

# WCSLIB 4.4 Reference Manual

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## 1 WCSLIB 4.4 and PGSBOX 4.4

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### 1.2 Copyright

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Correspondence concerning WCSLIB may be directed to:

Internet email: [mcalabre@atnf.csiro.au](mailto:mcalabre@atnf.csiro.au)

Postal address: Dr. Mark Calabretta

Australia Telescope National Facility, CSIRO

PO Box 76

Epping NSW 1710

AUSTRALIA

## 2 WCSLIB 4.4 Data Structure Index

### 2.1 WCSLIB 4.4 Data Structures

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## 5 WCSLIB 4.4 Data Structure Documentation

### 5.1 celprm Struct Reference

Celestial transformation parameters.

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

#### Data Fields

- [int flag](#)
- [int offset](#)
- [double phi0](#)
- [double theta0](#)
- [double ref](#) [4]
- [prjprm prj](#)

- double `euler` [5]
- int `latpreq`
- int `isolat`

### 5.1.1 Detailed Description

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.

### 5.1.2 Field Documentation

#### 5.1.2.1 int `celprm::flag`

(Given and returned) This flag must be set to zero 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.

#### 5.1.2.2 int `celprm::offset`

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

#### 5.1.2.3 double `celprm::phi0`

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

#### 5.1.2.4 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.

### 5.1.2.5 double `celprm::ref`

(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](http://www.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.

### 5.1.2.6 struct `prjprm celprm::prj`

(Given and returned) Projection parameters described in the prologue to [prj.h](http://www.wcsmath.h).

### 5.1.2.7 double `celprm::euler`

(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.

### 5.1.2.8 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>i</sub>a** 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>**.

### 5.1.2.9 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.

## 5.2 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]

#### 5.2.1 Detailed Description

[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.

#### 5.2.2 Field Documentation

##### 5.2.2.1 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.

##### 5.2.2.2 int [fitskey::keyid](#)

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

##### 5.2.2.3 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.

### 5.2.2.4 char `fitskey::keyword`

(*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.

### 5.2.2.5 int `fitskey::type`

(*Returned*) Keyvalue data type:

- 0: No keyvalue.
- 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 `wc-sconfig.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.

#### 5.2.2.6 int fitskey::padding

(An unused variable inserted for alignment purposes only.)

#### 5.2.2.7 int fitskey::i

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

#### 5.2.2.8 int64 fitskey::k

(Returned) 64-bit signed integer (`fitskey::type == 3`) data type in the `fitskey::keyvalue` union.

#### 5.2.2.9 int fitskey::l

(Returned) Very long integer (`fitskey::type == 4`) data type in the `fitskey::keyvalue` union.

#### 5.2.2.10 double fitskey::f

(Returned) Floating point (`fitskey::type == 5`) data type in the `fitskey::keyvalue` union.

#### 5.2.2.11 double fitskey::c

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

#### 5.2.2.12 char fitskey::s

(Returned) Null-terminated string (`fitskey::type == 8`) data type in the `fitskey::keyvalue` union.

#### 5.2.2.13 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.

#### 5.2.2.14 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.

#### 5.2.2.15 char fitskey::comment

(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 key-comments (i.e. those immediately following the '/' character), but not from **COMMENT** or **HISTORY** keyrecords or keyrecords without a value indicator ("=" in columns 9-80).

## 5.3 fitskeyid Struct Reference

Keyword indexing.

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

### Data Fields

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

### 5.3.1 Detailed Description

**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()**.

### 5.3.2 Field Documentation

#### 5.3.2.1 char fitskeyid::name

(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.

### 5.3.2.2 int fitskeyid::count

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

### 5.3.2.3 int fitskeyid::idx

(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.

## 5.4 linprm Struct Reference

Linear transformation parameters.

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

### Data Fields

- int flag
- int naxis
- double \* crpix
- double \* pc
- double \* cdelt
- double \* piximg
- double \* imgpix
- int unity
- int i\_naxis
- int m\_flag
- int m\_naxis
- double \* m\_crpix
- double \* m\_pc
- double \* m\_cdelt

### 5.4.1 Detailed Description

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*).

### 5.4.2 Field Documentation

#### 5.4.2.1 int linprm::flag

(Given and returned) This flag must be set to zero whenever any of the following members of the **linprm** struct are set or modified:

- **linprm::naxis** (q.v., not normally set by the user),

- `linprm::pc`,
- `linprm::cdelt`.

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 `linini()` 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.

#### 5.4.2.2 int `linprm::naxis`

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

If `linini()` 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.

#### 5.4.2.3 double \* `linprm::crpix`

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

#### 5.4.2.4 double \* `linprm::pc`

(Given) Pointer to the first element of the **PC**<sub>i\_ja</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.

#### 5.4.2.5 double \* `linprm::cdelt`

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

**5.4.2.6 double \* [linprm::piximg](#)**

(Returned) Pointer to the first element of the matrix containing the product of the **CDELT<sub>ia</sub>** diagonal matrix and the **PC<sub>i\_ja</sub>** matrix.

**5.4.2.7 double \* [linprm::imgpix](#)**

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

**5.4.2.8 int [linprm::unity](#)**

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

**5.4.2.9 int [linprm::i\\_naxis](#)**

(For internal use only.)

**5.4.2.10 int [linprm::m\\_flag](#)**

(For internal use only.)

**5.4.2.11 int [linprm::m\\_naxis](#)**

(For internal use only.)

**5.4.2.12 double \* [linprm::m\\_crpix](#)**

(For internal use only.)

**5.4.2.13 double \* [linprm::m\\_pc](#)**

(For internal use only.)

**5.4.2.14 double \* [linprm::m\\_cdelt](#)**

(For internal use only.)

**5.5 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 `pvrang`
- int `simplezen`
- int `equiareal`
- int `conformal`
- int `global`
- int `divergent`
- double `x0`
- double `y0`
- double `w` [10]
- int `n`
- int `padding`
- int(\* `prjx2s` )(PRJX2S\_ARGS)
- int(\* `prjs2x` )(PRJS2X\_ARGS)

### 5.5.1 Detailed Description

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.

### 5.5.2 Field Documentation

#### 5.5.2.1 int `prjprm::flag`

(Given and returned) This flag must be set to zero whenever any of the following **prjprm** struct 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.

#### 5.5.2.2 char `prjprm::code`

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

#### 5.5.2.3 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).

#### 5.5.2.4 double `prjprm::pv`

(Given) Projection parameters. These correspond to the **PV<sub>i</sub>\_ma** keywords in FITS, so `pv[0]` is **PV<sub>i</sub>\_0a**, `pv[1]` is **PV<sub>i</sub>\_1a**, etc., where *i* denotes the latitude-like axis. Many projections use `pv[1]` (**PV<sub>i</sub>\_1a**), some also use `pv[2]` (**PV<sub>i</sub>\_2a**) and **SZP** uses `pv[3]` (**PV<sub>i</sub>\_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`.

#### 5.5.2.5 double `prjprm::phi0`

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

#### 5.5.2.6 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.

#### 5.5.2.7 int `prjprm::bounds`

(Given) Controls strict bounds checking for the **AZP**, **SZP**, **TAN**, **SIN**, **ZPN**, and **COP** projections; set to zero to disable checking.

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

#### 5.5.2.8 char `prjprm::name`

(Returned) Long name of the projection.

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

#### 5.5.2.9 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.

**5.5.2.10 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.

**5.5.2.11 int prjprm::simplezen**

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

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

**5.5.2.12 int prjprm::equiareal**

(Returned) True if the projection is equal area.

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

**5.5.2.13 int prjprm::conformal**

(Returned) True if the projection is conformal.

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

**5.5.2.14 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.

**5.5.2.15 int prjprm::divergent**

(Returned) True if the projection diverges in latitude.

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

**5.5.2.16 double prjprm::x0**

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

**5.5.2.17 double prjprm::y0**

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

**5.5.2.18 double prjprm::w**

(Returned) Intermediate floating-point values derived from the projection parameters, 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`.

**5.5.2.19 int prjprm::n**

(Returned) Intermediate integer value (used only for the **ZPN** and **HPX** projections).



#### 5.5.2.20 int `prjprm::padding`

(An unused variable inserted for alignment purposes only.)

#### 5.5.2.21 `prjprm::prjx2s`

(*Returned*) Pointer to the projection ...

#### 5.5.2.22 `prjprm::prjs2x`

(*Returned*) ... and deprojection routines.

## 5.6 pscard Struct Reference

Store for `PSi_ma` keyrecords.

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

### Data Fields

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

### 5.6.1 Detailed Description

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.

### 5.6.2 Field Documentation

#### 5.6.2.1 int `pscard::i`

(*Given*) Axis number (1-relative), as in the FITS `PSi_ma` keyword.

#### 5.6.2.2 int `pscard::m`

(*Given*) Parameter number (non-negative), as in the FITS `PSi_ma` keyword.

#### 5.6.2.3 char `pscard::value`

(*Given*) Parameter value.

## 5.7 pvc card Struct Reference

Store for `PVi_ma` keyrecords.

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

**Data Fields**

- int `i`
- int `m`
- double `value`

**5.7.1 Detailed Description**

The `pvc` struct is used to pass the parsed contents of `PVi_ma` keyrecords to `wcsset()` via the `wcsprm` struct.

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

**5.7.2 Field Documentation****5.7.2.1 int `pvc::i`**

(Given) Axis number (1-relative), as in the FITS `PVi_ma` keyword.

**5.7.2.2 int `pvc::m`**

(Given) Parameter number (non-negative), as in the FITS `PVi_ma` keyword.

**5.7.2.3 double `pvc::value`**

(Given) Parameter value.

**5.8 `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 `padding`
- int(\* `spxX2P`)(SPX\_ARGS)
- int(\* `spxP2S`)(SPX\_ARGS)
- int(\* `spxS2P`)(SPX\_ARGS)
- int(\* `spxP2X`)(SPX\_ARGS)

### 5.8.1 Detailed Description

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.

### 5.8.2 Field Documentation

#### 5.8.2.1 `int spcprm::flag`

(Given and returned) This flag must be set to zero whenever any of the following `spcprm` structure 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.

#### 5.8.2.2 `char spcprm::type`

(Given) Four-letter spectral variable type, e.g. "ZOPT" for `CTYPEia = 'ZOPT-F2W'`. (Declared as `char[8]` for alignment reasons.)

#### 5.8.2.3 `char spcprm::code`

(Given) Three-letter spectral algorithm code, e.g. "F2W" for `CTYPEia = 'ZOPT-F2W'`.

#### 5.8.2.4 `double spcprm::crval`

(Given) Reference value (`CRVALia`), SI units.

#### 5.8.2.5 `double spcprm::restfrq`

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

#### 5.8.2.6 `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.

**5.8.2.7** `double spcprm::pv`

(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:

**5.8.2.8** `double spcprm::w`

(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.

**5.8.2.9** `int spcprm::isGrism`

(Returned) Grism coordinates?

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

**5.8.2.10** `int spcprm::padding`

(An unused variable inserted for alignment purposes only.)

**5.8.2.11** `spcprm::spxX2P`

(Returned) The first and ...

**5.8.2.12** `spcprm::spxP2S`

(Returned) ... 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](#).

**5.8.2.13 [spxprm::spxS2P](#)**

(Returned) The first and ...

**5.8.2.14 [spxprm::spxP2X](#)**

(Returned) ... the second of the pointers to the transformation functions in the two-step algorithm chain  $S \rightarrow P \leadsto X$  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](#).

**5.9 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 [denerfreq](#)
- 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](#)

### 5.9.1 Detailed Description

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.

### 5.9.2 Field Documentation

#### 5.9.2.1 double [spxprm::restfrq](#)

(Returned) Rest frequency [Hz].

#### 5.9.2.2 double [spxprm::restwav](#)

(Returned) Rest wavelength [m].

#### 5.9.2.3 int [spxprm::wavetype](#)

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

#### 5.9.2.4 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.

#### 5.9.2.5 double [spxprm::freq](#)

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

#### 5.9.2.6 double [spxprm::afreq](#)

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

#### 5.9.2.7 double [spxprm::ener](#)

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

**5.9.2.8 double `spxprm::wavn`**

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

**5.9.2.9 double `spxprm::vrad`**

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

**5.9.2.10 double `spxprm::wave`**

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

**5.9.2.11 double `spxprm::vopt`**

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

**5.9.2.12 double `spxprm::zopt`**

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

**5.9.2.13 double `spxprm::awav`**

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

**5.9.2.14 double `spxprm::velo`**

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

**5.9.2.15 double `spxprm::beta`**

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

**5.9.2.16 double `spxprm::dfreqafrq`**

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

**5.9.2.17 double `spxprm::dafrqfreq`**

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

**5.9.2.18 double `spxprm::dfregener`**

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

**5.9.2.19 double `spxprm::denerfreq`**

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

**5.9.2.20 double `spxprm::dfreqwavn`**

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

**5.9.2.21 double spxprm::dwavnfreq**

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

**5.9.2.22 double spxprm::dfreqvrad**

(Returned) Derivative of frequency with respect to radio velocity [1/m], and ...

**5.9.2.23 double spxprm::dvradfreq**

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

**5.9.2.24 double spxprm::dfreqwave**

(Returned) Derivative of frequency with respect to vacuum wavelength [1/m/s], and ...

**5.9.2.25 double spxprm::dwavefreq**

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

**5.9.2.26 double spxprm::dfreqawav**

(Returned) Derivative of frequency with respect to air wavelength, [1/m/s], and ...

**5.9.2.27 double spxprm::dawavfreq**

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

**5.9.2.28 double spxprm::dfreqvelo**

(Returned) Derivative of frequency with respect to relativistic velocity [1/m], and ...

**5.9.2.29 double spxprm::dvelofreq**

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

**5.9.2.30 double spxprm::dwavevopt**

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

**5.9.2.31 double spxprm::dvoptwave**

(Returned) ... vice versa [1/s] (*wavetype* && *velotype*).

**5.9.2.32 double spxprm::dwavezopt**

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

**5.9.2.33 double spxprm::dzoptwave**

(Returned) ... vice versa [1/m] (*wavetype* && *velotype*).



**5.9.2.34 double [spxprm::dwaveawav](#)**

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

**5.9.2.35 double [spxprm::dawavwave](#)**

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

**5.9.2.36 double [spxprm::dwavevelo](#)**

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

**5.9.2.37 double [spxprm::dvelowave](#)**

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

**5.9.2.38 double [spxprm::dawavvelo](#)**

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

**5.9.2.39 double [spxprm::dveloawav](#)**

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

**5.9.2.40 double [spxprm::dvelobeta](#)**

(Returned) Derivative of relativistic velocity with respect to relativistic beta [m/s] (constant, =  $c$ , the speed of light in vacuu0), and ...

**5.9.2.41 double [spxprm::dbetavelo](#)**

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

**5.10 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](#)
- 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](#)

### 5.10.1 Detailed Description

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.

### 5.10.2 Field Documentation

#### 5.10.2.1 int [tabprm::flag](#)

(Given and returned) This flag must be set to zero whenever any of the following **tabprm** structure 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.

#### 5.10.2.2 int [tabprm::M](#)

(Given or returned) Number of tabular coordinate axes.

If [tabini\(\)](#) is used to initialize the linprm 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.

### 5.10.2.3 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 linprm 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.

### 5.10.2.4 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  $\text{map}[m-1] == i-1$  for axis i in the N-dimensional image ( $1 \leq i \leq N$ ). In terms of the FITS keywords

$\text{map}[\text{PV}_i\text{a} - 1] == i - 1$ .

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 nelelem set to 1. In this case  $\text{map}[0] = 0$  regardless of the value of i.

### 5.10.2.5 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.

### 5.10.2.6 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;
```

### 5.10.2.7 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.

### 5.10.2.8 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](#)).

**5.10.2.9 int [tabprm::padding](#)**

(An unused variable inserted for alignment purposes only.)

**5.10.2.10 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).

**5.10.2.11 double \* [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  $p0[m] + \text{tabprm::delta}[m]$ .

**5.10.2.12 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  $\text{tabprm::p0}[m] + \text{delta}[m]$ .

**5.10.2.13 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.

**5.10.2.14 int [tabprm::m\\_flag](#)**

(For internal use only.)

**5.10.2.15 int [tabprm::m\\_M](#)**

(For internal use only.)

**5.10.2.16 int [tabprm::m\\_N](#)**

(For internal use only.)

**5.10.2.17 int [tabprm::set\\_M](#)**

(For internal use only.)

**5.10.2.18 int [tabprm::m\\_K](#)**

(For internal use only.)

**5.10.2.19 int [tabprm::m\\_map](#)**

(For internal use only.)

**5.10.2.20** int [tabprm::m\\_crval](#)

(For internal use only.)

**5.10.2.21** int [tabprm::m\\_index](#)

(For internal use only.)

**5.10.2.22** int [tabprm::m\\_indxs](#)

(For internal use only.)

**5.10.2.23** int [tabprm::m\\_coord](#)

(For internal use only.)

## 5.11 wcsprm Struct Reference

Coordinate transformation parameters.

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

### Data Fields

- int [flag](#)
- int [naxis](#)
- double \* [crpix](#)
- double \* [pc](#)
- double \* [cdelt](#)
- double \* [crval](#)
- char(\* [cunit](#) )[72]
- char(\* [ctype](#) )[72]
- double [lonpole](#)
- double [latpole](#)
- double [restfrq](#)
- double [restwav](#)
- int [npv](#)
- int [npvmax](#)
- [pvc](#)card \* [pv](#)
- int [nps](#)
- int [npsmax](#)
- [psc](#)ard \* [ps](#)
- double \* [cd](#)
- double \* [crota](#)
- int [altlin](#)
- int [padding](#)
- char [alt](#) [4]
- int [colnum](#)
- int \* [colax](#)
- char(\* [cname](#) )[72]
- double \* [crder](#)

- double \* [csyer](#)
- char [dateavg](#) [72]
- char [dateobs](#) [72]
- double [equinox](#)
- double [mjdavg](#)
- double [mjdobs](#)
- double [obsgeo](#) [3]
- char [radesys](#) [72]
- char [specsyz](#) [72]
- char [ssysobs](#) [72]
- double [velosyz](#)
- double [zsource](#)
- char [ssysrc](#) [72]
- double [velangl](#)
- char [wcsname](#) [72]
- int [ntab](#)
- int [nwtb](#)
- [tabprm](#) \* [tab](#)
- [wtbarr](#) \* [wtb](#)
- int \* [types](#)
- char [lngtyp](#) [8]
- char [latty](#) [8]
- int [lng](#)
- int [lat](#)
- int [spec](#)
- int [cubeface](#)
- [linprm](#) [lin](#)
- [celprm](#) [cel](#)
- [spcprm](#) [spc](#)
- 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]
- [pvcarr](#) \* [m\\_pv](#)
- [pscard](#) \* [m\\_ps](#)
- double \* [m\\_cd](#)
- double \* [m\\_crota](#)
- int \* [m\\_colax](#)
- char(\* [m\\_cname](#) )[72]
- double \* [m\\_crder](#)
- double \* [m\\_csyer](#)
- [tabprm](#) \* [m\\_tab](#)
- [wtbarr](#) \* [m\\_wtb](#)

### 5.11.1 Detailed Description

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*). Some of the former 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 [wcshto\(\)](#) 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 [wcsini\(\)](#) 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 [wcsphi\(\)](#) does - refer to the prologue of [wshdr.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.

### 5.11.2 Field Documentation

#### 5.11.2.1 int [wcsprm::flag](#)

(Given and returned) This flag must be set to zero whenever any of the following **wcsprm** struct 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](#).

This signals the initialization routine, `wcsset()`, to recompute the returned members of the `celprm` struct. `celset()` will reset flag to indicate that this has been done.

**PLEASE NOTE:** flag should be set to -1 when `wcsini()` 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.

#### 5.11.2.2 int `wcsprm::naxis`

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

If `wcsini()` 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.

#### 5.11.2.3 double \* `wcsprm::crpix`

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

#### 5.11.2.4 double \* `wcsprm::pc`

(Given) Address of the first element of the **PC**<sub>i\_ja</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.

#### 5.11.2.5 double \* `wcsprm::cdelt`

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

#### 5.11.2.6 double \* `wcsprm::crval`

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



### 5.11.2.7 `wcsprm::cunit`

(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.

### 5.11.2.8 `wcsprm::ctype`

(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.

### 5.11.2.9 `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 ...

### 5.11.2.10 `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 `wcsini()` (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 `wcsini()`, they will no longer have their default values.

### 5.11.2.11 `double wcsprm::restfrq`

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

### 5.11.2.12 `double wcsprm::restwav`

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

### 5.11.2.13 `int wcsprm::npv`

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

#### 5.11.2.14 int `wcsprm::npvmax`

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

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

#### 5.11.2.15 struct `pvc card` \* `wcsprm::pv`

(Given or returned) Address of the first element of an array of length `npvmax` of `pvc card` structs. Set by `wcsini()` if it allocates memory for `pv[]`, otherwise it must be set by the user. See also `wcsnpv()`.

As a FITS header parser encounters each **PVi\_ma** keyword it should load it into a `pvc card` 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  $(\phi_0, \theta_0)$ , the native longitude and latitude of the reference point given by **LONPOLEa** and **LATPOLEa**.

#### 5.11.2.16 int `wcsprm::nps`

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

#### 5.11.2.17 int `wcsprm::npsmax`

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

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

#### 5.11.2.18 struct `pscard` \* `wcsprm::ps`

(Given or returned) Address of the first element of an array of length `npsmax` of `pscard` structs. Set by `wcsini()` if it allocates memory for `ps[]`, otherwise it must be set by the user. See also `wcsnps()`.

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).

#### 5.11.2.19 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 ...

#### 5.11.2.20 double \* `wcsprm::crota`

(Given) ... those associated with the **CROTAia** 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**.

#### 5.11.2.21 int `wcsprm::altlin`

(Given) `altlin` is a bit flag that denotes which of the **PCi\_ja**, **CDi\_ja** and **CROTAia** 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  $\mathbf{CDi\_ja} = \mathbf{CDELTia} * \mathbf{PCi\_ja}$ , 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 **CROTAia**) 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 **CROTAia** which are to be ignored.

- Bit 2: **CROTAia** is present.

In the AIPS convention, **CROTAia** 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 **CDELTia**; any other **CROTAia** keywords are ignored.

**CROTAia** may not formally co-exist with **PCi\_ja**.

**CROTAia** and **CDELTia** may formally co-exist with **CDi\_ja** but if so are to be ignored.

**CDi\_ja** and **CROTAia** 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 **PCi\_ja** keyword is encountered:

```
altlin |= 1;
```

- Whenever a **CDi\_ja** keyword is encountered:

```
altlin |= 2;
```

- Whenever a **CROTAia** keyword is encountered:

