Selected Astronomical Constants

The Defining Constants (1) and Current Best Estimates (2) were adopted by the IAU 2009 GA, while the planetary equatorial radii (3), are taken from the report of the IAU WG on Cartographic Coordinates and Rotational Elements. For each quantity the list tabulates its description, symbol and value, and to the right, as appropriate, its uncertainty in units that the quantity is given in. Further information is given at foot of the table on the next page.

1 Defining Constants

1.1 Natural Defining Constant:

Speed of light	$c = 299\ 792\ 458\ \mathrm{m\,s^{-1}}$	

1.2 Auxiliary Defining Constants:

Gaussian gravitational constant	$k = 0{\cdot}017\ 202\ 098\ 95$	
$1 - \mathrm{d(TT)/d(TCG)}$	$L_G = 6{\cdot}969\ 290\ 134 \times 10^{-10}$	
$1 - \mathrm{d(TDB)/d(TCB)}$	$L_B = 1{\cdot}550\ 519\ 768 \times 10^{-8}$	
TDB − TCB at T_0 = 244 3144·5003 725	$\mathrm{TDB}_0 = -6{\cdot}55 \times 10^{-5}$ s	
Earth rotation angle (ERA) at J2000·0 UT1	$\theta_0 = 0{\cdot}779\ 057\ 273\ 2640$ revolutions	
Rate of advance of ERA	$\dot{\theta} = 1{\cdot}002\ 737\ 811\ 911\ 354\ 48$ revolutions UT1-day^{-1}	

2. Current Best Estimates (IAU 2009)

2.1 Natural Measurable Constant:

Constant of gravitation	$G = 6{\cdot}674\ 28 \times 10^{-11}\ \mathrm{m^3\,kg^{-1}\,s^{-2}}$	$\pm 6{\cdot}7 \times 10^{-15}$

2.2 Derived Constants:

Astronomical unit (unit distance)†	$au = A = 149\ 597\ 870\ 700$ m	± 3
Average value of $1 - \mathrm{d(TCG)/d(TCB)}$	$L_C = 1{\cdot}480\ 826\ 867\ 41 \times 10^{-8}$	$\pm 2 \times 10^{-17}$

2.3 Body Constants:

Mass Ratio: Moon to Earth	$M_M/M_E = 1{\cdot}230\ 003\ 71 \times 10^{-2}$	$\pm 4 \times 10^{-10}$
Mass Ratio: Sun to Mercury	$M_S/M_{Me} = 6{\cdot}023\ 6 \times 10^{6}$	$\pm 3 \times 10^{2}$
Mass Ratio: Sun to Venus	$M_S/M_{Ve} = 4{\cdot}085\ 237\ 19 \times 10^{5}$	$\pm 8 \times 10^{-3}$
Mass Ratio: Sun to Mars	$M_S/M_{Ma} = 3{\cdot}098\ 703\ 59 \times 10^{6}$	$\pm 2 \times 10^{-2}$
Mass Ratio: Sun to Jupiter	$M_S/M_J = 1{\cdot}047\ 348\ 644 \times 10^{3}$	$\pm 1{\cdot}7 \times 10^{-5}$
Mass Ratio: Sun to Saturn	$M_S/M_{Sa} = 3{\cdot}497\ 9018 \times 10^{3}$	$\pm 1 \times 10^{-4}$
Mass Ratio: Sun to Uranus	$M_S/M_U = 2{\cdot}290\ 298 \times 10^{4}$	$\pm 3 \times 10^{-2}$
Mass Ratio: Sun to Neptune	$M_S/M_N = 1{\cdot}941\ 226 \times 10^{4}$	$\pm 3 \times 10^{-2}$
Mass Ratio: Sun to Pluto	$M_S/M_P = 1{\cdot}365\ 66 \times 10^{8}$	$\pm 2{\cdot}8 \times 10^{4}$
Mass Ratio: Sun to Eris	$M_S/M_{Eris} = 1{\cdot}191 \times 10^{8}$	$\pm 1{\cdot}4 \times 10^{6}$
Mass Ratio: Ceres to Sun	$M_{Ceres}/M_S = 4{\cdot}72 \times 10^{-10}$	$\pm 3 \times 10^{-12}$
Mass Ratio: Pallas to Sun	$M_{Pallas}/M_S = 1{\cdot}03 \times 10^{-10}$	$\pm 3 \times 10^{-12}$
Mass Ratio: Vesta to Sun	$M_{Vesta}/M_S = 1{\cdot}35 \times 10^{-10}$	$\pm 3 \times 10^{-12}$
Equatorial radius for Earth	$a_E = a_e = 6\ 378\ 136{\cdot}6$ m	$\pm 0{\cdot}10$
Dynamical form-factor for the Earth	$J_2 = 0{\cdot}001\ 082\ 635\ 9$	$\pm 1 \times 10^{-10}$
Long-term variation in J_2	$\dot{J}_2 = -3{\cdot}001 \times 10^{-9}\ \mathrm{cy^{-1}}$	$\pm 6 \times 10^{-10}$
Heliocentric gravitational constant	$GM_S = 1{\cdot}327\ 124\ 420\ 99 \times 10^{20}\ \mathrm{m^3\,s^{-2}}$ (TCB)	$\pm 1 \times 10^{10}$
	$= 1{\cdot}327\ 124\ 400\ 41 \times 10^{20}\ \mathrm{m^3\,s^{-2}}$ (TDB)	$\pm 1 \times 10^{10}$
Geocentric gravitational constant	$GM_E = 3{\cdot}986\ 004\ 418 \times 10^{14}\ \mathrm{m^3\,s^{-2}}$ (TCB)	$\pm 8 \times 10^{5}$
	$= 3{\cdot}986\ 004\ 415 \times 10^{14}\ \mathrm{m^3\,s^{-2}}$ (TT)	$\pm 8 \times 10^{5}$
	$= 3{\cdot}986\ 004\ 356 \times 10^{14}\ \mathrm{m^3\,s^{-2}}$ (TDB)	$\pm 8 \times 10^{5}$
Potential of the geoid	$W_0 = 6{\cdot}263\ 685\ 60 \times 10^{7}\ \mathrm{m^2\,s^{-2}}$	$\pm 0{\cdot}5$
Nominal mean angular velocity of Earth rotation	$\omega = 7{\cdot}292\ 115 \times 10^{-5}\ \mathrm{rad\,s^{-1}}$	

