Corrections and clarifications for FITS WCS papers I, II, & III

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2013 September 21

Abstract

One significant correction and several minor corrections and clarifications for the three FITS World Coordinate System (WCS) papers have come to light since they were published in December 2002 (I & II) and January 2006 (III).

Keywords: astrometry – astronomical data bases: miscellaneous – methods: data analysis – techniques: image processing – techniques: radial velocities – techniques: spectroscopic

1. Corrections for Paper I

Corrections for Paper I (Greisen & Calabretta 2002):

1. The *s* subscript on the keywords in Fig. 1 should be *a*.
2. Table 2 gives the binary table form of the `PV`*i_ma* keywords as *i*`V`*n_ma*, and the pixel list form as `TV`*n_ma*.
   However, the forms *i*`PV`*n_ma* and `TPV`*n_ma* are also permitted if the number of characters occupied by *i*, *n*, *m*, and *a* do not cause the keyword name to exceed the eight character limit. This also applies for *i*`PS`*n_ma* and `TPS`*n_ma*, `TPC`*n_ma* and `TCD`*n_ma*.
   This is consistent with the usage in Tables 9 and 10 of Paper II which give `2PV5_1`, `2PV5_1A`, and `TPV3_1` as examples.
3. Table 2 mistakenly defined the pixel list form of `WCSNAME`*a* as `TWCS`*na*, it should have been the same as the form used for binary table image arrays, i.e. `WCSN`*na*.
   The 'T' in the pixel list form of keywords that are parameterized by axis number is meant to substitute for the axis number in the binary table form. Note that keywords defined in Papers II and III that are not parameterised by axis number have identical forms for binary tables and pixel lists. `TWCS`*na* is the only exception.
   Consequently, `WCSN`*na* may be used in place of `TWCS`*na* for pixel lists, but the latter must still be recognized by WCS header parsers.

2. Corrections and clarifications for Paper II

Corrections and clarifications for Paper II (Calabretta & Greisen 2002):

1. In Sect. 2.2, the default value of `LONPOLE`*a* must be modified with the addition of ϕ_0:

   - For $\delta_0 \geq \theta_0$, the default for `LONPOLE`*a* is ϕ_0.
   - For $\delta_0 < \theta_0$, the default for `LONPOLE`*a* is $\phi_0 + 180°$.

   Normally ϕ_0 is zero unless a non-zero value has been set for it in the `PV`*i*`_1`*a* card associated with the *longitude* axis.
   This default applies for all values of θ_0, including $\theta_0 = 90°$, although use of non-zero values of ϕ_0 are discouraged in that case.
2. In Sect. 2.2, for $\delta_0 = \theta_0$ it would have been better if `LONPOLE`*a* had defaulted to $\phi_0 + 180°$ rather than ϕ_0.
   For $\delta_0 = \theta_0 \neq \pm 90°$ the two values for ϕ_p (i.e. $\phi_0 + 180°$ and ϕ_0) have identical effects; the spherical coordinate transformation becomes a simple change in origin of longitude such that the celestial meridian through α_0 coincides with the native meridian through ϕ_0.
   However, in the particular case where $\delta_0 = \theta_0 = \pm 90°$, this condition only applies when `LONPOLE`*a* is equal to $\phi_0 + 180°$. For the standard default, ϕ_0, the celestial meridian through α_0 coincides with the native meridian through $\phi_0 + 180°$. This is an undesirable exception to what would otherwise be a useful general rule.
   Thus, when $\delta_0 = \theta_0 = \pm 90°$, it may be desirable to set `LONPOLE`*a* explicitly to $\phi_0 + 180°$ rather than let it default to ϕ_0. Such a change in ϕ_p by 180° must be compensated by incrementing α_0 (= α_p) by 180°.
3. In Sect. 2.3, it should be clarified that (ϕ_p, θ_p) and (α_p, δ_p) refer to *different* points; the common "p" subscript simply indicates that they refer to the "pole", but not the same pole. (ϕ_p, θ_p) are the native coordinates of the *celestial pole*, and (α_p, δ_p) are the celestial coordinates of the *native pole*, and generally the native and celestial poles do not coincide.
   On the other hand, (ϕ_0, θ_0) and (α_0, δ_0) do refer to the same, *fiducial*, point, usually the reference point of the projection.
4. In Sect. 2.4, it is stated incorrectly that Eqs. (8), (9), and (10) are derived from Eqs. (6) and (7).

   - Eq. (8) is derived from the second of Eqs. (2).
   - Eq. (9) is derived from the second of Eqs. (6) (or the second of Eqs. (7) which is identical).
   - Eq. (10) is derived from the second of Eqs. (5).

5. In Sect. 2.4, in computing α_p for non-polar (ϕ_0, θ_0), it should be clarified that if $\delta_0 = \pm 90°$ then $\alpha_p = \alpha_0$ regardless of the value of δ_p.
   That is, if $\delta_0 = \pm 90°$ *and* $\delta_p = \pm 90°$, then condition (1) applies, not (2).
6. In Sect. 2.4, in condition (6), if $\delta_0 = \theta_0 = 0$ and $\phi_p - \phi_0 = \pm 90°$, then δ_p is not determined and `LATPOLE`*a* specifies it completely.
   It is stated that "`LATPOLE`*a* has no default value in this case."

