Time Scales and Concepts

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Concepts

Clocks, Calendars, Chronometers: Measuring Time

Units of Time

Calendars

Expressing Date and Time

Clocks, Calendars, and Chronometers:
How do we measure time?

- Clock: daily cycle
  - Based on earth rotation – an angle measurement
  - Days are getting longer: ~2 ms per cy
  - Civil and astrometric significance
- Calendar: annual cycle
  - Year (defined by vernal equinox) is getting shorter: 0.8 s/cy
  - Astrometric applications
- Chronometer: elapsed time
  - Using SI second

Units of Time (since 19th century)

- Astrometric definitions
  - Tropical year (defined by vernal equinox; cubic)
  - Besselian year (defined by solar longitude 280°; linear)
  - Both are time-variable
- Need for a chronometer-quality standard of the second
  - Before 1967 the second was 1/31,556,925.9747 of the tropical year for 1900 January 0 at 12 h Ephemeris Time
  - Cumbersome to maintain, limited accuracy
- SI second
  - Based on ^{133}Cs hyperfine transition

Calendars

- The year expressed in unit of day
- The calendar wants a integer number of days
- Unfortunately, earth orbit and rotation are not perfectly synchronized
- Solution: leap days
  - First attempt (Julian calendar) worked for a while
  - Second attempt (Gregorian calendar, 1582) will be good for several thousands of years
  - Only requires an accuracy of order 10^{-6} over that range

Expressing Date & Time

- ISO-8601: [+0]2014-01-01T00:00:00.0
- Julian Day (JD): 2456658.5
- Modified Julian Day (MJD): 56658.0
- Besselian epoch: B2014.00157654
- Julian epoch: J2014.0
  - Julian century: 36525 days of 86400 s

Time Scales

Empirically Measured Time Scales
UTC
Earth-based Time Scales
TDB
Relativistic Issues, Coordinate Time
Time Scales Summary
Closing Comments

Time Scales: Empirically Measured

- UT1: Universal Time
  - Clock time scale
  - Angle measurement of earth rotation
- TAI: International Atomic Time
  - Chronometer time scale
  - Ensemble of atomic clocks
  - Based on SI second
  - Measured on surface of the rotating geoid
- Problem: both are determined after the fact

UTC

- Bridge between the clocks and the chronometers
- Real-time distribution, based on a realization of TAI
    - This introduces uncertainty that is typically of order 5 ns

- Within 0.9 s of UT1
- Offset by integer number of seconds from TAI
    - Leap seconds as needed at end of June or December
    - Under IERS authority
    - Published 6 months ahead of time
    - 10^{-8} accuracy only lasts a few years

