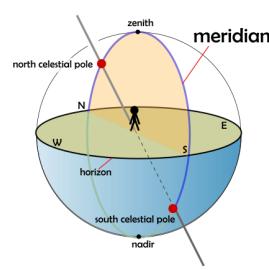


Ch 2 Time

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 vestigial of Babylonian sexagesimal system
 - ↳ use left fingers & right phalanges to count to 60!



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

* 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

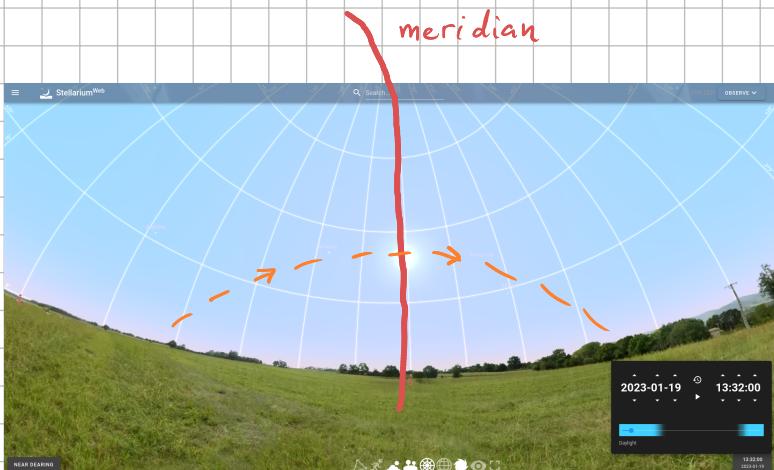
- 1) Julian
- 2) Heliocentric Julian
- 3) Gregorian

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

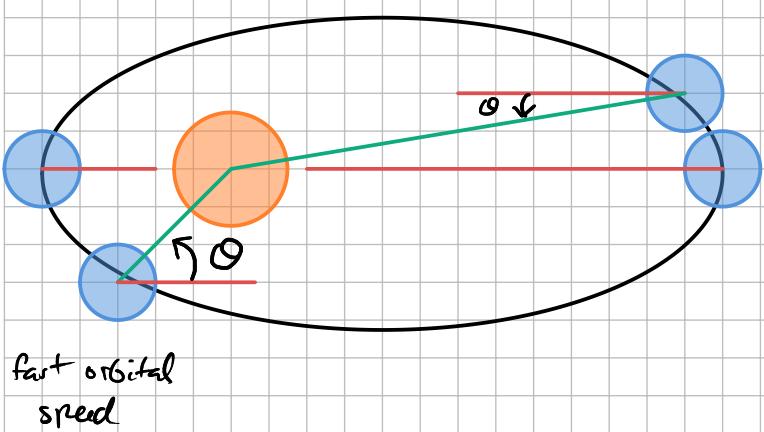
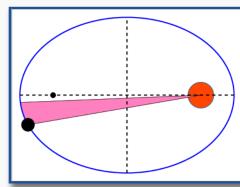


Show transition on stellarium site

ARTIC CIRCLE IN SUMMER

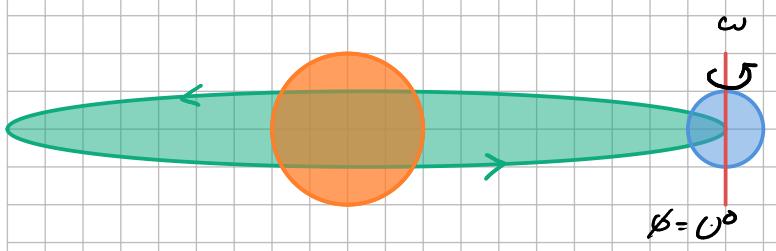


KEPLER 2ND LAW

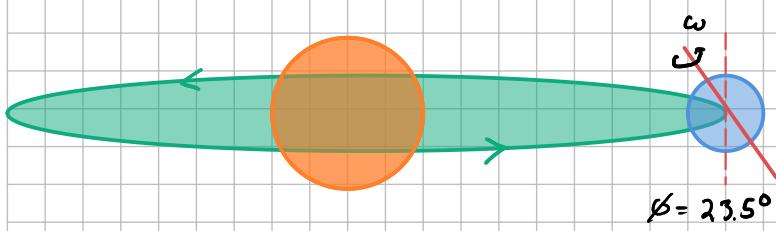
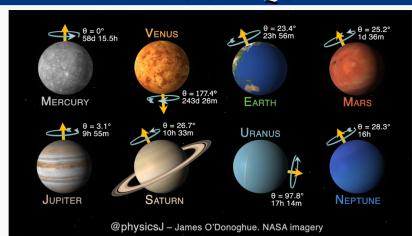


$$3^{\text{rd}} \text{ Law } P^2 \propto r^3$$

2) Tilt of Earth's axis (Obliquity)



