsprintf_set()</code>. For <code>ctrl &lt; 0</code>, WCS keyrecords processed by <code>wcsbth()</code> are removed from <code>header[]</code>:</p> <ul style="list-style-type: none"> <li>• -1: Remove only valid WCS keyrecords whose values were successfully extracted, nothing is reported.</li> <li>• -2: Also remove WCS keyrecords that were rejected, reporting each one and the reason that it was rejected.</li> <li>• -3: As above, and also report the number of coordinate representations (<code>nwcs</code>) found.</li> <li>• -11: Same as -1 but preserving global WCS-related keywords such as ' { <b>DATE,MJD</b> } - { <b>OBS, BEG, AVG, END</b> } ' and the other basic time-related keywords, and ' <b>OBSGEO-</b> { <b>X, Y, Z, L, B, H</b> } '.</li> </ul> <p>If any keyrecords are removed from <code>header[]</code> it will be null-terminated (NUL not being a legal FITS header character), otherwise it will contain its original complement of <code>nkeyrec</code> keyrecords and possibly not be null-terminated.</p>

in	<i>keysel</i>	<p>Vector of flag bits that may be used to restrict the keyword types considered:</p> <ul style="list-style-type: none"> <li>• <a href="#">WCSHDR_IMGHEAD</a>: Image header keywords.</li> <li>• <a href="#">WCSHDR_BIMGARR</a>: Binary table image array.</li> <li>• <a href="#">WCSHDR_PIXLIST</a>: Pixel list keywords.</li> </ul> <p>If zero, there is no restriction.</p> <p>Keywords such as <b>EQUI</b><sub>na</sub> or <b>RFRQ</b><sub>na</sub> that are common to binary table image arrays and pixel lists (including <b>WCSN</b><sub>na</sub> and <b>TWCS</b><sub>na</sub>, as explained in note 4 below) are selected by both <a href="#">WCSHDR_BIMGARR</a> and <a href="#">WCSHDR_PIXLIST</a>. Thus if inheritance via <a href="#">WCSHDR_ALLIMG</a> is enabled as discussed in note 5 and one of these shared keywords is present, then <a href="#">WCSHDR_IMGHEAD</a> and <a href="#">WCSHDR_PIXLIST</a> alone may be sufficient to cause the construction of coordinate descriptions for binary table image arrays.</p>
in	<i>colsel</i>	<p>Pointer to an array of table column numbers used to restrict the keywords considered by <b>wcsbth()</b>.</p> <p>A null pointer may be specified to indicate that there is no restriction. Otherwise, the magnitude of cols[0] specifies the length of the array:</p> <ul style="list-style-type: none"> <li>• cols[0] &gt; 0: the columns are included,</li> <li>• cols[0] &lt; 0: the columns are excluded.</li> </ul> <p>For the pixel list keywords <b>TP</b><sub>n_ka</sub> and <b>TC</b><sub>n_ka</sub> (and <b>TPC</b><sub>n_ka</sub> and <b>TCD</b><sub>n_ka</sub> if <a href="#">WCSHDR_LONGKEY</a> is enabled), it is an error for one column to be selected but not the other. This is unlike the situation with invalid keyrecords, which are simply rejected, because the error is not intrinsic to the header itself but arises in the way that it is processed.</p>
out	<i>nreject</i>	Number of WCS keywords rejected for syntax errors, illegal values, etc. Keywords not recognized as WCS keywords are simply ignored, refer also to note 5 below.
out	<i>nwcs</i>	Number of coordinate representations found.
out	<i>wcs</i>	<p>Pointer to an array of <a href="#">wcsprm</a> structs containing up to 27027 coordinate representations, refer to note 6 below.</p> <p>Memory for the array is allocated by <b>wcsbth()</b> which also invokes <b>wcsini()</b> for each struct to allocate memory for internal arrays and initialize their members to default values. Refer also to note 8 below. Note that <b>wcsset()</b> is not invoked on these structs.</p> <p>This allocated memory must be freed by the user, first by invoking <b>wcsfree()</b> for each struct, and then by freeing the array itself. A routine, <b>wcsvfree()</b>, is provided to do this (see below).</p>

## Returns

Status return value:

- 0: Success.
- 1: Null [wcsprm](#) pointer passed.
- 2: Memory allocation failed.
- 3: Invalid column selection.
- 4: Fatal error returned by Flex parser.

## Notes:

1. [wvspih\(\)](#) determines the number of coordinate axes independently for each alternate coordinate representation (denoted by the "a" value in keywords like **CTYPE**<sub>ia</sub>) from the higher of

- a **NAXIS**,
- b **WCSEXES**<sub>a</sub>,
- c The highest axis number in any parameterized WCS keyword. The keyvalue, as well as the keyword, must be syntactically valid otherwise it will not be considered.

If none of these keyword types is present, i.e. if the header only contains auxiliary WCS keywords for a particular coordinate representation, then no coordinate description is constructed for it.

**wcsbth()** is similar except that it ignores the **NAXIS** keyword if given an image header to process.

The number of axes, which is returned as a member of the **wcsprm** struct, may differ for different coordinate representations of the same image.

2. **wcspih()** and **wcsbth()** enforce correct FITS "keyword = value" syntax with regard to "=" occurring in columns 9 and 10.

However, they do recognize free-format character (NOST 100-2.0, Sect. 5.2.1), integer (Sect. 5.2.3), and floating-point values (Sect. 5.2.4) for all keywords.

3. Where **CROTA**<sub>n</sub>, **CD**<sub>i</sub><sub>j</sub><sub>a</sub>, and **PC**<sub>i</sub><sub>j</sub><sub>a</sub> occur together in one header **wcspih()** and **wcsbth()** treat them as described in the prologue to **wcs.h**.
4. WCS Paper I mistakenly defined the pixel list form of **WCSNAME**<sub>a</sub> as **TWCS**<sub>na</sub> instead of **WCSN**<sub>na</sub>; the 'T' is meant to substitute for the axis number in the binary table form of the keyword - note that keywords defined in WCS Papers II, III, and VII that are not parameterized by axis number have identical forms for binary tables and pixel lists. Consequently **wcsbth()** always treats **WCSN**<sub>na</sub> and **TWCS**<sub>na</sub> as equivalent.
5. **wcspih()** and **wcsbth()** interpret the *relax* argument as a vector of flag bits to provide fine-grained control over what non-standard WCS keywords to accept. The flag bits are subject to change in future and should be set by using the preprocessor macros (see below) for the purpose.

- **WCSHDR\_none**: Don't accept any extensions (not even those in the errata). Treat non-conformant keywords in the same way as non-WCS keywords in the header, i.e. simply ignore them.
- **WCSHDR\_all**: Accept all extensions recognized by the parser.
- **WCSHDR\_reject**: Reject non-standard keyrecords (that are not otherwise explicitly accepted by one of the flags below). A message will optionally be printed on stderr by default, or the stream set by **wcsprintf\_set()**, as determined by the *ctrl* argument, and *nreject* will be incremented.

This flag may be used to signal the presence of non-standard keywords, otherwise they are simply passed over as though they did not exist in the header. It is mainly intended for testing conformance of a FITS header to the WCS standard.

Keyrecords may be non-standard in several ways:

- The keyword may be syntactically valid but with keyvalue of incorrect type or invalid syntax, or the keycomment may be malformed.
- The keyword may strongly resemble a WCS keyword but not, in fact, be one because it does not conform to the standard. For example, "CRPIX01" looks like a **CRPIX**<sub>j</sub><sub>a</sub> keyword, but in fact the leading zero on the axis number violates the basic FITS standard. Likewise, "LONPOLE2" is not a valid **LONPOLE**<sub>a</sub> keyword in the WCS standard, and indeed there is nothing the parser can sensibly do with it.
- Use of the keyword may be deprecated by the standard. Such will be rejected if not explicitly accepted via one of the flags below.
- **WCSHDR\_strict**: As for **WCSHDR\_reject**, but also reject AIPS-convention keywords and all other deprecated usage that is not explicitly accepted.
- **WCSHDR\_CROTA**<sub>a</sub>: Accept **CROTA**<sub>a</sub> (**wcspih()**), **iCROT**<sub>na</sub> (**wcsbth()**), **TCROT**<sub>na</sub> (**wcsbth()**).
- **WCSHDR\_VELREF**<sub>a</sub>: Accept **VELREF**<sub>a</sub>. **wcspih()** always recognizes the AIPS-convention keywords, **CROTA**<sub>n</sub>, **EPOCH**, and **VELREF** for the primary representation (*a* = ') but alternates are non-standard. **wcsbth()** accepts **EPOCH**<sub>a</sub> and **VELREF**<sub>a</sub> only if **WCSHDR\_AUXIMG** is also enabled.
- **WCSHDR\_CD00i00j**: Accept **CD00i00j** (**wcspih()**).
- **WCSHDR\_PC00i00j**: Accept **PC00i00j** (**wcspih()**).

- **WCSHDR\_PROJ<sub>Pn</sub>**: Accept **PROJ<sub>Pn</sub>** (**wcspih()**). These appeared in early drafts of WCS Paper I+II (before they were split) and are equivalent to **CD<sub>i\_ja</sub>**, **PC<sub>i\_ja</sub>**, and **PV<sub>i\_ma</sub>** for the primary representation ( $a = 'j'$ ). **PROJ<sub>Pn</sub>** is equivalent to **PV<sub>i\_ma</sub>** with  $m = n \leq 9$ , and is associated exclusively with the latitude axis.
- **WCSHDR\_CD0<sub>i\_0ja</sub>**: Accept **CD0<sub>i\_0ja</sub>** (**wcspih()**).
- **WCSHDR\_PC0<sub>i\_0ja</sub>**: Accept **PC0<sub>i\_0ja</sub>** (**wcspih()**).
- **WCSHDR\_PV0<sub>i\_0ma</sub>**: Accept **PV0<sub>i\_0ja</sub>** (**wcspih()**).
- **WCSHDR\_PS0<sub>i\_0ma</sub>**: Accept **PS0<sub>i\_0ja</sub>** (**wcspih()**). Allow the numerical index to have a leading zero in doubly-parameterized keywords, for example, **PC01\_01**. WCS Paper I (Sects 2.1.2 & 2.1.4) explicitly disallows leading zeroes. The FITS 3.0 standard document (Sect. 4.1.2.1) states that the index in singly-parameterized keywords (e.g. **CTYPE<sub>ia</sub>**) "shall not have leading zeroes", and later in Sect. 8.1 that "leading zeroes must not be used" on **PV<sub>i\_ma</sub>** and **PS<sub>i\_ma</sub>**. However, by an oversight, it is silent on **PC<sub>i\_ja</sub>** and **CD<sub>i\_ja</sub>**.
- **WCSHDR\_DOBS<sub>n</sub>** (**wcsbth()** only): Allow **DOBS<sub>n</sub>**, the column-specific analogue of **DATE-OBS**. By an oversight this was never formally defined in the standard.
- **WCSHDR\_OBSGLBH<sub>n</sub>** (**wcsbth()** only): Allow **OBSGL<sub>n</sub>**, **OBSGB<sub>n</sub>**, and **OBSGH<sub>n</sub>**, the column-specific analogues of **OBSGEO-L**, **OBSGEO-B**, and **OBSGEO-H**. By an oversight these were never formally defined in the standard.
- **WCSHDR\_RADEC<sub>SY</sub>**: Accept **RADEC<sub>SY</sub>**. This appeared in early drafts of WCS Paper I+II and was subsequently replaced by **RADES<sub>Y</sub><sub>a</sub>**.  
**wcsbth()** accepts **RADEC<sub>SY</sub>** only if **WCSHDR\_AUXIMG** is also enabled.
- **WCSHDR\_EPOCH<sub>a</sub>**: Accept **EPOCH<sub>a</sub>**.
- **WCSHDR\_VSOURCE**: Accept **VSOURCE<sub>a</sub>** or **VSOU<sub>na</sub>** (**wcsbth()**). This appeared in early drafts of WCS Paper III and was subsequently dropped in favour of **ZSOURCE<sub>a</sub>** and **ZSOU<sub>na</sub>**.  
**wcsbth()** accepts **VSOURCE<sub>a</sub>** only if **WCSHDR\_AUXIMG** is also enabled.
- **#WCSHDR\_DATE<sub>REF</sub>**: Accept **DATE-REF**, **MJD-REF**, **MJD-REFI**, **MJD-REF<sub>F</sub>**, **JDREF**, **JD-REFI**, and **JD-REF<sub>F</sub>** as synonyms for the standard keywords, **DATE<sub>REF</sub>**, **MJDREF**, **MJDREFI**, **MJDREF<sub>F</sub>**, **JDREF**, **JDREFI**, and **JDREF<sub>F</sub>**. The latter buck the pattern set by the other date keywords (**{DATE,MJD}-{OBS,BEG,AVG,END}**), thereby increasing the potential for confusion and error.
- **WCSHDR\_LONGKEY** (**wcsbth()** only): Accept long forms of the alternate binary table and pixel list WCS keywords, i.e. with "a" non-blank. Specifically

jCRPX <sub>na</sub>	TCRPX <sub>na</sub>	↔ :	jCRPX <sub>n</sub>	jCRP <sub>na</sub>	TCRPX <sub>n</sub>	TCRP <sub>na</sub>	CRPIX <sub>ja</sub>
	TPC <sub>n_ka</sub>	↔ :		ijPC <sub>na</sub>		TP <sub>n_ka</sub>	PC <sub>i_ja</sub>
	TCD <sub>n_ka</sub>	↔ :		ijCD <sub>na</sub>		TC <sub>n_ka</sub>	CD <sub>i_ja</sub>
iCDLT <sub>na</sub>	TCDLT <sub>na</sub>	↔ :	iCDLT <sub>n</sub>	iCDEN <sub>a</sub>	TCDLT <sub>n</sub>	TCDEN <sub>a</sub>	CDELT <sub>ia</sub>
iCUNI <sub>na</sub>	TCUNI <sub>na</sub>	↔ :	iCUNI <sub>n</sub>	iCUN <sub>na</sub>	TCUNI <sub>n</sub>	TCUN <sub>na</sub>	CUNIT <sub>ia</sub>
iCTYP <sub>na</sub>	TCTYP <sub>na</sub>	↔ :	iCTYP <sub>n</sub>	iCTY <sub>na</sub>	TCTYP <sub>n</sub>	TCTY <sub>na</sub>	CTYPE <sub>ia</sub>
iCRVL <sub>na</sub>	TCRVL <sub>na</sub>	↔ :	iCRVL <sub>n</sub>	iCRV <sub>na</sub>	TCRVL <sub>n</sub>	TCRV <sub>na</sub>	CRVAL <sub>ia</sub>
iPV <sub>n_ma</sub>	TPV <sub>n_ma</sub>	↔ :		iV <sub>n_ma</sub>		TV <sub>n_ma</sub>	PV <sub>i_ma</sub>

<b>iPSn_ma</b>	<b>TPSn_ma</b>	↔		<b>iSn_ma</b>		<b>TSn_ma</b>	<b>PSi_ma</b>
		:					

where the primary and standard alternate forms together with the image-header equivalent are shown rightwards of the colon.

The long form of these keywords could be described as quasi- standard. **TPCn\_ka**, **iPVn\_ma**, and **TPVn\_ma** appeared by mistake in the examples in WCS Paper II and subsequently these and also **TCDn\_ka**, **iPSn\_ma** and **TPSn\_ma** were legitimized by the errata to the WCS papers.

Strictly speaking, the other long forms are non-standard and in fact have never appeared in any draft of the WCS papers nor in the errata. However, as natural extensions of the primary form they are unlikely to be written with any other intention. Thus it should be safe to accept them provided, of course, that the resulting keyword does not exceed the 8-character limit.

If [WCSHDR\\_CNAMn](#) is enabled then also accept

<b>iCNAMna</b>	<b>TCNAMna</b>	↔	--	<b>iCNana</b>	--	<b>TCNana</b>	<b>CNAMEia</b>
		:					
<b>iCRDEna</b>	<b>TCRDEna</b>	↔	--	<b>iCRDna</b>	--	<b>TCRDna</b>	<b>CRDERia</b>
		:					
<b>iCSYEna</b>	<b>TCSYEna</b>	↔	--	<b>iCSYna</b>	--	<b>TCSYna</b>	<b>CSYERia</b>
		:					
<b>TCZPHna</b>	<b>TCZPHna</b>	↔	--	<b>TCZPna</b>	--	<b>TCZPna</b>	<b>CZPHSia</b>
		:					
<b>iCPERna</b>	<b>TCPERna</b>	↔	--	<b>iCPRna</b>	--	<b>TCPRna</b>	<b>CPERIia</b>
		:					

Note that **CNAMEia**, **CRDERia**, **CSYERia**, **CZPHSia**, **CPERIia**, and their variants are not used by WCSLIB but are stored in the [wcsprm](#) struct as auxiliary information.

- [WCSHDR\\_CNAMn](#) ([wcsbth\(\)](#) only): Accept **iCNAMn**, **iCRDEn**, **iCSYEn**, **TCZPHn**, **iCPERn**, **TCNAMn**, **TCRDEn**, **TCSYEn**, **TCZPHn**, and **TCPERn**, i.e. with "a" blank. While non-standard, these are the obvious analogues of **iCTYPn**, **TCTYPn**, etc.
- [WCSHDR\\_AUXIMG](#) ([wcsbth\(\)](#) only): Allow the image-header form of an auxiliary WCS keyword with representation-wide scope to provide a default value for all images. This default may be overridden by the column-specific form of the keyword.

For example, a keyword like **EQUINOXa** would apply to all image arrays in a binary table, or all pixel list columns with alternate representation "a" unless overridden by **EQUIna**.

Specifically the keywords are:

<b>LONPOLEa</b>	for <b>LONPna</b>	
<b>LATPOLEa</b>	for <b>LATPna</b>	
<b>VELREF</b>		... (No column-specific form.)
<b>VELREFa</b>		... Only if <a href="#">WCSHDR_VELREFa</a> is set.

whose keyvalues are actually used by WCSLIB, and also keywords providing auxiliary information that is simply stored in the [wcsprm](#) struct:

<b>WCSNAME<sub>a</sub></b>	for <b>WCSN<sub>na</sub></b>	... Or <b>TWCS<sub>na</sub></b> (see below).
<b>DATE-OBS</b>	for <b>DOBS<sub>n</sub></b>	
<b>MJD-OBS</b>	for <b>MJDOB<sub>n</sub></b>	
<b>RADESYS<sub>a</sub></b>	for <b>RADE<sub>na</sub></b>	
<b>RADECSYS</b>	for <b>RADE<sub>na</sub></b>	... Only if <b>WCSHDR_RADECSYS</b> is set.
<b>EPOCH</b>		... (No column-specific form.)
<b>EPOCH<sub>a</sub></b>		... Only if <b>WCSHDR_EPOCH<sub>a</sub></b> is set.
<b>EQUINOX<sub>a</sub></b>	for <b>EQUIN<sub>a</sub></b>	

where the image-header keywords on the left provide default values for the column specific keywords on the right.

Note that, according to Sect. 8.1 of WCS Paper III, and Sect. 5.2 of WCS Paper VII, the following are always inherited:

<b>RESTFREQ</b>	for <b>RFRQ<sub>na</sub></b>
<b>RESTFRQ<sub>a</sub></b>	for <b>RFRQ<sub>na</sub></b>
<b>RESTWAV<sub>a</sub></b>	for <b>RWAV<sub>na</sub></b>

being those actually used by WCSLIB, together with the following auxiliary keywords, many of which do not have binary table equivalents and therefore can only be inherited:

<b>TIMESYS</b>		
<b>TREFPOS</b>	for <b>MJDA<sub>n</sub></b>	
<b>TREFDIR</b>	for <b>MJDA<sub>n</sub></b>	
<b>PLEPHEM</b>		
<b>TIMEUNIT</b>		
<b>DATEREF</b>		
<b>MJDREF</b>		
<b>MJDREFI</b>		
<b>MJDREFF</b>		
<b>JDREF</b>		
<b>JDREFI</b>		
<b>JDREFF</b>		
<b>TIMEOFFS</b>		
<b>DATE-BEG</b>		
<b>DATE-AVG</b>	for <b>DAVG<sub>n</sub></b>	
<b>DATE-END</b>		
<b>MJD-BEG</b>		
<b>MJD-AVG</b>	for <b>MJDA<sub>n</sub></b>	
<b>MJD-END</b>		

<b>JEPOCH</b>		
<b>BEPOCH</b>		
<b>TSTART</b>		
<b>TSTOP</b>		
<b>XPOSURE</b>		
<b>TELAPSE</b>		
<b>TIMSYER</b>		
<b>TIMRDER</b>		
<b>TIMEDEL</b>		
<b>TIMEPIXR</b>		
<b>OBSGEO-X</b>	for <b>OBSGX</b> <sub>n</sub>	
<b>OBSGEO-Y</b>	for <b>OBSGY</b> <sub>n</sub>	
<b>OBSGEO-Z</b>	for <b>OBSGZ</b> <sub>n</sub>	
<b>OBSGEO-L</b>	for <b>OBSGL</b> <sub>n</sub>	
<b>OBSGEO-B</b>	for <b>OBSGB</b> <sub>n</sub>	
<b>OBSGEO-H</b>	for <b>OBSGH</b> <sub>n</sub>	
<b>OBSORBIT</b>		
<b>SPECSYS</b> <sub>a</sub>	for <b>SPEC</b> <sub>n</sub> <sub>a</sub>	
<b>SSYSOBS</b> <sub>a</sub>	for <b>SOBS</b> <sub>n</sub> <sub>a</sub>	
<b>VELOSYS</b> <sub>a</sub>	for <b>VSYS</b> <sub>n</sub> <sub>a</sub>	
<b>VSOURCE</b> <sub>a</sub>	for <b>VSOU</b> <sub>n</sub> <sub>a</sub>	... Only if <b>WCSHDR_VSOURCE</b> is set.
<b>ZSOURCE</b> <sub>a</sub>	for <b>ZSOU</b> <sub>n</sub> <sub>a</sub>	
<b>SSYSSRC</b> <sub>a</sub>	for <b>SSRC</b> <sub>n</sub> <sub>a</sub>	
<b>VELANGL</b> <sub>a</sub>	for <b>VANG</b> <sub>n</sub> <sub>a</sub>	

Global image-header keywords, such as **MJD-OBS**, apply to all alternate representations, and would therefore provide a default value for all images in the header.

This auxiliary inheritance mechanism applies to binary table image arrays and pixel lists alike. Most of these keywords have no default value, the exceptions being **LONPOLE**<sub>a</sub> and **LATPOLE**<sub>a</sub>, and also **RADESYS**<sub>a</sub> and **EQUINOX**<sub>a</sub> which provide defaults for each other. Thus one potential difficulty in using **WCSHDR\_AUXIMG** is that of erroneously inheriting one of these four keywords.

Also, beware of potential inconsistencies that may arise where, for example, **DATE-OBS** is inherited, but **MJD-OBS** is overridden by **MJDOBN** and specifies a different time. Pairs in this category are:

DATE-OBS/DOBS <sub>n</sub>	versus	MJD-OBS/MJDOBN
DATE-AVG/DAVG <sub>n</sub>	versus	MJD-AVG/MJDAn
RESTFRQa/RFRQna	versus	RESTWAVa/RWAVna
OBSGEO-[XYZ]/OBSG[XYZ] <sub>n</sub>	versus	OBSGEO-[LBH]/OBSG[LBH] <sub>n</sub>

The **wcsfixi()** routines **datfix()** and **obsfix()** are provided to check the consistency of these and other such pairs of keywords.

Unlike **WCSHDR\_ALLIMG**, the existence of one (or all) of these auxiliary WCS image header keywords will not by itself cause a **wcsprm** struct to be created for alternate representation "a". This is because

they do not provide sufficient information to create a non-trivial coordinate representation when used in conjunction with the default values of those keywords that are parameterized by axis number, such as **CTYPEia**.

- **WCSHDR\_ALLIMG** (**wcsbth()** only): Allow the image-header form of *\*all\** image header WCS keywords to provide a default value for all image arrays in a binary table (n.b. not pixel list). This default may be overridden by the column-specific form of the keyword. For example, a keyword like **CRPIXja** would apply to all image arrays in a binary table with alternate representation "a" unless overridden by **jCRPna**. Specifically the keywords are those listed above for **WCSHDR\_AUXIMG** plus

<b>WCSAXESa</b>	for <b>WCAXna</b>
-----------------	-------------------

which defines the coordinate dimensionality, and the following keywords that are parameterized by axis number:

<b>CRPIXja</b>	for <b>jCRPna</b>	
<b>PCi_ja</b>	for <b>ijPCna</b>	
<b>CDi_ja</b>	for <b>ijCDna</b>	
<b>CDELTia</b>	for <b>iCDENa</b>	
<b>CROTAi</b>	for <b>iCROTn</b>	
<b>CROTAia</b>		... Only if <b>WCSHDR_CROTAia</b> is set.
<b>CUNITia</b>	for <b>iCUNna</b>	
<b>CTYPEia</b>	for <b>iCTYna</b>	
<b>CRVALia</b>	for <b>iCRVna</b>	
<b>PVi_ma</b>	for <b>iVn_ma</b>	
<b>PSi_ma</b>	for <b>iSn_ma</b>	
<b>CNAMEia</b>	for <b>iCNana</b>	
<b>CRDERia</b>	for <b>iCRDna</b>	
<b>CSYERia</b>	for <b>iCSYna</b>	
<b>CZPHSia</b>	for <b>TCZPna</b>	
<b>CPERIia</b>	for <b>iCPRna</b>	

where the image-header keywords on the left provide default values for the column specific keywords on the right.

This full inheritance mechanism only applies to binary table image arrays, not pixel lists, because in the latter case there is no well-defined association between coordinate axis number and column number (see note 9 below).

Note that **CNAMEia**, **CRDERia**, **CSYERia**, and their variants are not used by WCSLIB but are stored in the **wcsprm** struct as auxiliary information.

Note especially that at least one **wcsprm** struct will be returned for each "a" found in one of the image header keywords listed above:

- If the image header keywords for "a" **are not** inherited by a binary table, then the struct will not be associated with any particular

- table column number and it is up to the user to provide an association.
- If the image header keywords for "a" **are** inherited by a binary table image array, then those keywords are considered to be "exhausted" and do not result in a separate `wcsprm` struct.

For example, to accept `CD00i00j` and `PC00i00j` and reject all other extensions, use

```
relax = WCSHDR_reject | WCSHDR_CD00i00j | WCSHDR_PC00i00j;
```

The parser always treats **EPOCH** as subordinate to **EQUINOX**a if both are present, and **VSOURCE**a is always subordinate to **ZSOURCE**a.

Likewise, **VELREF** is subordinate to the formalism of WCS Paper III, see `spcaips()`.

Neither `wcspih()` nor `wcsbth()` currently recognize the AIPS-convention keywords **ALTRPIX** or **ALTRVAL** which effectively define an alternative representation for a spectral axis.

