Report of the IAU WGAS Sub-group on Issues on Time

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1 Introduction

Included in the nine adopted recommendations of the IAU Working Group on Reference Systems (Hughes, et. al., in 1991), were recommendations for the introduction of Geocentric Coordinate Time (TCG) and Barycentric Coordinate Time (TCB), the renaming of the Terrestrial Dynamical Time (TDT) as Terrestrial Time (TT), and the approval to continue the use of Barycentric Dynamical Time (TDB) when that is desirable. The relationships between these different time scales and the reason for their introduction was given by Seidelmann and Fukushima (1992). Since it was recognized that there were some unresolved issues as a result of these recommendations, a subcommittee of the Working Group on Astronomical Standards was established for Issues on Time. The following recommendations are made to resolve the issues which are currently recognized:

2 J2000.0 Definition

The event (epoch) J2000.0 is defined in the geocentric coordinate system, at the geocenter, as the date 2000 January 1.5 TT = Julian date 2451545.0 TT

Notes:

1. The previous definition of J2000.0 was in terms of TDB. For purposes of star catalogs, this difference is not significant. For ephemerides, care must be taken between the different time-like arguments in any case. Therefore, this definition is in terms of one of the "new" time-like arguments yet retains a continuity with the older time scales in the previous definition.

2. With the secular differences between TCB, TCG, and TT (= TDT), there are significant differences between the time scales at the epoch J2000.0, as shown by the following values:

$$\begin{aligned}
\mathrm{TT} &= \mathrm{TDB} + 0.^{\mathrm{s}}0000994\ldots - \frac{1}{c^2}\mathbf{v}_{\mathrm{E}}\cdot(\mathbf{x}-\mathbf{x}_{\mathrm{E}}) \\
\mathrm{TCB} &= \mathrm{TDB} + 11.^{\mathrm{s}}25362\ldots \\
\mathrm{TCG} &= \mathrm{TDB} + 0.^{\mathrm{s}}5057339\ldots - \frac{1}{c^2}\mathbf{v}_{\mathrm{E}}\cdot(\mathbf{x}-\mathbf{x}_{\mathrm{E}}) - P \\
\mathrm{TCG} &= \mathrm{TT} + 0.^{\mathrm{s}}505833\ldots \\
\mathrm{TCB} &= \mathrm{TCG} + 10.^{\mathrm{s}}74778\ldots + \frac{1}{c^2}\mathbf{v}_{\mathrm{E}}\cdot(\mathbf{x}-\mathbf{x}_{\mathrm{E}}) + P \\
\mathrm{UT1} &\cong \mathrm{TDB} - 65.^{\mathrm{s}}
\end{aligned}$$

where $\mathbf{x}_{\mathrm{E}}$ and $\mathbf{v}_{\mathrm{E}}$ denote the barycentric position and velocity of the Earth's center of mass at J2000.0, $\mathbf{x}$ denotes the barycentric position of the observer, c is the speed of light, and P are periodic terms, whose largest amplitude is 1.6 millisecond. The value of P for J2000.0 is $-0.^{\mathrm{s}}00009551$ and, for J2100.0, P is $-0.^{\mathrm{s}}00006488$. At J2100.0 = 2100 January 1.5 = Julian Date 2488070.0 TT

$$\mathrm{TT} = \mathrm{TDB} + 0.^{\mathrm{s}}0006958\ldots - \frac{1}{c^2}\mathbf{v}_{\mathrm{E}}\cdot(\mathbf{x}-\mathbf{x}_{\mathrm{E}})$$

I. Appenzeller (ed.), Highlights of Astronomy, Vol. 10, 193–196.

$$\begin{aligned}
\mathrm{TCB} &= \mathrm{TDB} + 60.^{\mathrm{s}}18387\ldots \\
\mathrm{TCG} &= \mathrm{TDB} + 2.^{\mathrm{s}}705167\ldots - \frac{1}{c^2}\mathbf{v}_{\mathrm{E}}\cdot(\mathbf{x}-\mathbf{x}_{\mathrm{E}}) - P \\
\mathrm{TCG} &= \mathrm{TT} + 2.^{\mathrm{s}}70517411\ldots \\
\mathrm{TCB} &= \mathrm{TCG} + 57.^{\mathrm{s}}47869\ldots + \frac{1}{c^2}\mathbf{v}_{\mathrm{E}}\cdot(\mathbf{x}-\mathbf{x}_{\mathrm{E}}) + P \\
\mathrm{UT1} &\cong \mathrm{TDB} - 130^{\mathrm{s}}
\end{aligned}$$

3. The Systeme International (SI) second is defined as the duration of 9 192631 770 cycles of radiation corresponding to the transition between two hyperfine levels of the ground state of cesium 133.

