Selected Astronomical Constants

The IAU 2009 System of Astronomical Constants (1) published in the IAU WG report on Numerical Standards for Fundamental Astronomy (NSFA, 2011) and updated by resolution B2 of the IAU XXVIII General Assembly (2012), (2) planetary equatorial radii, from the IAU WG report on Cartographic Coordinates and Rotational Elements: 2015 (2018), and (3) other useful constants. Tabulated for each quantity is its description, symbol and value, and, as appropriate, its uncertainty in units in which the quantity is given. Further information is given at the foot of the table on the next page.

1 IAU 2009/2012 System of Astronomical Constants[1]

1.1 Natural Defining Constant:

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

1.2 Auxiliary Defining Constants:

Astronomical unit[2]	$au = 149\,597\,870\,700$ m	
$1 - $ d(TT)/d(TCG)	$L_G = 6{\cdot}969\,290\,134 \times 10^{-10}$	
$1 - $ d(TDB)/d(TCB)	$L_B = 1{\cdot}550\,519\,768 \times 10^{-8}$	
TDB$-$TCB at T$_0 = 244\,3144{\cdot}5003\,725$(TCB)	$\mathrm{TDB}_0 = -6{\cdot}55 \times 10^{-5}$ 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}	

1.3 Natural Measurable Constant:

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

1.4 Other Constants:

Average value of $1 - $ d(TCG)/d(TCB)	$L_C = 1{\cdot}480\,826\,867\,41 \times 10^{-8}$	$\pm 2 \times 10^{-17}$

1.5 Body Constants:

Solar mass parameter[2]	$GM_S = 1{\cdot}327\,124\,420\,99 \times 10^{20}$ m^3 s^{-2} (TCB)	$\pm 1 \times 10^{10}$
	$= 1{\cdot}327\,124\,400\,41 \times 10^{20}$ m^3 s^{-2} (TDB)	$\pm 1 \times 10^{10}$
Equatorial radius for Earth	$a_E = a_e = 6\,378\,136{\cdot}6$ m (TT)	$\pm 0{\cdot}1$
Dynamical form-factor for the Earth	$J_2 = 0{\cdot}001\,082\,635\,9$	$\pm 1 \times 10^{-10}$
Time rate of change in J_2	$\dot{J}_2 = -3{\cdot}0 \times 10^{-9}$ cy^{-1}	$\pm 6 \times 10^{-10}$
Geocentric gravitational constant	$GM_E = 3{\cdot}986\,004\,418 \times 10^{14}$ m^3 s^{-2} (TCB)	$\pm 8 \times 10^5$
	$= 3{\cdot}986\,004\,415 \times 10^{14}$ m^3 s^{-2} (TT)	$\pm 8 \times 10^5$
	$= 3{\cdot}986\,004\,356 \times 10^{14}$ m^3 s^{-2} (TDB)	$\pm 8 \times 10^5$
Potential of the geoid	$W_0 = 6{\cdot}263\,685\,34 \times 10^7$ m^2 s^{-2}	$\pm 0{\cdot}5$
Nominal mean angular velocity of the Earth	$\omega = 7{\cdot}292\,115 \times 10^{-5}$ rad s^{-1} (TT)	
Mass Ratio: Moon to Earth	$M_M/M_E = 1{\cdot}230\,003\,71 \times 10^{-2}$	$\pm 4 \times 10^{-10}$

Ratio of the mass of the Sun to the mass of the Body

Mass Ratio: Sun to Mercury[3]	$M_S/M_{Me} = 6{\cdot}023\,6 \times 10^6$	$\pm 3 \times 10^2$
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[3]	$M_S/M_U = 2{\cdot}290\,298 \times 10^4$	$\pm 3 \times 10^{-2}$
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 (134340) Pluto[3]	$M_S/M_P = 1{\cdot}365\,66 \times 10^8$	$\pm 2{\cdot}8 \times 10^4$
Mass Ratio: Sun to (136199) Eris	$M_S/M_{Eris} = 1{\cdot}191 \times 10^8$	$\pm 1{\cdot}4 \times 10^6$