6. Depending on what flags have been set in its `relax` argument, `wcsbth()` could return as many as 27027 `wcsprm` structs:

- Up to 27 unattached representations derived from image header keywords.
- Up to 27 structs for each of up to 999 columns containing an image arrays.
- Up to 27 structs for a pixel list.

Note that it is considered legitimate for a column to contain an image array and also form part of a pixel list, and in particular that `wcsbth()` does not check the **TFORM** keyword for a pixel list column to check that it is scalar.

In practice, of course, a realistic binary table header is unlikely to contain more than a handful of images.

In order for `wcsbth()` to create a `wcsprm` struct for a particular coordinate representation, at least one WCS keyword that defines an axis number must be present, either directly or by inheritance if `WCSHDR_ALLIMG` is set.

When the image header keywords for an alternate representation are inherited by a binary table image array via `WCSHDR_ALLIMG`, those keywords are considered to be "exhausted" and do not result in a separate `wcsprm` struct. Otherwise they do.

7. Neither `wcspih()` nor `wcsbth()` check for duplicated keywords, in most cases they accept the last encountered.
8. `wcspih()` and `wcsbth()` use `wcsnpv()` and `wcsnps()` (refer to the prologue of `wcs.h`) to match the size of the `pv[]` and `ps[]` arrays in the `wcsprm` structs to the number in the header. Consequently there are no unused elements in the `pv[]` and `ps[]` arrays, indeed they will often be of zero length.
9. The FITS WCS standard for pixel lists assumes that a pixel list defines one and only one image, i.e. that each row of the binary table refers to just one event, e.g. the detection of a single photon or neutrino, for which the device "pixel" coordinates are stored in separate scalar columns of the table.

In the absence of a standard for pixel lists - or even an informal description! - let alone a formal mechanism for identifying the columns containing pixel coordinates (as opposed to pixel values or metadata recorded at the time the photon or neutrino was detected), WCS Paper I discusses how the WCS keywords themselves may be used to identify them.

In practice, however, pixel lists have been used to store multiple images. Besides not specifying how to identify columns, the pixel list convention is also silent on the method to be used to associate table columns with image axes.

An additional shortcoming is the absence of a formal method for associating global binary-table WCS keywords, such as **WCSNna** or **MJDOBn**, with a pixel list image, whether one or several.

In light of these uncertainties, **wcsbth()** simply collects all WCS keywords for a particular pixel list coordinate representation (i.e. the "a" value in **TCTYna**) into one **wcsprm** struct. However, these alternates need not be associated with the same table columns and this allows a pixel list to contain up to 27 separate images. As usual, if one of these representations happened to contain more than two celestial axes, for example, then an error would result when **wcsset()** is invoked on it. In this case the "colsel" argument could be used to restrict the columns used to construct the representation so that it only contained one pair of celestial axes.

Global, binary-table WCS keywords are considered to apply to the pixel list image with matching alternate (e.g. the "a" value in **LONPna** or **EQUIna**), regardless of the table columns the image occupies. In other words, the column number is ignored (the "n" value in **LONPna** or **EQUIna**). This also applies for global, binary-table WCS keywords that have no alternates, such as **MJDOBn** and **OBSGXn**, which match all images in a pixel list. Take heed that this may lead to counterintuitive behaviour, especially where such a keyword references a column that does not store pixel coordinates, and moreso where the pixel list stores only a single image. In fact, as the column number, n, is ignored for such keywords, it would make no difference even if they referenced non-existent columns. Moreover, there is no requirement for consistency in the column numbers used for such keywords, even for **OBSGXn**, **OBSGYn**, and **OBSGZn** which are meant to define the elements of a coordinate vector. Although it would surely be perverse to construct a pixel list like this, such a situation may still arise in practice where columns are deleted from a binary table.

The situation with global, binary-table WCS keywords becomes potentially even more confusing when image arrays and pixel list images coexist in one binary table. In that case, a keyword such as **MJDOBn** may legitimately appear multiple times with n referencing different image arrays. Which then is the one that applies to the pixel list images? In this implementation, it is the last instance that appears in the header, whether or not it is also associated with an image array.

## wcstab()

```
int wcstab (
    struct wcsprm * wcs)
```

Tabular construction routine.

**wcstab()** assists in filling in the information in the **wcsprm** struct relating to coordinate lookup tables.

Tabular coordinates ('**TAB**') present certain difficulties in that the main components of the lookup table - the multidimensional coordinate array plus an index vector for each dimension - are stored in a FITS binary table extension (BINTABLE). Information required to locate these arrays is stored in **PVi\_ma** and **PSi\_ma** keywords in the image header.

**wcstab()** parses the **PV<sub>i</sub>\_ma** and **PS<sub>i</sub>\_ma** keywords associated with each '**TAB**' axis and allocates memory in the **wcsprm** struct for the required number of **tabprm** structs. It sets as much of the **tabprm** struct as can be gleaned from the image header, and also sets up an array of **wtbarr** structs (described in the prologue of **wtbarr.h**) to assist in extracting the required arrays from the BINTABLE extension(s).

It is then up to the user to allocate memory for, and copy arrays from the BINTABLE extension(s) into the **tabprm** structs. A CFITSIO routine, **fits\_read\_wcstab()**, has been provided for this purpose, see **getwcstab.h**. **wcsset()** will automatically take control of this allocated memory, in particular causing it to be freed by **wcsfree()**; the user must not attempt to free it after **wcsset()** has been called.

Note that **wcspih()** and **wcsbth()** automatically invoke **wcstab()** on each of the **wcsprm** structs that they return.

### Parameters

in, out	wcs	Coordinate transformation parameters (see below). <b>wcstab()</b> sets ntab, tab, nwtb and wtb, allocating memory for the tab and wtb arrays. This allocated memory will be freed automatically by <b>wcsfree()</b> .
---------	-----	--

### Returns

Status return value:

- 0: Success.
- 1: Null **wcsprm** pointer passed.
- 2: Memory allocation failed.
- 3: Invalid tabular parameters.

For returns > 1, a detailed error message is set in **wcsprm::err** if enabled, see **wcserr\_enable()**.

### wcsidx()

```
int wcsidx (
    int nwcs,
    struct wcsprm ** wcs,
    int alts[27])
```

Index alternate coordinate representations.

**wcsidx()** returns an array of 27 indices for the alternate coordinate representations in the array of **wcsprm** structs returned by **wcspih()**. For the array returned by **wcsbth()** it returns indices for the unattached (colnum == 0) representations derived from image header keywords - use **wcsbidx()** for those derived from binary table image arrays or pixel lists keywords.

### Parameters

in	nwcs	Number of coordinate representations in the array.
in	wcs	Pointer to an array of <b>wcsprm</b> structs returned by <b>wcspih()</b> or <b>wcsbth()</b> .

out	<i>alts</i>	<p>Index of each alternate coordinate representation in the array: <code>alts[0]</code> for the primary, <code>alts[1]</code> for 'A', etc., set to -1 if not present.</p> <p>For example, if there was no 'P' representation then</p> <pre>alts['P'-'A'+1] == -1;</pre> <p>Otherwise, the address of its <code>wcsprm</code> struct would be</p> <pre>wcs + alts['P'-'A'+1];</pre>
-----	-------------	---

## Returns

Status return value:

- 0: Success.
- 1: Null `wcsprm` pointer passed.

## wcsbidx()

```
int wcsbidx (
    int nwcs,
    struct wcsprm ** wcs,
    int type,
    short alts[1000][28])
```

Index alternate coordinate representations.

**wcsbidx()** returns an array of 999 x 27 indices for the alternate coordinate representations for binary table image arrays xor pixel lists in the array of `wcsprm` structs returned by `wcsbth()`. Use `wcsidx()` for the unattached representations derived from image header keywords.

## Parameters

in	<i>nwcs</i>	Number of coordinate representations in the array.
in	<i>wcs</i>	Pointer to an array of <code>wcsprm</code> structs returned by <code>wcsbth()</code> .
in	<i>type</i>	<p>Select the type of coordinate representation:</p> <ul style="list-style-type: none"> <li>• 0: binary table image arrays,</li> <li>• 1: pixel lists.</li> </ul>
out	<i>alts</i>	<p>Index of each alternate coordinate representation in the array: <code>alts[col][0]</code> for the primary, <code>alts[col][1]</code> for 'A', to <code>alts[col][26]</code> for 'Z', where <code>col</code> is the 1-relative column number, and <code>col == 0</code> is used for unattached image headers. Set to -1 if not present.</p> <p><code>alts[col][27]</code> counts the number of coordinate representations of the chosen type for each column.</p> <p>For example, if there was no 'P' representation for column 13 then</p> <pre>alts[13]['P'-'A'+1] == -1;</pre> <p>Otherwise, the address of its <code>wcsprm</code> struct would be</p> <pre>wcs + alts[13]['P'-'A'+1];</pre>

## Returns

Status return value:

- 0: Success.
- 1: Null `wcsprm` pointer passed.

**wcsvfree()**

```
int wcsvfree (
    int * nwcs,
    struct wcsprm ** wcs)
```

Free the array of `wcsprm` structs.

**wcsvfree()** frees the memory allocated by `wcspih()` or `wcsbth()` for the array of `wcsprm` structs, first invoking `wcsfree()` on each of the array members.

**Parameters**

in, out	<code>nwcs</code>	Number of coordinate representations found; set to 0 on return.
in, out	<code>wcs</code>	Pointer to the array of <code>wcsprm</code> structs; set to 0x0 on return.

**Returns**

Status return value:

- 0: Success.
- 1: Null `wcsprm` pointer passed.

**wcshdo()**

```
int wcshdo (
    int ctrl,
    struct wcsprm * wcs,
    int * nkeyrec,
    char ** header)
```

Write out a `wcsprm` struct as a FITS header.

**wcshdo()** translates a `wcsprm` struct into a FITS header. If the `colnum` member of the struct is non-zero then a binary table image array header will be produced. Otherwise, if the `colax[]` member of the struct is set non-zero then a pixel list header will be produced. Otherwise, a primary image or image extension header will be produced.

If the struct was originally constructed from a header, e.g. by `wcspih()`, the output header will almost certainly differ in a number of respects:

- The output header only contains WCS-related keywords. In particular, it does not contain syntactically-required keywords such as **SIMPLE**, **NAXIS**, **BITPIX**, or **END**.
- Elements of the **PCi\_ja** matrix will be written if and only if they differ from the unit matrix. Thus, if the matrix is unity then no elements will be written.
- The redundant keywords **MJDREF**, **JDREF**, **JDREFI**, **JDREFF**, all of which duplicate **MJDREFI** + **MJDREFF**, are never written. **OBSGEO-[LBH]** are not written if **OBSGEO-[XYZ]** are defined.
- Deprecated (e.g. **CROTA<sub>n</sub>**, **RESTFREQ**, **VELREF**, **RADECSYS**, **EPOCH**, **VSOURCE<sub>a</sub>**) or non-standard usage will be translated to standard (this is partially dependent on whether `wcsfix()` was applied).
- Additional keywords such as **WCSAXES<sub>a</sub>**, **CUNIT<sub>ia</sub>**, **LONPOLE<sub>a</sub>** and **LATPOLE<sub>a</sub>** may appear.

---

• Quantities will be converted to the units used internally, basically SI with the addition of degrees.  
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- Floating-point quantities may be given to a different decimal precision.
- The original keycomments will be lost, although **wcshdo()** tries hard to write meaningful comments.

## Parameters

in	<i>ctrl</i>	<p>Vector of flag bits that controls the degree of permissiveness in departing from the published WCS standard, and also controls the formatting of floating-point keyvalues. Set it to zero to get the default behaviour.</p> <p>Flag bits for the degree of permissiveness:</p> <ul style="list-style-type: none"> <li>• <a href="#">WCSHDO_none</a>: Recognize only FITS keywords defined by the published WCS standard.</li> <li>• <a href="#">WCSHDO_all</a>: Admit all recognized informal extensions of the WCS standard.</li> </ul> <p>Fine-grained control of the degree of permissiveness is also possible as explained in the notes below.</p> <p>As for controlling floating-point formatting, by default <b>wcshdo()</b> uses "%20.12G" for non-parameterized keywords such as <b>LONPOLE<sub>a</sub></b>, and attempts to make the header more human-readable by using the same "f" format for all values of each of the following parameterized keywords: <b>CRPIX<sub>ja</sub></b>, <b>PC<sub>i_ja</sub></b>, and <b>CDELT<sub>ia</sub></b> (n.b. excluding <b>CRVAL<sub>ia</sub></b>). Each has the same field width and precision so that the decimal points line up. The precision, allowing for up to 15 significant digits, is chosen so that there are no excess trailing zeroes. A similar formatting scheme applies by default for distortion function parameters. However, where the values of, for example, <b>CDELT<sub>ia</sub></b> differ by many orders of magnitude, the default formatting scheme may cause unacceptable loss of precision for the lower-valued keyvalues. Thus the default behaviour may be overridden:</p> <ul style="list-style-type: none"> <li>• <a href="#">WCSHDO_P12</a>: Use "%20.12G" format for all floating- point keyvalues (12 significant digits).</li> <li>• <a href="#">WCSHDO_P13</a>: Use "%21.13G" format for all floating- point keyvalues (13 significant digits).</li> <li>• <a href="#">WCSHDO_P14</a>: Use "%22.14G" format for all floating- point keyvalues (14 significant digits).</li> <li>• <a href="#">WCSHDO_P15</a>: Use "%23.15G" format for all floating- point keyvalues (15 significant digits).</li> <li>• <a href="#">WCSHDO_P16</a>: Use "%24.16G" format for all floating- point keyvalues (16 significant digits).</li> <li>• <a href="#">WCSHDO_P17</a>: Use "%25.17G" format for all floating- point keyvalues (17 significant digits).</li> </ul> <p>If more than one of the above flags are set, the highest number of significant digits prevails. In addition, there is an ancillary flag:</p> <ul style="list-style-type: none"> <li>• <a href="#">WCSHDO_EFMT</a>: Use "E" format instead of the default "G" format above.</li> </ul> <p>Note that excess trailing zeroes are stripped off the fractional part with "G" (which never occurs with "E"). Note also that the higher-precision options eat into the keycomment area. In this regard, <a href="#">WCSHDO_P14</a> causes minimal disruption with "G" format, while <a href="#">WCSHDO_P13</a> is appropriate with "E".</p>
in, out	<i>wcs</i>	Pointer to a <a href="#">wcsprm</a> struct containing coordinate transformation parameters. Will be initialized if necessary.
out	<i>nkeyrec</i>	Number of FITS header keyrecords returned in the "header" array.
out	<i>header</i>	<p>Pointer to an array of char holding the header. Storage for the array is allocated by <b>wcshdo()</b> in blocks of 2880 bytes (32 x 80-character keyrecords) and must be freed by the user to avoid memory leaks. See <a href="#">wcsdealloc()</a>.</p> <p>Each keyrecord is 80 characters long and is <i>*NOT*</i> null-terminated, so the first keyrecord starts at (*header)[0], the second at (*header)[80], etc.</p>

## Returns

Status return value (associated with `wcs_errmsg[]`):

- 0: Success.
- 1: Null `wcsprm` pointer passed.
- 2: Memory allocation failed.
- 3: Linear transformation matrix is singular.
- 4: Inconsistent or unrecognized coordinate axis types.
- 5: Invalid parameter value.
- 6: Invalid coordinate transformation parameters.
- 7: Ill-conditioned coordinate transformation parameters.

For returns  $> 1$ , a detailed error message is set in `wcsprm::err` if enabled, see `wcserr_enable()`.

## Notes:

1. `wcshdo()` interprets the *relax* argument as a vector of flag bits to provide fine-grained control over what non-standard WCS keywords to write. The flag bits are subject to change in future and should be set by using the preprocessor macros (see below) for the purpose.

- `WCSHDO_none`: Don't use any extensions.
- `WCSHDO_all`: Write all recognized extensions, equivalent to setting each flag bit.
- `WCSHDO_safe`: Write all extensions that are considered to be safe and recommended.
- `WCSHDO_DOBSn`: Write **DOBS<sub>n</sub>**, the column-specific analogue of **DATE-OBS** for use in binary tables and pixel lists. WCS Paper III introduced **DATE-AVG** and **DAVG<sub>n</sub>** but by an oversight **DOBS<sub>n</sub>** (the obvious analogy) was never formally defined by the standard. The alternative to using **DOBS<sub>n</sub>** is to write **DATE-OBS** which applies to the whole table. This usage is considered to be safe and is recommended.
- `WCSHDO_TPCn_ka`: WCS Paper I defined

- **TP<sub>n</sub>\_ka** and **TC<sub>n</sub>\_ka** for pixel lists

but WCS Paper II uses **TPC<sub>n</sub>\_ka** in one example and subsequently the errata for the WCS papers legitimized the use of

- **TPC<sub>n</sub>\_ka** and **TCD<sub>n</sub>\_ka** for pixel lists

provided that the keyword does not exceed eight characters. This usage is considered to be safe and is recommended because of the non-mnemonic terseness of the shorter forms.

- `WCSHDO_PVn_ma`: WCS Paper I defined

- **iV<sub>n</sub>\_ma** and **iS<sub>n</sub>\_ma** for bintables and
- **TV<sub>n</sub>\_ma** and **TS<sub>n</sub>\_ma** for pixel lists

but WCS Paper II uses **iPV<sub>n</sub>\_ma** and **TPV<sub>n</sub>\_ma** in the examples and subsequently the errata for the WCS papers legitimized the use of

- **iPV<sub>n</sub>\_ma** and **iPS<sub>n</sub>\_ma** for bintables and
- **TPV<sub>n</sub>\_ma** and **TPS<sub>n</sub>\_ma** for pixel lists

provided that the keyword does not exceed eight characters. This usage is considered to be safe and is recommended because of the non-mnemonic terseness of the shorter forms.

- `WCSHDO_CRPXna`: For historical reasons WCS Paper I defined

- **jCRPX<sub>n</sub>**, **iCDLT<sub>n</sub>**, **iCUNI<sub>n</sub>**, **iCTYP<sub>n</sub>**, and **iCRVL<sub>n</sub>** for bintables and
- **TCRPX<sub>n</sub>**, **TCDLT<sub>n</sub>**, **TCUNI<sub>n</sub>**, **TCTYP<sub>n</sub>**, and **TCRVL<sub>n</sub>** for pixel lists

for use without an alternate version specifier. However, because of the eight-character keyword constraint, in order to accommodate column numbers greater than 99 WCS Paper I also defined

- **jCRP**<sub>na</sub>, **iCDE**<sub>na</sub>, **iCUN**<sub>na</sub>, **iCTY**<sub>na</sub> and **iCRV**<sub>na</sub> for bintables and
- **TCRP**<sub>na</sub>, **TCDE**<sub>na</sub>, **TCUN**<sub>na</sub>, **TCTY**<sub>na</sub> and **TCRV**<sub>na</sub> for pixel lists

for use with an alternate version specifier (the "a"). Like the PC, CD, PV, and PS keywords there is an obvious tendency to confuse these two forms for column numbers up to 99. It is very unlikely that any parser would reject keywords in the first set with a non-blank alternate version specifier so this usage is considered to be safe and is recommended.

- **WCSHDO\_CNAM**<sub>na</sub>: WCS Papers I and III defined
  - **iCNA**<sub>na</sub>, **iCRD**<sub>na</sub>, and **iCSY**<sub>na</sub> for bintables and
  - **TCNA**<sub>na</sub>, **TCRD**<sub>na</sub>, and **TCSY**<sub>na</sub> for pixel lists

By analogy with the above, the long forms would be

- **iCNAM**<sub>na</sub>, **iCRDE**<sub>na</sub>, and **iCSYE**<sub>na</sub> for bintables and
- **TCNAM**<sub>na</sub>, **TCRDE**<sub>na</sub>, and **TCSYE**<sub>na</sub> for pixel lists

Note that these keywords provide auxiliary information only, none of them are needed to compute world coordinates. This usage is potentially unsafe and is not recommended at this time.

- **WCSHDO\_WCSN**<sub>na</sub>: In light of **wcsbth()** note 4, write **WCSN**<sub>na</sub> instead of **TWCS**<sub>na</sub> for pixel lists. While **wcsbth()** treats **WCSN**<sub>na</sub> and **TWCS**<sub>na</sub> as equivalent, other parsers may not. Consequently, this usage is potentially unsafe and is not recommended at this time.

## 8.29.5 Variable Documentation

### wcshdr\_errmsg

```
const char* wcshdr_errmsg[] [extern]
```

Status return messages.

Error messages to match the status value returned from each function. Use **wcs\_errmsg[]** for status returns from **wcsldo()**.

## 8.30 wcshdr.h

[Go to the documentation of this file.](#)

```
00001 /*=====
00002  WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003  Copyright (C) 1995-2025, Mark Calabretta
00004
00005  This file is part of WCSLIB.
00006
00007  WCSLIB is free software: you can redistribute it and/or modify it under the
00008  terms of the GNU Lesser General Public License as published by the Free
00009  Software Foundation, either version 3 of the License, or (at your option)
00010  any later version.
00011
00012  WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013  WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
00014  FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015  more details.
00016
00017  You should have received a copy of the GNU Lesser General Public License
00018  along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020  Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021  http://www.atnf.csiro.au/people/Mark.Calabretta
00022  $Id: wcshdr.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023 *=====
00024 *
00025 * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026 * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027 * overview of the library.
```

```

00028 *
00029 *
00030 * Summary of the wcsshr routines
00031 * -----
00032 * Routines in this suite are aimed at extracting WCS information from a FITS
00033 * file. The information is encoded via keywords defined in
00034 *
00035 * "Representations of world coordinates in FITS",
00036 * Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)
00037 *
00038 * "Representations of celestial coordinates in FITS",
00039 * Calabretta, M.R., & Greisen, E.W. 2002, A&A, 395, 1077 (WCS Paper II)
00040 *
00041 * "Representations of spectral coordinates in FITS",
00042 * Greisen, E.W., Calabretta, M.R., Valdes, F.G., & Allen, S.L.
00043 * 2006, A&A, 446, 747 (WCS Paper III)
00044 *
00045 * "Representations of distortions in FITS world coordinate systems",
00046 * Calabretta, M.R. et al. (WCS Paper IV, draft dated 2004/04/22),
00047 * available from http://www.atnf.csiro.au/people/Mark.Calabretta
00048 *
00049 * "Representations of time coordinates in FITS -
00050 * Time and relative dimension in space",
00051 * Rots, A.H., Bunclark, P.S., Calabretta, M.R., Allen, S.L.,
00052 * Manchester, R.N., & Thompson, W.T. 2015, A&A, 574, A36 (WCS Paper VII)
00053 *
00054 * These routines provide the high-level interface between the FITS file and
00055 * the WCS coordinate transformation routines.
00056 *
00057 * Additionally, function wcsshr() is provided to write out the contents of a
00058 * wcsprm struct as a FITS header.
00059 *
00060 * Briefly, the anticipated sequence of operations is as follows:
00061 *
00062 * - 1: Open the FITS file and read the image or binary table header, e.g.
00063 * using CFITSIO routine fits_hdr2str().
00064 *
00065 * - 2: Parse the header using wcsprh() or wcsbth(); they will automatically
00066 * interpret 'TAB' header keywords using wcstab().
00067 *
00068 * - 3: Allocate memory for, and read 'TAB' arrays from the binary table
00069 * extension, e.g. using CFITSIO routine fits_read_wcstab() - refer to
00070 * the prologue of getwcstab.h. wcsset() will automatically take
00071 * control of this allocated memory, in particular causing it to be
00072 * freed by wcsfree().
00073 *
00074 * - 4: Translate non-standard WCS usage using wcsfix(), see wcsfix.h.
00075 *
00076 * - 5: Initialize wcsprm struct(s) using wcsset() and calculate coordinates
00077 * using wcssp2s() and/or wcss2p(). Refer to the prologue of wcs.h for a
00078 * description of these and other high-level WCS coordinate
00079 * transformation routines.
00080 *
00081 * - 6: Clean up by freeing memory with wcsvfree().
00082 *
00083 * In detail:
00084 *
00085 * - wcsprh() is a high-level FITS WCS routine that parses an image header. It
00086 * returns an array of up to 27 wcsprm structs on each of which it invokes
00087 * wcstab().
00088 *
00089 * - wcsbth() is the analogue of wcsprh() for use with binary tables; it
00090 * handles image array and pixel list keywords. As an extension of the FITS
00091 * WCS standard, it also recognizes image header keywords which may be used
00092 * to provide default values via an inheritance mechanism.
00093 *
00094 * - wcstab() assists in filling in members of the wcsprm struct associated
00095 * with coordinate lookup tables ('TAB'). These are based on arrays stored
00096 * in a FITS binary table extension (BINTABLE) that are located by PVi_ma
00097 * keywords in the image header.
00098 *
00099 * - wcsidx() and wcsbdx() are utility routines that return the index for a
00100 * specified alternate coordinate descriptor in the array of wcsprm structs
00101 * returned by wcsprh() or wcsbth().
00102 *
00103 * - wcsvfree() deallocates memory for an array of wcsprm structs, such as
00104 * returned by wcsprh() or wcsbth().
00105 *
00106 * - wcsshr() writes out a wcsprm struct as a FITS header.
00107 *
00108 *
00109 * wcsprh() - FITS WCS parser routine for image headers
00110 * -----
00111 * wcsprh() is a high-level FITS WCS routine that parses an image header,
00112 * either that of a primary HDU or of an image extension. All WCS keywords
00113 * defined in Papers I, II, III, IV, and VII are recognized, and also those
00114 * used by the AIPS convention and certain other keywords that existed in early

```

```

00115 * drafts of the WCS papers as explained in wcsbth() note 5. wcspih() also
00116 * handles keywords associated with non-standard distortion functions described
00117 * in the prologue of dis.h.
00118 *
00119 * Given a character array containing a FITS image header, wcspih() identifies
00120 * and reads all WCS keywords for the primary coordinate representation and up
00121 * to 26 alternate representations. It returns this information as an array of
00122 * wcsprm structs.
00123 *
00124 * wcspih() invokes wcstab() on each of the wcsprm structs that it returns.
00125 *
00126 * Use wcsbth() in preference to wcspih() for FITS headers of unknown type;
00127 * wcsbth() can parse image headers as well as binary table and pixel list
00128 * headers, although it cannot handle keywords relating to distortion
00129 * functions, which may only exist in an image header (primary or extension).
00130 *
00131 * Given and returned:
00132 *   header   char[]   Character array containing the (entire) FITS image
00133 *                   header from which to identify and construct the
00134 *                   coordinate representations, for example, as might be
00135 *                   obtained conveniently via the CFITSIO routine
00136 *                   fits_hdr2str().
00137 *
00138 *                   Each header "keyrecord" (formerly "card image")
00139 *                   consists of exactly 80 7-bit ASCII printing characters
00140 *                   in the range 0x20 to 0x7e (which excludes NUL, BS,
00141 *                   TAB, LF, FF and CR) especially noting that the
00142 *                   keyrecords are NOT null-terminated.
00143 *
00144 *                   For negative values of ctrl (see below), header[] is
00145 *                   modified so that WCS keyrecords processed by wcspih()
00146 *                   are removed from it.
00147 *
00148 * Given:
00149 *   nkeyrec   int      Number of keyrecords in header[].
00150 *
00151 *   relax     int      Degree of permissiveness:
00152 *                       0: Recognize only FITS keywords defined by the
00153 *                           published WCS standard.
00154 *                       WCSHDR_all: Admit all recognized informal
00155 *                           extensions of the WCS standard.
00156 *                       Fine-grained control of the degree of permissiveness
00157 *                       is also possible as explained in wcsbth() note 5.
00158 *
00159 *   ctrl      int      Error reporting and other control options for invalid
00160 *                       WCS and other header keyrecords:
00161 *                       0: Do not report any rejected header keyrecords.
00162 *                       1: Produce a one-line message stating the number
00163 *                           of WCS keyrecords rejected (nreject).
00164 *                       2: Report each rejected keyrecord and the reason
00165 *                           why it was rejected.
00166 *                       3: As above, but also report all non-WCS
00167 *                           keyrecords that were discarded, and the number
00168 *                           of coordinate representations (nwcs) found.
00169 *                       4: As above, but also report the accepted WCS
00170 *                           keyrecords, with a summary of the number
00171 *                           accepted as well as rejected.
00172 *                       The report is written to stderr by default, or the
00173 *                       stream set by wcsprintf_set().
00174 *
00175 *                       For ctrl < 0, WCS keyrecords processed by wcspih()
00176 *                       are removed from header[]:
00177 *                       -1: Remove only valid WCS keyrecords whose values
00178 *                           were successfully extracted, nothing is
00179 *                           reported.
00180 *                       -2: As above, but also remove WCS keyrecords that
00181 *                           were rejected, reporting each one and the
00182 *                           reason that it was rejected.
00183 *                       -3: As above, and also report the number of
00184 *                           coordinate representations (nwcs) found.
00185 *                       -11: Same as -1 but preserving global WCS-related
00186 *                            keywords such as '{DATE,MJD}-{OBS,BEG,AVG,END}',
00187 *                            and the other basic time-related keywords, and
00188 *                            'OBSGEO-{X,Y,Z,L,B,H}'.
00189 *                       If any keyrecords are removed from header[] it will
00190 *                       be null-terminated (NUL not being a legal FITS header
00191 *                       character), otherwise it will contain its original
00192 *                       complement of nkeyrec keyrecords and possibly not be
00193 *                       null-terminated.
00194 *
00195 * Returned:
00196 *   nreject   int*      Number of WCS keywords rejected for syntax errors,
00197 *                       illegal values, etc. Keywords not recognized as WCS
00198 *                       keywords are simply ignored. Refer also to wcsbth()
00199 *                       note 5.
00200 *
00201 *   nwcs      int*      Number of coordinate representations found.

