A Recommendations on terminology by the 2003-2006 IAU NFA Working Group (August 2006)

The final recommendations on terminology associated with the IAU 2000/2006 resolutions of the IAU Working Group on "Nomenclature for fundamental astronomy" (NFA) are the following (see Capitaine *et al.*, 2007):

1. *Using existing terms (e.g. right ascension) in extended ways for the terminology associated with the new paradigm with a clear specification, rather than introducing new names.*

2. *Using "equinox based" and "CIO based" for referring to the classical and new paradigms, respectively.*

Comment: the "Celestial/Terrestrial Intermediate Origin" with the acronym CIO/TIO is proposed here as the updated terminology to replace the IAU 2000 "Celestial/Terrestrial Ephemeris Origin" with the acronym CEO/TEO (see below items 3 and 4 and the proposed resolution).

3. *Using "intermediate" to describe (i) the moving geocentric celestial reference system defined in the IAU 2000 resolutions (i.e. containing the CIP and the CIO), and (ii) the moving terrestrial reference system containing the CIP and the TIO.*

Comment the term "intermediate" has been chosen to specify that these systems are intermediary systems between the geocentric celestial reference system and the terrestrial reference system, which are realized by using the models, constants and procedures that are conventionally accepted; it conventionally separates the instantaneous celestial orientation of the Earth into components we label polar motion (in the terrestrial reference system) and precession-nutation (in the celestial reference system).

4. *Harmonizing the name of the pole and the origin to "intermediate" and therefore changing CEO/TEO to CIO/TIO.*

5. *Using "system" in a broad sense rather than "frame" in this context of the intermediary system/frame.*

6. *Using special designations for particular realizations of the intermediate celestial reference system.*

Comment: this applies for example to "the IAU 2000A system" to designate the system which is realized by transforming the geocentric celestial reference system GCRS to the intermediate system using the IAU 2000A precession-nutation and associated frame biases at J2000.0 (the GCRS being transformed from the BCRS by using the coordinate transformation specified in the IAU 2000 Resolution B1.3).

7. *Keeping the classical terminology for "true equator and equinox" (or "true equinox based") for the classical equatorial system.*

8. *Choosing "equinox right ascension" (or "RA with respect to the equinox") and "intermediate right ascension" (or "CIO right ascension", or "RA with respect to the CIO"), for the azimuthal coordinate along the equator in the classical and new paradigms, respectively.* (Note that right ascensions and declinations with respect to the ICRS are usually designated by α_{ICRS}, δ_{ICRS}).

Comment: this is to be specified only once in the presentation of a paper if there is some risk of misunderstanding. Afterwards, "right ascension" alone is sufficient.

9. *Giving the name "equation of the origins" to the distance between the CIO and the equinox along the intermediate equator, the sign of this quantity being such that it represents the CIO right ascension of the equinox, or equivalently, the difference between the Earth Rotation Angle and Greenwich apparent sidereal time.*

10. *Retaining "apparent places" and "mean places" in the equinox based system.*

11. *Not introducing "apparent intermediate places" in the CIO based system, but introducing instead "intermediate places".*

12. *Using "ITRF zero-meridian" to designate the plane passing through the geocenter, ITRF pole and ITRF x-origin and using, if necessary, "TIO meridian" to designate the moving plane passing through the geocenter, the CIP and the TIO.*

13. *Fixing the default orientation of the BCRS so that for all practical applications, unless otherwise stated, the BCRS is assumed to be oriented according to the ICRS axes.*

Comment: Once the BCRS is spatially oriented according to the ICRS, the spatial GCRS coordinates get an "ICRS-induced" orientation.

14. *Re-defining Barycentric Dynamical Time (TDB) as a fixed linear function of TCB*:

$$\mathrm{TDB} = \mathrm{TCB} - \mathrm{L_B} \times (\mathrm{JD_{TCB}} - \mathrm{T_0}) \times 86400 + \mathrm{TDB_0},$$

where $\mathrm{T_0} = 2443144.5003725$,

and $\mathrm{L_B} = 1.550519768 \times 10^{-8}$ and $\mathrm{TDB_0} = -6.55 \times 10^{-5}$ s are defining constants.

