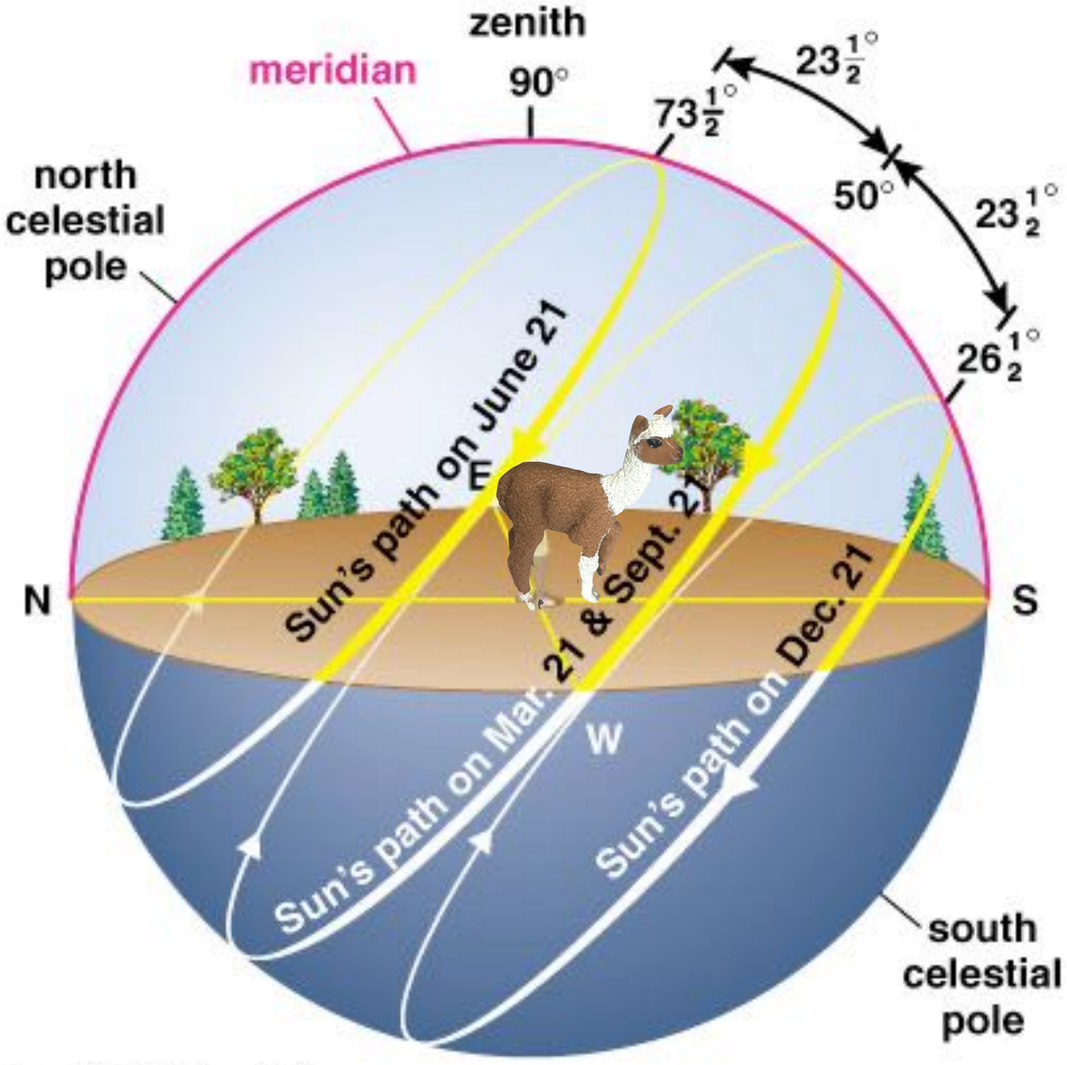
Week 2: Orbits and Gravity

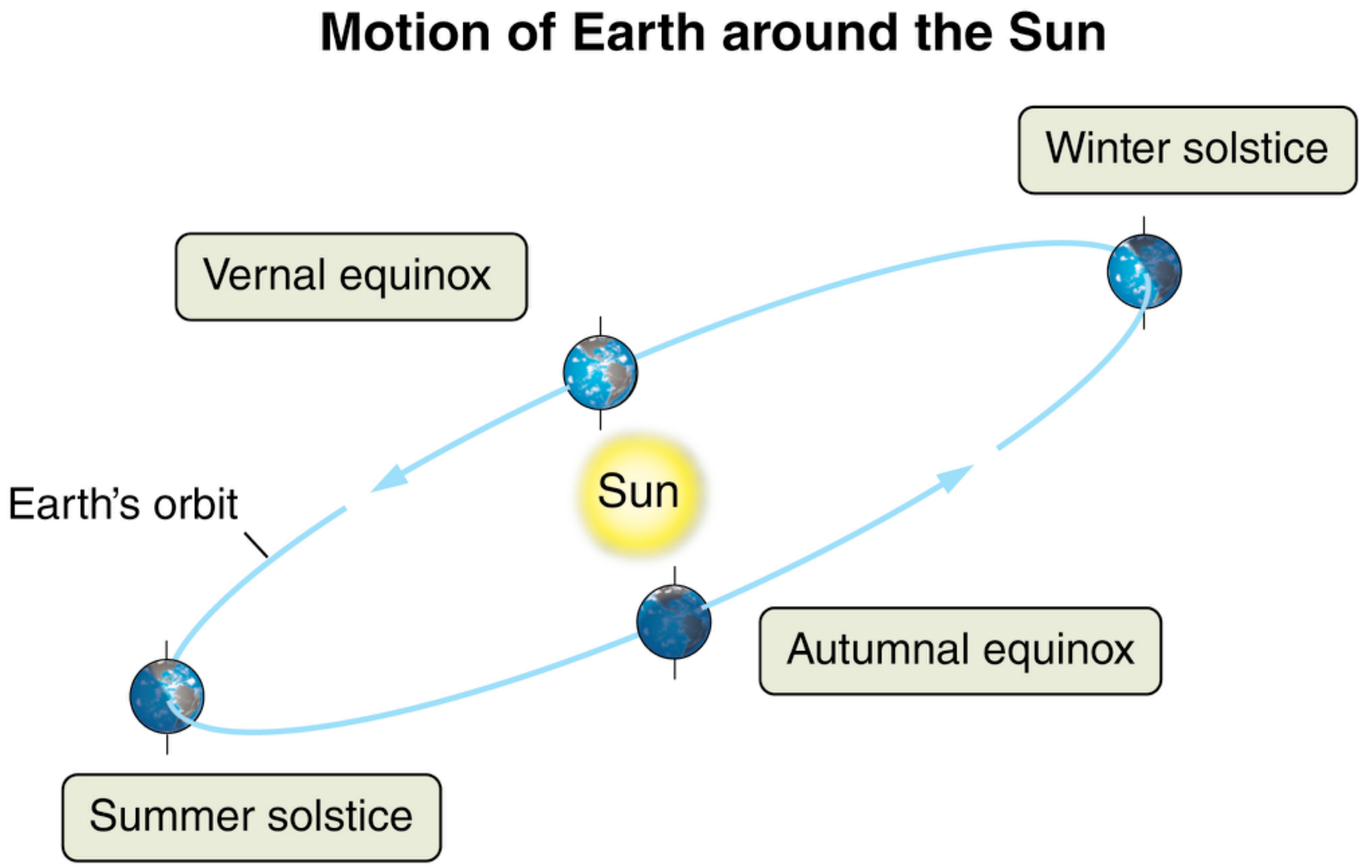
Please complete the Student Info and Pre-course Asssessment, if you haven't yet

HW1 due on Thursday

Read indicated sections of Ch. 2 & 3

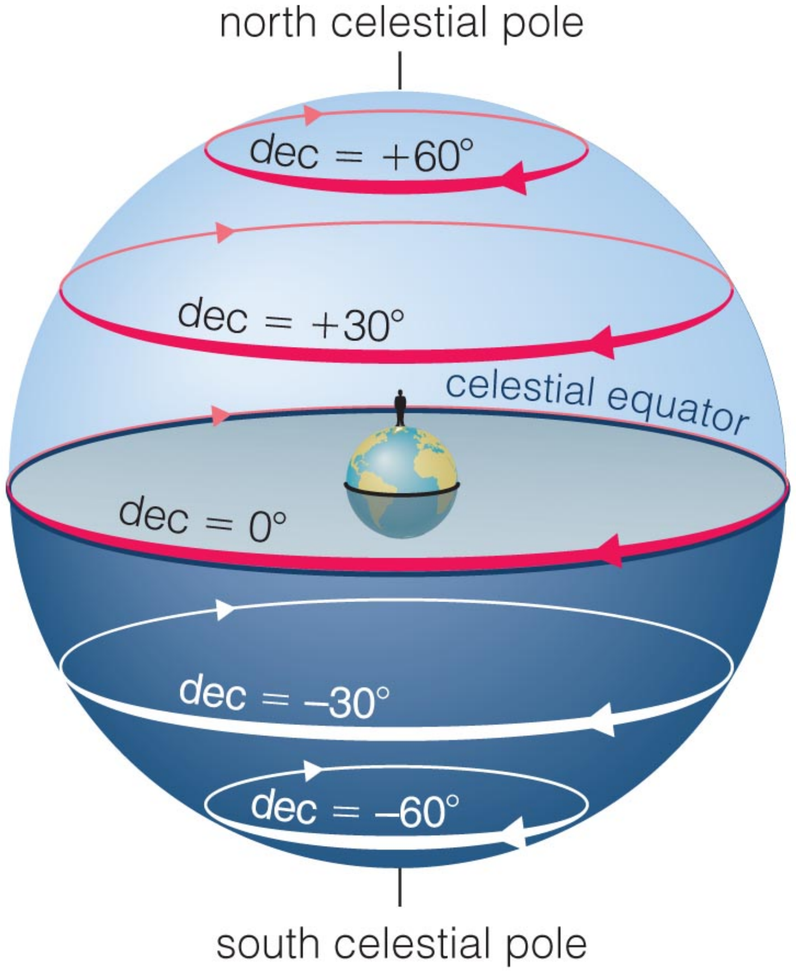
Max altitude of the Sun determined by where we are on Earth and where the Earth is in its orbit

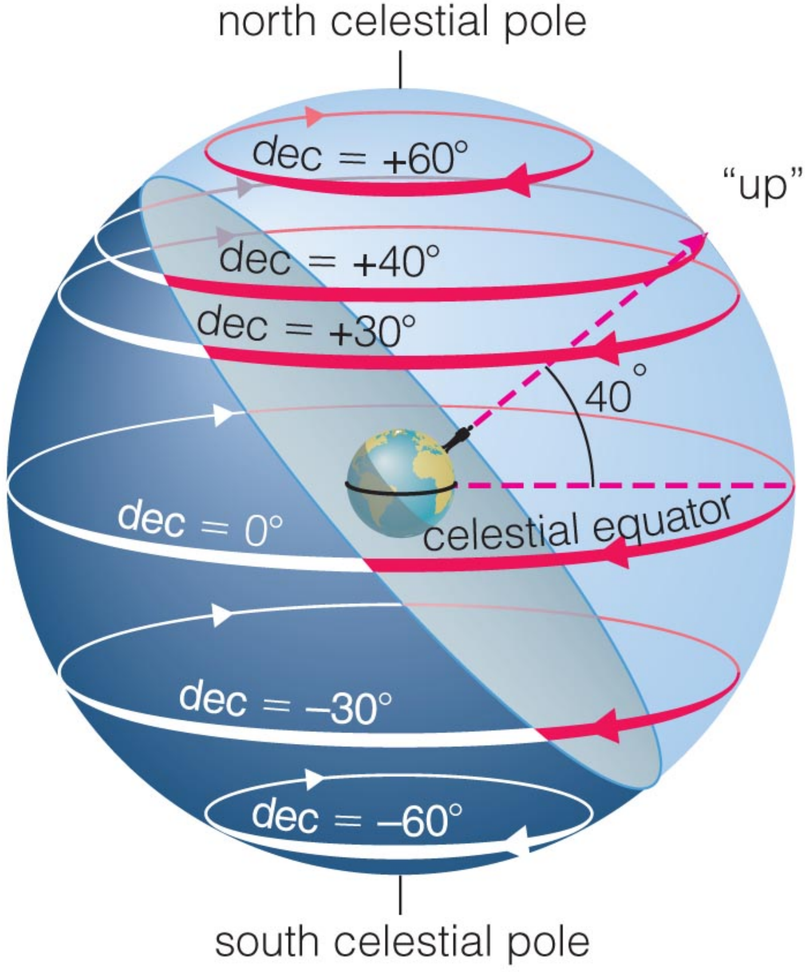




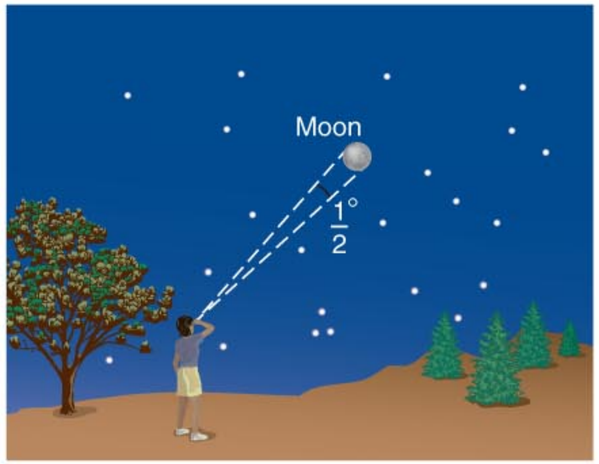
http://www.youtube.com/watch?v=Xm_Cn8-DCNc

