New concepts and models for Earth orientation transformation

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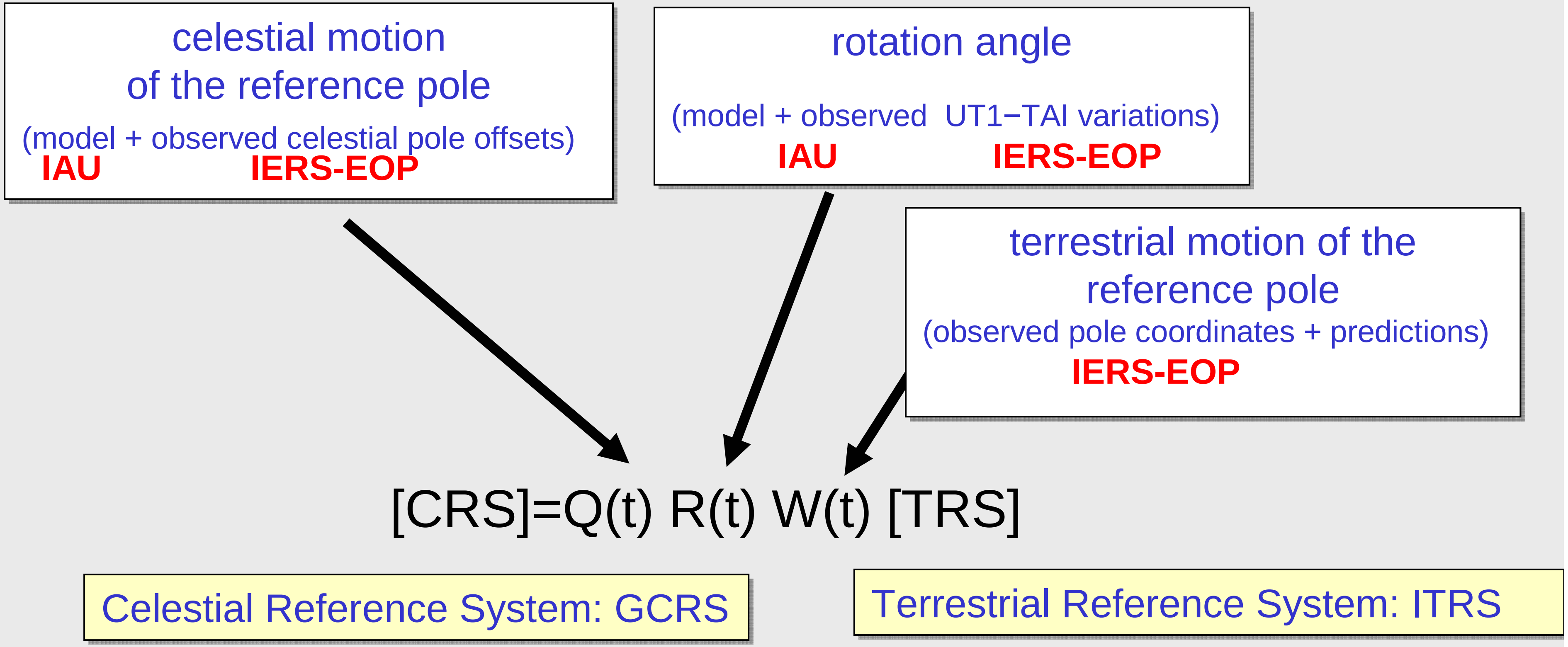
Earth orientation transformation



Transformation between celestial and terrestrial systems

The IAU 2000-2009 Resolutions on reference systems

after the IAU 1997 adoption of the ICRS/HCRS; to prepare the future μas accuracy

		IAU 2000 Resolutions	IAU 2006 Resolutions	IAU 2009 Resolutions
reference systems		Resolution B1.3 *Definition of BCRS and GCRS* Resolution B1.5 *Extended Relativistic framework for time transformation*		Resolution B2 *Adoption of ICRF2*
concepts nomenclature	models	Resolution B1.6 *IAU 2000 Precession-Nutation Model*	Resolution B1 *Adoption of the P03 Precession and definition of the ecliptic*	Resolution B1 *Adoption of the IAU 2009 system of astronomical constants*
	EOP	Resolution B1.7 *Definition of Celestial Intermediate Pole* Resolution B1.8 *Definition and use of CEO and TEO*	Resolution B2 *Supplement to the IAU 2000 Resolutions on reference systems* Rec 1: Harmonizing « intermediate » to the pole and the origin (CIP, CIO) Rec 2: Default orientation of the BCRS/GCRS	
	time scales	Resolution B1.9 *Re-definition of TT*	Resolution B3 *Re-definition of TDB*	

IAU 2000 Resolutions (and IUGG 2003)
concerning the transformation between the celestial and terrestrial systems

IAU Resolution B1.3
Definition of BCRS and GCRS

IAU Resolution B1.6
IAU 2000 Precession-Nutation Model

IAU Resolution B1.7
Definition of Celestial Intermediate Pole (CIP)

IAU Resolution B1.8
Definition and use of CEO and TEO (intermediate origins)

