Astronomical Constants

The IAU 2009 System of Astronomical Constants (1) as published in the Report of the IAU Working Group on Numerical Standards for Fundamental Astronomy (NSFA, 2011), (2) planetary equatorial radii, taken from the report of the IAU WG on Cartographic Coordinates and Rotational Elements: 2009 (2011), and lastly (3) other useful constants. 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. IAU 2009 System of Astronomical Constants

1.1 Natural Defining Constant:

Speed of light \( c = 299 792 458 \text{ m s}^{-1} \)

1.2 Auxiliary Defining Constants:

- Gaussian gravitational constant \( k = 0.017 202 098 95 \)
- Heliocentric gravitational constant \( L_G = 6.669 290 134 \times 10^{-10} \text{ m s}^{-2} \)
- Earth rotation angle (ERA) at J2000.0 UT1 \( \theta_1 = 0.779 057 273 2640 \) revolutions
- Rate of advance of ERA \( \dot{\theta} = 1.002 737 811 911 354 48 \text{ revolutions UT1-day}^{-1} \)

1.3 Natural Measurable Constant:

Constant of gravitation \( G = 6.674 28 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2} \pm 6.7 \times 10^{-15} \)

1.4 Other Constants:

- Astronomical unit (unit distance) \( au = A = 149 597 870 700 \text{ m} \pm 3 \)
- Average value of 1 - d(TCG)/d(TCB) \( L_C = 1.480 826 867 41 \times 10^{-8} \pm 2 \times 10^{-17} \)

1.5 Body Constants:

- Heliocentric gravitational constant \( GM_\odot = 1.327 124 420 99 \times 10^{20} \text{ m}^3 \text{ s}^{-2} (\text{TCB}) \pm 1 \times 10^{10} \text{ (TDB)} \pm 1 \times 10^{10} \)
- Equatorial radius for Earth \( a_\odot = a_E = 6.378 136 6 \text{ m} (\text{TDB}) \pm 0.1 \)
- Dynamical form-factor for the Earth \( J_2 = 0.001 082 635 9 \pm 1 \times 10^{-10} \)
- Time rate of change in \( J_2 \) \( \dot{J}_2 = -3.0 \times 10^{-9} \text{ cy}^{-1} \pm 6 \times 10^{-10} \)
- Geocentric gravitational constant \( GM_\odot = 3.986 004 148 \times 10^{14} \text{ m}^3 \text{ s}^{-2} (\text{TCB}) \pm 8 \times 10^{5} \text{ (TDB)} \pm 8 \times 10^{5} \)
- Potential of the geoid \( W_0 = 6.263 685 60 \times 10^{-3} \text{ m}^2 \text{ s}^{-2} \pm 0.5 \)
- Nominal mean angular velocity of the Earth \( \omega = 7.292 115 \times 10^{-5} \text{ rad s}^{-1} (\text{TT}) \)
- Mass Ratio: Moon to Earth \( M_M/M_\odot = 1.230 003 71 \times 10^{-3} \pm 4 \times 10^{-10} \)
- Mass Ratio: Sun to the mass of the Body

1.6 Mass Ratios:

- Mass Ratio: Sun to Mercury \( M_S/M_{\text{Mer}} = 6.023 6 \times 10^{6} \pm 3 \times 10^{2} \)
- Mass Ratio: Sun to Venus \( M_S/M_{\text{V}} = 4.085 237 19 \times 10^{5} \pm 8 \times 10^{-5} \)
- Mass Ratio: Sun to Mars \( M_S/M_{\text{M}} = 3.098 703 59 \times 10^{6} \pm 2 \times 10^{-2} \)
- Mass Ratio: Sun to Jupiter \( M_S/M_{J} = 1.047 354 644 \times 10^{8} \pm 1 \times 10^{-5} \)
- Mass Ratio: Sun to Saturn \( M_S/M_{S} = 3.497 9018 \times 10^{8} \pm 1 \times 10^{-4} \)
- Mass Ratio: Sun to Uranus \( M_S/M_{U} = 2.290 298 \times 10^{8} \pm 3 \times 10^{-2} \)
- Mass Ratio: Sun to Neptune \( M_S/M_{N} = 1.941 226 \times 10^{8} \pm 3 \times 10^{-2} \)
- Mass Ratio: Sun to (134340) Pluto \( M_S/M_{P} = 1.365 66 \times 10^{8} \pm 2 \times 10^{4} \)
- Mass Ratio: Sun to (136199) Eris \( M_S/M_{Eris} = 1.191 \times 10^{8} \pm 1 \times 10^{6} \)