Additional points

- *Considering a terminology associated with other types of apparent places, although it may be required for specific use, has not been considered as being essential for common astronomical use and is therefore not part of the NFA WG terminology recommendations.*

- *No WG consensus having been reached for having strict rules for using or not using capitals for names for origins, poles and systems, no recommendation on this issue is proposed by the WG. The policy adopted throughout the NFA document is to capitalize those terms that are defined in IAU or IUGG resolutions.*

B IAU Resolutions Adopted at the XXVIth General Assembly (2006)

B.1 IAU 2006 Resolution B1 on Adoption of the P03 Precession Theory and Definition of the Ecliptic

The XXVIth International Astronomical Union General Assembly,
Noting

1. the need for a precession theory consistent with dynamical theory,
2. that, while the precession portion of the IAU 2000A precession-nutation model, recom-mended for use beginning on 1 January 2003 by resolution B1.6 of the XXIVth IAU General Assembly, is based on improved precession rates with respect to the IAU 1976 precession, it is not consistent with dynamical theory, and
3. that resolution B1.6 of the XXIVth General Assembly also encourages the development of new expressions for precession consistent with the IAU 2000A precession-nutation model, and

Recognizing

1. that the gravitational attraction of the planets make a significant contribution to the motion of the Earths equator, making the terms lunisolar precession and planetary precession misleading,
2. the need for a definition of the ecliptic for both astronomical and civil purposes, and
3. that in the past, the ecliptic has been defined both with respect to an observer situated in inertial space (inertial definition) and an observer comoving with the ecliptic (rotating definition),

Accepts

the conclusions of the IAU Division I Working Group on Precession and the Ecliptic published in Hilton et al. (2006, Celest. Mech. 94, 351), and

Recommends

1. that the terms lunisolar precession and planetary precession be replaced by precession of the equator and precession of the ecliptic, respectively,
2. that, beginning on 1 January 2009, the precession component of the IAU 2000A precession-nutation model be replaced by the P03 precession theory, of Capitaine et al. (2003, A&A, 412, 567-586) for the precession of the equator (Eqs. 37) and the precession of the ecliptic (Eqs. 38); the same paper provides the polynomial developments for the P03 primary angles and a number of derived quantities for use in both the equinox based and CIO based paradigms,
3. that the choice of precession parameters be left to the user, and
4. that the ecliptic pole should be explicitly defined by the mean orbital angular momentum vector of the Earth-Moon barycenter in the Barycentric Celestial Reference System (BCRS), and this definition should be explicitly stated to avoid confusion with other, older definitions.

Notes

1. Formulas for constructing the precession matrix using various parameterizations are given in Eqs. 1, 6, 7, 11, 12 and 22 of Hilton et al. (2006). The recommended polynomial developments for the various parameters are given in Table 1 of the same paper, including the P03 expressions set out in expressions (37) to (41) of Capitaine et al. (2003) and Tables 3-5 of Capitaine et al. (2005).
2. The time rate of change in the dynamical form factor in P03 is $dJ_2/dt = -0.3001 \times 10^{-9} century^{-1}$.

B.2 IAU 2006 Resolution B2 on the Supplement to the IAU 2000 Resolutions on reference systems

Recommendation 1. Harmonizing the name of the pole and origin to "intermediate"
The XXVIth International Astronomical Union General Assembly,
Noting

1. the adoption of resolutions IAU B1.1 through B1.9 by the IAU General Assembly of 2000,

2. that the International Earth Rotation and Reference Systems Service (IERS) and the Standards Of Fundamental Astronomy (SOFA) activity have made available the models, procedures, data and software to implement these resolutions operationally, and that the Almanac Offices have begun to implement them beginning with their 2006 editions, and
3. the recommendations of the IAU Working Group on "Nomenclature for Fundamental Astronomy" (IAU Transactions XXVIA, 2005), and

Recognizing

1. that using the designation "intermediate" to refer to both the pole and the origin of the new systems linked to the Celestial Intermediate Pole and the Celestial or Terrestrial Ephemeris origins, defined in Resolutions B1.7 and B1.8, respectively would improve the consistency of the nomenclature, and
2. that the name "Conventional International Origin" with the potentially conflicting acronym CIO is no longer commonly used to refer to the reference pole for measuring polar motion as it was in the past by the International Latitude Service,