IAU 2006 Resolutions (and IUGG 2007)
concerning the transformation between the celestial and terrestrial systems

IAU Resolution B1
Adoption of the P03 Precession and definition of the ecliptic

(recommended by the IAU WG « Precession and the ecliptic »: 2003-2006)

IAU Resolution B2
Supplement to the IAU 2000 Resolutions on reference systems

Rec 1: Harmonizing intermediate to the pole and the origin (CIP with CIO and TIO)
Recom 2: Default orientation of the BCRS and GCRS

(recommended by the IAU WG « Nomenclature for Fundamental Astronomy »: 2003-2006)

IAU Resolution B3
Re-definition of TDB

(recommended by the IAU WG « Nomenclature for Fundamental Astronomy »: 2003-2006)

IAU 2009 Resolutions

Resolution	Aim
Adoption of the IAU 2009 System of astronomical constants	to adopt an improved system of astronomical constants consistent with the current measurement accuracy

recommended by the IAU WG «Numerical Standards in Fundamental astronomy »

Adoption of the 2d realization of the ICRF	to improve the realization of the ICRF with densification of the frame and a more precise definition of the axes

Realized by the IERS/IVS WG and recommended by the IAU WG «ICRF2»

ICRF2 was aligned to ICRF1 by using a set of stable sources common to ICRF1-ext2

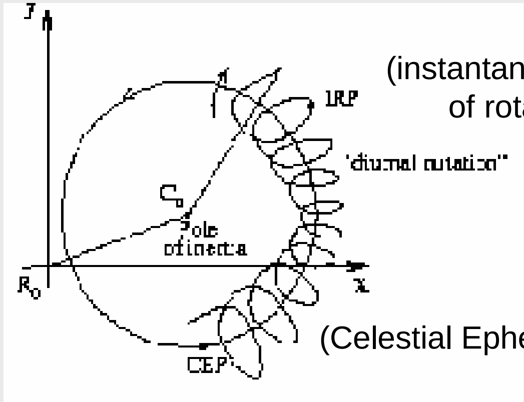
→ follows the IAU 1997 definition of the ICRS

Consequences on the concepts and definitions

Expression of the Earth’s orientation

1. The Celestial Intermediate Pole

IAU 1980: the CEP definition



(instantaneous pole of rotation)

(Celestial Ephemeris Pole)

IAU 2000: the CIP definition

extension of the CEP definition in the high frequencies

(with frequency σ, such that : $\sigma_{TRS} = \sigma_{CRS} - 1$)

frequency in the ITRS –3.5 –2.5 –1.5 –0.5 +0.5 +1.5 (cpsd)

------ polar motion | | **polar motion ------**

|nutation|

frequency in the GCRS –2.5 –1.5 –0.5 +0.5 +1.5 +2.5 (cpsd)

CIP defined by the convention :

celestial motion of the CIP: IAU 2000 precession-nutation for periods > 2 days + offsets

nutations of the CIP with periods < 2 days included in model for pole motion in the ITRS

allows us to clarify the models to be used for high frequency polar motion

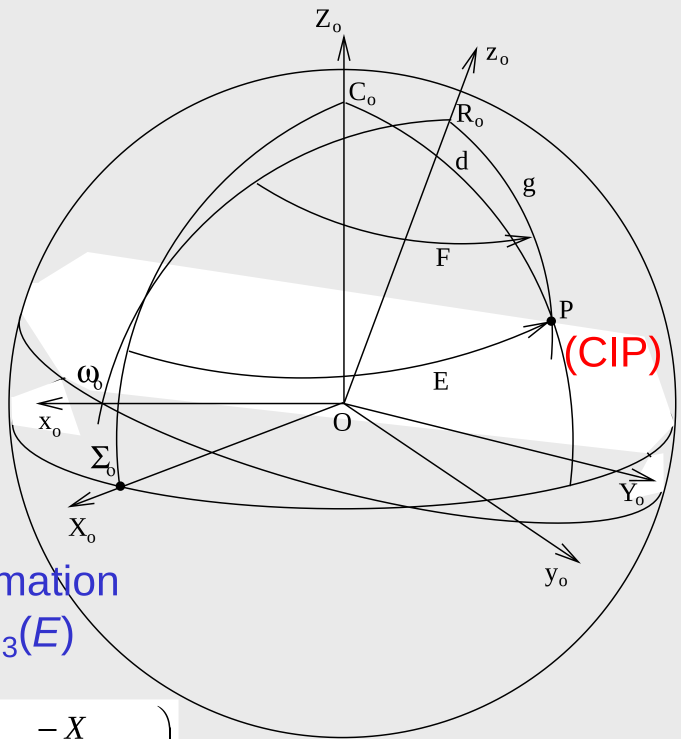
Expression of the Earth's orientation

2. The GCRS and ITRS coordinates of the CIP

GCRS position
of the CIP : *E, d*

$X = \sin d \cos E$
$Y = \sin d \sin E$

$(GX_0Y_0Z_0)$: GCRS
with the equatorial origin Σ_0



ITRS position
of the CIP : *F, g*

$x_P = \sin g \cos F$
$y_P = -\sin g \sin F$

$(Gx_0y_0z_0)$: ITRS
with the equatorial origin ω_0

GCRS to CIRS transformation
$C(t) = R_3(-E-s)R_2(d)R_3(E)$

$$C(t) = R_3(-s) \bullet \begin{pmatrix} 1-aX^2 & -aXY & -X \\ -aXY & 1-aY^2 & -Y \\ X & Y & 1-a(X^2+Y^2) \end{pmatrix}$$

