IAU Division I Working Group "Nomenclature for Fundamental Astronomy" (NFA)

NFA WG EXPLANATORY DOCUMENT

B) EXPLANATION OF THE PROPOSED TERMINOLOGY

23 December 2005

The purpose of this document is to facilitate the understanding of the IAU 2000 resolutions and their implementation. It includes 1) the NFA IAU 2000 Glossary, 2) a table containing the categorized list of terms, 3) a chart of the transformation process and 4) two tables, one containing an alphabetic list of abbreviations and acronyms, and the other table containing a list of symbols.

The NFA IAU 2000 Glossary provides a set of detailed definitions that best explain all the terms required for implementing the IAU 2000 resolutions. It includes a few newly proposed terms, and terms that have some impact on the definitions, as well as some more general definitions.

Note: 1) some of the definitions prior to the IAU 2000 resolutions may not be compliant with relativity, 2) although the following definitions are provided with capitals this does not mean that they must be used with capitals. The policy adopted throughout this document is to capitalize those terms that are defined in IAU or IUGG resolutions. This includes the words that are represented by the abbreviations ICRS, ICRF, HCRF, ITRS, ITRF, BCRS, GCRS, CIP, CIO, TIO, ERA, CIRS, TIRS, TAI, TCB, TCG, TDB, TDT and TT.

The Working Group has had detailed discussions on the following definitions:

Barycentric Celestial Reference System (BCRS)
Barycentric Dynamical Time (TDB)
Barycentric Ephemeris Time (T_{eph})
Celestial Intermediate Origin (CIO)
Celestial Intermediate Reference System (CIRS)
CIO locator
CIO right ascension and declination
epoch
equation of the origin (EO)
equinox right ascension
Geocentric Celestial Reference System (GCRS)
Geocentric Terrestrial Reference System (GTRS)
ICRS place
intermediate equator
intermediate place
intermediate right ascension and declination
International Celestial Reference Frame (ICRF)
International Celestial Reference System (ICRS)
International Terrestrial Reference Frame (ITRF)
International Terrestrial Reference System (ITRS)
Julian century
Julian date
Julian year
right ascension
Terrestrial Intermediate Origin (TIO)
Terrestrial Intermediate Reference System (TIRS)
Terrestrial Time (TT)
TIO locator

The other sections include lists, charts and tables that provide complementary and supporting material to facilitate the understanding and implementation of the IAU 2000 resolutions, as well as illustrating the Glossary. Section 2 contains a list of terms (excluding those on time) that are used in the process of implementing the Resolutions; they have been grouped by categories in order to help the users to see where the CIO based method fits into the long established equinox based approach. Section 3 provides a chart to illustrate the various stages showing the BCRS -> GCRS -> ITRS transformations in the framework of General Relativity (Resolution B.3) and the parallel CIO and equinox based processes (Resolution B1.8); the Chart is schematic and is supplied as an aid to understanding, and not as WG recommendations.

1) IAU NFA 2000 GLOSSARY

Those definitions corresponding to the IAU 2000 resolutions are given in *italic* type. The newly proposed definitions are underlined while superseded definitions are given in a smaller font.

aberration: the apparent angular displacement of the observed position of a celestial object from its geometric position, caused by the finite velocity of light in combination with the motions of the observer and of the observed object. Annual aberration is due to the motion of the Earth around the Sun, while diurnal aberration is due to the Earth's rotation. In star catalogs of the pre-1984.0 era, it was common to include the secular part of stellar aberration (the so-called e-terms) in the published star positions.

apparent place: a geocentric position (e.g. apparent right ascension and declination) in the true equinox and equator of date reference system at a specified date.

apparent right ascension and declination: angular coordinates in the true equator and equinox of date reference system at a specified date. They are geocentric positions differing from the ICRS positions by annual parallax, gravitational light deflection due to the solar system bodies except the Earth, annual aberration, and the time-dependent rotation describing the transformation from the GCRS to the Celestial Intermediate Reference System (they are similar to intermediate positions in the CIO based system but the apparent right ascension origin is at the equinox). Note that apparent declination is identical to intermediate declination.

astrometric place: direction of a solar system body formed by applying the correction for the barycentric motion of this body during the light time to the geometric geocentric position referred to the ICRS. Such a position is then directly comparable with the astrometric position of a star formed by applying the corrections for proper motion and annual parallax to the catalog direction at J2000. The gravitational deflection of light is ignored. For high-accuracy applications, gravitational light deflection effects need to be considered, and the adopted policy declared.

barycentric: centered at the solar system barycenter.

Barycentric Celestial Reference System (BCRS): *a system of barycentric space-time coordinates for the solar system within the framework of General Relativity with metric tensor specified by the IAU 2000 Resolution B1.3. Formally, the metric tensor of the BCRS does not fix the coordinates completely, leaving the final orientation of the spatial axes undefined. However, for all practical applications, unless otherwise stated, the BCRS is assumed to be oriented according to the ICRS axes.*

Barycentric Coordinate Time (TCB): the coordinate time of the BCRS; it is related to Geocentric Coordinate Time (TCG) and Terrestrial Time (TT) by relativistic transformations that include secular terms.

Barycentric Dynamical Time (TDB): a time scale originally intended to serve as an independent time argument of barycentric ephemerides and equations of motion. TDB was defined by the IAU 1976 resolutions to differ from Terrestrial Time (TT) only by periodic terms. Later it became clear that this condition cannot be satisfied rigorously. The IAU 1991 resolutions defined TDB as a linear function of TCB without fixing the rate ratio. Each ephemeris defines its own version of TDB: the linear drift between TDB and TCB is chosen so that the rates of TDB and TT are as close as possible for the time span covered by the particular ephemeris. TDB is sometimes designated by T_{eph}.

Barycentric Ephemeris Time (T_{eph}): see Barycentric Dynamical Time (TDB).

BCRS: see Barycentric Celestial Reference System.

catalog equinox: the intersection of the hour circle of zero right ascension of a star catalog with the celestial equator.

catalog place: a star catalog position.

Celestial Ephemeris Origin (CEO): *the original name for the Celestial Intermediate Origin (CIO) given in the IAU 2000 resolutions.*

Celestial Ephemeris Pole (CEP): used from 1984 to 2003 with the IAU 1980 Theory of Nutation as the reference pole for nutation and polar motion; the axis of figure for the mean surface of a model Earth in which the free motion has zero amplitude. This pole was originally defined as having no nearly-diurnal nutation with respect to a space-fixed or Earth-fixed coordinate system and being realized by the IAU 1980 nutation. It was afterwards determined by using VLBI observations of celestial pole offsets. It is now replaced by the CIP, which is defined by IAU 2000 Resolution B1.7.

