

A new definition of Barycentric Dynamical Time

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The Story of TDB

Solar-system ephemerides originally used solar time. But variable Earth rotation meant that in effect the ephemeris itself had to become the clock. The result was a dynamical time scale called Ephemeris Time.

- 1958: Ephemeris Time defined formally.
- 1976: relativistic replacements for ET introduced.
- 1979: time scales named - barycentric one called TDB.

The TDB definition quickly became recognized as flawed.

- 1991: TCB introduced, supposedly superseding TDB.

Use of TDB continues (also JPL's T_{eph} , same basic idea).

- 2006: IAU Division I Working Group on Nomenclature for Fundamental Astronomy proposes redefinition of TDB.

IAU NFA WG

<http://syrtel.obspm.fr/iauWGnfa/>

IAU Working Group "Nomenclature for Fundamental Astronomy"

Nicole CAPITAINE	Paris Observatory, France, <i>Chair</i>
Alexandre H. ANDREI	Observatorio Nacional, Brazil, Commission 8 Representative
Mark CALABRETTA	ATNF, Australia, Commission 5 Representative
Veronique DEHANT	ROB, Belgique, Commission 19 President
Toshio FUKUSHIMA	NAO, Japan, Division I President
Bernard GUINOT	Paris Observatory, France
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George KAPLAN	USNO, USA
Sergei KLIONER	Lohrmann Observatory, Germany
Jean KOVALEVSKY	OCA, France
Irina KUMKOVA	IAA, Russia
Chopo MA	GSFC, USA
Dennis D. MCCARTHY	USNO, USA
Ken SEIDELMANN	Virginia University, USA
Patrick WALLACE	HMNAO, RAL, UK

The WG has also benefited from advice from **M.Soffel**, **G.Petit** and **E.M.Standish**.

TCB and TT

- TT is close to proper time at the Earth's surface.
- TCB is the natural coordinate time scale to use for barycentric problems: solar system dynamics, pulsar timing etc.
- If the same events are labelled using both TCB and TT (terrestrial time), differences are seen, due to:
 - the TT clock's speed in the solar-system rest frame, and
 - the immersion of the TT clock in the gravitational potential of the Sun and other bodies.

Barycentric Coordinate Time

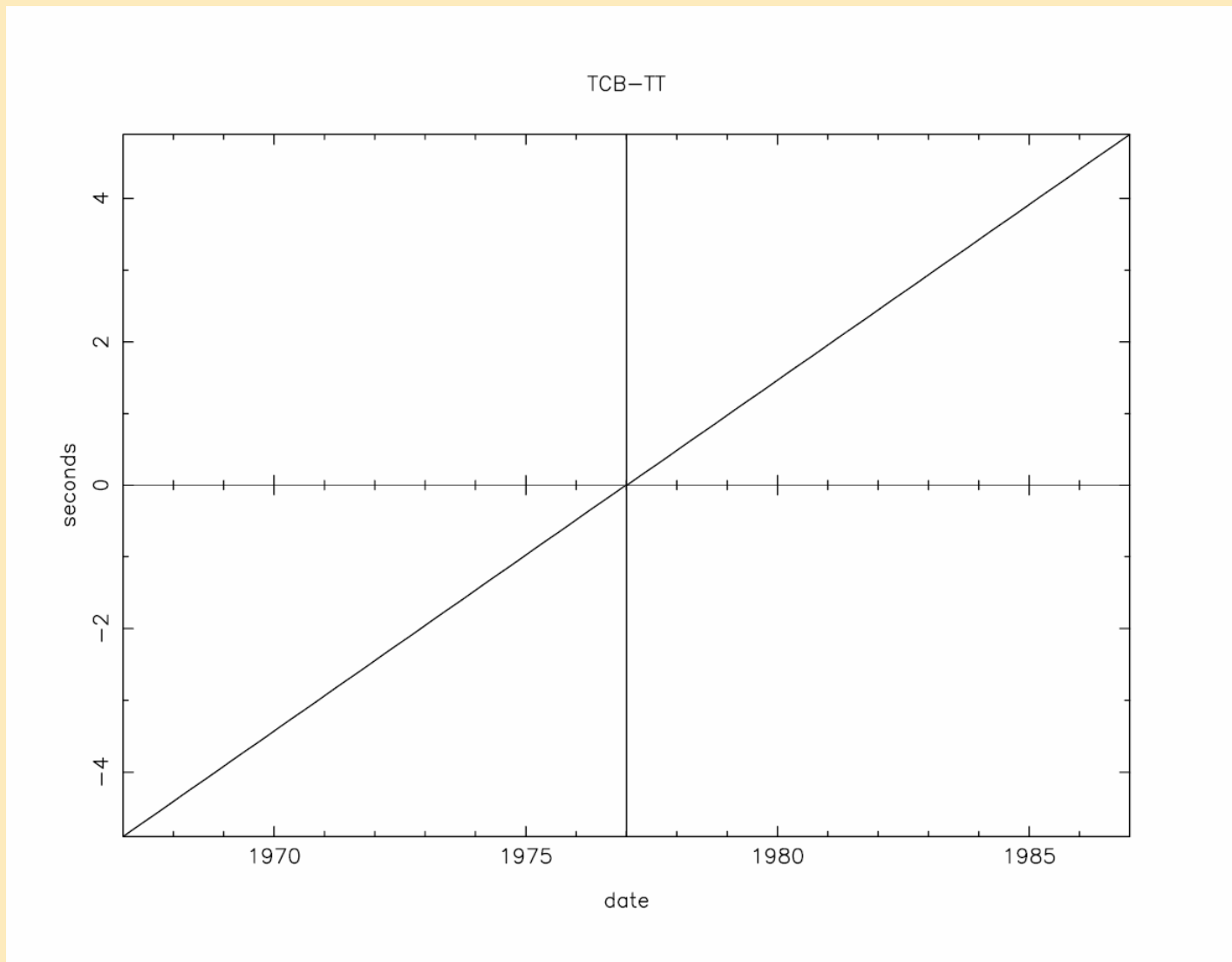
$$\begin{array}{l}
 \text{TCB} \rightarrow \\
 \text{TT (at geocenter)} \rightarrow \tau \quad \square \quad t \stackrel{\circ}{\alpha} \frac{1}{c^2} \int \left[\overset{\text{potential at geocenter}}{\Phi_{\dots}(\mathbf{b}_r)} + \overset{\text{speed}}{\frac{1}{2} \left| \frac{d\mathbf{b}_{\dots}}{dt} \right|^2} \right] dt
 \end{array}$$