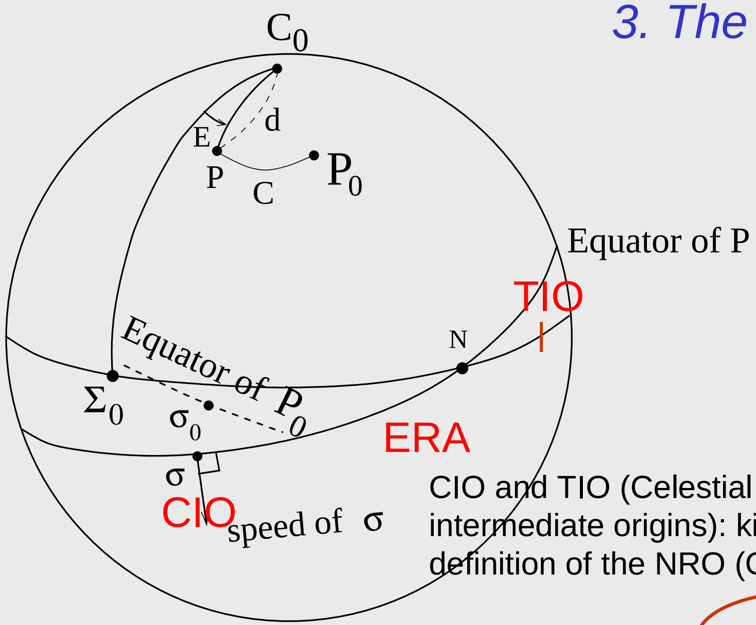
ITRS to TIRS transformation
$W(t) = R_3(-F-s')R_2(g)\, R_3(F)$

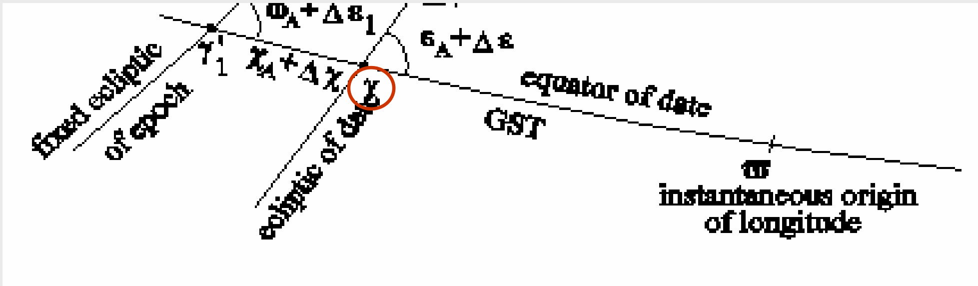
$W(t) = R_3(-s')R_2(x_p)\, R_1(y_p)$

Use of *X*, *Y*: allows a parallel representation between the GCRS and ITRS motions of the CIP

Expression of the Earth's orientation

3. The Earth Rotation Angle





CIO and TIO (Celestial and terrestrial intermediate origins): kinematical definition of the NRO (Guinot 1979)

γ (equinox) : geometrical definition dependent on both the equator and ecliptic motions

ERA: *Earth rotation angle* **replaces** GST: *Greenwhich sidereal time*

ERA : angle from the CIO (σ) to the TIO (ω)