Celestial Intermediate Origin (CIO): origin for right ascension on the intermediate equator in the Celestial Intermediate Reference System. It is the non-rotating origin in the GCRS that is recommended by the IAU 2000 Resolution B 1.8, where it was designated the Celestial Ephemeris Origin**.** The CIO was originally set close to the GCRS meridian and throughout 1900-2100 stays within 0.1 arcseconds of this alignment.

Celestial Intermediate Pole (CIP): *geocentric equatorial pole defined by IAU 2000 Resolution B1.7 as being the intermediate pole, in the transformation from the GCRS to the ITRS, separating nutation from polar motion. It replaced the CEP on 1 January 2003. Its GCRS position results from (i) the part of precession-nutation with periods greater than 2 days, and (ii) the retrograde diurnal part of polar motion (including the free core nutation, FCN) and (iii) the frame bias. Its ITRS position results from (i) the part of polar motion which is outside the retrograde diurnal band in the ITRS and (ii) the motion in the ITRS corresponding to nutations with periods less than 2 days. The motion of the CIP is realized by the IAU 2000A precession-nutation plus time-dependent corrections provided by the IERS.*

Celestial Intermediate Reference System (CIRS): geocentric reference system related to the GCRS by a time-dependent rotation taking into account precession-nutation. It is defined by the intermediate equator (of the CIP) and CIO on a specific date. It is similar to the system based on the true equator and equinox of date, but the equatorial origin is at the CIO. Since the acronym for this system is close to another acronym (namely ICRS), it is suggested that wherever possible the complete name is used.

celestial pole offsets: time-dependent corrections to the precession-nutation model, determined by observations. The IERS provides the celestial pole offsets in the form of the differences, *dX* and *dY*, of the CIP coordinates in the GCRS with respect to the IAU 2000A precession-nutation model (i.e. the CIP is realized by the IAU 2000A precession-nutation plus these celestial pole offsets). In parallel the IERS also provides the offsets, $d\psi$ and $d\varepsilon$, in longitude and obliquity with respect to the IAU 1976/1980 precession/nutation model.

celestial pole offsets at J2000.0: offset of the direction of the CIP at J2000.0 with respect to the GCRS provided by the current precession-nutation. These offsets are often called frame bias.

CEO: see Celestial Ephemeris Origin.

CEP: see Celestial Ephemeris Pole.

CIO: see Celestial Intermediate Origin.

CIO locator (denoted s): the difference between the GCRS right ascension and the intermediate right ascension of the intersection of the GCRS and intermediate equators. The CIO was originally set close to the mean equinox at J2000.0. As a consequence of precession-nutation the CIO moves according to the kinematical property of the non-rotating origin. The CIO is currently located by using the quantity *s*.

CIO right ascension and declination: see intermediate right ascension and declination.

CIP: see Celestial Intermediate Pole.

CIRS: see Celestial Intermediate Reference System.

CTRS: see Conventional Terrestrial Reference System.

Conventional International Origin: the international origin of polar motion adopted for use by the former International Latitude Service (ILS). It was defined in 1967 by an adopted set of astronomical latitudes of the 5 stations of the ILS. It approximately coincided with the mean pole of 1903.0 as determined by the ILS. To avoid ambiguity, this origin should be designated by its full name. This designation should be avoided for the current origin (the ITRF pole) of the polar motion, which no longer coincides with the conventional international origin.

Conventional Terrestrial Reference System (CTRS): term used in the IUGG Resolution N°2 (1991) for designating the ideal terrestrial system to be defined from a geocentric non-rotating system by a spatial rotation. It is proposed to replace this designation by GTRS.

date: a reading of a time scale.

day: an interval of 86400 seconds. The day, and related conventional units such as the Julian year and Julian century, may be used with any continuous time scale (TCG, TCB, TT, TDB, ...). In precise work the time scale should be specified (e.g. 1 TT day). This also applies to UT1 when used as a time scale. Note that for UTC, on the days that leap seconds are added, the day can be 86401 (or 86399) seconds.

declination: angular distance north or south of the celestial equator. It is measured along the hour circle passing through the celestial object. Declination is usually given in combination with right ascension or hour angle.

dynamical mean equinox: the ascending node of the ecliptic on the mean equator. The mean equinox of epoch (to which the recent analytical and numerical solutions for the Moon and planets refer) corresponds to the definition of the ecliptic in its "inertial" sense. It differs by 93.66 mas from the "rotational dynamical mean equinox of J2000.0", which was intended to coincide with the FK5 equinox.

Earth Rotation Angle (ERA): *angle measured along the intermediate equator of the Celestial Intermediate Pole (CIP) between the Terrestrial Intermediate Origin (TIO) and the Celestial Intermediate Origin (CIO), positively in the retrograde direction. It is related to UT1 by a conventionally adopted expression in which ERA is a linear function of UT1 (see IAU Resolution B1.8). Its time derivative is the Earth's angular velocity. Previously, it has been referred to as the stellar angle.*

ecliptic: the plane perpendicular to the mean orbital angular momentum vector of the Earth-Moon barycenter. There is no unique interpretation; an ecliptic is defined by means of the angles of the precession theory.

Ephemeris time (ET): the time scale used prior to 1984 as the independent variable in gravitational theories of the solar system, with its unit and origin conventionally defined. It was superseded by TT and TDB.

epoch: a fixed date used to reckon time for expressing time varying quantities. It is often expressed in the system of Julian date, marked by the prefix J (e.g. J2000.0), with the Julian year of 365.25 days as unit. The term is also used to designate the date and time of an observation, e.g. "epoch of observation", which would be better expressed by 'date of observation'.

equation of the equinoxes: the right ascension of the mean equinox referred to the true equator and equinox; alternatively the difference between apparent sidereal time and mean sidereal time (GAST – GMST).

equation of the origins: distance between the equinox and the CIO along the intermediate equator; it is the CIO right ascension of the equinox; alternatively the difference between the Earth Rotation Angle and Greenwich apparent sidereal time (ERA – GAST).

equinox: either of the two points at which the ecliptic intersects the celestial equator; also the time at which the Sun passes through either of these intersection points; i.e., when the apparent longitude of the Sun is 0° or 180°. When required, the equinox can be designated by the ephemeris of the Earth from which it is obtained (e.g. vernal equinox of DE 405). By 2100 the equinox will have moved 1.4° from the ICRS meridian, due to the precession of the equinoxes.

equinox right ascension: right ascension that is measured from the equinox; also simply called right ascension.

ERA: see Earth Rotation Angle.

ET: see Ephemeris time.

