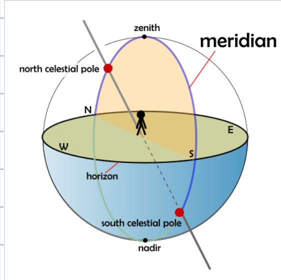
Ch 2 Time

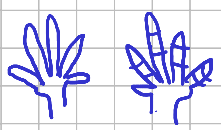
Solar Noon - the sun reaches its apparent highest point in the sky
└ the sun crosses an observer's Meridian

Meridian - great circle passing through celestial poles
& observer's zenith



- Dividing a 'day' into 24 hours is seemingly arbitrary (potentially predating ancient Egyptians)
  - └ depending on the system used to define the hour, the length of a hour could change. (Greeks split daylight into 12 equal segments and darkness in 12 segments too)

- Splitting hour & minute into 60 segments is vestiged of Babylonian sexagesimal system
  - use left fingers & right phalanges to count to 60!



- 4 fingers w/ 3 phalanges = 12 (right)
- 5 digits on left → 5×12 = 60

* Daily Motion of Sol is original basis of our timekeeping systems *

Types of time
1) Solar time
2) Dynamical time
3) Sidereal time

Types of Calendar
1) Julien
2) Heliocentric Julien
3) Gregorian

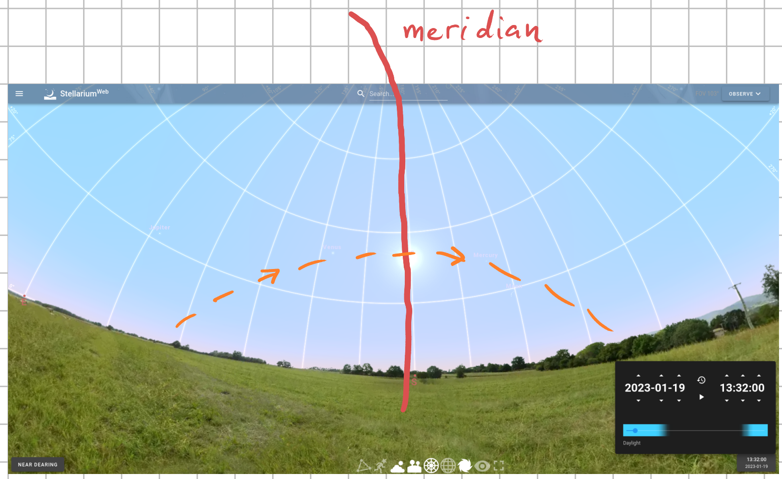
Solar time

Suppose you define noon to be when the sun crosses your meridian line.

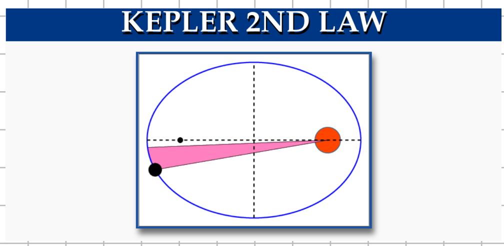
- You track noon w/ a sundial & an accurate watch.
  - from May - Nov sundial noon occurs before watch noon
  - from Feb - July sundial noon occurs after watch noon

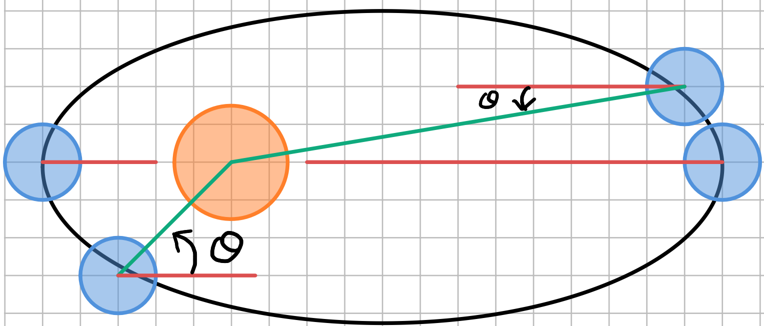
- Two reasons for this discrepancy
  1) elliptical orbit
  2) obliquity