```
altlin |= 4;
```

If none of these bits are set the **PCi\_ja** 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 **PCi\_ja** by `wcsset()` and are invisible to the lower-level WCSLIB routines. In particular, `wcsset()` resets `wcsprm::cdelt` to unity if **CDi\_ja** is present (and no **PCi\_ja**).

If **CROTAia** are present but none is associated with the latitude axis (and no **PCi\_ja** or **CDi\_ja**), then `wcsset()` reverts to a unity **PCi\_ja** matrix.

#### 5.11.2.22 int `wcsprm::padding`

(An unused variable inserted for alignment purposes only.)

#### 5.11.2.23 char `wcsprm::alt`

(Given, auxiliary) Character code for alternate coordinate descriptions (i.e. the 'a' in keyword names such as **CTYPEia**). 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.

**5.11.2.24 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.

**5.11.2.25 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.

**5.11.2.26 `wcsprm::cname`**

(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.

**5.11.2.27 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>.

**5.11.2.28 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>.

**5.11.2.29 char `wcsprm::dateavg`**

(Given, auxiliary) The date of a representative mid-point of the observation in ISO format, *yyyy-mm-ddThh:mm:ss*.

**5.11.2.30 char `wcsprm::dateobs`**

(Given, auxiliary) The date of the start of the observation unless otherwise explained in the comment field of the **DATE-OBS** keyword, in ISO format, *yyyy-mm-ddThh:mm:ss*.

**5.11.2.31 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.

**5.11.2.32 double `wcsprm::mjdavg`**

(Given, auxiliary) Modified Julian Date (MJD = JD - 2400000.5), **MJD-AVG**, corresponding to **DATE-AVG**.

**5.11.2.33 double [wcsprm::mjdots](#)**

(Given, auxiliary) Modified Julian Date ( $\text{MJD} = \text{JD} - 2400000.5$ ), **MJD-OBS**, corresponding to **DATE-OBS**.

**5.11.2.34 double [wcsprm::obsgeo](#)**

(Given, auxiliary) Location of the observer in a standard terrestrial reference frame, **OBSGEO-X**, **OBSGEO-Y**, **OBSGEO-Z** [m].

**5.11.2.35 char [wcsprm::radesys](#)**

(Given, auxiliary) The equatorial or ecliptic coordinate system type, **RADESYS**<sub>a</sub>.

**5.11.2.36 char [wcsprm::specsys](#)**

(Given, auxiliary) Spectral reference frame (standard of rest), **SPECSYS**<sub>a</sub>, and ...

**5.11.2.37 char [wcsprm::ssysobs](#)**

(Given, auxiliary) ... the actual frame in which there is no differential variation in the spectral coordinate across the field-of-view, **SSYSOBS**<sub>a</sub>.

**5.11.2.38 double [wcsprm::velosys](#)**

(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, **VELOSYS**<sub>a</sub>.

**5.11.2.39 double [wcsprm::zsource](#)**

(Given, auxiliary) The redshift, **ZSOURCE**<sub>a</sub>, of the source, and ...

**5.11.2.40 char [wcsprm::ssyssrc](#)**

(Given, auxiliary) ... the spectral reference frame (standard of rest) in which this was measured, **SSYSSRC**<sub>a</sub>.

**5.11.2.41 double [wcsprm::velangl](#)**

(Given, auxiliary) The angle [deg] that should be used to decompose an observed velocity into radial and transverse components.

**5.11.2.42 char [wcsprm::wcsname](#)**

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

**5.11.2.43 int [wcsprm::ntab](#)**

(Given) See [wcsprm::tab](#).

**5.11.2.44 int [wcsprm::nwtb](#)**

(Given) See [wcsprm::wtb](#).

**5.11.2.45 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.

**5.11.2.46 struct [wtbarr](#) \* [wcsprm::wtb](#)**

(Given) Address of the first element of an array of nwtb wtbarr 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.

**5.11.2.47 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.
- 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.

#### 5.11.2.48 char [wcsprm::lngtyp](#)

(Returned) Four-character WCS celestial longitude and ...

#### 5.11.2.49 char [wcsprm::lattyp](#)

(Returned) ... latitude axis types. e.g. "RA", "DEC", "GLON", "GLAT", etc. extracted from '**RA-**', '**DEC-**', '**GLON**', '**GLAT**', etc. in the first four characters of **CTYPE<sub>ia</sub>** but with trailing dashes removed. (Declared as char[8] for alignment reasons.)

#### 5.11.2.50 int [wcsprm::lng](#)

(Returned) Index for the longitude coordinate, and ...

#### 5.11.2.51 int [wcsprm::lat](#)

(Returned) ... index for the latitude coordinate, and ...

#### 5.11.2.52 int [wcsprm::spec](#)

(Returned) ... index for the spectral coordinate in the `imgcrd[][]` and `world[][]` arrays in the API of [wvsp2s\(\)](#), [wvss2p\(\)](#) and [wvsmix\(\)](#).

These may also serve as indices into the `pixcrd[][]` array provided that the **PC<sub>i\_j</sub>** matrix does not transpose axes.

#### 5.11.2.53 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 [wvs.h](#)).

#### 5.11.2.54 struct [linprm](#) [wcsprm::lin](#)

(Returned) Linear transformation parameters (usage is described in the prologue to [lin.h](#)).

#### 5.11.2.55 struct [celprm](#) [wcsprm::cel](#)

(Returned) Celestial transformation parameters (usage is described in the prologue to [cel.h](#)).

#### 5.11.2.56 struct [specprm](#) [wcsprm::spc](#)

(Returned) Spectral transformation parameters (usage is described in the prologue to [spc.h](#)).

#### 5.11.2.57 int [wcsprm::m\\_flag](#)

(For internal use only.)

**5.11.2.58** int [wcsprm::m\\_naxis](#)

(For internal use only.)

**5.11.2.59** double \* [wcsprm::m\\_crpix](#)

(For internal use only.)

**5.11.2.60** double \* [wcsprm::m\\_pc](#)

(For internal use only.)

**5.11.2.61** double \* [wcsprm::m\\_cdelt](#)

(For internal use only.)

**5.11.2.62** double \* [wcsprm::m\\_cval](#)

(For internal use only.)

**5.11.2.63** [wcsprm::m\\_cunit](#)

(For internal use only.)

**5.11.2.64** [wcsprm::m\\_ctype](#)

(For internal use only.)

**5.11.2.65** struct [pvcard](#) \* [wcsprm::m\\_pv](#)

(For internal use only.)

**5.11.2.66** struct [psccard](#) \* [wcsprm::m\\_ps](#)

(For internal use only.)

**5.11.2.67** double \* [wcsprm::m\\_cd](#)

(For internal use only.)

**5.11.2.68** double \* [wcsprm::m\\_crota](#)

(For internal use only.)

**5.11.2.69** int \* [wcsprm::m\\_colax](#)

(For internal use only.)

**5.11.2.70** [wcsprm::m\\_cname](#)

(For internal use only.)



**5.11.2.71** double \* [wcsprm::m\\_order](#)

(For internal use only.)

**5.11.2.72** double \* [wcsprm::m\\_csyer](#)

(For internal use only.)

**5.11.2.73** struct [tabprm](#) \* [wcsprm::m\\_tab](#)

(For internal use only.)

**5.11.2.74** struct [wtbarr](#) \* [wcsprm::m\\_wtb](#)

(For internal use only.)

## 5.12 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](#)
- int \* [dimlen](#)
- double \*\* [arrayp](#)

### 5.12.1 Detailed Description

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 [wcs.h](#) itself.

### 5.12.2 Field Documentation

#### 5.12.2.1 int wtbarr::i

(Given) Image axis number.

#### 5.12.2.2 int wtbarr::m

(Given) wstab array axis number for index vectors.

#### 5.12.2.3 int wtbarr::kind

(Given) Character identifying the wstab array type:

- c: coordinate array,
- i: index vector.

#### 5.12.2.4 char wtbarr::extnam

(Given) EXTNAME identifying the binary table extension.

#### 5.12.2.5 int wtbarr::extver

(Given) EXTVER identifying the binary table extension.

#### 5.12.2.6 int wtbarr::extlev

(Given) EXTLEV identifying the binary table extension.

#### 5.12.2.7 char wtbarr::ttype

(Given) TTYPE<sub>n</sub> identifying the column of the binary table that contains the wstab array.

#### 5.12.2.8 long wtbarr::row

(Given) Table row number.

#### 5.12.2.9 int wtbarr::ndim

(Given) Expected dimensionality of the wstab array.

#### 5.12.2.10 int \* wtbarr::dimlen

(Given) Address of the first element of an array of int of length ndim into which the wstab array axis lengths are to be written.

#### 5.12.2.11 double \*\* wtbarr::arrayp

(Given) Pointer to an array of double which is to be allocated by the user and into which the wstab array is to be written.

5.12.2.12 int\* [wtbarr::dimlen](#)

5.12.2.13 double\*\* [wtbarr::arrayp](#)

## 6 WCSLIB 4.4 File Documentation

### 6.1 cel.h File Reference

```
#include "prj.h"
```

#### Data Structures

- struct [celprm](#)  
*Celestial transformation parameters.*

#### Defines

- #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.*

#### Functions

- int [celini](#) (struct [celprm](#) \*cel)  
*Default constructor for the [celprm](#) struct.*
- int [celprt](#) (const struct [celprm](#) \*cel)  
*Print routine for the [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.*

### 6.1.1 Detailed Description

These routines implement the part of the FITS World Coordinate System (WCS) standard that deals with celestial coordinates. They 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, and another, `celprt()`, to print its contents.

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`.

### 6.1.2 Define Documentation

#### 6.1.2.1 `#define CELLEN (sizeof(struct celprm)/sizeof(int))`

Size of the `celprm` struct in `int` units, used by the Fortran wrappers.

#### 6.1.2.2 `#define celini_errmsg cel_errmsg`

##### Deprecated

Added for backwards compatibility, use `cel_errmsg` directly now instead.

#### 6.1.2.3 `#define celprt_errmsg cel_errmsg`

##### Deprecated

Added for backwards compatibility, use `cel_errmsg` directly now instead.

#### 6.1.2.4 #define celset\_errmsg [cel\\_errmsg](#)

##### Deprecated

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

#### 6.1.2.5 #define celx2s\_errmsg [cel\\_errmsg](#)

##### Deprecated

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

#### 6.1.2.6 #define cels2x\_errmsg [cel\\_errmsg](#)

##### Deprecated

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

### 6.1.3 Function Documentation

#### 6.1.3.1 int celini (struct [celprm](#) \* *cel*)

**celini()** sets all members of a [celprm](#) struct to default values. It should be used to initialize every [celprm](#) struct.

##### Parameters:

→ *cel* Celestial transformation parameters.

##### Returns:

Status return value:

- 0: Success.
- 1: Null [celprm](#) pointer passed.

#### 6.1.3.2 int celprt (const struct [celprm](#) \* *cel*)

**celprt()** prints the contents of a [celprm](#) struct. Mainly intended for diagnostic purposes.

##### Parameters:

← *cel* Celestial transformation parameters.

##### Returns:

Status return value:

- 0: Success.
- 1: Null [celprm](#) pointer passed.

**6.1.3.3 int celset (struct *celprm* \* *cel*)**

**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.

**Parameters:**

↔ *cel* 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.

**6.1.3.4 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*[])**

**celx2s()** transforms  $(x, y)$  coordinates in the plane of projection to celestial coordinates  $(\alpha, \delta)$ .

**Parameters:**

↔ *cel* Celestial transformation parameters.

← *nx, ny* Vector lengths.

← *sxy, sll* Vector strides.

← *x, y* Projected coordinates in pseudo "degrees".

→ *phi, theta* Longitude and latitude  $(\phi, \theta)$  in the native coordinate system of the projection [deg].

→ *lng, lat* Celestial longitude and latitude  $(\alpha, \delta)$  of the projected point [deg].

→ *stat* Status return value for each vector element:

- 0: Success.
- 1: Invalid value of  $(x, y)$ .

**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.

**6.1.3.5** `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[])`

`cels2x()` transforms celestial coordinates  $(\alpha, \delta)$  to  $(x, y)$  coordinates in the plane of projection.

**Parameters:**

- ↔ *cel* Celestial transformation parameters.
- ← *nlng, nlat* Vector lengths.
- ← *sll, sxy* Vector strides.
- ← *lng, lat* Celestial longitude and latitude  $(\alpha, \delta)$  of the projected point [deg].
- *phi, theta* Longitude and latitude  $(\phi, \theta)$  in the native coordinate system of the projection [deg].
- *x, y* Projected coordinates in pseudo "degrees".
- *stat* Status return value for each vector element:
  - 0: Success.
  - 1: Invalid value of  $(\alpha, \delta)$ .

**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.

## 6.1.4 Variable Documentation

**6.1.4.1** `const char * cel\_errmsg[]`

Status messages to match the status value returned from each function.

## 6.2 fitshdr.h File Reference

```
#include "wcsconfig.h"
```

**Data Structures**

- struct [fitskeyid](#)  
*Keyword indexing.*
- struct [fitskey](#)  
*Keyword/value information.*

## Defines

- #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.*

## 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.*

### 6.2.1 Detailed Description

[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.



## 6.2.2 Define Documentation

### 6.2.2.1 #define FITSHDR\_KEYWORD 0x01

Bit mask for the status flag bit-vector returned by [fitshdr\(\)](#) indicating illegal keyword syntax.

### 6.2.2.2 #define FITSHDR\_KEYVALUE 0x02

Bit mask for the status flag bit-vector returned by [fitshdr\(\)](#) indicating illegal keyvalue syntax.

### 6.2.2.3 #define FITSHDR\_COMMENT 0x04

Bit mask for the status flag bit-vector returned by [fitshdr\(\)](#) indicating illegal keycomment syntax.

### 6.2.2.4 #define FITSHDR\_KEYREC 0x08

Bit mask for the status flag bit-vector returned by [fitshdr\(\)](#) indicating an illegal keyrecord, e.g. an END keyrecord with trailing text.

### 6.2.2.5 #define FITSHDR\_CARD 0x08

#### Deprecated

Added for backwards compatibility, use *FITSHDR\_KEYREC* instead.

### 6.2.2.6 #define FITSHDR\_TRAILER 0x10

Bit mask for the status flag bit-vector returned by [fitshdr\(\)](#) indicating a keyrecord following a valid END keyrecord.

### 6.2.2.7 #define KEYIDLEN (sizeof(struct fitskeyid)/sizeof(int))

### 6.2.2.8 #define KEYLEN (sizeof(struct fitskey)/sizeof(int))

## 6.2.3 Typedef Documentation

### 6.2.3.1 [int64](#)

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 [fitshdr.h](#) as

```
#ifdef WCSLIB_INT64
    typedef WCSLIB_INT64 int64;
#else
    typedef int int64[3];
#endif
```

See [fitskey::type](#).

### 6.2.4 Function Documentation

**6.2.4.1** `int fitshdr (const char header[ ], int nkeyrec, int nkeyids, struct fitskeyid keyids[ ], int * nreject, struct fitskey ** keys)`

**fitshdr()** parses a character array containing a FITS header, extracting all keywords and their values into an array of `fitskey` structs.

#### Parameters:

- ← **header** Character array containing the (entire) FITS header, for example, as might be obtained conveniently via the CFITSIO routine `fits_hdr2str()`.  
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.
- ← **nkeyrec** Number of keyrecords in header[].
- ← **nkeyids** Number of entries in keyids[].
- ↔ **keyids** While all keywords are extracted from the header, keyids[] provides a convenient way of indexing them. The `fitskeyid` struct contains three members; `fitskeyid::name` must be set by the user while `fitskeyid::count` and `fitskeyid::name` are returned by **fitshdr()**. All matched keywords will have their `fitskey::keyno` member negated.
- **nreject** Number of header keyrecords rejected for syntax errors.
- **keys** Pointer to an array of nkeyrec `fitskey` structs containing all keywords and keyvalues extracted from the header.  
Memory for the array is allocated by **fitshdr()** and this must be freed by the user by invoking `free()` on the array.

#### Returns:

Status return value:

- 0: Success.
- 1: Null `fitskey` pointer passed.
- 2: Memory allocation failed.
- 3: Fatal error returned by Flex parser.

#### 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 keycomment, 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.

## 6.2.5 Variable Documentation

### 6.2.5.1 `const char * fitshdr_errmsg[ ]`

Error messages to match the status value returned from each function.

## 6.3 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.*

### 6.3.1 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.

### 6.3.2 Function Documentation

#### 6.3.2.1 int fits\_read\_wcstab (fitsfile \*fptr, int nwtb, `wtbarr` \*wtb, int \*status)

`fits_read_wcstab()` extracts arrays from a binary table required in constructing 'TAB' coordinates.

#### Parameters:

- ← *fptr* Pointer to the file handle returned, for example, by the `fits_open_file()` routine in CFITSIO.
- ← *nwtb* Number of arrays to be read from the binary table(s).
- ↔ *wtb* Address of the first element of an array of `wtbarr` typedefs. This `wtbarr` typedef is defined to match the `wtbarr` struct defined in WCSLIB. An array of such structs returned by the WCSLIB function `wcstab()` as discussed in the notes below.
- *status* CFITSIO status value.

#### Returns:

CFITSIO status value.

#### Notes:

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 wt barr *w;
```

while within CFITSIO they are simply

```
wt barr *w;
```

As suggested by the commonality of the names, these are really the same aggregate data type. However, in passing a (struct `wt barr *`) to `fits_read_wcstab()` a cast to (wt barr \*) 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 `wt barr` struct in `wcs.h` is renamed by preprocessor macro substitution to `wt barr_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 `wt barr` typedef.

## 6.4 `lin.h` File Reference

### Data Structures

- struct `linprm`  
*Linear transformation parameters.*

### Defines

- #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.*

## Functions

- `int linini` (int alloc, int naxis, struct `linprm` \*lin)  
*Default constructor for the `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 linprt` (const struct `linprm` \*lin)  
*Print routine for the `linprm` struct.*
- `int linset` (struct `linprm` \*lin)  
*Setup routine for the `linprm` struct.*
- `int linp2x` (struct `linprm` \*lin, int ncoord, int nelelem, const double pixcrd[ ], double imgcrd[ ])  
*Pixel-to-world linear transformation.*
- `int linx2p` (struct `linprm` \*lin, int ncoord, int nelelem, const double imgcrd[ ], double pixcrd[ ])  
*World-to-pixel linear transformation.*
- `int matinv` (int n, const double mat[ ], double inv[ ])  
*Matrix inversion.*

## Variables

- `const char * lin_errmsg` [ ]  
*Status return messages.*

### 6.4.1 Detailed Description

These routines apply the linear transformation defined by the FITS WCS standard. They 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.

Three routines, `linini()`, `lincpy()`, and `linfree()` are provided to manage the `linprm` struct, and another, `linprt()`, prints its contents.

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 matrix inversion routine, `matinv()`, is included. It uses LU-triangular factorization with scaled partial pivoting.

## 6.4.2 Define Documentation

### 6.4.2.1 #define LINLEN (sizeof(struct [linprm](#))/sizeof(int))

Size of the [linprm](#) struct in *int* units, used by the Fortran wrappers.

### 6.4.2.2 #define linini\_errmsg [lin\\_errmsg](#)

#### Deprecated

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

### 6.4.2.3 #define lincpy\_errmsg [lin\\_errmsg](#)

#### Deprecated

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

### 6.4.2.4 #define linfree\_errmsg [lin\\_errmsg](#)

#### Deprecated

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

### 6.4.2.5 #define linprt\_errmsg [lin\\_errmsg](#)

#### Deprecated

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

### 6.4.2.6 #define linset\_errmsg [lin\\_errmsg](#)

#### Deprecated

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

### 6.4.2.7 #define linp2x\_errmsg [lin\\_errmsg](#)

#### Deprecated

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

### 6.4.2.8 #define linx2p\_errmsg [lin\\_errmsg](#)

#### Deprecated

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

### 6.4.3 Function Documentation

#### 6.4.3.1 int linini (int alloc, int naxis, struct linprm \* lin)

**linini()** allocates memory for arrays in a **linprm** struct and sets all members of the struct to default values.

**PLEASE NOTE:** every **linprm** struct should be initialized by **linini()**, 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 **linini()** will actually be used to allocate memory.

##### Parameters:

- ← **alloc** If true, allocate memory unconditionally for arrays in the **linprm** 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.)
- ← **naxis** The number of world coordinate axes, used to determine array sizes.
- ↔ **lin** Linear transformation parameters. Note that, in order to initialize memory management **linprm::flag** should be set to -1 when **lin** is initialized for the first time (memory leaks may result if it had already been initialized).

##### Returns:

Status return value:

- 0: Success.
- 1: Null **linprm** pointer passed.
- 2: Memory allocation failed.

#### 6.4.3.2 int lincpy (int alloc, const struct linprm \* linsrc, struct linprm \* lindst)

**lincpy()** does a deep copy of one **linprm** struct to another, using **linini()** 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:

- ← **alloc** If true, allocate memory for the **crpix**, **pc**, and **cdelt** 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.
- ← **linsrc** Struct to copy from.
- ↔ **lindst** Struct to copy to. **linprm::flag** should be set to -1 if **lindst** 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.



**6.4.3.3 int linfree (struct linprm \* lin)**

**linfree()** frees memory allocated for the **linprm** arrays by **linini()** and/or **linset()**. **linini()** 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 **linini()**.

**Parameters:**

← **lin** Linear transformation parameters.

**Returns:**

Status return value:

- 0: Success.
- 1: Null **linprm** pointer passed.

**6.4.3.4 int linprt (const struct linprm \* lin)**

**linprt()** prints the contents of a **linprm** struct.

**Parameters:**

← **lin** Linear transformation parameters.

**Returns:**

Status return value:

- 0: Success.
- 1: Null **linprm** pointer passed.

**6.4.3.5 int linset (struct linprm \* lin)**

**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.

**Parameters:**

↔ **lin** Linear transformation parameters.

**Returns:**

Status return value:

- 0: Success.
- 1: Null **linprm** pointer passed.
- 2: Memory allocation failed.
- 3: **PCi\_ja** matrix is singular.

### 6.4.3.6 int linp2x (struct **linprm** \* *lin*, int *ncoord*, int *nelem*, const double *pixcrd*[ ], double *imgcrd*[ ])

**linp2x()** transforms pixel coordinates to intermediate world coordinates.

#### Parameters:

- ↔ *lin* Linear transformation parameters.
- ← *ncoord, nelem* The number of coordinates, each of vector length *nelem* but containing *lin.naxis* coordinate elements.
- ← *pixcrd* Array of pixel coordinates.
- *imgcrd* 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.

### 6.4.3.7 int linx2p (struct **linprm** \* *lin*, int *ncoord*, int *nelem*, const double *imgcrd*[ ], double *pixcrd*[ ])

**linx2p()** transforms intermediate world coordinates to pixel coordinates.

#### Parameters:

- ↔ *lin* Linear transformation parameters.
- ← *ncoord, nelem* The number of coordinates, each of vector length *nelem* but containing *lin.naxis* coordinate elements.
- ← *imgcrd* Array of intermediate world coordinates.
- *pixcrd* Array of pixel coordinates. Status return value:
  - 0: Success.
  - 1: Null **linprm** pointer passed.
  - 2: Memory allocation failed.
  - 3: **PCi\_ja** matrix is singular.

