CHAPTER 1 NUMERICAL STANDARDS

The tables herein and the succeeding chapters list the IERS Standards for constants, models, and reference frames. The format for the constants parallels that of the Project MERIT Standards. The tables are organized into three columns: the item, the standard value, and comments. The comments note departures from the IAU values and direct the reader to the appropriate chapter for an expanded discussion or listing of values. In some cases, the succeeding chapters contain tutorial material that might prove helpful. Algorithms are, in some cases, provided to clarify a formulation.

REFERENCES

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NUMERICAL STANDARDS

ITEM	RECOMMENDED VALUE	COMMENTS
ASTRONOMICAL CONSTANTS		
Defining Constants		
- Gaussian Gravitational Constant	$k = 0.01720209895$	
- Velocity of Light	$c = 2.99792458 \times 10^{8} ms^{-1}$	
Primary Constants		
- Astronomical Unit in Light-Seconds	$\tau_A = 499.00478370$ s	IAU (1976) Value = 499.004782 s.
- Equatorial Radius of the Earth	$a_e = 6378136$ m	IUGG Value; IAU Value = 6378140.
- Dynamical Form Factor for Earth	$J_2 = 0.001082626$ $\dot{J}_2 = -2.8 \times 10^{-11}\ yr^{-1}$	Use value in adopted gravity model adjusted to include zero frequency tide.
- Geocentric Constant of Gravitation	$GM_\oplus = 3.98600440 \times 10^{14} m^3 s^{-2}$	IAU (1976) Value = $3.986005 \times 10^{14} m^3 s^{-2}$. Barycentric value given by $GM_{\oplus TDB} = (1-L)GM_\oplus$ where $L = 1.4808 \times 10^{-8}$.
- Constant of Gravitation	$G = 6.67259 \times 10^{-11} m^3 kg^{-1} s^{-2}$	
- Earth-Moon Mass Ratio	$\mu = 0.012300034$	IAU (1976) Value = 0.0123002.
- General Precession in Longitude Per Century for J2000.0	$p = 5029\overset{''}{.}0966$	
- Obliquity of the Ecliptic for J2000.0	$\epsilon_0 = 23°\ 26'\ 21\overset{''}{.}4119$	IAU (1976) Value = 23°26'21".448. Recommended values use rotating definition (see Chapter 4).
Derived Constants		
- Nutation Constant for J2000.0	This constant is superseded by the adoption of the IAU 1980 nutation based on the Wahr Nutation Model. See Ch. 4 for the recommended Nutation Series in longitude and obliquity.	
- Astronomical Unit	$A = c\tau_A = 1.4959787066 \times 10^{11}$ m	IAU (1976) Value = $1.49597870 \times 10^{11}$ m.
- Solar Parallax	$\pi_\odot = \mathrm{Sin}^{-1}(a_e/A) = 8\overset{''}{.}794144$	IAU (1976) Value = 8".794148.
- Aberration Constant for J2000.0	The aberration corrections are calculated directly from ephemeris files.	IAU (1976) Value = 20".49552.
- Earth Flattening	$f^{-1} = 298.257$	Uses the IAG (1975) value of $\omega = 7.292115 \times 10^{-5}$ rad s^{-1}.
- Heliocentric Constant for Gravitation	$GM_\odot = 1.32712440 \times 10^{20} m^3 s^{-2}$	IAU (1976) Value = $1.32712438 \times 10^{20} m^3 s^{-2}$.

NUMERICAL STANDARDS
(continued)