which can be written as...

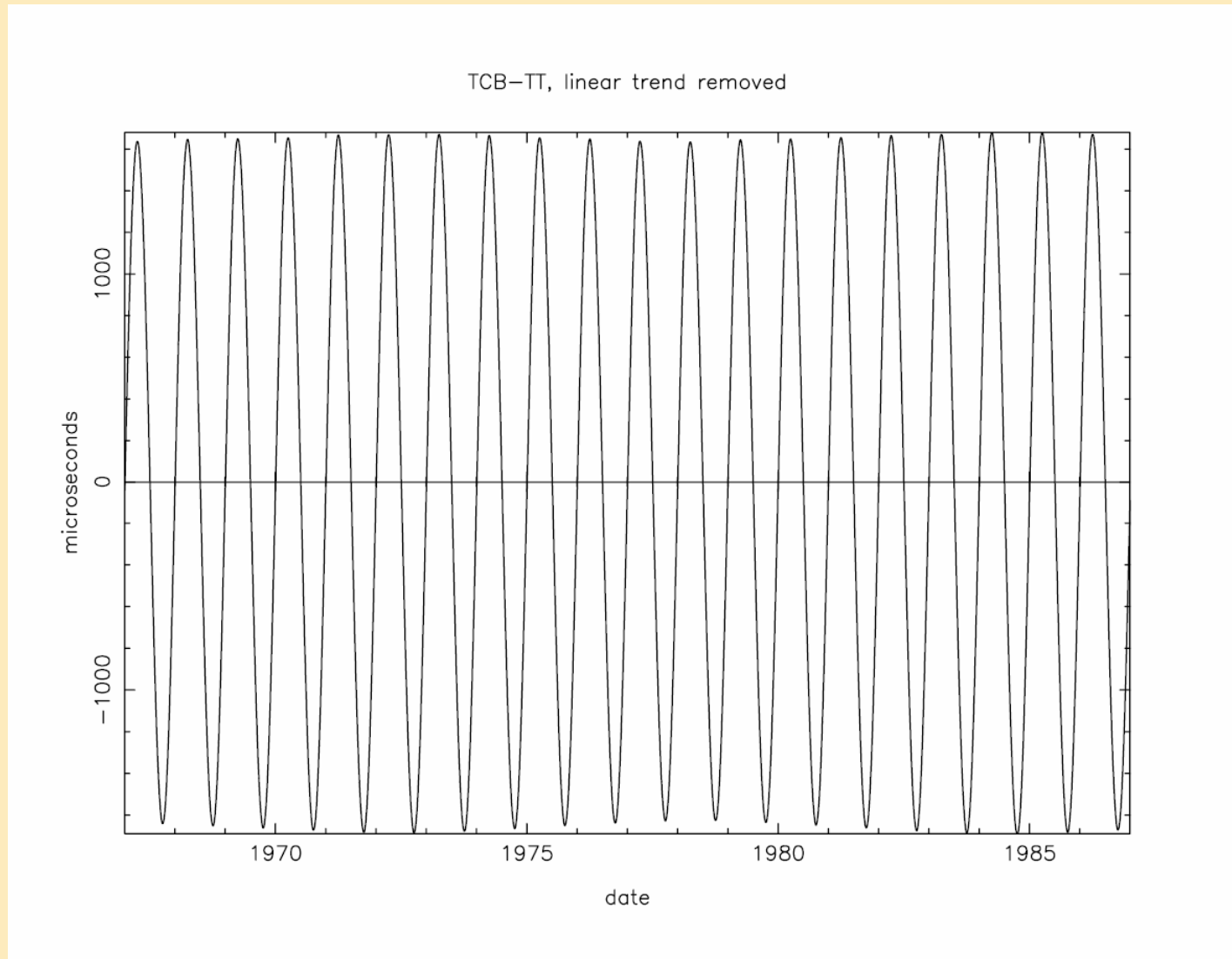
$$\begin{array}{l}
 \text{TCB} - \text{TT (at geocenter)} \rightarrow t - \tau = a_0 + \overset{\text{rate}}{a_1 t} + \underset{\sim \text{periodic residual}}{P}
 \end{array}$$