1.7 Ration of the mass of the Body to the mass of the Sun

- Mass Ratio: (1) Ceres to Sun \( M_{\text{Ceres}}/M_S = 4.72 \times 10^{-10} \pm 3 \times 10^{-12} \)
- Mass Ratio: (2) Pallas to Sun \( M_{\text{Pallas}}/M_S = 1.03 \times 10^{-10} \pm 3 \times 10^{-12} \)
- Mass Ratio: (4) Vesta to Sun \( M_{\text{Vesta}}/M_S = 1.35 \times 10^{-10} \pm 3 \times 10^{-12} \)

All values of the masses from Mars to Eris are the sum of the masses of the celestial body and its satellites.
Selected Astronomical Constants (continued)

1.6 Initial Values at J2000-0:

Mean obliquity of the ecliptic \( \epsilon_{J2000.0} = \epsilon_0 = 23\,\!\!:\!\!:\!\!26\,\!\!:\!\!\!21^\prime\!406 = 84.381\!\!:\!\!2406 \pm 0.001 \)

2 Constants from IAU WG on Cartographic Coordinates and Rotational Elements 2009

Equatorial radii in km:

Mercury 2 439.7 \pm 1.0 Jupiter 71 492 \pm 4 (134340) Pluto 1 195 \pm 5

Venus 6 051.8 \pm 1.0 Saturn 60 268 \pm 4

Earth 6 378 1366 \pm 0.0001 Uranus 25 559 \pm 4 Moon (mean) 1 737.4 \pm 1

Mars 3 939 19 \pm 1.0 Neptune 24 764 \pm 15 Sun 696 000

3 Other Constants

- Light-time for unit distance \( ^\dagger \) \( \tau_A = A/c = 499\!\!:\!\!004 783 84 \pm 1 \times 10^{-5} \)
- Mass Ratio: Earth to Moon \( M_E/M_M = 1/\mu = 81\!\!:\!\!300 568 \pm 3 \times 10^{-5} \)
- Mass of the Sun \( M_S = S = GM_S/G = 1.9884 \times 10^{30} \) kg \( \pm 2 \times 10^{20} \)
- Mass of the Earth \( M_E = E = GM_E/G = 5.9722 \times 10^{24} \) kg \( \pm 6 \times 10^{20} \)
- Mass Ratio: Sun to Earth + Moon \( (S/E)/(1+\mu) = 328 900 \pm 596 \) \( \pm 7 \times 10^{-4} \)
- Earth, reciprocal of flattening (IERS 2010) \( 1/f = 298.256 42 \pm 1 \times 10^{-5} \)
- Rates of precession at J2000-0 (IAU 2006)
  - General precession in longitude \( \psi = 0.508 \pm 195 \) per Julian century (TDB)
  - Rate of change in obliquity \( \omega = -1.052 \pm 745 \) per Julian century (TDB)
  - Precession of the equator in longitude \( \dot{\psi} = 0.388 \pm 507 \) per Julian century (TDB)
  - Precession of the equator in obliquity \( \dot{\omega} = -0.025 \pm 754 \) per Julian century (TDB)

Solar parallax \( \pi_0 = \sin^{-1}(a_\mu/A) = 8\!\!:\!\!794 143 \)

- Constant of aberration at epoch J2000-0 \( \kappa = 20.495 51 \pm 4 \times 10^{-4} \)

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

- Jupiter Io 4.704 \times 10^{-5} Saturn Titan 2.366 \times 10^{-4}
- Europa 2.528 \times 10^{-5} Uranus Titania 4.06 \times 10^{-5}
- Ganymede 7.805 \times 10^{-5} Oberon 3.47 \times 10^{-5}
- Callisto 5.667 \times 10^{-5} Neptune Triton 2.089 \times 10^{-4}

Users are advised to check the NSFA’s website at at http://maia.usno.navy.mil/NSFA for the latest list of ‘Current Best Estimates’. This 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 (\( \text{D} \)) 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 that of the Sun (\( M_S \)). The dimensions of \( k^2 \) are those of the constant of gravitation (\( G \)), which are \( A^3 M_S^{-1} \text{D}^{-2} \), i.e. \( m^3\text{kg}^{-1}\text{s}^{-2} \).

\(^\dagger\)The astronomical unit of length (the \( \text{au} \)) in metres is that length \( A = \sqrt{(GM_S)}/k^2 \), where \( k \) is the Gaussian gravitational constant and \( GM_S, \) the heliocentric gravitational constant (TDB-compatible value), are tabulated on the previous page. \( \text{Note} \) that at present (2011 September) the \( \text{au} \) is considered to be TDB-compatible and no TCB-compatible value has been agreed.