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 :

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

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)

$$m = 2, 3, 4, 5, 6, 7, 8, \text{ or } 9$$

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

`CDELT`n 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

`CRVAL`n clarified

- Value at the reference pixel in the standard coordinates specified in `CTYPE`n

`LONGPOLE` keyword added for generality

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

`PROJP`j 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 $\mathtt{PC}iiijjj$ 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, $\mathtt{CROTA}n$ should be written along with $\mathtt{PC}iiijjj$.
7. For longitude axis i and latitude axis j, the conversion is

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