NUMERICAL STANDARDS IN THE ASTRONOMICAL ALMANAC

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ABSTRACT. *The Astronomical Almanac* (AsA), a joint publication of Her Majesty's Nautical Almanac Office (HMNAO) and the Nautical Almanac Office of the U.S. Naval Observatory (USNAO), is a worldwide reference standard for astronomy. As such, the offices strive to adhere to the standards set forth by the larger astronomical community. However, sometimes the astronomical community is not clear as to what standards should be followed. There are standards that are promulgated formally, such as via IAU resolutions, some are informal but generally recognized as customary and common practice, while others seem to be adopted only within a particular field. This paper looks at various ephemerides, constants, parameters and models used in the AsA and the decision-making process that determines how they are selected for inclusion in the book.

1. THE MAIN STANDARDS FOR *THE ASTRONOMICAL ALMANAC*

The standards to which the AsA adheres may be divided into four areas. These are formal standards, informal but widely recognized standards, informally recognized practices and lastly the requirement to be consistent. Clearly, there should not be competing formal standards.

Our aim is to always follow formal standards. These are set down by the International Astronomical Union (IAU) via its resolutions and working groups (WG) and the *Technical Notes* of the International Earth Rotation and Reference Systems Service (IERS). The International Association of Geodesy (IAG) also provide various formal standards which are relevant to astronomy (e.g., the radius of the Earth).

Examples of pertinent IAU resolutions are those on the use of the International Celestial Reference System (ICRS) and ICRS-based catalogues and ephemerides, time scales, and precession-nutation. In recent years there have been WGs that have reported on "nomenclature" and "precession and the ecliptic". This work and the resulting resolutions all feed into the almanac. There is also the IAU-SOFA software which provides definitive algorithms for many of these models. Then there are examples like photometric standards and the rotational elements for the planets. The latter come from the IAU inter division WG on Cartographic and Coordinates and Rotational Elements.

There are many data sources and computational techniques that are not formalized within resolutions, but are world-recognized; most have been documented in refereed journals. Choosing between competing standards is done via numerical comparisons, usability, origin, and wider astronomical community acceptance. For example there is no IAU resolution that prescribes which planetary ephemeris to use. We have been using the Jet Propulsion Laboratory's (JPL) ephemeris since the 1984 edition (DE200/LE200). This was updated, for the 2003 AsA prepared in 2001, to JPL's DE405/LE405 ephemeris. This not only provided improvement in planetary positions but was also referred to the ICRS. Other recognized standards relate to satellite orbital parameters and magnitude coefficients. Similarly, rise and set times are only given to the nearest minute of time and the standard amount of refraction at the horizon is $34'$.

The requirements of astronomers, our customers, also matter. Often there are similar data sources and computational methods that have scientific justification. Other times new, formally recognized techniques have not been fully accepted by users. Selection of which to use and maintain is made by customary practices within HMNAO and USNAO, or a clearly-defined user need to maintain past data sets.

An example where the user community have specific requirements, which maintains links with the past, is for the solar physical ephemeris. Here Carrington's elements and reference system is still the reference system of choice. On the other hand, currently, the almanac is still publishing apparent places, i.e. right ascension and declination with respect to the true equator and equinox of date. This is despite the fact that the IAU has recommended that right ascension should be measured from the celestial intermediate origin (CIO).

Within all these standards and practices it is necessary to try to be consistent. An example of inconsistency occurs in eclipse calculations, where old constants and IAU values are still being used as they are the required standard. On the other hand, with the requirements of more accurate positions and need to include relativity, it is becoming clear that constants must be scaled so that their units are consistent within the system that is being used.

The following table contains a selection of some of the standards that the AsA follows. A full list, valid for the 2009 edition of the AsA may be found on HMNAO's website at http://www.hmnao.com.

