Representations of Celestial Coordinates in FITS

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Initial (1979) FITS Coordinate Specification

Keywords

`CTYPE`n Coordinate type (8 characters)
`CRPIX`n Reference pixel location
`CRVAL`n Coordinate value at reference pixel
`CDELT`n Coordinate increment at reference pixel
`CROTA`n Coordinate "rotation"

Problems with this

- Types inadequate for celestial coordinates, velocities
- Physical meaning of reference pixel undefined
- Rotation undefined, inadequate for general use
- No provision for skew in images

AIPS 1983 enhancements

- Types defined for some celestial coordinates, velocities
- Reference pixel defined as tangent point
- Rotation limited to celestial coordinates
- Still no skew or offset rotations
- Limited view of projective geometries

Proposed FITS Coordinate Specification

New Keywords for All Coordinate Types

`CUNIT`n coordinate units string

- the units used in `CRVAL`n and `CDELT`n
- simple SI units (and degrees) preferred
- allowed units and format of string to be discussed

`PC`$nnnmmm$ Matrix

- Replaces `CROTA`n keywords
- Allows skew, offset and general rotations
- Allows dissimilar coordinates to be rotated together
- Relative coordinates given by linear transform :

$$\begin{pmatrix} x \\ y \\ z \\ \vdots \end{pmatrix} = \begin{pmatrix} \texttt{CDELT1} & 0 & 0 & \dots \\ 0 & \texttt{CDELT2} & 0 & \dots \\ 0 & 0 & \texttt{CDELT3} & \dots \\ \vdots & \vdots & \vdots & \ddots \end{pmatrix} \begin{pmatrix} \texttt{PC001001} & \texttt{PC001002} & \texttt{PC001003} & \dots \\ \texttt{PC002001} & \texttt{PC002002} & \texttt{PC002003} & \dots \\ \texttt{PC003001} & \texttt{PC003002} & \texttt{PC003003} & \dots \\ \vdots & \vdots & \vdots & \ddots \end{pmatrix} \begin{pmatrix} i - i_0 \\ j - j_0 \\ k - k_0 \\ \vdots \end{pmatrix}$$

Proposed FITS Coordinate Specification

New Keywords for All Coordinate Types

Secondary description(s) of coordinate axis n

- CmVALn coordinate value at reference pixel
- CmPIXn reference pixel array location
- CmELTn coordinate increment at reference pixel
- CmYPEn axis type (8 characters)
- CmNITn units of CmVALn and CmELTn (character valued as CUNITm)

$m = 2, 3, 4, 5, 6, 7, 8,$ or 9

Astrometry-related keywords added

- EQUINOX replaces EPOCH for the epoch of the mean equator and equinox in years
- MJD-OBS modified Julian date of observation in days
- RADECSYS frame of reference of equatorial coordinates as FK4, FK4-NO-E, FK5, GAPPT

Proposed FITS Coordinate Specification

Keywords for Celestial Coordinates

`CTYPE`n format defined

- First 4 characters give type of "standard coordinate system" as
  equatorial — `RA--` and `DEC-`
  galactic — `GLON` and `GLAT`
  ecliptic — `ELON` and `ELAT`
- Second 4 characters give type of projection as `-`*ccc*
  where *ccc* defined by convention, such as
  `SIN`, `TAN`, `ARC`, `AIT`

`CRPIX`n meaning defined by projection

- Each projection has "native coordinate system "
- Reference pixel is native north pole $(0, 90°)$ for
  azimuthal and conical projections
- Reference pixel is native origin $(0, 0)$ for
  cylindrical and conventional projections

Proposed FITS Coordinate Specification

Celestial Coordinates Continued

CDELTn clarified

- Increment in physical units per pixel of physical axis n
- Applied after pixel rotation and skew
- This linear physical "coordinate" then converted by non-linear formulæ to true physical coordinates

CRVALn clarified

- Value at the reference pixel in the standard coordinates specified in CTYPEn

LONGPOLE keyword added for generality

- Native longitude of north pole of standard system
- Default value is 180°

PROJPj keywords added to define some projections

Proposed FITS Coordinate Specification

Conventions and Matters of "Good Form"

1. The center of each pixel is its location.
2. Default viewing convention:
   - First pixel at lower left corner,
   - First axis displayed along horizontal,
   - Second axis displayed along vertical.
3. Diagonal elements of PC*iiijjj* should predominate.
   - Do not hide transpositions in the PC matrix.
4. Forbid rotation into axes which have only integral values.
5. NCP projection (of WSRT) changed to offset SIN projection.
6. When possible, CROTAn should be written along with PC*iiijjj*.
7. For longitude axis i and latitude axis j, the conversion is

$$\begin{pmatrix} \texttt{PC}iiiiii & \texttt{PC}iiijjj \\ \texttt{PC}jjjiii & \texttt{PC}jjjjjj \end{pmatrix} = \begin{pmatrix} \cos(\texttt{CROTA}j) & -\sin(\texttt{CROTA}j) \\ \sin(\texttt{CROTA}j) & \cos(\texttt{CROTA}j) \end{pmatrix} .$$