### 6.4.3.8 matinv (int *n*, const double *mat*[ ], double *inv*[ ])

**matinv()** performs matrix inversion using LU-triangular factorization with scaled partial pivoting.

#### Parameters:

- ← *n* Order of the matrix ( $n \times n$ ).
- ← *mat* Matrix to be inverted, stored as *mat*[*i**n* + *j*] where *i* and *j* are the row and column indices respectively.
- *inv* Inverse of *mat* with the same storage convention.

**Returns:**

Status return value:

- 0: Success.
- 2: Memory allocation failed.
- 3: Singular matrix.

**6.4.4 Variable Documentation****6.4.4.1 `const char * lin_errmsg[ ]`**

Error messages to match the status value returned from each function.

**6.5 log.h File Reference****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.*

**6.5.1 Detailed Description**

These routines implement the part of the FITS WCS standard that deals with logarithmic coordinates. They 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.

**6.5.2 Function Documentation****6.5.2.1 `int logx2s` (double *crval*, int *nx*, int *sx*, int *slogc*, const double *x[ ]*, double *logc[ ]*, int *stat[ ]*)**

`logx2s()` transforms intermediate world coordinates to logarithmic coordinates.

**Parameters:**

- ↔ *crval* Log-coordinate reference value (**CRVAL**<sub>ia</sub>).
- ← *nx* Vector length.
- ← *sx* Vector stride.
- ← *slogc* Vector stride.
- ← *x* Intermediate world coordinates, in SI units.
- *logc* Logarithmic coordinates, in SI units.
- *stat* Status return value status for each vector element:
  - 0: Success.
  - 1: Invalid value of x.

**Returns:**

Status return value:

- 0: Success.
- 2: Invalid log-coordinate reference value.
- 3: One or more of the x coordinates were invalid, as indicated by the stat vector.

**6.5.2.2 int logs2x (double crval, int nlogc, int slogc, int sx, const double logc[ ], double x[ ], int stat[ ])**

**logs2x()** transforms logarithmic world coordinates to intermediate world coordinates.

**Parameters:**

- ↔ *crval* Log-coordinate reference value (**CRVAL**<sub>ia</sub>).
- ← *nlogc* Vector length.
- ← *slogc* Vector stride.
- ← *sx* Vector stride.
- ← *logc* Logarithmic coordinates, in SI units.
- *x* Intermediate world coordinates, in SI units.
- *stat* Status return value status for each vector element:
  - 0: Success.
  - 1: Invalid value of logc.

**Returns:**

Status return value:

- 0: Success.
- 2: Invalid log-coordinate reference value.

**6.5.3 Variable Documentation****6.5.3.1 const char \* log\_errmsg[ ]**

Error messages to match the status value returned from each function.

## 6.6 prj.h File Reference

### Data Structures

- struct [prjprm](#)  
*Projection parameters.*

### Defines

- #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 [prjpri\\_errmsg](#) [prj\\_errmsg](#)  
*Deprecated.*
- #define [prjset\\_errmsg](#) [prj\\_errmsg](#)  
*Deprecated.*
- #define [prjx2s\\_errmsg](#) [prj\\_errmsg](#)  
*Deprecated.*
- #define [prjs2x\\_errmsg](#) [prj\\_errmsg](#)  
*Deprecated.*

### Functions

- int [prjini](#) (struct [prjprm](#) \*prj)  
*Default constructor for the [prjprm](#) struct.*
- int [prjpri](#) (const struct [prjprm](#) \*prj)  
*Print routine for the [prjprm](#) struct.*
- int [prjset](#) (struct [prjprm](#) \*prj)  
*Generic setup routine for the [prjprm](#) struct.*
- int [prjx2s](#) (PRJX2S\_ARGS)

*Generic Cartesian-to-spherical deprojection.*

- int [prjs2x](#) (PRJS2X\_ARGS)  
*Generic spherical-to-Cartesian projection.*
- int [azpset](#) (struct [prjprm](#) \*prj)  
*Set up a [prjprm](#) struct for the **zenithal/azimuthal perspective** (AZP) projection.*
- int [azpx2s](#) (PRJX2S\_ARGS)  
*Cartesian-to-spherical transformation for the **zenithal/azimuthal perspective** (AZP) projection.*
- int [azps2x](#) (PRJS2X\_ARGS)  
*Spherical-to-Cartesian transformation for the **zenithal/azimuthal perspective** (AZP) projection.*
- int [szpset](#) (struct [prjprm](#) \*prj)  
*Set up a [prjprm](#) struct for the **slant zenithal perspective** (SZP) projection.*
- int [szpx2s](#) (PRJX2S\_ARGS)  
*Cartesian-to-spherical transformation for the **slant zenithal perspective** (SZP) projection.*
- int [szps2x](#) (PRJS2X\_ARGS)  
*Spherical-to-Cartesian transformation for the **slant zenithal perspective** (SZP) projection.*
- int [tanset](#) (struct [prjprm](#) \*prj)  
*Set up a [prjprm](#) struct for the **gnomonic** (TAN) projection.*
- int [tanx2s](#) (PRJX2S\_ARGS)  
*Cartesian-to-spherical transformation for the **gnomonic** (TAN) projection.*
- int [tans2x](#) (PRJS2X\_ARGS)  
*Spherical-to-Cartesian transformation for the **gnomonic** (TAN) projection.*
- int [stgset](#) (struct [prjprm](#) \*prj)  
*Set up a [prjprm](#) struct for the **stereographic** (STG) projection.*
- int [stgx2s](#) (PRJX2S\_ARGS)  
*Cartesian-to-spherical transformation for the **stereographic** (STG) projection.*
- int [stgs2x](#) (PRJS2X\_ARGS)  
*Spherical-to-Cartesian transformation for the **stereographic** (STG) projection.*
- int [sinset](#) (struct [prjprm](#) \*prj)  
*Set up a [prjprm](#) struct for the **orthographic/synthesis** (SIN) projection.*
- int [sinx2s](#) (PRJX2S\_ARGS)  
*Cartesian-to-spherical transformation for the **orthographic/synthesis** (SIN) projection.*
- int [sins2x](#) (PRJS2X\_ARGS)  
*Spherical-to-Cartesian transformation for the **orthographic/synthesis** (SIN) projection.*

- `int arcset` (struct `prjprm` \*prj)  
*Set up a `prjprm` struct for the **zenithal/azimuthal equidistant** (ARC) projection.*
- `int arcx2s` (PRJX2S\_ARGS)  
*Cartesian-to-spherical transformation for the **zenithal/azimuthal equidistant** (ARC) projection.*
- `int arcs2x` (PRJS2X\_ARGS)  
*Spherical-to-Cartesian transformation for the **zenithal/azimuthal equidistant** (ARC) projection.*
- `int zpnset` (struct `prjprm` \*prj)  
*Set up a `prjprm` struct for the **zenithal/azimuthal polynomial** (ZPN) projection.*
- `int zpnx2s` (PRJX2S\_ARGS)  
*Cartesian-to-spherical transformation for the **zenithal/azimuthal polynomial** (ZPN) projection.*
- `int 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 [merset](#) (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 [parset](#) (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 [tscx2s](#) (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.*

## 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](#) [27][4]  
*Recognized three-letter projection codes.*

### 6.6.1 Detailed Description

These routines implement the spherical map projections defined by the FITS WCS standard. They 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, and another, [prjpri\(\)](#), to print its contents.

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.
- `prjprt()` Routine to print the `prjprm` struct.
- `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()`, `arcox2s()`, `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()`, `pcosx2s()`, `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)

#### 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` 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 no 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  $\theta$ .

#### 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.

### 6.6.2 Define Documentation

#### 6.6.2.1 #define PVN 30

The total number of projection parameters numbered 0 to **PVN**-1.

#### 6.6.2.2 #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[]
```

Preprocessor macro used for declaring deprojection function prototypes.

#### 6.6.2.3 #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[]
```

Preprocessor macro used for declaring projection function prototypes.

**6.6.2.4 #define PRJLEN (sizeof(struct prjprm)/sizeof(int))**

Size of the `prjprm` struct in *int* units, used by the Fortran wrappers.

**6.6.2.5 #define prjini\_errmsg prj\_errmsg****Deprecated**

Added for backwards compatibility, use `prj_errmsg` directly now instead.

**6.6.2.6 #define prjpri\_errmsg prj\_errmsg****Deprecated**

Added for backwards compatibility, use `prj_errmsg` directly now instead.

**6.6.2.7 #define prjset\_errmsg prj\_errmsg****Deprecated**

Added for backwards compatibility, use `prj_errmsg` directly now instead.

**6.6.2.8 #define prjx2s\_errmsg prj\_errmsg****Deprecated**

Added for backwards compatibility, use `prj_errmsg` directly now instead.

**6.6.2.9 #define prjs2x\_errmsg prj\_errmsg****Deprecated**

Added for backwards compatibility, use `prj_errmsg` directly now instead.

**6.6.3 Function Documentation****6.6.3.1 int prjini (struct prjprm \* prj)**

`prjini()` sets all members of a `prjprm` struct to default values. It should be used to initialize every `prjprm` struct.

**Parameters:**

→ *prj* Projection parameters.

**Returns:**

Status return value:

- 0: Success.
- 1: Null `prjprm` pointer passed.

**6.6.3.2 int prjprt (const struct prjprm \* prj)**

**prjprt()** prints the contents of a **prjprm** struct.

**Parameters:**

← **prj** Projection parameters.

**Returns:**

Status return value:

- 0: Success.
- 1: Null **prjprm** pointer passed.

**6.6.3.3 int prjset (struct prjprm \* prj)**

**prjset()** sets up a **prjprm** struct according to information supplied within it.

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.

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.

**Parameters:**

↔ **prj** Projection parameters.

**Returns:**

Status return value:

- 0: Success.
- 1: Null **prjprm** pointer passed.
- 2: Invalid projection parameters.

**6.6.3.4 int prjx2s (PRJX2S\_ARGS)**

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:**

↔ **prj** Projection parameters.

← **nx, ny** Vector lengths.

← **sxy, spt** Vector strides.

← **x, y** Projected coordinates.

→ **phi, theta** Longitude and latitude  $(\phi, \theta)$  of the projected point in native spherical coordinates [deg].

→ **stat** Status return value for each vector element:

- 0: Success.

- 1: Invalid value of  $(x, y)$ .

**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.

**6.6.3.5 int prjs2x (PRJS2X\_ARGS)**

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:**

- $\leftrightarrow$  *prj* Projection parameters.
- $\leftarrow$  *nphi, ntheta* Vector lengths.
- $\leftarrow$  *spt, sxy* Vector strides.
- $\leftarrow$  *phi, theta* Longitude and latitude  $(\phi, \theta)$  of the projected point in native spherical coordinates [deg].
- $\rightarrow$  *x, y* Projected coordinates.
- $\rightarrow$  *stat* Status return value for each vector element:
  - 0: Success.
  - 1: Invalid value of  $(\phi, \theta)$ .

**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.

**6.6.3.6 int azpset (struct prjprm \* prj)**

**azpset()** sets up a [prjprm](#) struct for a **zenithal/azimuthal perspective** (AZP) projection.

See [prjset\(\)](#) for a description of the API.

**6.6.3.7 int azpx2s (PRJX2S\_ARGS)**

**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.



**6.6.3.8 int azps2x (PRJS2X\_ARGS)**

**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.

**6.6.3.9 int szpset (struct prjprm \* prj)**

**szpset()** sets up a [prjprm](#) struct for a **slant zenithal perspective** (SZP) projection.

See [prjset\(\)](#) for a description of the API.

**6.6.3.10 int szpx2s (PRJX2S\_ARGS)**

**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.

**6.6.3.11 int szps2x (PRJS2X\_ARGS)**

**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.

**6.6.3.12 int tanset (struct prjprm \* prj)**

**tanset()** sets up a [prjprm](#) struct for a **gnomonic** (TAN) projection.

See [prjset\(\)](#) for a description of the API.

**6.6.3.13 int tanx2s (PRJX2S\_ARGS)**

**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.

**6.6.3.14 int tans2x (PRJS2X\_ARGS)**

**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.

**6.6.3.15 int stgset (struct prjprm \* prj)**

**stgset()** sets up a [prjprm](#) struct for a **stereographic** (STG) projection.

See [prjset\(\)](#) for a description of the API.

**6.6.3.16 int stgx2s (PRJX2S\_ARGS)**

**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.

#### 6.6.3.17 int stgs2x (PRJS2X\_ARGS)

**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.

#### 6.6.3.18 int sinset (struct prjprm \* prj)

**sinset()** sets up a [prjprm](#) struct for an **orthographic/synthesis** (SIN) projection.

See [prjset\(\)](#) for a description of the API.

#### 6.6.3.19 int sinx2s (PRJX2S\_ARGS)

**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.

#### 6.6.3.20 int sins2x (PRJS2X\_ARGS)

**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.

#### 6.6.3.21 int arcset (struct prjprm \* prj)

**arcset()** sets up a [prjprm](#) struct for a **zenithal/azimuthal equidistant** (ARC) projection.

See [prjset\(\)](#) for a description of the API.

#### 6.6.3.22 int arcx2s (PRJX2S\_ARGS)

**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.

#### 6.6.3.23 int arcs2x (PRJS2X\_ARGS)

**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.

#### 6.6.3.24 int zpnset (struct prjprm \* prj)

**zpnset()** sets up a [prjprm](#) struct for a **zenithal/azimuthal polynomial** (ZPN) projection.

See [prjset\(\)](#) for a description of the API.

**6.6.3.25 int zpnx2s (PRJX2S\_ARGS)**

**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.

**6.6.3.26 int zpns2x (PRJS2X\_ARGS)**

**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.

**6.6.3.27 int zeaset (struct prjprm \* prj)**

**zeaset()** sets up a [prjprm](#) struct for a **zenithal/azimuthal equal area** (ZEA) projection.

See [prjset\(\)](#) for a description of the API.

**6.6.3.28 int zeax2s (PRJX2S\_ARGS)**

**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.

**6.6.3.29 int zeas2x (PRJS2X\_ARGS)**

**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.

**6.6.3.30 int airset (struct prjprm \* prj)**

**airset()** sets up a [prjprm](#) struct for an **Airy** (AIR) projection.

See [prjset\(\)](#) for a description of the API.

**6.6.3.31 int airx2s (PRJX2S\_ARGS)**

**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.

**6.6.3.32 int airs2x (PRJS2X\_ARGS)**

**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.

**6.6.3.33 int cypset (struct prjprm \* prj)**

**cypset()** sets up a [prjprm](#) struct for a **cylindrical perspective** (CYP) projection.

See [prjset\(\)](#) for a description of the API.

#### 6.6.3.34 int cypx2s (PRJX2S\_ARGS)

**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.

#### 6.6.3.35 int cyps2x (PRJS2X\_ARGS)

**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.

#### 6.6.3.36 int ceaset (struct prjprm \* prj)

**ceaset()** sets up a [prjprm](#) struct for a **cylindrical equal area** (CEA) projection.

See [prjset\(\)](#) for a description of the API.

#### 6.6.3.37 int ceax2s (PRJX2S\_ARGS)

**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.

#### 6.6.3.38 int ceas2x (PRJS2X\_ARGS)

**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.

#### 6.6.3.39 int carset (struct prjprm \* prj)

**carset()** sets up a [prjprm](#) struct for a **plate carrée** (CAR) projection.

See [prjset\(\)](#) for a description of the API.

#### 6.6.3.40 int carx2s (PRJX2S\_ARGS)

**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.

#### 6.6.3.41 int cars2x (PRJS2X\_ARGS)

**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.

**6.6.3.42 int merset (struct [prjprm](#) \* *prj*)**

**merset()** sets up a [prjprm](#) struct for a **Mercator** (MER) projection.

See [prjset\(\)](#) for a description of the API.

**6.6.3.43 int merx2s (PRJX2S\_ARGS)**

**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.

**6.6.3.44 int mers2x (PRJS2X\_ARGS)**

**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.

**6.6.3.45 int sflset (struct [prjprm](#) \* *prj*)**

**sflset()** sets up a [prjprm](#) struct for a **Sanson-Flamsteed** (SFL) projection.

See [prjset\(\)](#) for a description of the API.

**6.6.3.46 int sflx2s (PRJX2S\_ARGS)**

**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.

**6.6.3.47 int sfls2x (PRJS2X\_ARGS)**

**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.

**6.6.3.48 int parset (struct [prjprm](#) \* *prj*)**

**parset()** sets up a [prjprm](#) struct for a **parabolic** (PAR) projection.

See [prjset\(\)](#) for a description of the API.

**6.6.3.49 int parx2s (PRJX2S\_ARGS)**

**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.

**6.6.3.50 int pars2x (PRJS2X\_ARGS)**

**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.

#### 6.6.3.51 int molset (struct [prjprm](#) \* *prj*)

**molset()** sets up a [prjprm](#) struct for a **Mollweide** (MOL) projection.

See [prjset\(\)](#) for a description of the API.

#### 6.6.3.52 int molx2s (PRJX2S\_ARGS)

**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.

#### 6.6.3.53 int mols2x (PRJS2X\_ARGS)

**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.

#### 6.6.3.54 int aitset (struct [prjprm](#) \* *prj*)

**aitset()** sets up a [prjprm](#) struct for a **Hammer-Aitoff** (AIT) projection.

See [prjset\(\)](#) for a description of the API.

#### 6.6.3.55 int aitx2s (PRJX2S\_ARGS)

**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.

#### 6.6.3.56 int aits2x (PRJS2X\_ARGS)

**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.

#### 6.6.3.57 int copset (struct [prjprm](#) \* *prj*)

**copset()** sets up a [prjprm](#) struct for a **conic perspective** (COP) projection.

See [prjset\(\)](#) for a description of the API.

#### 6.6.3.58 int copx2s (PRJX2S\_ARGS)

**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.

**6.6.3.59 int cops2x (PRJS2X\_ARGS)**

**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.

**6.6.3.60 int coeset (struct prjprm \* prj)**

**coeset()** sets up a [prjprm](#) struct for a **conic equal area** (COE) projection.

See [prjset\(\)](#) for a description of the API.

**6.6.3.61 int coex2s (PRJX2S\_ARGS)**

**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.

**6.6.3.62 int coes2x (PRJS2X\_ARGS)**

**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.

**6.6.3.63 int codset (struct prjprm \* prj)**

**codset()** sets up a [prjprm](#) struct for a **conic equidistant** (COD) projection.

See [prjset\(\)](#) for a description of the API.

**6.6.3.64 int codx2s (PRJX2S\_ARGS)**

**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.

**6.6.3.65 int cods2x (PRJS2X\_ARGS)**

**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.

**6.6.3.66 int cooset (struct prjprm \* prj)**

**cooset()** sets up a [prjprm](#) struct for a **conic orthomorphic** (COO) projection.

See [prjset\(\)](#) for a description of the API.

**6.6.3.67 int coox2s (PRJX2S\_ARGS)**

**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.

#### 6.6.3.68 int coos2x (PRJS2X\_ARGS)

**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.

#### 6.6.3.69 int bonset (struct [prjprm](#) \* *prj*)

**bonset()** sets up a [prjprm](#) struct for a **Bonne** (BON) projection.

See [prjset\(\)](#) for a description of the API.

#### 6.6.3.70 int bonx2s (PRJX2S\_ARGS)

**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.

#### 6.6.3.71 int bons2x (PRJS2X\_ARGS)

**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.

#### 6.6.3.72 int pcset (struct [prjprm](#) \* *prj*)

**pcset()** sets up a [prjprm](#) struct for a **polyconic** (PCO) projection.

See [prjset\(\)](#) for a description of the API.

#### 6.6.3.73 int pcox2s (PRJX2S\_ARGS)

**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.

#### 6.6.3.74 int pcos2x (PRJS2X\_ARGS)

**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.

#### 6.6.3.75 int tscset (struct [prjprm](#) \* *prj*)

**tscset()** sets up a [prjprm](#) struct for a **tangential spherical cube** (TSC) projection.

See [prjset\(\)](#) for a description of the API.



**6.6.3.76 int tscx2s (PRJX2S\_ARGS)**

**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.

**6.6.3.77 int tscs2x (PRJS2X\_ARGS)**

**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.

**6.6.3.78 int cscset (struct prjprm \* prj)**

**cscset()** sets up a [prjprm](#) struct for a **COBE spherical cube** (CSC) projection.

See [prjset\(\)](#) for a description of the API.

**6.6.3.79 int cscx2s (PRJX2S\_ARGS)**

**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.

**6.6.3.80 int cscs2x (PRJS2X\_ARGS)**

**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.

**6.6.3.81 int qscset (struct prjprm \* prj)**

**qscset()** sets up a [prjprm](#) struct for a **quadrilateralized spherical cube** (QSC) projection.

See [prjset\(\)](#) for a description of the API.

**6.6.3.82 int qscx2s (PRJX2S\_ARGS)**

**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.

**6.6.3.83 int qscs2x (PRJS2X\_ARGS)**

**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.

**6.6.3.84 int hpxset (struct prjprm \* prj)**

**hpxset()** sets up a [prjprm](#) struct for a **HEALPix** (HPX) projection.

See [prjset\(\)](#) for a description of the API.

#### 6.6.3.85 int `hpxx2s` (PRJX2S\_ARGS)

`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.

#### 6.6.3.86 int `hpxs2x` (PRJS2X\_ARGS)

`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.

### 6.6.4 Variable Documentation

#### 6.6.4.1 const char \* `prj_errmsg` []

Error messages to match the status value returned from each function.

#### 6.6.4.2 const int `CONIC`

Identifier for conic projections, see [prjprm::category](#).

#### 6.6.4.3 const int `CONVENTIONAL`

Identifier for conventional projections, see [prjprm::category](#).

#### 6.6.4.4 const int `CYLINDRICAL`

Identifier for cylindrical projections, see [prjprm::category](#).

#### 6.6.4.5 const int `POLYCONIC`

Identifier for polyconic projections, see [prjprm::category](#).

#### 6.6.4.6 const int `PSEUDOCYLINDRICAL`

Identifier for pseudocylindrical projections, see [prjprm::category](#).

#### 6.6.4.7 const int `QUADCUBE`

Identifier for quadcube projections, see [prjprm::category](#).

#### 6.6.4.8 const int `ZENITHAL`

Identifier for zenithal/azimuthal projections, see [prjprm::category](#).

#### 6.6.4.9 const int `HEALPIX`

Identifier for the HEALPix projection, see [prjprm::category](#).

#### 6.6.4.10 const char [prj\\_categories](#)[9][32]

Names of the projection categories, all in lower-case except for "HEALPix".

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

#### 6.6.4.11 const int [prj\\_ncode](#)

The number of recognized three-letter projection codes (currently 27), see [prj\\_codes](#).

#### 6.6.4.12 const char [prj\\_codes](#)[27][4]

List of all recognized three-letter projection codes (currently 27), e.g. SIN, TAN, etc.