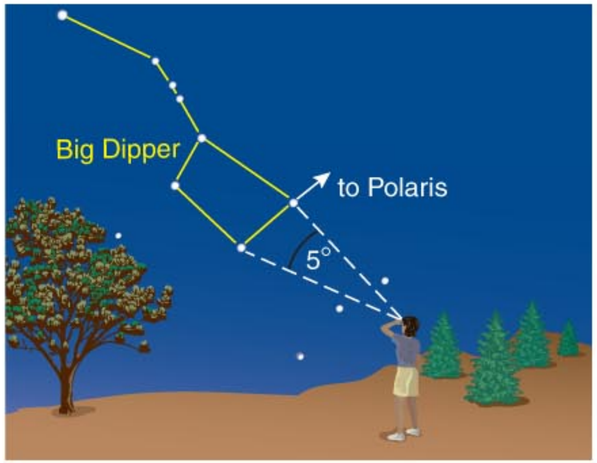
Right Ascension & Declination

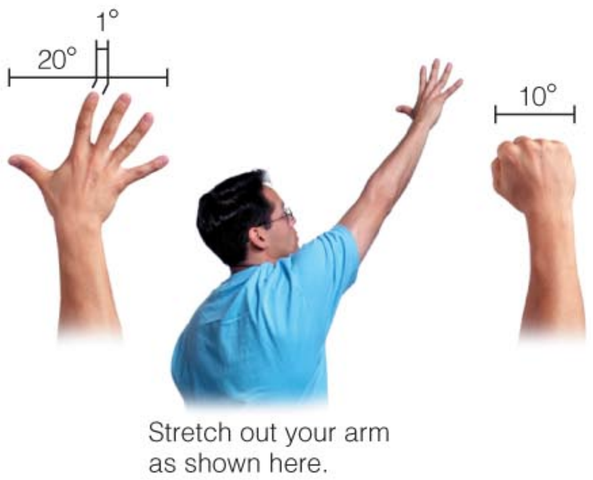




Angular Sizes / Distances on the Celestial Sphere



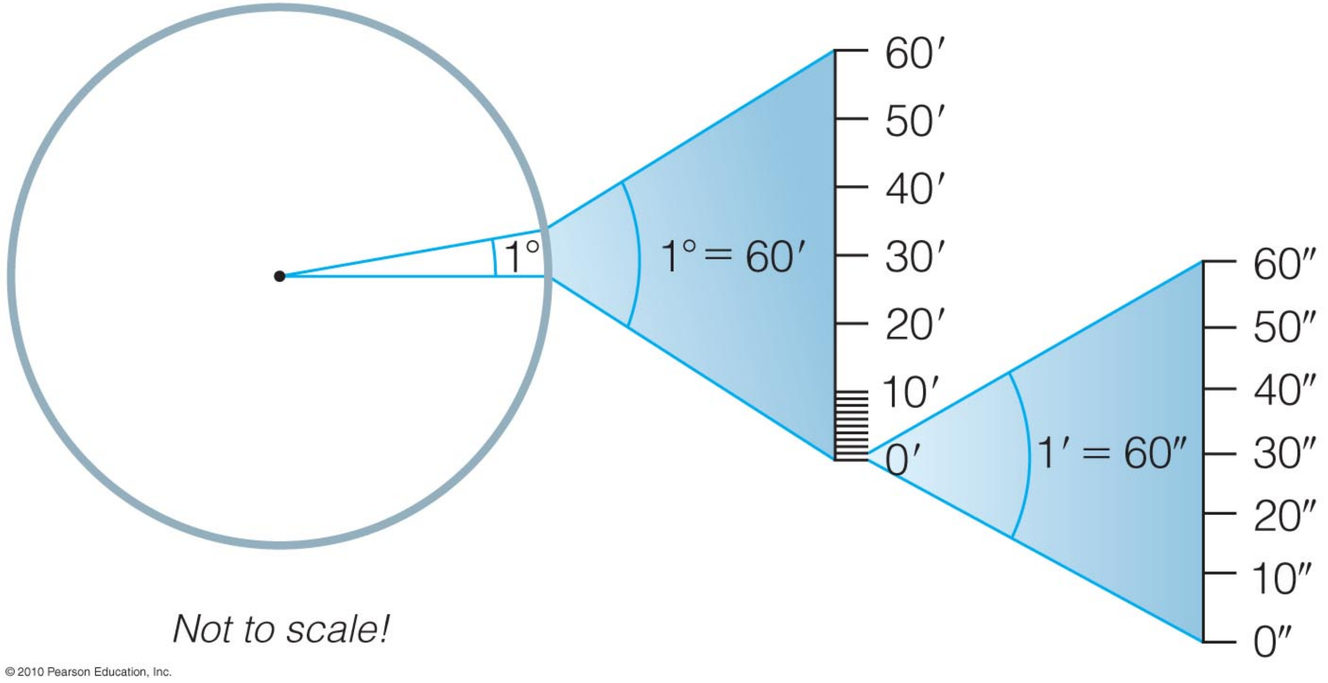




Stretch out your arm as shown here.

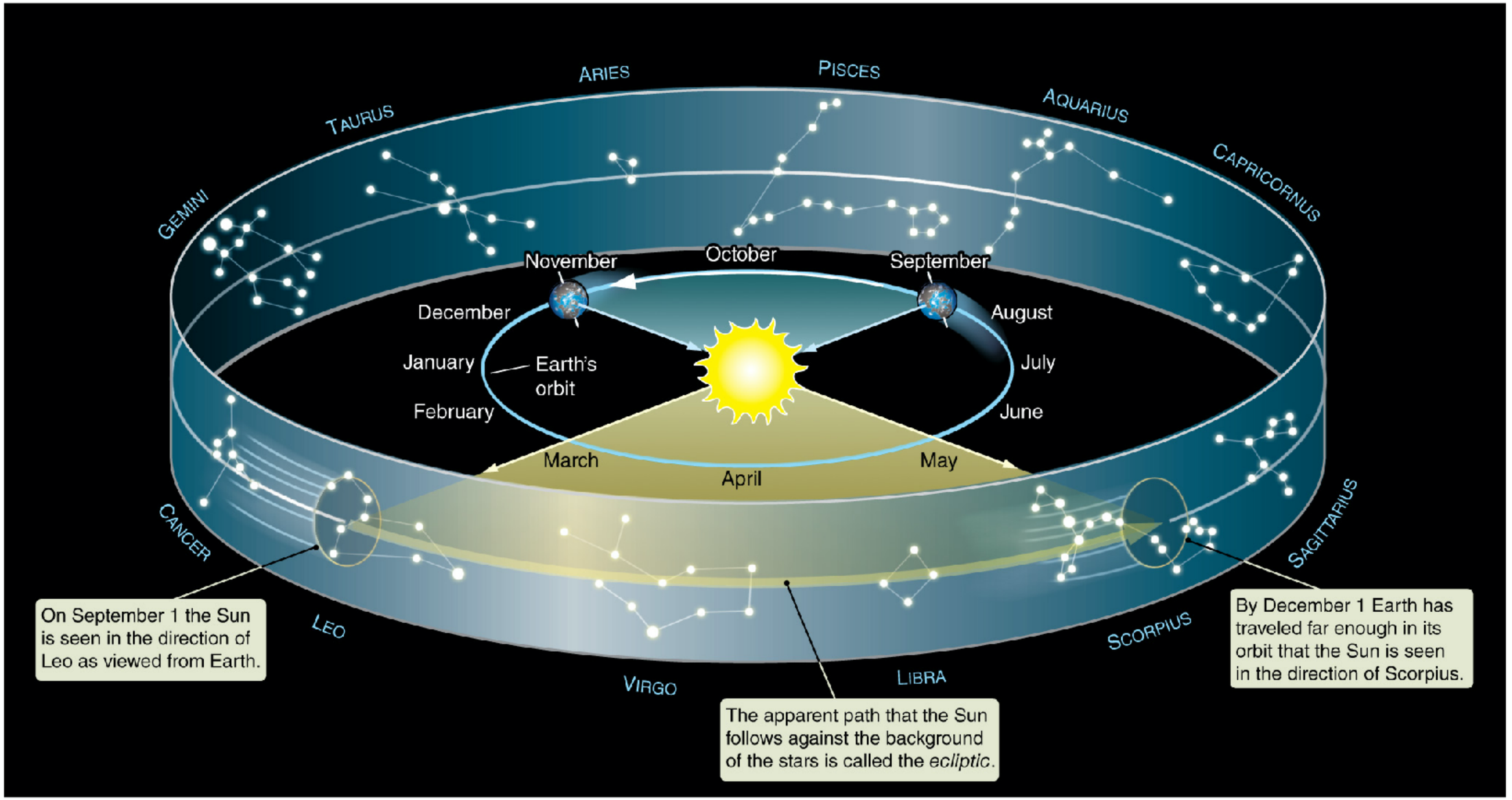
Right Ascension

- tells time, marking when stars cross an Hour Angle of 0^h
- can be quoted either in degrees or hours/minutes/seconds where $24^h = 360^o$
- differences of RA DO NOT correspond to angular differences except when Dec = 0^o



Not to scale!