GST = Angle from the equinox to the origin of longitudes

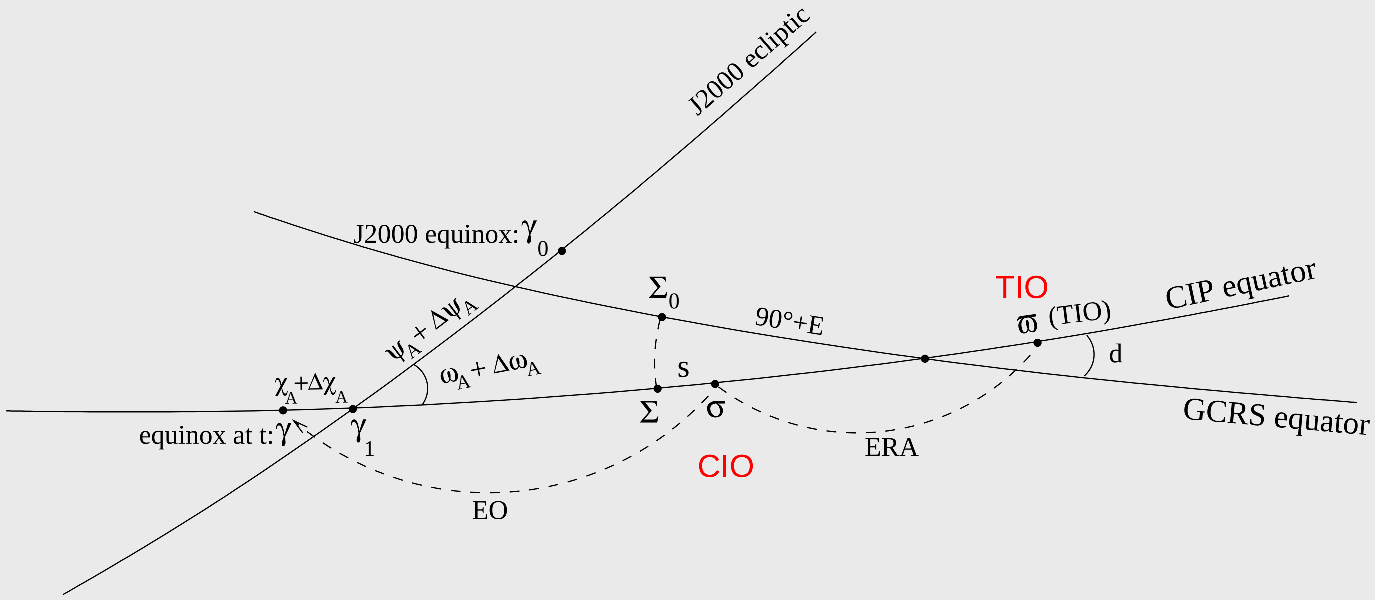
Linear relation between ERA and UT1 (Capitaine, Guinot, McCarthy 2000)

$$ERA(T\mathrm{u}) = 2\pi\,(0.7790572732640\;\; + 1.00273781191135448 \times T\mathrm{u}$$

$$T_{\mathrm{u}}\text{: Julian UT1 date} - 2451545.0$$

allows a clear separation between ERA and PN

Link between various origins, quantities and reference systems



γ: *equinox at t : intersection of the CIP equator with the mean ecliptic of date*

γ_1 *: intersection of the CIP equator with the J2000 ecliptic*

σ: CIO; ω: TIO

EO: *equation of the origins =* $\sigma\,\gamma$ *;* ERA: *Earth rotation angle =* $\sigma\,\omega$

GST = ERA − EO

Intermediate reference systems defined by CIP and TIO: CIRS; by CIP and CIO: TIRS

(Capitaine et al. 2006)

Table 1 IAU 2009 System of Astronomical Constants

Constant	Description	Value
		Natural Defining Constant
c	Speed of Light	2.99792458×10^{8} m s^{-1}
		Auxiliary Defining Constants
k[a]	Gaussian gravitational constant	$1.720209895 \times 10^{-2}$
L_{G}	1−d(TT)/d(TCG)	$6.969290134 \times 10^{-10}$
L_{B}	1−d(TDB)/d(TCB)	$1.550519768 \times 10^{-8}$
TDB_0[b]	TDB−TCB at T_0	-6.55×10^{-5} s
θ_0[c]	Earth rotation angle at J2000.0	0.7790572732640 revolutions
$d\theta$/dUT1[c]	Rate of advance of Earth rotation angle	1.00273781191135448 revolutions UT1-day^{-1}

Constant	Description	Value	Uncertainty
		Natural Measurable Constants	
G	Constant of gravitation	6.67428×10^{-11} m^{3}kg^{-1}s^{-2}	6.7×10^{-15} m^{3}kg^{-1}s^{-2}
		Other Constants	
au[d]	Astronomical unit	$1.49597870700 \times 10^{11}$ m	3 m
L_{C}	Average value of 1−d(TCG)/d(TCB)	$1.48082686741 \times 10^{-8}$	2×10^{-17}
		Body Constants[e]	
GM_{S}	Heliocentric gravitational constant	$1.32712442099 \times 10^{20}$ m^{3}s^{-2} (TCB-compatible) $1.32712440041 \times 10^{20}$ m^{3}s^{-2} (TDB-compatible)	1.0×10^{10} m^{3}s^{-2} (TCB-compatible) 1.0×10^{10} m^{3}s^{-2} (TDB-compatible)
a_{E}[f]	Equatorial radius of the Earth	6.3781366×10^{6} m (TT-compatible)	1×10^{-1} m (TT-compatible)
J_2[f]	Dynamical form factor	1.0826359×10^{-3}	1×10^{-10}
J_2	Time rate of change in J_2	-3.0×10^{-9} cy^{-1}	6×10^{-10} cy^{-1}
GM_{E}	Geocentric gravitational constant	$3.986004418 \times 10^{14}$ m^{3}s^{-2} (TCB-compatible) $3.986004415 \times 10^{14}$ m^{3}s^{-2} (TT-compatible) $3.986004356 \times 10^{14}$ m^3 s^{-2} (TDB-compatible)	8×10^{5} m^3 s^{-2} (TCB-compatible) 8×10^{5} m^3 s^{-2} (TT-compatible) 8×10^{5} m^3 s^{-2} (TDB-compatible)
W_0	Potential of the geoid	6.26368560×10^{7} m^{2}s^{-2}	5×10^{-1} m^{2}s^{-2}
ω[g]	Nominal mean angular velocity of the Earth	7.292115×10^{-5} rad s^{-1} (TT-compatible)	—
$M_{\mathrm{M}}/M_{\mathrm{E}}$	Ratio of the mass of the Moon to the Earth	$1.23000371 \times 10^{-2}$	4×10^{-10}