1) Elliptical shape of Earth's orbit



Show transition on stellarium site



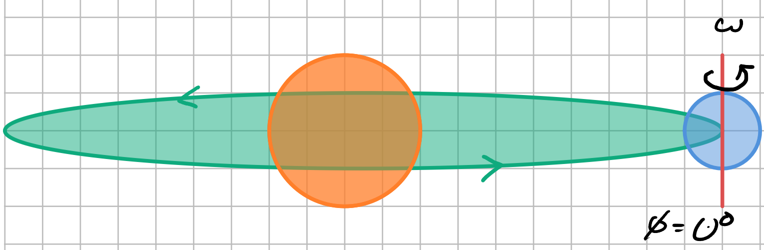


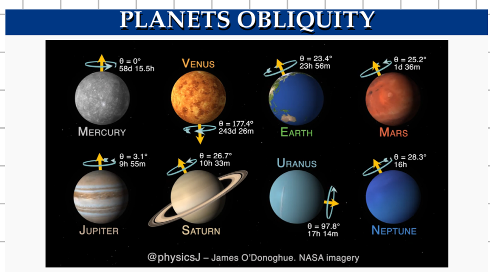
slow orbital speed

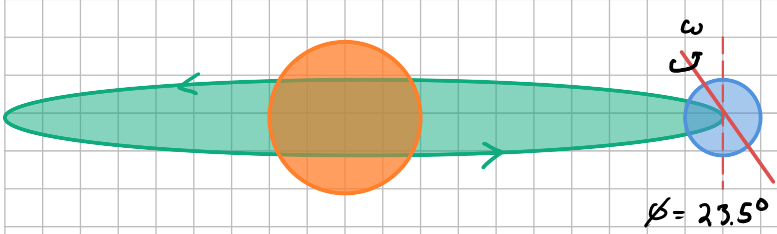
3rd Law $P^2 \alpha\, r^3$

fast orbital speed

2) Tilt of Earth's axis (obliquity)



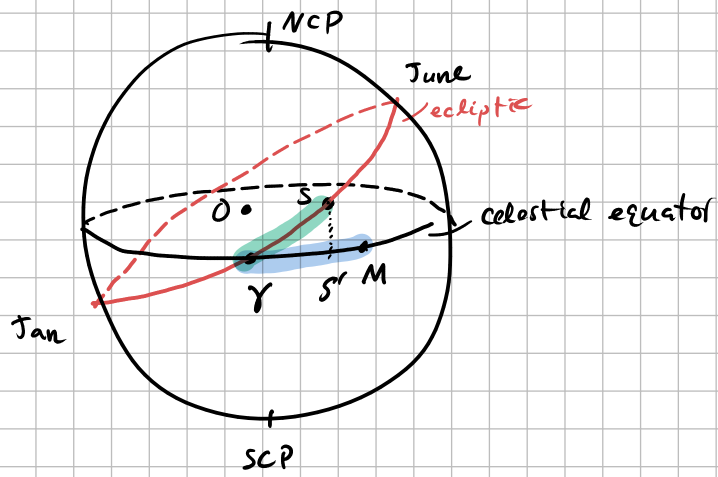




Visualizing this time discrepancy

Consider the path of the sun (S) along the ecliptic (assume uniform speed)

Now imagine a fictitious or Mean sun moving along the the celestial equator (same uniform speed)



$$|\gamma S| = |\gamma M|$$

(S' is projection of S onto celestial equator)

From $\gamma \rightarrow$ June S' is behind M!

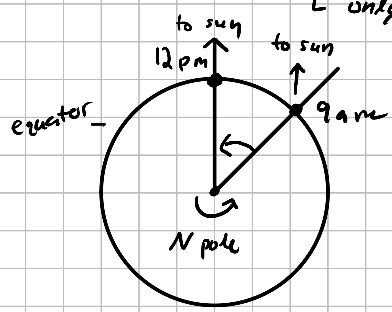
Equation of time captures the combined effect of both (elliptical orbit & obliquity)

Equation of time = (True Solar time) − (Mean Solar time)

$$EoT = TST - MST$$

True Solar time (TST) = time recorded by sundial (NOT uniform)

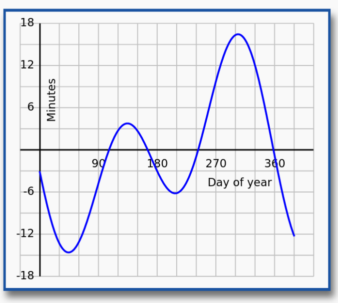
↳ only valid for observers on agreed upon longitude



Mean Solar time (MST) = day in MST is average of all TST days in one year.