The Ecliptic: Sun's path on the Celestial Sphere



The Ecliptic

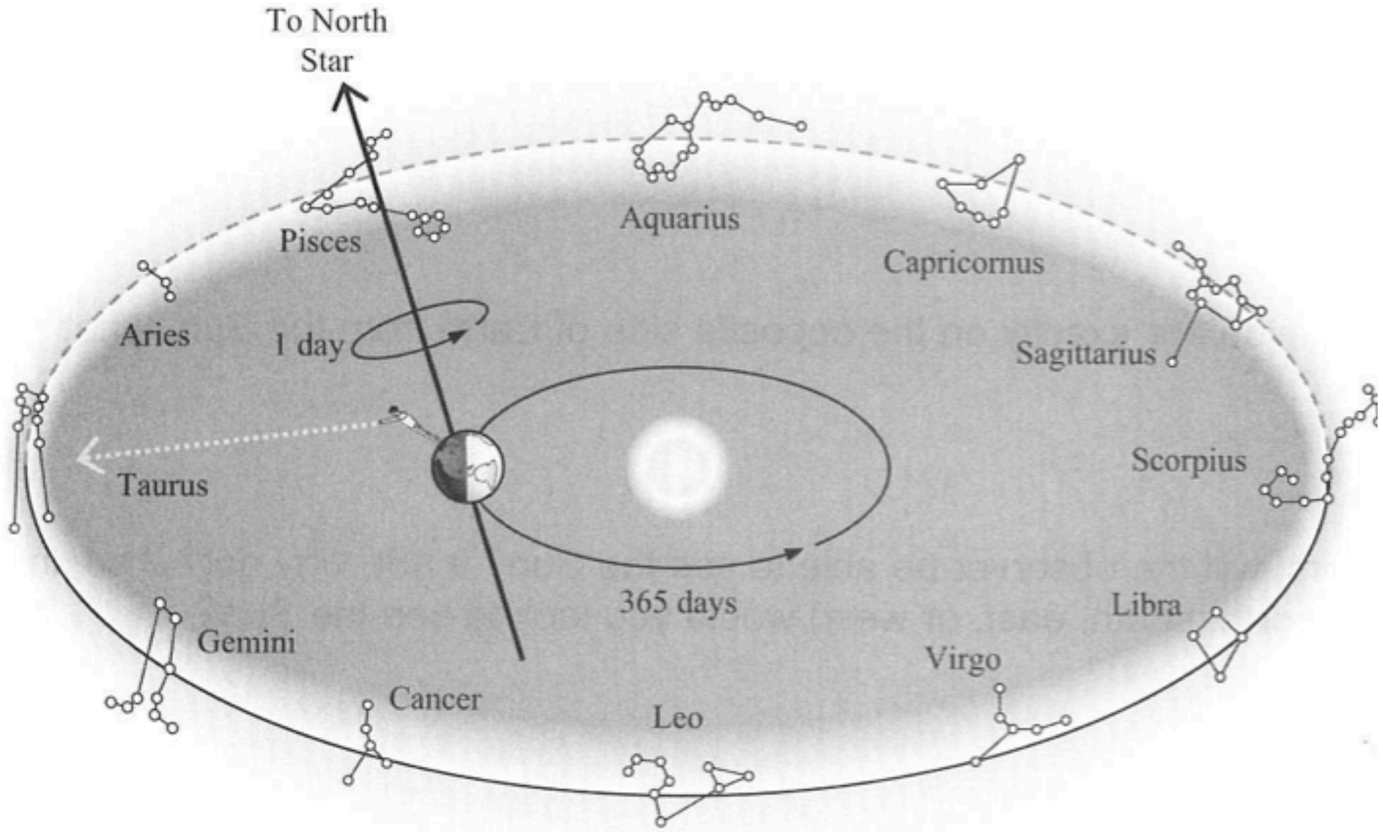


Figure 1

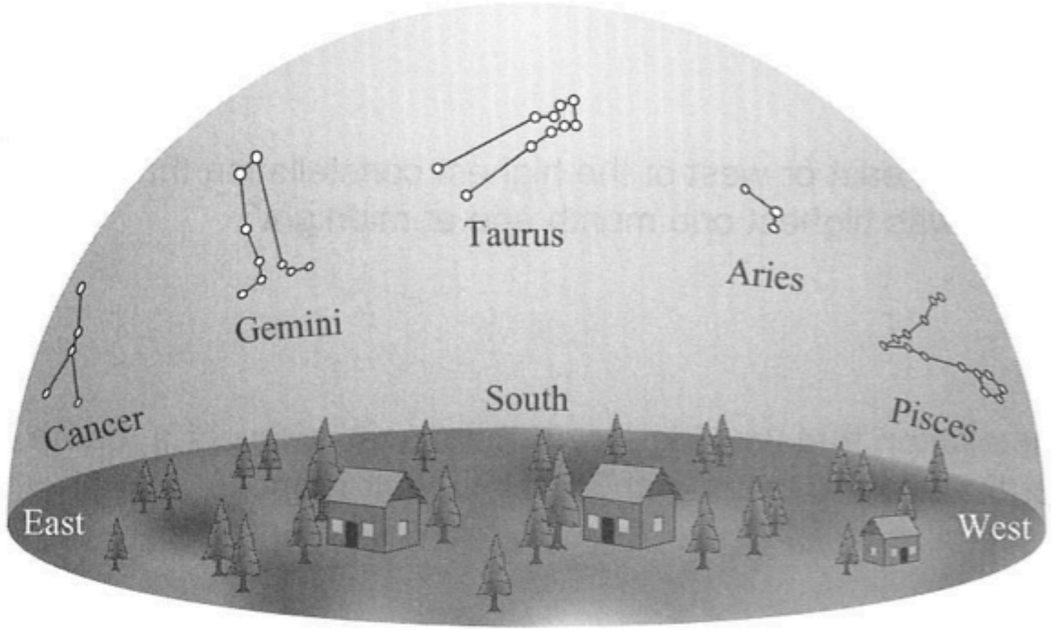
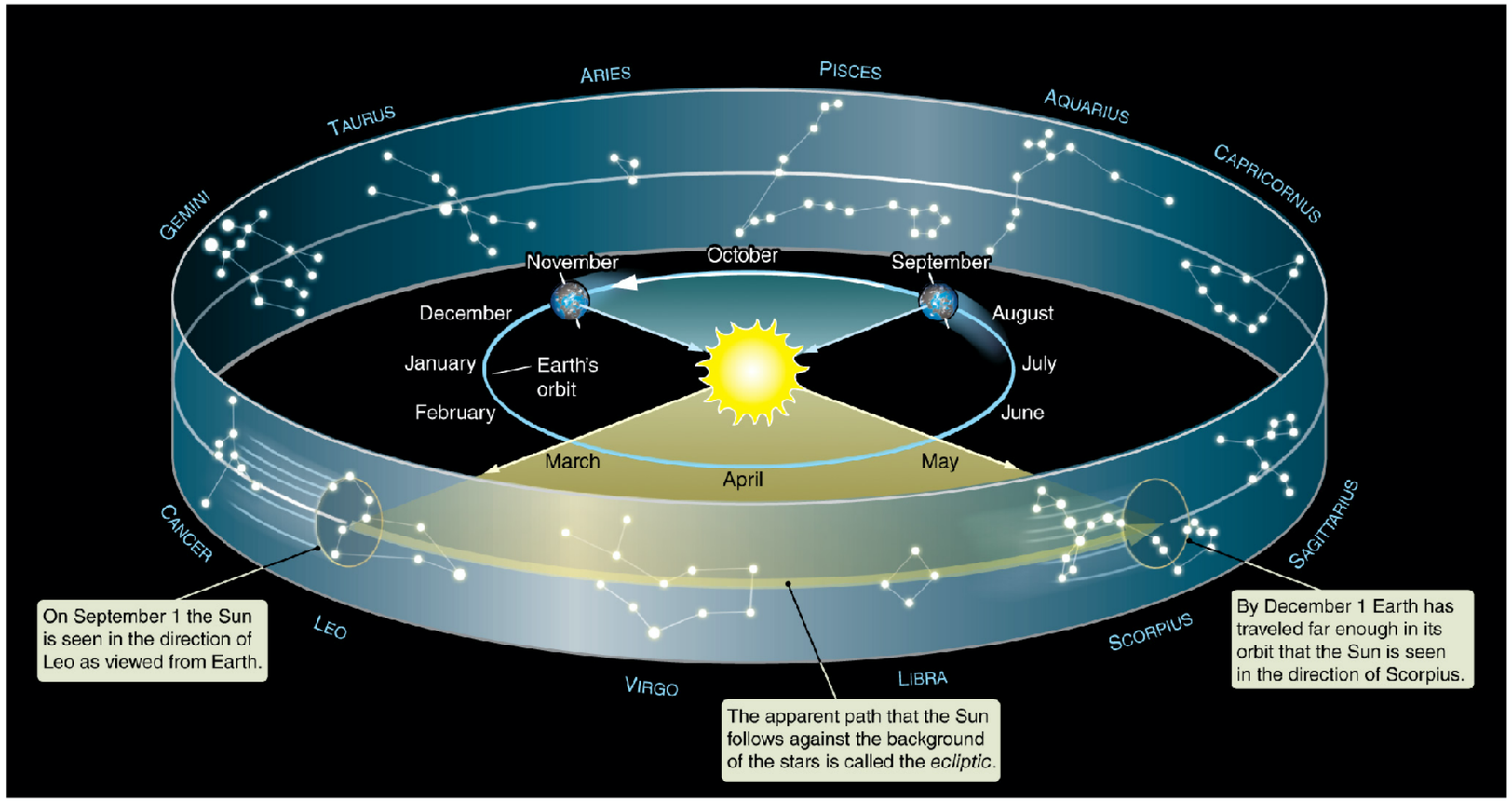


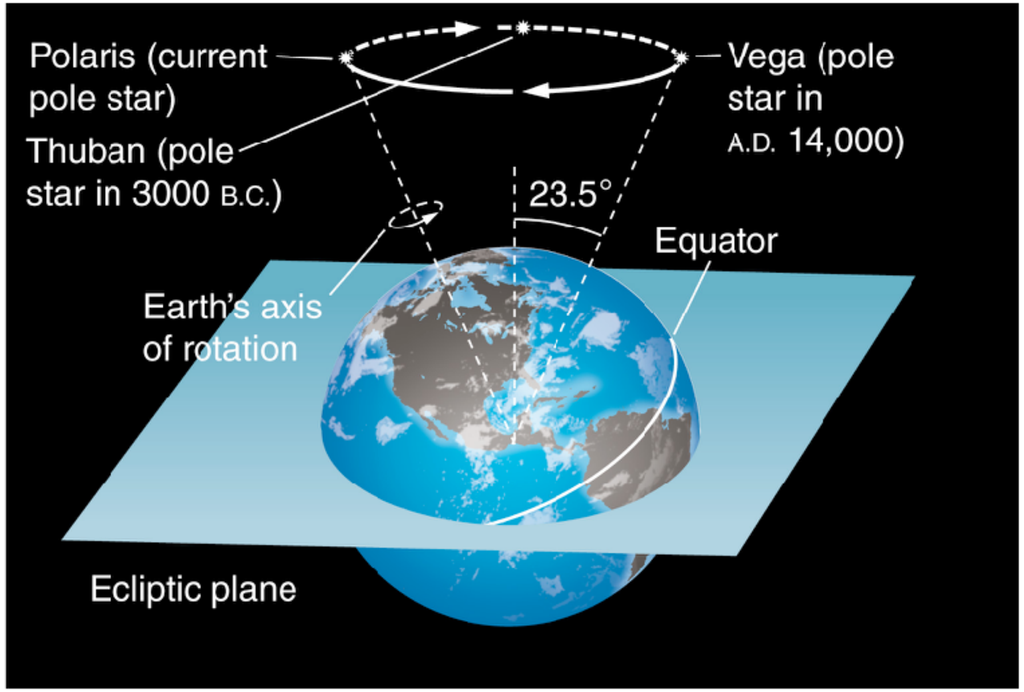
Figure 2

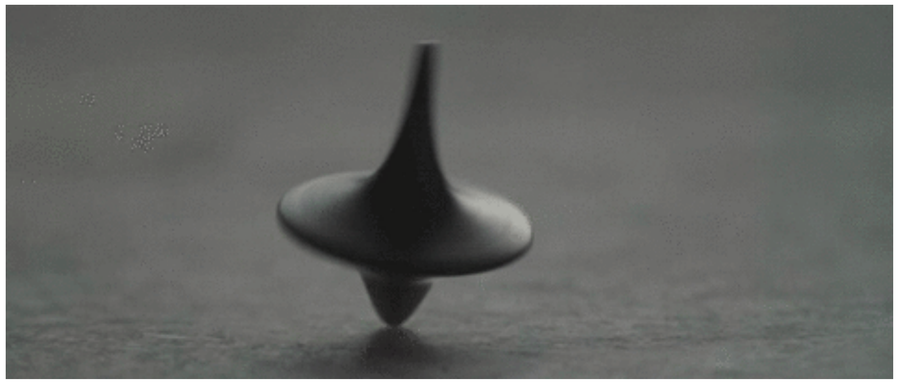
Hey you, what's your sign?

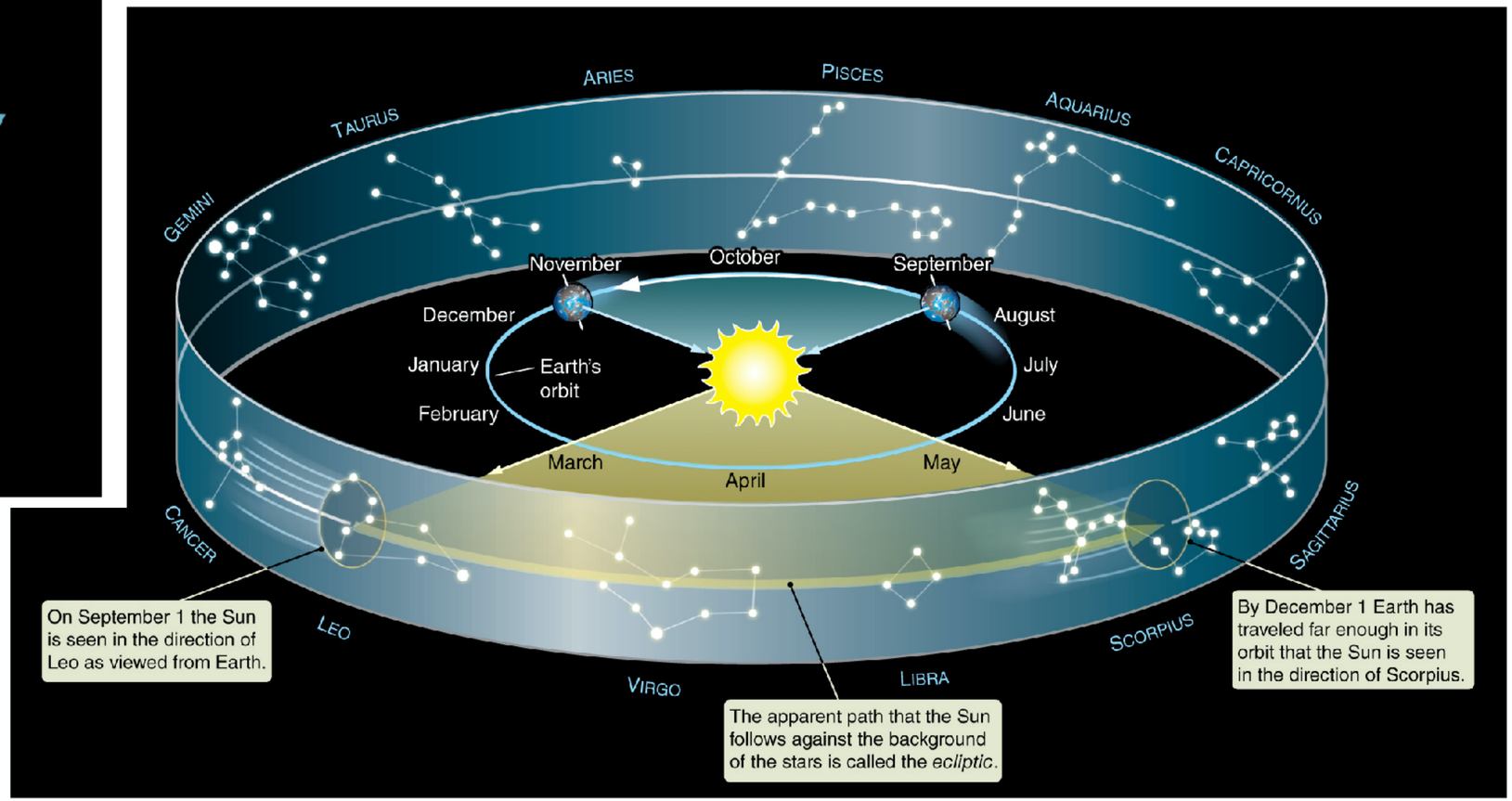
Astrology
is
bunk!