3 Julian Century

The Julian century will be defined as 36525 days of TT.

Notes:

1. This is consistent with the adoption of the epochs in terms of Terrestrial Time and the time interval between the epochs is in the same time scale.
2. Then a Julian Century of 36525 days of TT implies an equivalent time period in the other time-like arguments of:

$$\begin{aligned}
\mathrm{TCG}: 36525^{\mathrm{d}} + 2.^{\mathrm{s}}199340787\ldots &= 36525.^{\mathrm{d}}00002546 \\
\mathrm{TCB}: 36525^{\mathrm{d}} + 48.^{\mathrm{s}}93024815\ldots &= 36525.^{\mathrm{d}}00056632
\end{aligned}$$

4 Relationship between mean and apparent Sidereal Time

Beginning with February 26, 1997 (date subject to change based on additional information), the relationship between Greenwich Mean Sidereal Time (GMST) and Greenwich Apparent Sidereal Time (GAST), shall be:

$$\mathrm{GAST} = \mathrm{GMST} + \Delta\psi\cos\varepsilon_0 + 0''.00264\sin\Omega + 0''.000063\sin 2\Omega$$

where $\Delta\psi$ is the nutation in longitude, ε_0 is the mean obliquity of the ecliptic, and Ω is the longitude of the lunar node.

Notes:

1. International Earth Rotation Service Board has recommended the inclusion of the two terms based on the longitude of the lunar node, because they are now detectable in observations for determining Sidereal time, while in the past they were too small to be detected. The suggestion is to introduce these terms on February 26, 1997, at the time when their value is zero so there would be no discontinuity in Sidereal Time and UT1.
2. The periodic terms, were determined by Aoki and Kinoshita (1983) for the accumulated precession and nutation in right ascension. The effect of these terms on the estimation of UT1 has been described by Gontier and Capitaine (1991).
3. The expression can be interpreted as redefining the equation of the equinox, if you consider that as the difference between the time scales. However the equation of the equinox is really defined in geometric terms.

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5 TCB and TCG

It is recommended that when possible, new ephemerides should be developed in terms of the time-like arguments, Barycentric Coordinate Time, and Geocentric Coordinate Time and a system of astronomical constants consistent with these relativistic time-like arguments. When this is not possible, the constants should be specified in terms of a specific time-like argument.

Note:

1. As indicated in Seidelmann and Fukushima, the values of constants depend upon the time units. With time-like arguments of TCB and TCG, the relativistic transformations are consistent with a single set of values. With the time-like arguments of TDB, the geocentric constants are different from the barycentric constants, and appropriate transformations must be made between the values.

6 Ephemeris Time

The ephemeris time revised (ETR), for use as a time scale prior to the availability of TAI or AT, is defined as follows:

1) Ephemeris time revised (ETR) is reckoned from the instant 1958 Jan 0^d0^h TAI at which time ETR has the value 1958 Jan $0^d0^h0^m32.^s184$, and

2) The unit of time of ETR is the SI second.

Notes:

1. The definition of TT prior to the availability of TAI was not specified, and was left to be determined from the ephemerides according to the definition of Ephemeris Time. At the present, the epoch of ephemeris time is specified in terms of the geometric mean longitude of the Sun under the old system of constants with Newcomb's theory of the Sun. However, geometric mean longitude of the Sun means there is an expression for the mean longitude of the Sun for which perturbations and aberrations will be added to obtain the apparent position. With numerical integrations, there is no such expression, and for general theories, the expression depends on the long-period perturbation terms.

2. The epoch is presently defined for 1900. The continuity with TT is desired at the epoch 1955, when it could be determined.

3. For purposes of consistency, it seems desirable to redefine ephemeris time in terms of the SI second. One disadvantage of this is that it will not be the unit of time directly available from the ephemerides. The time available from the ephemerides would be the Tropical Year as with the current definition of ephemeris time, but that is dependent upon the constant of precession used and the ephemeris of the Sun being used.

4. As it is defined, ETR is a conceptual time. It will lead to realizations which could be given special designations such as ETR1. These realizations will be realizations of TT before the existence of atomic time. In the spirit of IAU Resolution AA (1991), these realizations could be designated as TT (ETR1). It would then be straightforward to obtain TCB(ETR1), TCG(ETR1), etc when needed.

7 ΔT Tables

Since the values of ΔT, ET-UT, or TT - UT are dependent upon the ephemerides, the value of the secular acceleration of the Moon, the reference system, the constants, and the method of determining ΔT, it is recommended that when values of ΔT are given, the dependence upon the basis for the determination be specified, along with the means of properly correcting the values.

Note:

1. Correspondingly when using previously tabulated values for ΔT, users should be aware that corrections in the versions may be necessary to utilize the tables with different reference systems and ephemerides.

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