## 6.7 spc.h File Reference

```
#include "spc.h"
```

### Data Structures

- struct [spcprm](#)  
*Spectral transformation parameters.*

### Defines

- #define [SPCLEN](#) (sizeof(struct [spcprm](#))/sizeof(int))  
*Size of the spcprm struct in int units.*
- #define [spcini\\_errmsg](#) [spc\\_errmsg](#)  
*Deprecated.*
- #define [spcpvt\\_errmsg](#) [spc\\_errmsg](#)  
*Deprecated.*
- #define [spcset\\_errmsg](#) [spc\\_errmsg](#)  
*Deprecated.*
- #define [spcx2s\\_errmsg](#) [spc\\_errmsg](#)  
*Deprecated.*
- #define [spcs2x\\_errmsg](#) [spc\\_errmsg](#)  
*Deprecated.*

### Functions

- int [spcini](#) (struct [spcprm](#) \*spc)  
*Default constructor for the spcprm struct.*

- int [spcprt](#) (const struct [spcprm](#) \*spc)  
*Print routine for the 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 [spctyp](#) (const char ctype[ ], char stype[ ], char scode[ ], char sname[ ], char units[ ], char \*ptype, char \*xtype, int \*restreq)  
*Spectral **CTYPE**<sub>ia</sub> keyword analysis.*
- int [spcspx](#) (const char ctypeS[ ], double crvalS, double restfrq, double restwav, char \*ptype, char \*xtype, int \*restreq, double \*crvalX, double \*dXdS)  
*Spectral keyword analysis.*
- int [spcxps](#) (const char ctypeS[ ], double crvalX, double restfrq, double restwav, char \*ptype, char \*xtype, int \*restreq, double \*crvalS, double \*dSdX)  
*Spectral keyword synthesis.*
- int [spectrn](#) (const char ctypeS1[ ], double crvalS1, double cdeltS1, double restfrq, double restwav, char ctypeS2[ ], double \*crvalS2, double \*cdeltS2)  
*Spectral keyword translation.*

## Variables

- const char \* [spc\\_errmsg](#) [ ]  
*Status return messages.*

### 6.7.1 Detailed Description

These routines implement the part of the FITS WCS standard that deals with spectral coordinates. They 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, and another, [spcprt\(\)](#), to print its contents.

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:

- `spctyp()` checks a spectral **CTYPE<sub>ia</sub>** keyword for validity and returns information derived from it.
- Spectral keyword analysis routine `spcspx()` computes the values of the *X*-type spectral variables for the *S*-type variables supplied.
- Spectral keyword synthesis routine, `spcxps()`, computes the *S*-type variables for the *X*-types supplied.
- Given a set of spectral keywords, a translation routine, `spectrn()`, produces the corresponding set for the specified spectral **CTYPE<sub>ia</sub>**.

### 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 **CTYPE<sub>ia</sub>** 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 **CTYPE<sub>ia</sub>** 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.

**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.

## 6.7.2 Define Documentation

### 6.7.2.1 `#define SPCLLEN (sizeof(struct spcprm)/sizeof(int))`

Size of the `spcprm` struct in *int* units, used by the Fortran wrappers.

### 6.7.2.2 `#define spcini_errmsg spc\_errmsg`

**Deprecated**

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

### 6.7.2.3 `#define spcpvt_errmsg spc\_errmsg`

**Deprecated**

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

### 6.7.2.4 `#define spcset_errmsg spc\_errmsg`

**Deprecated**

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

### 6.7.2.5 `#define spcx2s_errmsg spc\_errmsg`

**Deprecated**

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

### 6.7.2.6 `#define spcs2x_errmsg spc\_errmsg`

**Deprecated**

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

### 6.7.3 Function Documentation

#### 6.7.3.1 int spcini (struct [spcprm](#) \* *spc*)

**spcini()** sets all members of a `spcprm` struct to default values. It should be used to initialize every `spcprm` struct.

**Parameters:**

↔ *spc* Spectral transformation parameters.

**Returns:**

Status return value:

- 0: Success.
- 1: Null `spcprm` pointer passed.

#### 6.7.3.2 int spcpri (const struct [spcprm](#) \* *spc*)

**spcpri()** prints the contents of a `spcprm` struct.

**Parameters:**

← *spc* Spectral transformation parameters.

**Returns:**

Status return value:

- 0: Success.
- 1: Null `spcprm` pointer passed.

#### 6.7.3.3 int spcset (struct [spcprm](#) \* *spc*)

**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 anything other than a predefined magic value.

**Parameters:**

↔ *spc* Spectral transformation parameters.

**Returns:**

Status return value:

- 0: Success.
- 1: Null `spcprm` pointer passed.
- 2: Invalid spectral parameters.

**6.7.3.4** `int spcx2s (struct spcprm * spc, int nx, int sx, int sspec, const double x[], double spec[], int stat[])`

`spcx2s()` transforms intermediate world coordinates to spectral coordinates.

**Parameters:**

- ↔ *spc* Spectral transformation parameters.
- ← *nx* Vector length.
- ← *sx* Vector stride.
- ← *sspec* Vector stride.
- ← *x* Intermediate world coordinates, in SI units.
- *spec* Spectral coordinates, in SI units.
- *stat* Status return value status for each vector element:
  - 0: Success.
  - 1: Invalid value of *x*.

**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.

**6.7.3.5** `int spcs2x (struct spcprm * spc, int nspec, int sspec, int sx, const double spec[], double x[], int stat[])`

`spcs2x()` transforms spectral world coordinates to intermediate world coordinates.

**Parameters:**

- ↔ *spc* Spectral transformation parameters.
- ← *nspec* Vector length.
- ← *sspec* Vector stride.
- ← *sx* Vector stride.
- ← *spec* Spectral coordinates, in SI units.
- *x* Intermediate world coordinates, in SI units.
- *stat* Status return value status for each vector element:
  - 0: Success.
  - 1: Invalid value of *spec*.

**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.



### 6.7.3.6 int spctyp (const char *ctype*[], char *stype*[], char *scode*[], char *sname*[], char *units*[], char \**ptype*, char \**xtype*, int \**restreq*)

**spctyp()** 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). It recognizes and translates AIPS-convention spectral **CTYPE<sub>ia</sub>** keyvalues.

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.

#### Parameters:

- ← **ctype** The **CTYPE<sub>ia</sub>** keyvalue, (eight characters with null termination).
- **stype** The four-letter name of the *S*-type spectral variable copied or translated from *ctype*. If a non-zero pointer is given, the array must accomodate a null-terminated string of length 5.
- **scode** The three-letter spectral algorithm code copied or translated from *ctype*. Logarithmic ('LOG') and tabular ('TAB') codes are also recognized. If a non-zero pointer is given, the array must accomodate a null-terminated string of length 4.
- **sname** Descriptive name of the *S*-type spectral variable. If a non-zero pointer is given, the array must accomodate a null-terminated string of length 22.
- **units** SI units of the *S*-type spectral variable. If a non-zero pointer is given, the array must accomodate a null-terminated string of length 8.
- **ptype** Character code for the *P*-type spectral variable derived from *ctype*, one of 'F', 'W', 'A', or 'V'.
- **xtype** Character code for the *X*-type spectral variable derived from *ctype*, 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 ('LOG') and tabular ('TAB') axes.
- **restreq** Multivalued flag that indicates whether rest frequency or wavelength is required to compute spectral variables for this **CTYPE<sub>ia</sub>**:
  - 0: Not required.
  - 1: Required for the conversion between *S*- and *P*-types (e.g. 'ZOPT-F2W').
  - 2: Required for the conversion between *P*- and *X*-types (e.g. 'BETA-W2V').
  - 3: Required for the conversion between *S*- and *P*-types, and between *P*- and *X*-types, but not between *S*- and *X*-types (this applies only for 'VRAD-V2F', 'VOPT-V2W', and 'ZOPT-V2W').

Thus the rest frequency or wavelength is required for spectral coordinate computations (i.e. between *S*- and *X*-types) only if

```
restreq%3 != 0
```

.

#### Returns:

Status return value:

- 0: Success.
- 2: Invalid spectral parameters (not a spectral **CTYPE<sub>ia</sub>**).

**6.7.3.7** `int spcspix (const char ctypeS[], double crvalS, double restfrq, double restwav, char * ptype, char * xtype, int * restreq, double * crvalX, double * dXdS)`

`spcspix()` analyses the **CTYPE<sub>ia</sub>** and **CRVAL<sub>ia</sub>** FITS spectral axis keyword values and returns information about the associated *X*-type spectral variable.

**Parameters:**

- ← *ctypeS* Spectral axis type, i.e. the **CTYPE<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 **CTYPE<sub>ia</sub>**) may be set to '?' (it will not be reset).
- ← *crvalS* Value of the *S*-type spectral variable at the reference point, i.e. the **CRVAL<sub>ia</sub>** keyvalue, SI units.
- ← *restfrq, restwav* 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 'FREQ' -> 'ZOPT-F2W', but not required for 'VELO-F2V' -> 'ZOPT-F2W'.
- *ptype* Character code for the *P*-type spectral variable derived from *ctypeS*, one of 'F', 'W', 'A', or 'V'.
- *xtype* Character code for the *X*-type spectral variable derived from *ctypeS*, one of 'F', 'W', 'A', or 'V'. Also, 'w' and 'a' are synonymous to 'W' and 'A' for grisms in vacuo and air respectively; *crvalX* and *dXdS* (see below) will conform to these.
- *restreq* Multivalued flag that indicates whether rest frequency or wavelength is required to compute spectral variables for this **CTYPE<sub>ia</sub>**, as for `spectyp()`.
- *crvalX* Value of the *X*-type spectral variable at the reference point, SI units.
- *dXdS* The derivative,  $dX/dS$ , evaluated at the reference point, SI units. Multiply the **CDELTA<sub>ia</sub>** keyvalue by this to get the pixel spacing in the *X*-type spectral coordinate.

**Returns:**

Status return value:

- 0: Success.
- 2: Invalid spectral parameters.

**6.7.3.8** `int spcxps (const char ctypeS[], double crvalX, double restfrq, double restwav, char * ptype, char * xtype, int * restreq, double * crvalS, double * dSdX)`

`spcxps()`, 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 **CDELTA<sub>ia</sub>**. See above for an explanation of the *S*-, *P*-, and *X*-type spectral variables.

**Parameters:**

- ← *ctypeS* The required spectral axis type, i.e. the **CTYPE<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 **CTYPE<sub>ia</sub>**) may be set to '?' (it will not be reset).
- ← *crvalX* Value of the *X*-type spectral variable at the reference point (N.B. NOT the **CRVAL<sub>ia</sub>** keyvalue), SI units.
- ← *restfrq, restwav* 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 'FREQ' -> 'ZOPT-F2W', but not required for 'VELO-F2V' -> 'ZOPT-F2W'.

- **ptype** Character code for the *P*-type spectral variable derived from `ctypeS`, one of 'F', 'W', 'A', or 'V'.
- **xtype** Character code for the *X*-type spectral variable derived from `ctypeS`, one of 'F', 'W', 'A', or 'V'. Also, 'w' and 'a' are synonymous to 'W' and 'A' for grisms; `crvalX` and `cdeltX` must conform to these.
- **restreq** Multivalued flag that indicates whether rest frequency or wavelength is required to compute spectral variables for this **CTYPE<sub>ia</sub>**, as for `spectyp()`.
- **crvalS** Value of the *S*-type spectral variable at the reference point (i.e. the appropriate **CRVAL<sub>ia</sub>** keyvalue), SI units.
- **dSdX** 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 **CDELTA<sub>ia</sub>** keyvalue.

#### Returns:

Status return value:

- 0: Success.
- 2: Invalid spectral parameters.

#### 6.7.3.9 int spectrn (const char ctypeS1[], double crvalS1, double cdeltS1, double restfrq, double restwav, char ctypeS2[], double \* crvalS2, double \* cdeltS2)

`spectrn()` 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.

#### Parameters:

- ← **ctypeS1** Spectral axis type, i.e. the **CTYPE<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 **CTYPE<sub>ia</sub>**) may be set to '?' (it will not be reset). AIPS-convention spectral types are accepted for `ctypeS1` but the Doppler frame encoded within them will not be used.
- ← **crvalS1** Value of the *S*-type spectral variable at the reference point, i.e. the **CRVAL<sub>ia</sub>** keyvalue, SI units.
- ← **cdeltS1** Increment of the *S*-type spectral variable at the reference point, SI units.
- ← **restfrq, restwav** 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 'FREQ' -> 'ZOPT-F2W', but not required for 'VELO-F2V' -> 'ZOPT-F2W'.
- ↔ **ctypeS2** 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, `ctypeS1` and the first four characters of `ctypeS2`. 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). AIPS-convention spectral types are not accepted for `ctypeS2`.
- **crvalS2** Value of the new *S*-type spectral variable at the reference point, i.e. the new **CRVAL<sub>ia</sub>** keyvalue, SI units.
- **cdeltS2** Increment of the new *S*-type spectral variable at the reference point, i.e. the new **CDELTA<sub>ia</sub>** keyvalue, SI units.

**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.

**6.7.4 Variable Documentation****6.7.4.1 `const char * spc_errmsg[ ]`**

Error messages to match the status value returned from each function.

**6.8 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 slt`, `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[ ]`)  
*Angular distance and position angle.*

**6.8.1 Detailed Description**

The WCS spherical coordinate transformations are implemented via separate functions, `sphx2s()` and `sphs2x()`, for the transformation in each direction.

A utility function, `sphdpa()`, uses these to compute the angular distance and position angle from a given point on the sky to a number of other points.

**6.8.2 Function Documentation****6.8.2.1 `int sphx2s` (`const double eul[5]`, `int nphi`, `int ntheta`, `int spt`, `int sxy`, `const double phi[ ]`, `const double theta[ ]`, `double lng[ ]`, `double lat[ ]`)**

`sphx2s()` transforms native coordinates of a projection to celestial coordinates.

**Parameters:**

← *eul* Euler angles for the transformation:

- 0: Celestial longitude of the native pole [deg].
- 1: Celestial colatitude of the native pole, or native colatitude of the celestial pole [deg].

- 2: Native longitude of the celestial pole [deg].
- 3:  $\cos(\text{eul}[1])$
- 4:  $\sin(\text{eul}[1])$

← *nphi,ntheta* Vector lengths.

← *spt,sxy* Vector strides.

← *phi,theta* Longitude and latitude in the native coordinate system of the projection [deg].

→ *lng,lat* Celestial longitude and latitude [deg].

#### Returns:

Status return value:

- 0: Success.

#### 6.8.2.2 int sphs2x (const double eul[5], int nlng, int nlat, int sll, int spt, const double lng[ ], const double lat[ ], double phi[ ], double theta[ ])

**sphs2x()** transforms celestial coordinates to the native coordinates of a projection.

#### Parameters:

← *eul* Euler angles for the transformation:

- 0: Celestial longitude of the native pole [deg].
- 1: Celestial colatitude of the native pole, or native colatitude of the celestial pole [deg].
- 2: Native longitude of the celestial pole [deg].
- 3:  $\cos(\text{eul}[1])$
- 4:  $\sin(\text{eul}[1])$

← *nlng,nlat* Vector lengths.

← *sll,spt* Vector strides.

← *lng,lat* Celestial longitude and latitude [deg].

→ *phi,theta* Longitude and latitude in the native coordinate system of the projection [deg].

#### Returns:

Status return value:

- 0: Success.

#### 6.8.2.3 int sphdpa (int nfield, double lng0, double lat0, const double lng[ ], const double lat[ ], double dist[ ], double pa[ ])

**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.

#### Parameters:

← *nfield* The number of field points.

← *lng0,lat0* Spherical coordinates of the reference point [deg].

← *lng,lat* Spherical coordinates of the field points [deg].

→ *dist,pa* Angular distance and position angle [deg].

#### Returns:

Status return value:

- 0: Success.

#### Notes:

**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.

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°).

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° or 180° (within rounding tolerance). **sphdpa()** will return an arbitrary position angle in such circumstances.

## 6.9 spx.h File Reference

### Data Structures

- struct **spxprm**  
*Spectral variables and their derivatives.*

### Defines

- #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.*

## Functions

- int [specx](#) (const char \*type, double spec, double restfreq, double restwav, struct [spxprm](#) \*specs)  
*Spectral cross conversions (scalar).*
- 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](#) []  
*Status return messages.*

### 6.9.1 Detailed Description

[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.

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:

- `freqafreq()` frequency -> angular frequency
- `afreqfreq()` 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.

#### 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.

## 6.9.2 Define Documentation

### 6.9.2.1 #define SPXLEN (sizeof(struct spxprm)/sizeof(int))

Size of the spxprm struct in *int* units, used by the Fortran wrappers.

### 6.9.2.2 #define SPX\_ARGS

**Value:**

```
double param, int nspec, int instep, int outstep, \
        const double inspec[], double outspec[], int stat[]
```

Preprocessor macro used for declaring spectral conversion function prototypes.

## 6.9.3 Function Documentation

### 6.9.3.1 int specx (const char \* *type*, double *spec*, double *restfrq*, double *restwav*, struct spxprm \* *specs*)

Given one spectral variable **specx()** computes all the others, plus the required derivatives of each with respect to the others.

**Parameters:**

- ← *type* The type of spectral variable given by spec, **FREQ**, **AFRQ**, **ENER**, **WAVN**, **VRAD**, **WAVE**, **VOPT**, **ZOPT**, **AWAV**, **VELO**, or **BETA** (case sensitive).
- ← *spec* The spectral variable given, in SI units.
- ← *restfrq, restwav* 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 **FREQ**, **AFRQ**, **ENER**, **WAVN**, **WAVE**, or **AWAV** the others can be computed without knowledge of the rest frequency. Likewise, **VRAD**, **VOPT**, **ZOPT**, **VELO**, and **BETA**.
- ↔ *specs* 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.

### 6.9.3.2 int freqafrq (SPX\_ARGS)

**freqafrq()** converts frequency to angular frequency.

**Parameters:**

- ← *param* Ignored.
- ← *nspec* Vector length.

- ← *instep, outstep* Vector strides.
- ← *inspec* Input spectral variables, in SI units.
- *outspec* Output spectral variables, in SI units.
- *stat* Status return value for each vector element:
  - 0: Success.
  - 1: Invalid value of inspec.

**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.

**6.9.3.3 int afrqfreq (SPX\_ARGS)**

**afrqfreq()** converts angular frequency to frequency.

See [freqafrq\(\)](#) for a description of the API.

**6.9.3.4 int freqener (SPX\_ARGS)**

**freqener()** converts frequency to photon energy.

See [freqafrq\(\)](#) for a description of the API.

**6.9.3.5 int enerfreq (SPX\_ARGS)**

**enerfreq()** converts photon energy to frequency.

See [freqafrq\(\)](#) for a description of the API.

**6.9.3.6 int freqwavn (SPX\_ARGS)**

**freqwavn()** converts frequency to wave number.

See [freqafrq\(\)](#) for a description of the API.

**6.9.3.7 int wavnfreq (SPX\_ARGS)**

**wavnfreq()** converts wave number to frequency.

See [freqafrq\(\)](#) for a description of the API.

**6.9.3.8 int freqwave (SPX\_ARGS)**

**freqwave()** converts frequency to vacuum wavelength.

See [freqafrq\(\)](#) for a description of the API.

**6.9.3.9 int wavefreq (SPX\_ARGS)**

**wavefreq()** converts vacuum wavelength to frequency.

See [freqafrq\(\)](#) for a description of the API.

**6.9.3.10 int freqawav (SPX\_ARGS)**

**freqawav()** converts frequency to air wavelength.

See [freqafrq\(\)](#) for a description of the API.

**6.9.3.11 int awavfreq (SPX\_ARGS)**

**awavfreq()** converts air wavelength to frequency.

See [freqafrq\(\)](#) for a description of the API.

**6.9.3.12 int waveawav (SPX\_ARGS)**

**waveawav()** converts vacuum wavelength to air wavelength.

See [freqafrq\(\)](#) for a description of the API.

**6.9.3.13 int awavwave (SPX\_ARGS)**

**awavwave()** converts air wavelength to vacuum wavelength.

See [freqafrq\(\)](#) for a description of the API.

**6.9.3.14 int velobeta (SPX\_ARGS)**

**velobeta()** converts relativistic velocity to relativistic beta.

See [freqafrq\(\)](#) for a description of the API.

**6.9.3.15 int betavelo (SPX\_ARGS)**

**betavelo()** converts relativistic beta to relativistic velocity.

See [freqafrq\(\)](#) for a description of the API.

**6.9.3.16 int freqvelo (SPX\_ARGS)**

**freqvelo()** converts frequency to relativistic velocity.

**Parameters:**

- ← *param* Rest frequency [Hz].
- ← *nspec* Vector length.
- ← *instep, outstep* Vector strides.
- ← *inspec* Input spectral variables, in SI units.
- *outspec* Output spectral variables, in SI units.
- *stat* Status return value for each vector element:
  - 0: Success.
  - 1: Invalid value of inspec.

**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.

#### 6.9.3.17 int velofreq (SPX\_ARGS)

**velofreq()** converts relativistic velocity to frequency.

See [freqvelo\(\)](#) for a description of the API.

#### 6.9.3.18 int freqvrad (SPX\_ARGS)

**freqvrad()** converts frequency to radio velocity.

See [freqvelo\(\)](#) for a description of the API.

#### 6.9.3.19 int vradfreq (SPX\_ARGS)

**vradfreq()** converts radio velocity to frequency.

See [freqvelo\(\)](#) for a description of the API.

#### 6.9.3.20 int wavevelo (SPX\_ARGS)

**wavevelo()** converts vacuum wavelength to relativistic velocity.

##### Parameters:

- ← *param* Rest wavelength in vacuo [m].
- ← *nspec* Vector length.
- ← *instep, outstep* Vector strides.
- ← *inspec* Input spectral variables, in SI units.
- *outspec* Output spectral variables, in SI units.
- *stat* Status return value for each vector element:
  - 0: Success.
  - 1: Invalid value of inspec.

##### 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.

#### 6.9.3.21 int velowave (SPX\_ARGS)

**velowave()** converts relativistic velocity to vacuum wavelength.

See [freqvelo\(\)](#) for a description of the API.

**6.9.3.22 int awavvelo (SPX\_ARGS)**

**awavvelo()** converts air wavelength to relativistic velocity.

See [freqvelo\(\)](#) for a description of the API.

**6.9.3.23 int veloawav (SPX\_ARGS)**

**veloawav()** converts relativistic velocity to air wavelength.

See [freqvelo\(\)](#) for a description of the API.

**6.9.3.24 int wavevopt (SPX\_ARGS)**

**wavevopt()** converts vacuum wavelength to optical velocity.

See [freqvelo\(\)](#) for a description of the API.

**6.9.3.25 int voptwave (SPX\_ARGS)**

**voptwave()** converts optical velocity to vacuum wavelength.

See [freqvelo\(\)](#) for a description of the API.

**6.9.3.26 int wavezopt (SPX\_ARGS)**

**wavevopt()** converts vacuum wavelength to redshift.

See [freqvelo\(\)](#) for a description of the API.