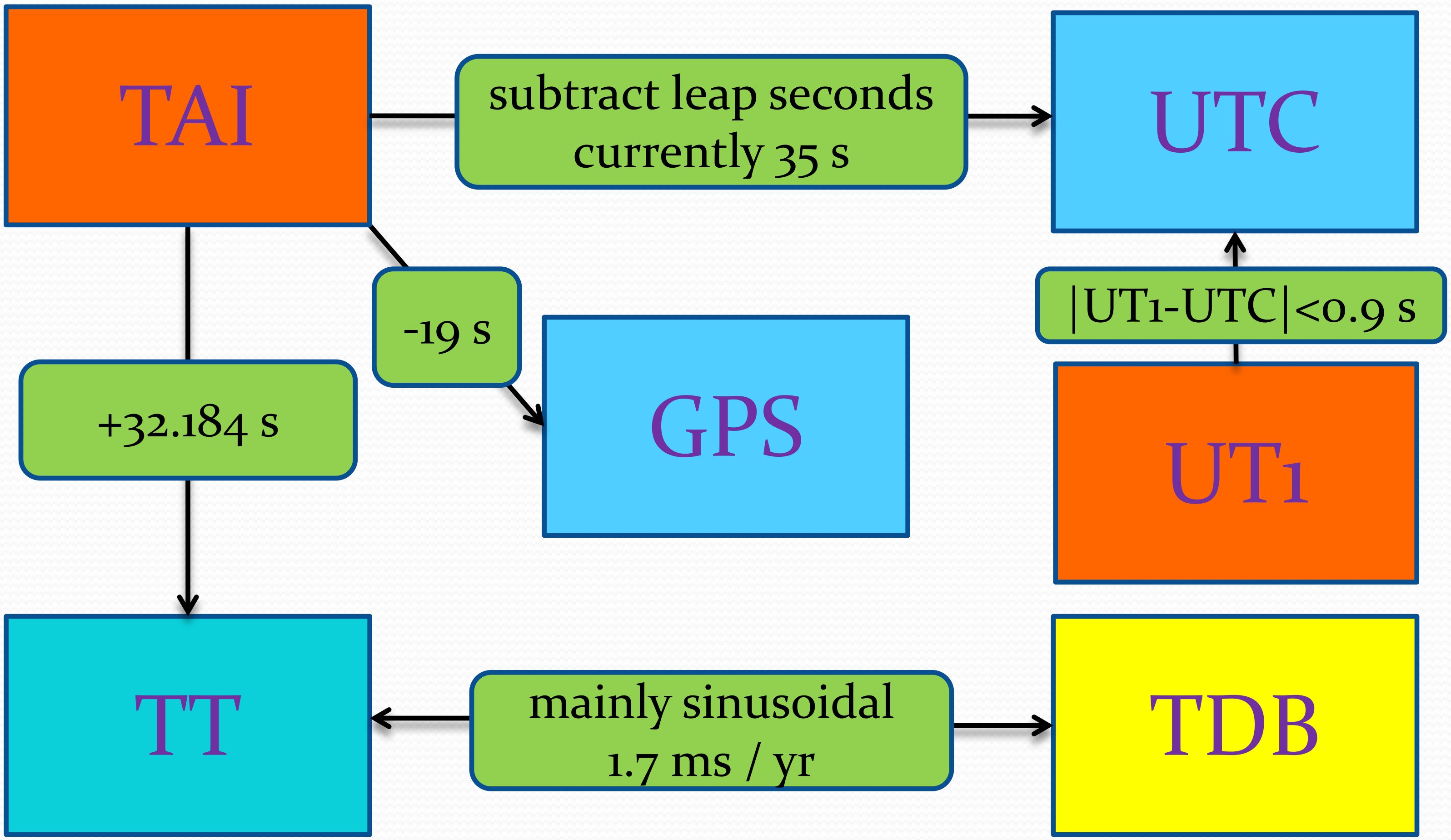
Earth-based Time Scales

- ET: Ephemeris Time
  - Prior to 1967
- TT: Terrestrial Time
  - Official IAU time; on the rotating geoid; continues ET
- TAI: International Atomic Time
  - TT – TAI = 32.184 s
- UT1; Universal Time
  - Represents earth rotation
- UTC: Universal Time Coordinated; GMT
  - Distributed time, with leap seconds; currently 35 s behind TAI
  - Within 0.9 s of UT1; links clocks and chronometers
- GPS: GPS's Time Scale
  - TAI – GPS = 19 s

Barycentric Dynamical Time

- Needed for astronomical purposes to remove effects related to the earth’s orbit
- TDB runs on average at same rate as TT, but corrected for eccentricity of earth orbit (< 2 ms)
- In addition, barycentric conversion usually requires corrections for:
  - Geometric path length delay (< 500 s)
  - Shapiro delay (< 0.2 ms)
  - Römer delay (typically < 0.1 ms)

