(Preprint) AAS 13-520

UTC IN ASTRONOMICAL METADATA STANDARDS

Arnold H. Rots*

There are a number of data and data-format standards in use in the astronomical community that include a high level of specificity regarding the metadata information that they require to describe the astronomical coordinates of the data, including time. For FITS the metadata standards are defined in a series of World Coordinate System (WCS) papers, the latest of which is on Time. Within the Virtual Observatory community there is a Space-Time Coordinate metadata standard which is very similar. This paper presents how UTC is dealt with in these standards. In actual coding implementations the leap second file published by USNO is an essential resource.

INTRODUCTION

The accuracy and rigor with which time information has been recorded in the metadata associated with astronomical observations has generally been determined by two factors: the accuracy of the clock available to the observer and the observer's interest (or lack thereof) in preserving temporal metadata. The former breaks down into a number of sub-factors: the accuracy with which the clock information can be read out, the relative stability of the clock, the knowledge of some universal (global) time scale and how to tie that to the clock, earth rotation information, geographic location, etc. The latter is less well determined and can be hard to assess. Generally, it has depended on the timing accuracy that the observer was personally interested in. That means that astrometrists, ephemeris compilers, and those studying phenomena in the solar system have done fairly well. As far as all others are concerned, minutes, days, months, or even years were often deemed accurate enough. Only when pulsars entered the stage and radio interferometry came into common use, roughly at the same time, did timing accuracy become more important to a larger segment of the community.

One might wonder whether any of this matters. It does. With the increasing prominence of data archives in the research arena, we have seen a dramatic rise in the reuse of observational data. For instance, 60% of the observations in the archive of the Chandra X-ray Observatory have been featured three or more times in refereed journal articles after nine years. What this says is that observational data are at least as, if not more, important to the community in their usage by others than by the original observer. And that leads us to consider that, although the original observer might know very well what metadata are needed to what accuracy for his or her own purposes (as laid out in the original observing proposal), that person should not presume to know what will be required by future users of those data. The moral of the story is: collect and preserve as much

* Archive astrophysicist, Chandra X-ray Center, Smithsonian Astrophysical Observatory, 60 Garden Street – MS 67, Cambridge, MA 02138, USA

metadata as you can and as accurately as you can. That, in turn, leads us to the bottom line: this can only happen when there are good metadata standards.

STANDARDS

To get a complete record, we need to collect the following time metadata for an observation:

- The actual time stamp (clock reading)
- The time scale of the time stamp
- The location (or, ideally, the state vector) of the observer
- The direction in which the observation was made (i.e., its celestial coordinates)
- The fiducial location (e.g., barycenter) to which the time stamp has been reduced (by path-length compensation) — if applicable
- The time resolution
- The relative time error (short-term stability of the clock)
- The absolute time error

One should note that there are a fair number of items in this list that contain information on spatial coordinates. This is not accidental. One cannot accurately fix an event's temporal location without information about its spatial location; the reverse is also true.

These metadata requirements need to be formalized as part of a (meta)data standard. I will highlight two such broad-based standards: FITS and the IVOA.

FITS

The Flexible Image Transport System (FITS)[1] is an astronomical file format standard controlled by the International Astronomical Union (IAU). Its origins go back to the mid-1970s when it was designed as a file format standard that allowed astronomers to transport digital images from one computer to another, from one observatory to another. Fairly soon it started to be used as an archival file format, too. At that point its major shortcoming regarding metadata became apparent: although FITS carefully defines the syntax of its metadata, it does not define their semantics. That was especially serious where it concerned the coordinate metadata. Subsequently, work started on a series of World Coordinate System (WCS) definition papers. At this point three have been adopted: spatial coordinates,[2] projections,[3] and spectral and Doppler velocity coordinates.[4] A fourth one, on time,[5] is close to completion. My co-authors are Peter Bunclark (regrettably now deceased), Mark Calabretta, Steve Allen, Dick Manchester, and Bill Thompson.

This standard *in statu nascendi* allows time in all common time scales: TT (and ET), TAI, GPS, TDB, TCG, TCB, UTC (and GMT), UT1. It recognizes a number of standard locations: observer, geocenter, barycenter, heliocenter, planets, earth-moon barycenter. Time stamps are allowed to be expressed in (limited) ISO-8601, JD, MJD, or elapsed time since a reference time. It allows several units and incorporates limited expressions of duration. It also attempts to restore some order in the way authors present time information—sometimes without any indication of time scale and/or reference location, sometimes with self-invented cute time scales such as TJD or BJD.