2.4 Initial Values at J2000·0:

Mean obliquity of the ecliptic	$\epsilon_{J2000{\cdot}0} = \epsilon_0 = 23^\circ\ 26'\ 21''\!.406 = 84\ 381''\!.406$	$\pm 0''\!.001$

Selected Astronomical Constants (continued)

3 Constants from IAU WG on Cartographic Coordinates and Rotational Elements (2007)

Equatorial radii in km:

Mercury	2 439·7 ±1·0	Jupiter	71 492 ± 4	Pluto	1 195 ±5
Venus	6 051·8 ±1·0	Saturn	60 268 ± 4		
Earth	6 378·14 ±0·01	Uranus	25 559 ± 4	Moon (mean)	1 737·4 ±1
Mars	3 396·19 ±0·1	Neptune	24 764 ±15	Sun	696 000

4 Other Constants

Light-time for unit distance†	$\tau_A = A/c = 499^{s}004\ 783\ 84$	$\pm 1 \times 10^{-8}$
	$1/\tau_A = 173{\cdot}144\ 632\ 674$ au/d	$\pm 3 \times 10^{-9}$
Mass Ratio: Earth to Moon	$M_E/M_M = 1/\mu = 81{\cdot}300\ 568$	$\pm 3 \times 10^{-6}$
Mass Ratio: Sun to Earth	$GM_S/GM_E = 332\ 946{\cdot}0487$	$\pm 0{\cdot}0007$
Mass of the Sun	$M_S = S = GM_S/G = 1{\cdot}9884 \times 10^{30}$ kg	$\pm 2 \times 10^{26}$
Mass of the Earth	$M_E = E = GM_E/G = 5{\cdot}9722 \times 10^{24}$ kg	$\pm 6 \times 10^{20}$
Mass Ratio: Sun to Earth + Moon	$(S/E)/(1+\mu) = 328\ 900{\cdot}5596$	$\pm 7 \times 10^{-4}$
Earth, reciprocal of flattening (IERS 2003)	$1/f = 298{\cdot}256\ 42$	$\pm 1 \times 10^{-5}$
Rates of precession at J2000·0 (IAU 2006)		
General precession in longitude	$p_A = 5028''\!.796\ 195$ per Julian century (TDB)	
Rate of change in obliquity	$\dot\epsilon = -46''\!.836\ 769$ per Julian century (TDB)	
Precession of the equator in longitude	$\dot\psi = 5038''\!.481\ 507$ per Julian century (TDB)	
Precession of the equator in obliquity	$\dot\omega = -0''\!.025\ 754$ per Julian century (TDB)	
Constant of nutation at epoch J2000·0	$N = 9''\!.2052\ 331$	
Solar parallax	$\pi_\odot = \sin^{-1}(a_e/A) = 8''\!.794\ 143$	
Constant of aberration at epoch J2000·0	$\kappa = 20''\!.495\ 51$	

Masses of the larger natural satellites: mass satellite/mass of the planet (see pages F3, F5)

Jupiter	Io	$4{\cdot}704 \times 10^{-5}$	**Saturn**	Titan	$2{\cdot}366 \times 10^{-4}$
	Europa	$2{\cdot}528 \times 10^{-5}$	**Uranus**	Titania	$4{\cdot}06 \times 10^{-5}$
	Ganymede	$7{\cdot}805 \times 10^{-5}$		Oberon	$3{\cdot}47 \times 10^{-5}$
	Callisto	$5{\cdot}667 \times 10^{-5}$	**Neptune**	Triton	$2{\cdot}089 \times 10^{-4}$

Users are advised to check the website of the IAU WG on Numerical Standards for Fundamental Astronomy (NFSA) at http://maia.usno.navy.mil/NSFA.html for the latest list of 'Current Best Estimates'. The NFSA website also has detailed information about the constants, and all the relevant references.

This almanac, in certain circumstances, may not use constants from this list. The reasons and those constants used are given at the end of Section L *Notes and References*.

Units

The units meter (m), kilogram (kg), and SI second (s) are the units of length, mass and time in the International System of Units (SI).

The astronomical unit of time is a time interval of one day (D) of 86400 seconds. An interval of 36525 days is one Julian century. Some constants that involve time, either directly or indirectly need to be compatible with the underlying time-scales. In order to specify this (TDB) or (TCB) or (TT), as appropriate, is included after the unit to indicate that the value of the constant is compatible with the specified time-scale, for example, TDB-compatible.

The astronomical unit of mass is the mass of the Sun (M_S). The dimensions of k^2 are those of the constant of gravitation (G), which are $A^3 M_S^{-1} D^{-2}$, i.e. $m^3\,kg^{-1}\,s^{-2}$.

The astronomical unit† of length (the *au*) in metres is that length $A = \sqrt[3]{(GM_S D^2/k^2)}$, where k, the Gaussian gravitational constant and GM_S, the heliocentric gravitational constant (TDB-compatible value), are tabulated on the previous page. **Note** that at present (2009 September) the *au* is considered to be TDB-compatible and no TCB-compatible value has been agreed.