FCN: see free core nutation.

fixed ecliptic: The ecliptic of a given ephemeris at an adopted epoch. Such a fixed ecliptic has a specified obliquity and crosses the ICRS equator at a specified offset from the ICRS origin.

frame bias: the three offsets of the Celestial Intermediate Reference System with respect to the GCRS; the first two offsets are the celestial pole offsets at J2000.0 and the third is the offset in right ascension of the mean dynamical equinox of J2000.0.

free core nutation (FCN): free retrograde diurnal mode in the motion of the Earth's rotation axis with respect to the Earth, due to non-alignment of the rotation axis of the core and of the mantle; it is a long period (of 432 days) free nutation of the CIP in the GCRS.

GAST (GST): see Greenwich sidereal time.

GCRS: see Geocentric Celestial Reference System.

GCRS CIP coordinates: direction cosines *X, Y,* of the CIP in the GCRS; these quantities are often multiplied by $1296000''/2\pi$ in order to represent the approximate values in arcseconds of the corresponding angles with respect to the polar axis of the GCRS.

GMST: see Greenwich mean sidereal time.

geocentric: referring to the center of the Earth.

Geocentric Celestial Reference System (GCRS): *a system of geocentric space-time coordinates within the framework of General Relativity with metric tensor specified by the IAU 2000 Resolution B1.3. The GCRS is defined such that the transformation between BCRS and GCRS spatial coordinates contains no rotation component, so that GCRS is kinematically non-rotating with respect to BCRS. The equations of motion of, for example, an Earth satellite, with respect to the GCRS will contain relativistic Coriolis forces that come mainly from geodesic precession. The spatial orientation of the GCRS is derived from that of the BCRS, that is, unless otherwise stated, by the orientation of the ICRS.*

Geocentric Coordinate Time (TCG): coordinate time of the GCRS based on the SI second. It is related to Terrestrial Time (TT) by a conventional linear transformation.

Geocentric Terrestrial Reference System (GTRS): a system of geocentric space-time coordinates within the framework of General Relativity, co-rotating with the Earth, and related to the GCRS by a spatial rotation which takes into account the Earth orientation parameters. It replaces the previously defined Conventional Terrestrial Reference System.

geodesic precession and nutation: the largest components (in fact the only non-negligible ones) of the relativistic rotation of the GCRS with respect to a dynamically non-rotating geocentric reference system in the framework of General Relativity. Geodesic precession is the secular part of the rotation and geodesic nutation is the periodic part. Geodesic precession and nutation are included in the IAU 2000 precession-nutation model.

Greenwich mean sidereal time (GMST): Greenwich hour angle of the mean equinox defined by a conventional relationship to Earth Rotation Angle or equivalently to UT1.

Greenwich sidereal time (GST): Greenwich apparent sidereal time (GAST), the hour angle of the true equinox from the Terrestrial Intermediate Origin (TIO) meridian (Greenwich or International meridian).

GTRS: see Geocentric Terrestrial Reference System

IAU 2000 precession-nutation: *IAU Resolution B1.6 recommends the IAU 2000A precession-nutation model for those who need a model at 0.2 mas level. It represents the CIP. An abridged model, designated IAU 2000B, is available for those who require a model at the 1 mas level.*

ICRF: see International Celestial Reference Frame.

ICRS: see International Celestial Reference System.

ICRS place: a direction in ICRS coordinates, (e.g. ICRS right ascension, the right ascension measured from the ICRS origin on the ICRS equator, and ICRS declination, the declination measured from the ICRS equator).

intermediate equator: equatorial plane through the center of the Earth and perpendicular to the direction of the Celestial Intermediate Pole (CIP) at some epoch (it is synonymous with the instantaneous equator or true equator of date, or equator of the CIP).

intermediate place: direction of an object in the Celestial Intermediate Reference System (e.g. intermediate right ascension and declination), analogous to an apparent place in the equinox based system, but the origin for intermediate right ascension is at the CIO.

intermediate right ascension and declination: angular coordinates measured in the Celestial Intermediate Reference System at a specified date**.** They specify a geocentric direction that differs from the ICRS direction by annual parallax, gravitational light deflection due to the solar system bodies, except the Earth, annual aberration, and the time-dependent rotation describing the transformation from the GCRS to the Celestial Intermediate Reference System. They are similar to apparent right ascension and declination when referring to the equinox based system. Note that intermediate declination is identical to apparent declination.

International Atomic Time (TAI): a widely used practical realization of TT with a fixed shift from the latter due to historical reasons (see TT); it is a continuous time scale, now calculated at the Bureau International des Poids et Mesures (BIPM), using data from some three hundred atomic clocks in over fifty national laboratories in accordance with the definition of the SI second**.**

International Celestial Reference Frame (ICRF): a set of extragalactic objects whose adopted positions and uncertainties realize the ICRS axes and give the uncertainties of the axes. It is also the name of the radio catalog whose 212 defining sources is currently the most accurate realization of the ICRS. Note that the orientation of the ICRF catalog was carried over from earlier IERS radio catalogs and was within the errors of the standard stellar and dynamic frames at the time of adoption. Successive revisions of the ICRF are intended to minimize rotation from its original orientation. Other realizations of the ICRS have specific names (e.g. Hipparcos Celestial Reference Frame).

International Celestial Reference System (ICRS): the idealized barycentric coordinate system to which celestial positions are referred. It is kinematically non-rotating with respect to the ensemble of distant extragalactic objects. It has no intrinsic orientation but was aligned close to the mean equator and dynamical equinox of J2000.0 for continuity with previous fundamental reference systems. Its orientation is independent of epoch, ecliptic or equator and is realized by a list of adopted coordinates of extragalactic sources.

International Terrestrial Reference Frame (ITRF): a realization of ITRS by a set of instantaneous coordinates (and velocities) of reference points distributed on the topographic surface of the Earth (mainly space geodetic stations and related markers). Currently the ITRF provides a model for estimating, to high accuracy, the instantaneous positions of these points, which is the sum of conventional corrections provided by the IERS Convention center (solid Earth tides, pole tides, ...) and of a "regularized" position. At present, the latter is modeled by a piecewise linear function, the linear part accounting for such effects as tectonic plate motion, post-glacial rebound, and the piecewise aspect representing discontinuities such as seismic displacements. The initial orientation of the ITRF is that of the BIH Terrestrial System at epoch 1984.0.

International Terrestrial Reference System (ITRS): a specific GTRS for which the co-rotation condition is defined as no residual rotation with regard to the Earth's surface**,** and the geocenter is understood as the center of mass of the whole Earth system, including oceans and atmosphere (IUGG Resolution 2, Vienna 1991). It was aligned close to the mean equator of 1900 and the Greenwich meridian, for continuity with previous terrestrial reference systems. The ITRS is the recommended system to express positions on the Earth.