```

```

00202 *
00203 *   wcs          struct wcsprm**
00204 *               Pointer to an array of wcsprm structs containing up to
00205 *               27 coordinate representations.
00206 *
00207 *               Memory for the array is allocated by wcsprh() which
00208 *               also invokes wcsini() for each struct to allocate
00209 *               memory for internal arrays and initialize their
00210 *               members to default values. Refer also to wcsbth()
00211 *               note 8. Note that wcsset() is not invoked on these
00212 *               structs.
00213 *
00214 *               This allocated memory must be freed by the user, first
00215 *               by invoking wcsfree() for each struct, and then by
00216 *               freeing the array itself. A routine, wcsvfree(), is
00217 *               provided to do this (see below).
00218 *
00219 * Function return value:
00220 *   int          Status return value:
00221 *               0: Success.
00222 *               1: Null wcsprm pointer passed.
00223 *               2: Memory allocation failed.
00224 *               4: Fatal error returned by Flex parser.
00225 *
00226 * Notes:
00227 *   1: Refer to wcsbth() notes 1, 2, 3, 5, 7, and 8.
00228 *
00229 *
00230 * wcsbth() - FITS WCS parser routine for binary table and image headers
00231 * -----
00232 * wcsbth() is a high-level FITS WCS routine that parses a binary table header.
00233 * It handles image array and pixel list WCS keywords which may be present
00234 * together in one header.
00235 *
00236 * As an extension of the FITS WCS standard, wcsbth() also recognizes image
00237 * header keywords in a binary table header. These may be used to provide
00238 * default values via an inheritance mechanism discussed in note 5 (c.f.
00239 * WCSHDR_AUXIMG and WCSHDR_ALLIMG), or may instead result in wcsprm structs
00240 * that are not associated with any particular column. Thus wcsbth() can
00241 * handle primary image and image extension headers in addition to binary table
00242 * headers (it ignores NAXIS and does not rely on the presence of the TFIELDS
00243 * keyword).
00244 *
00245 * All WCS keywords defined in Papers I, II, III, and VII are recognized, and
00246 * also those used by the AIPS convention and certain other keywords that
00247 * existed in early drafts of the WCS papers as explained in note 5 below.
00248 *
00249 * wcsbth() sets the colnum or colax[] members of the wcsprm structs that it
00250 * returns with the column number of an image array or the column numbers
00251 * associated with each pixel coordinate element in a pixel list. wcsprm
00252 * structs that are not associated with any particular column, as may be
00253 * derived from image header keywords, have colnum == 0.
00254 *
00255 * Note 6 below discusses the number of wcsprm structs returned by wcsbth(),
00256 * and the circumstances in which image header keywords cause a struct to be
00257 * created. See also note 9 concerning the number of separate images that may
00258 * be stored in a pixel list.
00259 *
00260 * The API to wcsbth() is similar to that of wcsprh() except for the addition
00261 * of extra arguments that may be used to restrict its operation. Like
00262 * wcsprh(), wcsbth() invokes wcstab() on each of the wcsprm structs that it
00263 * returns.
00264 *
00265 * Given and returned:
00266 *   header  char[]  Character array containing the (entire) FITS binary
00267 *                   table, primary image, or image extension header from
00268 *                   which to identify and construct the coordinate
00269 *                   representations, for example, as might be obtained
00270 *                   conveniently via the CFITSIO routine fits_hdr2str().
00271 *
00272 *                   Each header "keyrecord" (formerly "card image")
00273 *                   consists of exactly 80 7-bit ASCII printing
00274 *                   characters in the range 0x20 to 0x7e (which excludes
00275 *                   NUL, BS, TAB, LF, FF and CR) especially noting that
00276 *                   the keyrecords are NOT null-terminated.
00277 *
00278 *                   For negative values of ctrl (see below), header[] is
00279 *                   modified so that WCS keyrecords processed by wcsbth()
00280 *                   are removed from it.
00281 *
00282 * Given:
00283 *   nkeyrec  int     Number of keyrecords in header[].
00284 *
00285 *   relax    int     Degree of permissiveness:
00286 *                   0: Recognize only FITS keywords defined by the
00287 *                   published WCS standard.
00288 *                   WCSHDR_all: Admit all recognized informal

```

```

00289 *           extensions of the WCS standard.
00290 *           Fine-grained control of the degree of permissiveness
00291 *           is also possible, as explained in note 5 below.
00292 *
00293 *   ctrl      int      Error reporting and other control options for invalid
00294 *                       WCS and other header keyrecords:
00295 *                       0: Do not report any rejected header keyrecords.
00296 *                       1: Produce a one-line message stating the number
00297 *                           of WCS keyrecords rejected (nreject).
00298 *                       2: Report each rejected keyrecord and the reason
00299 *                           why it was rejected.
00300 *                       3: As above, but also report all non-WCS
00301 *                           keyrecords that were discarded, and the number
00302 *                           of coordinate representations (nwcs) found.
00303 *                       4: As above, but also report the accepted WCS
00304 *                           keyrecords, with a summary of the number
00305 *                           accepted as well as rejected.
00306 *           The report is written to stderr by default, or the
00307 *           stream set by wcsprintf_set().
00308 *
00309 *           For ctrl < 0, WCS keyrecords processed by wcsbth()
00310 *           are removed from header[]:
00311 *           -1: Remove only valid WCS keyrecords whose values
00312 *               were successfully extracted, nothing is
00313 *               reported.
00314 *           -2: Also remove WCS keyrecords that were rejected,
00315 *               reporting each one and the reason that it was
00316 *               rejected.
00317 *           -3: As above, and also report the number of
00318 *               coordinate representations (nwcs) found.
00319 *           -11: Same as -1 but preserving global WCS-related
00320 *               keywords such as '{DATE,MJD}-{OBS,BEG,AVG,END}',
00321 *               and the other basic time-related keywords, and
00322 *               'OBSGEO-{X,Y,Z,L,B,H}'.
00323 *           If any keyrecords are removed from header[] it will
00324 *           be null-terminated (NUL not being a legal FITS header
00325 *           character), otherwise it will contain its original
00326 *           complement of nkeyrec keyrecords and possibly not be
00327 *           null-terminated.
00328 *
00329 *   keyssel    int      Vector of flag bits that may be used to restrict the
00330 *                       keyword types considered:
00331 *                       WCSHDR_IMGHEAD: Image header keywords.
00332 *                       WCSHDR_BIMGARR: Binary table image array.
00333 *                       WCSHDR_PIXLIST: Pixel list keywords.
00334 *           If zero, there is no restriction.
00335 *
00336 *           Keywords such as EQUIna or RFRQna that are common to
00337 *           binary table image arrays and pixel lists (including
00338 *           WCSNna and TWCsna, as explained in note 4 below) are
00339 *           selected by both WCSHDR_BIMGARR and WCSHDR_PIXLIST.
00340 *           Thus if inheritance via WCSHDR_ALLIMG is enabled as
00341 *           discussed in note 5 and one of these shared keywords
00342 *           is present, then WCSHDR_IMGHEAD and WCSHDR_PIXLIST
00343 *           alone may be sufficient to cause the construction of
00344 *           coordinate descriptions for binary table image arrays.
00345 *
00346 *   colsel     int*     Pointer to an array of table column numbers used to
00347 *                       restrict the keywords considered by wcsbth().
00348 *
00349 *           A null pointer may be specified to indicate that there
00350 *           is no restriction. Otherwise, the magnitude of
00351 *           cols[0] specifies the length of the array:
00352 *           cols[0] > 0: the columns are included,
00353 *           cols[0] < 0: the columns are excluded.
00354 *
00355 *           For the pixel list keywords TPn_ka and TCn_ka (and
00356 *           TPCn_ka and TCDn_ka if WCSHDR_LONGKEY is enabled), it
00357 *           is an error for one column to be selected but not the
00358 *           other. This is unlike the situation with invalid
00359 *           keyrecords, which are simply rejected, because the
00360 *           error is not intrinsic to the header itself but
00361 *           arises in the way that it is processed.
00362 *
00363 * Returned:
00364 *   nreject     int*     Number of WCS keywords rejected for syntax errors,
00365 *                       illegal values, etc. Keywords not recognized as WCS
00366 *                       keywords are simply ignored, refer also to note 5
00367 *                       below.
00368 *
00369 *   nwcs        int*     Number of coordinate representations found.
00370 *
00371 *   wcs         struct wcsprm**
00372 *           Pointer to an array of wcsprm structs containing up
00373 *           to 27027 coordinate representations, refer to note 6
00374 *           below.
00375 *

```

```

00376 *      Memory for the array is allocated by wcsbth() which
00377 *      also invokes wcsini() for each struct to allocate
00378 *      memory for internal arrays and initialize their
00379 *      members to default values. Refer also to note 8
00380 *      below. Note that wcsset() is not invoked on these
00381 *      structs.
00382 *
00383 *      This allocated memory must be freed by the user, first
00384 *      by invoking wcsfree() for each struct, and then by
00385 *      freeing the array itself. A routine, wcsvfree(), is
00386 *      provided to do this (see below).
00387 *
00388 * Function return value:
00389 *      int      Status return value:
00390 *      0: Success.
00391 *      1: Null wcsprm pointer passed.
00392 *      2: Memory allocation failed.
00393 *      3: Invalid column selection.
00394 *      4: Fatal error returned by Flex parser.
00395 *
00396 * Notes:
00397 * 1: wcspih() determines the number of coordinate axes independently for
00398 *    each alternate coordinate representation (denoted by the "a" value in
00399 *    keywords like CTYPa) from the higher of
00400 *
00401 *      a: NAXIS,
00402 *      b: WCSAXESa,
00403 *      c: The highest axis number in any parameterized WCS keyword. The
00404 *      keyvalue, as well as the keyword, must be syntactically valid
00405 *      otherwise it will not be considered.
00406 *
00407 *    If none of these keyword types is present, i.e. if the header only
00408 *    contains auxiliary WCS keywords for a particular coordinate
00409 *    representation, then no coordinate description is constructed for it.
00410 *
00411 *    wcsbth() is similar except that it ignores the NAXIS keyword if given
00412 *    an image header to process.
00413 *
00414 *    The number of axes, which is returned as a member of the wcsprm
00415 *    struct, may differ for different coordinate representations of the
00416 *    same image.
00417 *
00418 * 2: wcspih() and wcsbth() enforce correct FITS "keyword = value" syntax
00419 *    with regard to "=" occurring in columns 9 and 10.
00420 *
00421 *    However, they do recognize free-format character (NOST 100-2.0,
00422 *    Sect. 5.2.1), integer (Sect. 5.2.3), and floating-point values
00423 *    (Sect. 5.2.4) for all keywords.
00424 *
00425 * 3: Where CROTAn, CDi_ja, and PCi_ja occur together in one header wcspih()
00426 *    and wcsbth() treat them as described in the prologue to wcs.h.
00427 *
00428 * 4: WCS Paper I mistakenly defined the pixel list form of WCSNAMEa as
00429 *    TWCSna instead of WCSNna; the 'T' is meant to substitute for the axis
00430 *    number in the binary table form of the keyword - note that keywords
00431 *    defined in WCS Papers II, III, and VII that are not parameterized by
00432 *    axis number have identical forms for binary tables and pixel lists.
00433 *    Consequently wcsbth() always treats WCSNna and TWCSna as equivalent.
00434 *
00435 * 5: wcspih() and wcsbth() interpret the "relax" argument as a vector of
00436 *    flag bits to provide fine-grained control over what non-standard WCS
00437 *    keywords to accept. The flag bits are subject to change in future and
00438 *    should be set by using the preprocessor macros (see below) for the
00439 *    purpose.
00440 *
00441 *    - WCSHDR_none: Don't accept any extensions (not even those in the
00442 *      errata). Treat non-conformant keywords in the same way as
00443 *      non-WCS keywords in the header, i.e. simply ignore them.
00444 *
00445 *    - WCSHDR_all: Accept all extensions recognized by the parser.
00446 *
00447 *    - WCSHDR_reject: Reject non-standard keyrecords (that are not otherwise
00448 *      explicitly accepted by one of the flags below). A message will
00449 *      optionally be printed on stderr by default, or the stream set
00450 *      by wcsprintf_set(), as determined by the ctrl argument, and
00451 *      nreject will be incremented.
00452 *
00453 *    This flag may be used to signal the presence of non-standard
00454 *    keywords, otherwise they are simply passed over as though they
00455 *    did not exist in the header. It is mainly intended for testing
00456 *    conformance of a FITS header to the WCS standard.
00457 *
00458 *    Keyrecords may be non-standard in several ways:
00459 *
00460 *    - The keyword may be syntactically valid but with keyvalue of
00461 *      incorrect type or invalid syntax, or the keycomment may be
00462 *      malformed.

```

```

00463 *
00464 *      - The keyword may strongly resemble a WCS keyword but not, in
00465 *      fact, be one because it does not conform to the standard.
00466 *      For example, "CRPIX01" looks like a CRPIXja keyword, but in
00467 *      fact the leading zero on the axis number violates the basic
00468 *      FITS standard. Likewise, "LONPOLE2" is not a valid
00469 *      LONPOLEa keyword in the WCS standard, and indeed there is
00470 *      nothing the parser can sensibly do with it.
00471 *
00472 *      - Use of the keyword may be deprecated by the standard. Such
00473 *      will be rejected if not explicitly accepted via one of the
00474 *      flags below.
00475 *
00476 *      - WSHDR_strict: As for WSHDR_reject, but also reject AIPS-convention
00477 *      keywords and all other deprecated usage that is not explicitly
00478 *      accepted.
00479 *
00480 *      - WSHDR_CROTAia: Accept CROTAia (wvspih()),
00481 *      iCROTna (wvsbth()),
00482 *      TCROTna (wvsbth()).
00483 *
00484 *      - WSHDR_VELREFa: Accept VELREFa.
00485 *      wvspih() always recognizes the AIPS-convention keywords,
00486 *      CROTAn, EPOCH, and VELREF for the primary representation
00487 *      (a = ' ') but alternates are non-standard.
00488 *
00489 *      wvsbth() accepts EPOCHa and VELREFa only if WSHDR_AUXIMG is
00490 *      also enabled.
00491 *
00492 *      - WSHDR_CD00i00j: Accept CD00i00j (wvspih()).
00493 *      - WSHDR_PC00i00j: Accept PC00i00j (wvspih()).
00494 *      - WSHDR_PROJPn: Accept PROJPN (wvspih()).
00495 *      These appeared in early drafts of WCS Paper I+II (before they
00496 *      were split) and are equivalent to CDi_ja, PCi_ja, and PVi_ma
00497 *      for the primary representation (a = ' '). PROJPN is
00498 *      equivalent to PVi_ma with m = n <= 9, and is associated
00499 *      exclusively with the latitude axis.
00500 *
00501 *      - WSHDR_CD0i_0ja: Accept CD0i_0ja (wvspih()).
00502 *      - WSHDR_PC0i_0ja: Accept PC0i_0ja (wvspih()).
00503 *      - WSHDR_PV0i_0ma: Accept PV0i_0ja (wvspih()).
00504 *      - WSHDR_PS0i_0ma: Accept PS0i_0ja (wvspih()).
00505 *      Allow the numerical index to have a leading zero in doubly-
00506 *      parameterized keywords, for example, PC01_01. WCS Paper I
00507 *      (Sects 2.1.2 & 2.1.4) explicitly disallows leading zeroes.
00508 *      The FITS 3.0 standard document (Sect. 4.1.2.1) states that the
00509 *      index in singly-parameterized keywords (e.g. CTYPEia) "shall
00510 *      not have leading zeroes", and later in Sect. 8.1 that "leading
00511 *      zeroes must not be used" on PVi_ma and PSi_ma. However, by an
00512 *      oversight, it is silent on PCi_ja and CDi_ja.
00513 *
00514 *      - WSHDR_DOBSn (wvsbth() only): Allow DOBSn, the column-specific
00515 *      analogue of DATE-OBS. By an oversight this was never formally
00516 *      defined in the standard.
00517 *
00518 *      - WSHDR_OBSGLBhn (wvsbth() only): Allow OBSGLn, OBSGBn, and OBSGHn,
00519 *      the column-specific analogues of OBSGEO-L, OBSGEO-B, and
00520 *      OBSGEO-H. By an oversight these were never formally defined in
00521 *      the standard.
00522 *
00523 *      - WSHDR_RADECSYS: Accept RADECSYS. This appeared in early drafts of
00524 *      WCS Paper I+II and was subsequently replaced by RADESYSa.
00525 *
00526 *      wvsbth() accepts RADECSYS only if WSHDR_AUXIMG is also
00527 *      enabled.
00528 *
00529 *      - WSHDR_EPOCHa: Accept EPOCHa.
00530 *
00531 *      - WSHDR_VSOURCE: Accept VSOURCEa or VSOUNa (wvsbth()). This appeared
00532 *      in early drafts of WCS Paper III and was subsequently dropped
00533 *      in favour of ZSOURCEa and ZSOUNa.
00534 *
00535 *      wvsbth() accepts VSOURCEa only if WSHDR_AUXIMG is also
00536 *      enabled.
00537 *
00538 *      - WSHDR_DATEREf: Accept DATE-REF, MJD-REF, MJD-REFI, MJD-REFF, JDREF,
00539 *      JD-REFI, and JD-REFF as synonyms for the standard keywords,
00540 *      DATEREf, MJDREFI, MJDREFF, JDREF, JDREFI, and JDREFF.
00541 *      The latter buck the pattern set by the other date keywords
00542 *      ({DATE,MJD}-{OBS,BEG,AVG,END}), thereby increasing the
00543 *      potential for confusion and error.
00544 *
00545 *      - WSHDR_LONGKEY (wvsbth() only): Accept long forms of the alternate
00546 *      binary table and pixel list WCS keywords, i.e. with "a" non-
00547 *      blank. Specifically
00548 *
00549 *      jCRPXna TCRPXna : jCRPXn jCRPna TCRPXn TCRPna CRPIXja
00550 *      - TPCn_ka : - ijPCna - TPN_ka PCi_ja

```

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00550 #          -      TCDn_ka : -      ijCDna      -      TCn_ka  CDi_ja
00551 #          iCDLTna TCDLTna : iCDLTn  iCDEna  TCDLTn  TCDEna  CDELTia
00552 #          iCUNIna TCUNIna : iCUNIn  iCUNna  TCUNIn  TCUNna  CUNITia
00553 #          iCTYPna TCTYPna : iCTYPn  iCTYna  TCTYPn  TCTYna  CTYPEia
00554 #          iCRVLna TCRVLna : iCRVLn  iCRVna  TCRVLn  TCRVna  CRVALia
00555 #          iPVn_ma  TPVn_ma : -      iVn_ma      -      TVn_ma  PVi_ma
00556 #          iPSn_ma  TPSn_ma : -      iSn_ma      -      TSn_ma  PSi_ma
00557 *
00558 *      where the primary and standard alternate forms together with
00559 *      the image-header equivalent are shown rightwards of the colon.
00560 *
00561 *      The long form of these keywords could be described as quasi-
00562 *      standard. TPCn_ka, iPVn_ma, and TPVn_ma appeared by mistake
00563 *      in the examples in WCS Paper II and subsequently these and
00564 *      also TCDn_ka, iPSn_ma and TPSn_ma were legitimized by the
00565 *      errata to the WCS papers.
00566 *
00567 *      Strictly speaking, the other long forms are non-standard and
00568 *      in fact have never appeared in any draft of the WCS papers nor
00569 *      in the errata. However, as natural extensions of the primary
00570 *      form they are unlikely to be written with any other intention.
00571 *      Thus it should be safe to accept them provided, of course,
00572 *      that the resulting keyword does not exceed the 8-character
00573 *      limit.
00574 *
00575 *      If WCSHDR_CNAMn is enabled then also accept
00576 *
00577 #          iCNAMna  TCNAMna : ---  iCNAna      ---  TCNAna  CNAMEia
00578 #          iCRDEna  TCRDEna : ---  iCRDna      ---  TCRDna  CRDERia
00579 #          iCSYEna  TCSYEna : ---  iCSYna      ---  TCSYna  CSYERia
00580 #          iCZPHna  TCZPHna : ---  iCZPna      ---  TCZPna  CZPHSia
00581 #          iCPERna  TCPERna : ---  iCPRna      ---  TCPRna  CPERIia
00582 *
00583 *      Note that CNAMEia, CRDERia, CSYERia, CZPHSia, CPERIia, and
00584 *      their variants are not used by WCSLIB but are stored in the
00585 *      wcsprm struct as auxiliary information.
00586 *
00587 *      - WCSHDR_CNAMn (wcsbth() only): Accept iCNAMn, iCRDEn, iCSYEn, iCZPHn,
00588 *      iCPERn, TCNAMn, TCRDEn, TCSYEn, TCZPHn, and TCPERn, i.e. with
00589 *      "a" blank. While non-standard, these are the obvious analogues
00590 *      of iCTYPn, TCTYPn, etc.
00591 *
00592 *      - WCSHDR_AUXIMG (wcsbth() only): Allow the image-header form of an
00593 *      auxiliary WCS keyword with representation-wide scope to
00594 *      provide a default value for all images. This default may be
00595 *      overridden by the column-specific form of the keyword.
00596 *
00597 *      For example, a keyword like EQUINOXa would apply to all image
00598 *      arrays in a binary table, or all pixel list columns with
00599 *      alternate representation "a" unless overridden by EQUIIna.
00600 *
00601 *      Specifically the keywords are:
00602 *
00603 #          LONPOLEa  for LONPna
00604 #          LATPOLEa  for LATPna
00605 #          VELREF    -          ... (No column-specific form.)
00606 #          VELREFa   -          ... Only if WCSHDR_VELREFa is set.
00607 *
00608 *      whose keyvalues are actually used by WCSLIB, and also keywords
00609 *      providing auxiliary information that is simply stored in the
00610 *      wcsprm struct:
00611 *
00612 #          WCSNAMEa  for WCSNna  ... Or TWCSna (see below).
00613 #
00614 #          DATE-OBS  for DOBSn
00615 #          MJD-OBS   for MJDOBn
00616 #
00617 #          RADESYSa  for RADEna
00618 #          RADECSYS  for RADEna  ... Only if WCSHDR_RADECSYS is set.
00619 #          EPOCH     -          ... (No column-specific form.)
00620 #          EPOCHa    -          ... Only if WCSHDR_EPOCHa is set.
00621 #          EQUINOXa  for EQUIIna
00622 *
00623 *      where the image-header keywords on the left provide default
00624 *      values for the column specific keywords on the right.
00625 *
00626 *      Note that, according to Sect. 8.1 of WCS Paper III, and
00627 *      Sect. 5.2 of WCS Paper VII, the following are always inherited:
00628 *
00629 #          RESTFREQ  for RFRQna
00630 #          RESTFRQa  for RFRQna
00631 #          RESTWAVa  for RWAQna
00632 *
00633 *      being those actually used by WCSLIB, together with the
00634 *      following auxiliary keywords, many of which do not have binary
00635 *      table equivalents and therefore can only be inherited:
00636 *

