Astronomical Data Analysis Software and Systems IV
ASP Conference Series, Vol. 77, 1995
R. A. Shaw, H. E. Payne, and J. J. E. Hayes, eds.

Representations of Celestial Coordinates in FITS

E. W. Greisen

National Radio Astronomy Observatory

M. Calabretta

Australia Telescope National Facility

Abstract. The initial descriptions of the FITS format provided a simplified method for describing the physical coordinate values of the image pixels, but deliberately did not specify any of the detailed conventions required to convey the complexities of actual image projections. Building on conventions in wide use within astronomy, this paper proposes changes to the simple methods for describing coordinates and proposes detailed conventions for describing most of the methods by which spherical coordinates may be projected onto a two-dimensional plane. Simple methods for converting from the existing coordinate conventions are described. This paper does not attempt to address the politically sensitive questions of frequency/velocity coordinates, nor does it address various other types of coordinates, such as time.

1. Introduction

The initial paper describing the Flexible Image Transport System, or FITS format, (Wells, Greisen, & Harten 1981) proposed keywords to describe the physical coordinates of the image. They were `CRPIX`n for the reference pixel location on pixel axis n, `CRVAL`n for the coordinate value at that pixel, `CDELT`n for the increment at that pixel in the coordinate value, and `CTYPE`n for the type of coordinate. Coordinate rotation—of an unspecified nature—was allowed, and a few possible values for `CTYPE`n were proposed. The original authors chose to defer discussion of the technical details of coordinate specification until the basic FITS format was accepted generally and until a deeper understanding of image coordinate specification and computation could be obtained.

The time for that discussion is now. While participating in the development of the AIPS software package of the National Radio Astronomy Observatory, Greisen (1983) developed FITS-like syntax and semantics to define both velocity and celestial coordinates. The latter have been widely used for interchanging imagery from a number of instruments at widely differing spectral domains and are fundamental to the present proposal. Greisen defined the reference pixel for celestial coordinates to be the tangent point of the projection. He specified that the first four characters of `CTYPE`n should be used to give the type of celestial coordinate while the next four characters specified the type of projection (e.g., `DEC--TAN`). Greisen (1983) gave the mathematics for four projections: orthographic (`SIN`), gnomic (`TAN`), zenithal equidistant (`ARC`), and a special coordinate used by East-West radio interferometers (`NCP`). In a second paper, Greisen (1986) added specifications for the stereographic (`STG`), sinusoidal (`GLS`), Hammer-Aitoff (`AIT`), and Mercator (`MER`) projections. The current proposal (Greisen and Calabretta, 1994) extends these earlier, widely tested proposals to clarify the logical process by which celestial coordinates are computed, and to specify a very wide range of possible projections. In addition, the current proposal specifies a method to define skew, offset rotations, and even rotations of axes of different physical type into each other. It also specifies a method to describe the units of the coordinates and to provide a second coordinate description for an axis.

2. Coordinate Computation

In the current proposal, we regard the conversion from simple pixel counts to a full coordinate description as a multi-step process containing one optional and four required steps. These steps are indicated conceptually in Figure 1. The first and optional step is used to correct the actual image pixel numbers into those which would have been recorded by an ideal instrument. The corrections in this "pixel regularization table" are expected to be rather small, so that they may be ignored except in high precision computations. In the second step, for all types of coordinates, the vector of reference pixels is subtracted from the vector of pixel numbers and the result multiplied by a pixel conversion (`PC`*iiijjj*) matrix to convert from pixel numbers to offsets from the reference pixel along physical axes but still in pixel units. The third step is a multiplication by a diagonal matrix (`CDELT`i) to convert to relative coordinate in physical units.

The fourth step in the process of finding the true coordinates depends on the type of axis given in `CTYPE`n. For simple linear axes, the true coordinate is found by adding the offset found above to the reference pixel value given by `CRVAL`n. Otherwise, some function of the offset(s), the `CRVAL`n, and, perhaps, other parameters must be established by convention and agreement. For celestial coordinates, the proposed fourth step involves converting the linear offsets into longitudes and latitudes in the "native coordinate system" for the specified type of projection. These are rotated, in the fifth step, by the usual spherical formulæ to longitudes and latitudes in the desired standard coordinates (e.g., Equatorial, Galactic, etc.) The native coordinate system is, for azimuthal and conical projections, one which has its north pole at the reference pixel. For cylindrical and conventional projections, the native coordinate system has its origin at the reference pixel. The rotation from native to standard coordinates is illustrated in Figure 2. The keyword `LONGPOLE` is proposed to specify the native longitude of the north pole of the standard system. The default value for `LONGPOLE` is to be 180 degrees to support current usage. Extra keywords `PROJP`j are defined to provide additional parametric information needed by some of the projections.