Quantity		**Reference, Comment**
Reference systems: ICRS	IAU 1997	Resolution B2, T*rans. IAU*, **XXIIIB**.
BCRS, GCRS	IAU 2000	Resolutions B1.3 and B1.4, respectively, *Trans. IAU*, **XXIVB**.
Time scales: TAI	IAU 1967	Adopted 1971.
TT	IAU 2000	Resolution B1.9, TT = TAI + $32^{\mathrm{s}}184$·
TDB	IAU 2006	Resolution B3.
Standard epoch; century; day; secs	IAU 1976	J2000·0 , JD2451545·0 TT, 2000 Jan 1 12^{h} TT, Julian cy= 36525^{d}, day of 86400^{s}.
Software		USNO/HMNAO, NOVAS v3, IAU-SOFA library.
Vector/Matrix approach	IAU 1976	
Positions		Apparent (not intermediate) places tabulated at 0^{h} TT.
		Minor planets and Pluto astrometric positions tabulated at 0^{h} TT.
Stars space motion		No light time included; NOVAS v3 includes simple light time formulation.
		IAU-SOFA uses Stumpff, P., A&A **144**, 232-240, 1985.
Transit times		Transit over the ephemeris meridian.
Magnitudes: Mercury & Venus		Hilton, J.L., AJ, **129**, 2902, 2005, AJ, **130**, 2928, 2005.
Mars - Pluto		Harris, D.L., *Planets & Satellites*, eds. Kuiper, G.P.& Middlehurst, B.L., **272**, 1961.
Planetary & lunar ephemerides		JPL DE405/LE405 ephemerides Standish, E.M., JPL IOM 312.F-98-048, 1998.
T_{eph}		Standish, E.M., A&A, **336**, 381-384.
Light time, unit distance		$\tau_A = 499{\cdot}004783806 1\,\mathrm{ms}^{-1}$, $c\tau_A = 14959787069 1\,\mathrm{m}$.
Categorizing Pluto	IAU 2006	Resolutions 5 & 6; Pluto is a dwarf planet.
Minor planet ephemerides	USNO	AE98, AJ, **117**, 1077, 1999. Also USNO ephemeris AE2001.
ICRS star catalogues	ESA, USNO	Hipparcos, Tycho-2, UCAC2, USNO-B; many other object catalogues are used.
Physical ephemerides, ...	IAU 2006	WG Cartographic Coordinates & Rotational Elements, Report 10,
Sun, Planets and Pluto;		Seidelmann, P.K., et al., *Celest. Mech.*, **98**, 155-180, 2007.
and for Sun	1863	Based on Carrington, R.C., *Observations of the Spots of the Sun* and updated by
	1992	Seidelmann P.K., et al., *Explanatory Supplement to the AsA*, p 397.
Lunar librations	Eckhardt	*The Moon and the Planets*, **25**, 3, 1981; High Precision Earth Rotation &
(but using IAU inclination)	1982	Earth-Moon Dynamics , ed. Calame, O., 193-198, 1982.
Earth rotation angle / UT1	IAU 2000	Resolution B1.8, Trans. IAU, **XXIVB**.
GMST / UT1	IAU 2006	Capitaine, N., Wallace, P.T., and Chapront, J., A&A, **432**, 355-367, 2005.
Equation of Origins	IAU 2006	IAU WG on Nomenclature, Trans IAU, **XXVIB**.
Precession; variety of angles;	IAU 2006	Resolution B1, *Celest. Mech.*, **94**, 351-367, 2006,
ϵ_{A}, ψ_{J}, ϕ_{J}, γ_{J} χ_{A}, ω_{A}, ψ_{A}, ϵ_0		P03: Capitaine, N., Wallace, P.T., & Chapront, J., A&A, **412**, 567-586, 2003, and
z_{A}, θ_{A}, ζ_{A}		Wallace, P.T., and Capitaine, N., A&A, **459**, 981-985, 2006.
Nutation $\Delta\psi$, $\Delta\epsilon$	IAU 2000A	Resolution B1.6, Trans. IAU, **XXIVB**. Implementations:
		IERS Conventions 2003, *Technical Note 32*, eds. McCarthy, D.D. & Petit, G.,
		USNO Circular 179, Kaplan, G., and IAU-SOFA routine NUT00A.
adjustments at the μas level	IAU 2006	Resolution B1: due to IAU 2006 precession, included by IAU-SOFA in NUT06A.
CIP & CIO Locator; X, Y, & s	IAU 2006	Resolution B1 & B2. Capitaine, N., & Wallace, P.T., A&A, **450**, 855-872, 2006.
Eclipses	IAU 1982	$k = 0{\cdot}2725076$, Moon's apparent SD= $\sin^{-1}(k \sin \pi)$,
k also used for occultations	1963	consistent with Watts datum APAE, XVII, 1963. Lunar radius = $1737{\cdot}97\,\mathrm{km}$.
	IAU 1976	Sun's SD at 1 au $15'59''\!.64$.
Rise/Set phenomena	IAU	Nearest minute of time. Upper limb on the horizon with $34'$ of refraction.
Phases of Moon, Lunation		Brown, E. W., MNRAS, **93**, 603, 1933. No. 1 - 1923 January 16.

Figure 1: Some of the main standards for *The Astronomical Almanac*