# CURRENT STATUS OF THE IAU WORKING GROUP FOR NUMERICAL STANDARDS OF FUNDAMENTAL ASTRONOMY

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ABSTRACT. At the 2006 International Astronomical Union (IAU) General Assembly (GA), a proposal was adopted to form the Working Group (WG) for Numerical Standards of Fundamental Astronomy. The goal of the WG is to update the "IAU Current Best Estimates" conforming with IAU Resolutions, the International Earth Rotation and Reference Systems Service (IERS) Conventions, and the Système International d'Unités (SI). Changes to the numerical standards have been precipitated by the adoption of a new precession model, the redefinition of Barycentric Dynamical Time (TDB), and the significant improvement of the accuracy of recent estimates for a number of constants. To date, eleven additional constants have been added to the provisional list of Current Best Estimates (CBEs), one has been superseded, one has been removed, and the numerical values for ten previous constants have been replaced by newer values. In addition, the working group has looked into larger issues such as identifying the best methods for maintaining an IAU list of CBEs, the best ways of properly documenting the CBE list, and whether a new IAU System of Constants should be recommended to the IAU General Assembly. The current status of WG activities and anticipated future directions are presented.

## 1. INTRODUCTION

The International Astronomical Union (IAU) Working Group (WG) on Numerical Standards for Fundamental Astronomy has been tasked with updating the IAU Current Best Estimates (CBEs), conforming with the IAU Resolutions, IERS Conventions and Système International d'Unités whenever possible. As part of its effort to achieve this, the WG is working in close cooperation with IAU Commissions 4 and 52, the IERS, and the BIPM Consultative Committee for Units.

This is the third IAU WG to be tasked with producing CBEs and is adding to the legacy of the two previous WGs. The first Sub-group on Numerical Standards of the IAU WG on Astronomical Standards was headed by E.M. Standish and the WG report (Standish, 1995) established the rules which are still used today. For instance, this group decided on the two-tiered approach to the astronomical constants that we are currently using (*i.e.* having both an official system of constants and a set of CBEs), specified the content of the file of the current best estimates, and also created the first CBEs for a list of IAU constants.

This work was continued by T. Fukushima and his IAU WG on Astronomical Standards (Fukushima, 2000; Fukushima, 2003). Many of the updates concerned work on constants in a general relativistic framework and improved estimates of the precession constant. This revised list of CBEs remains the currently adopted list of IAU CBEs. The excellent work of both these WGs has helped to establish the precedent and allows us to improve incrementally the values for which there are now better estimates.

## 2. CHANGES SINCE THE LAST CURRENT BEST ESTIMATES

In addition to the need to update the CBEs because of improved estimates, there have also been significant changes that impact the IAU CBEs. Since the IAU CBEs were adopted, the IERS Conventions 2003 (McCarthy and Petit, 2004), a document widely used by the astronomical and geodetic communities, has been produced. This reference contains estimates of many of the constants included in the IAU CBEs.

One significant development was the adoption of a new precession model with IAU 2006 Resolution

B1. This resolution accepted the conclusion of the IAU Division I Working Group on Precession and the Ecliptic (Hilton *et al.*, 2006) and adopted the P03 precession theory of Capitaine *et al.* (2003). This resolution also replaced the terms "lunisolar precession" and "planetary precession" with "precession of the equator" and "precession of the ecliptic." Another change is the redefinition of Barycentric Dynamical Time (TDB) that occurred with the adoption of IAU 2006 Resolution B3. Moreover, IAU 2000 Resolution B1.8 introduced a conventional relationship that defines UT1 from the Earth Rotation Angle (ERA). In doing so, it introduced two defining constants for UT1.

These resolutions fundamentally alter the status of the associated constants. For instance, the general precession found in the IAU CBEs is no longer the appropriate quantity to describe precession. Also, the status of the relativistic constant $L_B$ was changed to a defining constant.

## 3. CHANGES TO THE CURRENT BEST ESTIMATES

The current WG started where the previous IAU WG tasked with providing CBEs left off, by using the existing IAU CBEs as the starting draft. From this starting point, the WG has proceeded to update the CBEs based on internationally adopted values and recent research. Some examples are adopting values:

- from IAU Resolutions;
- from the Committee on Data for Science and Technology (CODATA) 2006;
- based on recent research to modify most of the planetary masses and adding masses for Ceres, Pallas, Vesta, and Eris. These improvements are possible due to years of high-precision observations of spacecraft as they near planets and their satellites.

The interim CBEs serve two significant purposes. First, they keep the IAU CBEs consistent, where possible, with international standards. Second, they also keep the constants consistent with the most accurate estimates currently available, which is vital for enabling progress in research.

