Resolution B3
on recommended nominal conversion constants for selected solar and planetary properties

Proposed by IAU Inter-Division A-G Working Group on Nominal Units for Stellar & Planetary Astronomy

August 13, 2015

The XXIXth International Astronomical Union General Assembly,

Recognizing

that notably different values of the solar mass, radius, luminosity, effective temperature, total solar irradiance, of the masses and radii of the Earth and Jupiter, and of the Newtonian constant of gravitation G have been used by researchers to express and derive fundamental stellar and planetary properties,

Noting

1. that neither the solar nor the planetary masses and radii are secularly constant and that their instantaneous values are gradually being determined more precisely through improved observational techniques and methods of data analysis, and
2. that the common practice of expressing the stellar and planetary properties in units of the properties of the Sun, the Earth, or Jupiter inevitably leads to unnecessary systematic differences that are becoming apparent with the

rapidly increasing accuracy of spectroscopic, photometric, and interferometric observations of stars and extrasolar planets[1], and

3. that the universal constant of gravitation G is currently one of the least precisely determined constants, whereas the error in the product $GM_{\odot}$ is five orders of magnitude smaller (Petit & Luzum 2010, and references therein),

Recommends

In all scientific publications in which **accurate** values of basic stellar or planetary properties are derived or quoted:

1. that whenever expressing stellar properties in units of the solar radius, total solar irradiance, solar luminosity, solar effective temperature, or solar mass parameter, that the nominal values $\mathcal{R}^{\rm N}_{\odot}$, $\mathcal{S}^{\rm N}_{\odot}$, $\mathcal{L}^{\rm N}_{\odot}$, $\mathcal{T}^{\rm N}_{\rm eff\odot}$, and $(\mathcal{GM})^{\rm N}_{\odot}$, be used, respectively, which are by definition *exact* and are expressed in SI units. These *nominal* values should be understood as conversion factors only — chosen to be close to the current commonly accepted estimates (see table below) — not as the true solar properties. Their consistent use in all relevant formulas and/or model calculations will guarantee a uniform conversion to SI units. Symbols such as $L_{\odot}$ and $R_{\odot}$, for example, should only be used to refer to actual estimates of the solar luminosity and solar radius (with uncertainties),

2. that the same be done for expressing planetary properties in units of the equatorial and polar radii of the Earth and Jupiter (i.e., adopting nominal values $\mathcal{R}^{\rm N}_{e\rm E}$, $\mathcal{R}^{\rm N}_{p\rm E}$, $\mathcal{R}^{\rm N}_{e\rm J}$, and $\mathcal{R}^{\rm N}_{p\rm J}$, expressed in meters), and the nominal terrestrial and jovian mass parameters $(\mathcal{GM})^{\rm N}_{\rm E}$ and $(\mathcal{GM})^{\rm N}_{\rm J}$, respectively (expressed in units of $\rm m^3\,s^{-2}$). Symbols such as $\rm GM_E$, listed in the IAU 2009 system of astronomical constants (Luzum et al. 2011), should be used only to refer to actual estimates (with uncertainties),

3. that the IAU (2015) System of Nominal Solar and Planetary Conversion Constants be adopted as listed below:

SOLAR CONVERSION CONSTANTS		
$1\mathcal{R}^{\rm N}_\odot$	=	6.957×10^8 m
$1\mathcal{S}^{\rm N}_\odot$	=	1361 W m^{-2}
$1\mathcal{L}^{\rm N}_\odot$	=	3.828×10^{26} W
$1\mathcal{T}^{\rm N}_{\rm eff\odot}$	=	5772 K
$1(\mathcal{GM})^{\rm N}_\odot$	=	$1.327\,124\,4 \times 10^{20}$ m^{3}s^{-2}

PLANETARY CONVERSION CONSTANTS		
$1\,\mathcal{R}^{\rm N}_{e\rm E}$	=	6.3781×10^6 m
$1\,\mathcal{R}^{\rm N}_{p\rm E}$	=	6.3568×10^6 m
$1\,\mathcal{R}^{\rm N}_{e\rm J}$	=	7.1492×10^7 m
$1\,\mathcal{R}^{\rm N}_{p\rm J}$	=	6.6854×10^7 m
$1\,(\mathcal{GM})^{\rm N}_{\rm E}$	=	$3.986\,004 \times 10^{14}$ m^3 s^{-2}
$1\,(\mathcal{GM})^{\rm N}_{\rm J}$	=	$1.266\,865\,3 \times 10^{17}$ m^3 s^{-2}