**6.9.3.27 int zoptwave (SPX\_ARGS)**

**zoptwave()** converts redshift to vacuum wavelength.

See [freqvelo\(\)](#) for a description of the API.

**6.9.4 Variable Documentation****6.9.4.1 const char \* [spx\\_errmsg](#) [ ]**

Error messages to match the status value returned from each function.

**6.10 tab.h File Reference****Data Structures**

- struct [tabprm](#)  
*Tabular transformation parameters.*

**Defines**

- #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.*

## 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 [tabfree](#) (struct [tabprm](#) \*tab)  
*Destructor for the tabprm struct.*
- int [tabprt](#) (const struct [tabprm](#) \*tab)  
*Print routine for the 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.*

### 6.10.1 Detailed Description

These routines implement the part of the FITS WCS standard that deals with tabular coordinates, i.e. coordinates that are defined via a lookup table. They 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, and another, [tabprt\(\)](#), to print its contents.

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.

### 6.10.2 Define Documentation

#### 6.10.2.1 `#define` `TABLEN` (`sizeof(struct tabprm)/sizeof(int)`)

Size of the `tabprm` struct in *int* units, used by the Fortran wrappers.

#### 6.10.2.2 `#define` `tabini_errmsg` [tab\\_errmsg](#)

##### Deprecated

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

#### 6.10.2.3 `#define` `tabcpy_errmsg` [tab\\_errmsg](#)

##### Deprecated

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

#### 6.10.2.4 `#define` `tabfree_errmsg` [tab\\_errmsg](#)

##### Deprecated

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



**6.10.2.5 #define tabprt\_errmsg [tab\\_errmsg](#)****Deprecated**

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

**6.10.2.6 #define tabset\_errmsg [tab\\_errmsg](#)****Deprecated**

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

**6.10.2.7 #define tabx2s\_errmsg [tab\\_errmsg](#)****Deprecated**

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

**6.10.2.8 #define tabs2x\_errmsg [tab\\_errmsg](#)****Deprecated**

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

**6.10.3 Function Documentation****6.10.3.1 int tabini (int *alloc*, int *M*, const int *K*[], struct [tabprm](#) \* *tab*)**

**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:**

- ← ***alloc*** 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.)
- ← ***M*** The number of tabular coordinate axes.
- ← ***K*** 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 [tabprm](#) arrays and therefore the amount of memory to allocate for them. Their values are copied into the [tabprm](#) 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 [tabprm](#) struct. These together with the *K* vector must be set separately before calling [tabset\(\)](#).

↔ **tab** Tabular transformation parameters. Note that, in order to initialize memory management **tabprm::flag** should be set to -1 when tab 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.

#### 6.10.3.2 int tabmem (struct **tabprm** \* **tab**)

**tabmem()** takes control of memory allocated by the user for arrays in the tabprm struct.

#### Parameters:

↔ **tab** Tabular transformation parameters.

#### Returns:

Status return value:

- 0: Success.
- 1: Null tabprm pointer passed.

#### 6.10.3.3 int tabcpy (int **alloc**, const struct **tabprm** \* **tabsrc**, struct **tabprm** \* **tabdst**)

**tabcpy()** does a deep copy of one tabprm struct to another, using **tabini()** to allocate memory for its arrays if required. Only the "information to be provided" part of the struct is copied; a call to **tabset()** is required to set up the remainder.

#### Parameters:

← **alloc** 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.)

← **tabsrc** Struct to copy from.

↔ **tabdst** Struct to copy to. **tabprm::flag** should be set to -1 if tabdst 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.

#### 6.10.3.4 int tabfree (struct tabprm \* tab)

**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:

→ **tab** Coordinate transformation parameters.

##### Returns:

Status return value:

- 0: Success.
- 1: Null tabprm pointer passed.

#### 6.10.3.5 int tabprt (const struct tabprm \* tab)

**tabprt()** prints the contents of a tabprm struct.

##### Parameters:

← **tab** Tabular transformation parameters.

##### Returns:

Status return value:

- 0: Success.
- 1: Null tabprm pointer passed.

#### 6.10.3.6 int tabset (struct tabprm \* tab)

**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.

##### Parameters:

↔ **tab** Tabular transformation parameters.

##### Returns:

Status return value:

- 0: Success.
- 1: Null tabprm pointer passed.
- 3: Invalid tabular parameters.

### 6.10.3.7 int tabx2s (struct **tabprm** \* *tab*, int *ncoord*, int *nelem*, const double *x*[], double *world*[], int *stat*[])

**tabx2s()** transforms intermediate world coordinates to world coordinates using coordinate lookup.

#### Parameters:

- ↔ **tab** Tabular transformation parameters.
- ← **ncoord,nelem** The number of coordinates, each of vector length nelem.
- ← **x** Array of intermediate world coordinates, SI units.
- **world** Array of world coordinates, in SI units.
- **stat** Status return value status for each coordinate:
  - 0: Success.
  - 1: Invalid intermediate world coordinate.

#### 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.

### 6.10.3.8 int tabs2x (struct **tabprm** \* *tab*, int *ncoord*, int *nelem*, const double *world*[], double *x*[], int *stat*[])

**tabs2x()** transforms world coordinates to intermediate world coordinates.

#### Parameters:

- ↔ **tab** Tabular transformation parameters.
- ← **ncoord,nelem** The number of coordinates, each of vector length nelem.
- ← **world** Array of world coordinates, in SI units.
- **x** Array of intermediate world coordinates, SI units.
- **stat** Status return value status for each vector element:
  - 0: Success.
  - 1: Invalid world coordinate.

#### 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.

## 6.10.4 Variable Documentation

### 6.10.4.1 const char \* **tab\_errmsg**[]

Error messages to match the status value returned from each function.

## 6.11 wcs.h File Reference

```
#include "lin.h"
#include "cel.h"
#include "spc.h"
#include "tab.h"
```

### Data Structures

- struct [pvcard](#)  
*Store for PVi\_ma keyrecords.*
- struct [pscard](#)  
*Store for PSi\_ma keyrecords.*
- struct [wtbarr](#)  
*Extraction of coordinate lookup tables from BINTABLE.*
- struct [wcsprm](#)  
*Coordinate transformation parameters.*

### Defines

- #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 [WCSLEN](#) (sizeof(struct [wcsprm](#))/sizeof(int))  
*Size of the wcsprm struct in int units.*
- #define [wscopy](#)(alloc, wcssrc, wcsdst) wcsub(alloc, wcssrc, 0, 0, wcsdst)  
*Copy routine for the wcsprm struct.*

- `#define wcsini_errmsg wcs_errmsg`  
*Deprecated.*
- `#define wcssub_errmsg wcs_errmsg`  
*Deprecated.*
- `#define wcsncpy_errmsg wcs_errmsg`  
*Deprecated.*
- `#define wcsfree_errmsg wcs_errmsg`  
*Deprecated.*
- `#define wcsprt_errmsg wcs_errmsg`  
*Deprecated.*
- `#define wcsset_errmsg wcs_errmsg`  
*Deprecated.*
- `#define wcp2s_errmsg wcs_errmsg`  
*Deprecated.*
- `#define wcss2p_errmsg wcs_errmsg`  
*Deprecated.*
- `#define wcmix_errmsg wcs_errmsg`  
*Deprecated.*

## Functions

- `int wcsnpv (int n)`  
*Memory allocation for **PV**i\_ma.*
- `int wcsnps (int n)`  
*Memory allocation for **PS**i\_ma.*
- `int wcsini (int alloc, int naxis, struct wcsprm *wcs)`  
*Default constructor for the wcsprm struct.*
- `int wcssub (int alloc, const struct wcsprm *wcssrc, int *nsub, int axes[ ], struct wcsprm *wcsdst)`  
*Subimage extraction routine for the wcsprm struct.*
- `int wcsfree (struct wcsprm *wcs)`  
*Destructor for the wcsprm struct.*
- `int wcsprt (const struct wcsprm *wcs)`  
*Print routine for the wcsprm struct.*
- `int wcsset (struct wcsprm *wcs)`

*Setup routine for the wcsprm struct.*

- int [wvsp2s](#) (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 [wcsp2p](#) (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 [wvsmix](#) (struct [wcsprm](#) \*wcs, int mixpix, int mixcel, const double vspan[ ], double vstep, int viter, double world[ ], double phi[ ], double theta[ ], double imgcrd[ ], double pixcrd[ ])

*Hybrid coordinate transformation.*

- int [wcsptr](#) (struct [wcsprm](#) \*wcs, int \*i, char ctype[9])

*Spectral axis translation.*

## Variables

- const char \* [wcs\\_errmsg](#) [ ]

*Status return messages.*

### 6.11.1 Detailed Description

These routines 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. They 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.

Three routines, [wcsini\(\)](#), [wcsub\(\)](#), and [wcfree\(\)](#) are provided to manage the [wcsprm](#) struct and another, [wvsptr\(\)](#), to prints its contents. Refer to the description of the [wcsprm](#) struct for an explanation of the anticipated usage of these routines. [wcscopy\(\)](#), which does a deep copy of one [wcsprm](#) struct to another, is defined as a preprocessor macro function that invokes [wcsub\(\)](#).

A setup routine, [wcset\(\)](#), 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 [wcset\(\)](#) but this need not be called explicitly - refer to the explanation of [wcsprm::flag](#).

[wvsp2s\(\)](#) 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, [wvsmix\(\)](#), iteratively solves for the unknown elements.

[wcsptr\(\)](#) translates the spectral axis in a [wcsprm](#) struct. For example, a 'FREQ' axis may be translated into 'ZOPT-F2W' and vice versa.

#### 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 `wcss2p()` translate the **CUBEFACE** axis representation to the single plane representation understood by the lower-level WCSLIB projection routines.

## 6.11.2 Define Documentation

### 6.11.2.1 #define WCSSUB\_LONGITUDE 0x1001

Mask to use for extracting the longitude axis when sub-imaging, refer to the *axes* argument of `wcssub()`.

### 6.11.2.2 #define WCSSUB\_LATITUDE 0x1002

Mask to use for extracting the latitude axis when sub-imaging, refer to the *axes* argument of `wcssub()`.

### 6.11.2.3 #define WCSSUB\_CUBEFACE 0x1004

Mask to use for extracting the **CUBEFACE** axis when sub-imaging, refer to the *axes* argument of `wcssub()`.

### 6.11.2.4 #define WCSSUB\_CELESTIAL 0x1007

Mask to use for extracting the celestial axes (longitude, latitude and cubeface) when sub-imaging, refer to the *axes* argument of `wcssub()`.

### 6.11.2.5 #define WCSSUB\_SPECTRAL 0x1008

Mask to use for extracting the spectral axis when sub-imaging, refer to the *axes* argument of `wcssub()`.

### 6.11.2.6 #define WCSSUB\_STOKES 0x1010

Mask to use for extracting the **STOKES** axis when sub-imaging, refer to the *axes* argument of `wcssub()`.

### 6.11.2.7 #define WCSLEN (sizeof(struct wcsprm)/sizeof(int))

Size of the `wcsprm` struct in *int* units, used by the Fortran wrappers.

### 6.11.2.8 #define wscopy(alloc, wcssrc, wcsdst) wcssub(alloc, wcssrc, 0, 0, wcsdst)

`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.



**6.11.2.9 #define wcsini\_errmsg [wcs\\_errmsg](#)****Deprecated**

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

**6.11.2.10 #define wcssub\_errmsg [wcs\\_errmsg](#)****Deprecated**

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

**6.11.2.11 #define wscopy\_errmsg [wcs\\_errmsg](#)****Deprecated**

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

**6.11.2.12 #define wcsfree\_errmsg [wcs\\_errmsg](#)****Deprecated**

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

**6.11.2.13 #define wcsprt\_errmsg [wcs\\_errmsg](#)****Deprecated**

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

**6.11.2.14 #define wcsset\_errmsg [wcs\\_errmsg](#)****Deprecated**

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

**6.11.2.15 #define wcsp2s\_errmsg [wcs\\_errmsg](#)****Deprecated**

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

**6.11.2.16 #define wcss2p\_errmsg [wcs\\_errmsg](#)****Deprecated**

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

**6.11.2.17** `#define wcmix_errmsg` [wcs\\_errmsg](#)**Deprecated**

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

**6.11.3 Function Documentation****6.11.3.1** `int wcsnpv (int n)`

`wcsnpv()` changes the value of NPVMAX (default 64). This global variable controls the number of `PVi_ma` keywords that `wcsini()` should allocate space for.

**PLEASE NOTE:** This function is not thread-safe.

**Parameters:**

← *n* Value of NPVMAX; ignored if < 0.

**Returns:**

Current value of NPVMAX.

**6.11.3.2** `int wcsnps (int n)`

`wcsnps()` changes the values of NPSMAX (default 8). This global variable controls the number of `PSi_ma` keywords that `wcsini()` should allocate space for.

**PLEASE NOTE:** This function is not thread-safe.

**Parameters:**

← *n* Value of NPSMAX; ignored if < 0.

**Returns:**

Current value of NPSMAX.

**6.11.3.3** `int wcsini (int alloc, int naxis, struct wcsprm * wcs)`

`wcsini()` optionally allocates memory for arrays in a `wcsprm` struct and sets all members of the struct to default values. Memory is allocated for up to NPVMAX `PVi_ma` keywords or NPSMAX `PSi_ma` keywords per WCS representation. These may be changed via `wcsnpv()` and `wcsnps()` before `wcsini()` is called.

**PLEASE NOTE:** every `wcsprm` struct should be initialized by `wcsini()`, 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 `wcsini()` will actually be used to allocate memory.

**Parameters:**

← *alloc* If true, allocate memory unconditionally for the `crpix`, etc. arrays.

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.)

← **axis** 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.

↔ **wcs** Coordinate transformation parameters.

Note that, in order to initialize memory management, `wcsprm::flag` should be set to -1 when wcs is initialized for the first time (memory leaks may result if it had already been initialized).

#### Returns:

Status return value:

- 0: Success.
- 1: Null wcsprm pointer passed.
- 2: Memory allocation failed.

#### 6.11.3.4 int wcssub (int alloc, const struct wcsprm \* wcssrc, int \* nsub, int axes[], struct wcsprm \* wcsdst)

**wcssub()** extracts the coordinate description for a subimage from a wcsprm struct. It does a deep copy, using **wcsini()** to allocate memory for its arrays if required. Only the "information to be provided" part of the struct is extracted; a call to **wcsset()** is required to set up the remainder.

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 **PCi\_ja** 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.

Note that while the required elements of the tabprm array are extracted, the wtbar array is not. (Thus it is not appropriate to call **wcssub()** after **wcstab()** but before filling the tabprm structs - refer to **wcshdr.h**.)

#### Parameters:

← **alloc** 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.

← **wcssrc** Struct to extract from.

↔ **nsub**

↔ **axes** Vector of length \*nsub containing the image axis numbers (1-relative) to extract. Order is significant; axes[0] is the axis number of the input image that corresponds to the first axis in the subimage, etc.

nsub (the pointer) may be set to zero, and so also may nsub, to indicate the number of axes in the input image; the number of axes will be returned if nsub != 0. axes itself (the pointer) may be set to zero to indicate the first \*nsub axes in their original order.

Set both nsub and axes to zero to do a deep copy of one wcsprm struct to another.

Subimage extraction by coordinate axis type may be done by setting the elements of axes[] to the following special preprocessor macro values:

- WCSSUB\_LONGITUDE: Celestial longitude.
- WCSSUB\_LATITUDE: Celestial latitude.
- WCSSUB\_CUBEFACE: Quadcube **CUBEFACE** axis.
- WCSSUB\_SPECTRAL: Spectral axis.
- WCSSUB\_STOKES: Stokes axis.

Refer to the notes (below) for further usage examples.

On return, `*nsub` will contain 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). `axes[]` will contain the axis numbers that were extracted. 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 `wcsset()`.

↔ **wcsdst** Struct describing the subimage. `wcsprm::flag` should be set to -1 if `wcsdst` was not previously initialized (memory leaks may result if it was previously initialized).

#### 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.

#### Notes:

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 cubeface 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.

#### 6.11.3.5 int wcsfree (struct `wcsprm` \* `wcs`)

`wcsfree()` frees memory allocated for the `wcsprm` arrays by `wcsini()` and/or `wcsset()`. `wcsini()` 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 `wcsini()`.

#### Parameters:

→ **wcs** Coordinate transformation parameters.

**Returns:**

Status return value:

- 0: Success.
- 1: Null wcsprm pointer passed.

**6.11.3.6 int wcsprt (const struct [wcsprm](#) \* *wcs*)**

**wcsprt()** prints the contents of a [wcsprm](#) struct.

**Parameters:**

← *wcs* Coordinate transformation parameters.

**Returns:**

Status return value:

- 0: Success.
- 1: Null [wcsprm](#) pointer passed.

**6.11.3.7 int wcsset (struct [wcsprm](#) \* *wcs*)**

**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 it also recognizes **GLS** as a synonym for **SFL**. It does alias translation for the AIPS spectral types ('**FREQ-LSR**', '**FELO-HEL**', etc.) but without changing the input header keywords.

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.

**Parameters:**

↔ *wcs* 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.

**6.11.3.8** `int wcs2s (struct wcsprm * wcs, int ncoord, int nelem, const double pixcrd[], double imgcrd[], double phi[], double theta[], double world[], int stat[])`

`wcs2s()` transforms pixel coordinates to world coordinates.

**Parameters:**

- ↔ *wcs* Coordinate transformation parameters.
- ← *ncoord,nelem* 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 **NAXIS** keyword unless *ncoord* == 1, in which case *nelem* is not used.
- ← *pixcrd* Array of pixel coordinates.
- *imgcrd* Array of intermediate world coordinates. For celestial axes, *imgcrd*[[*wcs.lng*]] and *imgcrd*[[*wcs.lat*]] are the projected *x*-, and *y*-coordinates in pseudo "degrees". For spectral axes, *imgcrd*[[*wcs.spec*]] is the intermediate spectral coordinate, in SI units.
- *phi,theta* Longitude and latitude in the native coordinate system of the projection [deg].
- *world* Array of world coordinates. For celestial axes, *world*[[*wcs.lng*]] and *world*[[*wcs.lat*]] are the celestial longitude and latitude [deg]. For spectral axes, *imgcrd*[[*wcs.spec*]] is the intermediate spectral coordinate, in SI units.
- *stat* Status return value for each coordinate:
  - 0: Success.
  - 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.

**6.11.3.9** `int wcss2p (struct wcsprm * wcs, int ncoord, int nelem, const double world[], double phi[], double theta[], double imgcrd[], double pixcrd[], int stat[])`

`wcss2p()` transforms world coordinates to pixel coordinates.

**Parameters:**

- ↔ *wcs* Coordinate transformation parameters.
- ← *ncoord,nelem* 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 **NAXIS** keyword unless *ncoord* == 1, in which case *nelem* is not used.
- ← *world* 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.

- *phi,theta* Longitude and latitude in the native coordinate system of the projection [deg].
- *imgcrd* Array of intermediate world coordinates. For celestial axes, `imgcrd[][wcs.lng]` and `imgcrd[][wcs.lat]` are the projected *x*-, and *y*-coordinates in pseudo "degrees". For quadcube projections with a **CUBEFACE** 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.
- *pixcrd* Array of pixel coordinates.
- *stat* Status return value for each coordinate:
  - 0: Success.
  - 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.

#### 6.11.3.10 `int wcmix (struct wcsprm * wcs, int mixpix, int mixcel, const double vspan[], double vstep, int viter, double world[], double phi[], double theta[], double imgcrd[], double pixcrd[])`

`wcmix()`, 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:

- ↔ *wcs* Indices for the celestial coordinates obtained by parsing the `wcsprm::ctype`[].
- ← *mixpix* Which element of the pixel coordinate is given.
- ← *mixcel* Which element of the celestial coordinate is given:
  - 1: Celestial longitude is given in `world[wcs.lng]`, latitude returned in `world[wcs.lat]`.
  - 2: Celestial latitude is given in `world[wcs.lat]`, longitude returned in `world[wcs.lng]`.
- ← *vspan* 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.
- ← *vstep* Step size for solution search [deg]. If zero, a sensible, although perhaps non-optimal default will be used.
- ← *viter* 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.
- ↔ *world* 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.

- *phi,theta* Longitude and latitude in the native coordinate system of the projection [deg].
- *imgcrd* Image coordinate elements. `imgcrd[wcs.lng]` and `imgcrd[wcs.lat]` are the projected *x*-, and *y*-coordinates in pseudo "degrees".
- ↔ *pixcrd* 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.

**Notes:**

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.

**6.11.3.11 int wcssptr (struct `wcsprm` \* *wcs*, int \* *i*, char *ctype*[9])**

`wcssptr()` translates the spectral axis in a `wcsprm` struct. For example, a 'FREQ' axis may be translated into 'ZOPT-F2W' and vice versa.

**Parameters:**

- ↔ *wcs* Coordinate transformation parameters.
- ↔ *i* Index of the spectral axis (0-relative). If given < 0 it will be set to the first spectral axis identified from the `ctype[]` keyvalues in the `wcsprm` struct.



↔ *ctype* Required spectral **CTYPE**<sub>ia</sub>. Wildcarding may be used as for the *ctypeS2* argument to [spctrn\(\)](#) as described in the prologue of [spc.h](#), 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).

### 6.11.4 Variable Documentation

#### 6.11.4.1 `const char * wcs_errmsg[ ]`

Error messages to match the status value returned from each function.

## 6.12 wcsfix.h File Reference

```
#include "wcs.h"
```

### Defines

- #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 [UNITFIX](#) 2  
*Index of [unitfix\(\)](#) status value in vector returned by [wcsfix\(\)](#).*
- #define [CELFIX](#) 3  
*Index of [celfix\(\)](#) status value in vector returned by [wcsfix\(\)](#).*
- #define [SPCFIX](#) 4  
*Index of [spcfix\(\)](#) status value in vector returned by [wcsfix\(\)](#).*
- #define [CYLFIX](#) 5  
*Index of [cylfix\(\)](#) status value in vector returned by [wcsfix\(\)](#).*

- #define **NWCSFIX** 6  
*Number of elements in the status vector returned by `wcsfix()`.*
- #define **cylfix\_errmsg wcsfix\_errmsg**  
*Deprecated.*

## Functions

- int **wcsfix** (int ctrl, const int naxis[ ], struct **wcsprm** \*wcs, int stat[ ])
   
*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 **unitfix** (int ctrl, struct **wcsprm** \*wcs)
   
*Correct aberrant **CUNITi\_a** keyvalues.*
- int **celfix** (struct **wcsprm** \*wcs)
   
*Translate AIPS-convention celestial projection types.*
- int **spcfix** (struct **wcsprm** \*wcs)
   
*Translate AIPS-convention spectral types.*
- int **cylfix** (const int naxis[ ], struct **wcsprm** \*wcs)
   
*Fix malformed cylindrical projections.*

## Variables

- const char \* **wcsfix\_errmsg** [ ]
   
*Status return messages.*

### 6.12.1 Detailed Description

Routines in this suite identify and translate various forms of non-standard construct that are known to occur in FITS WCS headers. These range from the translation of non-standard values for standard WCS keywords, to the repair of malformed coordinate representations.