ITRF: see International Terrestrial Reference Frame.

ITRF meridian: the plane passing through the geocenter, ITRF pole and ITRF *x*-origin.

ITRS: see International Terrestrial Reference System.

ITRS CIP coordinates: direction cosines of the CIP in the ITRS, also called pole coordinates. They are currently expressed in the form of *x* and *y* coordinates, in arcseconds, the values of which represent the corresponding angles with respect to the polar axis of the ITRS. The sign convention is such that *x* is positive towards the *x*-origin of the ITRS and *y* is in the direction 90° to the west of *x*.

J2000.0: defined in the framework of General Relativity by IAU Resolution C7 (1994) as being the event (epoch) at the geocenter and at the date 2000 January 1.5 TT = Julian Date 245 1545.0 TT. Note that this event has different dates in different time scales.

Julian century: a period of 100 Julian years (36525 days). The Julian century as a unit of time may be used with any continuous time scale (TCG, TCB, TT, TDB). In precise work the time scale should be specified (e.g. 1 TT Julian century). Note that this extends the IAU Resolution C7 (1994) where Julian century was defined as 36525 TT days.

Julian date: the interval of time in days and fractions of a day since 4713 B.C. January 1, Greenwich noon, approximately. The Julian date can be used with any time scale (TCG, TCB, TT, TDB). In precise work, the Julian date in TT, TCG and TCB, has its origin fixed according to the IAU 1991 Resolutions by the condition that on 1977 January 1, $00^h\ 00^m\ 00^s$ TAI at the geocenter, the readings of TT, TCG and TCB are 1977 January 1, $00^h\ 00^m\ 32^s.184$ (JD 244 3144.5003725). The equivalent TDB reading depends on the adopted ephemeris (for example, the same reading for TDB(DE405) is JD 244 3144.5003725 – 65.564518 μs). The Modified Julian date is JD – 240 0000.5.

Julian year: a period of 365.25 days. The Julian year as a unit of time may be used with any continuous time scale (TCG, TCB, TT, TDB). In precise work the time scale should be specified (e.g. 1 TT Julian year).

mean equator: equator associated with a celestial pole whose direction is determined only by the precession portion of the precession-nutation transformation**.**

mean equinox: equinox associated with the mean equator.

mean place: position of an object on the celestial sphere referred to the mean equator and equinox at a standard epoch.

non-rotating origin: in the context of the GCRS or the ITRS, the point on the intermediate equator such that its instantaneous motion with respect to the system (GCRS or ITRS as appropriate) has no component along the intermediate equator (i.e. its instantaneous motion is perpendicular to the intermediate equator). It is called the CIO and TIO in the GCRS and ITRS, respectively.

nutation: forced periodic part of the motion of the pole of rotation of a freely rotating body that is undergoing torque from external gravitational forces.

observed place: a topocentric place that includes the effect of refraction**.**

offset in right ascension: expression used to describe the equatorial offset at J2000 of the GCRS right ascension of the inertial dynamical mean equinox (see frame bias).

parallax: the difference in apparent direction of an object as seen from two different locations; annual parallax refers to the difference in directions as seen from the barycenter and the geocenter, while diurnal parallax refers to the component of parallax due to the observer's separation from the geocenter.

polar motion: the motion of the Earth's pole with respect to the ITRS. The main components are the Chandlerian free motion with a period of approximately 430 days, and an annual motion. It also includes sub-daily variations caused by ocean tides and periodic motions driven by gravitational torques with periods less than two days. Sub-daily variations are not included in the values distributed by the IERS, and are therefore to be added, after interpolation to the date of interest, using a model provided by the IERS Conventions.

pole coordinates: angular coordinates of the pole with respect to the terrestrial system (see ITRS CIP coordinates).

precession: the uniformly progressing motion of the pole of rotation of a freely rotating body, undergoing torque from external gravitational forces. In the case of the Earth, the precession of the equator is caused by solar system objects acting on the Earth's equatorial bulge making the pole of rotation describe a 26000-year orbit around the ecliptic pole; the precession of the equinox results both from the precession of the equator and the precession of the ecliptic, which is the secular part of the motion of the ecliptic with respect to the fixed ecliptic.

precession-nutation: the ensemble of effects of external torques on the motion in space of the rotation axis of a freely rotating body (see the separate entries for precession and nutation below), or alternatively, the forced motion of the pole of rotation due to those external torques. In the case of the Earth, a practical definition consistent with the IAU 2000 resolutions is that precession-nutation is the motion of the CIP in the GCRS, including FCN and other corrections to the standard models: precession is the secular part of this motion plus the term of 26000-year period and nutation is that part of the CIP motion not classed as precession.

proper place: direction of an object in the GCRS (e.g. right ascension and declination); geocentric place that is corrected for light-time, light deflection, annual parallax and annual aberration**.**

reference frame: practical realization of a reference system, usually as a catalog of positions and motions of a certain number of fiducial points. For instance, the ICRF is the realization of the ICRS, where the ICRF points have no proper motions.

reference system: theoretical concept of a system of coordinates, including time and standards necessary to specify the bases used to define the position and motion of objects in time and space.

refraction: the bending of a ray of light as it passed through the Earth's atmosphere. Most commonly calculated using pressure, temperature, humidity and wavelength.

right ascension: angular distance measured eastward along the celestial equator from the CIO, or equinox, to the hour circle passing through the celestial object. Right ascension is given either in arc or time units. It is essential that the origin, CIO or equinox, of the right ascension be specified.

stellar angle: the original term used for the Earth Rotation Angle (ERA) in the first definition of the non-rotating origin.

sidereal time: the measure of the angle defined by the apparent diurnal motion of the equinox; hence, a measure of the rotation of the Earth with respect to the celestial reference frame rather than the Sun. It is often expressed in hours, minutes, and seconds, one hour being equal to 15º.

TAI: see International Atomic Time**.**

TCB: see Barycentric Coordinate Time.

TCG: see Geocentric Coordinate Time.

TDB: see Barycentric Dynamical Time.

TDT: see Terrestrial Dynamical Time.

TEO: see Terrestrial Ephemeris Origin.

Terrestrial Dynamical Time (TDT): time scale for apparent geocentric ephemerides defined by a 1979 IAU resolution and in 1991 was replaced by Terrestrial Time (TT).