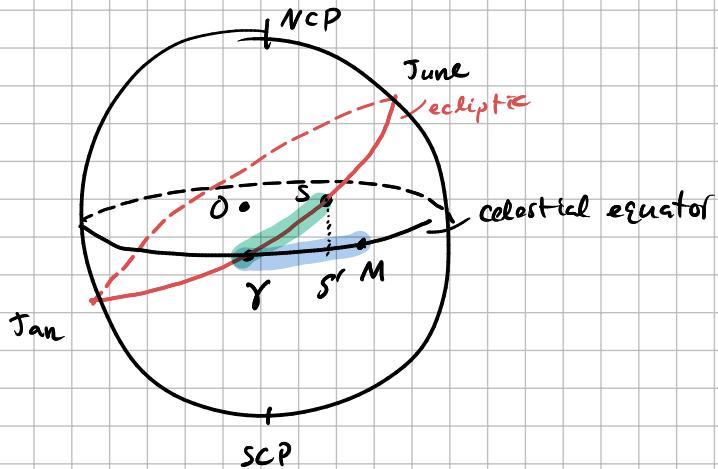
PLANETS OBLIQUITY



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 celestial equator (same uniform speed)



$$|S| = |M|$$

(S' is projection of S onto celestial equator)

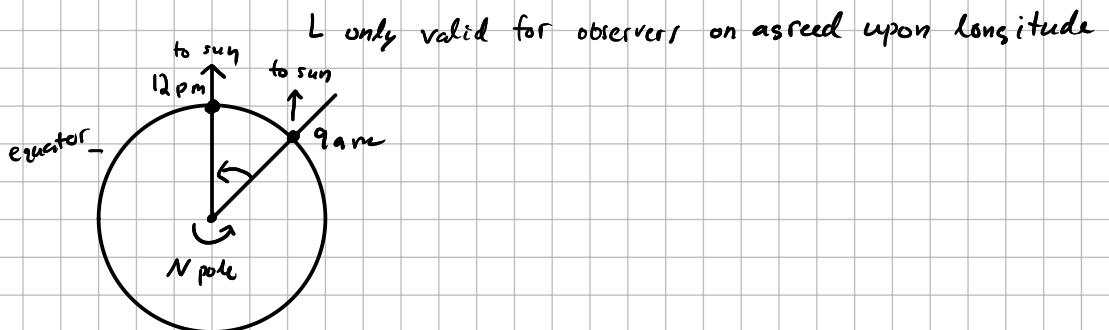
From $\gamma \rightarrow$ June S' is behind M !

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

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

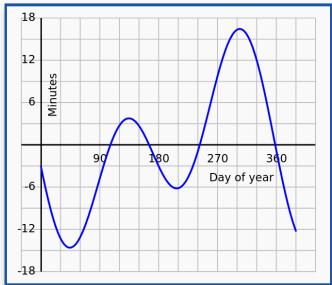
$$EOT = TST - MST$$

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



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

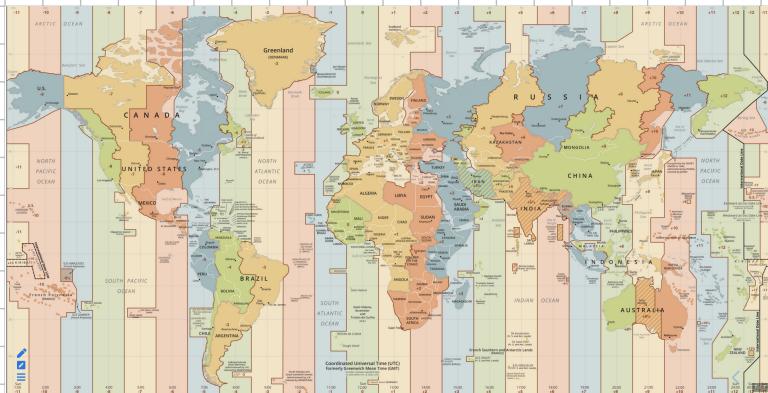


Above the x-axis, sundial is ahead of local mean time.
(Sundial is "fast")

time zones on Earth

- we've divided Earth into 24 time zones

$$360^\circ = 24 \text{ time zones} \Rightarrow 15^\circ \text{ per time zone}$$



- in 1884 Greenwich England chosen as 0° longitude
- increases toward East decreases toward West

