Selected 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) and updated by resolution B2 of the IAU XXVIII General Assembly (2012), (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 the foot of the table on the next page.

1 IAU 2009/2012 System of Astronomical Constants

1.1 Natural Defining Constant:

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

1.2 Auxiliary Defining Constants:

Astronomical unit (\( au \)) = 149 597 870 700 m

\( 1 - \frac{d(\text{TNT})}{d(\text{TDB})} = \frac{L_{\odot}}{L_{\oplus}} = \frac{L_{\oplus}}{L_{\oplus}} = \frac{L_{\oplus}}{L_{\oplus}} = 1.550 519 768 \times 10^{-8} \)

TDB – TCB at \( T_0 = 344 \, 3144 - 5003 \, 725 \) (TCB) \( \frac{\text{TDB}}{\text{TCB}} = -6.55 \times 10^{-3} \) s

Earth rotation angle (ERA) at J2000-0 UT1 \( \theta_0 = 0.779 057 273 264 \) revolutions

Rate of advance of ERA \( \dot{\theta} = 1.002 737 811 911 354 48 \) 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:

Average value of \( 1 - \frac{d(\text{TNT})}{d(\text{TDB})} \) \( L_C = 1.480 826 674 \times 10^{-8} \) \( \pm 2 \times 10^{-17} \)

1.5 Body Constants:

Solar mass parameter \( M_{\odot} = 1.327 124 209 99 \times 10^{20} \, \text{m}^3 \, \text{s}^{-2} \) (TCB) \( \pm 1 \times 10^{-10} \)

Equatorial radius for Earth \( a_E = a_E = 6.378 136.6 \) m (TT) \( \pm 0.1 \)

Dynamical form-factor for the Earth \( J_2 = 0.001 082 635 \) \( \pm 1 \times 10^{-10} \)

Time rate of change in \( J_2 \) \( J_2 = -3.0 \times 10^{-9} \) \( \text{cm} \, \text{s}^{-1} \) \( \pm 6 \times 10^{-10} \)

Geocentric gravitational constant \( G M_E = 3.986 004 15 \times 10^{6} \) m\(^3\)s\(^{-2}\) (TT) \( \pm 8 \times 10^{-5} \)

Potential of the geoid \( W_0 = 6.263 685 \) \( \times 10^{7} \) m\(^2\)s\(^{-2}\) \( \pm 0.5 \)

Nominal mean angular velocity of the Earth \( \omega = 7.292 115 \times 10^{-4} \) rad s\(^{-1}\) (TT)

Mass Ratio: Moon to Earth \( M_M/M_E = 1.23 \times 10^{-2} \) \( \pm 4 \times 10^{-10} \)

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

Mass Ratio: Sun to Mercury \( M_S/M_{\text{Mer}} = 0.023 6 \times 10^{6} \) \( \pm 3 \times 10^{-2} \)

Mass Ratio: Sun to Venus \( M_S/M_{\text{V}} = 0.048 237 19 \times 10^{4} \) \( \pm 8 \times 10^{-3} \)

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 \( M_S/M_{\text{J}} = 1.047 348 644 \times 10^{3} \) \( \pm 1.7 \times 10^{-5} \)

Mass Ratio: Sun to Saturn \( M_S/M_{\text{Sa}} = 3.497 901 8 \times 10^{3} \) \( \pm 1 \times 10^{-4} \)

Mass Ratio: Sun to Uranus \( M_S/M_{\text{U}} = 2.90 298 298 \times 10^{4} \) \( \pm 3 \times 10^{-2} \)

Mass Ratio: Sun to Neptune \( M_S/M_{\text{Ne}} = 1.941 226 2 \times 10^{6} \) \( \pm 3 \times 10^{-2} \)

Mass Ratio: Sun to (134340) Pluto \( M_S/M_{\text{P}} = 1.365 66 \times 10^{8} \) \( \pm 2.8 \times 10^{4} \)

Mass Ratio: Sun to (136199) Eris \( M_S/M_{\text{E}} = 1.191 \times 10^{8} \) \( \pm 1.4 \times 10^{6} \)

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

Mass Ratio: (1) Ceres to Sun \( M_{\text{C}}/M_{S} = 4.72 \times 10^{-10} \) \( \pm 3 \times 10^{-12} \)

Mass Ratio: (2) Pallas to Sun \( M_{\text{P}}/M_{S} = 1.03 \times 10^{-10} \) \( \pm 3 \times 10^{-12} \)