Earth's axis wobbles like a top: called Precession







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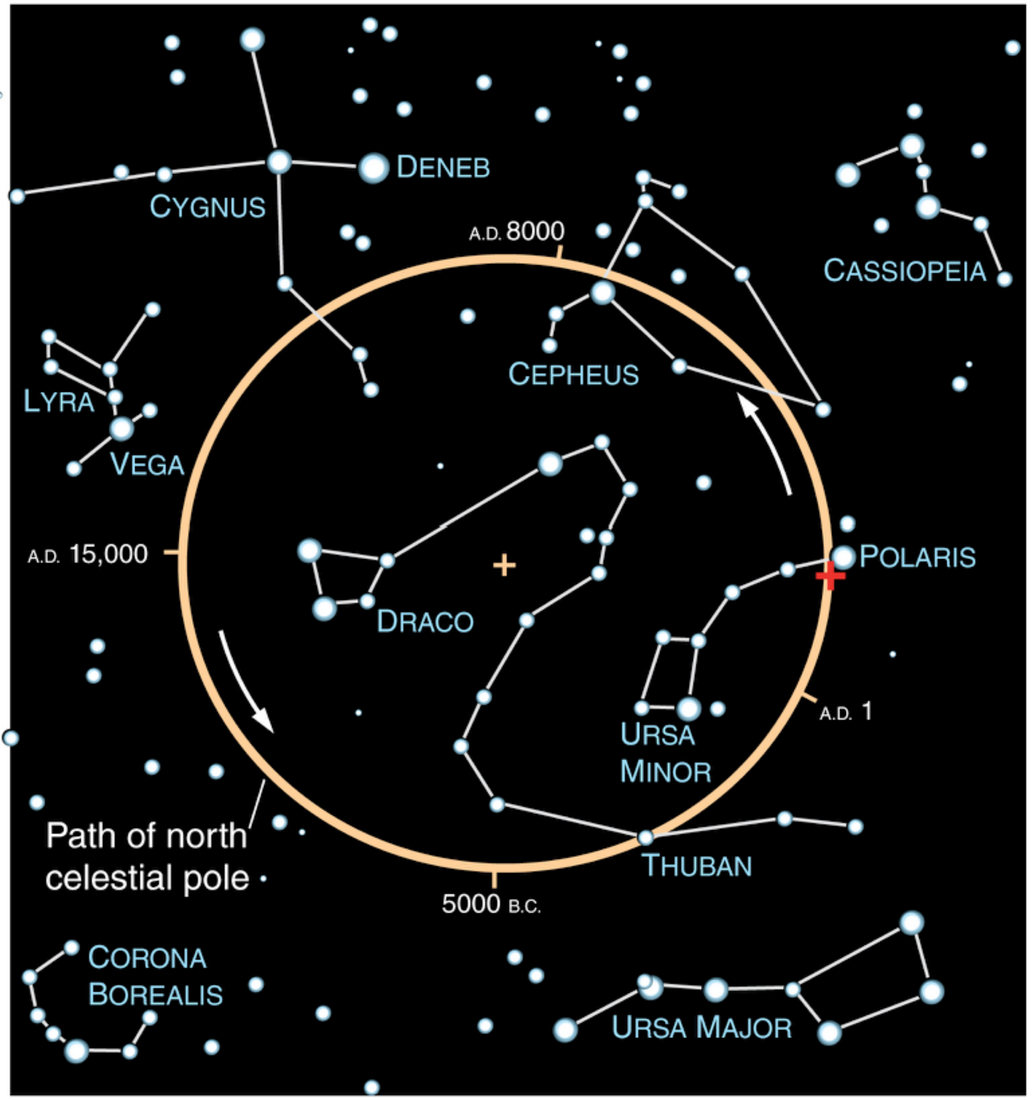
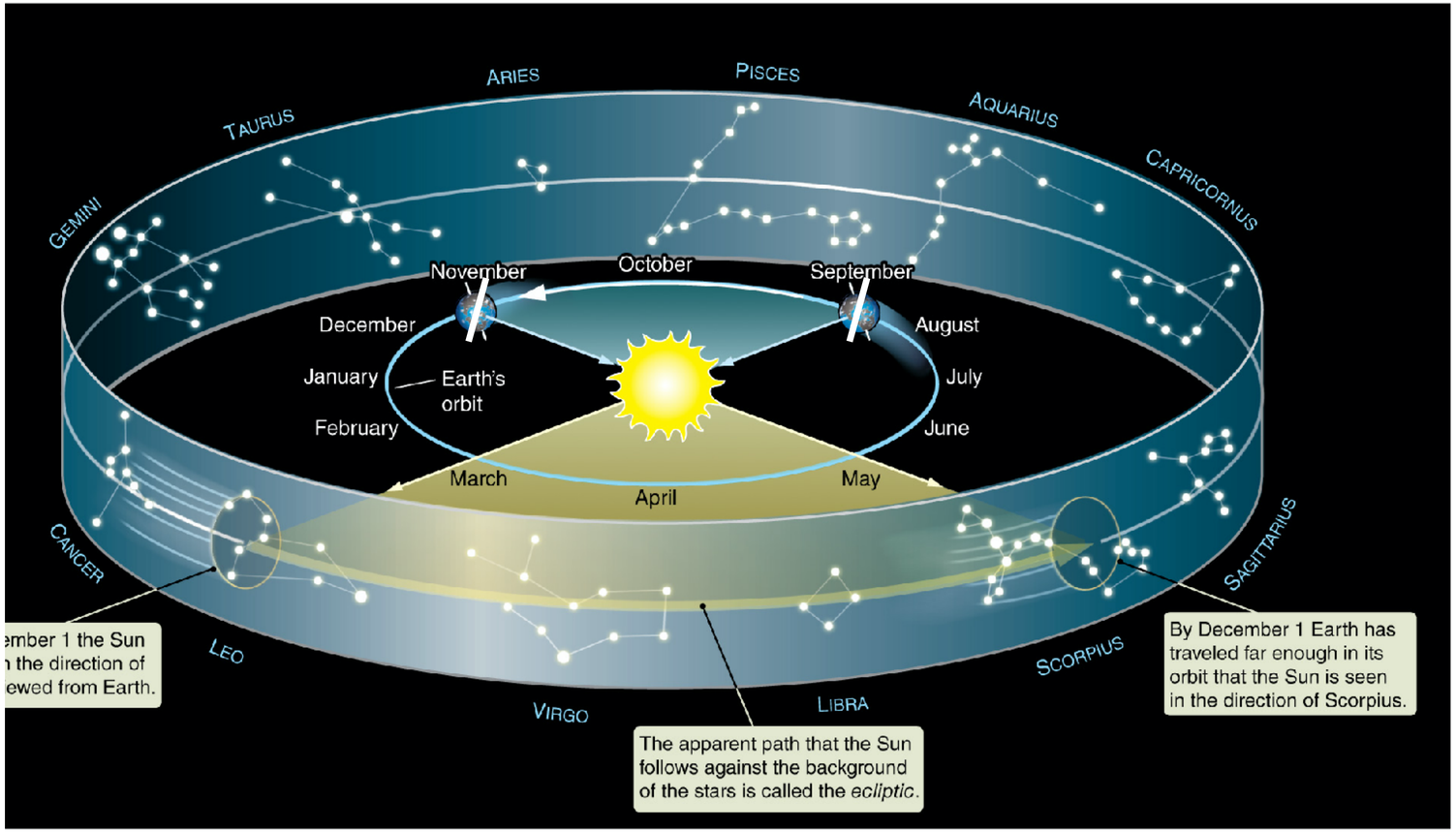




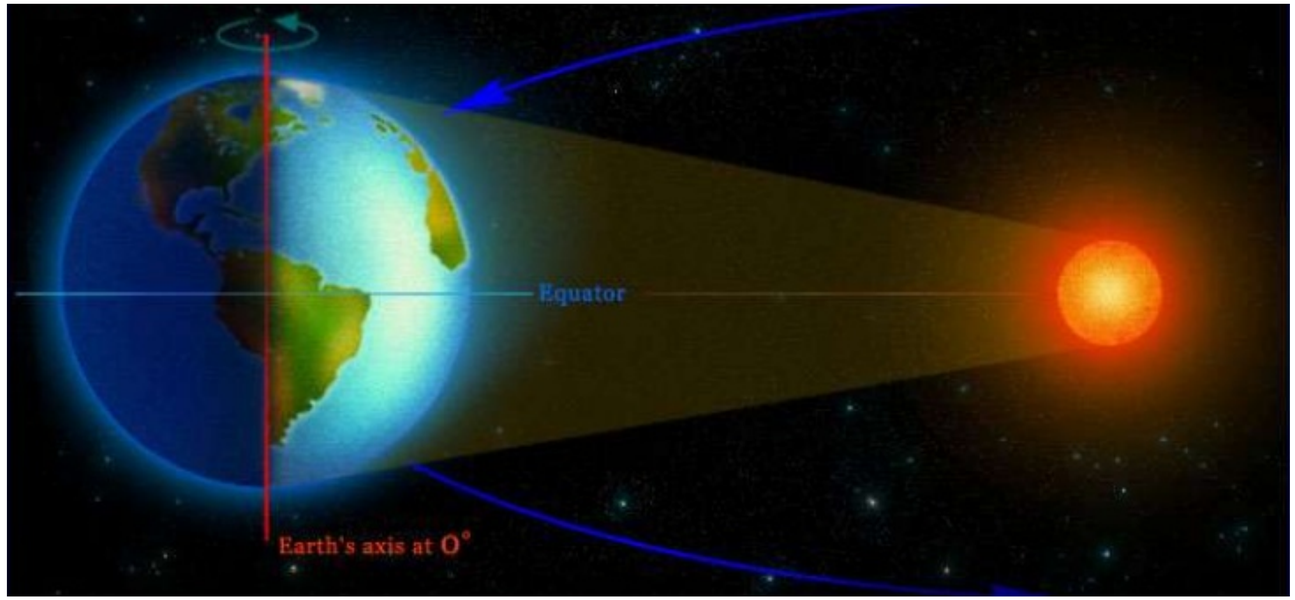
Because of precession, the RA & Dec of a star are always changing!

To keep sane, astronomers use coordinates from a particular time, referred to as the Epoch; at present, we use Epoch J2000, the RA/Dec objects had at midnight on January 1st, 2000.

To actually locate a star or object when observing, the coordinates must be “precessed”.

This “precession of the equinoxes” has a rate of ~50” per year (modest optical telescopes tend to have angular resolutions of ~1” and fields of view of a few arcminutes across, so this rate is quite significant!

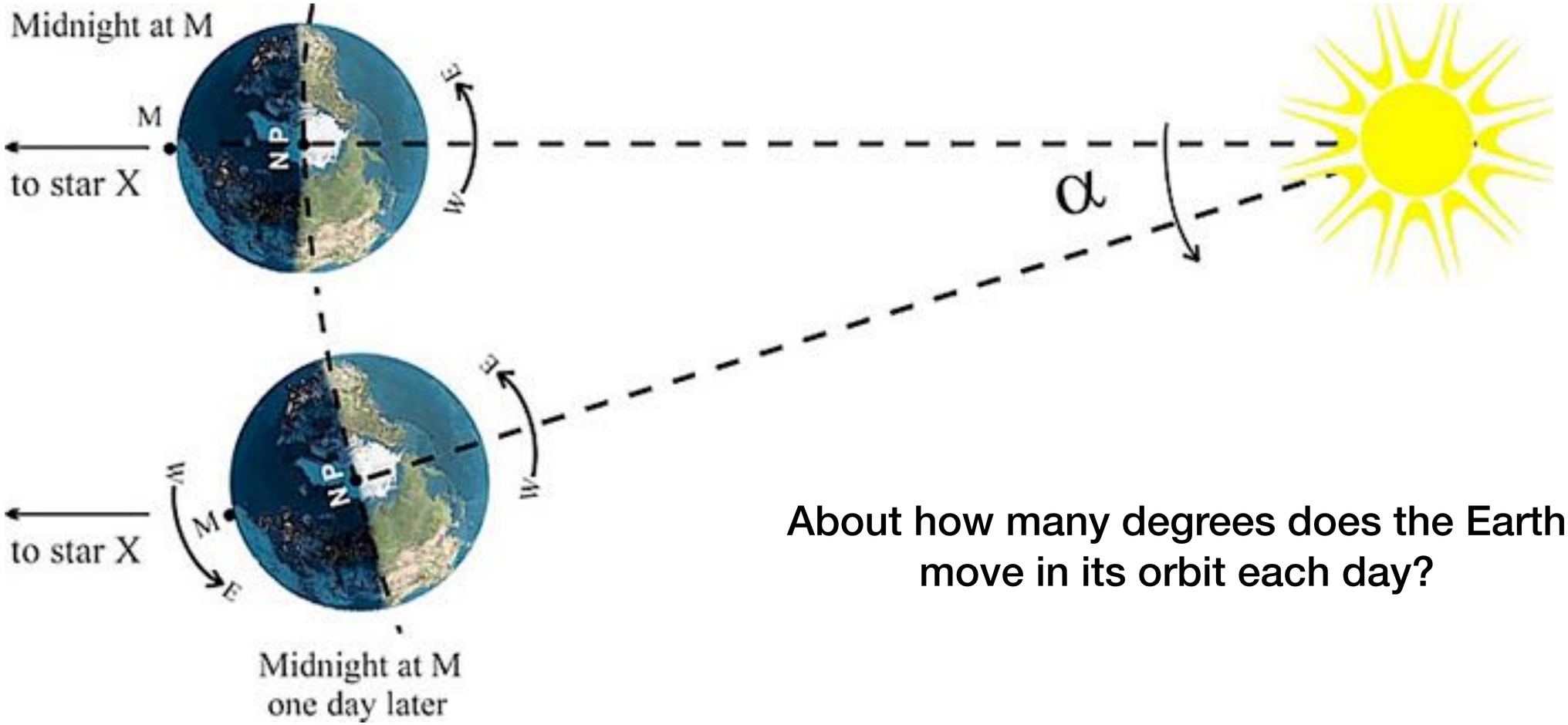
Imagine that a team of highly advanced -- but extremely mischievous aliens -- has changed the tilt of Earth's rotation axis, relative to its orbital plane, from 23.5° to 0°.



