

THE ASTRONOMICAL UNITS

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ABSTRACT. The IAU-1976 System of astronomical constants includes three astronomical units (i.e. for time, mass and length). This paper reports on the status of the astronomical unit of length (ua) and mass (M_{Sun}) within the context of the recent IAU Resolutions on reference systems and the use of modern observations in the solar system. We especially look at a possible re-definition of the ua as an astronomical unit of length defined through a fixed relation to the SI metre by a defining number.

1. INTRODUCTION

The IAU-1976 System of astronomical constants includes three astronomical units, namely the astronomical unit of time, the day, D , which is related to the SI by a defining number ($D=86400$ s), the astronomical unit of mass, i.e. the mass of the Sun, M_{Sun} , and the astronomical unit of length, ua. Questions related to the definition, numerical value and role of the astronomical units have been discussed in a number of papers, e.g. (Capitaine & Guinot 1995), (Guinot 1995), (Huang et al. 1995), (Standish 1995, 2004) and (Klioner 2007). The aim of this paper is to report on recent views on these topics.

The role of the astronomical unit of time, which (as is the Julian century of 36 525 days) is to provide a unit of time of convenient size for astronomy, does not need further discussion. In the dynamics of the solar system, the unit of mass appears only through the products GM (dimension L^3T^{-2}). The gravitational constant G having a relative uncertainty of about 10^{-5} , only relative masses are obtained accurately. For these reasons we restrict our discussion to the unit of length. We recall first its historical basis and current use, then we consider a reform which might be desirable.

2. THE SI AND THE ASTRONOMICAL UNIT OF LENGTH (UA)

Physicists and astronomers have a common goal: transferring the quality of the measurement of time to that of length. This can be achieved by assigning conventional values to physical constants whose dimensions are only time and length. However an essential condition is the possibility of a realization of the unit of length with a satisfactory accuracy.

In physics, the metre of the SI has been defined in 1983 from a fixed value of the speed of light. This was made possible by the progress in the measure of optical frequencies providing wavelengths and then lengths in metre by interferometry. Of course the direct use of the definition is especially useful for distances encountered in geodesy and astronomy.

In astronomy, the unit of length (ua) is, in fact, defined by the adoption of a conventional value of GM_{Sun} [The official definition in the IAU-1976 System of astronomical constants, rather obscure, refers to the Gaussian gravitational constant, k (with $k^2 = G$ in astronomical units), whose value has never been changed]. The realization of the ua was based on the measurement of mean motions and on the laws of Newtonian dynamics (i.e. Kepler's third law: $n^2a^3 = GM_{Sun}$ for a planet of negligible mass).

This conceptual difference between physicists and astronomers can be explained by the poor accuracy of evaluation of distances in SI through classical astrometric measurements: parallaxes, radial velocities, annual aberration leading to relative uncertainties of order 10^{-4} . As long as the value GM_{Sun} remains conventional, the link between the ua and the SI metre is subject to measurement and has an uncertainty.

3. EVOLUTION OF MEASUREMENTS AND MODELS, CONSEQUENCES

High accuracy positioning in the solar system is now based mainly on range and Doppler measurements, especially for telluric bodies (Moon, Mercury, Venus, Mars, ...) (Standish 2004, Pitjeva, 2005, Fienga et al. 2006, Folkner et al. 2008). Moreover, the space-time references have been defined in General

Relativity framework in 1991, with further improvements from 2000 to present. In the adopted metrics, the GM s of celestial bodies remain meaningful quantities.

For the telluric bodies, for which there are precise range and Doppler measurements, coordinates are obtained in metres with a very high accuracy and GM_{Sun} is obtained in SI units with a relative uncertainty of 4×10^{-9} (according to IERS Conventions 2003). For the planets for which observations are mainly angular measurements (Jupiter, Saturn, etc.), the relative distances are determined as with old observations and the scale in SI of the global solution is provided by the GM_{Sun} value obtained from telluric bodies, as above. If very precise angular measurements for some bodies of the solar system are available, it may happen that the use of the experimental value for GM_{Sun} leads to less precise absolute distance in SI than the relative distances. This is quite similar to the effect of the use of the experimental value for the ua on distances expressed in ua as it is currently defined.

4. POSSIBLE REFORM IN THE STATUS OF THE ASTRONOMICAL UNITS

Basically there are two possibilities, both valid in the Newtonian context as well as in general relativity:

- GM_{Sun} conventionally fixed in astronomical units and the SI value of the ua estimated, which corresponds to the current official status of the ua,
- GM_{Sun} estimated in SI from the observations and the ua, if needed, conventionally expressed as a fixed number of SI metres, which would correspond to a reform in the status of the ua.

In the latter case, the use of the ua is a simple change of unit. This ua has the same character as the metre: it is defined as a unit of proper length (Huang et al. 1995). Therefore its relation to the metre is not affected by changes in the relativistic metric (introduction of scaling factors).

5. CONCLUSION

A re-definition of the ua through a fixed relation to the SI metre by a defining number (whose value should be in agreement with the current best estimate of the ua for continuity reasons) appears desirable for modern dynamics of the solar system. This would mean:

- determining experimentally GM_{Sun} which would cease to have a “fixed” value in astronomical units,
- limiting the role of the ua to that of a unit of length of “convenient” size for some applications.

Such a change of status of the ua would

- be a great simplification for the users of the astronomical constants,
- let possible variations of the mass of the Sun, and/or G , appear directly,
- avoid an unnecessary deviation from the SI.

6. REFERENCES

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