Time Scales Realization



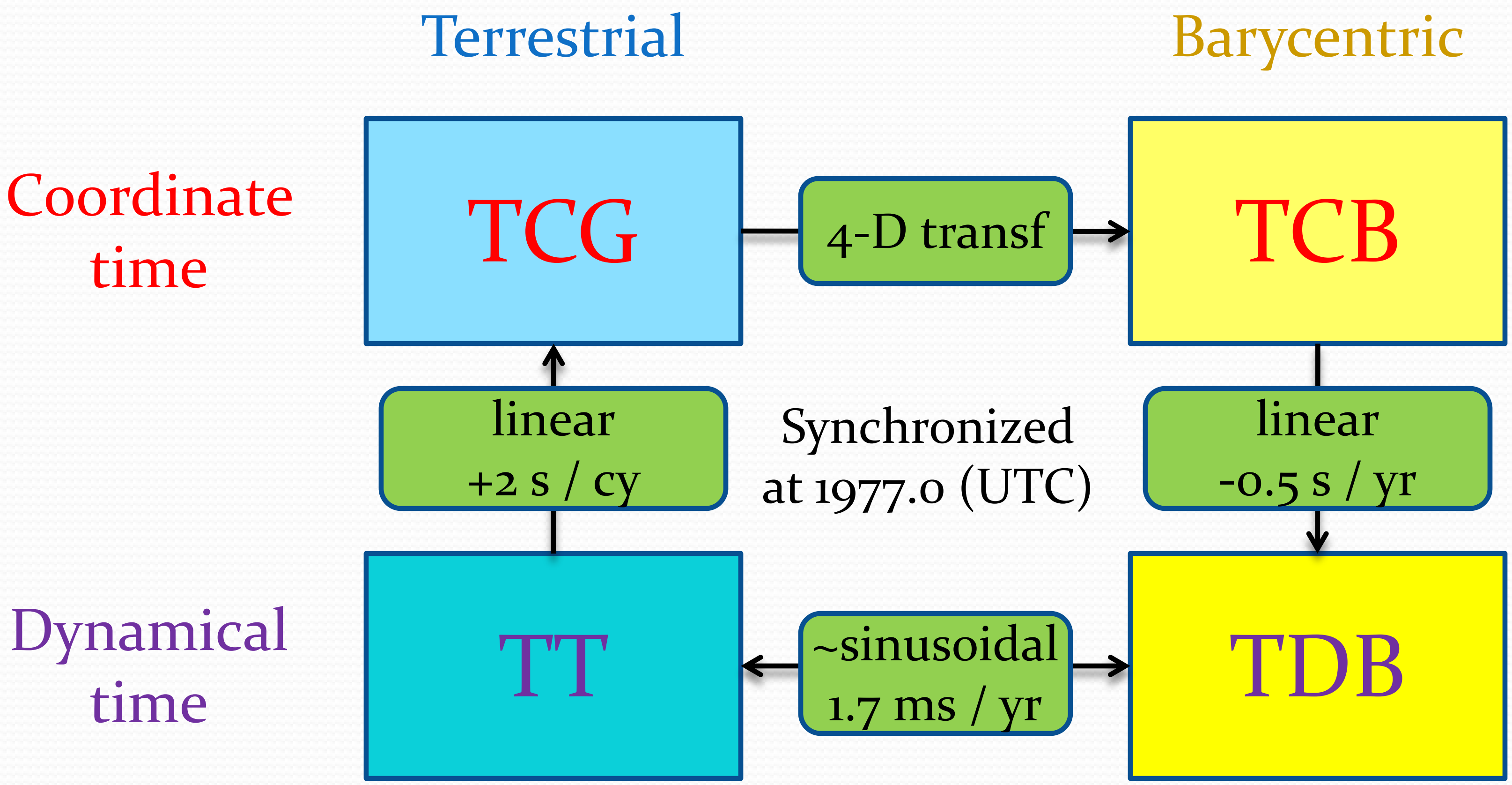
Relativistic Trouble

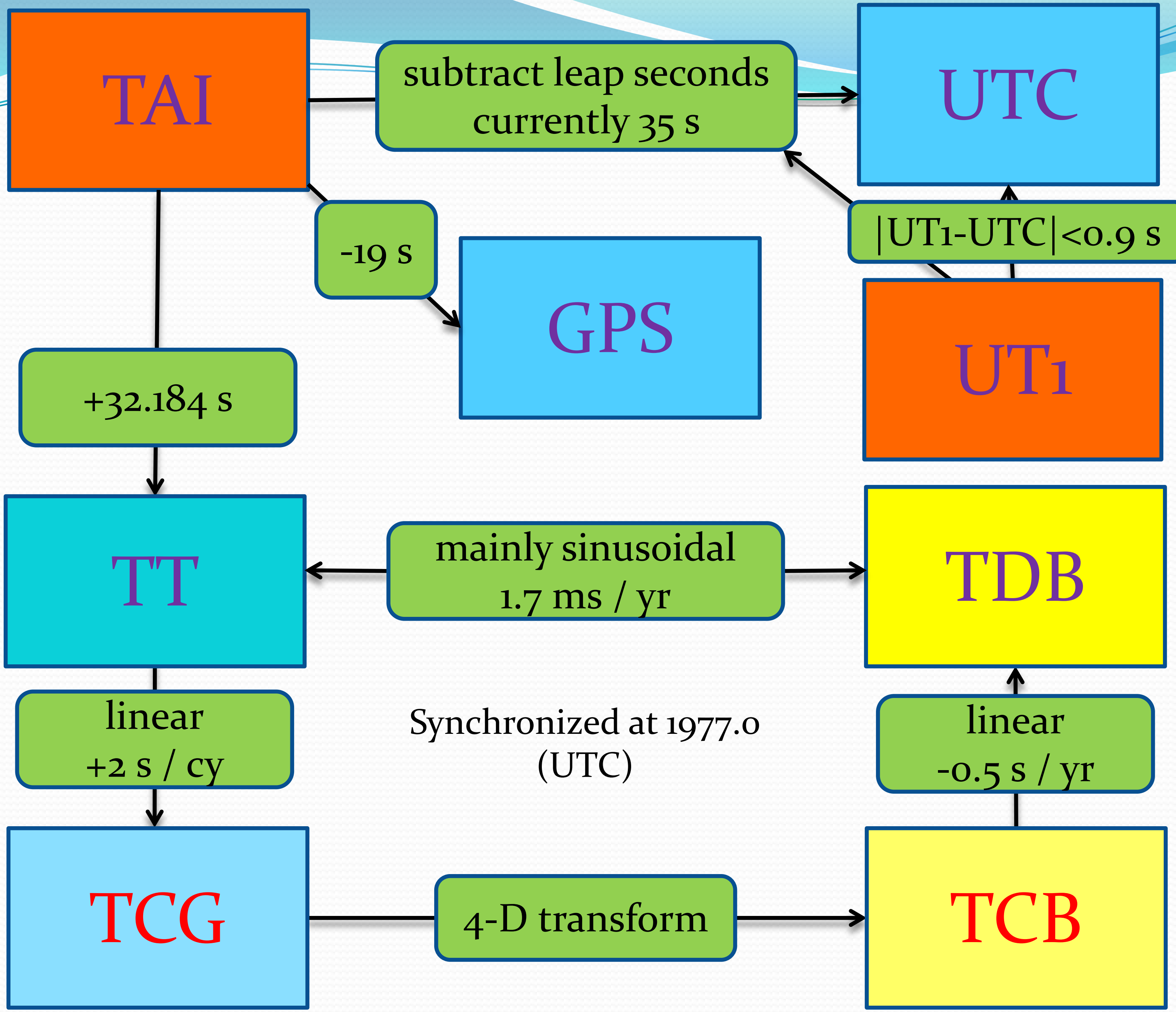
- SI second:
  - 9,192,631,770 cycles of radiation due to transition between two hyperfine levels of ^{133}Cs
- Clock at lower gravitational potential speeds up, clock in motion slows down
  - A clock in LEO would lose 8.5 ms per year, but in LEO people don't bother, just synchronize
- TDB-TT corrects for the eccentricity of the earth's orbit only: the variation it causes in earth motion and gravitational potential

Real Relativistic Trouble

- But having a clock run synchronously with TT at the barycenter (as TDB does) has nasty consequences: it's seconds don't correspond anymore to 9,192,631,770 ^{133}Cs cycles; i.e., fundamental physical constants change
- Solution: Coordinate Time
  - TCG – faster than TT by $6.969290134 \times 10^{-10}$
  - TCB – faster than TDB by 1.550505×10^{-8}
  - Both synchronized with TT and TDB at 1977.0 (UTC)

Practical Time Scales Model




TAI
subtract leap seconds
currently 35 s
UTC
-19 s
GPS
|UT1-UTC|<0.9 s
UT1
+32.184 s
TT
mainly sinusoidal
1.7 ms / yr
TDB
linear
+2 s / cy
Synchronized at 1977.0
(UTC)
linear
-0.5 s / yr
TCG
4-D transform
TCB

Some Random Closing Comments

- A time scale for any location in the solar system:
  derive from TCB, similar to TCG
- It's helpful to have a location attached to time stamps:
  geocenter, barycenter, topocenter,…
- ISO-8601, JD, MJD do NOT imply a time scale:
  it needs to be specified explicitly
- DO NOT use incompatible locations and time scales:
  like UTC/barycenter or TDB/geocenter
- DO NOT use JD or MJD to express UTC:
  the UTC day is not guaranteed to be 86400 s
- Preferred time scales for astronomical applications:
  TT & TDB or TCG & TCB
- FITS and IVOA have (or will have) recognized standards
  that include these time scales

Salvador Dali knew time is a tricky subject