#### Non-standard keyvalues:

AIPS-convention celestial projection types, **NCP** and **GLS**, and spectral types, **'FREQ-LSR'**, **'FELO-HEL'**, etc., set in **CTYPEi\_a** 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 the `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**, **PROJPa**, **EPOCH**, **VELREF** or **VSOURCEa** keywords; this may be done by the FITS WCS header parser supplied with WCSLIB, refer to `wcshdr.h`.

`wcsfix()` applies 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 and derive `mjdobs` from it if not already set. Alternatively, if `mjdobs` is set and `dateobs` isn't, then derive `dateobs` from it.
- `unitfix()`: translate some commonly used but non-standard unit strings in the **CUNITia** keyvalues, e.g. **'DEG'** -> **'deg'**.
- `celfix()`: translate AIPS-convention celestial projection types, **NCP** and **GLS**, in `ctype[]` as set from **CTYPEia**.
- `specfix()`: translate AIPS-convention spectral types, **'FREQ-LSR'**, **'FELO-HEL'**, etc., 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.

### 6.12.2 Define Documentation

#### 6.12.2.1 #define CDFIX 0

Index of the status value returned by `cdfix()` in the status vector returned by `wcsfix()`.

#### 6.12.2.2 #define DATFIX 1

Index of the status value returned by `datfix()` in the status vector returned by `wcsfix()`.

#### 6.12.2.3 #define UNITFIX 2

Index of the status value returned by `unitfix()` in the status vector returned by `wcsfix()`.

**6.12.2.4 #define CELFIX 3**

Index of the status value returned by [celfix\(\)](#) in the status vector returned by [wcsfix\(\)](#).

**6.12.2.5 #define SPCFIX 4**

Index of the status value returned by [spcfix\(\)](#) in the status vector returned by [wcsfix\(\)](#).

**6.12.2.6 #define CYLFIX 5**

Index of the status value returned by [cylfix\(\)](#) in the status vector returned by [wcsfix\(\)](#).

**6.12.2.7 #define NWCSFIX 6**

Number of elements in the status vector returned by [wcsfix\(\)](#).

**6.12.2.8 #define cylfix\_errmsg [wcsfix\\_errmsg](#)****Deprecated**

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

**6.12.3 Function Documentation****6.12.3.1 int [wcsfix](#) (int *ctrl*, const int *naxis*[ ], struct [wcsprm](#) \* *wcs*, int *stat*[ ])**

[wcsfix\(\)](#) applies all of the corrections handled separately by [datfix\(\)](#), [unitfix\(\)](#), [celfix\(\)](#), [spcfix\(\)](#) and [cylfix\(\)](#).

**Parameters:**

- ← *ctrl* Do potentially unsafe translations of non-standard unit strings as described in the usage notes to [wcsutrn\(\)](#).
- ← *naxis* Image axis lengths. If this array pointer is set to zero then [cylfix\(\)](#) will not be invoked.
- ↔ *wcs* Coordinate transformation parameters.
- *stat* Status returns from each of the functions. Use the preprocessor macros NWCSFIX to dimension this vector and CDFIX, DATFIX, UNITFIX, CELFIX, SPCFIX and CYLFIX to access its elements. A status value of -2 is set for functions that were not invoked.

**Returns:**

Status return value:

- 0: Success.
- 1: One or more of the translation functions returned an error.

**6.12.3.2 int [cdfix](#) (struct [wcsprm](#) \* *wcs*)**

[cdfix\(\)](#) sets the diagonal element of the  $\mathbf{CD}_{i\_ja}$  matrix to unity if all  $\mathbf{CD}_{i\_ja}$  keywords associated with a given axis were omitted. According to Paper I, if any  $\mathbf{CD}_{i\_ja}$  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.

**Parameters:**

↔ **wcs** Coordinate transformation parameters.

**Returns:**

Status return value:

- -1: No change required (not an error).
- 0: Success.
- 1: Null wcsprm pointer passed.

**6.12.3.3 int datfix (struct wcsprm \* wcs)**

**datfix()** translates the old **DATE-OBS** date format set in **wcsprm::dateobs** to year-2000 standard form (yyyy-mm-ddThh:mm:ss) and derives **MJD-OBS** from it if not already set. Alternatively, if **wcsprm::mjdobs** is set and **wcsprm::dateobs** isn't, then **datfix()** derives **wcsprm::dateobs** from it. If both are set but disagree by more than half a day then status 5 is returned.

**Parameters:**

↔ **wcs** Coordinate transformation parameters. **wcsprm::dateobs** and/or **wcsprm::mjdobs** 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.

**Notes:**

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*.

**6.12.3.4 int unitfix (int ctrl, struct wcsprm \* wcs)**

**unitfix()** applies **wcsutrn()** to translate non-standard **CUNIT**<sub>ia</sub> keyvalues, e.g. 'DEG' -> 'deg', also stripping off unnecessary whitespace.

**Parameters:**

← **ctrl** Do potentially unsafe translations described in the usage notes to **wcsutrn()**.  
 ↔ **wcs** Coordinate transformation parameters.

**Returns:**

Status return value:

- -1: No change required (not an error).
- 0: Success.
- 1: Null wcsprm pointer passed.

**6.12.3.5 int celfix (struct [wcsprm](#) \* *wcs*)**

**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**. If the `pv[]` array was initially allocated by [wcsini\(\)](#) then the array will be expanded if necessary. Otherwise, error 2 will be returned if two empty slots are not already available for use.

**Parameters:**

↔ *wcs* Coordinate transformation parameters. [wcsprm::ctype\[\]](#) and/or [wcsprm::pv\[\]](#) 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.

**6.12.3.6 int spcfix (struct [wcsprm](#) \* *wcs*)**

**spcfix()** translates AIPS-convention spectral coordinate types, '**FREQ,FELO,VELO**}-{**OBS,HEL,LSR**}' (e.g. '**FREQ-LSR**', '**FELO-HEL**', '**VELO-OBS**') set in [wcsprm::ctype\[\]](#).

**Parameters:**

↔ *wcs* Coordinate transformation parameters. [wcsprm::ctype\[\]](#) and/or [wcsprm::specsys](#) may be changed.

**Returns:**

tatus 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.

### 6.12.3.7 int cylfix (const int *naxis*[], struct [wcsprm](#) \* *wcs*)

**cylfix()** fixes WCS keyvalues for malformed cylindrical projections that suffer from the problem described in Sect. 7.3.4 of Paper I.

#### Parameters:

- ← *naxis* Image axis lengths.
- ↔ *wcs* Coordinate transformation parameters.

#### Returns:

- tatus 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.

### 6.12.4 Variable Documentation

#### 6.12.4.1 const char \* [wcsfix\\_errmsg](#)[]

Error messages to match the status value returned from each function.

## 6.13 wshdr.h File Reference

```
#include "wcs.h"
```

#### Defines

- #define [WCSHDR\\_none](#) 0x00000000  
*Bit mask for [wvspih\(\)](#) and [wvsbth\(\)](#) - reject all extensions.*
- #define [WCSHDR\\_all](#) 0x000FFFFF  
*Bit mask for [wvspih\(\)](#) and [wvsbth\(\)](#) - accept all extensions.*
- #define [WCSHDR\\_reject](#) 0x10000000  
*Bit mask for [wvspih\(\)](#) and [wvsbth\(\)](#) - reject non-standard keywords.*
- #define [WCSHDR\\_CROTAia](#) 0x00000001  
*Bit mask for [wvspih\(\)](#) and [wvsbth\(\)](#) - accept **CROTAia**, **iCROTna**, **TCROTna**.*

- #define **WCSHDR\_EPOCHa** 0x00000002  
*Bit mask for `wcspih()` and `wcsbth()` - accept **EPOCHa**.*
- #define **WCSHDR\_VELREFa** 0x00000004  
*Bit mask for `wcspih()` and `wcsbth()` - accept **VELREFa**.*
- #define **WCSHDR\_CD00i00j** 0x00000008  
*Bit mask for `wcspih()` and `wcsbth()` - accept **CD00i00j**.*
- #define **WCSHDR\_PC00i00j** 0x00000010  
*Bit mask for `wcspih()` and `wcsbth()` - accept **PC00i00j**.*
- #define **WCSHDR\_PROJp** 0x00000020  
*Bit mask for `wcspih()` and `wcsbth()` - accept **PROJp**.*
- #define **WCSHDR\_RADECSYS** 0x00000040  
*Bit mask for `wcspih()` and `wcsbth()` - accept **RADECSYS**.*
- #define **WCSHDR\_VSOURCE** 0x00000080  
*Bit mask for `wcspih()` and `wcsbth()` - accept **VSOURCEa**.*
- #define **WCSHDR\_DOBSn** 0x00000100  
*Bit mask for `wcspih()` and `wcsbth()` - accept **DOBSn**.*
- #define **WCSHDR\_LONGKEY** 0x00000200  
*Bit mask for `wcspih()` and `wcsbth()` - accept long forms of the alternate binary table and pixel list WCS keywords.*
- #define **WCSHDR\_CNAMn** 0x00000400  
*Bit mask for `wcspih()` and `wcsbth()` - accept **iCNAMn**, **TCNAMn**, **iCRDEn**, **TCRDEn**, **iCSYEn**, **TC-SYEn**.*
- #define **WCSHDR\_AUXIMG** 0x00000800  
*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** 0x00001000  
*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** 0x00010000  
*Bit mask for `wcsbth()` - restrict to image header keywords only.*
- #define **WCSHDR\_BIMGARR** 0x00020000  
*Bit mask for `wcsbth()` - restrict to binary table image array keywords only.*
- #define **WCSHDR\_PIXLIST** 0x00040000  
*Bit mask for `wcsbth()` - restrict to pixel list keywords only.*
- #define **WCSHDO\_none** 0x00



Bit mask for *wshdo()* - don't write any extensions.

- #define **WCSHDO\_all** 0xFF  
Bit mask for *wshdo()* - write all extensions.
- #define **WCSHDO\_safe** 0x0F  
Bit mask for *wshdo()* - write safe extensions only.
- #define **WCSHDO\_DOBSn** 0x01  
Bit mask for *wshdo()* - write **DOBSn**.
- #define **WCSHDO\_TPCn\_ka** 0x02  
Bit mask for *wshdo()* - write **TPCn\_ka**.
- #define **WCSHDO\_PVn\_ma** 0x04  
Bit mask for *wshdo()* - write **iPVn\_ma**, **TPVn\_ma**, **iPSn\_ma**, **TPSn\_ma**.
- #define **WCSHDO\_CRPXna** 0x08  
Bit mask for *wshdo()* - write **jCRPXna**, **TCRPXna**, **iCDLTna**, **TCDLTna**, **iCUNIna**, **TCUNIna**, **iCTYPna**, **TCTYPna**, **iCRVLna**, **TCRVLna**.
- #define **WCSHDO\_CNAMna** 0x10  
Bit mask for *wshdo()* - write **iCNAMna**, **TCNAMna**, **iCRDEna**, **TCRDEna**, **iCSYEna**, **TCSYEna**.
- #define **WCSHDO\_WCSNna** 0x20  
Bit mask for *wshdo()* - write **WCSNna** instead of **TWCSna**.

## 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 keyset, 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 [wcsrdo](#) (int relax, struct [wcsrpr](#) \*wcs, int \*nkeyrec, char \*\*header)

*Write out a [wcsrpr](#) struct as a FITS header.*

## Variables

- const char \* [wcsrdr\\_errmsg](#) [ ]

*Status return messages.*

### 6.13.1 Detailed Description

Routines in this suite are aimed at extracting WCS information from a FITS file. They provide the high-level interface between the FITS file and the WCS coordinate transformation routines.

Additionally, function [wcsrdo](#)() is provided to write out the contents of a [wcsrpr](#) 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 [wcsrpih\(\)](#) 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 free'd by [wcsfree\(\)](#).
- 4: Translate non-standard WCS usage using [wcsfix\(\)](#), see [wcsfix.h](#).
- 5: Initialize [wcsrpr](#) struct(s) using [wcsset\(\)](#) and calculate coordinates using [wcsr2s\(\)](#) 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:

- [wcsrpih\(\)](#) is a high-level FITS WCS routine that parses an image header. It returns an array of up to 27 [wcsrpr](#) structs on each of which it invokes [wcstab\(\)](#).
- [wcsbth\(\)](#) is the analogue of [wcsrpih\(\)](#) 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 [wcsrpr](#) 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 [wcsrpr](#) structs returned by [wcsrpih\(\)](#) or [wcsbth\(\)](#).

- `wcsvfree()` deallocates memory for an array of `wcsprm` structs, such as returned by `wcspih()` or `wcsbth()`.
- `wcsdo()` writes out a `wcsprm` struct as a FITS header.

### 6.13.2 Define Documentation

#### 6.13.2.1 `#define WCSHDR_none 0x00000000`

Bit mask for the *relax* argument of `wcspih()` and `wcsbth()` - reject all extensions.

Refer to `wcsbth()` note 5.

#### 6.13.2.2 `#define WCSHDR_all 0x000FFFFF`

Bit mask for the *relax* argument of `wcspih()` and `wcsbth()` - accept all extensions.

Refer to `wcsbth()` note 5.

#### 6.13.2.3 `#define WCSHDR_reject 0x10000000`

Bit mask for the *relax* argument of `wcspih()` and `wcsbth()` - reject non-standard keywords.

Refer to `wcsbth()` note 5.

#### 6.13.2.4 `#define WCSHDR_CROTAia 0x00000001`

Bit mask for the *relax* argument of `wcspih()` and `wcsbth()` - accept `CROTAia`, `iCROTna`, `TCROTna`.

Refer to `wcsbth()` note 5.

#### 6.13.2.5 `#define WCSHDR_EPOCHa 0x00000002`

Bit mask for the *relax* argument of `wcspih()` and `wcsbth()` - accept `EPOCHa`.

Refer to `wcsbth()` note 5.

#### 6.13.2.6 `#define WCSHDR_VELREFa 0x00000004`

Bit mask for the *relax* argument of `wcspih()` and `wcsbth()` - accept `VELREFa`.

Refer to `wcsbth()` note 5.

#### 6.13.2.7 `#define WCSHDR_CD00i00j 0x00000008`

Bit mask for the *relax* argument of `wcspih()` and `wcsbth()` - accept `CD00i00j`.

Refer to `wcsbth()` note 5.

#### 6.13.2.8 `#define WCSHDR_PC00i00j 0x00000010`

Bit mask for the *relax* argument of `wcspih()` and `wcsbth()` - accept `PC00i00j`.

Refer to `wcsbth()` note 5.

**6.13.2.9 #define WSHDR\_PROJPn 0x00000020**

Bit mask for the *relax* argument of [wcspih\(\)](#) and [wcsbth\(\)](#) - accept **PROJP**<sub>n</sub>.

Refer to [wcsbth\(\)](#) note 5.

**6.13.2.10 #define WSHDR\_RADECSYS 0x00000040**

Bit mask for the *relax* argument of [wcspih\(\)](#) and [wcsbth\(\)](#) - accept **RADECSYS**.

Refer to [wcsbth\(\)](#) note 5.

**6.13.2.11 #define WSHDR\_VSOURCE 0x00000080**

Bit mask for the *relax* argument of [wcspih\(\)](#) and [wcsbth\(\)](#) - accept **VSOURCE**<sub>a</sub>.

Refer to [wcsbth\(\)](#) note 5.

**6.13.2.12 #define WSHDR\_DOBSn 0x00000100**

Bit mask for the *relax* argument of [wcspih\(\)](#) and [wcsbth\(\)](#) - accept **DOBS**<sub>n</sub>.

Refer to [wcsbth\(\)](#) note 5.

**6.13.2.13 #define WSHDR\_LONGKEY 0x00000200**

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.

**6.13.2.14 #define WSHDR\_CNAMn 0x00000400**

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.

**6.13.2.15 #define WSHDR\_AUXIMG 0x00000800**

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.

**6.13.2.16 #define WSHDR\_ALLIMG 0x00001000**

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.

**6.13.2.17 #define WSHDR\_IMGHEAD 0x00010000**

Bit mask for the *keysel* argument of [wcsbth\(\)](#) - restrict keyword types considered to image header keywords only.

**6.13.2.18 #define WSHDR\_BIMGARR 0x00020000**

Bit mask for the *keysel* argument of [wscbth\(\)](#) - restrict keyword types considered to binary table image array keywords only.

**6.13.2.19 #define WSHDR\_PIXLIST 0x00040000**

Bit mask for the *keysel* argument of [wscbth\(\)](#) - restrict keyword types considered to pixel list keywords only.

**6.13.2.20 #define WSHDO\_none 0x00**

Bit mask for the *relax* argument of [wshdo\(\)](#) - don't write any extensions.

Refer to the notes for [wshdo\(\)](#).

**6.13.2.21 #define WSHDO\_all 0xFF**

Bit mask for the *relax* argument of [wshdo\(\)](#) - write all extensions.

Refer to the notes for [wshdo\(\)](#).

**6.13.2.22 #define WSHDO\_safe 0x0F**

Bit mask for the *relax* argument of [wshdo\(\)](#) - write only extensions that are considered safe.

Refer to the notes for [wshdo\(\)](#).

**6.13.2.23 #define WSHDO\_DOBSn 0x01**

Bit mask for the *relax* argument of [wshdo\(\)](#) - write **DOBS<sub>n</sub>**, the column-specific analogue of DATE-OBS for use in binary tables and pixel lists.

Refer to the notes for [wshdo\(\)](#).

**6.13.2.24 #define WSHDO\_TPCn\_ka 0x02**

Bit mask for the *relax* argument of [wshdo\(\)](#) - write **TPC<sub>n</sub>\_ka** if less than eight characters instead of **TP<sub>n</sub>\_ka**.

Refer to the notes for [wshdo\(\)](#).

**6.13.2.25 #define WSHDO\_PVn\_ma 0x04**

Bit mask for the *relax* argument of [wshdo\(\)](#) - write **iPV<sub>n</sub>\_ma**, **TPV<sub>n</sub>\_ma**, **iPS<sub>n</sub>\_ma**, **TPS<sub>n</sub>\_ma**, if less than eight characters instead of **iV<sub>n</sub>\_ma**, **TV<sub>n</sub>\_ma**, **iS<sub>n</sub>\_ma**, **TS<sub>n</sub>\_ma**.

Refer to the notes for [wshdo\(\)](#).

**6.13.2.26 #define WSHDO\_CRPXna 0x08**

Bit mask for the *relax* argument of [wshdo\(\)](#) - write **jCRPX<sub>na</sub>**, **TCRPX<sub>na</sub>**, **iCDLT<sub>na</sub>**, **TCDLT<sub>na</sub>**, **iCUN<sub>na</sub>**, **TCUN<sub>na</sub>**, **iCTYP<sub>na</sub>**, **TCTYP<sub>na</sub>**, **iCRVL<sub>na</sub>**, **TCRVL<sub>na</sub>**, if less than eight characters instead of **jCRP<sub>na</sub>**, **TCRP<sub>na</sub>**, **iCDE<sub>na</sub>**, **TCDE<sub>na</sub>**, **iCUN<sub>na</sub>**, **TCUN<sub>na</sub>**, **iCTY<sub>na</sub>**, **TCTY<sub>na</sub>**, **iCRV<sub>na</sub>**, **TCRV<sub>na</sub>**.

Refer to the notes for [wshdo\(\)](#).

**6.13.2.27 #define WSHDO\_CNAMna 0x10**

Bit mask for the *relax* argument of [wshdo\(\)](#) - write *iCNAMna*, *TCNAMna*, *iCRDEna*, *TCRDEna*, *iCSYEna*, *TCSYEna*, if less than eight characters instead of *iCNana*, *TCNana*, *iCRDna*, *TCRDna*, *iCSYna*, *TCSYna*.

Refer to the notes for [wshdo\(\)](#).

**6.13.2.28 #define WSHDO\_WCSNna 0x20**

Bit mask for the *relax* argument of [wshdo\(\)](#) - write *WCSNna* instead of *TWCSna*.

Refer to the notes for [wshdo\(\)](#).

**6.13.3 Function Documentation****6.13.3.1 int wcspih (char \* header, int nkeyrec, int relax, int ctrl, int \* nreject, int \* nwcs, struct wcsprm \*\* wcs)**

**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, and III 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.

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.

**Parameters:**

↔ **header** 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 [fits\\_hdr2str\(\)](#).

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 **wcspih()** are removed from it.

← **nkeyrec** Number of keyrecords in *header[]*.

← **relax** Degree of permissiveness:

- 0: Recognize only FITS keywords defined by the published WCS standard.
- [WSHDR\\_all](#): Admit all recognized informal extensions of the WCS standard.

Fine-grained control of the degree of permissiveness is also possible as explained in [wcsbth\(\)](#) note 5.

← **ctrl** Error reporting and other control options for invalid WCS and other header keyrecords:

- 0: Do not report any rejected header keyrecords.
- 1: Produce a one-line message stating the number of WCS keyrecords rejected (*nreject*).
- 2: Report each rejected keyrecord and the reason why it was rejected.
- 3: As above, but also report all non-WCS keyrecords that were discarded, and the number of coordinate representations (*nwcs*) found.

The report is written to stderr.

For `ctrl < 0`, WCS keyrecords processed by `wcspih()` are removed from `header[]`:

- -1: Remove only valid WCS keyrecords whose values were successfully extracted, nothing is reported.
- -2: Also remove WCS keyrecords that were rejected, reporting each one and the reason that it was rejected.
- -3: As above, and also report the number of coordinate representations (`nwcs`) found.
- -11: Same as -1 but preserving the basic keywords '`{DATE,MJD}`'-'`{OBS,AVG}`' and '`OBSGEO-{X,Y,Z}`'.

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.

→ ***nreject*** Number of WCS keywords rejected for syntax errors, illegal values, etc. Keywords not recognized as WCS keywords are simply ignored. Refer also to `wcsbth()` note 5.

→ ***nwcs*** Number of coordinate representations found.

→ ***wcs*** Pointer to an array of `wcsprm` structs containing up to 27 coordinate representations.

Memory for the array is allocated by `wcspih()` which also invokes `wcsini()` for each struct to allocate memory for internal arrays and initialize their members to default values. Refer also to `wcsbth()` note 8. Note that `wcsset()` is not invoked on these structs.

This allocated memory must be freed by the user, first by invoking `wcsfree()` for each struct, and then by freeing the array itself. A routine, `wcsvfree()`, is provided to do this (see below).

#### Returns:

Status return value:

- 0: Success.
- 1: Null `wcsprm` pointer passed.
- 2: Memory allocation failed.
- 4: Fatal error returned by Flex parser.

#### Notes:

Refer to `wcsbth()` notes 1, 2, 3, 5, 7, and 8.

#### 6.13.3.2 `int wcsbth(char * header, int nkeyrec, int relax, int ctrl, int keyset, int * colsel, int * nreject, int * nwcs, struct wcsprm ** wcs)`

`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, and III 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:

↔ **header** 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 `fits_hdr2str()`.