Mass Ratio: (4) Vesta to Sun \( M_{\text{V}}/M_{S} = 1.35 \times 10^{-10} \) \( \pm 3 \times 10^{-12} \)

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

continued …
ASTRONOMICAL CONSTANTS

Selected Astronomical Constants (continued)

1.6 Initial Values at J2000-0:

Mean obliquity of the ecliptic
\[ \epsilon_{2000-0} = \epsilon_0 = 23° 26' 21"' 0406, \pm 0° 001 \]

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

Equatorial radii in km:

- Mercury: 2 439 ± 1
- Venus: 6 051 ± 1
- Earth: 6 378 1366 ± 0
- Mars: 3 396 19 ± 1
- Jupiter: 71 492 ± 4
- Saturn: 60 268 ± 4
- Uranus: 25 559 ± 4
- Neptune: 24 764 ± 15
- Sun: 696 000

3 Other Constants

- Light-time for unit distance: \( t_A = au/c = 499'004 783 84 \)
  \[ 1/t_A = 173-144 632 674 \, au/d \]
- Mass Ratio: Earth to Moon: \( M_{\text{E}}/M_{\text{M}} = 1/\mu = 81 300 568 \, \pm 3 \times 10^{-6} \)
- Mass of the Sun: \( M_{\odot} = GM_{\odot}/G = 1 9884 \times 10^{30} \, \text{kg} \, \pm 2 \times 10^{-8} \)
- Mass of the Earth: \( M_{\text{E}} = E = GM_{\text{E}}/G = 5 9722 \times 10^{24} \, \text{kg} \, \pm 6 \times 10^{-8} \)
- Mass Ratio: Sun to Earth: \( (S/E)/(1 + \mu) = 328 900 5596 \, \pm 7 \times 10^{-8} \)
- 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: \( \dot{\psi} = 5028^7 796 195 \, \text{per Julian century (TDB)} \)
- Rate of change in obliquity: \( \dot{\epsilon} = -46^9 836 769 \, \text{per Julian century (TDB)} \)
- Precession of the equator in longitude: \( \omega = -60^7 025 754 \, \text{per Julian century (TDB)} \)
- Precession of the equator in obliquity: \( \dot{\omega} = -0^7 0487 \, \text{per Julian century (TDB)} \)
- Constant of nutation at epoch J2000-0: \( N = 9^2 2052 331 \)
- Solar parallax: \( \pi_0 = \sin^{-1}(a_c/A) = 8^\circ 794 143 \)
- Constant of aberration at epoch J2000-0: \( \psi = 20^\circ 495 51 \)

Rates of precession at J2000-0 (IAU 2006):

- General precession in longitude: \( \dot{\epsilon} = 5028^7 796 195 \, \text{per Julian century (TDB)} \)
- Rate of change in obliquity: \( \dot{\epsilon} = -46^9 836 769 \, \text{per Julian century (TDB)} \)
- Precession of the equator in longitude: \( \omega = -60^7 025 754 \, \text{per Julian century (TDB)} \)
- Precession of the equator in obliquity: \( \dot{\omega} = -0^7 0487 \, \text{per Julian century (TDB)} \)
- Constant of nutation at epoch J2000-0: \( N = 9^2 2052 331 \)
- Solar parallax: \( \pi_0 = \sin^{-1}(a_c/A) = 8^\circ 794 143 \)
- Constant of aberration at epoch J2000-0: \( \psi = 20^\circ 495 51 \)

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

<table>
<thead>
<tr>
<th>Planet</th>
<th>Mass ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Io</td>
<td>10^{-5}</td>
</tr>
<tr>
<td>Europa</td>
<td>10^{-5}</td>
</tr>
<tr>
<td>Ganymede</td>
<td>10^{-5}</td>
</tr>
<tr>
<td>Callisto</td>
<td>10^{-5}</td>
</tr>
</tbody>
</table>


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 365.25 days is one Julian century. Some constants that involve time, whether 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.

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) is re-defined as a conventional unit of length (resolution B2, IAU XXVII 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 \( GM_\odot \) is renamed the solar mass parameter. Further details are given in Section L Notes and References.

3 These values are those of the IAU 2009 System of Astronomical Constants. In May 2015 new best estimates were agreed (see the NSFA website at http://maia.usno.navy.mil/NSFA/NSFA_cbe.html).