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00637 #          TIMESYS          -
00638 #          TREFPOS    for TRPOSn
00639 #          TREFDIR    for TRDIRn
00640 #          PLEPHEM     -
00641 #          TIMEUNIT     -
00642 #          DATEREF      -
00643 #          MJDREF       -
00644 #          MJDREFI      -
00645 #          MJDREFF      -
00646 #          JDREF        -
00647 #          JDREFI       -
00648 #          JDREFF       -
00649 #          TIMEOFFS     -
00650 #
00651 #          DATE-BEG      -
00652 #          DATE-AVG    for DAVGn
00653 #          DATE-END     -
00654 #          MJD-BEG      -
00655 #          MJD-AVG    for MJDA n
00656 #          MJD-END      -
00657 #          JEPOCH       -
00658 #          BEPOCH       -
00659 #          TSTART       -
00660 #          TSTOP        -
00661 #          XPOSURE       -
00662 #          TELAPSE      -
00663 #
00664 #          TIMSYER      -
00665 #          TIMRDER      -
00666 #          TIMEDEL      -
00667 #          TIMEPIXR     -
00668 #
00669 #          OBSGEO-X    for OBSGXn
00670 #          OBSGEO-Y    for OBSGYn
00671 #          OBSGEO-Z    for OBSGZn
00672 #          OBSGEO-L    for OBSGLn
00673 #          OBSGEO-B    for OBSGBn
00674 #          OBSGEO-H    for OBSGHn
00675 #          OBSORBIT     -
00676 #
00677 #          SPECSYSa    for SPECna
00678 #          SSYSOBSa    for SOBSna
00679 #          VELOSYSa    for VSYSn
00680 #          VSOURCEa    for VSOUNa ... Only if WCSHDR_VSOURCE is set.
00681 #          ZSOURCEa    for ZSOUNa
00682 #          SSYSSRCa    for SSRcna
00683 #          VELANGLa    for VANGna
00684 *
00685 *      Global image-header keywords, such as MJD-OBS, apply to all
00686 *      alternate representations, and would therefore provide a
00687 *      default value for all images in the header.
00688 *
00689 *      This auxiliary inheritance mechanism applies to binary table
00690 *      image arrays and pixel lists alike. Most of these keywords
00691 *      have no default value, the exceptions being LONPOLEa and
00692 *      LATPOLEa, and also RADESYSa and EQUINOXa which provide
00693 *      defaults for each other. Thus one potential difficulty in
00694 *      using WCSHDR_AUXIMG is that of erroneously inheriting one of
00695 *      these four keywords.
00696 *
00697 *      Also, beware of potential inconsistencies that may arise where,
00698 *      for example, DATE-OBS is inherited, but MJD-OBS is overridden
00699 *      by MJDOBN and specifies a different time. Pairs in this
00700 *      category are:
00701 *
00702 *          DATE-OBS/DOBSn      versus      MJD-OBS/MJDOBN
00703 *          DATE-AVG/DAVGn      versus      MJD-AVG/MJDA n
00704 *          RESTFRQa/FRFQna      versus      RESTWAVa/RWAVna
00705 *          OBSGEO-[XYZ]/OBSG[XYZ]n versus OBSGEO-[LBH]/OBSG[LBH]n
00706 *
00707 *      The wcsfixi() routines datfix() and obsfix() are provided to
00708 *      check the consistency of these and other such pairs of
00709 *      keywords.
00710 *
00711 *      Unlike WCSHDR_ALLIMG, the existence of one (or all) of these
00712 *      auxiliary WCS image header keywords will not by itself cause a
00713 *      wcsprm struct to be created for alternate representation "a".
00714 *      This is because they do not provide sufficient information to
00715 *      create a non-trivial coordinate representation when used in
00716 *      conjunction with the default values of those keywords that are
00717 *      parameterized by axis number, such as CTYPEia.
00718 *
00719 *      - WCSHDR_ALLIMG (wcsbth() only): Allow the image-header form of *all*
00720 *      image header WCS keywords to provide a default value for all
00721 *      image arrays in a binary table (n.b. not pixel list). This
00722 *      default may be overridden by the column-specific form of the
00723 *      keyword.

```

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00724 *
00725 *      For example, a keyword like CRPIXja would apply to all image
00726 *      arrays in a binary table with alternate representation "a"
00727 *      unless overridden by jCRPna.
00728 *
00729 *      Specifically the keywords are those listed above for
00730 *      WCSHDR_AUXIMG plus
00731 *
00732 #      WCSAXESa  for WCAXna
00733 *
00734 *      which defines the coordinate dimensionality, and the following
00735 *      keywords that are parameterized by axis number:
00736 *
00737 #      CRPIXja   for jCRPna
00738 #      PCi_ja    for ijPCna
00739 #      CDi_ja    for ijCDna
00740 #      CDELTia   for iCDEna
00741 #      CROTAi    for iCROtn
00742 #      CROTAia   -          ... Only if WCSHDR_CROTAia is set.
00743 #      CUNITia   for iCUNna
00744 #      CTYPEia   for iCTYna
00745 #      CRVALia   for iCRVna
00746 #      PVi_ma    for iVn_ma
00747 #      PSi_ma    for iSn_ma
00748 #
00749 #      CNAMEia   for iCNAa
00750 #      CRDERia   for iCRDna
00751 #      CSYERia   for iCSYna
00752 #      CZPHSia   for iCZPna
00753 #      CPERIa    for iCPRna
00754 *
00755 *      where the image-header keywords on the left provide default
00756 *      values for the column specific keywords on the right.
00757 *
00758 *      This full inheritance mechanism only applies to binary table
00759 *      image arrays, not pixel lists, because in the latter case
00760 *      there is no well-defined association between coordinate axis
00761 *      number and column number (see note 9 below).
00762 *
00763 *      Note that CNAMEia, CRDERia, CSYERia, and their variants are
00764 *      not used by WCSLIB but are stored in the wcsprm struct as
00765 *      auxiliary information.
00766 *
00767 *      Note especially that at least one wcsprm struct will be
00768 *      returned for each "a" found in one of the image header
00769 *      keywords listed above:
00770 *
00771 *      - If the image header keywords for "a" ARE NOT inherited by a
00772 *      binary table, then the struct will not be associated with
00773 *      any particular table column number and it is up to the user
00774 *      to provide an association.
00775 *
00776 *      - If the image header keywords for "a" ARE inherited by a
00777 *      binary table image array, then those keywords are considered
00778 *      to be "exhausted" and do not result in a separate wcsprm
00779 *      struct.
00780 *
00781 *      For example, to accept CD00i00j and PC00i00j and reject all other
00782 *      extensions, use
00783 *
00784 =      relax = WCSHDR_reject | WCSHDR_CD00i00j | WCSHDR_PC00i00j;
00785 *
00786 *      The parser always treats EPOCH as subordinate to EQUINOXa if both are
00787 *      present, and VSOURCEa is always subordinate to ZSOURCEa.
00788 *
00789 *      Likewise, VELREF is subordinate to the formalism of WCS Paper III, see
00790 *      spcaips().
00791 *
00792 *      Neither wcspih() nor wcsbth() currently recognize the AIPS-convention
00793 *      keywords ALTRPIX or ALTRVAL which effectively define an alternative
00794 *      representation for a spectral axis.
00795 *
00796 *      6: Depending on what flags have been set in its "relax" argument,
00797 *      wcsbth() could return as many as 27027 wcsprm structs:
00798 *
00799 *      - Up to 27 unattached representations derived from image header
00800 *      keywords.
00801 *
00802 *      - Up to 27 structs for each of up to 999 columns containing an image
00803 *      arrays.
00804 *
00805 *      - Up to 27 structs for a pixel list.
00806 *
00807 *      Note that it is considered legitimate for a column to contain an image
00808 *      array and also form part of a pixel list, and in particular that
00809 *      wcsbth() does not check the TFORM keyword for a pixel list column to
00810 *      check that it is scalar.

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00811 *
00812 *      In practice, of course, a realistic binary table header is unlikely to
00813 *      contain more than a handful of images.
00814 *
00815 *      In order for wcsbth() to create a wcsprm struct for a particular
00816 *      coordinate representation, at least one WCS keyword that defines an
00817 *      axis number must be present, either directly or by inheritance if
00818 *      WCSHDR_ALLIMG is set.
00819 *
00820 *      When the image header keywords for an alternate representation are
00821 *      inherited by a binary table image array via WCSHDR_ALLIMG, those
00822 *      keywords are considered to be "exhausted" and do not result in a
00823 *      separate wcsprm struct. Otherwise they do.
00824 *
00825 *      7: Neither wcspih() nor wcsbth() check for duplicated keywords, in most
00826 *      cases they accept the last encountered.
00827 *
00828 *      8: wcspih() and wcsbth() use wcsnpv() and wcsnps() (refer to the prologue
00829 *      of wcs.h) to match the size of the pv[] and ps[] arrays in the wcsprm
00830 *      structs to the number in the header. Consequently there are no unused
00831 *      elements in the pv[] and ps[] arrays, indeed they will often be of
00832 *      zero length.
00833 *
00834 *      9: The FITS WCS standard for pixel lists assumes that a pixel list
00835 *      defines one and only one image, i.e. that each row of the binary table
00836 *      refers to just one event, e.g. the detection of a single photon or
00837 *      neutrino, for which the device "pixel" coordinates are stored in
00838 *      separate scalar columns of the table.
00839 *
00840 *      In the absence of a standard for pixel lists - or even an informal
00841 *      description! - let alone a formal mechanism for identifying the columns
00842 *      containing pixel coordinates (as opposed to pixel values or metadata
00843 *      recorded at the time the photon or neutrino was detected), WCS Paper I
00844 *      discusses how the WCS keywords themselves may be used to identify them.
00845 *
00846 *      In practice, however, pixel lists have been used to store multiple
00847 *      images. Besides not specifying how to identify columns, the pixel list
00848 *      convention is also silent on the method to be used to associate table
00849 *      columns with image axes.
00850 *
00851 *      An additional shortcoming is the absence of a formal method for
00852 *      associating global binary-table WCS keywords, such as WCSNna or MJDOBn,
00853 *      with a pixel list image, whether one or several.
00854 *
00855 *      In light of these uncertainties, wcsbth() simply collects all WCS
00856 *      keywords for a particular pixel list coordinate representation (i.e.
00857 *      the "a" value in TCTYna) into one wcsprm struct. However, these
00858 *      alternates need not be associated with the same table columns and this
00859 *      allows a pixel list to contain up to 27 separate images. As usual, if
00860 *      one of these representations happened to contain more than two
00861 *      celestial axes, for example, then an error would result when wcsset()
00862 *      is invoked on it. In this case the "colsel" argument could be used to
00863 *      restrict the columns used to construct the representation so that it
00864 *      only contained one pair of celestial axes.
00865 *
00866 *      Global, binary-table WCS keywords are considered to apply to the pixel
00867 *      list image with matching alternate (e.g. the "a" value in LONPna or
00868 *      EQUIna), regardless of the table columns the image occupies. In other
00869 *      words, the column number is ignored (the "n" value in LONPna or
00870 *      EQUIna). This also applies for global, binary-table WCS keywords that
00871 *      have no alternates, such as MJDOBn and OBGXn, which match all images
00872 *      in a pixel list. Take heed that this may lead to counterintuitive
00873 *      behaviour, especially where such a keyword references a column that
00874 *      does not store pixel coordinates, and moreso where the pixel list
00875 *      stores only a single image. In fact, as the column number, n, is
00876 *      ignored for such keywords, it would make no difference even if they
00877 *      referenced non-existent columns. Moreover, there is no requirement for
00878 *      consistency in the column numbers used for such keywords, even for
00879 *      OBGXn, OBGYn, and OBGZn which are meant to define the elements of a
00880 *      coordinate vector. Although it would surely be perverse to construct a
00881 *      pixel list like this, such a situation may still arise in practice
00882 *      where columns are deleted from a binary table.
00883 *
00884 *      The situation with global, binary-table WCS keywords becomes
00885 *      potentially even more confusing when image arrays and pixel list images
00886 *      coexist in one binary table. In that case, a keyword such as MJDOBn
00887 *      may legitimately appear multiple times with n referencing different
00888 *      image arrays. Which then is the one that applies to the pixel list
00889 *      images? In this implementation, it is the last instance that appears
00890 *      in the header, whether or not it is also associated with an image
00891 *      array.
00892 *
00893 *
00894 *      wcstab() - Tabular construction routine
00895 *      -----
00896 *      wcstab() assists in filling in the information in the wcsprm struct relating
00897 *      to coordinate lookup tables.

```

```

00898 *
00899 * Tabular coordinates ('TAB') present certain difficulties in that the main
00900 * components of the lookup table - the multidimensional coordinate array plus
00901 * an index vector for each dimension - are stored in a FITS binary table
00902 * extension (BINTABLE). Information required to locate these arrays is stored
00903 * in PVi_ma and PSi_ma keywords in the image header.
00904 *
00905 * wcstab() parses the PVi_ma and PSi_ma keywords associated with each 'TAB'
00906 * axis and allocates memory in the wcsprm struct for the required number of
00907 * tabprm structs. It sets as much of the tabprm struct as can be gleaned from
00908 * the image header, and also sets up an array of wtarr structs (described in
00909 * the prologue of wtarr.h) to assist in extracting the required arrays from
00910 * the BINTABLE extension(s).
00911 *
00912 * It is then up to the user to allocate memory for, and copy arrays from the
00913 * BINTABLE extension(s) into the tabprm structs. A CFITSIO routine,
00914 * fits_read_wcstab(), has been provided for this purpose, see getwcstab.h.
00915 * wcsset() will automatically take control of this allocated memory, in
00916 * particular causing it to be freed by wcsfree(); the user must not attempt
00917 * to free it after wcsset() has been called.
00918 *
00919 * Note that wcsipih() and wcsbth() automatically invoke wcstab() on each of the
00920 * wcsprm structs that they return.
00921 *
00922 * Given and returned:
00923 *   wcs      struct wcsprm*
00924 *           Coordinate transformation parameters (see below).
00925 *
00926 *           wcstab() sets ntab, tab, nwtab and wtb, allocating
00927 *           memory for the tab and wtb arrays. This allocated
00928 *           memory will be freed automatically by wcsfree().
00929 *
00930 * Function return value:
00931 *   int      Status return value:
00932 *           0: Success.
00933 *           1: Null wcsprm pointer passed.
00934 *           2: Memory allocation failed.
00935 *           3: Invalid tabular parameters.
00936 *
00937 *           For returns > 1, a detailed error message is set in
00938 *           wcsprm::err if enabled, see wcserr_enable().
00939 *
00940 *
00941 * wcsidx() - Index alternate coordinate representations
00942 * -----
00943 * wcsidx() returns an array of 27 indices for the alternate coordinate
00944 * representations in the array of wcsprm structs returned by wcsipih(). For
00945 * the array returned by wcsbth() it returns indices for the unattached
00946 * (colnum == 0) representations derived from image header keywords - use
00947 * wcsbidx() for those derived from binary table image arrays or pixel lists
00948 * keywords.
00949 *
00950 * Given:
00951 *   nwcs      int      Number of coordinate representations in the array.
00952 *
00953 *   wcs      const struct wcsprm**
00954 *           Pointer to an array of wcsprm structs returned by
00955 *           wcsipih() or wcsbth().
00956 *
00957 * Returned:
00958 *   alts      int[27]   Index of each alternate coordinate representation in
00959 *                       the array: alts[0] for the primary, alts[1] for 'A',
00960 *                       etc., set to -1 if not present.
00961 *
00962 *           For example, if there was no 'P' representation then
00963 *
00964 *           alts['P'-'A'+1] == -1;
00965 *
00966 *           Otherwise, the address of its wcsprm struct would be
00967 *
00968 *           wcs + alts['P'-'A'+1];
00969 *
00970 * Function return value:
00971 *   int      Status return value:
00972 *           0: Success.
00973 *           1: Null wcsprm pointer passed.
00974 *
00975 *
00976 * wcsbidx() - Index alternate coordinate representations
00977 * -----
00978 * wcsbidx() returns an array of 999 x 27 indices for the alternate coordinate
00979 * representations for binary table image arrays xor pixel lists in the array of
00980 * wcsprm structs returned by wcsbth(). Use wcsidx() for the unattached
00981 * representations derived from image header keywords.
00982 *
00983 * Given:
00984 *   nwcs      int      Number of coordinate representations in the array.

```

```

00985 *
00986 *   wcs          const struct wcsprm**
00987 *               Pointer to an array of wcsprm structs returned by
00988 *               wcsbth().
00989 *
00990 *   type         int          Select the type of coordinate representation:
00991 *                           0: binary table image arrays,
00992 *                           1: pixel lists.
00993 *
00994 * Returned:
00995 *   alts         short[1000][28]
00996 *               Index of each alternate coordinate representation in the
00997 *               array: alts[col][0] for the primary, alts[col][1] for
00998 *               'A', to alts[col][26] for 'Z', where col is the
00999 *               1-relative column number, and col == 0 is used for
01000 *               unattached image headers. Set to -1 if not present.
01001 *
01002 *               alts[col][27] counts the number of coordinate
01003 *               representations of the chosen type for each column.
01004 *
01005 *               For example, if there was no 'P' representation for
01006 *               column 13 then
01007 *
01008 *               alts[13]['P'-'A'+1] == -1;
01009 *
01010 *               Otherwise, the address of its wcsprm struct would be
01011 *
01012 *               wcs + alts[13]['P'-'A'+1];
01013 *
01014 * Function return value:
01015 *   int          Status return value:
01016 *               0: Success.
01017 *               1: Null wcsprm pointer passed.
01018 *
01019 *
01020 * wcsvfree() - Free the array of wcsprm structs
01021 * -----
01022 * wcsvfree() frees the memory allocated by wcspih() or wcsbth() for the array
01023 * of wcsprm structs, first invoking wcsfree() on each of the array members.
01024 *
01025 * Given and returned:
01026 *   nwcs         int*         Number of coordinate representations found; set to 0
01027 *                           on return.
01028 *
01029 *   wcs          struct wcsprm**
01030 *               Pointer to the array of wcsprm structs; set to 0x0 on
01031 *               return.
01032 *
01033 * Function return value:
01034 *   int          Status return value:
01035 *               0: Success.
01036 *               1: Null wcsprm pointer passed.
01037 *
01038 *
01039 * wcshdo() - Write out a wcsprm struct as a FITS header
01040 * -----
01041 * wcshdo() translates a wcsprm struct into a FITS header. If the colnum
01042 * member of the struct is non-zero then a binary table image array header will
01043 * be produced. Otherwise, if the colax[] member of the struct is set non-zero
01044 * then a pixel list header will be produced. Otherwise, a primary image or
01045 * image extension header will be produced.
01046 *
01047 * If the struct was originally constructed from a header, e.g. by wcspih(),
01048 * the output header will almost certainly differ in a number of respects:
01049 *
01050 * - The output header only contains WCS-related keywords. In particular, it
01051 *   does not contain syntactically-required keywords such as SIMPLE, NAXIS,
01052 *   BITPIX, or END.
01053 *
01054 * - Elements of the PCi_ja matrix will be written if and only if they differ
01055 *   from the unit matrix. Thus, if the matrix is unity then no elements
01056 *   will be written.
01057 *
01058 * - The redundant keywords MJDREF, JDREF, JDREFI, JDREFF, all of which
01059 *   duplicate MJDREFI + MJDREFF, are never written. OBSGEO-[LBH] are not
01060 *   written if OBSGEO-[XYZ] are defined.
01061 *
01062 * - Deprecated (e.g. CROTAn, RESTFREQ, VELREF, RADECSYS, EPOCH, VSOURCEa) or
01063 *   non-standard usage will be translated to standard (this is partially
01064 *   dependent on whether wcsfix() was applied).
01065 *
01066 * - Additional keywords such as WCSAXESa, CUNITia, LONPOLEa and LATPOLEa may
01067 *   appear.
01068 *
01069 * - Quantities will be converted to the units used internally, basically SI
01070 *   with the addition of degrees.
01071 *

```

```

01072 * - Floating-point quantities may be given to a different decimal precision.
01073 *
01074 * - The original keycomments will be lost, although wcsndo() tries hard to
01075 *   write meaningful comments.
01076 *
01077 * - Keyword order will almost certainly be changed.
01078 *
01079 * Keywords can be translated between the image array, binary table, and pixel
01080 * lists forms by manipulating the colnum or colax[] members of the wcsprm
01081 * struct.
01082 *
01083 * Given:
01084 *   ctrl      int      Vector of flag bits that controls the degree of
01085 *                       permissiveness in departing from the published WCS
01086 *                       standard, and also controls the formatting of
01087 *                       floating-point keyvalues. Set it to zero to get the
01088 *                       default behaviour.
01089 *
01090 * Flag bits for the degree of permissiveness:
01091 *   WCSHDO_none: Recognize only FITS keywords defined by
01092 *                 the published WCS standard.
01093 *   WCSHDO_all: Admit all recognized informal extensions
01094 *               of the WCS standard.
01095 * Fine-grained control of the degree of permissiveness
01096 * is also possible as explained in the notes below.
01097 *
01098 * As for controlling floating-point formatting, by
01099 * default wcsndo() uses "%20.12G" for non-parameterized
01100 * keywords such as LONPOLEa, and attempts to make the
01101 * header more human-readable by using the same "%f"
01102 * format for all values of each of the following
01103 * parameterized keywords: CRPIXja, PCi_ja, and CDELTia
01104 * (n.b. excluding CRVALia). Each has the same field
01105 * width and precision so that the decimal points line
01106 * up. The precision, allowing for up to 15 significant
01107 * digits, is chosen so that there are no excess trailing
01108 * zeroes. A similar formatting scheme applies by
01109 * default for distortion function parameters.
01110 *
01111 * However, where the values of, for example, CDELTia
01112 * differ by many orders of magnitude, the default
01113 * formatting scheme may cause unacceptable loss of
01114 * precision for the lower-valued keyvalues. Thus the
01115 * default behaviour may be overridden:
01116 *   WCSHDO_P12: Use "%20.12G" format for all floating-
01117 *                 point keyvalues (12 significant digits).
01118 *   WCSHDO_P13: Use "%21.13G" format for all floating-
01119 *                 point keyvalues (13 significant digits).
01120 *   WCSHDO_P14: Use "%22.14G" format for all floating-
01121 *                 point keyvalues (14 significant digits).
01122 *   WCSHDO_P15: Use "%23.15G" format for all floating-
01123 *                 point keyvalues (15 significant digits).
01124 *   WCSHDO_P16: Use "%24.16G" format for all floating-
01125 *                 point keyvalues (16 significant digits).
01126 *   WCSHDO_P17: Use "%25.17G" format for all floating-
01127 *                 point keyvalues (17 significant digits).
01128 * If more than one of the above flags are set, the
01129 * highest number of significant digits prevails. In
01130 * addition, there is an ancillary flag:
01131 *   WCSHDO_EFMT: Use "%E" format instead of the default
01132 *                 "%G" format above.
01133 * Note that excess trailing zeroes are stripped off the
01134 * fractional part with "%G" (which never occurs with
01135 * "%E"). Note also that the higher-precision options
01136 * eat into the keycomment area. In this regard,
01137 * WCSHDO_P14 causes minimal disruption with "%G" format,
01138 * while WCSHDO_P13 is appropriate with "%E".
01139 *
01140 * Given and returned:
01141 *   wcs      struct wcsprm*
01142 *                       Pointer to a wcsprm struct containing coordinate
01143 *                       transformation parameters. Will be initialized if
01144 *                       necessary.
01145 *
01146 * Returned:
01147 *   nkeyrec  int*       Number of FITS header keyrecords returned in the
01148 *                       "header" array.
01149 *
01150 *   header   char**     Pointer to an array of char holding the header.
01151 *                       Storage for the array is allocated by wcsndo() in
01152 *                       blocks of 2880 bytes (32 x 80-character keyrecords)
01153 *                       and must be freed by the user to avoid memory leaks.
01154 *                       See wcsdealloc().
01155 *
01156 * Each keyrecord is 80 characters long and is *NOT*
01157 * null-terminated, so the first keyrecord starts at
01158 * (*header)[0], the second at (*header)[80], etc.

```

```

01159 *
01160 * Function return value:
01161 *     int          Status return value (associated with wcs_errmsg[]):
01162 *         0: Success.
01163 *         1: Null wcsprm pointer passed.
01164 *         2: Memory allocation failed.
01165 *         3: Linear transformation matrix is singular.
01166 *         4: Inconsistent or unrecognized coordinate axis
01167 *            types.
01168 *         5: Invalid parameter value.
01169 *         6: Invalid coordinate transformation parameters.
01170 *         7: Ill-conditioned coordinate transformation
01171 *            parameters.
01172 *
01173 *         For returns > 1, a detailed error message is set in
01174 *         wcsprm::err if enabled, see wcserr_enable().
01175 *
01176 * Notes:
01177 * 1: wcsldo() interprets the "relax" argument as a vector of flag bits to
01178 *    provide fine-grained control over what non-standard WCS keywords to
01179 *    write. The flag bits are subject to change in future and should be set
01180 *    by using the preprocessor macros (see below) for the purpose.
01181 *
01182 * - WCSHDO_none: Don't use any extensions.
01183 *
01184 * - WCSHDO_all: Write all recognized extensions, equivalent to setting
01185 *    each flag bit.
01186 *
01187 * - WCSHDO_safe: Write all extensions that are considered to be safe and
01188 *    recommended.
01189 *
01190 * - WCSHDO_DOBSn: Write DOBSn, the column-specific analogue of DATE-OBS
01191 *    for use in binary tables and pixel lists. WCS Paper III
01192 *    introduced DATE-AVG and DAVGn but by an oversight DOBSn (the
01193 *    obvious analogy) was never formally defined by the standard.
01194 *    The alternative to using DOBSn is to write DATE-OBS which
01195 *    applies to the whole table. This usage is considered to be
01196 *    safe and is recommended.
01197 *
01198 * - WCSHDO_TPCn_ka: WCS Paper I defined
01199 *
01200 *     - TPN_ka and TCn_ka for pixel lists
01201 *
01202 *     but WCS Paper II uses TPCn_ka in one example and subsequently
01203 *     the errata for the WCS papers legitimized the use of
01204 *
01205 *     - TPCn_ka and TCDn_ka for pixel lists
01206 *
01207 *     provided that the keyword does not exceed eight characters.
01208 *     This usage is considered to be safe and is recommended because
01209 *     of the non-mnemonic terseness of the shorter forms.
01210 *
01211 * - WCSHDO_PVn_ma: WCS Paper I defined
01212 *
01213 *     - iVn_ma and iSn_ma for bintables and
01214 *     - TVn_ma and TSn_ma for pixel lists
01215 *
01216 *     but WCS Paper II uses iPVn_ma and TPVn_ma in the examples and
01217 *     subsequently the errata for the WCS papers legitimized the use
01218 *     of
01219 *
01220 *     - iPVn_ma and iPSn_ma for bintables and
01221 *     - TPVn_ma and TPSn_ma for pixel lists
01222 *
01223 *     provided that the keyword does not exceed eight characters.
01224 *     This usage is considered to be safe and is recommended because
01225 *     of the non-mnemonic terseness of the shorter forms.
01226 *
01227 * - WCSHDO_CRPXna: For historical reasons WCS Paper I defined
01228 *
01229 *     - jCRPXn, iCDLTn, iCUNIn, iCTYPn, and iCRVLn for bintables and
01230 *     - TCRPXn, TCDLTn, TCUNIn, TCTYPn, and TCRVLn for pixel lists
01231 *
01232 *     for use without an alternate version specifier. However,
01233 *     because of the eight-character keyword constraint, in order to
01234 *     accommodate column numbers greater than 99 WCS Paper I also
01235 *     defined
01236 *
01237 *     - jCRPna, iCDEna, iCUNna, iCTYna and iCRVna for bintables and
01238 *     - TCRPna, TCDEna, TCUNna, TCTYna and TCRVna for pixel lists
01239 *
01240 *     for use with an alternate version specifier (the "a"). Like
01241 *     the PC, CD, PV, and PS keywords there is an obvious tendency to
01242 *     confuse these two forms for column numbers up to 99. It is
01243 *     very unlikely that any parser would reject keywords in the
01244 *     first set with a non-blank alternate version specifier so this
01245 *     usage is considered to be safe and is recommended.