Ratio of the mass of the Body to the mass of the Sun

Mass Ratio: (1) Ceres to Sun[3]	$M_{Ceres}/M_S = 4{\cdot}72 \times 10^{-10}$	$\pm 3 \times 10^{-12}$
Mass Ratio: (2) Pallas to Sun	$M_{Pallas}/M_S = 1{\cdot}03 \times 10^{-10}$	$\pm 3 \times 10^{-12}$
Mass Ratio: (4) Vesta to Sun[3]	$M_{Vesta}/M_S = 1{\cdot}35 \times 10^{-10}$	$\pm 3 \times 10^{-12}$

All values of the masses from Mars to Eris are the sum of the masses of the celestial body and its satellites.

1.6 Initial Values at J2000·0:

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

Selected Astronomical Constants (continued)

2 Constants from IAU WG on Cartographic Coordinates and Rotational Elements 2015

Equatorial radii in km:

Mercury	2 440·53	±0·04	Jupiter	71 492 ± 4	(134340) Pluto	1 188·3	±1·6
Venus	6 051·8	±1·0	Saturn	60 268 ± 4			
Earth	6 378·1366	±0·0001	Uranus	25 559 ± 4	Moon (mean)	1 737·4	±1
Mars	3 396·19	±0·1	Neptune	24 764 ±15	Sun	695 700[4]	

3 Other Constants

Light-time for unit distance[2]	$\tau_A = au/c = 499^s.004\ 783\ 84$ $1/\tau_A = 173{\cdot}144\ 632\ 674$ au/d	
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	$GM_S/GM_E = 332\ 946{\cdot}0487$	$\pm 7 \times 10^{-4}$
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 2010)	$1/f = 298{\cdot}256\ 42$	$\pm 1 \times 10^{-5}$
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	$\pi_\odot = \sin^{-1}(a_e/au) = 8''.794\ 143$	
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	$4{\cdot}705 \times 10^{-5}$	**Uranus**	Ariel	$1{\cdot}49 \times 10^{-5}$
	Europa	$2{\cdot}528 \times 10^{-5}$		Umbriel	$1{\cdot}41 \times 10^{-5}$
	Ganymede	$7{\cdot}805 \times 10^{-5}$		Titania	$3{\cdot}94 \times 10^{-5}$
	Callisto	$5{\cdot}667 \times 10^{-5}$		Oberon	$3{\cdot}32 \times 10^{-5}$
Saturn	Titan	$2{\cdot}367 \times 10^{-4}$	**Neptune**	Triton	$2{\cdot}089 \times 10^{-4}$

The IAU Working Group on Numerical Standards for Fundamental Astronomy maintains a website, see http://asa.hmnao.com, which contains an agreed list of **Current Best Estimates** together with detailed information about the constants, and relevant references. See footnotes below for more details.

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

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, for example TDB-compatible. To specify the time scale that the value of the constant is compatible with, (TDB), (TCB) or (TT) is included after the unit.

[1] The IAU 2009 System of Astronomical Constants classifies the constants into the groups shown. This may be redefined and users should check the NSFA website for updates.

[2] The astronomical unit of length (au) in metres is re-defined as a conventional unit of length (resolution B2, IAU XXVIII GA 2012) in agreement with the value adopted by IAU 2009 Resolution B2; it is to be used with all time scales such as TCB, TDB, TCG, TT, etc. Also the heliocentric gravitational constant GM_S is renamed the solar mass parameter. Further details are given in Section L *Notes and References*.

[3] In May 2015 new best estimates were agreed (see http://asa.hmnao.com). Values printed here are those of the IAU 2009 System of Astronomical Constants.

[4] The value printed here is that from the report of the IAU WG on Cartographic Coordinates and Rotational Elements: 2015 (2018) and is the value used throughout this almanac. Further details are given in Section L *Notes and References*.