defined as zero at 1977 Jan 1.0 TAI (geocenter)

TCB-TT (at geocenter)



$$\text{TCB}_{gc} - \text{TT}_{gc}, \text{ de-trended} \equiv \text{TDB}_{gc} - \text{TT}_{gc}$$



1976/1979 TDB definition

- It was stated that TDB and TT should differ by periodic terms only.
- What was actually meant by “periodic terms” was P in the expression:

$$t - \tau = a_0 + a_1 t + P$$

- It would have been better to say “terms free from a linear trend” or something like that.
- Over-literal interpretation of “periodic terms” has caused problems ever since.

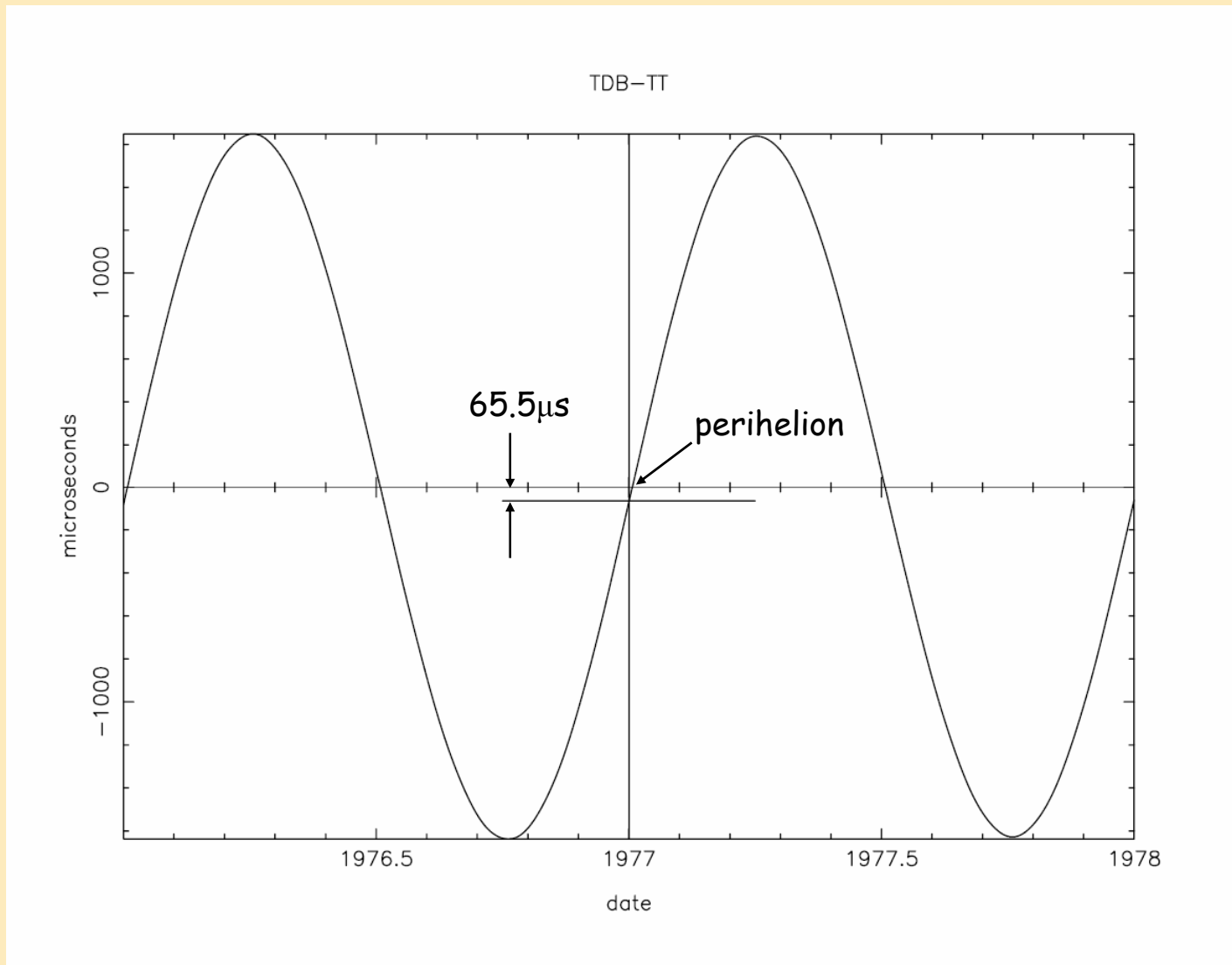
1991 statements about TDB

- TCB was introduced as the appropriate coordinate time for barycentric ephemerides.
- TDB was recognized as a linear scaling of TCB:

$$t_{TCB} - t_{TDB} = L_B (t - t_0)$$

- Unfortunately, in concentrating on the rate change L_B , this overlooked the issue of epoch alignment.

TDB-TT around 1977 Jan 1.0 TAI



TDB and the NFA WG

- The NFA WG could not reach consensus on a description of TDB as it is currently understood:
 - disagreements on how literally to take “periodic terms”.
 - the lack of a rigorous definition of TDB **even in principle**.
 - the epoch inconsistency between the two IAU “definitions”.
 - the fact that JPL had independently implemented the TDB “idea” and had called the result T_{eph} .
- It was easier to **redefine** TDB, and so a draft IAU resolution was prepared.

TDB redefinition - choices

- The choice was between:
 - a) a clearer description of the original TDB "idea", or
 - b) a selected linear relationship with TCB.
- Because (a) amounts to a "family" of time scales, (b) was chosen.
- Two variants were offered:
 - A. TDB-TT centered on zero, or
 - B. TDB synchronized with TT and TCB at the epoch event.
- Because (B) would lead to inconsistency with existing TDB-TT models and with T_{eph} , there was a strong consensus for (A).

