TOWARD AN IAU 2012 RESOLUTION FOR THE RE-DEFINITION OF THE ASTRONOMICAL UNIT OF LENGTH

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ABSTRACT. This contribution to the Journées 2011 discussion concerns the draft Resolution proposal to the IAU 2012 General Assembly for a re-definition of the astronomical unit. That proposal is based on the paper by Capitaine et al. (2011) and on subsequent discussions within the IAU Working Group on "Numerical Standards for Fundamental astronomy", either by e-mail, or during the WG meeting after the Journées 2010 in Paris. The purpose is to re-define the astronomical unit (of length) as a fixed number of SI metres through a defining constant; that constant should be, for continuity reason, the value for the current best estimate of that quantity in metres as adopted by IAU 2009 Resolution B2 (i.e 149 597 870 700 m). After recalling the properties of the IAU 1976 astronomical unit and its status in the IAU 2009 System of astronomical constants, we explain the main reasons for a change; we present and discuss the proposed new definition. One important consequence is that the heliocentric gravitational constant, $GM_{\rm S}$, would cease to have a "fixed" value in astronomical units and will have to be determined experimentally. This would be compliant with modern dynamics of the solar system as it would let possible variations of $GM_{\rm S}$ appear directly. Moreover, this would avoid an unnecessary deviation from the Système International d'Unités (SI) and should be used with all the time scales (including TCB, TDB, TCG and TT). This draft IAU Resolution proposal is submitted for discussion to IAU Division 1 and, more widely, to the astronomical community.

1. THE IAU 1976 DEFINITION OF THE ASTRONOMICAL UNIT

The International Astronomical Union (IAU) 1976 System of Astronomical Constants specifies the units for the dynamics of the solar system; this includes the day (D = 86400 s), the mass of the Sun, M_S, and the astronomical unit of length (i.e. the astronomical unit), the definition of which is based on the value of the Gaussian gravitational constant.

The IAU 1976 definition is: "The astronomical unit of length is that length (A) for which the Gaussian gravitational constant (k) takes the value of 0.01720209895 when the units of measurements are the astronomical units of length, mass and time. The dimensions of k^2 are those of the constant of gravitation (G), i.e., $L^3M^{-1}T^{-2}$. The term "unit distance" is also for the length A."

The aim of the above definition was to provide accurate relative distances (expressed in astronomical units) in the solar system, when absolute distances could not be estimated with high accuracy. The consequences were the following:

- the Gaussian gravitational constant k was a "defining constant" of the IAU 1976 System, with the value $k = 0.017\ 202\ 098\ 95$ from Gauss (1809),

- the value of the astronomical unit in metres was determined observationally, i.e. fitted to a planetary ephemeris with a certain uncertainty; note that, the "primary constant" in the IAU 1976 System was the light time τ_A for unit distance while the unit distance, $A = c\tau_A$ was a "derived constant",

- the value in SI units of the heliocentric gravitational constant (or Sun mass parameter), $GM_{\rm S}$, had to be derived from k, along with the adopted value for the astronomical unit in metres, using the formula: $GM_{\rm S} = A^3k^2/D^2$ (1); it was a "derived constant" of the IAU 1976 System,

- the use of Equation (1), made the value of the astronomical unit of mass in SI dependent on the value of the astronomical unit of length.

2. THE IAU 2009 SYSTEM OF ASTRONOMICAL CONSTANTS

The IAU 2009 System of astronomical constants adopted by IAU 2009 Resolution B2 retained the IAU 1976 definition of the astronomical unit. The Gaussian gravitational constant, k, is listed in the IAU 2009 System (see Table 1) as an "auxiliary defining constant" (with its IAU 1976 numerical value) that has to be used to define the astronomical unit and its relationship with $GM_{\rm S}$.

Constant	Description	Value	Uncertainty
		Auxiliary Defining Constants	
k	Gaussian gravitational constant	$1.720209895 \times 10^{-2}$	
Constant	Description	Value	Uncertainty
		Other Constants	
au	Astronomical unit	$1.49597870700 \times 10^{11}$ m (TDB compatible)	3 m (TDB compatible)
		Body Constants	
$GM_{\rm S}$	Heliocentric gravitational constant	$1.32712442099 \times 10^{20}$ m^{3}s^{-2} (TCB-compatible)	1.0×10^{10} m^{3}s^{-2} (TCB-compatible)
		$1.32712440041 \times 10^{20}$ m^{3}s^{-2} (TDB-compatible)	1.0×10^{10} m^{3}s^{-2} (TDB-compatible)

Table 1: Extract of the IAU 2009 System of Astronomical Constants (from Luzum et al., 2011).

The IAU 2009 value of the astronomical unit (cf. Table 1) has been taken from Pitjeva & Standish (2009); it is an average of recent estimates for the astronomical unit defined by k. The value is compatible with Barycentric Dynamical Time (TDB). There was no accepted definition for the TCB-compatible value of the au at the time of the adoption of the IAU 2009 system.