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 `wcsbth()` are removed from it.

← **nkeyrec** Number of keyrecords in `header[]`.

← **relax** Degree of permissiveness:

- 0: Recognize only FITS keywords defined by the published WCS standard.
- `WCSHDR_all`: Admit all recognized informal extensions of the WCS standard.

Fine-grained control of the degree of permissiveness is also possible, as explained in note 5 below.

← **ctrl** Error reporting and other control options for invalid WCS and other header keyrecords:

- 0: Do not report any rejected header keyrecords.
- 1: Produce a one-line message stating the number of WCS keyrecords rejected (`nreject`).
- 2: Report each rejected keyrecord and the reason why it was rejected.
- 3: As above, but also report all non-WCS keyrecords that were discarded, and the number of coordinate representations (`nwcs`) found.

The report is written to `stderr`.

For `ctrl < 0`, WCS keyrecords processed by `wcsbth()` are removed from `header[]`:

- -1: Remove only valid WCS keyrecords whose values were successfully extracted, nothing is reported.
- -2: Also remove WCS keyrecords that were rejected, reporting each one and the reason that it was rejected.
- -3: As above, and also report the number of coordinate representations (`nwcs`) found.
- -11: Same as -1 but preserving the basic keywords '`{DATE,MJD}`'-`{OBS,AVG}`' and '`OBSGEO- {X,Y,Z}`'.

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.

← **keysel** Vector of flag bits that may be used to restrict the keyword types considered:

- `WCSHDR_IMGHEAD`: Image header keywords.
- `WCSHDR_BIMGARR`: Binary table image array.
- `WCSHDR_PIXLIST`: Pixel list keywords.



If zero, there is no restriction.

Keywords such as **EQUIna** or **RFRQna** that are common to binary table image arrays and pixel lists (including **WCSNna** and **TWCSna**, as explained in note 4 below) are selected by both **WCSHDR\_BIMGARR** and **WCSHDR\_PIXLIST**. Thus if inheritance via **WCSHDR\_ALLIMG** is enabled as discussed in note 5 and one of these shared keywords is present, then **WCSHDR\_IMGHEAD** and **WCSHDR\_PIXLIST** alone may be sufficient to cause the construction of coordinate descriptions for binary table image arrays.

← **colsel** Pointer to an array of table column numbers used to restrict the keywords considered by **wcsbth()**.

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:

- **cols[0] > 0**: the columns are included,
- **cols[0] < 0**: the columns are excluded.

For the pixel list keywords **TPn\_ka** and **TCn\_ka** (and **TPCn\_ka** and **TCDn\_ka** if **WCSHDR\_LONGKEY** 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.

→ **nreject** 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.

→ **nwcs** Number of coordinate representations found.

→ **wcs** Pointer to an array of **wcsprm** structs containing up to 27027 coordinate representations, refer to note 6 below.

Memory for the array is allocated by **wcsbth()** which also invokes **wcsini()** for each struct to allocate memory for internal arrays and initialize their members to default values. Refer also to note 8 below. Note that **wcsset()** is not invoked on these structs.

This allocated memory must be freed by the user, first by invoking **wcsfree()** for each struct, and then by freeing the array itself. A routine, **wcsvfree()**, is provided to do this (see below).

### 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. **wcspih()** determines the number of coordinate axes independently for each alternate coordinate representation (denoted by the "a" value in keywords like **CTYPEi\_a**) from the higher of
  - (a) **NAXIS**,
  - (b) **WCSAXESa**,
  - (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>ja**, and **PC<sub>i\_</sub>ja** 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 and III that are not parameterised 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 keywords (that are not otherwise accepted). A message will optionally be printed on stderr, 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.

Useful for testing conformance of a FITS header to the WCS standard.

- **WCSHDR\_CROTAia**: Accept **CROTA<sub>ia</sub>** (**wcspih()**), **iCROT<sub>na</sub>** (**wcsbth()**), **TCROT<sub>na</sub>** (**wcsbth()**).
- **WCSHDR\_EPOCHa**: Accept **EPOCH<sub>a</sub>**.
- **WCSHDR\_VELREFa**: 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\_PROJPn**: Accept **PROJP<sub>n</sub>** (**wcspih()**). These appeared in early drafts of WCS Paper I+II (before they were split) and are equivalent to **CD<sub>i\_</sub>ja**, **PC<sub>i\_</sub>ja**, and **PV<sub>i\_</sub>ma** for the primary representation (*a* = ' '). **PROJP<sub>n</sub>** is equivalent to **PV<sub>i\_</sub>ma** with *m* = *n* ≤ 9, and is associated exclusively with the latitude axis.
- **WCSHDR\_RADECSYS**: Accept **RADECSYS**. This appeared in early drafts of WCS Paper I+II and was subsequently replaced by **RADESYS<sub>a</sub>**.  
**wcsbth()** accepts **RADECSYS** only if **WCSHDR\_AUXIMG** is also enabled.

- **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\_DOBSn** (**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\_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>	CR-PIX <sub>ja</sub>
	TPC <sub>n_ka</sub>	:		ijPC <sub>na</sub>		TP <sub>n_ka</sub>	PCi <sub>ja</sub>
	TCD <sub>n_ka</sub>	:		ijCD <sub>na</sub>		TC <sub>n_ka</sub>	CDi <sub>ja</sub>
iCDLT <sub>na</sub>	TCDLT <sub>na</sub>	:	iCDLT <sub>n</sub>	iCDE <sub>na</sub>	TCDLT <sub>n</sub>	TCDE <sub>na</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>	TC-TYP <sub>na</sub>	:	iCTYP <sub>n</sub>	iCTY <sub>na</sub>	TC-TYP <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>	CR-VAL <sub>ia</sub>
iPV <sub>n_ma</sub>	TPV <sub>n_ma</sub>	:		iV <sub>n_ma</sub>		TV <sub>n_ma</sub>	PVi <sub>ma</sub>
iPS <sub>n_ma</sub>	TPS <sub>n_ma</sub>	:		iS <sub>n_ma</sub>		TS <sub>n_ma</sub>	PSi <sub>ma</sub>

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. **TPC**<sub>n\_ka</sub>, **iPV**<sub>n\_ma</sub>, and **TPV**<sub>n\_ma</sub> appeared by mistake in the examples in WCS Paper II and subsequently these and also **TCD**<sub>n\_ka</sub>, **iPS**<sub>n\_ma</sub> and **TPS**<sub>n\_ma</sub> 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

iCNAM <sub>na</sub>	TC-NAM <sub>na</sub>	:	—	iCNA <sub>na</sub>	—	TCNA <sub>na</sub>	CNAME <sub>ia</sub>
iCRDE <sub>na</sub>	TCRDE <sub>na</sub>	:	—	iCRD <sub>na</sub>	—	TCRD <sub>na</sub>	CRDER <sub>ia</sub>
iCSYE <sub>na</sub>	TC-SYE <sub>na</sub>	:	—	iCSY <sub>na</sub>	—	TCSY <sub>na</sub>	CSYER <sub>ia</sub>

Note that **CNAME**<sub>ia</sub>, **CRDER**<sub>ia</sub>, **CSYER**<sub>ia</sub>, and their variants are not used by WCSLIB but are stored in the **wcsprm** struct as auxiliary information.

- **WCSHDR\_CNAMn** (**wcsbth**() only): Accept **iCNAM**<sub>n</sub>, **iCRDE**<sub>n</sub>, **iCSYE**<sub>n</sub>, **TCNAM**<sub>n</sub>, **TCRDE**<sub>n</sub>, and **TCSYE**<sub>n</sub>, i.e. with "a" blank. While non-standard, these are the obvious analogues of **iCTYP**<sub>n</sub>, **TCTYP**<sub>n</sub>, 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 **EQUINOX<sub>a</sub>** would apply to all image arrays in a binary table, or all pixel list columns with alternate representation "a" unless overridden by **EQUI<sub>na</sub>**.

Specifically the keywords are:

<b>LATPOLE<sub>a</sub></b>	for <b>LATP<sub>na</sub></b>
<b>LONPOLE<sub>a</sub></b>	for <b>LONP<sub>na</sub></b>
<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>

whose keyvalues are actually used by WCSLIB, and also keywords that provide auxiliary information that is simply stored in the [wcsprm](#) struct:

<b>EPOCH</b>		... (No column-specific form.)
<b>EPOCH<sub>a</sub></b>		... Only if <a href="#">WCSHDR_EPOCH<sub>a</sub></a> is set.
<b>EQUINOX<sub>a</sub></b>	for <b>EQUI<sub>na</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 <a href="#">WCSHDR_RADECSYS</a> is set.
<b>SPECSYS<sub>a</sub></b>	for <b>SPEC<sub>na</sub></b>	
<b>SSYSOBS<sub>a</sub></b>	for <b>SOBS<sub>na</sub></b>	
<b>SSYSSRC<sub>a</sub></b>	for <b>SSRC<sub>na</sub></b>	
<b>VELOSYS<sub>a</sub></b>	for <b>VSYS<sub>na</sub></b>	
<b>VELANGL<sub>a</sub></b>	for <b>VANG<sub>na</sub></b>	
<b>VELREF</b>		... (No column-specific form.)
<b>VELREF<sub>a</sub></b>		... Only if <a href="#">WCSHDR_VELREF<sub>a</sub></a> is set.
<b>VSOURCE<sub>a</sub></b>	for <b>VSOU<sub>na</sub></b>	... Only if <a href="#">WCSHDR_VSOURCE</a> is set.
<b>WCSNAME<sub>a</sub></b>	for <b>WCSN<sub>na</sub></b>	... Or <b>TWCS<sub>na</sub></b> (see below).
<b>ZSOURCE<sub>a</sub></b>	for <b>ZSOU<sub>na</sub></b>	
<b>DATE-AVG</b>	for <b>DAVG<sub>n</sub></b>	
<b>DATE-OBS</b>	for <b>DOBS<sub>n</sub></b>	
<b>MJD-AVG</b>	for <b>MJDA<sub>n</sub></b>	
<b>MJD-OBS</b>	for <b>MJDOB<sub>n</sub></b>	
<b>OBSGEO-X</b>	for <b>OBSGX<sub>n</sub></b>	
<b>OBSGEO-Y</b>	for <b>OBSGY<sub>n</sub></b>	
<b>OBSGEO-Z</b>	for <b>OBSGZ<sub>n</sub></b>	

where the image-header keywords on the left provide default values for the column specific keywords on the right.

Keywords in the last group, such as **MJD-OBS**, apply to all alternate representations, so **MJD-OBS** would 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 the only potential difficulty in using [WCSHDR\\_AUXIMG](#) is that of erroneously inheriting one of these four 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, such as **CTYPE<sub>i</sub><sub>a</sub>**, that are parameterized by axis number.

- [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 **CRPIX<sub>j</sub><sub>a</sub>** would apply to all image arrays in a binary table with alternate representation "a" unless overridden by **jCRP<sub>na</sub>**.

Specifically the keywords are those listed above for [WCSHDR\\_AUXIMG](#) plus

<b>WCSEXES<sub>a</sub></b>	for <b>WCAX<sub>na</sub></b>
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which defines the coordinate dimensionality, and the following keywords which are parameterized by axis number:

<b>CRPIX<sub>j</sub><sub>a</sub></b>	for <b>jCRP<sub>na</sub></b>	
<b>PC<sub>i</sub><sub>j</sub><sub>a</sub></b>	for <b>i jPC<sub>na</sub></b>	
<b>CD<sub>i</sub><sub>j</sub><sub>a</sub></b>	for <b>i jCD<sub>na</sub></b>	
<b>CDEL<sub>T</sub><sub>i</sub><sub>a</sub></b>	for <b>iCDE<sub>na</sub></b>	
<b>CROTA<sub>i</sub></b>	for <b>iCROT<sub>n</sub></b>	
<b>CROTA<sub>i</sub><sub>a</sub></b>		... Only if <a href="#">WCSHDR_CROTA<sub>i</sub><sub>a</sub></a> is set.
<b>CUNIT<sub>i</sub><sub>a</sub></b>	for <b>iCUN<sub>na</sub></b>	
<b>CTYPE<sub>i</sub><sub>a</sub></b>	for <b>iCTY<sub>na</sub></b>	
<b>CRVAL<sub>i</sub><sub>a</sub></b>	for <b>iCRV<sub>na</sub></b>	
<b>PV<sub>i</sub><sub>ma</sub></b>	for <b>iV<sub>n</sub><sub>ma</sub></b>	
<b>PS<sub>i</sub><sub>ma</sub></b>	for <b>iS<sub>n</sub><sub>ma</sub></b>	
<b>CNAME<sub>i</sub><sub>a</sub></b>	for <b>iCNA<sub>na</sub></b>	
<b>CRDER<sub>i</sub><sub>a</sub></b>	for <b>iCRD<sub>na</sub></b>	
<b>CSYER<sub>i</sub><sub>a</sub></b>	for <b>iCSY<sub>na</sub></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.

Note that **CNAME<sub>i</sub><sub>a</sub>**, **CRDER<sub>i</sub><sub>a</sub>**, **CSYER<sub>i</sub><sub>a</sub>**, 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<sub>a</sub>** if both are present, and **VSOURCE<sub>a</sub>** is always subordinate to **ZSOURCE<sub>a</sub>**.

Likewise, **VELREF** is subordinate to the formalism of WCS Paper III. In the AIPS convention **VELREF** has the following integer values:

- 1: LSR kinematic, originally described simply as "LSR" without distinction between the kinematic and dynamic definitions.
- 2: Barycentric, originally described as "HEL" meaning heliocentric.
- 3: Topocentric, originally described as "OBS" meaning geocentric but widely interpreted as topocentric.

AIPS++ extensions to **VELREF** are also recognized:

- 4: LSR dynamic.
- 5: Geocentric.
- 6: Source rest frame.
- 7: Galactocentric.

A radio convention velocity is denoted by adding 256 to these, otherwise an optical velocity is indicated.

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* xargument, `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.

In the absence of a formal mechanism for identifying the columns containing pixel coordinates (as opposed to pixel values or ancillary data recorded at the time the photon or neutrino was detected), 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.

**wcsbth()** simply collects all WCS keywords for a particular coordinate representation (i.e. the "a" value in **TCTY<sub>na</sub>**) 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.

### 6.13.3.3 int wcrstab (struct **wcsprm** \* *wcs*)

**wcrstab()** 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<sub>ma</sub>** and **PSi<sub>ma</sub>** keywords in the image header.

**wcrstab()** parses the **PVi<sub>ma</sub>** and **PSi<sub>ma</sub>** 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 **wcs.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\_wcrstab()**, has been provided for this purpose, see **getwcrstab.h**. **wcsset()** will automatically take control of this allocated memory, in particular causing it to be free'd by **wcsfree()**; the user must not attempt to free it after **wcsset()** has been called.

Note that **wcspih()** and **wcsbth()** automatically invoke **wcrstab()** on each of the **wcsprm** structs that they return.

#### Parameters:

↔ *wcs* Coordinate transformation parameters (see below).

**wcrstab()** sets *ntab*, *tab*, *nwtb* and *wtb*, allocating memory for the *tab* and *wtb* arrays. This allocated memory will be free'd automatically by **wcsfree()**.

#### Returns:

Status return value:

- 0: Success.
- 1: Null **wcsprm** pointer passed.

### 6.13.3.4 int wcridx (int *nwcs*, struct **wcsprm** \*\* *wcs*, int *alts*[27])

**wcridx()** 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 (column == 0) representations derived from image header keywords - use **wcsbidx()** for those derived from binary table image arrays or pixel lists keywords.

#### Parameters:

← *nwcs* Number of coordinate representations in the array.

- ← *wcs* Pointer to an array of [wcsprm](#) structs returned by [wcspih\(\)](#) or [wcsbth\(\)](#).
- *alts* Index of each alternate coordinate representation in the array: *alts*[0] for the primary, *alts*[1] for 'A', etc., set to -1 if not present.
- For example, if there was no 'P' representation then

```
alts['P'-'A'+1] == -1;
```

Otherwise, the address of its [wcsprm](#) struct would be

```
wcs + alts['P'-'A'+1];
```

#### Returns:

Status return value:

- 0: Success.
- 1: Null [wcsprm](#) pointer passed.

#### 6.13.3.5 int wcsbdx (int *nwcs*, struct [wcsprm](#) \*\* *wcs*, int *type*, short *alts*[1000][28])

[wcsbdx\(\)](#) 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:

- ← *nwcs* Number of coordinate representations in the array.
- ← *wcs* Pointer to an array of [wcsprm](#) structs returned by [wcsbth\(\)](#).
- ← *type* Select the type of coordinate representation:
- 0: binary table image arrays,
  - 1: pixel lists.
- *alts* Index of each alternate coordinate representation in the array: *alts*[col][0] for the primary, *alts*[col][1] for 'A', to *alts*[col][26] for 'Z', where col is the 1-relative column number, and col == 0 is used for unattached image headers. Set to -1 if not present.
- alts*[col][27] counts the number of coordinate representations of the chosen type for each column.
- For example, if there was no 'P' representation for column 13 then

```
alts[13]['P'-'A'+1] == -1;
```

Otherwise, the address of its [wcsprm](#) struct would be

```
wcs + alts[13]['P'-'A'+1];
```

#### Returns:

Status return value:

- 0: Success.
- 1: Null [wcsprm](#) pointer passed.



### 6.13.3.6 int wcsvfree (int \* *nwcs*, struct *wcsprm* \*\* *wcs*)

**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:

- ↔ *nwcs* Number of coordinate representations found; set to 0 on return.
- ↔ *wcs* Pointer to the array of *wcsprm* structs; set to 0 on return.

#### Returns:

Status return value:

- 0: Success.
- 1: Null *wcsprm* pointer passed.

### 6.13.3.7 int wshdo (int *relax*, struct *wcsprm* \* *wcs*, int \* *nkeyrec*, char \*\* *header*)

**wshdo()** 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**.
- Deprecated (e.g. **CROTA<sub>n</sub>**) or non-standard usage will be translated to standard (this is partially dependent on whether **wcsfix()** was applied).
- Quantities will be converted to the units used internally, basically SI with the addition of degrees.
- Floating-point quantities may be given to a different decimal precision.
- Elements of the **PC<sub>i\_</sub><sub>j</sub><sub>a</sub>** 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.
- Additional keywords such as **WCSAXES<sub>a</sub>**, **CUNIT<sub>ia</sub>**, **LONPOLE<sub>a</sub>** and **LATPOLE<sub>a</sub>** may appear.
- The original keycomments will be lost, although **wshdo()** tries hard to write meaningful comments.
- Keyword order may be changed.

Keywords can be translated between the image array, binary table, and pixel lists forms by manipulating the *colnum* or *colax[]* members of the *wcsprm* struct.

#### Parameters:

- ← *relax* Degree of permissiveness:

- 0: Recognize only FITS keywords defined by the published WCS standard.
- -1: Admit all informal extensions of the WCS standard.

Fine-grained control of the degree of permissiveness is also possible as explained in the notes below.

↔ **wcs** Pointer to a [wcsprm](#) struct containing coordinate transformation parameters. Will be initialized if necessary.

→ **nkeyrec** Number of FITS header keyrecords returned in the "header" array.

→ **header** Pointer to an array of char holding the header. Storage for the array is allocated by **wcshdo()** in blocks of 2880 bytes (32 x 80-character keyrecords) and must be free'd by the user to avoid memory leaks.

Each keyrecord is 80 characters long and is *\*NOT\** null-terminated, so the first keyrecord starts at (**\*header**)[0], the second at (**\*header**)[80], etc.

#### Returns:

Status return value:

- 0: Success.
- 1: Null [wcsprm](#) pointer passed.

#### Notes:

**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\_ka</sub>** and **TC<sub>n\_ka</sub>** for pixel lists

but WCS Paper II uses **TPC<sub>n\_ka</sub>** in one example and subsequently the errata for the WCS papers legitimized the use of

- **TPC<sub>n\_ka</sub>** and **TCD<sub>n\_ka</sub>** 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\_ma</sub>** and **iS<sub>n\_ma</sub>** for bintables and
- **TV<sub>n\_ma</sub>** and **TS<sub>n\_ma</sub>** for pixel lists

but WCS Paper II uses `iPVn_ma` and `TPVn_ma` in the examples and subsequently the errata for the WCS papers legitimized the use of

- `iPVn_ma` and `iPSn_ma` for bintables and
- `TPVn_ma` and `TPSn_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\\_CRPX<sub>na</sub>](#): For historical reasons WCS Paper I defined
  - `jCRPXn`, `iCDLTn`, `iCUNn`, `iCTYPn`, and `iCRVLn` for bintables and
  - `TCRPXn`, `TCDLTn`, `TCUNn`, `TCTYPn`, and `TCRVLn` 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

- `jCRPna`, `iCDEna`, `iCUNna`, `iCTYna` and `iCRVna` for bintables and
- `TCRPna`, `TCDEna`, `TCUNna`, `TCTYna` and `TCRVna` 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
  - `iCNAna`, `iCRDna`, and `iCSYna` for bintables and
  - `TCNAna`, `TCRDna`, and `TCSYna` for pixel lists

By analogy with the above, the long forms would be

- `iCNAMna`, `iCRDEna`, and `iCSYEna` for bintables and
- `TCNAMna`, `TCRDEna`, and `TCSYEna` 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 `WCSNna` instead of `TWCSna` for pixel lists. While [wcsbth\(\)](#) treats `WCSNna` and `TWCSna` as equivalent, other parsers may not. Consequently, this usage is potentially unsafe and is not recommended at this time.

## 6.13.4 Variable Documentation

### 6.13.4.1 `const char * wshdr_errmsg[]`

Error messages to match the status value returned from each function.

## 6.14 wcslib.h File Reference

```
#include "cel.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 "wcsfix.h"
#include "wcshdr.h"
#include "wcmath.h"
#include "wcstrig.h"
#include "wcsunits.h"
#include "wcsutil.h"
```

### 6.14.1 Detailed Description

This header file is provided purely for convenience. Use it to include all of the separate WCSLIB headers.

## 6.15 wcmath.h File Reference

### Defines

- #define [PI](#) 3.141592653589793238462643
- #define [D2R](#)  $\text{PI}/180.0$   
*Degrees to radians conversion factor.*
- #define [R2D](#)  $180.0/\text{PI}$   
*Radians to degrees conversion factor.*
- #define [SQRT2](#) 1.4142135623730950488
- #define [SQRT2INV](#)  $1.0/\text{SQRT2}$
- #define [UNDEFINED](#) 987654321.0e99  
*Value used to indicate an undefined quantity.*
- #define [undefined](#)(value) (value == UNDEFINED)  
*Macro used to test for an undefined quantity.*

### 6.15.1 Detailed Description

Definition of mathematical constants used by WCSLIB.

### 6.15.2 Define Documentation

#### 6.15.2.1 `#define PI 3.141592653589793238462643`

#### 6.15.2.2 `#define D2R PI/180.0`

Factor  $\pi/180^\circ$  to convert from degrees to radians.