Which of the following features of the celestial sphere would be altered? How?

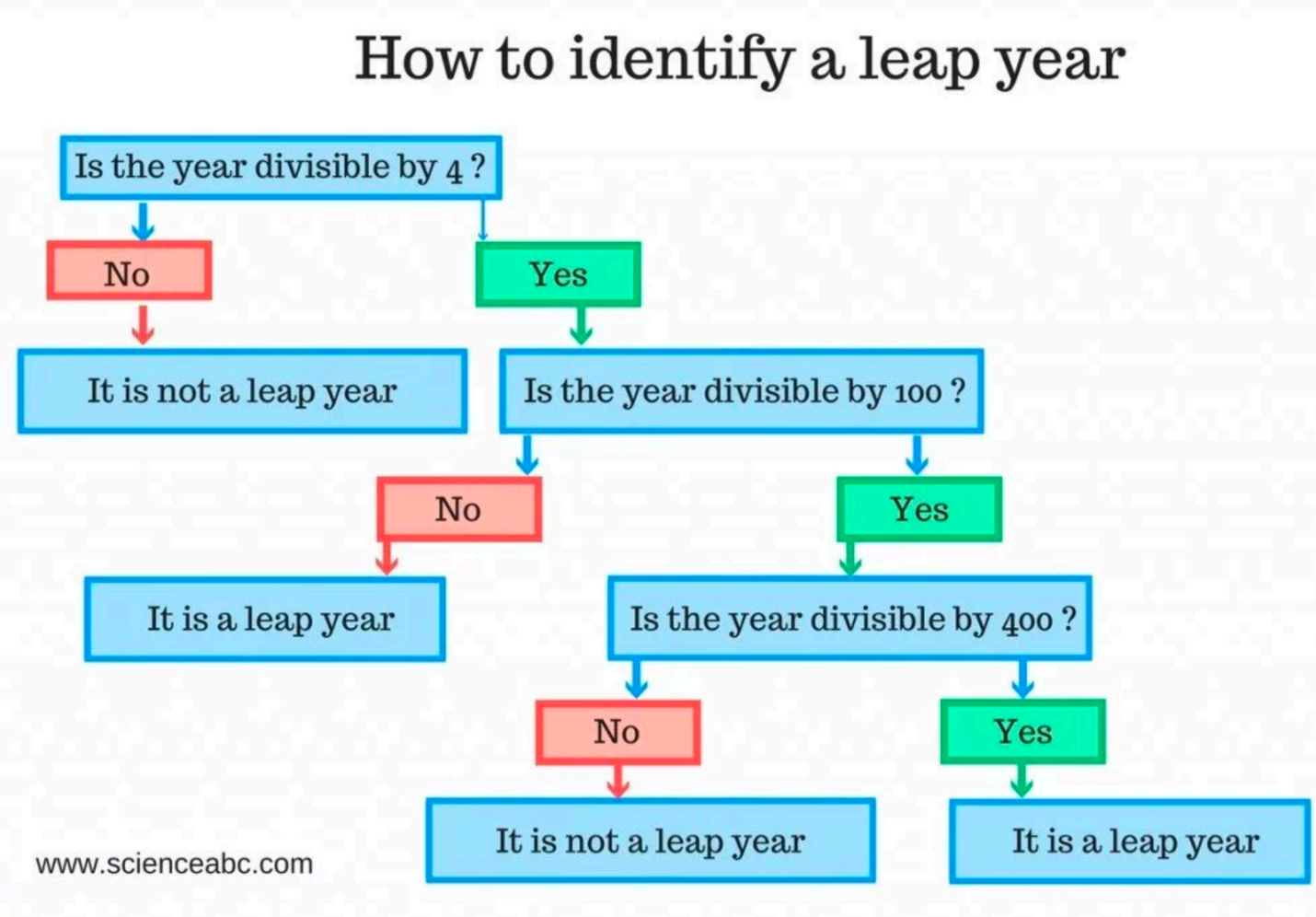
A. local altitude of the North Celestial Pole
B. the constellations along the ecliptic
C. length of the year
D. altitude of the Sun at noon on June 21st

Why star rise/set times change



About how many degrees does the Earth move in its orbit each day?

Calendars aren't trivial, because an orbit around the Sun takes 365.2422 days

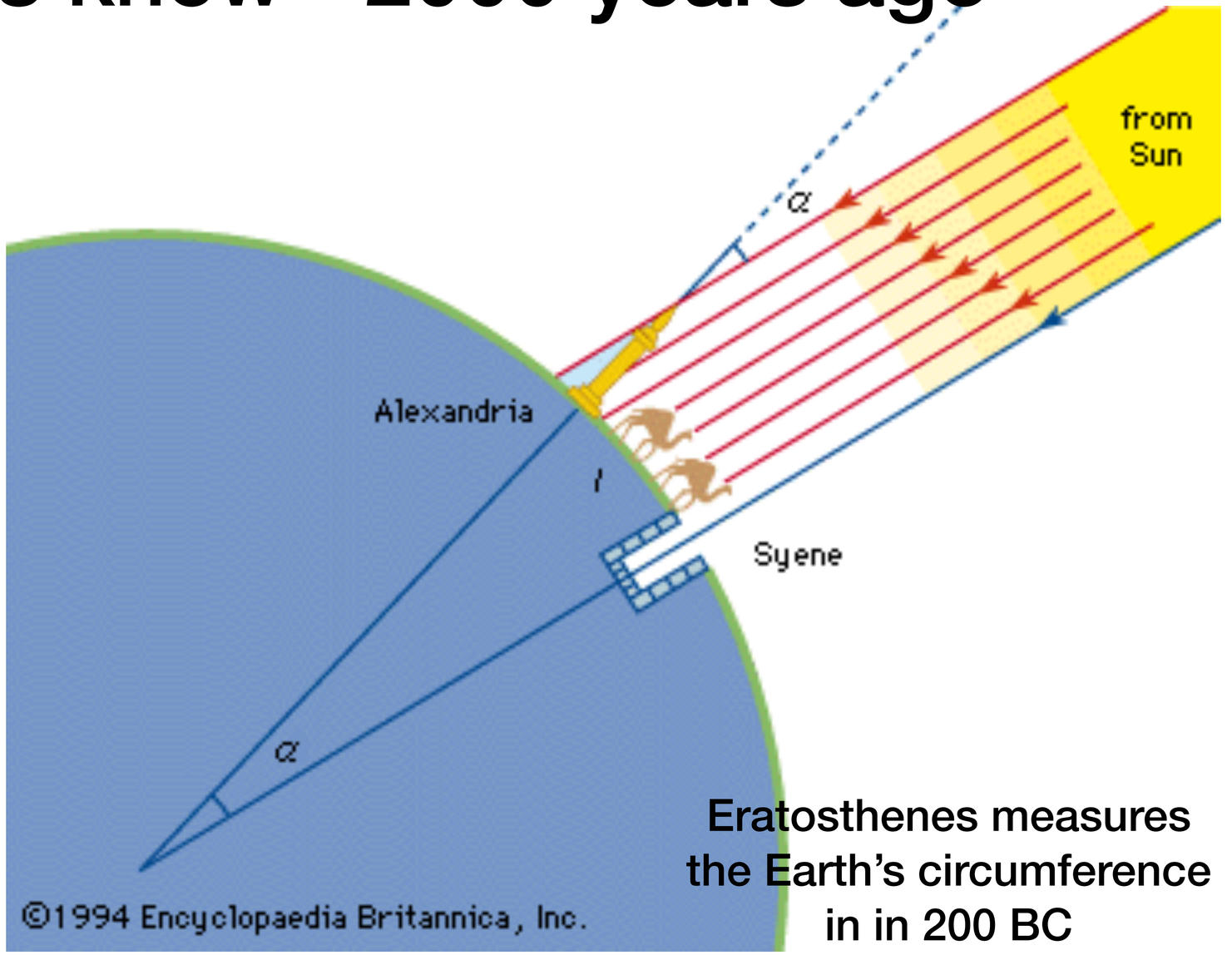


Julian calendar was used for over 1000 years (leap day every 4 years). Every 400 years, the calendar is offset from the seasons by 3 more days.

Gregorian Calendar (what we use today)

What the Greeks knew ~2000 years ago

- Accurate radius of the Earth
- Accurate estimate of the Earth-Moon distance and sizes
- Qualitatively correct estimate of the Earth-Sun distance (only wrong by a factor of 20!)
- Precession of the equinoxes not only known about, but accurately estimated
- Length of the year correctly measured to within 7min of true value
- Magnitude system for star brightnesses established (still use today)
- Aristarchus (mid 200s BC) argued for a Sun-centered universe



Eratosthenes measures the Earth's circumference in in 200 BC

These sizes and distances imply the Earth would be moving and rotating quite fast, yet it seems fairly obvious that the Earth is stationary.

Requiring the Earth to be at rest, with the Sun, Moon, and Planets “circling” it, turned out not to be a simple model.

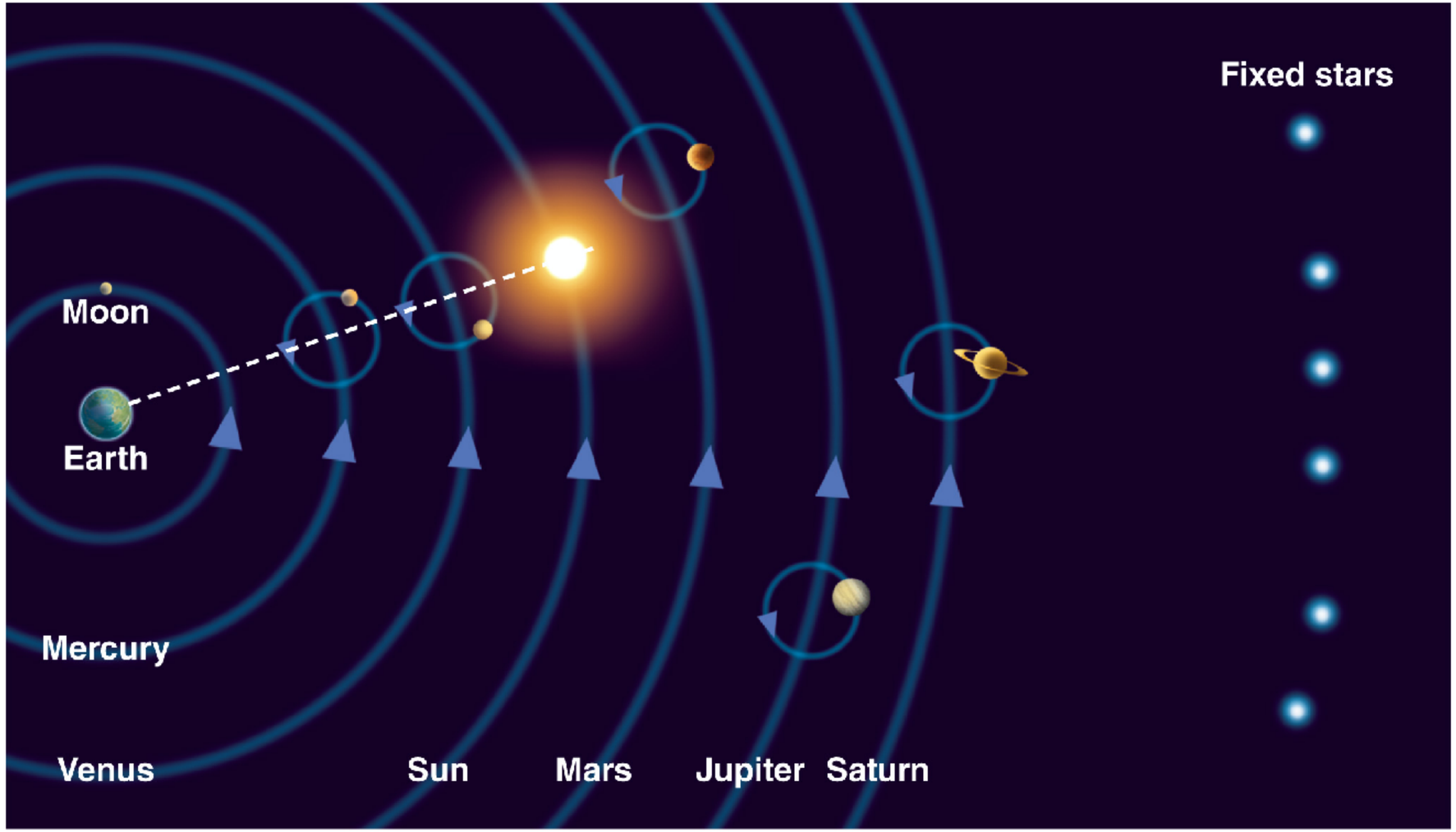
Goal: predict the motions of the planets against the “fixed stars”