There are three expressions of time stamps that are problematic:

- The use of Besselian epochs; although we give what we consider to be the most accurate conversion between Besselian and Julian epochs, we have to warn that there is no guarantee that authors using Besselian epochs actually used these values—most likely they did not. On the other hand, it seems unlikely that this level of uncertainty will be significant in comparison with the inherent uncertainty of time stamps expressed as Besselian epochs.
- The same is true for those who used the tropical year as a unit of time.
- The use of fractional (Modified) Julian Days in conjunction with UTC on days that include a leap second: don't do it.

As a note: although data authors may choose (in principle) any time scale they like for any of the recorded times, there is one exception: the metadata item that records the creation date and time of the file needs to be given in UTC.

Use of UTC, with or without leap seconds, does not pose a problem. Generally, one would apply the USNO leap second file.[6] When elapsed time since a UTC reference time stamp is used, the elapsed time is simply counted in elapsed SI seconds, including any leap seconds.

IVOA

The International Virtual Observatory Alliance was founded in order to foster interoperability in standards and infrastructure between data providers, in order to be able to present to the community, and indeed to the entire world, a one-stop-shopping experience to astronomical archives. We are not there by a long shot, but we have made a decent start with, among other things, several agreed-upon standards, including one of Space-Time Coordinate metadata (STC).[7] The underlying principle is what was noted above: spatial and temporal coordinates are intertwined and their metadata should be presented together. Temporal metadata are defined similarly to those in FITS (which is not surprising, considering that the lead author is the same), but the list of allowable spatial reference systems is longer and a reference location (from which the observation is made) is required, thus making observational data usable to those interested in the far field as well as the near field. It goes without saying that UTC is supported.

CONCLUSION

Astronomical metadata standards have no problem supporting UTC, with or without leap seconds, along with many other time scales. However, abolishing leap seconds will not remove the need for being able to deal with them, since we need to retain the ability to handle archival data. Code that handles the various time conversions often relies on the leap second file maintained by the US Naval Observatory. It is a low maintenance issue that only requires downloading a new version every six months (or monitoring changes and only making updates when necessary) and it is perfectly transparent.[*] Since there are several time scales that do not have leap seconds (that are "continuous", in the definition of some), it seems perfectly superfluous to make UTC join their ranks. Among the obvious candidates to be distributed as a "continuous" time scale (TT, TAI, GPS), TAI, with or without appropriate qualifier, is probably the most likely to gain acceptance. It would clearly be sensible to include TAI−UTC and UTC−UT1 in the distribution.

[*] Although a more modern communication format would be appreciated.

Allow me to make one more observation. There are two concepts of time: earth rotation (i.e., the measurement of an angle) and the counting of seconds. The former is represented among the time scales by UT1. All others, with the exception of UTC, are pure SI second counters. The unique position of UTC as the bridge between the two concepts of time scales would be lost if it were to be stripped of its leap seconds. UTC would be just another second-counting time scale and there would be none left that bridge the two types of time scales.

REFERENCES

[1] Pence, W.D., L. Chiappetti, C.G. Page, R.A. Shaw, E. Stobie (2010), "Definition of the Flexible Image Transport System (FITS), version 3.0." *Astronomy & Astrophysics*, Vol. 524, A42. (URL http://dx.doi.org/10.1051/0004-6361/201015362)

[2] Greisen, E.W., M.R. Calabretta, (2002), "Representations of World Coordinates in FITS." *Astronomy & Astrophysics*, Vol. 395, No. 3, pp. 1061-75. (URL http://dx.doi.org/10.1051/0004-6361:20021326)

[3] Greisen, E.W., M.R. Calabretta, (2002), "Representations of Celestial Coordinates in FITS." *Astronomy & Astrophysics*, Vol. 395, No. 3, pp. 1077-1022. (URL http://dx.doi.org/10.1051/0004-6361:20021327)

[4] Greisen, E.W., M.R. Calabretta, F.G. Valdes, S.L. Allen (2006), "Representations of Spectral Coordinates in FITS." *Astronomy & Astrophysics*, Vol. 447, No. 2, pp. 1077-1022. (URL http://dx.doi.org/10.1051/0004-6361:20053818)

[5] Rots, A.H., P.S. Bunclark, M.R. Calabretta, S.L. Allen, R.N. Manchester, W.T. Thompson (2013), "Representations of Time Coordinates in FITS." *Astronomy & Astrophysics* Manuscript No. WCSPaperV0.982, June 5, 2013. (URL http://hea-www.cfa.harvard.edu/~arots/TimeWCS/)

[6] USNO Leap Second File (URL http://maia.usno.navy.mil/ser7/tai-utc.dat)

[7] Rots, A.H. (2007), "Space-Time Coordinate Metadata for the Virtual Observatory (STC)." *International Virtual Observatory Alliance* Technical Specification. (URL http://www.ivoa.net/documents/latest/STC.html)