TDB redefinition - the proposal

- TDB to be defined through a conventional relationship with TCB:

$$\text{TDB} = \text{TCB} - L_B \times (\text{JD}_{\text{TCB}} - T_0) \times 86400 + \text{TDB}_0$$

- $T_0 = 2443144.5003725$ exactly.
- $\text{JD}_{\text{TCB}} = T_0$ for the event 1977 Jan 1.0 TAI at the geocenter and increases by 1.0 for each 86400s of TCB.
- $L_B = 1.550519768 \times 10^{-8}$ exactly.
- $\text{TDB}_0 = -6.55 \times 10^{-5} \text{ s}$ exactly.

Relationship with existing TDBs

- The redefined TDB is consistent with Fairhead & Bretagnon (1990) to 3ns.
- It is probably consistent with DE405 T_{eph} to a similar figure. *n.b.* The literature does not make this clear.

Relationship with future TCBs

- The relationship between TDB and TCB is fixed and will not change.
- The consequence of revised planetary masses (for example) will be that a linear drift appears between TDB and TT.
- It is unlikely that such a drift could be as large as 1ns per year.

What TDB is for

- TCB is the time scale of the Barycentric Celestial Reference System. Mixing BCRS and TDB would be improper. However, TDB can, if desired, be used as an alternative way to express TCB.
- Pulsar timing analysis can be done directly in TCB or can use TDB; under the new definition the two are completely equivalent.
- The redefined TDB is a good choice for ephemeris developers to adopt as the "user interface".

What TDB is not for

- The redefined TDB is not intended for applications where non-SI units and physical constants would then have to be employed.
 - It is merely Barycentric Coordinate Time with a linear transformation contrived, for convenience, to keep roughly in step with Terrestrial Time.
 - The draft resolution specifically encourages ephemeris development directly in TCB, which at present is not always the practice.

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