Terrestrial Ephemeris Origin (TEO): *the original name for the Terrestrial Intermediate Origin (TIO) given in the IAU 2000 resolutions.*

Terrestrial Intermediate Origin (TIO): origin of longitude in the Intermediate Terrestrial Reference System. It is the non-rotating origin in the ITRS that is recommended by the IAU 2000 Resolution B1.8, where it was designated Terrestrial Ephemeris Origin. The TIO was originally set at the ITRF origin of longitude and throughout 1900-2100 stays within 0.1 mas of the ITRF meridian.

Terrestrial Intermediate Reference System (TIRS): a geocentric reference system defined by the intermediate equator of the CIP and the TIO. It is related to the ITRS by polar motion and s' (see TIO locator). It is related to the Celestial Intermediate Reference System by a rotation of ERA around the CIP, which defines the common z-axis of the two systems. Since the acronym for this system is close to another acronym (namely ITRS)**,** it is suggested that wherever possible the complete name be used.

Terrestrial Time (TT): a coordinate time whose mean rate is close to the mean rate of the proper time of an observer located on the rotating geoid. At 1977 January 1.0 TAI exactly, the value of TT was 1977 January 1.0003725 exactly. **…..** It is related to the Geocentric Coordinate Time (TCG) by a conventional linear transformation provided by IAU Resolution B1.9. TT may be used as the independent time argument for geocentric ephemerides. An accurate realization of TT is TT (TAI) = TAI + $32^{s}.184$. In the past TT was called Terrestrial Dynamical Time (TDT).

TIO: see Terrestrial Intermediate Origin.

TIO locator (denoted *s′*): the difference between the ITRS longitude and the instantaneous longitude of the intersection of the ITRS and intermediate equators. The TIO was originally set at the ITRF origin of longitude. As a consequence of polar motion the TIO moves according to the kinematical property of the non-rotating origin. The TIO is currently located using the quantity s′, whose rate is of the order of 50 μas/cy which is due to the current polar motion.

TIO meridian: moving plane passing through the geocenter, the CIP and the TIO.

TIRS: see Terrestrial Intermediate Reference System.

topocentric: a place that is centered at the surface of the Earth and dependent on the geographic location.

true equator of date: see celestial intermediate equator.

true equinox of date: intersection of the ecliptic with the intermediate (true) equator and designated by the ephemeris of the Earth from which it is obtained (e.g. true equinox of DE 405).

TT: see Terrestrial Time.

Universal Time (UT): a measure of time that conforms, within a close approximation, to the mean diurnal motion of the Sun and serves as the basis of all civil timekeeping. The term "UT" is used to designate a member of the family of Universal Time scales (e.g. UTC, UT1).

Universal Time (UT1): angle of the Earth's rotation about the CIP axis defined by its conventional linear relation to the Earth Rotation Angle (ERA). It is related to Greenwich apparent sidereal time through the ERA (see equation of the origins). It is determined by observations (currently from VLBI observations of the diurnal motions of distant radio sources). UT1 can be regarded as a time determined by the rotation of the Earth. It can be obtained from the uniform time scale UTC by using the quantity *UT1–UTC*, which is provided by the IERS.

UT1 – UTC: difference between the UT1 parameter derived from observation and the uniform time scale UTC, the latter being currently defined as: $UTC = TAI + n$, where n is an integer number of seconds, such that $|UT1 - UTC| < 0^s.9$.

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2) LIST OF TERMS BY CATEGORY

Symbol	Abbreviation	Short Description	Comment or definition	CIO / Equinox Based
1. General				
	CIO based	for procedures using the CIO		CIO
	Equinox based	for procedures using the equinox		equinox
2. Systems				
2.1 Celestial systems				
	BCRS	Barycentric Celestial Reference System		
	GCRS	Geocentric Celestial Reference System		
	ICRS	International Celestial Reference System		
	CIRS	Celestial Intermediate Reference System	The CIO and CIP of date	CIO
	ERS	true equinox & equator of date reference system		equinox
		mean equinox and equator of date		equinox
2.2 Terrestrial systems				
	GTRS	Geocentric Terrestrial Reference System		
	ITRS	International Terrestrial Reference System		
	TIRS	Terrestrial Intermediate Reference System		CIO
3. Frames				
	ICRF	International Celestial Reference Frame		
	ITRF	International Terrestrial Reference Frame		
4. Origins				
		ICRS origin		
		J2000.0 origin		
	CIO	Celestial Intermediate Origin	positioned by CIO locator s	CIO
	TIO	Terrestrial Intermediate Origin	positioned by TIO locator s'	
		mean equinox		equinox
		true equinox		equinox
5. Poles & Pole coordinates				
		ICRS Pole		
		mean pole at J2000.0		
	CIP	Celestial Intermediate Pole		CIO & equinox
X, Y		GCRS coordinates of the CIP		CIO
x_p, y_p		ITRS coordinates of the CIP		

Symbol	Abbreviation	Short Description	Comment or definition	CIO / Equinox Based
6. Meridians				
		ITRF meridian		
		TIO meridian		
		Greenwich meridian (low precision)		
7. Coordinates				
α	RA	right ascension	generic term	
α_i	RA_i	intermediate right ascension, CIO right ascension	ERA-compatible	CIO
α_e	RA_e	equinox right ascension, right ascension with respect to the equinox, apparent right ascension	ST-compatible	equinox
α_{ICRS}	RA_{ICRS}	ICRS right ascension		
δ	Dec, DEC	declination	generic term	CIO & equinox
δ_{ICRS}	Dec_{ICRS}	declination measured from the ICRS equator		
λ,	Long	longitude	generic term	
ϕ, ϕ'	Lat	latitude, geocentric latitude	generic term	
8. Frame bias				
$\delta\psi_B$, $\delta\varepsilon_B$		frame bias in longitude and obliquity		
$d\alpha_0$		frame bias in right ascension, equinox offset at J2000.0		
ξ_0, η_0, $d\alpha_0$		frame bias in rectangular coordinates	ξ_0, η_0, are the celestial pole offsets at J2000.0	
9. Earth rotation relationships				
θ	ERA	Earth Rotation Angle		CIO
	GST	Greenwich (apparent) sidereal time (GAST)	GST = GAST GST = GMST + EE	equinox
	GMST	Greenwich mean sidereal time		equinox
	GHA Aries	Greenwich hour angle Aries	GAST	equinox
E_o	EO	equation of the origins	EO = θ – GST = θ – GAST	CIO & equinox
E_e	EE	equation of the equinoxes	EE = GAST – GMST	equinox