• Greenwich Mean time (GMT) = Universal time (UT)

• longitude = $(UT - \text{local mean time}) \times 15^\circ$

Dynamical Time

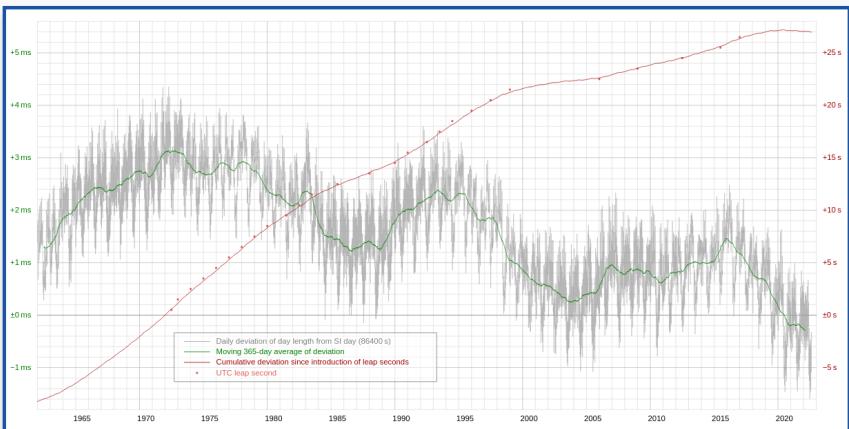
- The independent variable in equations of celestial mechanics

- 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 $\therefore \Delta T$ based on empirical measurements

DEVIATION OF DAY LENGTH FROM SI DAY



- Two types of Dynamical time

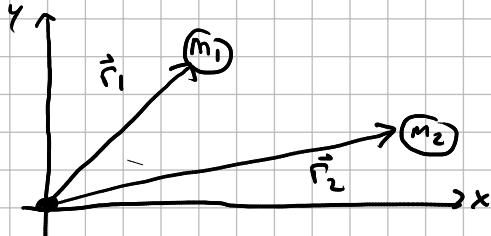
Terrestrial time (TT or TDT)

- $TDT = UT + \Delta T$

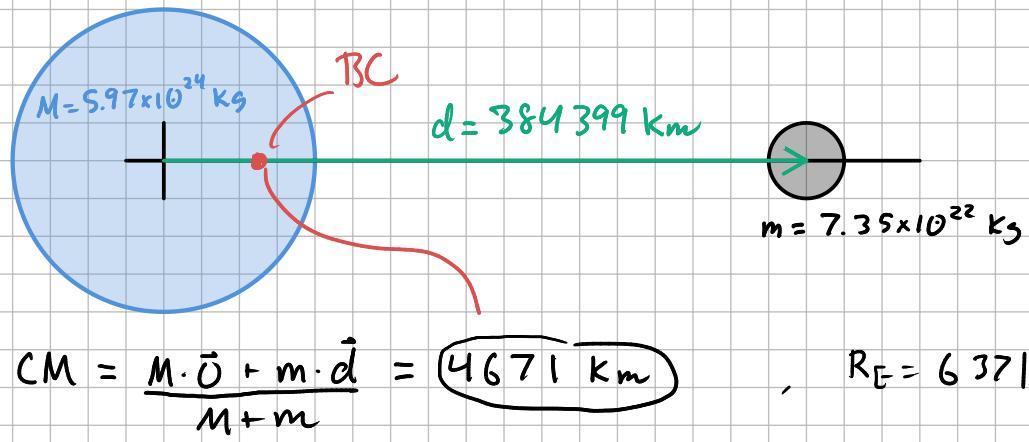
- defined by International Astronomical Union (IAU) for measurements made on Earth's Surface

Barycentric Dynamical Time (TDB)