Nomenclature for fundamental astronomy

IAU 2000/2006 Nomenclature

The Nomenclature in Fundamental Astronomy IAU WG provided an IAU 2006 Glossary including a set of detailed definitions (compliant with GR) that best explain all the terms required for implementing the IAU 2000 and IAU 2006 resolutions

- Barycentric Celestial Reference System (BCRS)
- Barycentric Dynamical Time (TDB)
- Celestial Intermediate Origin (CIO)
- Celestial Intermediate Reference System (CIRS)
- CIO locator
- CIO right ascension and declination
- epoch
- equation of the origins (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
- Teph
- Terrestrial Intermediate Origin (TIO)
- Terrestrial Intermediate Reference System (TIRS)
- Terrestrial Time (TT)
- TIO locator

http://syrte.obspm.fr/iauWGnfa/NFA_Glossary.html

The IAU 2000 NFA Glossary
a few examples of newly proposed terms

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 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).

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, according to IAU 2006 Resolution B2, for all practical applications, unless otherwise stated, the BCRS is assumed to be oriented according to the ICRS axes.

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 (c.f. IAU 2006 Resolution B2), unless otherwise stated, by the orientation of the ICRS.

http://syrte.obspm.fr/iauWGnfa/NFA_Glossary.html

The IAU 2000 NFA Glossary

a few examples of newly proposed terms

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.

Equation of the origins: distance between the CIO and the equinox 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).

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*.

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 mas/cy which is due to the current polar motion.

http://syrte.obspm.fr/iauWGnfa/NFA_Glossary.html

The IAU 2000 NFA Glossary

a few examples of newly proposed terms

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 precession-nutation plus time-dependent corrections provided by the IERS.

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 2000 Resolution B1.8). Its time derivative is the Earth's angular velocity. Previously, it has been referred to as the stellar angle.

Terrestrial Intermediate Reference System (TIRS): a geocentric reference system defined by the intermediate equator of the CIP and the TIO (IAU 2006 Resolution B2). 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.

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 (IAU 2006 Resolution B2). 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.

http://syrte.obspm.fr/iauWGnfa/NFA_Glossary.html

Consequences for high accuracy models

IAU 2006/2000A Precession-nutation

IAU 2000 (Resolution B1.6)

- **adopted** the IAU2000 precession-nutation (Mathews, Herring, Buffett 2002), which was implemented in the IERS Conventions 2003

IAU 2000A Nutation *(non-rigid Earth)*

IAU 2000 Precession = IAU 1976 *(Lieske et al. 1977)* + corrections to precession rates

$d\psi_A$ (IAU 2000) = −0.299 65"/c ; $d\omega_A$ (IAU 2000) = −0.025 24"/c

Celestial pole offsets *at J2000 (VLBI estimates)*

ξ_0 (IAU 2000) = −16.6170 mas ; η_0 (IAU 2000) = −6.8192 mas

IAU 2006 (Resolution B1)

- **adopted** the P03 precession (Capitaine, Chapront, Wallace, 2003) dynamical model consistent with IAU 2000A nutation and with non-rigid Earth parameters, which was implemented in the IERS Conventions 2010

- **recommended** improved definitions (ecliptic, precession of the equator, precession of the ecliptic)

The IAU 2000A Nutation

IAU 2000A nutation = Rigid Earth nutation (prograde & retrograde amplitudes)

∗ Transfer function

(i) Rigid Earth nutation: REN2000 (Souchay et al. 1999)

- Analytical solution providing semi-analytical series of 1365 elleiptical uni-solar and planetary terms (“in-phase” and “out-of-phase” components)
- Amplitudes between 17.2” and 0.1 mas ; periods between 3 d and 101 cy)

$\rightarrow$ REN2000 pairs of prograde and retrograde circular nutations

(ii) Transfer function: MHB 2000 (Mathews, Herring, Buffett 2002) applied to the REN 2000 circular nutations

- based on geophysical representation of the NRE effects
- with Basic Earth Parameters (BEP) fitted to VLBI data.

$\rightarrow$ 1365 elliptical luni-solar and planetary terms

Main features of the MHB 2000 transfer function

Transfer function derived by Mathews et al. (2002) from the solution of equations obtained by generalization of the *SOS equations* (Sasao et al. 1980) for the variations in rotation of the Earth's mantle and fluid core, with *Basic Earth Parameters (BEP)* based on *Model for the dynamics of the Earth's interior and for modeling the dissipative phenomena)and* fitted to VLBI data.