Symbol	Abbreviation	Short Description	Comment or definition	CIO / Equinox Based
10. Precession and Nutation Angles				
X, Y		the GCRS coordinates of the CIP that include frame bias, precession and nutation at date t		CIO
χ_A, ω_A, ψ_A ε_A		accumulated precession angles from epoch to date t		equinox
ε_0	Eps0	obliquity of ecliptic at J2000.0		
$\Delta\psi$, $\Delta\varepsilon$	Dpsi, Deps	nutation in longitude and obliquity at date t		equinox
11. Matrices – the symbols and abbreviations provided here are only suggestions				
C, **C**(X, Y, s)	*C2I*	matrix that transforms from the celestial (GCRS) to the Celestial Intermediate Reference System	"**C**" stands for "celestial to"	CIO
Q, **Q**(X, Y, s)	*I2C*	matrix from the Celestial Intermediate Reference System to the celestial (GCRS)	$\mathbf{Q} = \mathbf{C}^{-1}$ used by IERS.	CIO
B	*C2J*	frame bias matrix, GCRS to J2000.0		equinox
P	*J2m*	precession matrix, J2000.0 to mean equinox of date		equinox
N	*m2t*	nutation matrix, mean equinox of date to true equinox of date		equinox
NP	*J2t*	precession-nutation matrix, J2000.0 to true equinox of date		equinox
NPB	*C2t*	combined bias, precession, nutation matrix, GCRS to true equinox and equator of date		equinox
W(x_p, y_p, s')	*T2T*	polar motion matrix, matrix from the terrestrial system to the ITRS		CIO & equinox
12. Computation of Hour Angle: CIO & Equinox Based Methods				
θ	ERA	Earth Rotation Angle		CIO
	LERA	local Earth Rotation Angle	LERA = $\theta + \lambda$	CIO
H	GHA	Greenwich hour angle (measured from zero longitude)	$H = \theta - \alpha_i$ = GAST - α_e	CIO & equinox
h	LHA	local hour angle	$h = \theta + \lambda - \alpha_i$ = LAST - α_e	CIO & equinox
	GST (GAST)	Greenwich sidereal time (Greenwich apparent sidereal time)	GST = GAST GST = GMST + EE	equinox
	GMST	Greenwich mean sidereal time		equinox
	LMST	local mean sidereal time	LMST = GMST + λ	equinox
	LAST	local apparent sidereal time	LAST = GAST + λ	equinox
	LHA Aries	local hour angle Aries	LAST	equinox

3) CHART: TRANSFORMATION FROM ICRS TO OBSERVED PLACES OF STARS

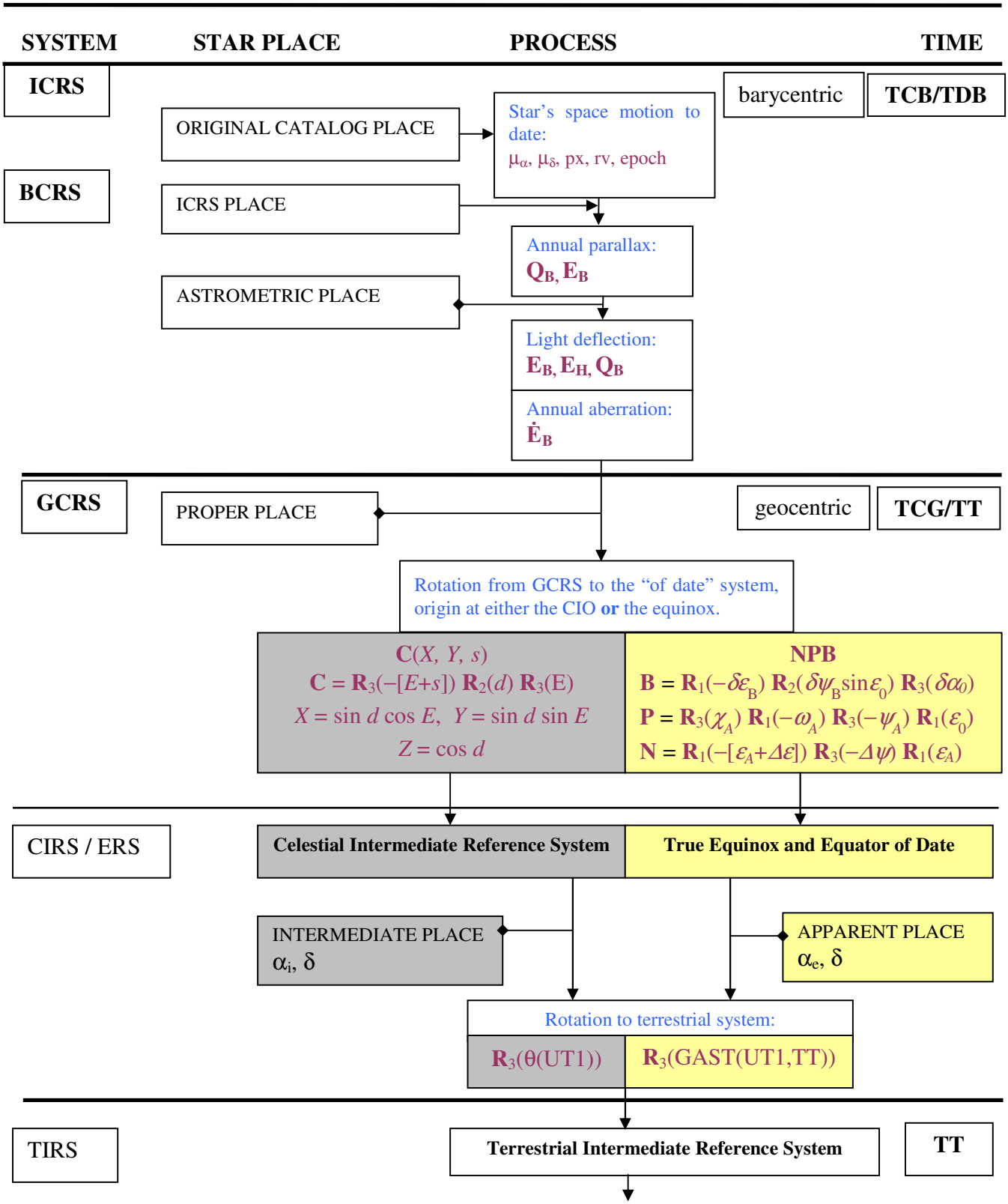
The aim is to highlight the CIO and Equinox based approaches and to specify in what order to apply the usual corrections (annual aberration, precession-nutation etc.) when predicting apparent star directions for a ground-based observer. In typical cases the BCRS to GCRS portion of the method, using existing annual aberration and light deflection formulations, is accurate to a small fraction of a milliarcsecond. However, the omission of light deflection by the planets could in extreme cases cause errors approaching 20 milliarcseconds and there are various other missing terms at the sub-milliarcsecond level.

