From Interacting Binaries to Exoplanets: Essential Modeling Tools
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Towards an Increased Accuracy of Fundamental Properties of Stars: Proposing a Set of Nominal Astrophysical Parameters and Constants

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Abstract. With the precision of space-borne photometers better than 100 ppm (i.e. MOST, CoRoT and Kepler), the derived stellar properties often suffer from systematic offsets due to the values used for solar mass, radius and luminosity, and to fundamental astrophysical constants. Stellar parameters are often expressed in terms of $L_\odot$, $M_\odot$ and $R_\odot$, but the actual values used vary from study to study. Here, we propose to adopt a nominal set of fundamental solar parameters that will impose consistency across published works and eliminate systematics that stem from inconsistent values. We further implore the community to rigorously use the official values of fundamental astrophysical constants set forth by the Committee on Data for Science and Technology (CODATA).

1. Motivation

It is customary to express stellar luminosities, masses and radii in terms of solar values $L_\odot$, $M_\odot$, $R_\odot$. Slightly different values of the adopted solar luminosity, mass and radius lead to measurable systematic differences in the determination of basic stellar parameters. For example, the Kepler mission (Borucki *et al.* 2011) routinely finds binaries with periods of the order of several months and longer. If we were to compute a separation between equal 1 solar mass components in a circular 200-day binary from different values of $M_\odot$ and $R_\odot$ adopted in the literature, the relative systematic error would be $\sim 4 \times 10^{-5}$. If we were to compute a separation by timing the eclipses in Kepler short cadence data, the stochastic uncertainty would be $\sim 5 \times 10^{-7}$, smaller by two orders of magnitude.

2. Precedent

The use of outdated and inappropriate physical constants that cause significant systematics in astronomy and geodesy has been seen before with the speed of light. In 1983, at the 17th Conférence Générale des Poids et Mesures (CGPM), the speed of light in vacuum was set to the exact value of 299,792,458 m/s. Consequently, the length of 1 meter was redefined as the distance traveled in vacuum in 1/299,792,458 s. In 1997, the IAU resolution redefined the bolometric magnitude. The zero point is no longer defined w.r.t. the bolometric luminosity of the Sun; now it corresponds to the exact value of $L = 3.055 \times 10^{28}$ W. This introduces an absolute scale of bolometric magnitudes, with continued convenience of $M_{\mathrm{bol},\odot} = 4.75$.

3. Proposal

We propose to:

(*a*) replace the solar luminosity $L_\odot$ and radius $R_\odot$ by the nominal values $\mathcal{L}^{\rm N}_\odot$ and $\mathcal{R}^{\rm N}_\odot$ that are by definition exact and expressed in SI units;

(*b*) compute stellar masses in terms of $M_\odot$ by noting that the measurement error of the product $GM_\odot$ is 5 orders of magnitude smaller than the error in G;

(*c*) compute stellar masses and temperatures in SI units by using the derived values $M^{2010}_\odot$ and $\mathcal{T}^{2010}_\odot$;

(*d*) clearly state the reference for the values of fundamental physical constants used.

		SOLAR PARAMETER VALUES:			FUNDAMENTAL CONSTANTS:
$1\mathcal{R}^{\rm N}_\odot$	=	6.95508×10^8 m	c	=	$299,792,458\,{\rm m\,s^{-1}}$
$1\mathcal{L}^{\rm N}_\odot$	=	3.846×10^{26} W	G	=	$6.67384(80) \times 10^{-11}\ {\rm m^3\,kg^{-1}\,s^{-2}}$
$1GM^{2010}_\odot$	=	$1.32712442099(10) \times 10^{20}\ {\rm m^3\,s^{-2}}$	σ	=	$5.670400(40) \times 10^{-8}\,{\rm W\,m^{-2}\,K^{-4}}$
$1M^{2010}_\odot$	=	1.988547×10^{30} kg			
$1\mathcal{T}^{2010}_\odot$	=	5779.57 K			

Table 1. Recommended values for solar parameters and fundamental astrophysical constants.

4. G vs. GM

The universal gravitational constant G is one of the least precisely determined fundamental constants in nature. In contrast, the error in the product $GM_\odot$ is 5 orders of magnitude smaller. While the value of the solar mass is, thus, inevitably uncertain due to the value of G, the stellar masses $M_1/M_\odot$ and $M_2/M_\odot$ may be readily written as a function of $GM_\odot$:

$$M_1/M_\odot = PK_2(K_1+K_2)^2\left(1-e^2\right)^{3/2}/(2\pi GM_\odot \sin^3 i)$$

$$M_2/M_\odot = PK_1(K_1+K_2)^2\left(1-e^2\right)^{3/2}/(2\pi GM_\odot \sin^3 i).$$

The same can be done for planet masses in exoplanetary research: $GM_{\rm Jup}$, $GM_\oplus$, and $GM_{\rm Moon}$ are determined to a much higher accuracy and those values should be used for computations of exoplanet masses.

5. Further information

A full list of references and details has been published in PASP (Harmanec & Prša, 2011). The radii of planets (most notably, Jupiter and Earth) should also be made nominal, and the following values used for extra-solar planet comparison:

Jupiter: $R = 71492$ km, $GM_{\rm J} = 126686535(2)\ {\rm km^3 s^{-2}}$
Earth: $R = 6371$ km, $GM_\oplus = 398600.4418(8)\ {\rm km^3 s^{-2}}$

References

Borucki *et al.*, 2011, *ApJ*, 728, 117
Harmanec & Prša 2011, *PASP*, 123, 976

M. Richards: The conference participants voted in favor of this proposal and recommended that an official IAU resolution be submitted at the 2012 IAU General Assembly to be held in China.

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