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 your 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-ddThh:mm:ss[.sss...]`
  - No time zones
  - Gregorian 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; $TT - TAI = 32.184\text{ s}$
- **UTC: Universal Time Coordinated; GMT**
  - Distributed time, with leap seconds; currently 34 s behind TAI
- **GPS: GPS’s Time Scale**
  - $TAI - GPS = 19\text{ s}$

Barycenter Correction

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

  - These terms transform TT into TDB

Time Scales Realization

- **TAI**
  - Subtract leap seconds currently $34\text{ s}$
  - $+32.184\text{ s}$

- **UTC**
  - $-19\text{ s}$

- **GPS**
  - Mainly sinusoidal $1.7\text{ ms/yr}$

- **TT**
  - $+32.184\text{ s}$

- **TDB**
How Long is a Second?
- Before 1967 the second was \( \frac{1}{31,556,925,9747} \) 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