For very precise reductions it is necessary to use a fully GR-based approach: for more details, see IERS Conventions 2003 (Chapter 11), Klioner 2003, or Kaplan 1998. Note also that the transformation from the ITRS to observed place set out in the chart would require more complicated steps in the GR framework to achieve microarcsecond accuracy. Similarly, in demanding interferometer applications such as VLBI the geometry of the baselines requires a fully relativistic treatment.

The chart summarizes the system, and the elements that are associated with that system, i.e. the name for the positions (place), the processes/corrections, the origin to which the coordinates are referred, and the time scale to use. In particular the blue type in the box in the "Process" column is the operation/correction to be applied, and the purple type indicates the quantities required for that process. CIO and equinox based processes are indicated using grey and yellow shading, respectively.

The following symbols, which are used only in the Chart and are defined below.

Symbol	**Meaning**
μ_α, μ_δ, px, rv	Proper motions in right ascension & declination, stellar parallax and radial velocity, respectively.
$\mathbf{Q_B}$	Barycentric position of the object, evaluated at the required TDB instant.
$\mathbf{E_B}$, $\dot{\mathbf{E}}_\mathbf{B}$	Barycentric position and velocity of the Earth, at the required TDB instant.
$\mathbf{E_H}$	Heliocentric position of the Earth, evaluated at the required TDB instant.
π	equatorial horizontal parallax of the object.
ϕ, ϕ', λ	Latitude, geodetic and geocentric, and longitude respectively.
ρ	geocentric distance of the object.
$\mathbf{R}_1, \mathbf{R}_2, \mathbf{R}_3$	represent the standard rotation matrices about the *x*, *y* and *z* axes, respectively. Where $\mathbf{R}_1 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\mu & \sin\mu \\ 0 & -\sin\mu & \cos\mu \end{pmatrix}$, $\mathbf{R}_2 = \begin{pmatrix} \cos\mu & 0 & -\sin\mu \\ 0 & 1 & 0 \\ \sin\mu & 0 & \cos\mu \end{pmatrix}$, $\mathbf{R}_3 = \begin{pmatrix} \cos\mu & \sin\mu & 0 \\ -\sin\mu & \cos\mu & 0 \\ 0 & 0 & 1 \end{pmatrix}$ and μ is the angle of rotation.


SYSTEM
STAR PLACE
PROCESS
TIME
ICRS
BCRS
ORIGINAL CATALOG PLACE
ICRS PLACE
ASTROMETRIC PLACE
Star's space motion to date:
μα, μδ, px, rv, epoch
Annual parallax:
QB, EB
Light deflection:
EB, EH, QB
Annual aberration:
ĖB
barycentric
TCB/TDB
GCRS
PROPER PLACE
geocentric
TCG/TT
Rotation from GCRS to the "of date" system, origin at either the CIO or the equinox.
C(X, Y, s)
C = R3(−[E+s]) R2(d) R3(E)
X = sin d cos E, Y = sin d sin E
Z = cos d
NPB
B = R1(−δεB) R2(δψB sinε0) R3(δα0)
P = R3(χA) R1(−ωA) R3(−ψA) R1(ε0)
N = R1(−[εA+Δε]) R3(−Δψ) R1(εA)
CIRS / ERS
Celestial Intermediate Reference System
True Equinox and Equator of Date
INTERMEDIATE PLACE
αi, δ
APPARENT PLACE
αe, δ
Rotation to terrestrial system:
R3(θ(UT1))
R3(GAST(UT1,TT))
TIRS
Terrestrial Intermediate Reference System
TT

continued …

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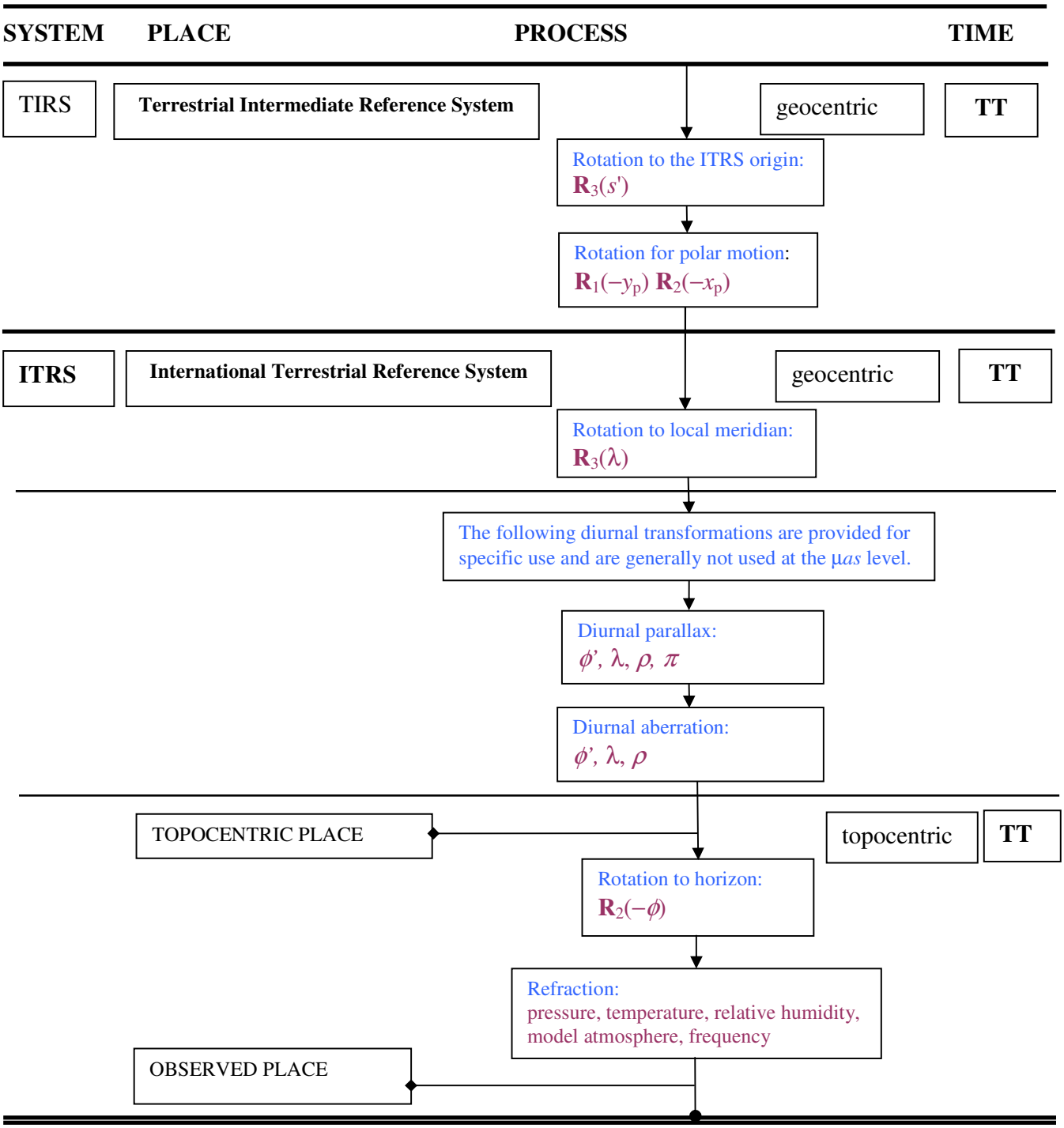
SYSTEM
PLACE
PROCESS
TIME
TIRS
Terrestrial Intermediate Reference System
geocentric
TT
Rotation to the ITRS origin:
R3(s')
Rotation for polar motion:
R1(−yp) R2(−xp)
ITRS
International Terrestrial Reference System
geocentric
TT
Rotation to local meridian:
R3(λ)
The following diurnal transformations are provided for specific use and are generally not used at the μas level.
Diurnal parallax:
ϕ', λ, ρ, π
Diurnal aberration:
ϕ', λ, ρ
TOPOCENTRIC PLACE
topocentric
TT
Rotation to horizon:
R2(−ϕ)
Refraction:
pressure, temperature, relative humidity, model atmosphere, frequency
OBSERVED PLACE