↳ our clocks are synced to MST

EQUATION OF TIME

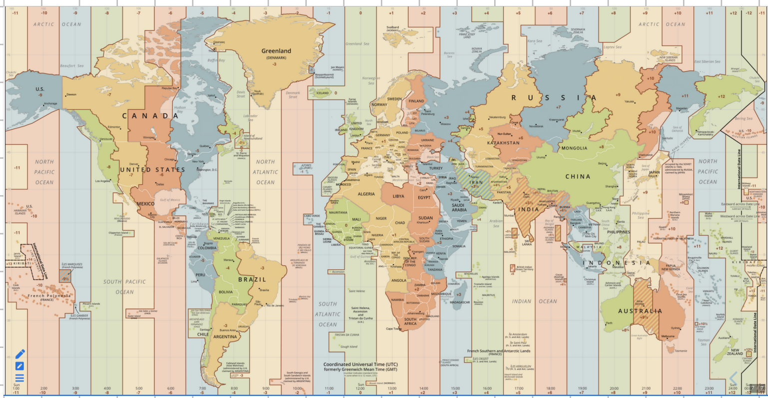


Above the x-axis, sundial is ahead of local mean time. (Sundial is "fast")

time zones on Earth

- we've divided Earth into 24 time zones

$360° = 24$ time zones $\Rightarrow$ $15°$ per time zone

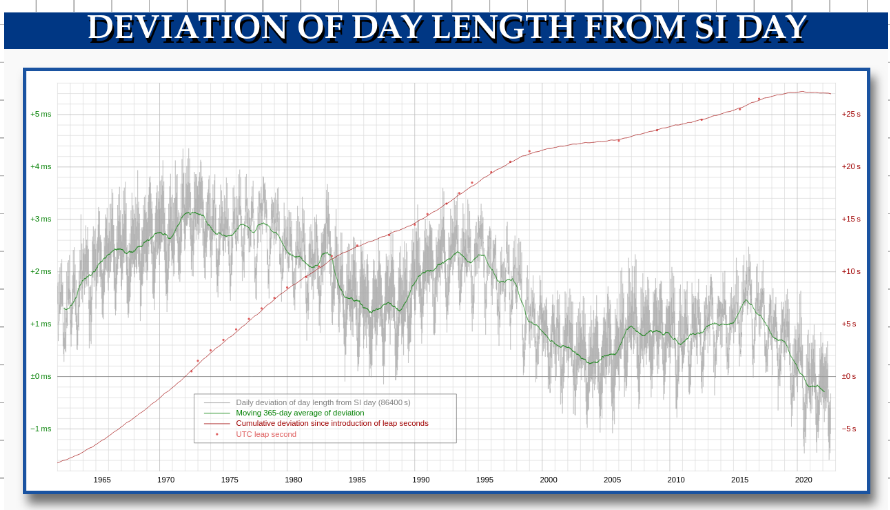


- in 1884 Greenwhich England choosen as $0°$ longitude
- increases towards East decreases towards West

- Greenwhich Mean time (GMT) = Universal time (UT)
- longitude = (UT − local mean time) × 15°

Dynamical Time

- The independent variable in equations of celestial mechanics
- necessary for precise measurements because Earth's rotation is increasing
- June 29, 2022 Earth's rotation took 8639998.41 milli-seconds
  ↳ 1.59ms less than 24 hrs
- increase is irregular ∴ ΔT based on empirical measurements



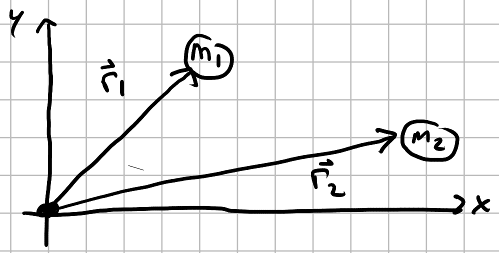
- Two types of Dynamical time

Terrestial time (TT or TDT)