Motion was not simple

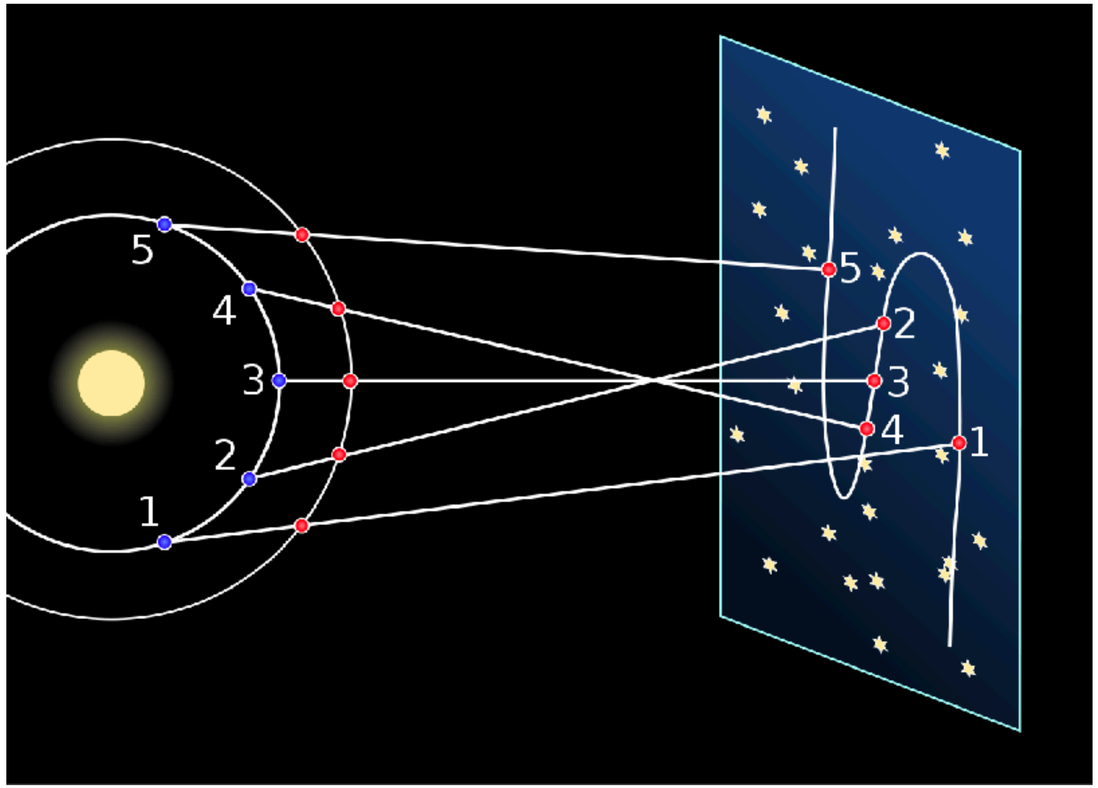
Models were built to explain them, and did OK — but discrepancies remained

The lack of perfect agreement implied the “true” description of planetary motion was still up for grabs

Epicycle Mania! Everything must move in circles, the perfectest of shapes

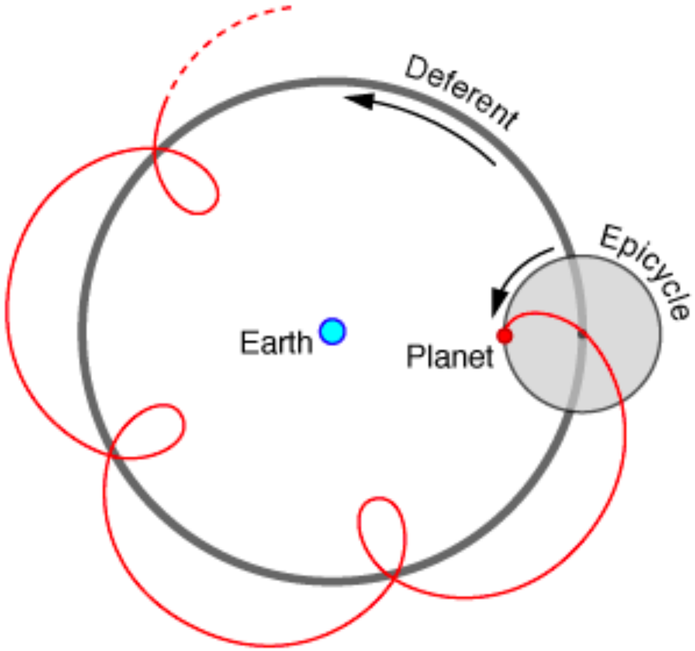


Epicycles



https://en.wikipedia.org/wiki/Apparent_retrograde_motion

Retrograde motion of Mars in 2005.
Credit astrophotographer Tunc Tezel



https://physics.weber.edu/schroeder/ua/BeforeCopernicus.html

Epicycle orbited around the Earth, which was offset from the center of the Deferent, at a constant *angular* rate as seen from *another* offset point called the Equant

The model contained philosophically-based presumptions (Earth-centered, motion circular) and is conceptually elegant at first blush.

But, circular motion alone badly matched observations, so additional circles and other tweaks were necessary (i.e., free parameters were added to the model)

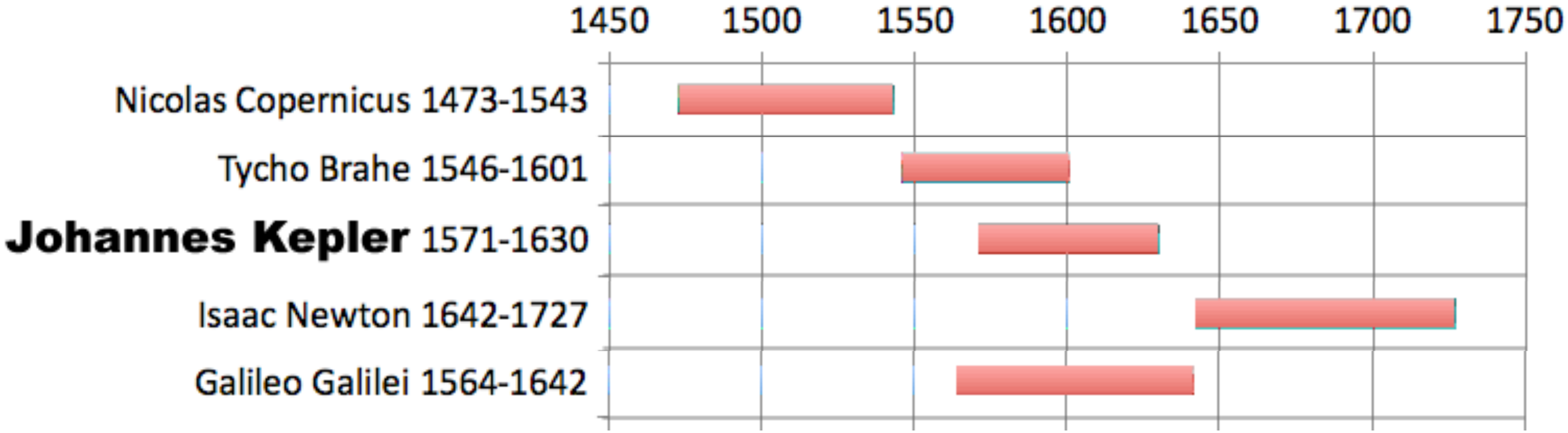
Sometimes this is necessary, if systems are complicated, but sometimes it means the model is wrong

Copernicus resurrected Aristarchus' heliocentric idea to simplify the model, which it did (somewhat), although it did NOT provide better predictions of planetary motions

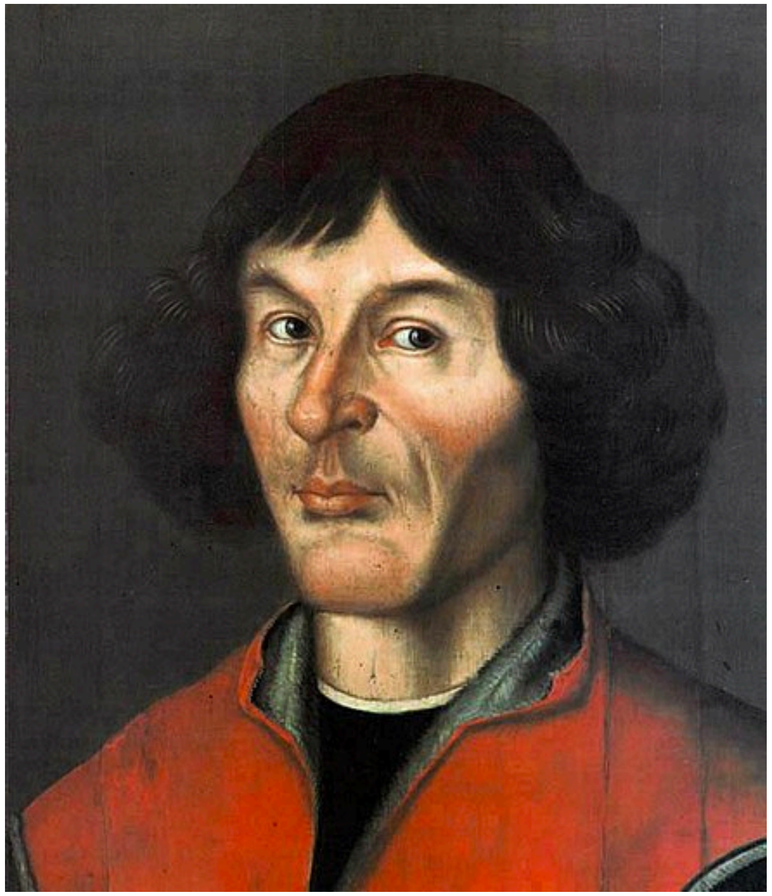
Invention of Science

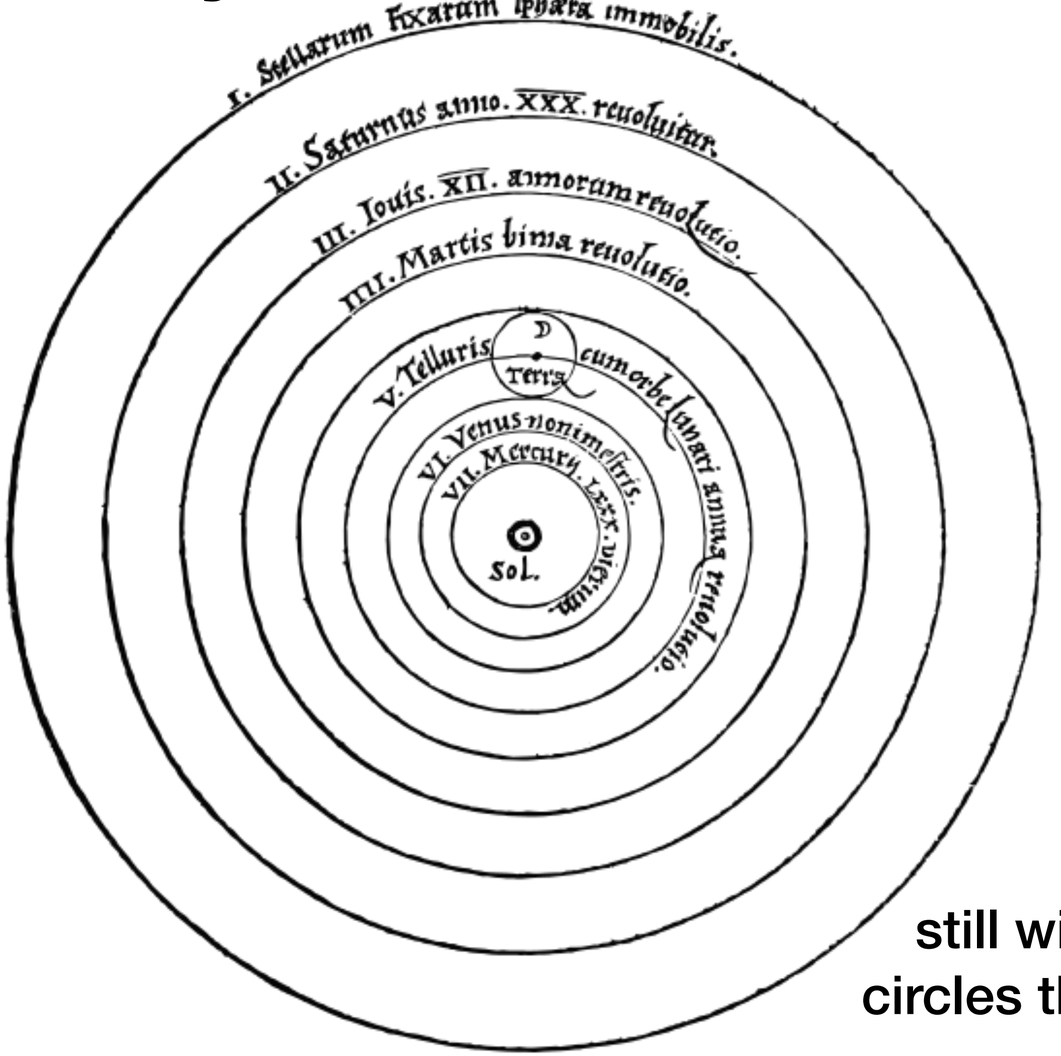
Observations —> Model/Theory —> Predictions