- $\boldsymbol{e, e_f}$: dynamical ellipticity of the Earth and its fluid core, respectively,
- $\boldsymbol{\kappa = ek_2/k_s, \gamma}$: compliance parameters representing the deformabilities of the whole Earth and its fluid core, respectively under tidal forcing,
- $\boldsymbol{K^{CMB}}$ and $\boldsymbol{K^{ICB}}$: core-mantle and outer core to inner core couplings due to the magnetic fields crossing the boundaries of the fluid core,

Basic Earth Parameters	Estimate	Correction to hydrostatic equilibrium
e_f	0.0026456 ±20	0.0000973
κ	0.0010340 ±92	-0.0000043
γ	0.0019662 ±14	0.0000007
e	0.0032845479 ±12	0.000037
Im $K^{(CMB)}$	-0.0000185 ±14	
Re $K^{(ICB)}$	0.00111 ±10	
Im $K^{(ICB)}$	-0.00078 ±13	
rms residuals	0.0132 mas	

MHB 2000 BEPs estimated from VLBI

The scale factor for the precession rate and nutation amplitudes is $\boldsymbol{S_{MHB} = H_d = e/(1 + e)}$.

P03 (IAU 2006) precession

- The P03 precession of the ecliptic is based on a fit to DE406 over a 2000-year interval, after removal of periodic terms using VSOP87.

- The P03 precession of the equator is based on semi-analytical integration of the Earth's precession equations, and is consistent with non-rigid Earth models.

- P03 has been verified by comparing with VLBI observations 1985-2005, with FCN taken into account.

Capitaine N., Wallace P.T., Chapront J. (2003, 2004, 2005))

Hilton et al. 2006: provides discussion and recommendation from the IAU WG on "Precession and the Ecliptic"

Main features of the (P03) IAU 2006 precession

- The IAU 2006 precession provides improved polynomial expressions for both the precession of the ecliptic and the precession of the equator, the latter being consistent with dynamical theory while matching the IAU 2000A precession rate for continuity reasons.

- The precession of the equator was derived from the dynamical equation expressing the motion of the mean pole about the ecliptic pole.

- The solution is based on:
  - the IAU 2000 precession rates in longitude and obliquity,
  - the value, ε_0 = 84381.406'', from Chapront et al. (2002*)* for the mean obliquity of the ecliptic at J2000.0,
  - contributions to the precession rates r_ψ , r_ε from Williams 1994, Brumberg et al. 1998, Mathews et al. 2002,
  - correction in the precession rate for the change in the J2000 obliquity from IAU2000 to P03,
  - $dJ_2/dt = -3.0 \times 10^{-11}$/ yr

P03 precession polynomial developments

basic quantities

	Source		t^0	t	t^2	t^3	t^4	t^5
Ecliptic	IAU 2000	P_A		4197.6	194.47	−0.179		
	P03			4199.094	193.9873	−0.22466	−0.000912	0.0000120
	IAU	Q_A		−46815.0	50.59	0.344		
	P03			−46811.015	51.0283	0.52413	−0.000646	−0.0000172
Equator	IAU 2000	ψ_A		5038478.750	−1072.59	−1.147		
	P03			5038481.507	−1079.0069	−1.14045	0.132851	−0.0000951
	IAU 2000	ω_A	84381448.0	−25.240	51.27	−7.726		
	P03		84381406.0	−25.754	51.2623	−7.72503	−0.000467	0.0003337