For the latest draft version, eleven additional constants have been added to the initial list ($L_B$, $TDB_0$, $\theta_0$, $\dot{\theta}$, $au$, $M_S/M_{Eris}$, $M_{Ceres}/M_S$, $M_{Pallas}/M_S$, $M_{Vesta}/M_S$, $GM_S$), one value has been removed ($\tau$), one constant has been superseded ($p$ by $\psi_{J2000}$), and the numerical values for ten additional constants have been replaced by more current, accurate values ($G$, $L_C$, $M_M/M_E$, $M_S/M_V$, $M_S/M_{Ma}$, $M_S/M_J$, $M_S/M_{Sa}$, $M_S/M_P$, $GM_E$, $\epsilon_0$).

## 4. ADDITIONAL CONCERNS

In addition to updating the list of CBEs, the WG is addressing the larger issues surrounding the adoption of IAU CBEs. These include the mechanism to keep the CBEs current and the way in which these constants will be provided, the procedure to document the theoretical context of the constants, and whether the IAU should revise its current list of adopted constants to be consistent with the new list of CBEs.

The mechanism for maintaining the IAU CBEs has been discussed and to date, three options have been considered. The current method is for the IAU to form a WG when it believes that the CBEs need to be updated. This method has worked in the past and there is no reason to believe that it would not work in the future. Another possibility would be to enlist the aid of the IERS Conventions Product Center to maintain the IAU CBEs. Since the IERS is an IAU service organization and it already has a mechanism in place to maintain CBEs, it is possible that the IERS Conventions could be used to maintain the IAU CBEs as well. The biggest problem with this method is that the user communities and the areas of research of the IERS and the IAU are slightly different and there is a possibility that these differences could be problematic. A third option is to create a permanent body within the IAU that would maintain the list of CBEs. One potential problem with this option is that currently, the IAU has no mechanism to maintain a standing body to handle this task. The general consensus of the WG is to request that IAU Commission 4 (Ephemerides) revise its terms of reference so that standards would fall under its purview.

When considering the way in which the IAU System of Constants will be provided, a few options have been suggested. The current method is to provide the Constants with the maximum accuracy provided by the supporting scientific research. However, another option has been suggested to provide the Constants with a decreased accuracy — essentially truncate the digits at the level where disagreement between estimates exists. This would allow for a longer "shelf life" for the constants. This method has the

advantage of keeping a list of constants with the highest possible accuracy (CBEs) while also creating a list of constants that will be more universally acceptable and have longer life. The latter point is particularly appropriate since the acceptance of any new System of Constants by the IAU General Assembly would be facilitated if the values to be adopted agreed (at least to the number of digits provided) with all reasonable research results and the longer life would be consistent with the long span between the adoption of new IAU System of Constants.

The way in which the constants $GM_S$, au, and k are treated have been debated extensively. While a majority agree that the preferable way to treat these constants is to set au as a defining constant, estimate $GM_S$, and eliminate k, there is a vocal minority that does not agree with this option. The discussion to resolve this issue is still ongoing.

There are multiple relativistic time scales (TCB, TCG, TDB, TT) that are appropriate for various applications. In order to meet the needs of these users, values that are compatible with different time scales will be provided for the CBEs. Providing values for multiple relativistic time scales will also warn users implicitly that they need to be careful to use the appropriate value for their specific task.

Another question that has been discussed is what constitutes an acceptable reference for documenting a numerical estimate. In this age of rapid analysis of data, it is possible to create estimates frequently in an electronic format. In order to ensure that the estimation process is based on scientifically accepted procedures, it will be required that all values be published in refereed journals.

Electronic information will play a much greater role with the CBEs than with the astronomical constants. While it might be useful to have the astronomical constants provided on the IAU web page, it is expected that in the future the CBEs will be maintained in electronic form only. In order for this to be feasible, it will be necessary to establish a formal approval process, implement version control on the electronic document, and maintain past version of the CBEs in a publicly accessible location. To make best use of the electronic media, it would be desirable to have the web page hosting the CBEs provide extensive background information, references, and possibly information regarding the interrelation of the constants.

## 5. UPDATE OF IAU SYSTEM OF CONSTANTS

There are now significant differences between the CBEs and the current IAU System of Constants. This is due to both increasing accuracy of estimates and to changes in astronomical theory. As a result of this, there is a consensus of the NSFA WG to recommend to the 2009 IAU General Assembly that the IAU System of Constants be updated.

It is anticipated that the IAU System of Constants will continue to be a set of numbers that are changed infrequently and will be used by people looking for definitive numbers from an authoritative source. It is anticipated that the recommended new System of Constants will be provided to the accuracy that different estimates are in agreement. Because of this, the values for the System of Constants are expected to be correct and only need to be updated as additional digits of accuracy become available.

Currently, the plan is to provide the CBEs as an electronic document since the consensus is that this is the best way to facilitate the most accurate estimates being available to the user community in a timely fashion. In order to ensure the integrity of the CBEs, a formal procedure for the adoption of new values and the archiving of older versions of the CBEs will need to be developed.

The NSFA WG will be recommending to the IAU General Assembly that IAU Commission 4 (Ephemerides) revise its terms of reference so that standards would fall under its purview. This will allow the IAU to have a standing body that will be responsible for maintaining standards including numerical values.

## 6. REFERENCES


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