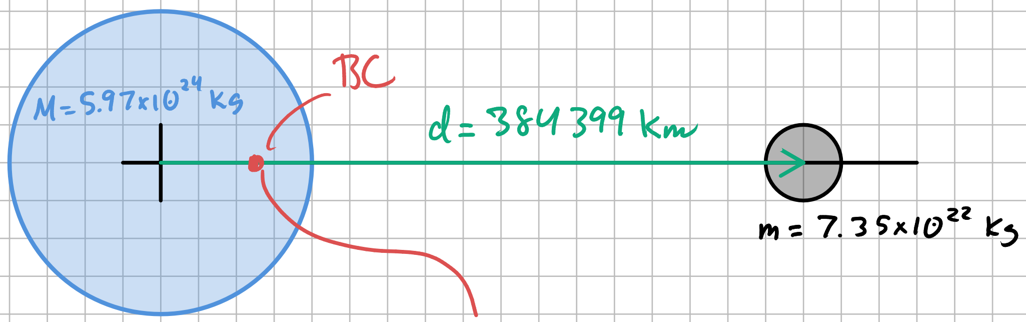
- $TDT = UT + \Delta T$
- defined by International Astronomical Union (IAU) for measurements made on Earth's Surface

Barycentric Dynamical Time (TDB)

- bary center = center of mass of two or more bodies



$$CM = \frac{\sum m_i \vec{r}_i}{\sum m_i}$$

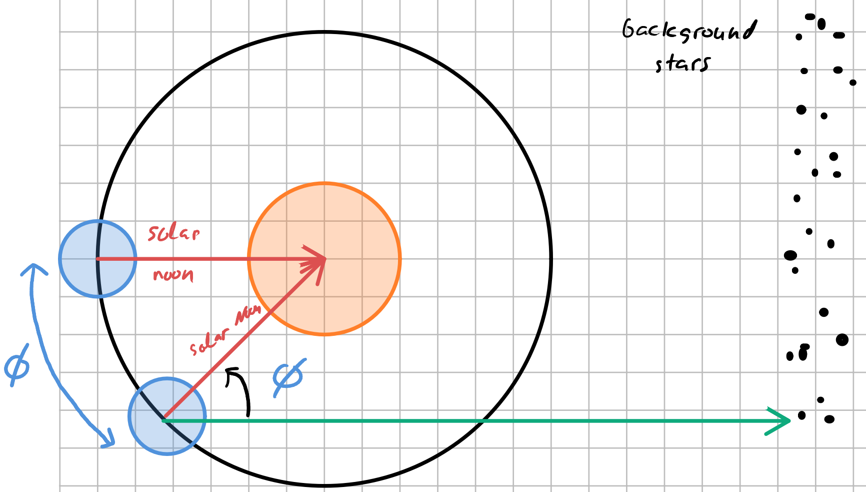


$$CM = \frac{M \cdot \vec{0} + m \cdot \vec{d}}{M + m} = \boxed{4671 \text{ km}}$$

, $R_E = 6371$ km

- TDB applies to Solar-System Barycentric ref frame
- takes into account time dilation

Sidereal time



ϕ = angle swept out by Earth every day

$$\phi = \frac{360^\circ}{365.25 \text{ day}} = 0.986^\circ \text{ per day}$$

solar day = 24 hours

sidereal day = solar day − (time of 1°)

$$\text{sidereal day} = 24\,hr - t$$

$$= 24\,hr - \frac{\phi}{\omega}$$

$$= 24\,hr - \frac{0.986^\circ}{1\,day} \cdot \frac{1}{\left(\frac{360^\circ}{24\,hr}\right)}$$

$$= 24\,hr - \frac{0.986^\circ}{1\,day} \cdot \frac{24\,hr}{360^\circ} \cdot \frac{60\,min}{1\,hr}$$

$$= 24\,hr - 3.944\,\text{minutes}$$

- Sidereal time use is that any object crosses the upper meridian when local sidereal time = object's right ascension