4) LISTS OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

Table 1: Abbreviations and Acronyms – Listed in Alphabetical Order

Abbreviation	Symbol	Term
A		*none*
B		
BCRS		Barycentric Celestial Reference System
C		
CEO		Celestial Ephemeris Origin (superseded)
CEP		Celestial Ephemeris Pole (superseded)
CIO		Celestial Intermediate Origin
CIP		Celestial Intermediate Pole
CIRS		Celestial Intermediate Reference System (acronym is not recommended)
CTRS		Conventional Terrestrial Reference System (superseded)
D		
Dec, DEC	δ	declination (generic)
Dec $_{\mathrm{ICRS}}$	δ_{ICRS}	declination measured from the ICRS equator
Dpsi, Deps	$\Delta\psi$, $\Delta\varepsilon$	nutation in longitude and obliquity
E		
EE	E_{e}	equation of the equinoxes
EO	E_{o}	equation of the origins
Eps	ε_A	obliquity of the ecliptic
Eps0	ε_0	obliquity of ecliptic at J2000.0
ERA	θ	Earth Rotation Angle
ERS		true equinox and equator of date reference system
ET		Ephemeris time (superseded)
F		
FCN		free core nutation
G		
GAST		Greenwich apparent sidereal time (GST)
GCRS		Geocentric Celestial Reference System
GHA	H	Greenwich hour angle
GHA Aries		Greenwich hour angle Aries
GMST		Greenwich mean sidereal time
GST		Greenwich sidereal time (GAST)
GTRS		Geocentric Terrestrial Reference System
H		*none*
I		
ICRF		International Celestial Reference Frame
ICRS		International Celestial Reference System

Abbreviation	Symbol	Term
IERS		International Earth Rotation and Reference Systems Service
ITRF		International Terrestrial Reference Frame
ITRS		International Terrestrial Reference System
J-K		*none*
L		
LAST		local apparent sidereal time
Lat	ϕ, ϕ'	latitude, geocentric latitude
LERA		local Earth Rotation Angle
LHA	h	local hour angle
LHA Aries		local hour angle Aries
LMST		local mean sidereal time
Long	λ	longitude
M-Q		*none*
R		
RA	α	right ascension (generic)
RA_e, RA_i	α_e	equinox right ascension, intermediate right ascension, respectively
RA_{ICRS}	α_{ICRS}	ICRS right ascension
S		*none*
T		
TAI		International Atomic Time
TCB		Barycentric Coordinate Time
TCG		Geocentric Coordinate Time
TDB		Barycentric Dynamical Time
TDT		Terrestrial Dynamical Time (superseded)
TEO		Terrestrial Ephemeris Origin (superseded)
TIO		Terrestrial Intermediate Origin
TIRS		Terrestrial Intermediate Reference System
TT		Terrestrial Time
U		
UT		Universal Time (UT, UT1)
UTC		Coordinated Universal Time
V-Z		*none*

Table 2) Symbols – Listed in Alphabetical Order

Symbol	Abbreviation	Term
α	RA	right ascension (generic)
α_e	RA_e	equinox right ascension
α_i	RA_i	intermediate right ascension
α_{ICRS}	RA_{ICRS}	ICRS right ascension

Symbol	Abbreviation	Term
δ	Dec, DEC	declination
δ_{ICRS}	Dec $_{\mathrm{ICRS}}$	declination measured from the ICRS equator
$d\alpha_0$		frame bias in RA, equinox offset at J2000.0
$\delta\psi_B$,		frame bias in longitude between GCRS and J2000.0
$\delta\varepsilon_B$		frame bias in obliquity between GCRS and J2000.0
$\Delta\varepsilon$	Deps	nutation in obliquity
$\Delta\psi$	Dpsi	nutation in longitude
ε_0	Eps0	obliquity of ecliptic at J2000.0
ε_A	Eps	obliquity of the ecliptic
ξ_0, η_0		celestial pole offsets at J2000.0
θ	ERA	Earth Rotation Angle
λ	Long	longitude
ϕ, ϕ'	Lat	latitude, geocentric latitude
ψ_A		precession angle in longitude
χ_A		planetary precession angle
ω_A		precession angle in obliquity
B		frame bias matrix, GCRS to J2000.0
C		matrix from the GCRS to the Celestial Intermediate Reference System
E_{e}	EE	equation of the equinoxes
E_{o}	EO	equation of the origins
H	GHA	Greenwich hour angle
h	LHA	local hour angle
N		nutation matrix, mean to true equinox of date
NP		precession-nutation matrix, J2000.0 to true equinox of date
NPB		combined bias, precession, nutation matrix, GCRS to EES
P		precession matrix, J2000.0 to mean equinox of date
Q		matrix from Celestial Intermediate Reference System to GCRS
s		positioning of the CIO on the equator of the CIP (CIO locator)
s'		positioning of the TIO on the equator of the CIP (TIO locator)
$\mathrm{T_{eph}}$		Barycentric Ephemeris Times
W		polar motion matrix, terrestrial to ITRS
X, Y		coordinates of the CIP in the GCRS
x_{p}, y_{p} or x, y		coordinates of the CIP in the ITRS

Note: Authors must always ensure that the symbols used in a particular document are defined adequately.

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