ITEM	RECOMMENDED VALUE	COMMENTS
Derived Constants (continued)		
- Ratio of the solar Mass to the Mass of the Earth	$GM_\odot/GM_{TDB}$ = 332,946.038	IAU (1976) Value = 332,946.0.
- Ratio of the Solar Mass to the Mass of the Earth-Moon System	$GM_\odot/GM_{TDB}(1 + \mu)$ = 328,900.55	IAU (1976) Value = 328,900.5.
- Solar Mass	$M_\odot$ = 1.9891 × 10^{30}kg	
System of Masses (Expressed in Reciprocal Solar Masses)		
- Mercury	6,023,600	
- Venus	408,523.5	
- Earth-Moon System	328,900.55	IAU (1976) Value = 328,900.5. (adjustable in LLR)
- Mars	3,098,710	
- Jupiter	1,047.350	IAU (1976) Value = 1,047.355.
- Saturn	3,498.0	IAU (1976) Value = 3,498.5.
- Uranus	22,960	IAU (1976) Value = 22,869.
- Neptune	19,314	
- Pluto-Charon	130,000,000	IAU (1976) Value = 3,000,000.
- Ceres	1.695 × 10^9	IAU (1976) Value = 1.7 × 10^9.
- Pallas	9.247 × 10^9	IAU (1976) Value = 9.1 × 10^9.
- Vesta	7.253 × 10^9	IAU (1976) Value = 8.3 × 10^9.
Lunar Gravitational Parameters for LLR		The values of these parameters are consistent with the DE200/LE200 ephemerides but they are adjustable in LLR.
$\gamma = (B-A)/C$	2.280043 × 10^{-4}	IAU (1976) Value = 2.278 × 10^{-4}.
$\beta = (C-A)/B$	6.316769 × 10^{-4}	IAU (1976) Value = 6.313 × 10^{-4}.
C/MR^{2*}	0.39053	IAU (1976) Value = 0.392.
I^*	5553".5	IAU (1976) Value = 5552".7 = 1° 32' 32".7.
GM^*	4902.7993 km^3/sec^2	

NUMERICAL STANDARDS
(continued)

ITEM	RECOMMENDED VALUE	COMMENTS
Lunar Gravitational Parameters for LLR (continued)		
Love Number (k_2)	0.0222	
Rotational Dissipation (k_2T)	4.643×10^{-3} days	
C_{20}	-2.02151×10^{-4}	IAU (1976) Value = -2.027×10^{-4}.
C_{22}*	2.2302×10^{-5}	IAU (1976) Value = $+2.23 \times 10^{-5}$.
C_{30}	-8.626×10^{-6}	IAU (1976) Value = -6×10^{-6}.
C_{31}	3.071×10^{-5}	IAU (1976) Value = $+2.9 \times 10^{-5}$.
S_{31}	5.6107×10^{-6}	IAU (1976) Value = $+4 \times 10^{-6}$.
C_{32}	4.8348×10^{-6}	IAU (1976) Value = $+4.8 \times 10^{-6}$.
S_{32}	1.684×10^{-6}	IAU (1976) Value = $+1.7 \times 10^{-6}$.
C_{33}	1.436×10^{-6}	IAU (1976) Value = $+1.8 \times 10^{-6}$.
S_{33}	-3.3435×10^{-7}	IAU (1976) Value = -1×10^{-6}.
C_{40}	1.5×10^{-7}	
C_{41}	-7.18×10^{-6}	
S_{41}	2.95×10^{-6}	
C_{42}	-1.440×10^{-6}	
S_{42}	-2.884×10^{-6}	
C_{43}	-8.5×10^{-8}	
S_{43}	-7.89×10^{-7}	
C_{44}	-1.549×10^{-7}	
S_{44}	5.64×10^{-8}	

*Derived Constants

DYNAMICAL MODELS

Geopotential

- Laser Satellites	GEM-T1	See Chapter 13.
- LLR	IAU (1976) zonals through degree 4 for DE200/LE200.	

NUMERICAL STANDARDS
(continued)

ITEM	RECOMMENDED VALUE	COMMENT
Drag		
- Ballistic Coefficient $\Psi = C_D A/m$	Lageos $A = 0.283\ m^2$ $m = 407.0\ kg$	C_D is an adjusted parameter.
Radiation Pressure		
- Reflectance Coefficient, C_R		See Chapter 14.
- Reflectance Model		See Chapter 14.
- Earth Radiation Pressure	Ignored	
- Penumbra Model	6402000 m 1738000 m	Radius of Earth for shadow model. Radius of Moon for shadow model.
Solid Earth Tides		See Chapter 6.
Ocean Tides	Schwiderski Ocean Tide Model	See Chapter 7.
Relativistic Corrections		
- Propagation		
- LLR	Retardation due to Sun and Earth	See Chapter 16.
- VLBI	Retardation and bending due to Sun, Earth, and Moon	See Chapter 16.
- SLR	Retardation due to Earth	See Chapter 16.
- Time Epoch and Interval		
- LLR, VLBI	Annual, diurnal, and other periodic terms	See Chapter 16.
- SLR	none	See Chapter 16.
- Dynamics		
- LLR	Barycentric (n-body) formulation (β=γ=1)	See Chapter 15.
- SLR	Geocentric (1-body) formulation (β=γ=1)	See Chapter 15.