```

```

01246 *
01247 *      - WCSHDO_CNAMna: WCS Papers I and III defined
01248 *
01249 *      - iCNana, iCRDna, and iCSYna for bintables and
01250 *      - TCNana, TCRDna, and TCSYna for pixel lists
01251 *
01252 *      By analogy with the above, the long forms would be
01253 *
01254 *      - iCNAMna, iCRDena, and iCSYena for bintables and
01255 *      - TCNAMna, TCRDena, and TCSYena for pixel lists
01256 *
01257 *      Note that these keywords provide auxiliary information only,
01258 *      none of them are needed to compute world coordinates. This
01259 *      usage is potentially unsafe and is not recommended at this
01260 *      time.
01261 *
01262 *      - WCSHDO_WCSNna: In light of wcsbth() note 4, write WCSNna instead of
01263 *      TWCSna for pixel lists. While wcsbth() treats WCSNna and
01264 *      TWCSna as equivalent, other parsers may not. Consequently,
01265 *      this usage is potentially unsafe and is not recommended at this
01266 *      time.
01267 *
01268 *
01269 * Global variable: const char *wcsshr_errmsg[] - Status return messages
01270 * -----
01271 * Error messages to match the status value returned from each function.
01272 * Use wcs_errmsg[] for status returns from wcsdo().
01273 *
01274 * =====*/
01275
01276 #ifndef WCSLIB_WCSHDR
01277 #define WCSLIB_WCSHDR
01278
01279 #include "wcs.h"
01280
01281 #ifdef __cplusplus
01282 extern "C" {
01283 #endif
01284
01285 #define WCSHDR_none      0x00000000
01286 #define WCSHDR_all       0x000FFFFF
01287 #define WCSHDR_reject    0x10000000
01288 #define WCSHDR_strict    0x20000000
01289
01290 #define WCSHDR_CROTAia    0x00000001
01291 #define WCSHDR_VELREFa    0x00000002
01292 #define WCSHDR_CD00i00j  0x00000004
01293 #define WCSHDR_PC00i00j  0x00000008
01294 #define WCSHDR_PROJPN     0x00000010
01295 #define WCSHDR_CD0i_0ja   0x00000020
01296 #define WCSHDR_PC0i_0ja   0x00000040
01297 #define WCSHDR_PV0i_0ma   0x00000080
01298 #define WCSHDR_PS0i_0ma   0x00000100
01299 #define WCSHDR_DOBSn      0x00000200
01300 #define WCSHDR_OBSGLBHn   0x00000400
01301 #define WCSHDR_RADECsys   0x00000800
01302 #define WCSHDR_EPOCHa     0x00001000
01303 #define WCSHDR_VSOURCE    0x00002000
01304 #define WCSHDR_DATEREf    0x00004000
01305 #define WCSHDR_LONGKEY    0x00008000
01306 #define WCSHDR_CNAMn      0x00010000
01307 #define WCSHDR_AUXIMG     0x00020000
01308 #define WCSHDR_ALLIMG     0x00040000
01309
01310 #define WCSHDR_IMGHEAD    0x00100000
01311 #define WCSHDR_BIMGARR    0x00200000
01312 #define WCSHDR_PIXLIST    0x00400000
01313
01314 #define WCSHDO_none       0x000000
01315 #define WCSHDO_all        0x0000FF
01316 #define WCSHDO_safe       0x00000F
01317 #define WCSHDO_DOBSn      0x000001
01318 #define WCSHDO_TPCn_ka    0x000002
01319 #define WCSHDO_PVn_ma     0x000004
01320 #define WCSHDO_CRPXna     0x000008
01321 #define WCSHDO_CNAMna     0x000010
01322 #define WCSHDO_WCSNna     0x000020
01323 #define WCSHDO_P12        0x001000
01324 #define WCSHDO_P13        0x002000
01325 #define WCSHDO_P14        0x004000
01326 #define WCSHDO_P15        0x008000
01327 #define WCSHDO_P16        0x010000
01328 #define WCSHDO_P17        0x020000
01329 #define WCSHDO_EFMT       0x400000
01330
01331
01332 extern const char *wcsshr_errmsg[];

```

```

01333
01334 enum wshdr_errmsg_enum {
01335     WSHDRERR_SUCCESS           = 0,      // Success.
01336     WSHDRERR_NULL_POINTER     = 1,      // Null wcsprm pointer passed.
01337     WSHDRERR_MEMORY           = 2,      // Memory allocation failed.
01338     WSHDRERR_BAD_COLUMN       = 3,      // Invalid column selection.
01339     WSHDRERR_PARSER           = 4,      // Fatal error returned by Flex
01340                                     // parser.
01341     WSHDRERR_BAD_TABULAR_PARAMS = 5      // Invalid tabular parameters.
01342 };
01343
01344 int wcspih(char *header, int nkeyrec, int relax, int ctrl, int *nreject,
01345            int *nwcs, struct wcsprm **wcs);
01346
01347 int wcsbth(char *header, int nkeyrec, int relax, int ctrl, int keysel,
01348            int *colsel, int *nreject, int *nwcs, struct wcsprm **wcs);
01349
01350 int wcstab(struct wcsprm *wcs);
01351
01352 int wcsidx(int nwcs, struct wcsprm **wcs, int alts[27]);
01353
01354 int wcsbdx(int nwcs, struct wcsprm **wcs, int type, short alts[1000][28]);
01355
01356 int wcsvfree(int *nwcs, struct wcsprm **wcs);
01357
01358 int wshdo(int ctrl, struct wcsprm *wcs, int *nkeyrec, char **header);
01359
01360
01361 #ifdef __cplusplus
01362 }
01363 #endif
01364
01365 #endif // WCSLIB_WSHDR

```

## 8.31 wcmath.h File Reference

### Macros

- #define [PI](#) 3.141592653589793238462643
- #define [D2R](#) [PI](#)/180.0  
*Degrees to radians conversion factor.*
- #define [R2D](#) 180.0/[PI](#)  
*Radians to degrees conversion factor.*
- #define [SQRT2](#) 1.4142135623730950488
- #define [SQRT2INV](#) 1.0/[SQRT2](#)
- #define [UNDEFINED](#) 987654321.0e99  
*Value used to indicate an undefined quantity.*
- #define [undefined](#)(value)  
*Macro used to test for an undefined quantity.*

### 8.31.1 Detailed Description

Definition of mathematical constants used by WCSLIB.

### 8.31.2 Macro Definition Documentation

#### PI

```
#define PI 3.141592653589793238462643
```

## D2R

```
#define D2R PI/180.0
```

Degrees to radians conversion factor.

Factor  $\pi/180^\circ$  to convert from degrees to radians.

## R2D

```
#define R2D 180.0/PI
```

Radians to degrees conversion factor.

Factor  $180^\circ/\pi$  to convert from radians to degrees.

## SQRT2

```
#define SQRT2 1.4142135623730950488
```

$\sqrt{2}$ , used only by [molset\(\)](#) (**MOL** projection).

## SQRT2INV

```
#define SQRT2INV 1.0/SQRT2
```

$1/\sqrt{2}$ , used only by [qscx2s\(\)](#) (**QSC** projection).

## UNDEFINED

```
#define UNDEFINED 987654321.0e99
```

Value used to indicate an undefined quantity.

Value used to indicate an undefined quantity (noting that NaNs cannot be used portably).

## undefined

```
#define undefined(  
    value)
```

### Value:

```
(value == UNDEFINED)
```

Macro used to test for an undefined quantity.

Macro used to test for an undefined value.

## 8.32 wcsmath.h

[Go to the documentation of this file.](#)

```

00001 /*=====
00002  WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003  Copyright (C) 1995-2025, Mark Calabretta
00004
00005  This file is part of WCSLIB.
00006
00007  WCSLIB is free software: you can redistribute it and/or modify it under the
00008  terms of the GNU Lesser General Public License as published by the Free
00009  Software Foundation, either version 3 of the License, or (at your option)
00010  any later version.
00011
00012  WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013  WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
00014  FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015  more details.
00016
00017  You should have received a copy of the GNU Lesser General Public License
00018  along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020  Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021  http://www.atnf.csiro.au/people/Mark.Calabretta
00022  $Id: wcsmath.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023 *=====
00024 *
00025 * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026 * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027 * overview of the library.
00028 *
00029 *
00030 * Summary of wcsmath.h
00031 * -----
00032 * Definition of mathematical constants used by WCSLIB.
00033 *
00034 *=====*/
00035
00036 #ifndef WCSLIB_WCSMATH
00037 #define WCSLIB_WCSMATH
00038
00039 #ifndef PI
00040 #undef PI
00041 #endif
00042
00043 #ifndef D2R
00044 #undef D2R
00045 #endif
00046
00047 #ifndef R2D
00048 #undef R2D
00049 #endif
00050
00051 #ifndef SQRT2
00052 #undef SQRT2
00053 #endif
00054
00055 #ifndef SQRT2INV
00056 #undef SQRT2INV
00057 #endif
00058
00059 #define PI 3.141592653589793238462643
00060 #define D2R PI/180.0
00061 #define R2D 180.0/PI
00062 #define SQRT2 1.4142135623730950488
00063 #define SQRT2INV 1.0/SQRT2
00064
00065 #ifndef UNDEFINED
00066 #undef UNDEFINED
00067 #endif
00068
00069 #define UNDEFINED 987654321.0e99
00070 #define undefined(value) (value == UNDEFINED)
00071
00072 #endif // WCSLIB_WCSMATH

```

## 8.33 wcsprintf.h File Reference

```

#include <inttypes.h>
#include <stdio.h>

```

## Macros

- `#define WCSPRINTF_PTR(str1, ptr, str2)`  
*Print addresses in a consistent way.*

## Functions

- `int wcsprintf_set (FILE *wcout)`  
*Set output disposition for `wcsprintf()` and `wcsfprintf()`.*
- `int wcsprintf (const char *format,...)`  
*Print function used by WCSLIB diagnostic routines.*
- `int wsfprintf (FILE *stream, const char *format,...)`  
*Print function used by WCSLIB diagnostic routines.*
- `const char * wcsprintf_buf (void)`  
*Get the address of the internal string buffer.*

### 8.33.1 Detailed Description

Routines in this suite allow diagnostic output from `celprt()`, `linprt()`, `prjprt()`, `spcprt()`, `tabprt()`, `wcsprt()`, and `wcserr_prt()` to be redirected to a file or captured in a string buffer. Those routines all use `wcsprintf()` for output. Likewise `wcsfprintf()` is used by `wcsbth()` and `wcspih()`. Both functions may be used by application programmers to have other output go to the same place.

### 8.33.2 Macro Definition Documentation

#### WCSPRINTF\_PTR

```
#define WCSPRINTF_PTR(
    str1,
    ptr,
    str2)
```

#### Value:

```
if (ptr) { \
    wcsprintf("%s%#" PRIxPTR "%s", (str1), (uintptr_t)(ptr), (str2)); \
} else { \
    wcsprintf("%s0x0%s", (str1), (str2)); \
}
```

Print addresses in a consistent way.

**WCSPRINTF\_PTR()** is a preprocessor macro used to print addresses in a consistent way.

On some systems the "p" format descriptor renders a NULL pointer as the string "0x0". On others, however, it produces "0" or even "(nil)". On some systems a non-zero address is prefixed with "0x", on others, not.

The **WCSPRINTF\_PTR()** macro ensures that a NULL pointer is always rendered as "0x0" and that non-zero addresses are prefixed with "0x" thus providing consistency, for example, for comparing the output of test programs.

### 8.33.3 Function Documentation

#### wcsprintf\_set()

Generated on Sun Dec 7 2025 00:49:01 for WCSLIB by Doxygen

```
int wcsprintf_set (
    FILE * wcout)
```

## Parameters

in	<i>wcsout</i>	Pointer to an output stream that has been opened for writing, e.g. by the <code>fopen()</code> stdio library function, or one of the predefined stdio output streams - <code>stdout</code> and <code>stderr</code> . If zero (NULL), output is written to an internally-allocated string buffer, the address of which may be obtained by <a href="#">wcsprintf_buf()</a> .
----	---------------	--

## Returns

Status return value:

- 0: Success.

## wcsprintf()

```
int wcsprintf (
    const char * format,
    ...)
```

Print function used by WCSLIB diagnostic routines.

**wcsprintf()** is used by [celprt\(\)](#), [linprt\(\)](#), [prjprt\(\)](#), [spcprt\(\)](#), [tabprt\(\)](#), [wcsprt\(\)](#), and [wcserr\\_prt\(\)](#) for diagnostic output which by default goes to `stdout`. However, it may be redirected to a file or string buffer via **wcsprintf\_set()**.

## Parameters

in	<i>format</i>	Format string, passed to one of the <code>printf(3)</code> family of stdio library functions.
in	...	Argument list matching format, as per <code>printf(3)</code> .

## Returns

Number of bytes written.

## wcsfprintf()

```
int wcsfprintf (
    FILE * stream,
    const char * format,
    ...)
```

Print function used by WCSLIB diagnostic routines.

**wcsfprintf()** is used by [wcsbth\(\)](#), and [wcspih\(\)](#) for diagnostic output which they send to `stderr`. However, it may be redirected to a file or string buffer via [wcsprintf\\_set\(\)](#).

## Parameters

in	<i>stream</i>	The output stream if not overridden by a call to <code>wcsprintf_set()</code> .
in	<i>format</i>	Format string, passed to one of the <code>printf(3)</code> family of stdio library functions.
in	...	Argument list matching format, as per <code>printf(3)</code> .

**Returns**

Number of bytes written.

**`wcsprintf_buf()`**

```
const char * wcsprintf_buf (
    void )
```

Get the address of the internal string buffer.

**`wcsprintf_buf()`** returns the address of the internal string buffer created when `wcsprintf_set()` is invoked with its `FILE*` argument set to zero.

**Returns**

Address of the internal string buffer. The user may free this buffer by calling `wcsprintf_set()` with a valid `FILE*`, e.g. `stdout`. The `free()` `stdlib` library function must NOT be invoked on this `const` pointer.

**8.34 `wcsprintf.h`**

[Go to the documentation of this file.](#)

```
00001 /*=====
00002  WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003  Copyright (C) 1995-2025, Mark Calabretta
00004
00005  This file is part of WCSLIB.
00006
00007  WCSLIB is free software: you can redistribute it and/or modify it under the
00008  terms of the GNU Lesser General Public License as published by the Free
00009  Software Foundation, either version 3 of the License, or (at your option)
00010  any later version.
00011
00012  WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013  WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
00014  FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015  more details.
00016
00017  You should have received a copy of the GNU Lesser General Public License
00018  along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020  Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021  http://www.atnf.csiro.au/people/Mark.Calabretta
00022  $Id: wcsprintf.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023  =====
00024  *
00025  * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026  * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027  * overview of the library.
00028  *
00029  *
00030  * Summary of the wcsprintf routines
00031  * -----
00032  * Routines in this suite allow diagnostic output from celprt(), linprt(),
00033  * prjprt(), spcprt(), tabprt(), wcsprt(), and wcserr_prt() to be redirected to
00034  * a file or captured in a string buffer. Those routines all use wcsprintf()
00035  * for output. Likewise wcsfprintf() is used by wcsbth() and wcspih(). Both
00036  * functions may be used by application programmers to have other output go to
00037  * the same place.
00038  *
```

```

00039 *
00040 * wcsprintf() - Print function used by WCSLIB diagnostic routines
00041 * -----
00042 * wcsprintf() is used by celprt(), linprt(), prjprt(), spcprt(), tabprt(),
00043 * wcsprt(), and wcserr_prt() for diagnostic output which by default goes to
00044 * stdout. However, it may be redirected to a file or string buffer via
00045 * wcsprintf_set().
00046 *
00047 * Given:
00048 *   format    char*      Format string, passed to one of the printf(3) family
00049 *                       of stdio library functions.
00050 *
00051 *   ...       mixed      Argument list matching format, as per printf(3).
00052 *
00053 * Function return value:
00054 *   int        Number of bytes written.
00055 *
00056 *
00057 * wcsfprintf() - Print function used by WCSLIB diagnostic routines
00058 * -----
00059 * wcsfprintf() is used by wcsbth(), and wcspih() for diagnostic output which
00060 * they send to stderr. However, it may be redirected to a file or string
00061 * buffer via wcsprintf_set().
00062 *
00063 * Given:
00064 *   stream     FILE*      The output stream if not overridden by a call to
00065 *                       wcsprintf_set().
00066 *
00067 *   format     char*      Format string, passed to one of the printf(3) family
00068 *                       of stdio library functions.
00069 *
00070 *   ...        mixed      Argument list matching format, as per printf(3).
00071 *
00072 * Function return value:
00073 *   int        Number of bytes written.
00074 *
00075 *
00076 * wcsprintf_set() - Set output disposition for wcsprintf() and wcsfprintf()
00077 * -----
00078 * wcsprintf_set() sets the output disposition for wcsprintf() which is used by
00079 * the celprt(), linprt(), prjprt(), spcprt(), tabprt(), wcsprt(), and
00080 * wcserr_prt() routines, and for wcsfprintf() which is used by wcsbth() and
00081 * wcspih().
00082 *
00083 * Given:
00084 *   wcsout     FILE*      Pointer to an output stream that has been opened for
00085 *                       writing, e.g. by the fopen() stdio library function,
00086 *                       or one of the predefined stdio output streams - stdout
00087 *                       and stderr. If zero (NULL), output is written to an
00088 *                       internally-allocated string buffer, the address of
00089 *                       which may be obtained by wcsprintf_buf().
00090 *
00091 * Function return value:
00092 *   int        Status return value:
00093 *               0: Success.
00094 *
00095 *
00096 * wcsprintf_buf() - Get the address of the internal string buffer
00097 * -----
00098 * wcsprintf_buf() returns the address of the internal string buffer created
00099 * when wcsprintf_set() is invoked with its FILE* argument set to zero.
00100 *
00101 * Function return value:
00102 *   const char *
00103 *               Address of the internal string buffer. The user may
00104 *               free this buffer by calling wcsprintf_set() with a
00105 *               valid FILE*, e.g. stdout. The free() stdlib library
00106 *               function must NOT be invoked on this const pointer.
00107 *
00108 *
00109 * WCSPRINTF_PTR() macro - Print addresses in a consistent way
00110 * -----
00111 * WCSPRINTF_PTR() is a preprocessor macro used to print addresses in a
00112 * consistent way.
00113 *
00114 * On some systems the "%p" format descriptor renders a NULL pointer as the
00115 * string "0x0". On others, however, it produces "0" or even "(nil)". On
00116 * some systems a non-zero address is prefixed with "0x", on others, not.
00117 *
00118 * The WCSPRINTF_PTR() macro ensures that a NULL pointer is always rendered as
00119 * "0x0" and that non-zero addresses are prefixed with "0x" thus providing
00120 * consistency, for example, for comparing the output of test programs.
00121 *
00122 * =====*/
00123
00124 #ifndef WCSLIB_WCSPRINTF
00125 #define WCSLIB_WCSPRINTF

```

```

00126
00127 #include <inttypes.h>
00128 #include <stdio.h>
00129
00130 #ifdef __cplusplus
00131 extern "C" {
00132 #endif
00133
00134 #define WCSPRINTF_PTR(str1, ptr, str2) \
00135     if (ptr) { \
00136         wcsprintf("%s%#" PRIxPTR "%s", (str1), (uintptr_t)(ptr), (str2)); \
00137     } else { \
00138         wcsprintf("%s0x0%s", (str1), (str2)); \
00139     }
00140
00141 int wcsprintf_set(FILE *wcout);
00142 int wcsprintf(const char *format, ...);
00143 int wcsfprintf(FILE *stream, const char *format, ...);
00144 const char *wcsprintf_buf(void);
00145
00146 #ifdef __cplusplus
00147 }
00148 #endif
00149
00150 #endif // WCSLIB_WCSPRINTF

```

## 8.35 wcsstrig.h File Reference

```

#include <math.h>
#include "wcsconfig.h"

```

### Macros

- #define [WCSTRIG\\_TOL](#) 1e-10  
*Domain tolerance for asin() and acos() functions.*

### Functions

- double [cosd](#) (double angle)  
*Cosine of an angle in degrees.*
- double [sind](#) (double angle)  
*Sine of an angle in degrees.*
- void [sincosd](#) (double angle, double \*sin, double \*cos)  
*Sine and cosine of an angle in degrees.*
- double [tand](#) (double angle)  
*Tangent of an angle in degrees.*
- double [acosd](#) (double x)  
*Inverse cosine, returning angle in degrees.*
- double [asind](#) (double y)  
*Inverse sine, returning angle in degrees.*
- double [atand](#) (double s)  
*Inverse tangent, returning angle in degrees.*
- double [atan2d](#) (double y, double x)  
*Polar angle of (x, y), in degrees.*

### 8.35.1 Detailed Description

When dealing with celestial coordinate systems and spherical projections (some moreso than others) it is often desirable to use an angular measure that provides an exact representation of the latitude of the north or south pole. The WCSLIB routines use the following trigonometric functions that take or return angles in degrees:

- [cosd\(\)](#)
- [sind\(\)](#)
- [tand\(\)](#)
- [acosd\(\)](#)
- [asind\(\)](#)
- [atand\(\)](#)
- [atan2d\(\)](#)
- [sincosd\(\)](#)

These "trigd" routines are expected to handle angles that are a multiple of  $90^\circ$  returning an exact result. Some C implementations provide these as part of a system library and in such cases it may (or may not!) be preferable to use them. WCSLIB provides wrappers on the standard trig functions based on radian measure, adding tests for multiples of  $90^\circ$ .

However, [wcstrig.h](#) also provides the choice of using preprocessor macro implementations of the trigd functions that don't test for multiples of  $90^\circ$  (compile with `-DWCSSTRIG_MACRO`). These are typically 20% faster but may lead to problems near the poles.

### 8.35.2 Macro Definition Documentation

#### WCSTRIG\_TOL

```
#define WCSTRIG_TOL 1e-10
```

Domain tolerance for `asin()` and `acos()` functions.

Domain tolerance for the `asin()` and `acos()` functions to allow for floating point rounding errors.

If  $v$  lies in the range  $1 < |v| < 1 + WCSTRIG\_TOL$  then it will be treated as  $|v| == 1$ .

### 8.35.3 Function Documentation

#### `cosd()`

```
double cosd (  
    double angle)
```

Cosine of an angle in degrees.

`cosd()` returns the cosine of an angle given in degrees.

**Parameters**

in	<i>angle</i>	[deg].
----	--------------	--------

**Returns**

Cosine of the angle.

**sind()**

```
double sind (  
    double angle)
```

Sine of an angle in degrees.

**sind()** returns the sine of an angle given in degrees.

**Parameters**

in	<i>angle</i>	[deg].
----	--------------	--------

**Returns**

Sine of the angle.

**sincosd()**

```
void sincosd (  
    double angle,  
    double * sin,  
    double * cos)
```

Sine and cosine of an angle in degrees.

**sincosd()** returns the sine and cosine of an angle given in degrees.

**Parameters**

in	<i>angle</i>	[deg].
out	<i>sin</i>	Sine of the angle.
out	<i>cos</i>	Cosine of the angle.

**Returns**

**Parameters**

in	<i>angle</i>	[deg].
----	--------------	--------

**Returns**

Tangent of the angle.

**acosd()**

```
double acosd (  
    double x)
```

Inverse cosine, returning angle in degrees.

**acosd()** returns the inverse cosine in degrees.

**Parameters**

in	<i>x</i>	in the range [-1,1].
----	----------	----------------------

**Returns**

Inverse cosine of *x* [deg].

**asind()**

```
double asind (  
    double y)
```

Inverse sine, returning angle in degrees.

**asind()** returns the inverse sine in degrees.

**Parameters**

in	<i>y</i>	in the range [-1,1].
----	----------	----------------------

**Returns**

Inverse sine of *y* [deg].

**atand()**

```
double atand (  
    double s)
```

Inverse tangent, returning angle in degrees.

**Parameters**

in	s	
----	---	--

**Returns**

Inverse tangent of s [deg].

**atan2d()**

```
double atan2d (
    double y,
    double x)
```

Polar angle of  $(x, y)$ , in degrees.

**atan2d()** returns the polar angle,  $\beta$ , in degrees, of polar coordinates  $(\rho, \beta)$  corresponding to Cartesian coordinates  $(x, y)$ . It is equivalent to the  $\arg(x, y)$  function of WCS Paper II, though with transposed arguments.

**Parameters**

in	y	Cartesian $y$ -coordinate.
in	x	Cartesian $x$ -coordinate.

**Returns**

Polar angle of  $(x, y)$  [deg].