4. that an object's mass can be quoted in nominal solar masses $\mathcal{M}^{\rm N}_\odot$ by taking the ratio $(GM)_{\rm object}/(\mathcal{GM})^{\rm N}_\odot$, or in corresponding nominal jovian and terrestrial masses, $\mathcal{M}^{\rm N}_{\rm J}$ and $\mathcal{M}^{\rm N}_{\rm E}$, respectively, dividing by $(\mathcal{GM})^{\rm N}_{\rm J}$ and $(\mathcal{GM})^{\rm N}_{\rm E}$,

5. that if SI masses are explicitly needed, they should be expressed in terms of $(GM)_{\rm object}/G$, where the estimate of the Newtonian constant G should be specified in the publication (for example, the 2014 CODATA value is $G = 6.67408\,(\pm0.00031) \times 10^{-11}$ m^3 kg^{-1} s^{-2}),

6. that if nominal volumes are needed, that a nominal terrestrial volume be derived as $4\,\pi\,\mathcal{R}^{\rm N\,2}_{e\rm E}\,\mathcal{R}^{\rm N}_{p\rm E}/3$, and nominal jovian volume as $4\,\pi\,\mathcal{R}^{\rm N\,2}_{e\rm J}\,\mathcal{R}^{\rm N}_{p\rm J}/3$.

Explanation

1. The need for increased accuracy has led to a requirement to distinguish between Barycentric Coordinate Time (TCB) and Barycentric Dynamical Time (TDB). For this reason the *nominal solar mass parameter* $(\mathcal{GM})^{\rm N}_\odot$ value is adopted as an exact number, given with a precision within which its TCB and TDB values agree (Luzum et al. 2011). This precision is considered to be sufficient for most applications in stellar and exoplanetary research for the forseeable future.

2. The *nominal solar radius* $\mathcal{R}_\odot^{\rm N}$ corresponds to the solar photospheric radius suggested by Haberreiter et al. (2008)[2], who resolved the long-standing discrepancy between the seismic and photospheric solar radii. This $\mathcal{R}_\odot^{\rm N}$ value is consistent with that adopted by Torres et al. (2010) in their recent compilation of updated radii of well observed eclipsing binary systems.

3. The *nominal total solar irradiance* $\mathcal{S}_\odot^{\rm N}$ corresponds to the mean total electromagnetic energy from the Sun, integrated over all wavelengths, incident per unit area per unit time at distance 1 au — also measured contemporarily as the *total solar irradiance* (TSI; e.g., Willson 1978) and known historically as the *solar constant* (Pouillet 1838). $\mathcal{S}_\odot^{\rm N}$ corresponds to the solar cycle 23-averaged TSI ($S_\odot = 1361$ ($\pm$ 1) W m^{-2}; 2σ uncertainty; Kopp et al., in prep.)[3].

4. The *nominal solar luminosity* $\mathcal{L}_\odot^{\rm N}$ corresponds to the mean solar radiative luminosity rounded to an appropriate number of significant figures. The current (2015) best estimate of the mean solar luminosity $L_\odot$ was calculated using the solar cycle-averaged TSI[3] and the IAU 2012 definition of the astronomical unit[4].

5. The *nominal solar effective temperature* $\mathcal{T}_{\rm eff\odot}^{\rm N}$ corresponds to the effective temperature calculated using the current (2015) best estimates of the solar radiative luminosity and photospheric radius, and the CODATA 2014 value for the Stefan-Boltzmann constant[5], rounded to an appropriate number of significant figures.

6. The parameters $\mathcal{R}_{e\rm E}^{\rm N}$ and $\mathcal{R}_{p\rm E}^{\rm N}$ correspond respectively to the Earth's "zero tide" equatorial and polar radii as adopted following 2003 and 2010 IERS Conventions (McCarthy & Petit 2004; Petit & Luzum 2010), the IAU 2009 system of astronomical constants (Luzum et al. 2011), and the IAU Working Group on Cartographic Coordinates and Rotational Elements (Archinal et al. 2011). If equatorial vs. polar radius is not explicitly specified, it should be understood that *nominal terrestrial radius* refers specifically to $\mathcal{R}_{e\rm E}^{\rm N}$, following common usage.

7. The parameters $\mathcal{R}_{e\rm J}^{\rm N}$ and $\mathcal{R}_{p\rm J}^{\rm N}$ correspond respectively to the one-bar equatorial and polar radii of Jupiter adopted by the IAU Working Group on Cartographic Coordinates and Rotational Elements 2009 (Archinal et al. 2011).