NUMERICAL STANDARDS
(continued)

ITEM	RECOMMENDED VALUE	COMMENTS
Empirical Force		
-LAGEOS	$C_T \times 10^{-12}$ m s^{-2} $\bar{V}/V$ per unit mass	C_T is an adjusted parameter that ranges from 0 to -6 over time. Mean value over LAGEOS lifetime is around -3.4.
Secular Acceleration of the Moon, $\dot{n}$		$\dot{n}$ is an adjusted parameter in LLR. Value in DE200/LE200 is near $-23.9/cy^2$.
MEASUREMENT MODEL		
Troposphere		
- SLR and LLR	Surface meteorology measurement plus Marini and Murray Model (1973).	See Chapter 10.
- VLBI		See Chapter 10. Water vapor radiometry if available-otherwise use model plus possible adjustment of vertical delay.
Satellite Center of Mass Correction		
- Lageos	0.24 m	
Solid Earth Tides Displacement	Wahr Solid Tide Model	See Chapter 6.
Ocean Loading Site Displacement	Schwiderski tides	See Chapter 8.
REFERENCE SYSTEMS	1984 Conventions except as noted.	
Conventional Inertial System	Mean equinox and equator of J2000.0	See Chapter 2.
Time Synchronization	UTC as given by BIPM	If using UTC(USNO), then use UTC(USNO)-UTC(BIPM) as published by BIPM to correct to UTC(BIPM).
Precession	IAU 1976	See Lieske, et al. (1977) for application.

NUMERICAL STANDARDS
(continued)

ITEM	RECOMMENDED VALUE	COMMENT
Nutation	IAU 1980	Based on Wahr Theory. Reference pole is the Celestial Ephemeris Pole (CEP). See Chapter 4.
Terrestrial Reference Frame		See Chapter 3.
Tidal Variations in UT1		See Chapter 11.
VLBI Radio Source Positions and Designations		See Chapter 2.
Tectonic Motion	AM0-2	See Chapter 9.
Ephemeris System	Astronomical Almanac, 1984 (DE200/LE200).	Uses the Equinox and Equator of J2000.0. Origin in right ascension is set equal to the dynamical equinox of J2000.0. See Chapter 4.
Lunar Reference Frame		
- Retro-Reflector Coordinates (meters)		These coordinates are consistent with the DE200/LE200 ephemeris system but they are adjustable in LLR.

Apollo 11

	X1	X2	X3
PA	1592012.174	690605.998	21006.310
ME	1591752.786	691221.955	20394.850
	R	LONG	LAT
PA	1735477.073	23.45093088	.69352820
ME	1735477.073	23.47299617	.67333975

NUMERICAL STANDARDS
(continued)

ITEM		RECOMMENDED VALUE		COMMENT
Apollo 14				
		X1	X2	X3
	PA	1652662.237	-521095.647	-109727.640
	ME	1652821.419	-520455.963	-110364.156
		R	LONG	LAT
	PA	1736339.050	-17.50041767	-3.62321101
	ME	1736339.050	-17.47866283	-3.64425710
Apollo 15				
		X1	X2	X3
	PA	1554686.268	98004.046	765010.082
	ME	1554942.413	98604.650	764412.078
		R	LONG	LAT
	PA	1735481.089	3.60702873	26.15530389
	ME	1735481.089	3.62847880	26.13331104
Lunakhod 2				
		X1	X2	X3
	PA	1339413.779	801793.356	756361.607
	ME	1339394.295	802310.618	755847.426
		R	LONG	LAT
	PA	1734642.539	30.90537743	25.85105146
	ME	1734642.539	30.92203167	25.83218088

PA = Principal Axis Coordinates
ME = Mean Earth Coordinates

Rotation Angles between mean Earth and principal axis coordinates are tau = 79.815, P1 = -79.350, P2 = 0.295 arcseconds.