Recommends

1. that, the designation "intermediate" be used to describe the moving celestial and terrestrial reference systems defined in the 2000 IAU Resolutions and the various related entities, and
2. that the terminology "Celestial Intermediate Origin" (CIO) and "Terrestrial Intermediate Origin" (Terrestrial Intermediate Origin) be used in place of the previously introduced "Celestial Ephemeris Origin" (Celestial Ephemeris Origin) and "Terrestrial Ephemeris Origin" (Terrestrial Ephemeris Origin), and
3. that authors carefully define acronyms used to designate entities of astronomical reference systems to avoid possible confusion.

Recommendation 2. Default orientation of the Barycentric Celestial Reference System (BCRS) and Geocentric Celestial Reference System (GCRS)
The XXVIth International Astronomical Union General Assembly,

Noting

1. the adoption of resolutions IAU B1.1 through B1.9 by the IAU General Assembly of 2000,
2. that the International Earth Rotation and Reference Systems Service (IERS) and the Standards Of Fundamental Astronomy (SOFA) activity have made available the models, procedures, data and software to implement these resolutions operationally, and that the Almanac Offices have begun to implement them beginning with their 2006 editions,
3. that, in particular, the systems of space-time coordinates defined by IAU 2000 Resolution B1.3 for (a) the solar system (called the Barycentric Celestial Reference System, BCRS) and (b) the Earth (called the Geocentric Celestial Reference System, GCRS) have begun to come into use,
4. the recommendations of the IAU Working Group on "Nomenclature for Fundamental Astronomy" (IAU Transactions XXVIA, 2005), and
5. a recommendation from the IAU Working Group on "Relativity in Celestial Mechanics, Astrometry and Metrology",

Recognizing

1. that the BCRS definition does not determine the orientation of the spatial coordinates,
2. that the natural choice of orientation for typical applications is that of the ICRS, and
3. that the GCRS is defined such that its spatial coordinates are kinematically non-rotating with respect to those of the BCRS,

Recommends

that the BCRS definition is completed with the following: "For all practical applications, unless otherwise stated, the BCRS is assumed to be oriented according to the ICRS axes. The orientation of the GCRS is derived from the ICRS-oriented BCRS."

B.3 IAU 2006 Resolution B3 on the Re-definition of Barycentric Dynamical Time, TDB

The XXVIth International Astronomical Union General Assembly,
Noting

1. that IAU Recommendation 5 of Commissions 4, 8 and 31 (1976) introduced, as a replacement for Ephemeris Time (ET), a family of dynamical time scales for barycentric ephemerides and a unique time scale for apparent geocentric ephemerides,
2. that IAU Resolution 5 of Commissions 4, 19 and 31 (1979) designated these time scales as Barycentric Dynamical Time (TDB) and Terrestrial Dynamical Time (TDT) respectively, the latter subsequently renamed Terrestrial Time (TT), in IAU Resolution A4, 1991,
3. that the difference between TDB and TDT was stipulated to comprise only periodic terms, and
4. that Recommendations III and V of IAU Resolution A4 (1991) (i) introduced the coordinate time scale Barycentric Coordinate Time (TCB) to supersede TDB, (ii) recognized that TDB was a linear transformation of TCB, and (iii) acknowledged that, where discontinuity with previous work was deemed to be undesirable, TDB could be used, and

Recognizing

1. that TCB is the coordinate time scale for use in the Barycentric Celestial Reference System,
2. the possibility of multiple realizations of TDB as defined currently,
3. the practical utility of an unambiguously defined coordinate time scale that has a linear relationship with TCB chosen so that at the geocenter the difference between this coordinate time scale and Terrestrial Time (TT) remains small for an extended time span,
4. the desirability for consistency with the Teph time scales used in the Jet Propulsion Laboratory (JPL) solar-system ephemerides and existing TDB implementations such as that of Fairhead & Bretagnon (*A&A* **229**, 240, 1990), and
5. the 2006 recommendations of the IAU Working Group on "Nomenclature for Fundamental Astronomy" (IAU Transactions XXVIB, 2006),

Recommends

that, in situations calling for the use of a coordinate time scale that is linearly related to Barycentric Coordinate Time (TCB) and, at the geocenter, remains close to Terrestrial Time (TT) for an extended time span, TDB be defined as the following linear transformation of TCB:
$TDB = TCB - L_B \times (JD_{TCB} - T_0) \times 86400 + TDB_0$, where $T_0 = 2443144.5003725$,
and $L_B = 1.550519768 \times 10^{-8}$ and $TDB_0 = -6.55 \times 10^{-5}$ s are defining constants.