The IAU 2009 value for $GM_{\rm S}$ (cf. Table 1) has been taken from Folkner et al. (2008); the TDB-compatible value was derived from Equation (1) by using the astronomical unit (as defined by k) fit to the DE421 ephemerides and is consistent with the IAU 2009 value of the au to within the errors of the estimate. The fact that the IAU 2009 $GM_{\rm S}$ value was not directly obtained from Equation (1) by using the IAU 2009 au value shows that the historical definition of the au is no more appropriate for being used with modern solar system ephemerides.

3. MODERN CONTEXT

Due to the huge improvement achieved in solar system ephemerides during the last decade, the definition and status of the au need to be re-considered. This was discussed recently by Klioner (2008), Capitaine & Guinot (2009) and Capitaine et al. (2011).

First, it should be noted that there is a need for a self-consistent set of units and numerical standards for use in modern dynamical astronomy in the framework of General Relativity. Therefore, the definition of the astronomical unit should be adapted to comply with this new context. If the historical status of the au were to be kept, it would be necessary to extend its definition to General Relativity. However, each of the considered options for such an extension would give rise to some difficulties in its application, so that extending the current definition of the astronomical unit to the relativistic framework would be very confusing.

Second, the accuracy of absolute distance measurements provided by modern observations in the solar system (ranging to planets, spacecraft observations, Very Long Baseline Interferometry (VLBI), etc.,) makes the use of relative distances (which was the reason for the historical definition of the au) unnecessary.

Third, modern planetary ephemerides (e.g. INPOP08, DE423, EPM2008) can now determine the solar mass parameter, $GM_{\rm Sun}$, directly in SI units and this quantity may vary with time. The direct estimation of GM_{Sun} has been first tested in the INPOP08 ephemerides (Fienga et al., 2009). The decrease of that quantity is expected to be detectable in a near future, i.e. when the accuracy has been improved by a factor 10. With the current definition of the *au*, the time dependence of GM_{Sun} leads to time-dependent astronomical units for length and mass; the use of such units to measure possible time variations of the solar mass parameters would be a non-sense.

These make clear that the IAU 1976 definition of the *au* currently appears as an intermediate unit only used for historical purposes and has to be changed. It it necessary to note, that although the definition of the au has to be revised, there is still a need (especially for expressing the distances in the solar system) for a unit of length approximating the Sun-Earth distance.

Another point that should be mentioned is that various symbols are presently in use for the astronomical unit and that adopting a new definition would give the opportunity to give an IAU recommendation for the symbol to be used.

4. DEFINING THE ASTRONOMICAL UNIT AS A FIXED NUMBER OF SI METRES

The proposal is to re-define the astronomical unit to be a conventional unit of length, i.e. astronomical unit = L_A metres exactly, L_A being a defining number; the defining number should be, for continuity reason, the value for the current best estimate of the astronomical unit in metres as adopted by IAU 2009 Resolution B2.

The Resolution proposal is based on the paper by Capitaine et al. (2011) and on subsequent discussions within the IAU Working Group on "Numerical Standards for Fundamental astronomy", either by e-mail, or during the WG meeting after the Journées 2010 in Paris.

Note that the Bureau International des Poids et Mesures (BIPM) Consultative Committee for Units (CCU) declared its support to move to a fixed relationship to the SI metre through a defining number determined by continuity (CCU 2009).

This new definition would change the status of the astronomical unit, which will limit its role to that of a unit of length of "convenient" size for some applications. The consequences will be as follows:

- k will not have a role any more; it should be deleted from the IAU System of astronomical constants,
- the experimental determination of the astronomical unit in SI unit will be abandoned,
- the SI value of GM_{Sun} will be determined experimentally.

This new definition would have the advantages of:

- being a great simplification for the users of the astronomical constants,
- letting possible variations of the mass parameter of the Sun (GM_{Sun}) to appear directly, and
- avoiding an unnecessary deviation from the SI,
- being in accordance with the adopted way (Klioner et al. 2009) to use the SI units for the relativistic time scales and associated quantities (i.e. so that, for distances in astronomical units, the TDB-compatible value is $(1 - L_B)\times$ the TCB-compatible value, $1 - L_B$ being the defining conversion factor between TCB and TDB).

5. THE DRAFT IAU 2012 RESOLUTION PROPOSAL

The draft Resolution proposal that is currently submitted to Division I recommends:

1. that the astronomical unit be re-defined to be a conventional unit of length equal to 149 597 870 700 m exactly, as adopted in IAU 2009 Resolution B2,
2. that this definition of the astronomical unit be used with all time scales (including TCB, TDB, TCG, and TT),
3. that the Gaussian gravitational constant k be deleted from the system of astronomical constants,
4. that the value of the heliocentric gravitation constant, GM_{Sun}, be determined observationally in SI units, and
5. that the unique symbol, *au*, be used for the astronomical unit.

6. CONCLUDING REMARKS

A revision of the definition and status of the astronomical unit have been shown to be necessary in order to make the system of astronomical constants best compliant with modern dynamical astronomy.

This is recommended in a draft Resolution proposal to the IAU 2012 General Assembly that re-defines the astronomical unit as a fixed number of SI metres through a defining constant.

The new definition will change the status of the astronomical unit of length, with a number of advantages as compared to the historical definition (still in use in the IAU 2009 System of astronomical constants) that have been discussed in the previous sections.

This proposal is submitted to the astronomical community before being proposed to be adopted at the next IAU GA (2012).

7. REFERENCES

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