# When Time is of the Essence

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## Do We Really Know What Time It Is?

- JD 2443144.5: is this unambiguous?
- Depends on required accuracy
- Full description:
  - Time stamp
  - Location of observer
  - Motion of observer
  - Time Scale used



## Absolute Time Uncertainty

- Contributors:
  - Instrumental delays
  - Clock calibration
  - Orbit ephemeris/geodetic position
- 1 μs accuracy is feasible on spacecraft, better on the ground
- Collect and record necessary metadata that's you responsibility (dare I mention STC?)



## Time Stamps

- Julian Date: changes at noon UTC
- Modified Julian Date: JD – 2400000.5
- ISO-8601, as used in FITS and VO:
  - *ccyy-mm-dd*T*hh*:*mm*:*ss*[.*sss...*]
  - No time zones
  - Gregorius and pre-1582 dates
  - Can only be used in the range 0001-01-01T00:00:00 to 9999-12-31T23:59:59

## Time Reference Positions

- Topocenter
  - Easy, but hard to compare, unless low accuracy
- Geocenter
  - Good for simultaneous measurements
  - Up to 20 ms for ground-based
- Barycenter
  - For long-term comparisons
  - Up to 500 s



## Earth-based Time Scales

- TT: Terrestrial Time
  - Official IAU time; on the rotating geoid; continues ET
- TAI: International Atomic Time
  - Timekeepers' time; TT – TAI = 32.184 s
- UTC: Universal Time Coordinated; GMT
  - Distributed time, with leap seconds; currently 34 s behind TAI
- GPS: GPS's Time Scale
  - TAI – GPS = 19 s



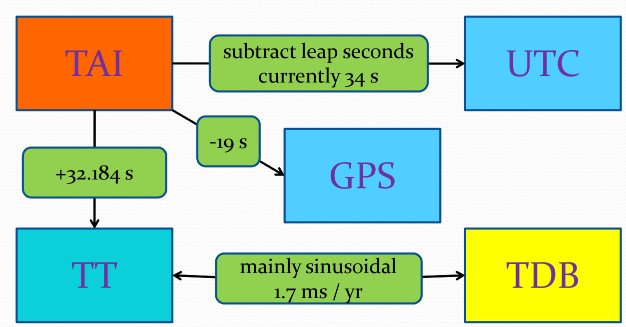
## Barycenter Correction

- Geometric path length delay (< 500 s)
- Shapiro delay (< 0.2 ms)
- Römer delay (typically < 0.1 ms)
- Eccentricity of earth orbit (< 2 ms)

- These terms transform TT into TDB



## Time Scales Realization



## How Long is a Second?

- Before 1967 the second was 1/31,556,925.9747 of the tropical year for 1900 January 0 at 12 h Ephemeris Time
- Until we changed to Julian epochs, we used Besselian epochs, based on Tropical Years
- Trouble is, Tropical Years are getting shorter: 0.8 s per century
- Julian epochs are based on a Julian Century: 36525 days of 86400 s
- The second is now defined by Cesium atomic transition



## 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
- In LEO we don't bother, just synchronize



## Real Relativistic Trouble

- But having a clock run synchronously at the barycenter (as TDB does) has nasty consequences: fundamental physical constants change
- Solution: Coordinate Time
  - TCG – faster than TT by $6.969290134 \times 10^{-10}$
  - TCB – faster than TDB by $1.550505 \times 10^{-8}$
  - Both synchronized with TT and TDB at 1977.0 (UTC)



## Practical Time Scales Model