Notes

1. JD_{TCB} is the TCB Julian date. Its value is $T_0 = 2443144.5003725$ for the event 1977 January 1 00h 00m 00s TAI at the geocenter, and it increases by one for each 86400 s of TCB.
2. The fixed value that this definition assigns to L_B is a current estimate of $L_C + L_G - L_C \times L_G$, where L_G is given in IAU Resolution B1.9 (2000) and L_C has been determined (Irwin & Fukushima, 1999, *A&A* **348**, 642) using the JPL ephemeris DE405. When using the JPL Planetary Ephemeris DE405, the defining L_B value effectively eliminates a linear drift between TDB and TT, evaluated at the geocenter. When realizing TCB using other ephemerides, the difference between TDB and TT, evaluated at the geocenter, may include some linear drift, not expected to exceed 1 ns per year.
3. The difference between TDB and TT, evaluated at the surface of the Earth, remains under 2 ms for several millennia around the present epoch.
4. The independent time argument of the JPL ephemeris DE405, which is called Teph (Standish, *A&A*, **336**, 381, 1998), is for practical purposes the same as TDB defined in this Resolution.
5. The constant term TDB_0 is chosen to provide reasonable consistency with the widely used $TDB - TT$ formula of Fairhead & Bretagnon (1990). n.b. The presence of TDB_0 means that TDB is not synchronized with TT, TCG and TCB at 1977 Jan 1.0 TAI at the geocenter.
6. For solar system ephemerides development the use of TCB is encouraged.

C IUGG Resolution 2 Adopted at the XXIVth General Assembly (2007)

Resolution 2: Geocentric and International Terrestrial Reference Systems (GTRS and ITRS)

The International Union of Geodesy and Geophysics

Considering

the increasing importance of geodetic reference systems in geosciences, and more generally in numerous scientific or technical activities, such as satellite navigation systems or geo-information,

Noting

the IUGG Resolution 2 and IAG Resolution 1, both adopted in 1991 at the Vienna General Assembly, defining the Conventional Terrestrial Reference System (CTRS)

Recognizing

the quality of the work done by several IAG services (IERS, IGS, ILRS, IVS, IDS,...) to actually realize these systems and provide regular access for numerous users within and beyond the geoscience community,

Endorses

1. the definition of a Geocentric Terrestrial Reference System (GTRS) as system of geocentric space-time coordinates within the framework of General Relativity, co-rotating with the Earth and related to Geocentric Celestial Reference System by a spatial rotation which takes into account the Earth orientation parameters, in agreement with the 2000 IAU resolution B1.3,
2. the definition of the International Terrestrial Reference System (ITRS) as the specific GTRS for which the orientation is operationally maintained in continuity with past international agreements (so-called BIH orientation), and

Adopts

the ITRS as preferred system for any scientific application, and

Urges

other communities such as geo-information, or navigation to do the same.

D IAU Resolutions Adopted at the XXVIIth General Assembly (2009)

D.1 IAU 2009 Resolution B2 on IAU 2009 astronomical constants

The XXVII General Assembly of International Astronomical Union,
Considering

1. the need for a self-consistent set of accurate numerical standards for use in astronomy,
2. that improved values of astronomical constants have been derived from recent observations and published in refereed journals, and
3. that conventional values have been adopted by IAU GA 2000 and IAU GA 2006 resolutions for a number of astronomical quantities,

Recognizing

1. the continuing need for a set of Current Best Estimates (CBEs) of astronomical constants, and
2. the need for an operational service to the astronomical community to maintain the CBEs

Recommends

1. that the list of previously published constants compiled in the report of the Working Group on Numerical Standards of Fundamental Astronomy (see http://maia.usno.navy.mil/NSFA/CBE.html) be adopted as the IAU (2009) System of Astronomical Constants.
2. that Current Best Estimates of Astronomical Constants be permanently maintained as an electronic document,
3. that, in order to ensure the integrity of the CBEs, IAU Division I develop a formal procedure to adopt new values and archive older versions of the CBEs, and
4. that the IAU establish within IAU Division I a permanent body to maintain the CBEs for fundamental astronomy.