derived quantities

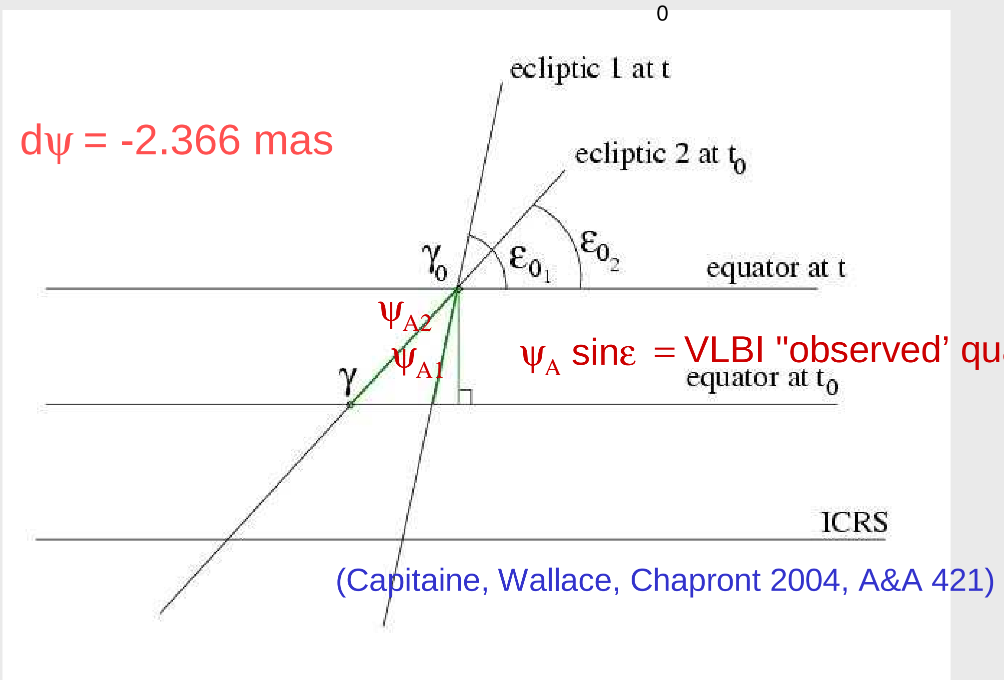
GCRS direction of the CIP and the CIO

Source	t^0	t	t^2	t^3	t^4	t^5
X	− 16.617	2004191.898	− 429.7829	−198.61834	0.007578	0.0059285
Y	− 6.951	−25.896	− 22407.2747	1.90059	1.112526	0.0001358
$s+XY/2$	0.094	3.80865	− 0.12268	− 72.57411	0.02798	0.01562

Effect of the conventional value of the obliquity of the ecliptic on the estimated precession-nutation parameters

- Ecliptic 1 used in pre-2003 VLBI procedures => ψ_{A1}
- Ecliptic 2 used for new precession model (cf P03) => ψ_{A2}

derived precession in longitude = projection of the VLBI observed quantity on the conventional ecliptic used in the VLBI software



Using parameters referred to an ecliptic is a big risk of introducing inconsistencies between different series of observations

IAU 2006 expressions for the GCRS coordinates of the CIP

$$X = -0.''016617 + 2004.''191898\, t - 0.''4297829\, t^2$$
$$- 0.''19861834\, t^3 - 0.''000007578\, t^4 + 0.''0000059285\, t^5$$
$$+ \Sigma_i\, [(a_{s,0})_i \sin(\text{ARGUMENT}) + (a_{c,0})_i \cos(\text{ARGUMENT})]$$
$$+ \Sigma_i\, [(a_{s,1})_i\, t \sin(\text{ARGUMENT}) + (a_{c,1})_i\, t \cos(\text{ARGUMENT})]$$
$$+ \Sigma_i\, [(a_{s,2})_i\, t^2 \sin(\text{ARGUMENT}) + (a_{c,2})_i\, t^2 \cos(\text{ARGUMENT})]$$
$$+ \ldots$$

$$Y = -0.''006951 - 0.''025896\, t - 22.''4072747\, t^2$$
$$+ 0.''00190059\, t^3 + 0.''001112526\, t^4 + 0.''0000001358\, t^5$$
$$+ \Sigma_i\, [(b_{c,0})_i \cos(\text{ARGUMENT}) + (b_{s,0})_i \sin(\text{ARGUMENT})]$$
$$+ \Sigma_i\, [(b_{c,1})_i\, t \cos(\text{ARGUMENT}) + (b_{s,1})_i\, t \sin(\text{ARGUMENT})]$$
$$+ \Sigma_i\, [(b_{c,2})_i\, t^2 \cos(\text{ARGUMENT}) + (b_{s,2})_i\, t^2 \sin(\text{ARGUMENT})]$$
$$+ \ldots$$

precession; frame-bias effects; nutation; cross terms precession x *nutation*

P03 adjustments to IAU 2000A nutation

For use with P03 precession, slight adjustments to the IAU 2000A nutation are needed:

- Change of nutation amplitudes (in longitude only) to take account of the revised obliquity : a geometrical effect.
- Change of nutation amplitudes (in both longitude and obliquity) due to the secular variation of the Earth's dynamical flattening: not considered in IAU 2000A.

The adjustments are (at present) small: a few microarcseconds.

The subscript R06 indicates that those adjustemnts are included

IAU 2006 adjustments to IAU 2000 nutation

effects of obliquity and J_2 rate on nutation

IAU 2006 – IAU 2000 precession:

$$dX = 155\,t - 2564\,t^2 + 2\,t^3 + 54\,t^4,$$
$$dY = -514\,t - 4\,t^2 + 58\,t^3 - 1\,t^4 - 1\,t^5.$$

IAU 2006 – IAU 2000 obliquity: 42 mas

in μas, time in cy

$$d_1\psi = -8.1\ \sin\Omega - 0.6\ \sin(2F - 2D + 2\Omega)$$

Obliquity effect : x ($\sin\varepsilon_{IAU}/\sin\varepsilon_{P03}$)

$$\begin{aligned} d_2\psi &= +47.8\,t\sin\Omega + 3.7\,t\sin(2F - 2D + 2\Omega) \\ &\quad +0.6\,t\sin(2F + 2\Omega) - 0.6\,t\sin 2(\Omega) \\ d_2\omega &= -25.6\,t\cos\Omega - 1.6\,t\cos(2F - 2D + 2\Omega) \end{aligned}$$