- barycenter = center of mass of two or more bodies

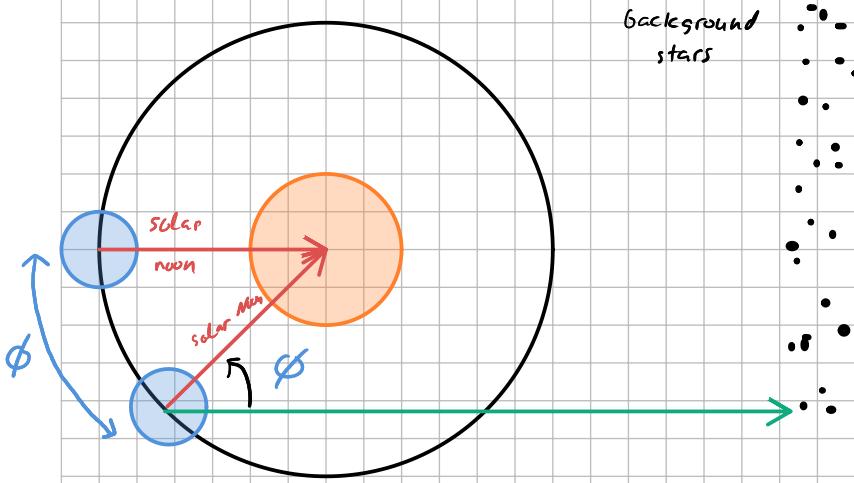


$$CM = \frac{\sum m_i \vec{r}_i}{\sum m_i}$$



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

Sidereal time



Background stars

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

sideral day = solar day - (time of 1°)

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

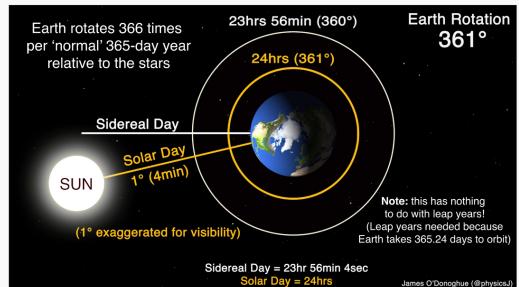
$$= 24\text{hr} - \frac{\theta}{\omega}$$

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

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

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

SIDEREAL DAY



Video Source

- 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

$$\frac{\text{mean solar seconds in solar day}}{\text{mean solar seconds in sidereal day}} = \frac{24\text{h}}{23^h 56^m 4.01^s} = \frac{86400\text{s}}{86164.0905\text{s}} = 1.00273791$$

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

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

3) Find Greenwich Sidereal time at time of interest (*Astronomical Almanac*)

4) Correct for observer's longitude, then calculate local sidereal time

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

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

$$1) 2214 + 0600 - 0100 = 2714 = 0314 \text{ UT May 9 2005}$$

~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 Greenwich sidereal time on May 9 2005 as
 $15^{\text{h}} 7^{\text{m}} 37.5544^{\text{s}} = 15.127098^{\text{h}}$ ∴

GST at $7^{\text{h}} 14^{\text{m}}$ is

$$\text{GST} = 15.127098^{\text{h}} + 3.242^{\text{h}} = 18.369098^{\text{h}}$$

4) Subtract longitude of Ames Town to get local sidereal time (LST)

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

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

$$\text{LST} = \text{GST} - \lambda$$

$$= 18.369098^{\text{h}} - 6.241315^{\text{h}}$$

$$= 12.127783^{\text{h}}$$

$$= 12^{\text{h}} 7^{\text{m}} 46^{\text{s}}$$

Calendars

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

$$\text{Jan 1, 2000 at 12:00 am} = 2,451,544.5 \text{ julian days}$$

Todays date in Julian can be calculated as

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

Y = Current Year, N = day # of the year,

L = # of leap days since Jan 1 2001

$$= \left\lfloor \frac{Y-2000}{4} \right\rfloor - \text{floor operator}$$

Why Jan 1 4713 BC?

solar cycle
every 28 years

lunar cycle
every 19 years

solar & lunar
cycle sync
every 532 years

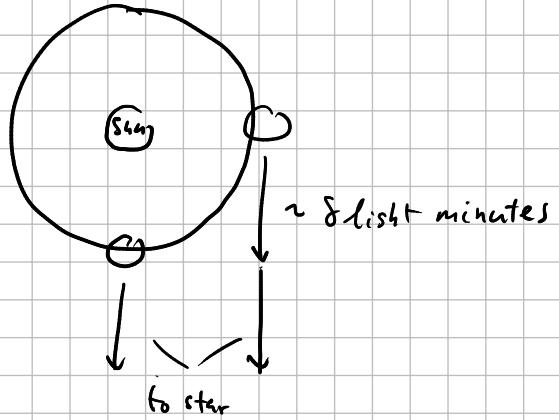
Example: today's date Jan 26 2023 in Julian is

$$\text{JD} = 2,451,544.5 + 365(2023-2000) + 26 + \left\lfloor \frac{(2023-2000)}{4} \right\rfloor$$

$$= 2,469,467.5$$

Heliocentric Julian Date

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



Julian & 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