D.2 IAU 2009 Resolution B3 on the Second Realization of the International Celestial Reference Frame

The XXVII General Assembly of International Astronomical Union,
noting

1. that Resolution B2 of the XXIII General Assembly (1997) resolved "That, as from 1 January 1998, the IAU celestial reference system shall be the International Celestial Reference System (ICRS)",
2. that Resolution B2 of the XXIII General Assembly (1997) resolved that the "fundamental reference frame shall be the International Celestial Reference Frame (ICRF) constructed by the IAU Working Group on Reference Frames",
3. that Resolution B2 of the XXIII General Assembly (1997) resolved that the "That IERS should take appropriate measures, in conjunction with the IAU Working Group on reference frames, to maintain the ICRF and its ties to the reference frames at other wavelengths",
4. that Resolution B7 of the XXIII General Assembly (1997) recommended "high-precision astronomical observing programs be organized in such a way that astronomical reference systems can be maintained at the highest possible accuracy for both northern and southern hemispheres",
5. that Resolution B1.1 of the XIV General Assembly (2000) recognized "the importance of continuing operational observations made with Very Long Baseline (VLBI) to maintain the ICRF",

Recognizing

1. that since the establishment of the ICRF, continued VLBI observations of ICRF sources have more than tripled the number of source observations,
2. that since the establishment of the iCRF, continued VLBI observations of extragalactic sources have significantly increased the number of sources whose positions are known with a high degree of accuracy,
3. that since the establishment of the ICRF, improved instrumentation, observation strategies, and application of state-of-the-art astrophysical and geophysical models have significantly improved both the data quality and analysis of the entire relevant astrometric and geodetic VLBI data set,

4. that a working group on the ICRF formed by the International Earth Rotation and Reference Systems Service (IERS) and the International VLBI Service for Geodesy and Astrometry (IVS), in conjunction with the IAU Division I Working Group on the Second Realization of the International Celestial Reference Frame has finalized a prospective second realization of the ICRF in a coordinate frame aligned to that of the ICRF to within the tolerance of the errors in the latter (see note 1),
5. that the prospective second realization of the ICRF as presented by the IAU Working Group on the Second Realization of the International Celestial Reference Frame represents a significant improvement in terms of source selection, coordinate accuracy, and total number of sources, and thus represents a significant improvement in the fundamental reference frame realization of the ICRS beyond the ICRF adopted by the XXIII General Assembly (1997),

Resolves

1. that from 01 January 2010 the fundamental astrometric realization of the International Celestial Reference System (ICRS) shall be the Second Realization of the International Celestial Reference Frame (ICRF2) as constructed by the IERS/IVS working group on the ICRF in conjunction with the IAU Division I Working Group on the Second Realization of the International Celestial Reference Frame (see note 1),
2. that the organizations responsible for astrometric and geodetic VLBI observing programs (e.g. IERS, IVS) take appropriate measures to continue existing and develop improved VLBI observing and analysis programs to both maintain and improve ICRF2,
3. that the IERS, together with other relevant organizations continue efforts to improve and densify high accuracy reference frames defined at other wavelengths and continue to improve ties between these reference frames and ICRF2.

Note 1: The Second Realization of the International Celestial Reference Frame by Very Long Baseline Interferometry, Presented on behalf of the IERS / IVS Working Group, Alan Fey and David Gordon (eds.). (IERS Technical Note ; 35) Frankfurt am Main: Verlag des Bundesamts für Kartographie und Geodäsie, 2009. See www.iers.org/MainDisp.csl?pid=46-25772[1] or hpiers.obspm.fr/icrs-pc/.

[1]New URL www.iers.org/TN35