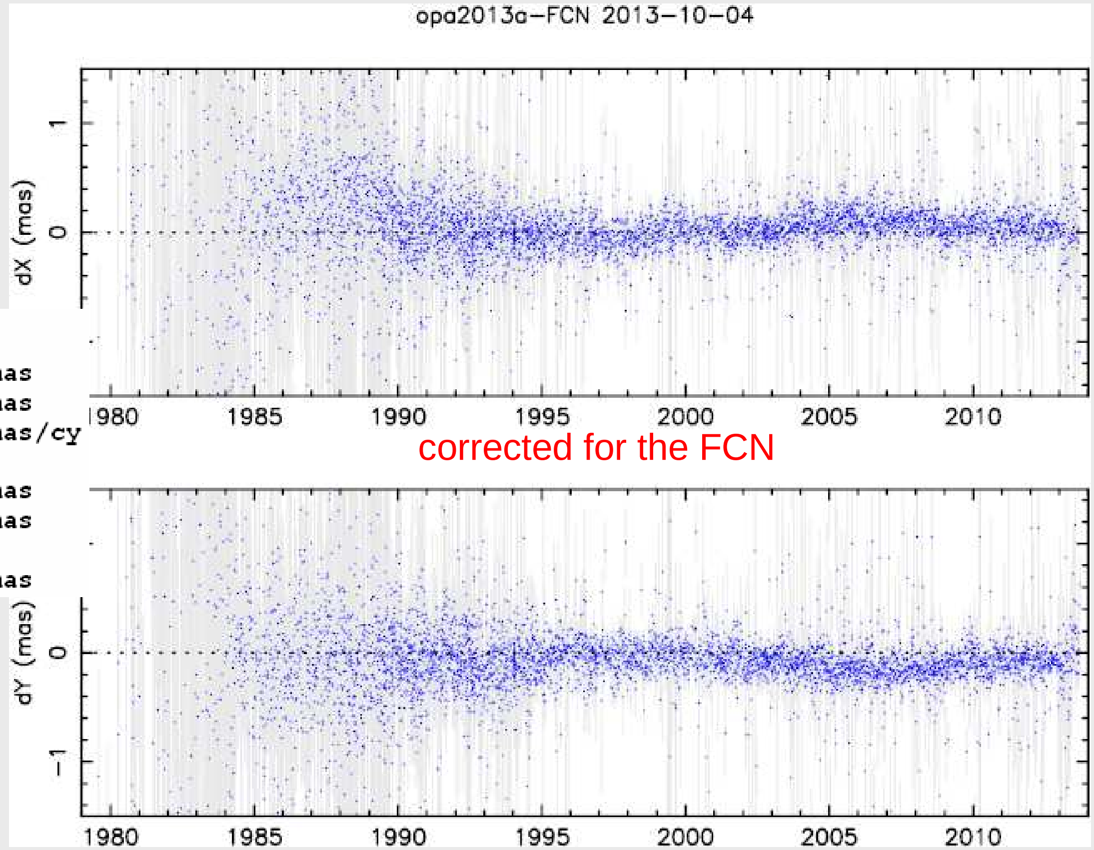
J_2 rate effect : x (J_2 rate /J_2) t

(J_2 rate /J_2 = –2.78 x 10^{-6})

$$\mathbf{dX = 18.9\ t\sin\Omega + 1.5\ t\ \sin(2F - 2D + 2\Omega)}$$
$$\mathbf{dY = -25.6\ t\cos\Omega - 1.6\ t\ \cos(2F - 2D + 2\Omega)}$$

« IAU 2006/2000A_R» precession-nutation

Differences between VLBI-observed celestial pole offsets w.r.t. IAU 2006/2000




```
              -- X ---------       -- Y ---------
Prefit wrms:  0.125                0.123          mas
         t^0  0.028 +- 0.001      -0.086 +- 0.001 mas
         t^1  0.083 +- 0.020      -0.039 +- 0.020 mas/cy
             -- Real ------       -- Imag ------
    ret 18.6  0.040 +- 0.001      -0.023 +- 0.001 mas
    pro 18.6  0.023 +- 0.001      -0.038 +- 0.001 mas
              -- X ---------       -- Y ---------
Postfit wrms: 0.118                0.116          mas
```

- Non-significant discrepancy in precession
- Discrepancies of the order of 50 µas in the amplitude of the 18.6 yr nutation

from the IVS OPA Analysis center

Summary

- The IAU 2000 and 2006 resolutions on reference systems have modified the way the Earth orientation (i.e. the transformation between the International Terrestrial Reference System (ITRS) and the Geocentric Celestial Reference system (GCRS) is expressed

- The IAU 2000, 2006 and 2009 resolutions have adopted high accuracy models for expressing the relevant quantities for the transformation from terrestrial to celestial systems.

- The concepts, nomenclature, models and conventions in fundamental astronomy based on the IAU 2000/2006 resolutions are suitable for modern and future realizations of the reference systems.

- This in particular allows the highest accurate realization of the celestial intermediate system linked to the CIP and the CIO that replaces the classical celestial system based on the true equator and equinox of date.

- The definition and the high accuracy realization of the celestial intermediate reference system based on the IAU 2000/2006 IAU Resolutions is consistent with micro-arcsecond accuracy of the celestial reference system and micro-arcsecond observational precision.

The end