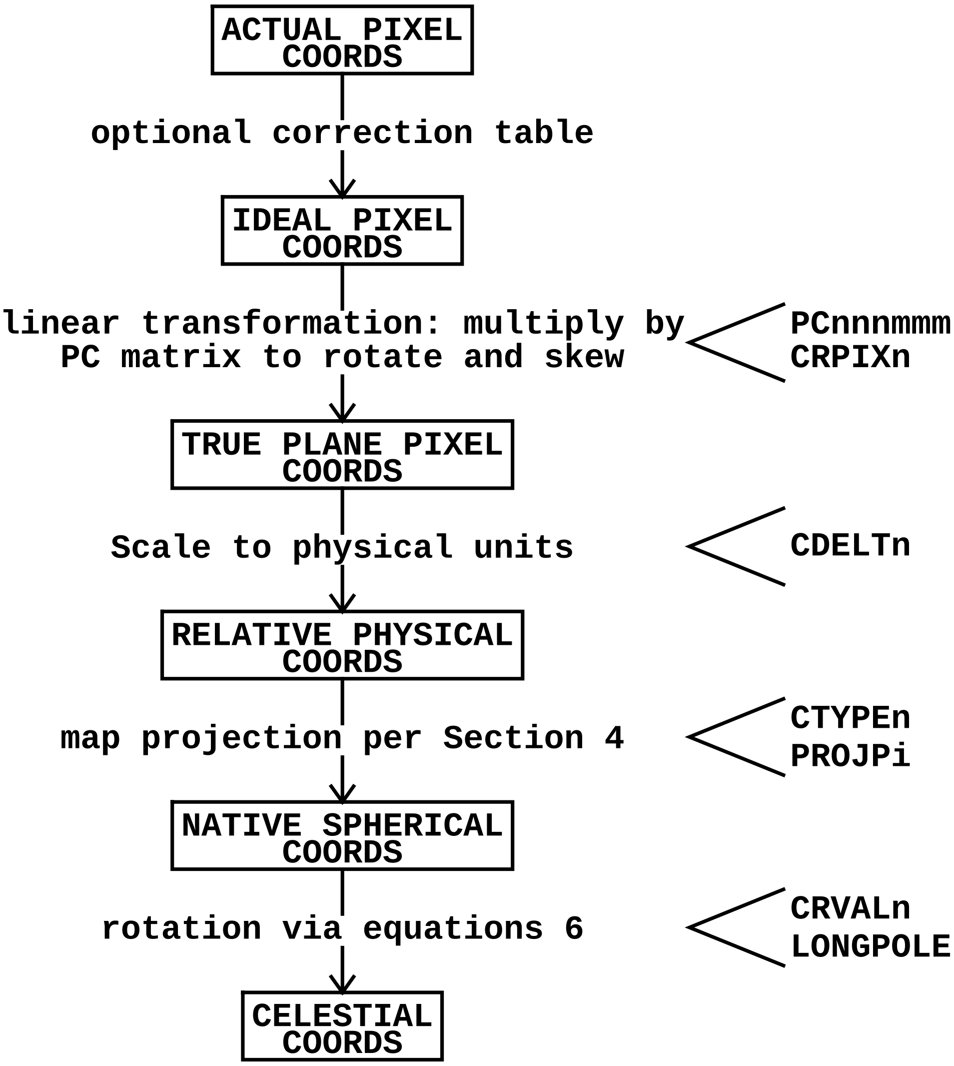

Figure 1. Conversion of pixel to celestial spherical coordinates

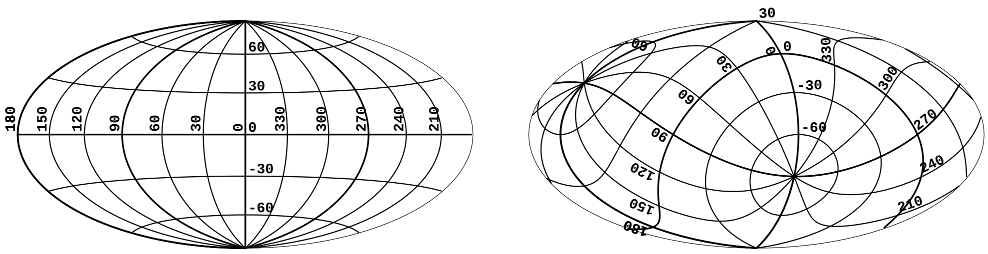

Figure 2. Conversion of native (left) to standard (right) spherical coordinates for the Hammer-Aitoff projection.

3. Other Proposed Conventions

The original FITS paper (Wells, Greisen, & Harten 1981) naively assumed that the units along each axis could be implied simply by the contents of the `CTYPE`n keyword and that they would be in the basic SI units. Outside of celestial coordinates, both of these assumptions have apparently failed in practice. Therefore we propose that a new character-valued keyword `CUNIT`n be added to describe the units used for coordinates on axis n. For celestial angular coordinates, following the proposed projection conventions, these units will be degrees (`'deg '`). Additional discussion and agreements will be needed to determine how one will represent other coordinate types.

In some cases, the axes of an image may be described as having more than one coordinate. An example of this would be the frequency, velocity, and wavelength along a spectral axis (only *one* of which, of course, could be linear). To allow up to 8 additional descriptions of each axis, we propose the addition of the follow optional, but now reserved, keywords.

`C`m`VAL`n	coordinate value at reference pixel
`C`m`PIX`n	reference pixel array location
`C`m`ELT`n	coordinate increment at reference pixel
`C`m`YPE`n	axis type (8 characters)
`C`m`NIT`n	units of `C`m`VAL`n and `C`m`ELT`n (character valued)

where $m = 2, 3, \ldots, 9$ for the second through ninth alternate axis coordinate and $n = 1, 2, \ldots, 999$ for axis 1 through 999.

To improve the use of these coordinates for astrometric purposes, three new keywords are proposed. `EQUINOX` replaces `EPOCH` for the epoch of the mean equator and equinox in years. `MJD-OBS` gives the modified Julian date of observation in days and `RADECSYS` gives the frame of reference of equatorial coordinates as `FK4`, `FK4-NO-E`, `FK5`, `GAPPT`.

References

Greisen, E. W. 1983, AIPS Memo No. 27 (Charlottesville, National Radio Astronomy Observatory)

Greisen, E. W. 1986, AIPS Memo No. 46 (Charlottesville, National Radio Astronomy Observatory)

Greisen E. W., Calabretta, M. 1994, in preparation[1]

Wells, D. C., Greisen, E. W., & Harten, R. H. 1981, A&AS, 44, 363

[1]http://fits.cv.nrao.edu/documents/wcs/wcs.html