**8.36 wcstrig.h**

[Go to the documentation of this file.](#)

```
00001 /*=====
00002  WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003  Copyright (C) 1995-2025, Mark Calabretta
00004
00005  This file is part of WCSLIB.
00006
00007  WCSLIB is free software: you can redistribute it and/or modify it under the
00008  terms of the GNU Lesser General Public License as published by the Free
00009  Software Foundation, either version 3 of the License, or (at your option)
00010  any later version.
00011
00012  WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013  WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
00014  FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015  more details.
00016
00017  You should have received a copy of the GNU Lesser General Public License
00018  along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020  Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021  http://www.atnf.csiro.au/people/Mark.Calabretta
00022  $Id: wcstrig.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023 *=====
00024 *
00025 * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026 * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027 * overview of the library.
00028 *
```

```

00029 *
00030 * Summary of the wcsstr routines
00031 * -----
00032 * When dealing with celestial coordinate systems and spherical projections
00033 * (some moreso than others) it is often desirable to use an angular measure
00034 * that provides an exact representation of the latitude of the north or south
00035 * pole. The WCSLIB routines use the following trigonometric functions that
00036 * take or return angles in degrees:
00037 *
00038 *   - cosd()
00039 *   - sind()
00040 *   - tand()
00041 *   - acosd()
00042 *   - asind()
00043 *   - atand()
00044 *   - atan2d()
00045 *   - sincosd()
00046 *
00047 * These "trigd" routines are expected to handle angles that are a multiple of
00048 * 90 degrees returning an exact result. Some C implementations provide these
00049 * as part of a system library and in such cases it may (or may not!) be
00050 * preferable to use them. WCSLIB provides wrappers on the standard trig
00051 * functions based on radian measure, adding tests for multiples of 90 degrees.
00052 *
00053 * However, wcsstr.h also provides the choice of using preprocessor macro
00054 * implementations of the trigd functions that don't test for multiples of
00055 * 90 degrees (compile with -DWCSTRIG_MACRO). These are typically 20% faster
00056 * but may lead to problems near the poles.
00057 *
00058 *
00059 * cosd() - Cosine of an angle in degrees
00060 * -----
00061 * cosd() returns the cosine of an angle given in degrees.
00062 *
00063 * Given:
00064 *   angle      double      [deg].
00065 *
00066 * Function return value:
00067 *   double      Cosine of the angle.
00068 *
00069 *
00070 * sind() - Sine of an angle in degrees
00071 * -----
00072 * sind() returns the sine of an angle given in degrees.
00073 *
00074 * Given:
00075 *   angle      double      [deg].
00076 *
00077 * Function return value:
00078 *   double      Sine of the angle.
00079 *
00080 *
00081 * sincosd() - Sine and cosine of an angle in degrees
00082 * -----
00083 * sincosd() returns the sine and cosine of an angle given in degrees.
00084 *
00085 * Given:
00086 *   angle      double      [deg].
00087 *
00088 * Returned:
00089 *   sin        *double      Sine of the angle.
00090 *
00091 *   cos        *double      Cosine of the angle.
00092 *
00093 * Function return value:
00094 *   void
00095 *
00096 *
00097 * tand() - Tangent of an angle in degrees
00098 * -----
00099 * tand() returns the tangent of an angle given in degrees.
00100 *
00101 * Given:
00102 *   angle      double      [deg].
00103 *
00104 * Function return value:
00105 *   double      Tangent of the angle.
00106 *
00107 *
00108 * acosd() - Inverse cosine, returning angle in degrees
00109 * -----
00110 * acosd() returns the inverse cosine in degrees.
00111 *
00112 * Given:
00113 *   x          double      in the range [-1,1].
00114 *
00115 * Function return value:

```

```

00116 *           double    Inverse cosine of x [deg].
00117 *
00118 *
00119 * asind() - Inverse sine, returning angle in degrees
00120 * -----
00121 * asind() returns the inverse sine in degrees.
00122 *
00123 * Given:
00124 *     y           double    in the range [-1,1].
00125 *
00126 * Function return value:
00127 *     double      Inverse sine of y [deg].
00128 *
00129 *
00130 * atand() - Inverse tangent, returning angle in degrees
00131 * -----
00132 * atand() returns the inverse tangent in degrees.
00133 *
00134 * Given:
00135 *     s           double
00136 *
00137 * Function return value:
00138 *     double      Inverse tangent of s [deg].
00139 *
00140 *
00141 * atan2d() - Polar angle of (x,y), in degrees
00142 * -----
00143 * atan2d() returns the polar angle, beta, in degrees, of polar coordinates
00144 * (rho,beta) corresponding to Cartesian coordinates (x,y). It is equivalent
00145 * to the arg(x,y) function of WCS Paper II, though with transposed arguments.
00146 *
00147 * Given:
00148 *     y           double    Cartesian y-coordinate.
00149 *
00150 *     x           double    Cartesian x-coordinate.
00151 *
00152 * Function return value:
00153 *     double      Polar angle of (x,y) [deg].
00154 *
00155 * =====*/
00156
00157 #ifndef WCSLIB_WCSTRIG
00158 #define WCSLIB_WCSTRIG
00159
00160 #include <math.h>
00161
00162 #include "wcsconfig.h"
00163
00164 #ifdef HAVE_SINCOS
00165 void sincos(double angle, double *sin, double *cos);
00166 #endif
00167
00168 #ifdef __cplusplus
00169 extern "C" {
00170 #endif
00171
00172
00173 #ifdef WCSTRIG_MACRO
00174
00175 // Macro implementation of the trigd functions.
00176 #include "wcmath.h"
00177
00178 #define cosd(X) cos((X)*D2R)
00179 #define sind(X) sin((X)*D2R)
00180 #define tand(X) tan((X)*D2R)
00181 #define acosd(X) acos(X)*R2D
00182 #define asind(X) asin(X)*R2D
00183 #define atand(X) atan(X)*R2D
00184 #define atan2d(Y,X) atan2(Y,X)*R2D
00185 #ifdef HAVE_SINCOS
00186 #define sincosd(X,S,C) sincos((X)*D2R, (S), (C))
00187 #else
00188 #define sincosd(X,S,C) *(S) = sin((X)*D2R); *(C) = cos((X)*D2R);
00189 #endif
00190 #else
00191 #else
00192
00193 // Use WCSLIB wrappers or native trigd functions.
00194
00195 double cosd(double angle);
00196 double sind(double angle);
00197 void sincosd(double angle, double *sin, double *cos);
00198 double tand(double angle);
00199 double acosd(double x);
00200 double asind(double y);
00201 double atand(double s);
00202 double atan2d(double y, double x);

```

```

00203
00204 // Domain tolerance for asin() and acos() functions.
00205 #define WCSTRIG_TOL 1e-10
00206
00207 #endif // WCSTRIG_MACRO
00208
00209
00210 #ifdef __cplusplus
00211 }
00212 #endif
00213
00214 #endif // WCSLIB_WCSTRIG

```

## 8.37 wcsunits.h File Reference

```
#include "wcserr.h"
```

### Macros

- `#define WCSUNITS_PLANE_ANGLE 0`  
*Array index for plane angle units type.*
- `#define WCSUNITS_SOLID_ANGLE 1`  
*Array index for solid angle units type.*
- `#define WCSUNITS_CHARGE 2`  
*Array index for charge units type.*
- `#define WCSUNITS_MOLE 3`  
*Array index for mole units type.*
- `#define WCSUNITS_TEMPERATURE 4`  
*Array index for temperature units type.*
- `#define WCSUNITS_LUMINTEN 5`  
*Array index for luminous intensity units type.*
- `#define WCSUNITS_MASS 6`  
*Array index for mass units type.*
- `#define WCSUNITS_LENGTH 7`  
*Array index for length units type.*
- `#define WCSUNITS_TIME 8`  
*Array index for time units type.*
- `#define WCSUNITS_BEAM 9`  
*Array index for beam units type.*
- `#define WCSUNITS_BIN 10`  
*Array index for bin units type.*
- `#define WCSUNITS_BIT 11`  
*Array index for bit units type.*
- `#define WCSUNITS_COUNT 12`  
*Array index for count units type.*
- `#define WCSUNITS_MAGNITUDE 13`  
*Array index for stellar magnitude units type.*
- `#define WCSUNITS_PIXEL 14`  
*Array index for pixel units type.*
- `#define WCSUNITS_SOLRATIO 15`  
*Array index for solar mass ratio units type.*
- `#define WCSUNITS_VOXEL 16`  
*Array index for voxel units type.*
- `#define WCSUNITS_NTYPE 17`  
*Number of entries in the units array.*

## Enumerations

- enum `wcsunits_errmsg_enum` {  
`UNITERR_SUCCESS` = 0 , `UNITERR_BAD_NUM_MULTIPLIER` = 1 , `UNITERR_DANGLING_BINOP` = 2 , `UNITERR_BAD_INITIAL_SYMBOL` = 3 ,  
`UNITERR_FUNCTION_CONTEXT` = 4 , `UNITERR_BAD_EXPON_SYMBOL` = 5 , `UNITERR_UNBAL_BRACKET` = 6 , `UNITERR_UNBAL_PAREN` = 7 ,  
`UNITERR_CONSEC_BINOPS` = 8 , `UNITERR_PARSER_ERROR` = 9 , `UNITERR_BAD_UNIT_SPEC` = 10 , `UNITERR_BAD_FUNCS` = 11 ,  
`UNITERR_UNSAFE_TRANS` = 12 }

## Functions

- int `wcsunitse` (const char have[], const char want[], double \*scale, double \*offset, double \*power, struct `wcserr` \*\*err)  
*FITS units specification conversion.*
- int `wcsutrne` (int ctrl, char unitstr[], struct `wcserr` \*\*err)  
*Translation of non-standard unit specifications.*
- int `wcsulexe` (const char unitstr[], int \*func, double \*scale, double units[WCSUNITS\_NTTYPE], struct `wcserr` \*\*err)  
*FITS units specification parser.*
- int `wcsunits` (const char have[], const char want[], double \*scale, double \*offset, double \*power)
- int `wcsutrn` (int ctrl, char unitstr[])
- int `wcsulex` (const char unitstr[], int \*func, double \*scale, double units[WCSUNITS\_NTTYPE])

## Variables

- const char \* `wcsunits_errmsg` []  
*Status return messages.*
- const char \* `wcsunits_types` []  
*Names of physical quantities.*
- const char \* `wcsunits_units` []  
*Names of units.*

### 8.37.1 Detailed Description

Routines in this suite deal with units specifications and conversions, as described in

"Representations of world coordinates in FITS",  
 Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)

The Flexible Image Transport System (FITS), a data format widely used in astronomy for data interchange and archive, is described in

"Definition of the Flexible Image Transport System (FITS), version 3.0",  
 Pence, W.D., Chiappetti, L., Page, C.G., Shaw, R.A., & Stobie, E. 2010,  
 A&A, 524, A42 - <http://dx.doi.org/10.1051/0004-6361/201015362>

#### See also http:

These routines perform basic units-related operations:

- `wcsunitse()`: given two unit specifications, derive the conversion from one to the other.
- `wcsutrne()`: translates certain commonly used but non-standard unit strings. It is intended to be called before `wcsulexe()` which only handles standard FITS units specifications.
- `wcsulexe()`: parses a standard FITS units specification of arbitrary complexity, deriving the conversion to canonical units.

### 8.37.2 Macro Definition Documentation

#### WCSUNITS\_PLANE\_ANGLE

```
#define WCSUNITS_PLANE_ANGLE 0
```

Array index for plane angle units type.

Array index for plane angle units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

#### WCSUNITS\_SOLID\_ANGLE

```
#define WCSUNITS_SOLID_ANGLE 1
```

Array index for solid angle units type.

Array index for solid angle units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

#### WCSUNITS\_CHARGE

```
#define WCSUNITS_CHARGE 2
```

Array index for charge units type.

Array index for charge units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

#### WCSUNITS\_MOLE

```
#define WCSUNITS_MOLE 3
```

Array index for mole units type.

Array index for mole ("gram molecular weight") units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

#### WCSUNITS\_TEMPERATURE

```
#define WCSUNITS_TEMPERATURE 4
```

Array index for temperature units type.

Array index for temperature units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

## WCSUNITS\_LUMINTEN

```
#define WCSUNITS_LUMINTEN 5
```

Array index for luminous intensity units type.

Array index for luminous intensity units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

## WCSUNITS\_MASS

```
#define WCSUNITS_MASS 6
```

Array index for mass units type.

Array index for mass units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

## WCSUNITS\_LENGTH

```
#define WCSUNITS_LENGTH 7
```

Array index for length units type.

Array index for length units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

## WCSUNITS\_TIME

```
#define WCSUNITS_TIME 8
```

Array index for time units type.

Array index for time units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

## WCSUNITS\_BEAM

```
#define WCSUNITS_BEAM 9
```

Array index for beam units type.

Array index for beam units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

## WCSUNITS\_BIN

```
#define WCSUNITS_BIN 10
```

Array index for bin units type.

Array index for bin units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

**WCSUNITS\_BIT**

```
#define WCSUNITS_BIT 11
```

Array index for bit units type.

Array index for bit units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

**WCSUNITS\_COUNT**

```
#define WCSUNITS_COUNT 12
```

Array index for count units type.

Array index for count units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

**WCSUNITS\_MAGNITUDE**

```
#define WCSUNITS_MAGNITUDE 13
```

Array index for stellar magnitude units type.

Array index for stellar magnitude units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

**WCSUNITS\_PIXEL**

```
#define WCSUNITS_PIXEL 14
```

Array index for pixel units type.

Array index for pixel units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

**WCSUNITS\_SOLRATIO**

```
#define WCSUNITS_SOLRATIO 15
```

Array index for solar mass ratio units type.

Array index for solar mass ratio units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

**WCSUNITS\_VOXEL**

```
#define WCSUNITS_VOXEL 16
```

Array index for voxel units type.

Array index for voxel units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

## WCSUNITS\_NTTYPE

```
#define WCSUNITS_NTTYPE 17
```

Number of entries in the units array.

Number of entries in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

### 8.37.3 Enumeration Type Documentation

#### wcsunits\_errmsg\_enum

```
enum wcsunits_errmsg_enum
```

##### Enumerator

UNITERR_SUCCESS	
UNITERR_BAD_NUM_MULTIPLIER	
UNITERR_DANGLING_BINOP	
UNITERR_BAD_INITIAL_SYMBOL	
UNITERR_FUNCTION_CONTEXT	
UNITERR_BAD_EXPON_SYMBOL	
UNITERR_UNBAL_BRACKET	
UNITERR_UNBAL_PAREN	
UNITERR_CONSEC_BINOPS	
UNITERR_PARSER_ERROR	
UNITERR_BAD_UNIT_SPEC	
UNITERR_BAD_FUNCS	
UNITERR_UNSAFE_TRANS	

### 8.37.4 Function Documentation

#### wcsunitse()

```
int wcsunitse (
    const char have[],
    const char want[],
    double * scale,
    double * offset,
    double * power,
    struct wcserr ** err)
```

FITS units specification conversion.

**wcsunitse()** derives the conversion from one system of units to another.

A deprecated form of this function, [wcsunits\(\)](#), lacks the `wcserr**` parameter.

## Parameters

in	<i>have</i>	FITS units specification to convert from (null-terminated), with or without surrounding square brackets (for inline specifications); text following the closing bracket is ignored.
in	<i>want</i>	FITS units specification to convert to (null-terminated), with or without surrounding square brackets (for inline specifications); text following the closing bracket is ignored.
out	<i>scale, offset, power</i>	Convert units using <pre>pow(scale*value + offset, power);</pre> <p>Normally <i>offset</i> is zero except for log() or ln() conversions, e.g. "log(MHz)" to "ln(<math>\leftrightarrow</math> Hz)". Likewise, <i>power</i> is normally unity except for exp() conversions, e.g. "exp(ms)" to "exp(/Hz)". Thus conversions ordinarily consist of</p> <pre>value *= scale;</pre>
out	<i>err</i>	If enabled, for function return values > 1, this struct will contain a detailed error message, see <a href="#">wcserr_enable()</a> . May be NULL if an error message is not desired. Otherwise, the user is responsible for deleting the memory allocated for the wcserr struct.

## Returns

Status return value:

- 0: Success.
- 1-9: Status return from [wcsulexe\(\)](#).
- 10: Non-conformant unit specifications.
- 11: Non-conformant functions.

scale is zeroed on return if an error occurs.

## wcsutrne()

```
int wcsutrne (
    int ctrl,
    char unitstr[],
    struct wcserr ** err)
```

Translation of non-standard unit specifications.

**wcsutrne()** translates certain commonly used but non-standard unit strings, e.g. "DEG", "MHZ", "KELVIN", that are not recognized by [wcsulexe\(\)](#), refer to the notes below for a full list. Compounds are also recognized, e.g. "JY/BEAM" and "KM/SEC/SEC". Extraneous embedded blanks are removed.

A deprecated form of this function, [wcsutrn\(\)](#), lacks the wcserr\*\* parameter.

## Parameters

<i>in</i>	<i>ctrl</i>	<p>Although "S" is commonly used to represent seconds, its translation to "s" is potentially unsafe since the standard recognizes "S" formally as Siemens, however rarely that may be used. The same applies to "H" for hours (Henry), and "D" for days (Debye). This bit-flag controls what to do in such cases:</p> <ul style="list-style-type: none"> <li>• 1: Translate "S" to "s".</li> <li>• 2: Translate "H" to "h".</li> <li>• 4: Translate "D" to "d".</li> </ul> <p>Thus <code>ctrl == 0</code> doesn't do any unsafe translations, whereas <code>ctrl == 7</code> does all of them.</p>
<i>in, out</i>	<i>unitstr</i>	<p>Null-terminated character array containing the units specification to be translated. Inline units specifications in a FITS header keycomment are also handled. If the first non-blank character in <code>unitstr</code> is '[' then the unit string is delimited by its matching ']'. Blanks preceding '[' will be stripped off, but text following the closing bracket will be preserved without modification.</p>
<i>in, out</i>	<i>err</i>	<p>If enabled, for function return values <math>&gt; 1</math>, this struct will contain a detailed error message, see <a href="#">wcserr_enable()</a>. May be NULL if an error message is not desired. Otherwise, the user is responsible for deleting the memory allocated for the <code>wcserr</code> struct.</p>

## Returns

Status return value:

- -1: No change was made, other than stripping blanks (not an error).
- 0: Success.
- 9: Internal parser error.
- 12: Potentially unsafe translation, whether applied or not (see notes).

## Notes:

1. Translation of non-standard unit specifications: apart from leading and trailing blanks, a case-sensitive match is required for the aliases listed below, in particular the only recognized aliases with metric prefixes are "KM", "KHZ", "MHZ", and "GHZ". Potentially unsafe translations of "D", "H", and "S", shown in parentheses, are optional.

Unit	Recognized aliases
----	-----
Angstrom	Angstroms angstrom angstroms
arcmin	arcmins, ARCMIN, ARCMINS
arcsec	arcsecs, ARCSEC, ARCSECS
beam	BEAM
byte	Byte
d	day, days, (D), DAY, DAYS
deg	degree, degrees, Deg, Degree, Degrees, DEG, DEGREE, DEGREES
GHz	GHZ
h	hr, (H), HR
Hz	hz, HZ
kHz	KHZ
Jy	JY
K	kelvin, kelvins, Kelvin, Kelvins, KELVIN, KELVINS
km	KM
m	metre, meter, metres, meters, M, METRE, METER, METRES, METERS
min	MIN
MHz	MHZ
Ohm	ohm
Pa	pascal, pascals, Pascal, Pascals, PASCAL, PASCALS
pixel	pixels, PIXEL, PIXELS
rad	radian, radians, RAD, RADIANT, RADIANS
s	sec, second, seconds, (S), SEC, SECOND, SECONDS
V	volt, volts, Volt, Volts, VOLT, VOLTS
yr	year, years, YR, YEAR, YEARS

The aliases "angstrom", "ohm", and "Byte" for (Angstrom, Ohm, and byte) are recognized by [wcsulexe\(\)](#) itself as an unofficial extension of the standard, but they are converted to the standard form here.

**wcsulexe()**

```
int wcsulexe (
    const char unitstr[],
    int * func,
    double * scale,
    double units[WCSUNITS_NTTYPE],
    struct wcserr ** err)
```

FITS units specification parser.

**wcsulexe()** parses a standard FITS units specification of arbitrary complexity, deriving the scale factor required to convert to canonical units - basically SI with degrees and "dimensionless" additions such as byte, pixel and count.

A deprecated form of this function, [wcsulex\(\)](#), lacks the *wcserr\*\** parameter.

**Parameters**

in	<i>unitstr</i>	Null-terminated character array containing the units specification, with or without surrounding square brackets (for inline specifications); text following the closing bracket is ignored.
out	<i>func</i>	Special function type, see note 4: <ul style="list-style-type: none"> <li>• 0: None</li> <li>• 1: log() ...base 10</li> <li>• 2: ln() ...base e</li> <li>• 3: exp()</li> </ul>
out	<i>scale</i>	Scale factor for the unit specification; multiply a value expressed in the given units by this factor to convert it to canonical units.
out	<i>units</i>	A units specification is decomposed into powers of 16 fundamental unit types: angle, mass, length, time, count, pixel, etc. Preprocessor macro <code>WCSUNITS_NTTYPE</code> is defined to dimension this vector, and others such as <code>WCSUNITS_PLANE_ANGLE</code> , <code>WCSUNITS_LENGTH</code> , etc. to access its elements. Corresponding character strings, <code>wcsunits_types[]</code> and <code>wcsunits_units[]</code> , are predefined to describe each quantity and its canonical units.
out	<i>err</i>	If enabled, for function return values $> 1$ , this struct will contain a detailed error message, see <a href="#">wcserr_enable()</a> . May be NULL if an error message is not desired. Otherwise, the user is responsible for deleting the memory allocated for the <i>wcserr</i> struct.

**Returns**

Status return value:

- 0: Success.
- 1: Invalid numeric multiplier.
- 2: Dangling binary operator.
- 3: Invalid symbol in INITIAL context.
- 4: Function in invalid context.
- 5: Invalid symbol in EXPON context.
- 6: Unbalanced bracket.
- 7: Unbalanced parenthesis.

- 8: Consecutive binary operators.
- 9: Internal parser error.

scale and units[] are zeroed on return if an error occurs.

#### Notes:

1. **wcsulexe()** is permissive in accepting whitespace in all contexts in a units specification where it does not create ambiguity (e.g. not between a metric prefix and a basic unit string), including in strings like "log (m \*\* 2)" which is formally disallowed.
2. Supported extensions:
  - "angstrom" (OGIP usage) is allowed in addition to "Angstrom".
  - "ohm" (OGIP usage) is allowed in addition to "Ohm".
  - "Byte" (common usage) is allowed in addition to "byte".
3. Table 6 of WCS Paper I lists eleven units for which metric prefixes are allowed. However, in this implementation only prefixes greater than unity are allowed for "a" (annum), "yr" (year), "pc" (parsec), "bit", and "byte", and only prefixes less than unity are allowed for "mag" (stellar magnitude).  
Metric prefix "P" (peta) is specifically forbidden for "a" (annum) to avoid confusion with "Pa" (Pascal, not peta-annum). Note that metric prefixes are specifically disallowed for "h" (hour) and "d" (day) so that "ph" (photons) cannot be interpreted as pico-hours, nor "cd" (candela) as centi-days.
4. Function types log(), ln() and exp() may only occur at the start of the units specification. The scale and units[] returned for these refers to the string inside the function "argument", e.g. to "MHz" in log(MHz) for which a scale of  $10^6$  will be returned.

#### wcsunits()

```
int wcsunits (
    const char have[],
    const char want[],
    double * scale,
    double * offset,
    double * power)
```

#### wcsutrn()

```
int wcsutrn (
    int ctrl,
    char unitstr[])
```

#### wcsulex()

```
int wcsulex (
    const char unitstr[],
    int * func,
    double * scale,
    double units[WCSUNITS_NTTYPE])
```

### 8.37.5 Variable Documentation

#### **wcsunits\_errmsg**

```
const char* wcsunits_errmsg[] [extern]
```

Status return messages.

Error messages to match the status value returned from each function.

#### **wcsunits\_types**

```
const char* wcsunits_types[] [extern]
```

Names of physical quantities.

Names for physical quantities to match the units vector returned by **wcsulexe()**:

- 0: plane angle
- 1: solid angle
- 2: charge
- 3: mole
- 4: temperature
- 5: luminous intensity
- 6: mass
- 7: length
- 8: time
- 9: beam
- 10: bin
- 11: bit
- 12: count
- 13: stellar magnitude
- 14: pixel
- 15: solar ratio
- 16: voxel

**wcsunits\_units**

```
const char* wcsunits_units[] [extern]
```

Names of units.

Names for the units (SI) to match the units vector returned by **wcsulexe()**:

- 0: degree
- 1: steradian
- 2: Coulomb
- 3: mole
- 4: Kelvin
- 5: candela
- 6: kilogram
- 7: metre
- 8: second

The remainder are dimensionless.

**8.38 wcsunits.h**

[Go to the documentation of this file.](#)

```
00001 /*=====
00002  WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003  Copyright (C) 1995-2025, Mark Calabretta
00004
00005  This file is part of WCSLIB.
00006
00007  WCSLIB is free software: you can redistribute it and/or modify it under the
00008  terms of the GNU Lesser General Public License as published by the Free
00009  Software Foundation, either version 3 of the License, or (at your option)
00010  any later version.
00011
00012  WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013  WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
00014  FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015  more details.
00016
00017  You should have received a copy of the GNU Lesser General Public License
00018  along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020  Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021  http://www.atnf.csiro.au/people/Mark.Calabretta
00022  $Id: wcsunits.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023 *=====
00024 *
00025 * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026 * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027 * overview of the library.
00028 *
00029 *
00030 * Summary of the wcsunits routines
00031 * -----
00032 * Routines in this suite deal with units specifications and conversions, as
00033 * described in
00034 *
00035 * "Representations of world coordinates in FITS",
00036 * Greisen, E.W., & Calabretta, M.R. 2002, A&A, 395, 1061 (WCS Paper I)
00037 *
00038 * The Flexible Image Transport System (FITS), a data format widely used in
00039 * astronomy for data interchange and archive, is described in
00040 *
```

```

00041 = "Definition of the Flexible Image Transport System (FITS), version 3.0",
00042 = Pence, W.D., Chiappetti, L., Page, C.G., Shaw, R.A., & Stobie, E. 2010,
00043 = A&A, 524, A42 - http://dx.doi.org/10.1051/0004-6361/201015362
00044 *
00045 * See also http://fits.gsfc.nasa.gov
00046 *
00047 * These routines perform basic units-related operations:
00048 *
00049 * - wcsunitse(): given two unit specifications, derive the conversion from
00050 *   one to the other.
00051 *
00052 * - wcsutrne(): translates certain commonly used but non-standard unit
00053 *   strings. It is intended to be called before wcsulexe() which only
00054 *   handles standard FITS units specifications.
00055 *
00056 * - wcsulexe(): parses a standard FITS units specification of arbitrary
00057 *   complexity, deriving the conversion to canonical units.
00058 *
00059 *
00060 * wcsunitse() - FITS units specification conversion
00061 * -----
00062 * wcsunitse() derives the conversion from one system of units to another.
00063 *
00064 * A deprecated form of this function, wcsunits(), lacks the wcserr**
00065 * parameter.
00066 *
00067 * Given:
00068 *   have      const char []
00069 *               FITS units specification to convert from (null-
00070 *               terminated), with or without surrounding square
00071 *               brackets (for inline specifications); text following
00072 *               the closing bracket is ignored.
00073 *
00074 *   want      const char []
00075 *               FITS units specification to convert to (null-
00076 *               terminated), with or without surrounding square
00077 *               brackets (for inline specifications); text following
00078 *               the closing bracket is ignored.
00079 *
00080 * Returned:
00081 *   scale,
00082 *   offset,
00083 *   power      double*   Convert units using
00084 *
00085 *               pow(scale*value + offset, power);
00086 *
00087 *               Normally offset is zero except for log() or ln()
00088 *               conversions, e.g. "log(MHz)" to "ln(Hz)". Likewise,
00089 *               power is normally unity except for exp() conversions,
00090 *               e.g. "exp(ms)" to "exp(/Hz)". Thus conversions
00091 *               ordinarily consist of
00092 *
00093 *               value *= scale;
00094 *
00095 *   err        struct wcserr **
00096 *               If enabled, for function return values > 1, this
00097 *               struct will contain a detailed error message, see
00098 *               wcserr_enable(). May be NULL if an error message is
00099 *               not desired. Otherwise, the user is responsible for
00100 *               deleting the memory allocated for the wcserr struct.
00101 *
00102 * Function return value:
00103 *   int        Status return value:
00104 *               0: Success.
00105 *               1-9: Status return from wcsulexe().
00106 *               10: Non-conformant unit specifications.
00107 *               11: Non-conformant functions.
00108 *
00109 *               scale is zeroed on return if an error occurs.
00110 *
00111 *
00112 * wcsutrne() - Translation of non-standard unit specifications
00113 * -----
00114 * wcsutrne() translates certain commonly used but non-standard unit strings,
00115 * e.g. "DEG", "MHZ", "KELVIN", that are not recognized by wcsulexe(), refer to
00116 * the notes below for a full list. Compounds are also recognized, e.g.
00117 * "JY/BEAM" and "KM/SEC/SEC". Extraneous embedded blanks are removed.
00118 *
00119 * A deprecated form of this function, wcsutrn(), lacks the wcserr** parameter.
00120 *
00121 * Given:
00122 *   ctrl      int        Although "S" is commonly used to represent seconds,
00123 *                           its translation to "s" is potentially unsafe since the
00124 *                           standard recognizes "S" formally as Siemens, however
00125 *                           rarely that may be used. The same applies to "H" for
00126 *                           hours (Henry), and "D" for days (Debye). This
00127 *                           bit-flag controls what to do in such cases:

```

```

00128 *          1: Translate "S" to "s".
00129 *          2: Translate "H" to "h".
00130 *          4: Translate "D" to "d".
00131 *      Thus ctrl == 0 doesn't do any unsafe translations,
00132 *      whereas ctrl == 7 does all of them.
00133 *
00134 *  Given and returned:
00135 *      unitstr  char []  Null-terminated character array containing the units
00136 *                        specification to be translated.
00137 *
00138 *      Inline units specifications in a FITS header
00139 *      keycomment are also handled.  If the first non-blank
00140 *      character in unitstr is '[' then the unit string is
00141 *      delimited by its matching ']'.  Blanks preceding '['
00142 *      will be stripped off, but text following the closing
00143 *      bracket will be preserved without modification.
00144 *
00145 *      err      struct wcserr **
00146 *      If enabled, for function return values > 1, this
00147 *      struct will contain a detailed error message, see
00148 *      wcserr_enable().  May be NULL if an error message is
00149 *      not desired.  Otherwise, the user is responsible for
00150 *      deleting the memory allocated for the wcserr struct.
00151 *
00152 *  Function return value:
00153 *      int      Status return value:
00154 *      -1: No change was made, other than stripping blanks
00155 *          (not an error).
00156 *      0: Success.
00157 *      9: Internal parser error.
00158 *      12: Potentially unsafe translation, whether applied
00159 *          or not (see notes).
00160 *
00161 *  Notes:
00162 *      1: Translation of non-standard unit specifications: apart from leading and
00163 *      trailing blanks, a case-sensitive match is required for the aliases
00164 *      listed below, in particular the only recognized aliases with metric
00165 *      prefixes are "KM", "KHZ", "MHZ", and "GHZ".  Potentially unsafe
00166 *      translations of "D", "H", and "S", shown in parentheses, are optional.
00167 *
00168 *      Unit      Recognized aliases
00169 *      ----
00170 *      Angstrom  Angstroms angstrom angstroms
00171 *      arcmin    arcmins, ARCMIN, ARCMINS
00172 *      arcsec    arcsecs, ARCSEC, ARCSECS
00173 *      beam      BEAM
00174 *      byte      Byte
00175 *      d          day, days, (D), DAY, DAYS
00176 *      deg        degree, degrees, Deg, Degree, Degrees, DEG, DEGREE,
00177 *                DEGREES
00178 *      GHz        GHZ
00179 *      h          hr, (H), HR
00180 *      Hz         hz, HZ
00181 *      kHz        KHZ
00182 *      Jy         JY
00183 *      K          kelvin, kelvins, Kelvin, Kelvins, KELVIN, KELVINS
00184 *      km         KM
00185 *      m          metre, meter, metres, meters, M, METRE, METER, METRES,
00186 *                METERS
00187 *      min        MIN
00188 *      MHz        MHZ
00189 *      Ohm        ohm
00190 *      Pa         pascal, pascals, Pascal, Pascals, PASCAL, PASCALS
00191 *      pixel      pixels, PIXEL, PIXELS
00192 *      rad        radian, radians, RAD, Radian, RADIANS
00193 *      s          sec, second, seconds, (S), SEC, SECOND, SECONDS
00194 *      V          volt, volts, Volt, Volts, VOLT, VOLTS
00195 *      yr         year, years, YR, YEAR, YEARS
00196 *
00197 *      The aliases "angstrom", "ohm", and "Byte" for (Angstrom, Ohm, and byte)
00198 *      are recognized by wcsulexe() itself as an unofficial extension of the
00199 *      standard, but they are converted to the standard form here.
00200 *
00201 *
00202 *  wcsulexe() - FITS units specification parser
00203 *  -----
00204 *  wcsulexe() parses a standard FITS units specification of arbitrary
00205 *  complexity, deriving the scale factor required to convert to canonical
00206 *  units - basically SI with degrees and "dimensionless" additions such as
00207 *  byte, pixel and count.
00208 *
00209 *  A deprecated form of this function, wcsulex(), lacks the wcserr** parameter.
00210 *
00211 *  Given:
00212 *      unitstr  const char []
00213 *      Null-terminated character array containing the units
00214 *      specification, with or without surrounding square

```

```

00215 *          brackets (for inline specifications); text following
00216 *          the closing bracket is ignored.
00217 *
00218 * Returned:
00219 *   func      int*      Special function type, see note 4:
00220 *                   0: None
00221 *                   1: log()   ...base 10
00222 *                   2: ln()    ...base e
00223 *                   3: exp()
00224 *
00225 *   scale      double*   Scale factor for the unit specification; multiply a
00226 *                   value expressed in the given units by this factor to
00227 *                   convert it to canonical units.
00228 *
00229 *   units      double[WCSUNITS_NTTYPE]
00230 *                   A units specification is decomposed into powers of 16
00231 *                   fundamental unit types: angle, mass, length, time,
00232 *                   count, pixel, etc. Preprocessor macro WCSUNITS_NTTYPE
00233 *                   is defined to dimension this vector, and others such
00234 *                   WCSUNITS_PLANE_ANGLE, WCSUNITS_LENGTH, etc. to access
00235 *                   its elements.
00236 *
00237 *                   Corresponding character strings, wcsunits_types[] and
00238 *                   wcsunits_units[], are predefined to describe each
00239 *                   quantity and its canonical units.
00240 *
00241 *   err        struct wcserr **
00242 *                   If enabled, for function return values > 1, this
00243 *                   struct will contain a detailed error message, see
00244 *                   wcserr_enable(). May be NULL if an error message is
00245 *                   not desired. Otherwise, the user is responsible for
00246 *                   deleting the memory allocated for the wcserr struct.
00247 *
00248 * Function return value:
00249 *   int        Status return value:
00250 *                   0: Success.
00251 *                   1: Invalid numeric multiplier.
00252 *                   2: Dangling binary operator.
00253 *                   3: Invalid symbol in INITIAL context.
00254 *                   4: Function in invalid context.
00255 *                   5: Invalid symbol in EXPON context.
00256 *                   6: Unbalanced bracket.
00257 *                   7: Unbalanced parenthesis.
00258 *                   8: Consecutive binary operators.
00259 *                   9: Internal parser error.
00260 *
00261 *                   scale and units[] are zeroed on return if an error
00262 *                   occurs.
00263 *
00264 * Notes:
00265 *   1: wcsulexe() is permissive in accepting whitespace in all contexts in a
00266 *       units specification where it does not create ambiguity (e.g. not
00267 *       between a metric prefix and a basic unit string), including in strings
00268 *       like "log (m ** 2)" which is formally disallowed.
00269 *
00270 *   2: Supported extensions:
00271 *       - "angstrom" (OGIP usage) is allowed in addition to "Angstrom".
00272 *       - "ohm" (OGIP usage) is allowed in addition to "Ohm".
00273 *       - "Byte" (common usage) is allowed in addition to "byte".
00274 *
00275 *   3: Table 6 of WCS Paper I lists eleven units for which metric prefixes are
00276 *       allowed. However, in this implementation only prefixes greater than
00277 *       unity are allowed for "a" (annum), "yr" (year), "pc" (parsec), "bit",
00278 *       and "byte", and only prefixes less than unity are allowed for "mag"
00279 *       (stellar magnitude).
00280 *
00281 *       Metric prefix "P" (peta) is specifically forbidden for "a" (annum) to
00282 *       avoid confusion with "Pa" (Pascal, not peta-annum). Note that metric
00283 *       prefixes are specifically disallowed for "h" (hour) and "d" (day) so
00284 *       that "ph" (photons) cannot be interpreted as pico-hours, nor "cd"
00285 *       (candela) as centi-days.
00286 *
00287 *   4: Function types log(), ln() and exp() may only occur at the start of the
00288 *       units specification. The scale and units[] returned for these refers
00289 *       to the string inside the function "argument", e.g. to "MHz" in log(MHz)
00290 *       for which a scale of 1e6 will be returned.
00291 *
00292 *
00293 * Global variable: const char *wcsunits_errmsg[] - Status return messages
00294 * -----
00295 * Error messages to match the status value returned from each function.
00296 *
00297 *
00298 * Global variable: const char *wcsunits_types[] - Names of physical quantities
00299 * -----
00300 * Names for physical quantities to match the units vector returned by
00301 * wcsulexe():

```

```

00302 * - 0: plane angle
00303 * - 1: solid angle
00304 * - 2: charge
00305 * - 3: mole
00306 * - 4: temperature
00307 * - 5: luminous intensity
00308 * - 6: mass
00309 * - 7: length
00310 * - 8: time
00311 * - 9: beam
00312 * - 10: bin
00313 * - 11: bit
00314 * - 12: count
00315 * - 13: stellar magnitude
00316 * - 14: pixel
00317 * - 15: solar ratio
00318 * - 16: voxel
00319 *
00320 *
00321 * Global variable: const char *wcsunits_units[] - Names of units
00322 * -----
00323 * Names for the units (SI) to match the units vector returned by wcsulexe():
00324 * - 0: degree
00325 * - 1: steradian
00326 * - 2: Coulomb
00327 * - 3: mole
00328 * - 4: Kelvin
00329 * - 5: candela
00330 * - 6: kilogram
00331 * - 7: metre
00332 * - 8: second
00333 *
00334 * The remainder are dimensionless.
00335 *=====*/
00336
00337 #ifndef WCSLIB_WCSUNITS
00338 #define WCSLIB_WCSUNITS
00339
00340 #include "wcserr.h"
00341
00342 #ifdef __cplusplus
00343 extern "C" {
00344 #endif
00345
00346
00347 extern const char *wcsunits_errmsg[];
00348
00349 enum wcsunits_errmsg_enum {
00350     UNITERR_SUCCESS = 0, // Success.
00351     UNITERR_BAD_NUM_MULTIPLIER = 1, // Invalid numeric multiplier.
00352     UNITERR_DANGLING_BINOP = 2, // Dangling binary operator.
00353     UNITERR_BAD_INITIAL_SYMBOL = 3, // Invalid symbol in INITIAL context.
00354     UNITERR_FUNCTION_CONTEXT = 4, // Function in invalid context.
00355     UNITERR_BAD_EXPON_SYMBOL = 5, // Invalid symbol in EXPON context.
00356     UNITERR_UNBAL_BRACKET = 6, // Unbalanced bracket.
00357     UNITERR_UNBAL_PAREN = 7, // Unbalanced parenthesis.
00358     UNITERR_CONSEC_BINOPS = 8, // Consecutive binary operators.
00359     UNITERR_PARSER_ERROR = 9, // Internal parser error.
00360     UNITERR_BAD_UNIT_SPEC = 10, // Non-conformant unit specifications.
00361     UNITERR_BAD_FUNCS = 11, // Non-conformant functions.
00362     UNITERR_UNSAFE_TRANS = 12 // Potentially unsafe translation.
00363 };
00364
00365 extern const char *wcsunits_types[];
00366 extern const char *wcsunits_units[];
00367
00368 #define WCSUNITS_PLANE_ANGLE 0
00369 #define WCSUNITS_SOLID_ANGLE 1
00370 #define WCSUNITS_CHARGE 2
00371 #define WCSUNITS_MOLE 3
00372 #define WCSUNITS_TEMPERATURE 4
00373 #define WCSUNITS_LUMINTEN 5
00374 #define WCSUNITS_MASS 6
00375 #define WCSUNITS_LENGTH 7
00376 #define WCSUNITS_TIME 8
00377 #define WCSUNITS_BEAM 9
00378 #define WCSUNITS_BIN 10
00379 #define WCSUNITS_BIT 11
00380 #define WCSUNITS_COUNT 12
00381 #define WCSUNITS_MAGNITUDE 13
00382 #define WCSUNITS_PIXEL 14
00383 #define WCSUNITS_SOLRATIO 15
00384 #define WCSUNITS_VOXEL 16
00385
00386 #define WCSUNITS_NTTYPE 17
00387
00388

```

```

00389 int wcsunitse(const char have[], const char want[], double *scale,
00390               double *offset, double *power, struct wcserr **err);
00391
00392 int wcsutrne(int ctrl, char unitstr[], struct wcserr **err);
00393
00394 int wcsulexe(const char unitstr[], int *func, double *scale,
00395             double units[WCSUNITS_NTTYPE], struct wcserr **err);
00396
00397 // Deprecated.
00398 int wcsunits(const char have[], const char want[], double *scale,
00399             double *offset, double *power);
00400 int wcsutrn(int ctrl, char unitstr[]);
00401 int wcsulex(const char unitstr[], int *func, double *scale,
00402            double units[WCSUNITS_NTTYPE]);
00403
00404 #ifdef __cplusplus
00405 }
00406 #endif
00407
00408 #endif // WCSLIB_WCSUNITS

```

## 8.39 wcsutil.h File Reference

### Functions

- void [wcsdealloc](#) (void \*ptr)  
*free memory allocated by WCSLIB functions.*
- void [wcsutil\\_strcvt](#) (int n, char c, int nt, const char src[], char dst[])  
*Copy character string with padding.*
- void [wcsutil\\_blank\\_fill](#) (int n, char c[])  
*Fill a character string with blanks.*
- void [wcsutil\\_null\\_fill](#) (int n, char c[])  
*Fill a character string with NULLs.*
- int [wcsutil\\_all\\_ival](#) (int nelelem, int ival, const int iarr[])  
*Test if all elements an int array have a given value.*
- int [wcsutil\\_all\\_dval](#) (int nelelem, double dval, const double darr[])  
*Test if all elements a double array have a given value.*
- int [wcsutil\\_all\\_sval](#) (int nelelem, const char \*sval, const char(\*sarr)[72])  
*Test if all elements a string array have a given value.*
- int [wcsutil\\_allEq](#) (int nvec, int nelelem, const double \*first)  
*Test for equality of a particular vector element.*
- int [wcsutil\\_dblEq](#) (int nelelem, double tol, const double \*arr1, const double \*arr2)  
*Test for equality of two arrays of type double.*
- int [wcsutil\\_intEq](#) (int nelelem, const int \*arr1, const int \*arr2)  
*Test for equality of two arrays of type int.*
- int [wcsutil\\_strEq](#) (int nelelem, char(\*arr1)[72], char(\*arr2)[72])  
*Test for equality of two string arrays.*
- void [wcsutil\\_setAll](#) (int nvec, int nelelem, double \*first)  
*Set a particular vector element.*
- void [wcsutil\\_setAli](#) (int nvec, int nelelem, int \*first)  
*Set a particular vector element.*
- void [wcsutil\\_setBit](#) (int nelelem, const int \*sel, int bits, int \*array)  
*Set bits in selected elements of an array.*
- char \* [wcsutil\\_fptr2str](#) (void(\*fptr)(void), char hex[19])  
*Translate pointer-to-function to string.*
- void [wcsutil\\_double2str](#) (char \*buf, const char \*format, double value)  
*Translate double to string ignoring the locale.*
- int [wcsutil\\_str2double](#) (const char \*buf, double \*value)  
*Translate string to a double, ignoring the locale.*
- int [wcsutil\\_str2double2](#) (const char \*buf, double \*value)  
*Translate string to doubles, ignoring the locale.*

### 8.39.1 Detailed Description

Simple utility functions. With the exception of [wcsdealloc\(\)](#), these functions are intended for **internal use only** by WCSLIB.

The internal-use functions are documented here solely as an aid to understanding the code. They are not intended for external use - the API may change without notice!

### 8.39.2 Function Documentation

#### wcsdealloc()

```
void wcsdealloc (
    void * ptr)
```

free memory allocated by WCSLIB functions.

**wcsdealloc()** invokes the `free()` system routine to free memory. Specifically, it is intended to free memory allocated (using `calloc()`) by certain WCSLIB functions (e.g. [wcshto\(\)](#), [wcsfixi\(\)](#), [fitshdr\(\)](#)), which it is the user's responsibility to deallocate.

In certain situations, for example multithreading, it may be important that this be done within the WCSLIB sharable library's runtime environment.

**PLEASE NOTE:** **wcsdealloc()** must not be used in place of the destructors for particular structs, such as [wcsfree\(\)](#), [celfree\(\)](#), etc.

#### Parameters

in, out	<i>ptr</i>	Address of the allocated memory.
---------	------------	----------------------------------

#### Returns

#### wcsutil\_strcvt()

```
void wcsutil_strcvt (
    int n,
    char c,
    int nt,
    const char src[],
    char dst[])
```

Copy character string with padding.

#### INTERNAL USE ONLY.

**wcsutil\_strcvt()** copies one character string to another up to the specified maximum number of characters.

If the given string is null-terminated, then the NULL character copied to the returned string, and all characters following it up to the specified maximum are replaced with the specified substitute character, either blank or NULL.

If the source string is not null-terminated and the substitute character is blank, then copy the maximum number of characters and do nothing further. However, if the substitute character is NULL, then the last character and all

**Parameters**

in	<i>n</i>	Maximum number of characters to copy.
in	<i>c</i>	Substitute character, either NULL or blank (anything other than NULL).
in	<i>nt</i>	If true, then dst is of length $n+1$ , with the last character always set to NULL.
in	<i>src</i>	Character string to be copied. If null-terminated, then need not be of length $n$ , otherwise it must be.
out	<i>dst</i>	Destination character string, which must be long enough to hold $n$ characters. Note that this string will not be null-terminated if the substitute character is blank.

**Returns****wcsutil\_blank\_fill()**

```
void wcsutil_blank_fill (
    int n,
    char c[])
```

Fill a character string with blanks.

**INTERNAL USE ONLY.**

**wcsutil\_blank\_fill()** pads a character sub-string with blanks starting with the terminating NULL character (if any).

**Parameters**

in	<i>n</i>	Length of the sub-string.
in, out	<i>c</i>	The character sub-string, which will not be null-terminated on return.

**Returns****wcsutil\_null\_fill()**

```
void wcsutil_null_fill (
    int n,
    char c[])
```

Fill a character string with NULLs.

**INTERNAL USE ONLY.**

**wcsutil\_null\_fill()** strips trailing blanks from a string (or sub-string) and propagates the terminating NULL character (if any) to the end of the string.

If the string is not null-terminated, then the last character and all consecutive blank characters preceding it will be replaced with NULLs.

Mainly used in the C library to strip trailing blanks from FITS keyvalues. Also used to make character strings intel-

**Parameters**

in	<i>n</i>	Number of characters.
in, out	<i>c</i>	The character (sub-)string.

**Returns****wcsutil\_all\_ival()**

```
int wcsutil_all_ival (  
    int nelem,  
    int ival,  
    const int iarr[])
```

Test if all elements an int array have a given value.

**INTERNAL USE ONLY.**

**wcsutil\_all\_ival()** tests whether all elements of an array of type int all have the specified value.

**Parameters**

in	<i>nelem</i>	The length of the array.
in	<i>ival</i>	Value to be tested.
in	<i>iarr</i>	Pointer to the first element of the array.

**Returns**

Status return value:

- 0: Not all equal.
- 1: All equal.

**wcsutil\_all\_dval()**

```
int wcsutil_all_dval (  
    int nelem,  
    double dval,  
    const double darr[])
```

Test if all elements a double array have a given value.

**INTERNAL USE ONLY.**

**wcsutil\_all\_dval()** tests whether all elements of an array of type double all have the specified value.

**Parameters**

in	<i>nelem</i>	The length of the array.
in	<i>dval</i>	Value to be tested.
in	<i>darr</i>	Pointer to the first element of the array.

**Returns**

Status return value:

- 0: Not all equal.
- 1: All equal.

**wcsutil\_all\_sval()**

```
int wcsutil_all_sval (  
    int nelem,  
    const char * sval,  
    const char(*) sarr[72])
```

Test if all elements a string array have a given value.

**INTERNAL USE ONLY.**

**wcsutil\_all\_sval()** tests whether the elements of an array of type char (\*)[72] all have the specified value.

**Parameters**

in	<i>nelem</i>	The length of the array.
in	<i>sval</i>	String to be tested.
in	<i>sarr</i>	Pointer to the first element of the array.

**Returns**

Status return value:

- 0: Not all equal.
- 1: All equal.

**wcsutil\_allEq()**

```
int wcsutil_allEq (  
    int nvec,  
    int nelem,  
    const double * first)
```

Test for equality of a particular vector element.

**INTERNAL USE ONLY.**

**wcsutil\_allEq()** tests for equality of a particular element in a set of vectors.

**Parameters**

in	<i>nvec</i>	The number of vectors.
in	<i>nelem</i>	The length of each vector.
in	<i>first</i>	<p>Pointer to the first element to test in the array. The elements tested for equality are</p> <pre> *first == *(first + nelem)       == *(first + nelem*2)           :       == *(first + nelem*(nvec-1)); </pre> <p>The array might be dimensioned as</p> <pre>double v[nvec][nelem];</pre>

**Returns**

Status return value:

- 0: Not all equal.
- 1: All equal.

**wcsutil\_dblEq()**

```
int wcsutil_dblEq (
    int nelem,
    double tol,
    const double * arr1,
    const double * arr2)
```

Test for equality of two arrays of type double.

**INTERNAL USE ONLY.**

**wcsutil\_dblEq()** tests for equality of two double-precision arrays.

**Parameters**

in	<i>nelem</i>	The number of elements in each array.
in	<i>tol</i>	Tolerance for comparison of the floating-point values. For example, for <code>tol == 1e-6</code> , all floating-point values in the arrays must be equal to the first 6 decimal places. A value of 0 implies exact equality.
in	<i>arr1</i>	The first array.
in	<i>arr2</i>	The second array

**Returns**

Status return value:

- 0: Not equal.
- 1: Equal.

**wcsutil\_intEq()**

```
int wcsutil_intEq (  
    int nelem,  
    const int * arr1,  
    const int * arr2)
```

Test for equality of two arrays of type int.

**INTERNAL USE ONLY.**

**wcsutil\_intEq()** tests for equality of two int arrays.

**Parameters**

in	<i>nelem</i>	The number of elements in each array.
in	<i>arr1</i>	The first array.
in	<i>arr2</i>	The second array

**Returns**

Status return value:

- 0: Not equal.
- 1: Equal.

**wcsutil\_strEq()**

```
int wcsutil_strEq (  
    int nelem,  
    char(*) arr1[72],  
    char(*) arr2[72])
```

Test for equality of two string arrays.

**INTERNAL USE ONLY.**

**wcsutil\_strEq()** tests for equality of two string arrays.

**Parameters**

in	<i>nelem</i>	The number of elements in each array.
in	<i>arr1</i>	The first array.
in	<i>arr2</i>	The second array

**Returns**

Status return value:

- 0: Not equal.
- 1: Equal.

**wcsutil\_setAll()**

```
void wcsutil_setAll (
    int nvec,
    int nelem,
    double * first)
```

Set a particular vector element.

**INTERNAL USE ONLY.**

**wcsutil\_setAll()** sets the value of a particular element in a set of vectors of type double.

**Parameters**

in	<i>nvec</i>	The number of vectors.
in	<i>nelem</i>	The length of each vector.
in, out	<i>first</i>	Pointer to the first element in the array, the value of which is used to set the others <pre>*(first + nelem) = *first; *(first + nelem*2) = *first; : *(first + nelem*(nvec-1)) = *first;</pre> The array might be dimensioned as <pre>double v[nvec][nelem];</pre>

**Returns****wcsutil\_setAli()**

```
void wcsutil_setAli (
    int nvec,
    int nelem,
    int * first)
```

Set a particular vector element.

**INTERNAL USE ONLY.**

**wcsutil\_setAli()** sets the value of a particular element in a set of vectors of type int.

**Parameters**

in	<i>nvec</i>	The number of vectors.
in	<i>nelem</i>	The length of each vector.

<i>in, out</i>	<i>first</i>	<p>Pointer to the first element in the array, the value of which is used to set the others</p> <pre> *(first + nelem) = *first; *(first + nelem*2) = *first; : *(first + nelem*(nvec-1)) = *first; </pre> <p>The array might be dimensioned as</p> <pre>int v[nvec][nelem];</pre>
----------------	--------------	---

## Returns

## wcsutil\_setBit()

```
void wcsutil_setBit (
    int nelem,
    const int * sel,
    int bits,
    int * array)
```

Set bits in selected elements of an array.

## INTERNAL USE ONLY.

**wcsutil\_setBit()** sets bits in selected elements of an array.

## Parameters

<i>in</i>	<i>nelem</i>	Number of elements in the array.
<i>in</i>	<i>sel</i>	Address of a selection array of length nelem. May be specified as the null pointer in which case all elements are selected.
<i>in</i>	<i>bits</i>	Bit mask.
<i>in, out</i>	<i>array</i>	Address of the array of length nelem.

## Returns

## wcsutil\_fptr2str()

```
char * wcsutil_fptr2str (
    void(* fptr ) (void),
    char hext[19])
```

Translate pointer-to-function to string.

## INTERNAL USE ONLY.

**wcsutil\_fptr2str()** translates a pointer-to-function to hexadecimal string representation for output. It is used by the various routines that print the contents of WCSLIB structs, noting that it is not strictly legal to type-pun a function pointer to void\*. See <http://stackoverflow.com/questions/2741683/how-to-format-a-function-pointer>

**Parameters**

in	<i>fptr</i>	
out	<i>hext</i>	Null-terminated string. Should be at least 19 bytes in size to accomodate a 64-bit address (16 bytes in hex), plus the leading "0x" and trailing '\0'.

**Returns**

The address of *hext*.

**wcsutil\_double2str()**

```
void wcsutil_double2str (  
    char * buf,  
    const char * format,  
    double value)
```

Translate double to string ignoring the locale.

**INTERNAL USE ONLY.**

**wcsutil\_double2str()** converts a double to a string, but unlike `sprintf()` it ignores the locale and always uses a '.' as the decimal separator. Also, unless it includes an exponent, the formatted value will always have a fractional part, ".0" being appended if necessary.

**Parameters**

out	<i>buf</i>	The buffer to write the string into.
in	<i>format</i>	The formatting directive, such as "f". This may be any of the forms accepted by <code>sprintf()</code> , but should only include a formatting directive and nothing else. For "g" and "G" formats, unless it includes an exponent, the formatted value will always have a fractional part, ".0" being appended if necessary.
in	<i>value</i>	The value to convert to a string.

**wcsutil\_str2double()**

```
int wcsutil_str2double (  
    const char * buf,  
    double * value)
```

Translate string to a double, ignoring the locale.

**INTERNAL USE ONLY.**

**wcsutil\_str2double()** converts a string to a double, but unlike `sscanf()` it ignores the locale and always expects a '.' as the decimal separator.

**Parameters**

in	<i>buf</i>	The string containing the value
out	<i>value</i>	The double value parsed from the string.

**wcsutil\_str2double2()**

```
int wcsutil_str2double2 (
    const char * buf,
    double * value)
```

Translate string to doubles, ignoring the locale.