Occam's Razor



Copernicus politely defies church orthodoxy (really just revisited 1700 year old Greek ideas)





still with the circles though…

Tycho Brahe's dope observations

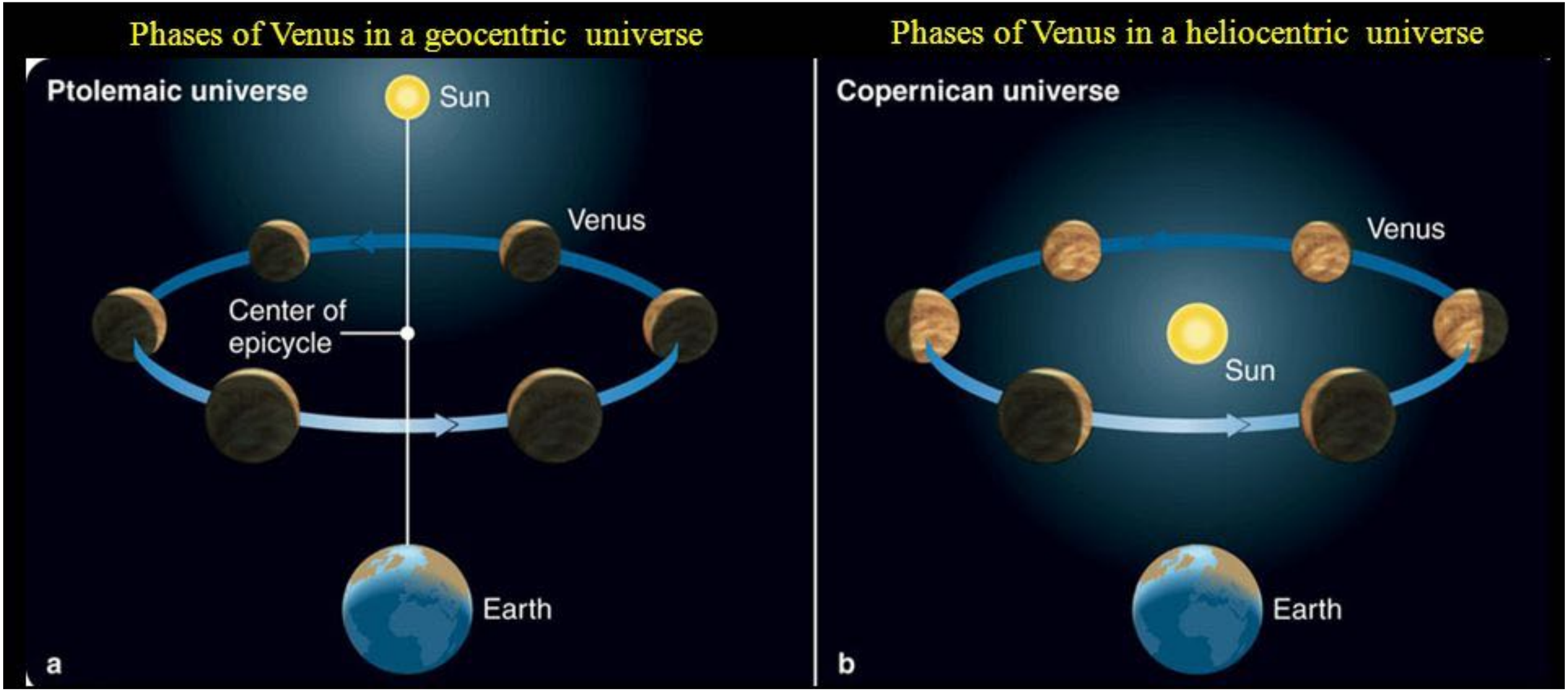
Made the best astronomical measurements before the age of the telescope

Failed to measure stellar parallaxes — concluded the Earth must be stationary

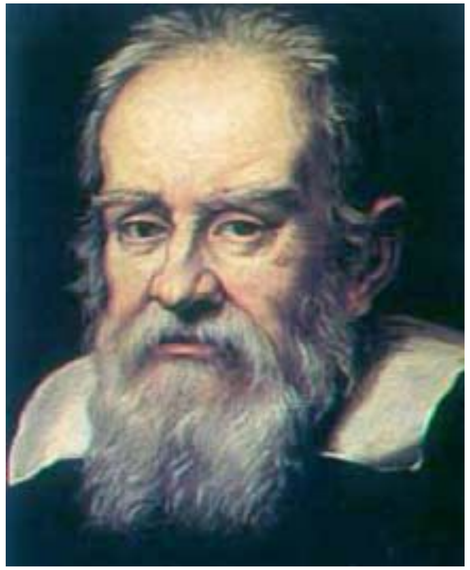
Built a hybrid model to reconcile the simpler Copernican idea with a stationary Earth

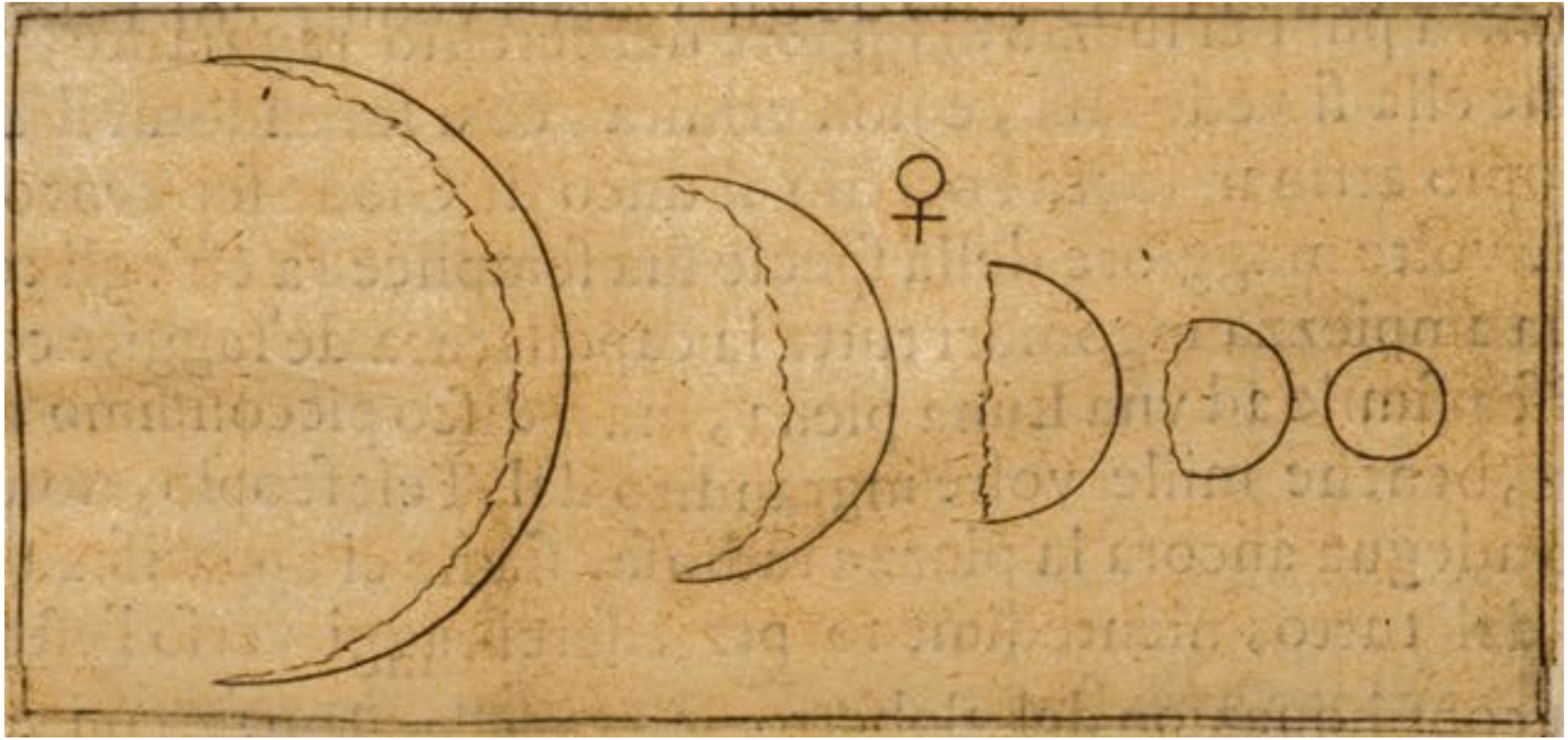
Had a metal nose, died heroically

Galileo performs a “crucial experiment”

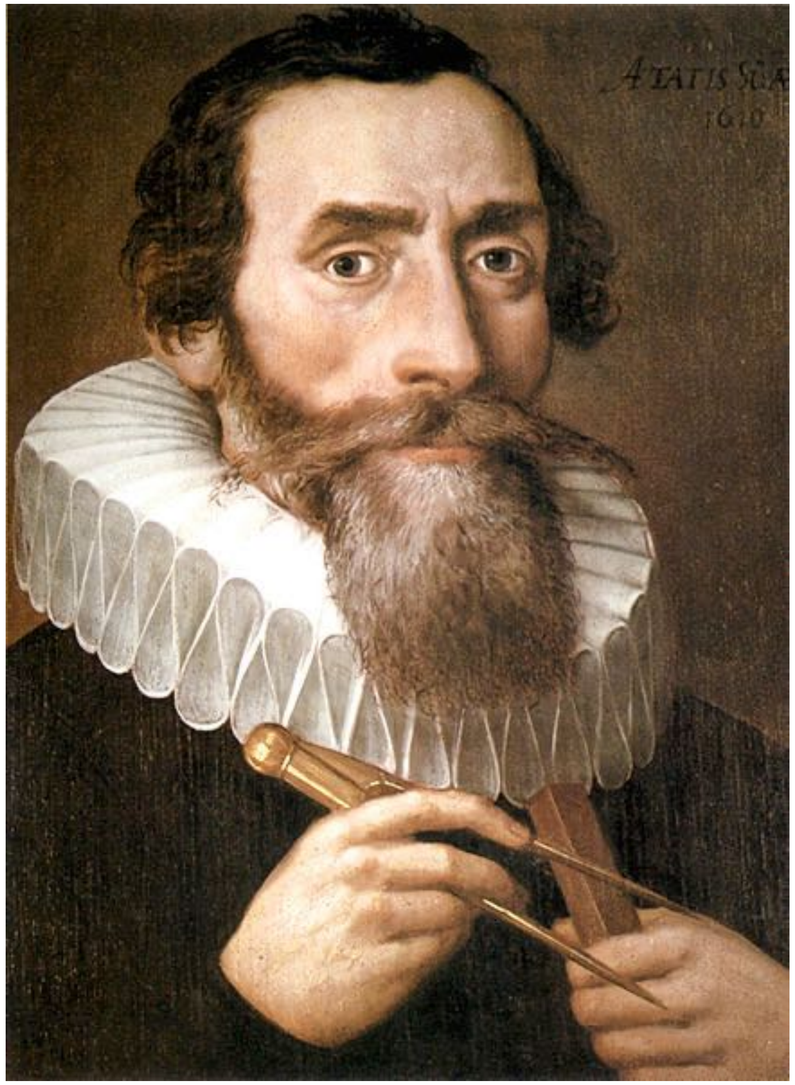


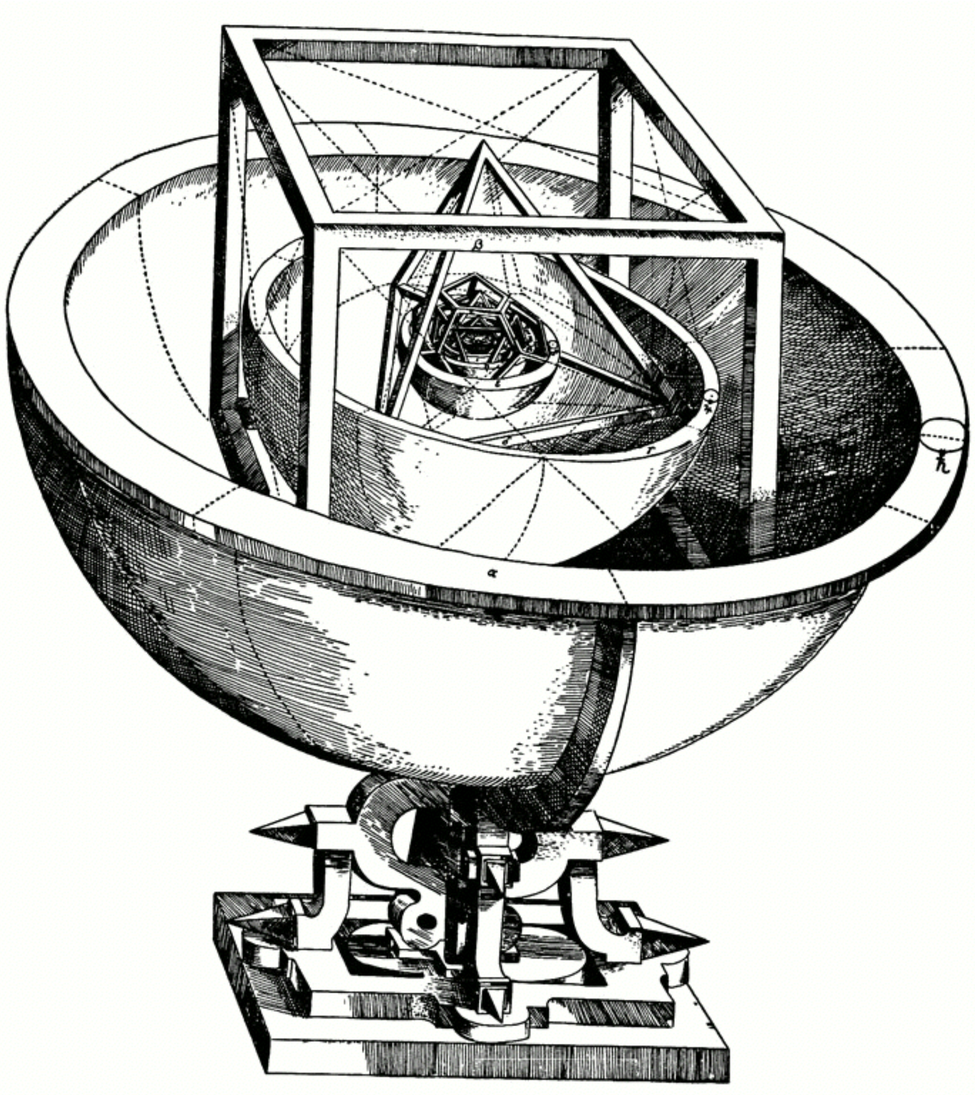
Galileo's observations of the phases of Venus in 1610