#### 6.15.2.3 `#define R2D 180.0/PI`

Factor  $180^\circ/\pi$  to convert from radians to degrees.

#### 6.15.2.4 `#define SQRT2 1.4142135623730950488`

$\sqrt{2}$ , used only by `molset()` (MOL projection).

#### 6.15.2.5 `#define SQRT2INV 1.0/SQRT2`

$1/\sqrt{2}$ , used only by `qscx2s()` (QSC projection).

#### 6.15.2.6 `#define UNDEFINED 987654321.0e99`

Value used to indicate an undefined quantity (noting that NaNs cannot be used portably).

#### 6.15.2.7 `#define undefined(value) (value == UNDEFINED)`

Macro used to test for an undefined value.

## 6.16 `wcstrig.h` File Reference

```
#include <math.h>
#include "wcsconfig.h"
```

### Defines

- `#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.*

### 6.16.1 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° 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°.

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 `-DWCSTRIG_MACRO`). These are typically 20% faster but may lead to problems near the poles.

## 6.16.2 Define Documentation

### 6.16.2.1 #define WCSTRIG\_TOL 1e-10

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  $|v| == 1$ .

## 6.16.3 Function Documentation

### 6.16.3.1 double cosd (double *angle*)

`cosd()` returns the cosine of an angle given in degrees.

#### Parameters:

← *angle* [deg].

#### Returns:

Cosine of the angle.

### 6.16.3.2 double sind (double *angle*)

`sind()` returns the sine of an angle given in degrees.

#### Parameters:

← *angle* [deg].

#### Returns:

Sine of the angle.

### 6.16.3.3 void sincosd (double *angle*, double \**sin*, double \**cos*)

`sincosd()` returns the sine and cosine of an angle given in degrees.

#### Parameters:

← *angle* [deg].

→ *sin* Sine of the angle.

→ *cos* Cosine of the angle.

#### Returns:

### 6.16.3.4 double tand (double *angle*)

`tand()` returns the tangent of an angle given in degrees.

#### Parameters:

← *angle* [deg].

**Returns:**

Tangent of the angle.

**6.16.3.5 double acosd (double x)**

**acosd()** returns the inverse cosine in degrees.

**Parameters:**

$\leftarrow x$  in the range  $[-1,1]$ .

**Returns:**

Inverse cosine of  $x$  [deg].

**6.16.3.6 double asind (double y)**

**asind()** returns the inverse sine in degrees.

**Parameters:**

$\leftarrow y$  in the range  $[-1,1]$ .

**Returns:**

Inverse sine of  $y$  [deg].

**6.16.3.7 double atand (double s)**

**atand()** returns the inverse tangent in degrees.

**Parameters:**

$\leftarrow s$

**Returns:**

Inverse tangent of  $s$  [deg].

**6.16.3.8 double atan2d (double y, double x)**

**atan2d()** returns the polar angle,  $\beta$ , in degrees, of polar coordinates  $(\rho, \beta)$  corresponding Cartesian coordinates  $(x, y)$ . It is equivalent to the  $\arg(x, y)$  function of WCS Paper II, though with transposed arguments.

**Parameters:**

$\leftarrow y$  Cartesian  $y$ -coordinate.

$\leftarrow x$  Cartesian  $x$ -coordinate.

**Returns:**

Polar angle of  $(x, y)$  [deg].



## 6.17 wcsunits.h File Reference

### Defines

- #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_NTTYPE 17`  
*Number of entries in the units array.*

## Functions

- `int wcsunits` (const char have[ ], const char want[ ], double \*scale, double \*offset, double \*power)  
*FITS units specification conversion.*
- `int wcsutrn` (int ctrl, char unitstr[ ])  
*Translation of non-standard unit specifications.*
- `int wcsulex` (const char unitstr[ ], int \*func, double \*scale, double units[ ])  
*FITS units specification parser.*

## Variables

- const char \* `wcsunits_errmsg` [ ]  
*Status return messages.*
- const char \* `wcsunits_types` [ ]  
*Names of physical quantities.*
- const char \* `wcsunits_units` [ ]  
*Names of units.*

### 6.17.1 Detailed Description

Routines in this suite deal with units specifications and conversions:

- `wcsunits()`: given two unit specifications, derive the conversion from one to the other.
- `wcsutrn()`: translates certain commonly used but non-standard unit strings. It is intended to be called before `wcsulex()` which only handles standard FITS units specifications.
- `wcsulex()`: parses a standard FITS units specification of arbitrary complexity, deriving the conversion to canonical units.

### 6.17.2 Define Documentation

#### 6.17.2.1 `#define WCSUNITS_PLANE_ANGLE 0`

Array index for plane angle units in the *units* array returned by `wcsulex()`, and the `wcsunits_types`[ ] and `wcsunits_units`[ ] global variables.

### 6.17.2.2 #define WCSUNITS\_SOLID\_ANGLE 1

Array index for solid angle units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

### 6.17.2.3 #define WCSUNITS\_CHARGE 2

Array index for charge units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

### 6.17.2.4 #define WCSUNITS\_MOLE 3

Array index for mole ("gram molecular weight") units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

### 6.17.2.5 #define WCSUNITS\_TEMPERATURE 4

Array index for temperature units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

### 6.17.2.6 #define WCSUNITS\_LUMINTEN 5

Array index for luminous intensity units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

### 6.17.2.7 #define WCSUNITS\_MASS 6

Array index for mass units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

### 6.17.2.8 #define WCSUNITS\_LENGTH 7

Array index for length units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

### 6.17.2.9 #define WCSUNITS\_TIME 8

Array index for time units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

### 6.17.2.10 #define WCSUNITS\_BEAM 9

Array index for beam units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

### 6.17.2.11 #define WCSUNITS\_BIN 10

Array index for bin units in the *units* array returned by [wcsulex\(\)](#), and the [wcsunits\\_types\[\]](#) and [wcsunits\\_units\[\]](#) global variables.

**6.17.2.12 #define WCSUNITS\_BIT 11**

Array index for bit units in the *units* array returned by `wcsulex()`, and the `wcsunits_types[]` and `wcsunits_units[]` global variables.

**6.17.2.13 #define WCSUNITS\_COUNT 12**

Array index for count units in the *units* array returned by `wcsulex()`, and the `wcsunits_types[]` and `wcsunits_units[]` global variables.

**6.17.2.14 #define WCSUNITS\_MAGNITUDE 13**

Array index for stellar magnitude units in the *units* array returned by `wcsulex()`, and the `wcsunits_types[]` and `wcsunits_units[]` global variables.

**6.17.2.15 #define WCSUNITS\_PIXEL 14**

Array index for pixel units in the *units* array returned by `wcsulex()`, and the `wcsunits_types[]` and `wcsunits_units[]` global variables.

**6.17.2.16 #define WCSUNITS\_SOLRATIO 15**

Array index for solar mass ratio units in the *units* array returned by `wcsulex()`, and the `wcsunits_types[]` and `wcsunits_units[]` global variables.

**6.17.2.17 #define WCSUNITS\_VOXEL 16**

Array index for voxel units in the *units* array returned by `wcsulex()`, and the `wcsunits_types[]` and `wcsunits_units[]` global variables.

**6.17.2.18 #define WCSUNITS\_NTTYPE 17**

Number of entries in the *units* array returned by `wcsulex()`, and the `wcsunits_types[]` and `wcsunits_units[]` global variables.

**6.17.3 Function Documentation****6.17.3.1 int wcsunits (const char *have*[], const char *want*[], double \* *scale*, double \* *offset*, double \* *power*)**

`wcsunits()` derives the conversion from one system of units to another.

**Parameters:**

- ← ***have*** FITS units specification to convert from (null-terminated), with or without surrounding square brackets (for inline specifications); text following the closing bracket is ignored.
- ← ***want*** FITS units specification to convert to (null-terminated), with or without surrounding square brackets (for inline specifications); text following the closing bracket is ignored.
- ***scale, offset, power*** Convert units using

```
pow(scale*value + offset, power);
```

Normally *offset* is zero except for log() or ln() conversions, e.g. "log(MHz)" to "ln(Hz)". Likewise, *power* is normally unity except for exp() conversions, e.g. "exp(ms)" to "exp(/Hz)". Thus conversions ordinarily consist of

```
value *= scale;
```

**Returns:**

Status return value:

- 0: Success.
- 1-9: Status return from [wcsulex\(\)](#).
- 10: Non-conformant unit specifications.
- 11: Non-conformant functions.

scale is zeroed on return if an error occurs.

**6.17.3.2 int wcsutrn (int *ctrl*, char *unitstr*[ ])**

**wcsutrn()** translates certain commonly used but non-standard unit strings, e.g. "DEG", "MHZ", "KELVIN", that are not recognized by [wcsulex\(\)](#), 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.

**Parameters:**

← **ctrl** 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:

- 1: Translate "S" to "s".
- 2: Translate "H" to "h".
- 4: Translate "D" to "d".

Thus `ctrl == 0` doesn't do any unsafe translations, whereas `ctrl == 7` does all of them.

↔ **unitstr** Null-terminated character array containing the units specification to be translated.

Inline units specifications in the a FITS header keycomment are also handled. If the first non-blank character in `unitstr` 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.

**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:**

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	angstrom
arcmin	arcmins, ARCMIN, ARCMINS
arcsec	arcsecs, ARCSEC, ARCSECS
beam	BEAM
byte	Byte
d	day, days, (D), DAY, DAYS
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 [wcsulex\(\)](#) itself as an unofficial extension of the standard, but they are converted to the standard form here.

### 6.17.3.3 int wcsulex (const char *unitstr*[ ], int \* *func*, double \* *scale*, double *units*[ ])

**wcsulex()** 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.

#### Parameters:

- ← ***unitstr*** Null-terminated character array containing the units specification, with or without surrounding square brackets (for inline specifications); text following the closing bracket is ignored.
- ***func*** Special function type, see note 4:
  - 0: None
  - 1: log() ...base 10
  - 2: ln() ...base e
  - 3: exp()
- ***scale*** Scale factor for the unit specification; multiply a value expressed in the given units by this factor to convert it to canonical units.
- ***units*** A units specification is decomposed into powers of 16 fundamental unit types: angle, mass, length, time, count, pixel, etc. Preprocessor macro WCSUNITS\_NTTYPE is defined to dimension this vector, and others such as WCSUNITS\_PLANE\_ANGLE, WCSUNITS\_LENGTH, etc. to access its elements.  
Corresponding character strings, `wcsunits_types[]` and `wcsunits_units[]`, are predefined to describe each quantity and its canonical units.

#### 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. **wcsulex()** 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.

### 6.17.4 Variable Documentation

#### 6.17.4.1 `const char * wcsunits_errmsg[ ]`

Error messages to match the status value returned from each function.

#### 6.17.4.2 `const char * wcsunits_types[ ]`

Names for physical quantities to match the units vector returned by **wcsulex()**:

- 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

#### 6.17.4.3 `const char * wcsunits_units[]`

Names for the units (SI) to match the units vector returned by `wcsulex()`:

- 0: degree
- 1: steradian
- 2: Coulomb
- 3: mole
- 4: Kelvin
- 5: candela
- 6: kilogram
- 7: metre
- 8: second

The remainder are dimensionless.



## 6.18 wcsutil.h File Reference

### Functions

- 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\\_allEq](#) (int *nvec*, int *nelem*, const double *\*first*)  
*Test for equality of a particular vector element.*
- void [wcsutil\\_setAll](#) (int *nvec*, int *nelem*, double *\*first*)  
*Set a particular vector element.*
- void [wcsutil\\_setAli](#) (int *nvec*, int *nelem*, int *\*first*)  
*Set a particular vector element.*
- void [wcsutil\\_setBit](#) (int *nelem*, const int *\*sel*, int *bits*, int *\*array*)  
*Set bits in selected elements of an array.*

### 6.18.1 Detailed Description

Simple utility functions used by WCSLIB. 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!

### 6.18.2 Function Documentation

#### 6.18.2.1 void [wcsutil\\_blank\\_fill](#) (int *n*, char *c*[])

[wcsutil\\_blank\\_fill](#)() pads a character string with blanks starting with the terminating NULL character.

Used by the Fortran wrapper functions in translating C character strings into Fortran CHARACTER variables.

#### Parameters:

- ← *n* Length of the character array, *c*[].
- ↔ *c* The character string. It will not be null-terminated on return.

#### Returns:

#### 6.18.2.2 void [wcsutil\\_null\\_fill](#) (int *n*, char *c*[])

[wcsutil\\_null\\_fill](#)() pads a character string with NULL characters.

Used mainly to make character strings intelligible in the GNU debugger - it prints the rubbish following the terminating NULL, obscuring the valid part of the string.

**Parameters:**

- ← *n* Number of characters.
- ↔ *c* The character string.

**Returns:****6.18.2.3 int wcsutil\_allEq (int *nvec*, int *nelem*, const double \**first*)**

**wcsutil\_allEq()** tests for equality of a particular element in a set of vectors.

**Parameters:**

- ← *nvec* The number of vectors.
- ← *nelem* The length of each vector.
- ← *first* Pointer to the first element to test in the array. The elements tested for equality are

```
*first == *(first + nelem)
      == *(first + nelem*2)
      :
      == *(first + nelem*(nvec-1));
```

The array might be dimensioned as

```
double v[nvec][nelem];
```

**Returns:**

Status return value:

- 0: Not all equal.
- 1: All equal.

**6.18.2.4 void wcsutil\_setAll (int *nvec*, int *nelem*, double \**first*)**

**wcsutil\_setAll()** sets the value of a particular element in a set of vectors.

**Parameters:**

- ← *nvec* The number of vectors.
- ← *nelem* The length of each vector.
- ↔ *first* Pointer to the first element in the array, the value of which is used to set the others

```
*(first + nelem) = *first;
*(first + nelem*2) = *first;
:
*(first + nelem*(nvec-1)) = *first;
```

The array might be dimensioned as

```
double v[nvec][nelem];
```

**Returns:**

**6.18.2.5 void wcsutil\_setAli (int *nvec*, int *nelem*, int \**first*)**

**wcsutil\_setAli()** sets the value of a particular element in a set of vectors.

**Parameters:**

- ← *nvec* The number of vectors.
- ← *nelem* The length of each vector.
- ↔ *first* Pointer to the first element in the array, the value of which is used to set the others

```
*(first + nelem) = *first;
*(first + nelem*2) = *first;
:
*(first + nelem*(nvec-1)) = *first;
```

The array might be dimensioned as

```
int v[nvec][nelem];
```

**Returns:****6.18.2.6 void wcsutil\_setBit (int *nelem*, const int \**sel*, int *bits*, int \**array*)**

**wcsutil\_setBit()** sets bits in selected elements of an array.

**Parameters:**

- ← *nelem* Number of elements in the array.
- ← *sel* Address of a selection array of length *nelem*. May be specified as the null pointer in which case all elements are selected.
- ← *bits* Bit mask.
- ↔ *array* Address of the array of length *nelem*.

**Returns:**

## 7 WCSLIB 4.4 Page Documentation

### 7.1 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 graticules and 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
- "Mapping on the HEALPix Grid" (HPX), Calabretta, M.R., & Roukema, B.F. 2007, MNRAS, 381, 865

Reprints of all published papers may be obtained from NASA's Astrophysics Data System (ADS), <http://adsabs.harvard.edu/>. Reprints of Papers I, II (+HPX) and III are available from <http://www.atnf.csiro.au/~mcalabre/>. 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>.

## 7.2 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/~mcalabre/WCS/>. The remainder of this document describes its use.
- **wcstools**, developed by Doug Mink, may be obtained from <http://tdc-www.harvard.edu/software/wcstools/>.
- **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 is also provided; go to the above site and then look at the section entitled "FITS-WCS Plotting Demo".

Python wrappers to **WCSLIB** are provided by

- The **Kapteyn Package** <http://www.astro.rug.nl/software/kapteyn/> by Hans Terlouw.
- **pywcs**, <http://stsdas.stsci.edu/astrolib/pywcs/> by Michael Droettboom.

Java is supported via

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

Recommended WCS-aware FITS image viewers:

- Bill Joye's **DS9** (<http://hea-www.harvard.edu/RD/ds9/>), and **Fv** by Pan Chai (<http://heasarc.gsfc.nasa.gov/fv/>) both handle 2-D images.

Currently (2009/08/18) 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 out-of-date by the time you read it, best do a web search):

- Fedora (RPM), <https://admin.fedoraproject.org/pkgdb/packages/name/wcslib>
- Fresh Ports (RPM), <http://www.freshports.org/astro/wcslib/>
- Gentoo, <http://packages.gentoo.org/package/sci-astronomy/wcslib>
- RPM (general) <http://v2.www.rpmseek.com/cat/Libraries.html?hl=com&cx=591:W>

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.

**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/>.

## 7.3 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.
  - [wcsldr.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 `wcsutrn()`).
- `wcsutrn.l` – Lexical translator for non-standard units specifications.

As a concrete example, within this layer the `CTYPEia` 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 `wcsulex()`).
  - `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.
- `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 trig functions that don't test for multiples of 90° (compile with `-DWCSTRIG_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.
- *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.

## 7.4 WCSLIB data structures

The WCSLIB routines are based on data structures specific to them: *wcsprm* for the *wcs.h,c* routines, *celprm* for *cel.h,c*, and likewise *specprm*, *linprm*, *priprm* and *tabprm*, 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 `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. `wcsini()`, `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 key-values 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` and `tabprm`) 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.

## 7.5 Memory management

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

- `wcsini()` 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 `linini()` for certain of these). Note that `wcsini()` 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.
- `linini()`: 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 `wcsini()` 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.



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.

`wcsini()` maintains a record of memory it has allocated and this is used by `wcsfree()` which `wcsini()` 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 `wcsini()` 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 `linini()`, `linfree()`, and `linset()` and to `tabini()`, `tabfree()`, and `tabset()`.

A memory leak will result if a `wcsprm`, `linprm` or `tabprm` struct goes out of scope before the memory has been *free'd*, either by the relevant routine, `wcsfree()`, `linfree()` or `tabfree()`, 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` or `tabprm` 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()` or `tabcpy()`.

## 7.6 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, multiples by the transformation matrix, and returns whole intermediate world coordinate vectors.

The routines that implement these steps, `wcsp2s()`, `wcss2p()`, `linp2x()`, `linx2p()`, `tabx2s()`, and `tabs2x()`, 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 `WCSEXES` 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 `wcsprm` (or `linprm`) 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 [wvsp2s\(\)](#) and [wvss2p\(\)](#).

**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.

### 7.6.1 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 [cels2x\(\)](#), 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 *nlng* \* *nlat* = 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  $n\text{lng} = 3$ ,  $n\text{lat} = 1$ :

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

The situation for `cels2s()` is similar; the  $x$ -coordinate (like  $\text{lng}$ ) 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 `wcss2p()`, 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.

### 7.6.2 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  $\text{lng}[]$  and  $\text{lat}[]$  vectors each have vector stride  $sll$ , while the  $x[]$  and  $y[]$  output vectors have stride  $sxy$ . However, the intermediate  $\text{phi}[]$  and  $\text{theta}[]$  arrays each have unit stride, as does the  $\text{stat}[]$  vector.

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

## 7.7 Thread-safety

With the following exceptions WCSLIB 4.4 is thread-safe:

- The C code generated by Flex is not re-entrant. Flex does have the capacity for producing re-entrant scanners but they have a different API. This may be handled by a compile-time option in future but in the meantime calls to the header parsers should be serialized via a mutex.
- The low-level functions `wcsnpv()` and `wcsnps()` are not thread-safe but within the library itself they are only used by the Flex scanners `wcspih()` and `wcsbth()`. They would rarely need to be used by application programmers.

## 7.8 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 vital for verifying the integrity of the mathematical routines.

- High level:

*twcstab* provides an example of high-level applications programming using WCSLIB and `CFIT-SIO`. 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 `wcshdr.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.

*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.

- Middle level:

*twcs* tests closure of `wcss2p()` and `wcsp2s()` for a number of selected projections. *twcsmix* verifies `wcsmix()` 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. *twcssub* tests the extraction of a coordinate description for a subimage from a `wcsprm` struct by `wcssub()`.

*tunits* tests `wcsutrn()`, `wcsunits()` and `wcsulex()`, the units specification translator, converter and parser, either interactively or using a list of units specifications contained in `units_test`.

- Low level:

*tlin*, *tlog*, *tpri1*, *tsph*, *tspc*, *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. *tprj1* 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 (**ZEA**, **CEA** and **COE**), and near divergent latitudes of projections such as the azimuthal perspective and stereographic projections (**AZP** and **STG**). Rounding errors may also carry points between faces of the quad-cube projections (**CSC**, **QSC**, and **TSC**). 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 (**CSC**) 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.

## 7.9 WCSLIB Fortran wrappers

The Fortran subdirectory contains wrappers, written in C, that allow Fortran programs to use WCSLIB.

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. These must be used in conjunction with wrappers on the routines provided to manage the structs in C, for example **WCSINI**, **WCSSUB**, **WCSCOPY**, **WCSFREE**, and **WCSVRT** which wrap **wcsini()**, **wcssub()**, **wscopy()**, **wcfree()**, and **wcvrt()**.

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 wherever 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.

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 **WCSINI**, 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.

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)

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

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

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

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

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

      etc.

*      Initialize.
      STATUS = WCSSET (WCS)

*      Find the "longitude" axis.
      STATUS = WCSGET (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 *wcspbm* struct.

Note that the data type of the third argument to the `*PUT` and `*GET` routines may differ 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. Compilers (e.g. *g77*) may warn of inconsistent usage of this argument but this can (usually) be safely ignored.

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

## 7.10 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/~mcalabre/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 subroutine `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, `pgwctl_()`, 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 `pgwctl_()`. In turn, `cpgsbox()` calls PGSBOX, which invokes `pgwctl_()` as an `EXTERNAL` subroutine. In this sequence, a complicated C struct defined by `cpgtest` is passed through PGSBOX to `pgwctl_()` 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.

## 7.11 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 `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 `cels2x_errmsg`** Added for backwards compatibility, use `cel_errmsg` directly now instead.

**Global `FITSHDR_CARD`** Added for backwards compatibility, use `FITSHDR_KEYREC` instead.

**Global `linini_errmsg`** Added for backwards compatibility, use `lin_errmsg` directly now 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 `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 [linp2x\\_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 [prjpvt\\_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 [prjs2x\\_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 [spcpvt\\_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 [spcs2x\\_errmsg](#) Added for backwards compatibility, use [spc\\_errmsg](#) directly now instead.

Global [tabini\\_errmsg](#) Added for backwards compatibility, use [tab\\_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 [tabpvt\\_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 [tabs2x\\_errmsg](#) Added for backwards compatibility, use [tab\\_errmsg](#) directly now instead.

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

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

Global [wscopy\\_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 [wcsprt\\_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 [wcp2s\\_errmsg](#) Added for backwards compatibility, use [wcs\\_errmsg](#) directly now instead.

Global [wcp2p\\_errmsg](#) Added for backwards compatibility, use [wcs\\_errmsg](#) directly now instead.

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

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

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