If equatorial vs. polar radius is not explicitly specified, it should be understood that *nominal jovian radius* refers specifically to $\mathcal{R}^{\rm N}_{e\rm J}$, following common usage.

8. The *nominal terrestrial mass parameter* $(\mathcal{GM})^{\rm N}_{\rm E}$ is adopted from the IAU 2009 system of astronomical constants (Luzum et al. 2011), but rounded to the precision within which its TCB and TDB values agree. The *nominal jovian mass parameter* $(\mathcal{GM})^{\rm N}_{\rm J}$ is calculated based on the mass parameter for the Jupiter system from the IAU 2009 system of astronomical constants (Luzum et al. 2011), subtracting off the contribution from the Galilean satellites (Jacobson et al. 2000). The quoted value is rounded to the precision within which the TCB and TDB values agree, and the uncertainties in the masses of the satellites are negligible.

9. The nominal value of a quantity Q can be transcribed in LaTeX with the help of the definitions listed below for use in the text and in equations:

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\newcommand{\Qnom}{\hbox{$\mathcal{Q}^{\rm N}_{\odot}$}}
\newcommand{\Qn}{\mathcal Q^{\rm N}_{\odot}}
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References

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Notes

[1] Note, e.g., that since projected rotational velocities of stars ($v \sin i$) are measured in SI units, the use of different values for the solar radius can lead to measurable differences in the rotational periods of giant stars (see Harmanec and Prša 2011).

[2] Haberreiter et al. (2008) determined the solar photospheric radius, defined to be where $\tau_{\rm Ross} = 2/3$, to be 695 658 (± 140) km. The adopted $\mathcal{R}^{\rm N}_{\odot}$ is based on this value, quoting an appropriate number of significant figures given the uncertainty, and differs slightly from the nominal solar radius tentatively proposed by Harmanec & Prša (2011) and Prša & Harmanec (2012).

[3] The TSI is variable at the ~0.08% (~1 $\mathrm{W\,m^{-2}}$) level and may be variable at slightly larger amplitudes over timescales of centuries. Modern spaceborne TSI instruments are absolutely calibrated at the 0.03% level (Kopp 2014). The TIM/SORCE experiment established a lower TSI value than previously reported based on the fully characterized TIM instrument (Kopp et al. 2005, Kopp & Lean 2011). This revised TSI scale was later confirmed by PREMOS/PICARD, the first spaceborne TSI radiometer that was irradiance-calibrated in vacuum at the TSI Radiometer Facility (TRF) with SI-traceability prior to launch (Schmutz et al. 2013). The DIARAD/PREMOS (Meftah et al. 2015), ACRIM3/ACRIMSat (Willson 2014), VIRGO/SoHO, and TCTE/STP-Sat3 (http://lasp.colorado.edu/home/tcte/) flight instruments are now consistent with this new TSI scale within instrument uncertainties, with the DIARAD, ACRIM3, and VIRGO having made post-launch corrections and the TCTE having been validated on the TRF prior to its 2013 launch. The Cycle 23 observations with these experiments are consistent with a mean TSI value of $S_{\odot} = 1361\ \mathrm{W\,m^{-2}}\ (\pm 1\ \mathrm{W\,m^{-2}}; 2\sigma)$. The uncertainty range includes contributions from the absolute accuracies of the latest TSI instruments as well as uncertainties in assessing a secular trend in TSI over solar cycle 23 using older measurements.

[4] Resolution B2 of the XXVIII General Assembly of the IAU in 2012 defined the astronomical unit *to be a conventional unit of length equal to 149 597 870 700 m exactly*. Using the current best estimate of the TSI (discussed in endnote 3), this is consistent with a current best estimate of the Sun's mean radiative luminosity of $L_{\odot} = 4\pi\,(1\,\mathrm{au})^2\, S_{\odot} = 3.8275\,(\pm 0.0014) \times 10^{26}\,\mathrm{W}$.

[5] The CODATA 2014 value for the Stefan-Boltzmann constant is $\sigma = 5.670\,367\,(\pm 0.000\,013) \times 10^{-8}\,\mathrm{W\,m^{-2}\,K^{-4}}$. The current best estimate for the solar effective temperature is calculated to be $T_{\rm eff,\odot} = 5772.0\,(\pm 0.8)\,\mathrm{K}$.