This should be interpreted to mean that LATPOLE*a* may legitimately take any value in the range $[-90°, +90°]$ and WCS header writers are obliged to specify it.
However, values of LATPOLE*a* outside this range should be interpreted as usual, i.e. values of LATPOLE*a* greater than $+90°$ denote $\delta_p = +90°$, and values of LATPOLE*a* less than $-90°$ denote $\delta_p = -90°$.
7. In Sect. 3, the term "IAU 1984" used in Table 2, and also later in Sects. 7.3.1, and 7.3.2, and Tables 5, 7, 9, and 10, is not strictly correct as there was no corresponding resolution of the IAU General Assembly in that year. It refers to the IAU 1976 resolution, with the 1980 nutation theory, which came into force in 1984.0.
8. In Sect. 3.1, a variant of the RADESYS*a* keyword, RADECSYS, appeared in early drafts of Paper II and was used in some data. It should be recognized as being equivalent to RADESYS for the primary coordinate description.
9. In Sect. 5.6.3, for the QSC projection, the equation for S following Eq. (178) should have $S = +1$ for $\eta = |\xi|$, hence

$$S = \begin{cases} +1 & \text{if } \xi > |\eta| \text{ or } \eta \geq |\xi| \\ -1 & \text{otherwise} \end{cases} .$$

In computing the inverse, the equation for ξ should be

$$\xi = \pm\sqrt{\frac{1-\zeta^2}{1+\omega^2}}, \qquad (182)$$

where the positive or negative solution is chosen so that ξ has the same sign as $x - \phi_c$. Likewise, the equation for η should be

$$\eta = \pm\sqrt{\frac{1-\zeta^2}{1+\omega^2}}, \qquad (184)$$

where the positive or negative solution is chosen so that η has the same sign as $y - \theta_c$.
10. The recipe given in Sect. 6.1.4 for translating the AIPS GLS projection to SFL is incorrect in that CRVAL*i* for the longitude axis should be applied as is, only CRVAL*i* for the latitude axis needs resetting to zero. CRPIX*j* must then be adjusted accordingly.

3. Corrections for Paper III

Corrections and clarifications for Paper III (Greisen et al. 2006):

1. The magnitude and direction of the LSRD velocity quoted in Table 12 is only approximate. In galactic Cartesian coordinates the velocity vector is $(+9, +12, +7)$ km s^{-1}.
Likewise, the galactic (ℓ, b) coordinates quoted for LSRK are only approximate as is implied by the footnote.
2. The spectral axis increments in the example header of Tables 14 and 15 were computed with a VELOSYS*a* value of the wrong sign. The correct values are

```
CDELT3F =  9.7664755E+04,
CDELT3Z = -2.1886463E+04,
CDELT3W = -1.5408599E-05,
CDELT3R = -2.0613235E+04,
CDELT3V = -2.1221247E+04.
```

Note that to reproduce the spectral axis reference values and increments to the number of decimal digits quoted in the paper, the values of RESTFRQ, CRVAL3, CDELT3, and CRVALZ should be considered given and the remainder, including VELOSYS*a*, derived from them.
To extra precision (unwarranted by science but useful for checking software) the value of VELOSYS*a*, computed from Eq. (14) using the value given for CRVAL3 and derived for CRVAL3F, is

```
VELOSYS = 26.108174E+03.
```

4. Timestamps

The original version of this document was dated 2004/01/23.
Erratum 1.2 was added on 2004/04/27,
and augmented on 2007/03/28.
Erratum 1.3 was added on 2007/12/22.
Erratum 2.7 was added on 2004/08/12.
Erratum 2.8 was added on 2004/06/08.
Erratum 2.9 was added on 2004/06/01.
Erratum 2.10 was added on 2013/09/21.
Erratum 3.1 was added on 2007/03/22.
Erratum 3.2 was added on 2007/03/22.

Acknowledgments. We thank David Berry (U.K. Starlink) for pointing out the significant correction (2.1) for Paper II.

Patrick Wallace (Starlink/HMNAO) pointed out the anomalous reference to IAU 1984 (2.7).

Dan Stahlke (Geophysical Institute, Uni. of Alaska) provided the corrections (2.9) to the QSC equations.

Pierre Hily-Blant (IRAM, Grenoble) pointed out the errors (3.2) in the header keyvalues of Tables 14 and 15 in Paper III.

Paddy Leahy prompted the correction (2.10) to the translation of the AIPS GLS projection.

The Australia Telescope is funded by the Commonwealth of Australia for operation as a National Facility managed by CSIRO.

The National Radio Astronomy Observatory is a facility of the (U.S.) National Science Foundation operated under cooperative agreement by Associated Universities, Inc.

References

Calabretta, M. R., & Greisen, E. W. 2002, A&A, 395, 1077 (Paper II)

Greisen, E. W., & Calabretta, M. R. 2002, A&A, 395, 1059 (Paper I)

Greisen, E. W., Calabretta M. R., Valdes, F. G., & Allen, S. L. 2006, A&A, 446, 747 (Paper III)