**INTERNAL USE ONLY.**

**wcsutil\_str2double2()** converts a string to a pair of doubles containing the integer and fractional parts. Unlike `sscanf()` it ignores the locale and always expects a '.' as the decimal separator.

**Parameters**

in	<i>buf</i>	The string containing the value
out	<i>value</i>	parts, parsed from the string.

**8.40 wcsutil.h**

[Go to the documentation of this file.](#)

```
00001 /*=====
00002  WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003  Copyright (C) 1995-2025, Mark Calabretta
00004
00005  This file is part of WCSLIB.
00006
00007  WCSLIB is free software: you can redistribute it and/or modify it under the
00008  terms of the GNU Lesser General Public License as published by the Free
00009  Software Foundation, either version 3 of the License, or (at your option)
00010  any later version.
00011
00012  WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013  WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
00014  FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015  more details.
00016
00017  You should have received a copy of the GNU Lesser General Public License
00018  along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020  Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021  http://www.atnf.csiro.au/people/Mark.Calabretta
00022  $Id: wcsutil.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023 *=====
00024 *
00025 * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026 * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027 * overview of the library.
00028 *
00029 *
00030 * Summary of the wcsutil routines
00031 * -----
00032 * Simple utility functions. With the exception of wcsdealloc(), these
00033 * functions are intended for internal use only by WCSLIB.
00034 *
00035 * The internal-use functions are documented here solely as an aid to
00036 * understanding the code. They are not intended for external use - the API
00037 * may change without notice!
00038 *
00039 *
```

```

00040 * wcsdealloc() - free memory allocated by WCSLIB functions
00041 * -----
00042 * wcsdealloc() invokes the free() system routine to free memory.
00043 * Specifically, it is intended to free memory allocated (using calloc()) by
00044 * certain WCSLIB functions (e.g. wcsldo(), wcsfixi(), fitshdr()), which it is
00045 * the user's responsibility to deallocate.
00046 *
00047 * In certain situations, for example multithreading, it may be important that
00048 * this be done within the WCSLIB sharable library's runtime environment.
00049 *
00050 * PLEASE NOTE: wcsdealloc() must not be used in place of the destructors for
00051 * particular structs, such as wcsfree(), celfree(), etc.
00052 *
00053 * Given and returned:
00054 *   ptr      void*      Address of the allocated memory.
00055 *
00056 * Function return value:
00057 *   void
00058 *
00059 *
00060 * wcsutil_strerror() - Copy character string with padding
00061 * -----
00062 * INTERNAL USE ONLY.
00063 *
00064 * wcsutil_strerror() copies one character string to another up to the specified
00065 * maximum number of characters.
00066 *
00067 * If the given string is null-terminated, then the NULL character copied to
00068 * the returned string, and all characters following it up to the specified
00069 * maximum, are replaced with the specified substitute character, either blank
00070 * or NULL.
00071 *
00072 * If the source string is not null-terminated and the substitute character is
00073 * blank, then copy the maximum number of characters and do nothing further.
00074 * However, if the substitute character is NULL, then the last character and
00075 * all consecutive blank characters preceding it will be replaced with NULLs.
00076 *
00077 * Used by the Fortran wrapper functions in translating C strings into Fortran
00078 * CHARACTER variables and vice versa.
00079 *
00080 * Given:
00081 *   n          int          Maximum number of characters to copy.
00082 *
00083 *   c          char         Substitute character, either NULL or blank (anything
00084 *                           other than NULL).
00085 *
00086 *   nt         int          If true, then dst is of length n+1, with the last
00087 *                           character always set to NULL.
00088 *
00089 *   src        char[]       Character string to be copied. If null-terminated,
00090 *                           then need not be of length n, otherwise it must be.
00091 *
00092 * Returned:
00093 *   dst        char[]       Destination character string, which must be long
00094 *                           enough to hold n characters. Note that this string
00095 *                           will not be null-terminated if the substitute
00096 *                           character is blank.
00097 *
00098 * Function return value:
00099 *   void
00100 *
00101 *
00102 * wcsutil_blank_fill() - Fill a character string with blanks
00103 * -----
00104 * INTERNAL USE ONLY.
00105 *
00106 * wcsutil_blank_fill() pads a character sub-string with blanks starting with
00107 * the terminating NULL character (if any).
00108 *
00109 * Given:
00110 *   n          int          Length of the sub-string.
00111 *
00112 * Given and returned:
00113 *   c          char[]       The character sub-string, which will not be
00114 *                           null-terminated on return.
00115 *
00116 * Function return value:
00117 *   void
00118 *
00119 *
00120 * wcsutil_null_fill() - Fill a character string with NULLs
00121 * -----
00122 * INTERNAL USE ONLY.
00123 *
00124 * wcsutil_null_fill() strips trailing blanks from a string (or sub-string) and
00125 * propagates the terminating NULL character (if any) to the end of the string.
00126 *

```

```

00127 * If the string is not null-terminated, then the last character and all
00128 * consecutive blank characters preceding it will be replaced with NULLs.
00129 *
00130 * Mainly used in the C library to strip trailing blanks from FITS keyvalues.
00131 * Also used to make character strings intelligible in the GNU debugger, which
00132 * prints the rubbish following the terminating NULL character, thereby
00133 * obscuring the valid part of the string.
00134 *
00135 * Given:
00136 *   n          int          Number of characters.
00137 *
00138 * Given and returned:
00139 *   c          char[]       The character (sub-)string.
00140 *
00141 * Function return value:
00142 *   void
00143 *
00144 *
00145 * wcsutil_all_ival() - Test if all elements an int array have a given value
00146 * -----
00147 * INTERNAL USE ONLY.
00148 *
00149 * wcsutil_all_ival() tests whether all elements of an array of type int all
00150 * have the specified value.
00151 *
00152 * Given:
00153 *   nelelem    int          The length of the array.
00154 *
00155 *   ival       int          Value to be tested.
00156 *
00157 *   iarr       const int[]
00158 *               Pointer to the first element of the array.
00159 *
00160 * Function return value:
00161 *   int         Status return value:
00162 *               0: Not all equal.
00163 *               1: All equal.
00164 *
00165 *
00166 * wcsutil_all_dval() - Test if all elements a double array have a given value
00167 * -----
00168 * INTERNAL USE ONLY.
00169 *
00170 * wcsutil_all_dval() tests whether all elements of an array of type double all
00171 * have the specified value.
00172 *
00173 * Given:
00174 *   nelelem    int          The length of the array.
00175 *
00176 *   dval       int          Value to be tested.
00177 *
00178 *   darr       const double[]
00179 *               Pointer to the first element of the array.
00180 *
00181 * Function return value:
00182 *   int         Status return value:
00183 *               0: Not all equal.
00184 *               1: All equal.
00185 *
00186 *
00187 * wcsutil_all_sval() - Test if all elements a string array have a given value
00188 * -----
00189 * INTERNAL USE ONLY.
00190 *
00191 * wcsutil_all_sval() tests whether the elements of an array of type
00192 * char (*)[72] all have the specified value.
00193 *
00194 * Given:
00195 *   nelelem    int          The length of the array.
00196 *
00197 *   sval       const char *
00198 *               String to be tested.
00199 *
00200 *   sarr       const char (*)[72]
00201 *               Pointer to the first element of the array.
00202 *
00203 * Function return value:
00204 *   int         Status return value:
00205 *               0: Not all equal.
00206 *               1: All equal.
00207 *
00208 *
00209 * wcsutil_allEq() - Test for equality of a particular vector element
00210 * -----
00211 * INTERNAL USE ONLY.
00212 *
00213 * wcsutil_allEq() tests for equality of a particular element in a set of

```

```

00214 * vectors.
00215 *
00216 * Given:
00217 *   nvec      int      The number of vectors.
00218 *
00219 *   nelem     int      The length of each vector.
00220 *
00221 *   first     const double*
00222 *             Pointer to the first element to test in the array.
00223 *             The elements tested for equality are
00224 *
00225 *             *first == *(first + nelem)
00226 *             == *(first + nelem*2)
00227 *             :
00228 *             == *(first + nelem*(nvec-1));
00229 *
00230 *             The array might be dimensioned as
00231 *
00232 *             double v[nvec][nelem];
00233 *
00234 * Function return value:
00235 *   int      Status return value:
00236 *           0: Not all equal.
00237 *           1: All equal.
00238 *
00239 *
00240 * wcsutil_dblEq() - Test for equality of two arrays of type double
00241 * -----
00242 * INTERNAL USE ONLY.
00243 *
00244 * wcsutil_dblEq() tests for equality of two double-precision arrays.
00245 *
00246 * Given:
00247 *   nelem     int      The number of elements in each array.
00248 *
00249 *   tol       double   Tolerance for comparison of the floating-point values.
00250 *                     For example, for tol == 1e-6, all floating-point
00251 *                     values in the arrays must be equal to the first 6
00252 *                     decimal places. A value of 0 implies exact equality.
00253 *
00254 *   arr1      const double*
00255 *             The first array.
00256 *
00257 *   arr2      const double*
00258 *             The second array
00259 *
00260 * Function return value:
00261 *   int      Status return value:
00262 *           0: Not equal.
00263 *           1: Equal.
00264 *
00265 *
00266 * wcsutil_intEq() - Test for equality of two arrays of type int
00267 * -----
00268 * INTERNAL USE ONLY.
00269 *
00270 * wcsutil_intEq() tests for equality of two int arrays.
00271 *
00272 * Given:
00273 *   nelem     int      The number of elements in each array.
00274 *
00275 *   arr1      const int*
00276 *             The first array.
00277 *
00278 *   arr2      const int*
00279 *             The second array
00280 *
00281 * Function return value:
00282 *   int      Status return value:
00283 *           0: Not equal.
00284 *           1: Equal.
00285 *
00286 *
00287 * wcsutil_strEq() - Test for equality of two string arrays
00288 * -----
00289 * INTERNAL USE ONLY.
00290 *
00291 * wcsutil_strEq() tests for equality of two string arrays.
00292 *
00293 * Given:
00294 *   nelem     int      The number of elements in each array.
00295 *
00296 *   arr1      const char**
00297 *             The first array.
00298 *
00299 *   arr2      const char**
00300 *             The second array

```

```

00301 *
00302 * Function return value:
00303 *      int      Status return value:
00304 *              0: Not equal.
00305 *              1: Equal.
00306 *
00307 *
00308 * wcsutil_setAll() - Set a particular vector element
00309 * -----
00310 * INTERNAL USE ONLY.
00311 *
00312 * wcsutil_setAll() sets the value of a particular element in a set of vectors
00313 * of type double.
00314 *
00315 * Given:
00316 *      nvec      int      The number of vectors.
00317 *
00318 *      nelem     int      The length of each vector.
00319 *
00320 * Given and returned:
00321 *      first     double*   Pointer to the first element in the array, the value
00322 *                          of which is used to set the others
00323 *
00324 *                          *(first + nelem) = *first;
00325 *                          *(first + nelem*2) = *first;
00326 *                          :
00327 *                          *(first + nelem*(nvec-1)) = *first;
00328 *
00329 *                          The array might be dimensioned as
00330 *
00331 *                          double v[nvec][nelem];
00332 *
00333 * Function return value:
00334 *      void
00335 *
00336 *
00337 * wcsutil_setAli() - Set a particular vector element
00338 * -----
00339 * INTERNAL USE ONLY.
00340 *
00341 * wcsutil_setAli() sets the value of a particular element in a set of vectors
00342 * of type int.
00343 *
00344 * Given:
00345 *      nvec      int      The number of vectors.
00346 *
00347 *      nelem     int      The length of each vector.
00348 *
00349 * Given and returned:
00350 *      first     int*      Pointer to the first element in the array, the value
00351 *                          of which is used to set the others
00352 *
00353 *                          *(first + nelem) = *first;
00354 *                          *(first + nelem*2) = *first;
00355 *                          :
00356 *                          *(first + nelem*(nvec-1)) = *first;
00357 *
00358 *                          The array might be dimensioned as
00359 *
00360 *                          int v[nvec][nelem];
00361 *
00362 * Function return value:
00363 *      void
00364 *
00365 *
00366 * wcsutil_setBit() - Set bits in selected elements of an array
00367 * -----
00368 * INTERNAL USE ONLY.
00369 *
00370 * wcsutil_setBit() sets bits in selected elements of an array.
00371 *
00372 * Given:
00373 *      nelem     int      Number of elements in the array.
00374 *
00375 *      sel       const int* Address of a selection array of length nelem. May
00376 *                          be specified as the null pointer in which case all
00377 *                          elements are selected.
00378 *
00379 *
00380 *      bits      int      Bit mask.
00381 *
00382 * Given and returned:
00383 *      array     int*      Address of the array of length nelem.
00384 *
00385 * Function return value:
00386 *      void
00387 *

```

```

00388 *
00389 * wcsutil_fptr2str() - Translate pointer-to-function to string
00390 * -----
00391 * INTERNAL USE ONLY.
00392 *
00393 * wcsutil_fptr2str() translates a pointer-to-function to hexadecimal string
00394 * representation for output. It is used by the various routines that print
00395 * the contents of WCSLIB structs, noting that it is not strictly legal to
00396 * type-pun a function pointer to void*. See
00397 * http://stackoverflow.com/questions/2741683/how-to-format-a-function-pointer
00398 *
00399 * Given:
00400 *   fptr      void(*)() Pointer to function.
00401 *
00402 * Returned:
00403 *   hext      char[19] Null-terminated string. Should be at least 19 bytes
00404 *               in size to accomodate a 64-bit address (16 bytes in
00405 *               hex), plus the leading "0x" and trailing '\0'.
00406 *
00407 * Function return value:
00408 *   char *    The address of hext.
00409 *
00410 *
00411 * wcsutil_double2str() - Translate double to string ignoring the locale
00412 * -----
00413 * INTERNAL USE ONLY.
00414 *
00415 * wcsutil_double2str() converts a double to a string, but unlike sprintf() it
00416 * ignores the locale and always uses a '.' as the decimal separator. Also,
00417 * unless it includes an exponent, the formatted value will always have a
00418 * fractional part, ".0" being appended if necessary.
00419 *
00420 * Returned:
00421 *   buf       char *    The buffer to write the string into.
00422 *
00423 * Given:
00424 *   format    char *    The formatting directive, such as "%f". This
00425 *               may be any of the forms accepted by sprintf(), but
00426 *               should only include a formatting directive and
00427 *               nothing else. For "%g" and "%G" formats, unless it
00428 *               includes an exponent, the formatted value will always
00429 *               have a fractional part, ".0" being appended if
00430 *               necessary.
00431 *
00432 *   value     double    The value to convert to a string.
00433 *
00434 *
00435 * wcsutil_str2double() - Translate string to a double, ignoring the locale
00436 * -----
00437 * INTERNAL USE ONLY.
00438 *
00439 * wcsutil_str2double() converts a string to a double, but unlike sscanf() it
00440 * ignores the locale and always expects a '.' as the decimal separator.
00441 *
00442 * Given:
00443 *   buf       char *    The string containing the value
00444 *
00445 * Returned:
00446 *   value     double *  The double value parsed from the string.
00447 *
00448 *
00449 * wcsutil_str2double2() - Translate string to doubles, ignoring the locale
00450 * -----
00451 * INTERNAL USE ONLY.
00452 *
00453 * wcsutil_str2double2() converts a string to a pair of doubles containing the
00454 * integer and fractional parts. Unlike sscanf() it ignores the locale and
00455 * always expects a '.' as the decimal separator.
00456 *
00457 * Given:
00458 *   buf       char *    The string containing the value
00459 *
00460 * Returned:
00461 *   value     double[2] The double value, split into integer and fractional
00462 *               parts, parsed from the string.
00463 *
00464 * =====*/
00465
00466 #ifndef WCSLIB_WCSUTIL
00467 #define WCSLIB_WCSUTIL
00468
00469 #ifdef __cplusplus
00470 extern "C" {
00471 #endif
00472
00473 void wcsdealloc(void *ptr);
00474

```

```

00475 void wcsutil_strcvt(int n, char c, int nt, const char src[], char dst[]);
00476
00477 void wcsutil_blank_fill(int n, char c[]);
00478 void wcsutil_null_fill (int n, char c[]);
00479
00480 int  wcsutil_all_ival(int nelem, int ival, const int iarr[]);
00481 int  wcsutil_all_dval(int nelem, double dval, const double darr[]);
00482 int  wcsutil_all_sval(int nelem, const char *sval, const char (*sarr)[72]);
00483 int  wcsutil_allEq (int nvec, int nelem, const double *first);
00484
00485 int  wcsutil_dblEq(int nelem, double tol, const double *arr1,
00486                  const double *arr2);
00487 int  wcsutil_intEq(int nelem, const int *arr1, const int *arr2);
00488 int  wcsutil_strEq(int nelem, char (*arr1)[72], char (*arr2)[72]);
00489 void wcsutil_setAll(int nvec, int nelem, double *first);
00490 void wcsutil_setAli(int nvec, int nelem, int *first);
00491 void wcsutil_setBit(int nelem, const int *sel, int bits, int *array);
00492 char *wcsutil_fptr2str(void (*fptr)(void), char hext[19]);
00493 void wcsutil_double2str(char *buf, const char *format, double value);
00494 int  wcsutil_str2double(const char *buf, double *value);
00495 int  wcsutil_str2double2(const char *buf, double *value);
00496
00497 #ifdef __cplusplus
00498 }
00499 #endif
00500
00501 #endif // WCSLIB_WCSUTIL

```

## 8.41 wt barr.h File Reference

### Data Structures

- struct [wtbarr](#)

*Extraction of coordinate lookup tables from BINTABLE.*

### 8.41.1 Detailed Description

The wtbarr struct is used by [wcstab\(\)](#) in extracting coordinate lookup tables from a binary table extension (BINTABLE) and copying them into the tabprm structs stored in wcsprm.

## 8.42 wt barr.h

[Go to the documentation of this file.](#)

```

00001 /*=====
00002  WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003  Copyright (C) 1995-2025, Mark Calabretta
00004
00005  This file is part of WCSLIB.
00006
00007  WCSLIB is free software: you can redistribute it and/or modify it under the
00008  terms of the GNU Lesser General Public License as published by the Free
00009  Software Foundation, either version 3 of the License, or (at your option)
00010  any later version.
00011
00012  WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013  WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
00014  FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015  more details.
00016
00017  You should have received a copy of the GNU Lesser General Public License
00018  along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020  Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021  http://www.atnf.csiro.au/people/Mark.Calabretta
00022  $Id: wt barr.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023  =====
00024  *
00025  * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026  * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027  * overview of the library.

```

```

00028 *
00029 *
00030 * Summary of the wt barr struct
00031 * -----
00032 * The wt barr struct is used by wcstab() in extracting coordinate lookup tables
00033 * from a binary table extension (BINTABLE) and copying them into the tabprm
00034 * structs stored in wcsprm.
00035 *
00036 *
00037 * wt barr struct - Extraction of coordinate lookup tables from BINTABLE
00038 * -----
00039 * Function wcstab(), which is invoked automatically by wcspih(), sets up an
00040 * array of wt barr structs to assist in extracting coordinate lookup tables
00041 * from a binary table extension (BINTABLE) and copying them into the tabprm
00042 * structs stored in wcsprm. Refer to the usage notes for wcspih() and
00043 * wcstab() in wcsshr.h, and also the prologue to tab.h.
00044 *
00045 * For C++ usage, because of a name space conflict with the wt barr typedef
00046 * defined in CFITSIO header fitsio.h, the wt barr struct is renamed to wt barr_s
00047 * by preprocessor macro substitution with scope limited to wt barr.h itself,
00048 * and similarly in wcs.h.
00049 *
00050 *     int i
00051 *         (Given) Image axis number.
00052 *
00053 *     int m
00054 *         (Given) wcstab array axis number for index vectors.
00055 *
00056 *     int kind
00057 *         (Given) Character identifying the wcstab array type:
00058 *             - c: coordinate array,
00059 *             - i: index vector.
00060 *
00061 *     char extnam[72]
00062 *         (Given) EXTNAME identifying the binary table extension.
00063 *
00064 *     int extver
00065 *         (Given) EXTVER identifying the binary table extension.
00066 *
00067 *     int extlev
00068 *         (Given) EXTLEV identifying the binary table extension.
00069 *
00070 *     char ttype[72]
00071 *         (Given) TTYPEn identifying the column of the binary table that contains
00072 *         the wcstab array.
00073 *
00074 *     long row
00075 *         (Given) Table row number.
00076 *
00077 *     int ndim
00078 *         (Given) Expected dimensionality of the wcstab array.
00079 *
00080 *     int *dimlen
00081 *         (Given) Address of the first element of an array of int of length ndim
00082 *         into which the wcstab array axis lengths are to be written.
00083 *
00084 *     double **arrayp
00085 *         (Given) Pointer to an array of double which is to be allocated by the
00086 *         user and into which the wcstab array is to be written.
00087 *
00088 * =====*/
00089
00090 #ifndef WCSLIB_WTBARR
00091 #define WCSLIB_WTBARR
00092
00093 #ifdef __cplusplus
00094 extern "C" {
00095 #define wt barr wt barr_s           // See prologue above.
00096 #endif
00097
00098 // For extracting wcstab arrays. Matches
00099 // the wt barr typedef defined in CFITSIO
00100 // header fitsio.h.
00101 struct wt barr {
00102     int i;           // Image axis number.
00103     int m;           // Array axis number for index vectors.
00104     int kind;        // wcstab array type.
00105     char extnam[72]; // EXTNAME of binary table extension.
00106     int extver;      // EXTVER of binary table extension.
00107     int extlev;      // EXTLEV of binary table extension.
00108     char ttype[72];  // TTYPEn of column containing the array.
00109     long row;        // Table row number.
00110     int ndim;        // Expected wcstab array dimensionality.
00111     int *dimlen;     // Where to write the array axis lengths.
00112     double **arrayp; // Where to write the address of the array
00113                     // allocated to store the wcstab array.
00114 };
00115
00116

```

```

00115 #ifdef __cplusplus
00116 #undef wt barr
00117 }
00118 #endif
00119
00120 #endif // WCSLIB_WTBARR

```

## 8.43 wcslib.h File Reference

```

#include "cel.h"
#include "dis.h"
#include "fitshdr.h"
#include "lin.h"
#include "log.h"
#include "prj.h"
#include "spc.h"
#include "sph.h"
#include "spx.h"
#include "tab.h"
#include "wcs.h"
#include "wcserr.h"
#include "wcsfix.h"
#include "wcshdr.h"
#include "wcsmath.h"
#include "wcsprintf.h"
#include "wcstrig.h"
#include "wcsunits.h"
#include "wcsutil.h"
#include "wtbarr.h"

```

### 8.43.1 Detailed Description

This header file is provided purely for convenience. Use it to include all of the separate WCSLIB headers.

## 8.44 wcslib.h

[Go to the documentation of this file.](#)

```

00001 /*=====
00002  WCSLIB 8.5 - an implementation of the FITS WCS standard.
00003  Copyright (C) 1995-2025, Mark Calabretta
00004
00005  This file is part of WCSLIB.
00006
00007  WCSLIB is free software: you can redistribute it and/or modify it under the
00008  terms of the GNU Lesser General Public License as published by the Free
00009  Software Foundation, either version 3 of the License, or (at your option)
00010  any later version.
00011
00012  WCSLIB is distributed in the hope that it will be useful, but WITHOUT ANY
00013  WARRANTY; without even the implied warranty of MERCHANTABILITY or FITNESS
00014  FOR A PARTICULAR PURPOSE. See the GNU Lesser General Public License for
00015  more details.
00016
00017  You should have received a copy of the GNU Lesser General Public License
00018  along with WCSLIB. If not, see http://www.gnu.org/licenses.
00019
00020  Author: Mark Calabretta, Australia Telescope National Facility, CSIRO.
00021  http://www.atnf.csiro.au/people/Mark.Calabretta
00022  $Id: wcslib.h,v 8.5 2025/12/06 13:47:41 mcalabre Exp $
00023  *=====
00024  *

```

```
00025 * WCSLIB 8.5 - C routines that implement the FITS World Coordinate System
00026 * (WCS) standard. Refer to the README file provided with WCSLIB for an
00027 * overview of the library.
00028 *
00029 * Summary of wcslib.h
00030 * -----
00031 * This header file is provided purely for convenience. Use it to include all
00032 * of the separate WCSLIB headers.
00033 *
00034 *=====*/
00035
00036 #ifndef WCSLIB_WCSLIB
00037 #define WCSLIB_WCSLIB
00038
00039 #include "cel.h"
00040 #include "dis.h"
00041 #include "fitshdr.h"
00042 #include "lin.h"
00043 #include "log.h"
00044 #include "prj.h"
00045 #include "spc.h"
00046 #include "sph.h"
00047 #include "spx.h"
00048 #include "tab.h"
00049 #include "wcs.h"
00050 #include "wcserr.h"
00051 #include "wcsfix.h"
00052 #include "wcshdr.h"
00053 #include "wcsmath.h"
00054 #include "wcsprintf.h"
00055 #include "wcstrig.h"
00056 #include "wcsunits.h"
00057 #include "wcsutil.h"
00058 #include "wtbarr.h"
00059
00060 #endif // WCSLIB_WCSLIB
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03663
03695     wcserr_enable(1);
03696     wcsprintf_set(stderr);
03697
03698     ...
03699
03700     if (wcsset(&wcs) {
03701         wcsperp(&wcs);
03702         return wcs.err->status;
03703     }
03704 @endverbatim
03705 In this example, if an error was generated in one of the prjset() functions,
03706 wcsperp() would print an error traceback starting with wcsset(), then
03707 celset(), and finally the particular projection-setting function that
03708 generated the error. For each of them it would print the status return value,
03709 function name, source file, line number, and an error message which may be
03710 more specific and informative than the general error messages reported in the
03711 first example. For example, in response to a deliberately generated error,
03712 the @c twcs test program, which tests wcserr among other things, produces a
03713 traceback similar to this:
03714 @verbatim
03715 ERROR 5 in wcsset() at line 1564 of file wcs.c:
03716   Invalid parameter value.
03717 ERROR 2 in celset() at line 196 of file cel.c:
03718   Invalid projection parameters.
03719 ERROR 2 in bonset() at line 5727 of file prj.c:
03720   Invalid parameters for Bonne's projection.
03721 @endverbatim
03722
03723 Each of the @ref structs "structs" in @ref overview "WCSLIB" includes a
03724 pointer, called @a err, to a wcserr struct. When an error occurs, a struct is
03725 allocated and error information stored in it. The wcserr pointers and the
03726 @ref memory "memory" allocated for them are managed by the routines that
03727 manage the various structs such as wcsinit() and wcsfree().
03728
03729 wcserr messaging is an opt-in system enabled via wcserr_enable(), as in the
03730 example above. If enabled, when an error occurs it is the user's
03731 responsibility to free the memory allocated for the error message using
03732 wcsfree(), celfree(), prjfree(), etc. Failure to do so before the struct goes
03733 out of scope will result in memory leaks (if execution continues beyond the
03734 error).
03735 */
03736
03737
03918
03919

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