Mean solar time → local sidereal time

1) Convert standard time to UT

2) Convert the solar interval since zero hour (0^h) UT to sidereal interval
   - multiplying UT (in hours) by

$$\frac{\text{mean solar seconds in solar day}}{\text{mean solar seconds in sidereal day}} = \frac{24^h}{23^h 56^m 4.01^s} = \frac{86400\,s}{86164.0905\,s} = 1.002\,737\,91$$

ex: $6^h 42^m$ UT is $6^h + 42^m \frac{1^h}{60\,min} = 6.7^h$ (solar interval)

$$\text{sidereal interval} = 6.7^h \cdot 1.00273791 = 6.718^h$$

3) Find Greenwhich Sidereal time at time of interest (Astronomical Almanac)

4) Correct for observers longitude, then calculate local sidereal time

$$L \quad \frac{15^\circ}{1^h}$$

example: Get local sidereal time for observer in Ames Iowa at 10:14 pm CDT on May 8 2005

1) $2214 + 0600 - 0100 = 2714 = 0314$ UT May 9 2005

day light savings time

2) 0^h to sidereal interval

$$3^h 14^m = 3.233^h$$

$$3.233^h \cdot 1.00273791 = \boxed{3.242 \text{ sidereal hr}}$$

3) Astronomical Almanac list Greenwhich sidereal time on May 9 2005 as

$15^h\ 7^m\ 37.5544^s = 15.127098^h$ ∴

GST at $3^h 14^m$ is

$$GST = 15.127098^h + 3.242^h = 18.369098^h$$

4) Subtract longitude of Ame Iowa to get local sidereal time (LST)

$$\lambda = 93^\circ\ 37'\ 11''\ W = 93^\circ + 37' \cdot \frac{1^\circ}{60'} + 11'' \cdot \frac{1^\circ}{60'} \cdot \frac{1'}{60''} = 93.61972^\circ$$

$$\lambda = 93.61972^\circ \cdot \frac{1^h}{15^\circ} = 6.241315^h$$

$$LST = GST - \lambda$$

$$= 18.369098^h - 6.241315^h$$

$$= 12.127783^h$$

$$= 12^h\ 7^m\ 40^s$$

Calendars

Julien Dates: Begins (day 1) is Jan 1 4713 BC. Days begin at noon. Continuously counting up. No reset for month or year.

Jan 1, 2000 at 12:00 am = 2,451,544.5 julien days

Todays date in Julien can be caclulated as

$$JD = 2{,}451{,}544.5 + 365(Y-2000) + N + L$$

Y = Current Year, N = day # of the year,
L = # of leap days since Jan 1 2001
$= \left\lfloor \frac{Y-2000}{4} \right\rfloor$ — floor operator

why Jan 1 4713 C?
solar cycle every 28 years
lunar cycle every 19 years
solar & lunar cycle sync every 532 years

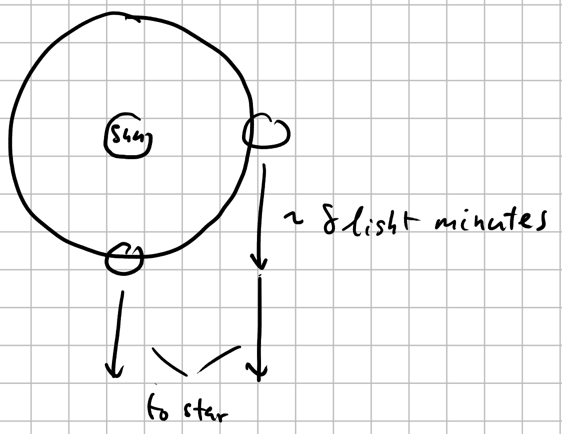
example: today's date Jan 26 2023 in Julien is

$$JD = 2451544.5 + 365(2023-2000) + 26 + \left\lfloor \frac{(2023-2000)}{4} \right\rfloor$$

$$= 2469467.5$$

Heliocentric Julian Date

- Take into account time delay of event due to position of Earth around Sol.



Julien & Gregorian calendars

- would be nice to have spring start on same day every year.
  - Earth's precession & sidereal year = 365.2563^d prevent this calendar