Kepler's Insight





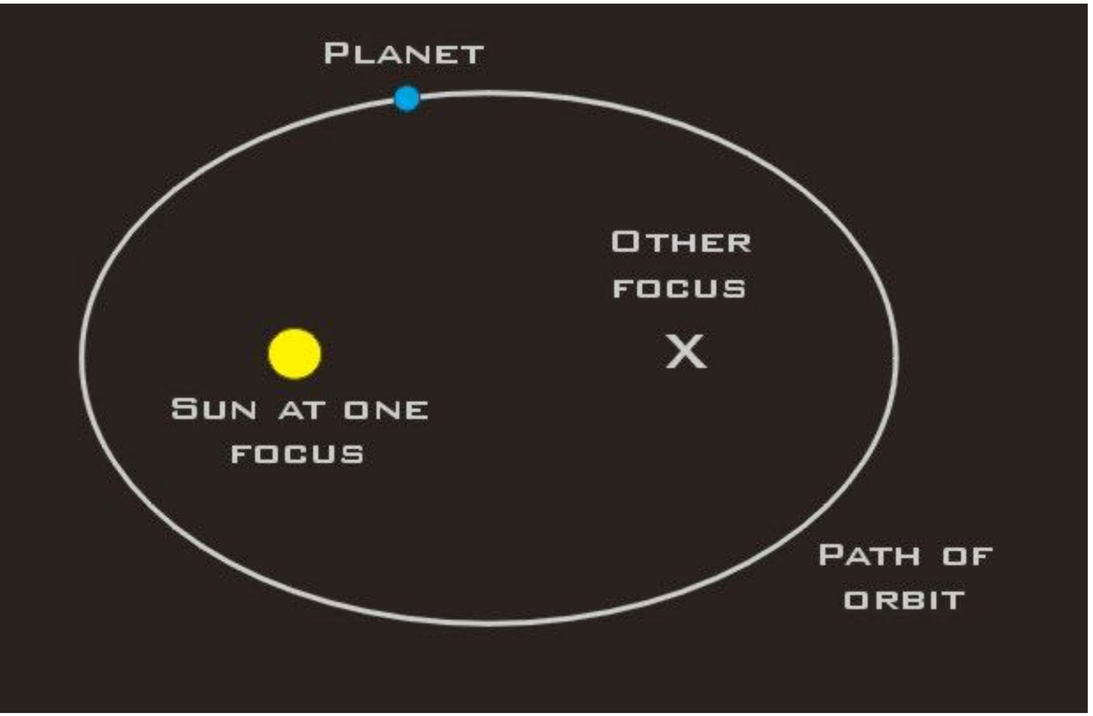
- trusted Tycho's data
- thought Copernicus' Sun-centered model was right
- believed Ptolemy's and Copernicus' assumption that orbits were circular was correct

These assumptions were inconsistent — at least one of them had to be wrong.

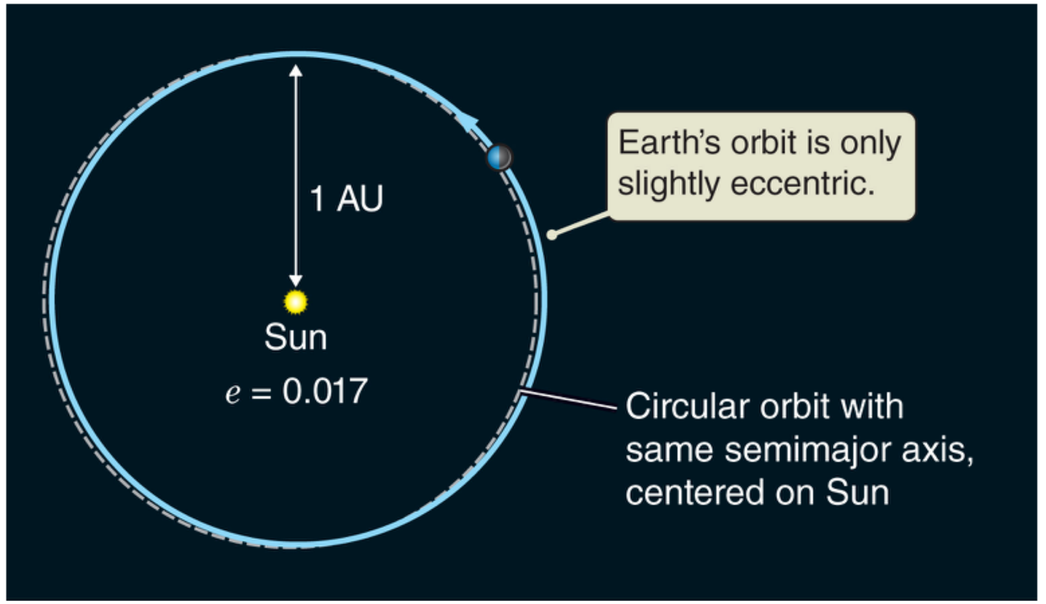
Like a good scientist, Kepler trusted the data most and abandoned circles

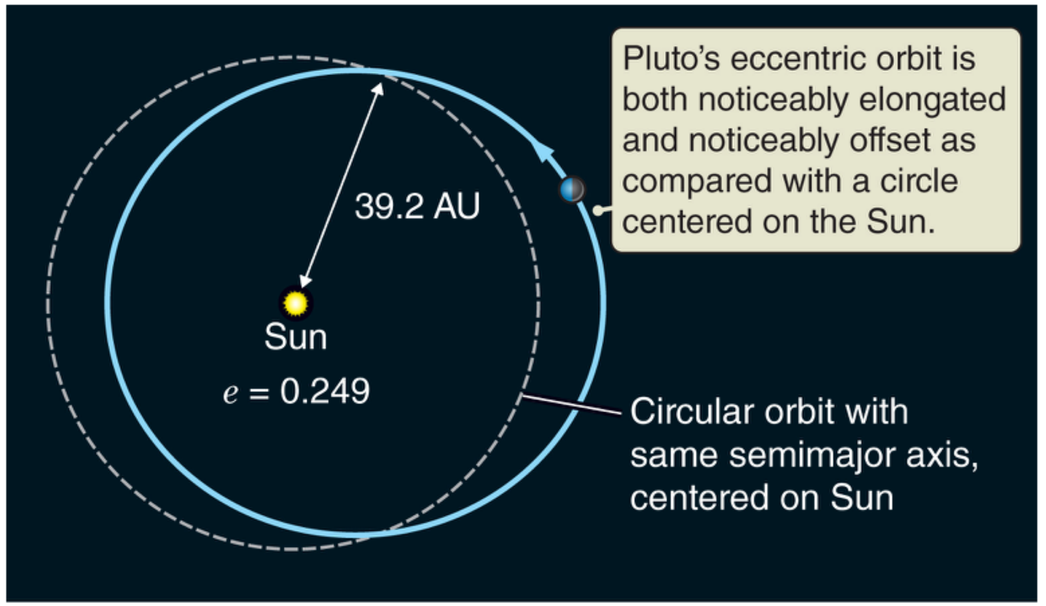
Kepler's 3 Laws!

1) Planets move around the Sun on elliptical paths, with the Sun at one focus of the ellipse



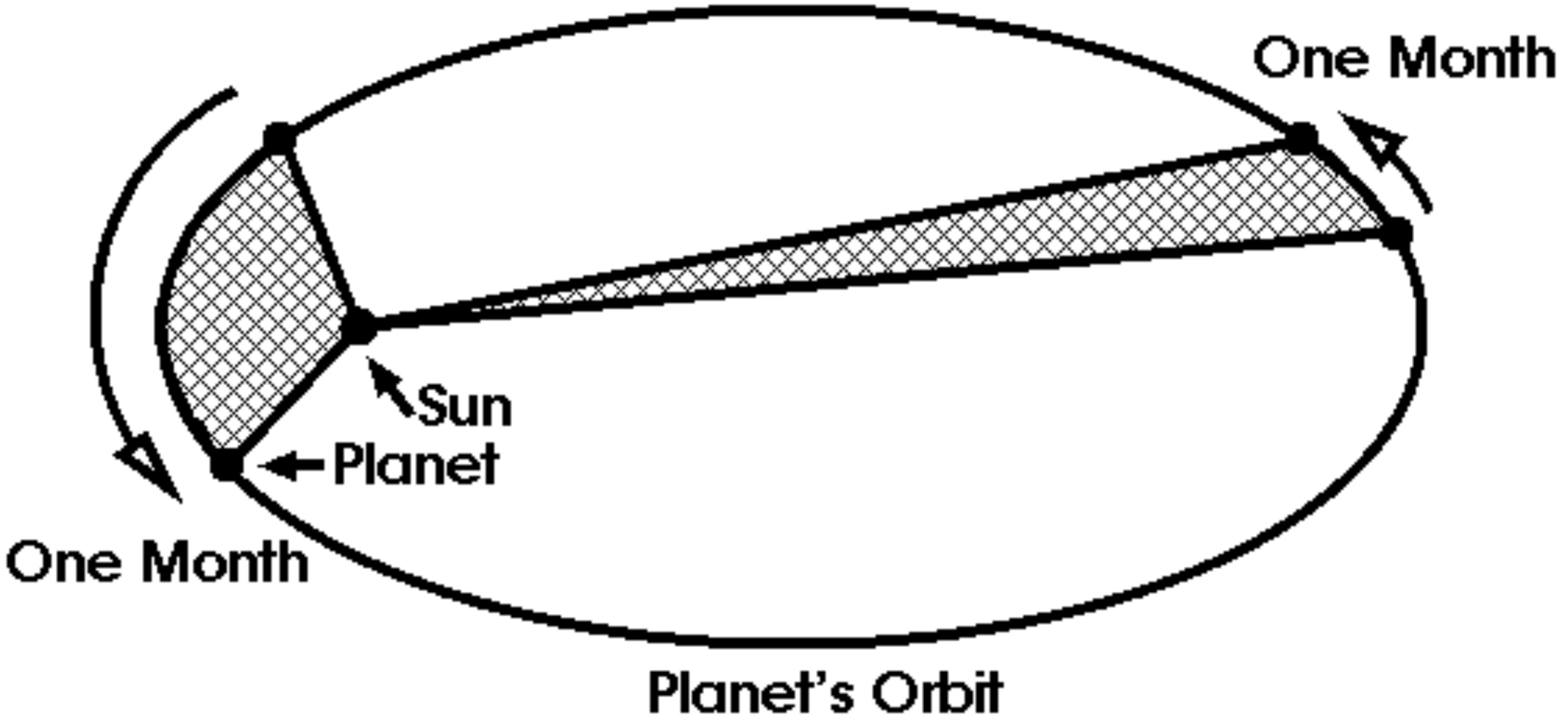
Major Axis





Kepler's 3 Laws!

2) The area of the ellipse traced out by the motion of the planet in a given period of time is always the same: "equal areas in equal times"



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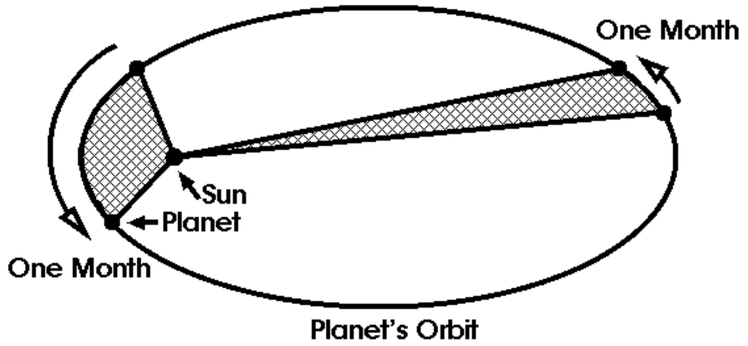
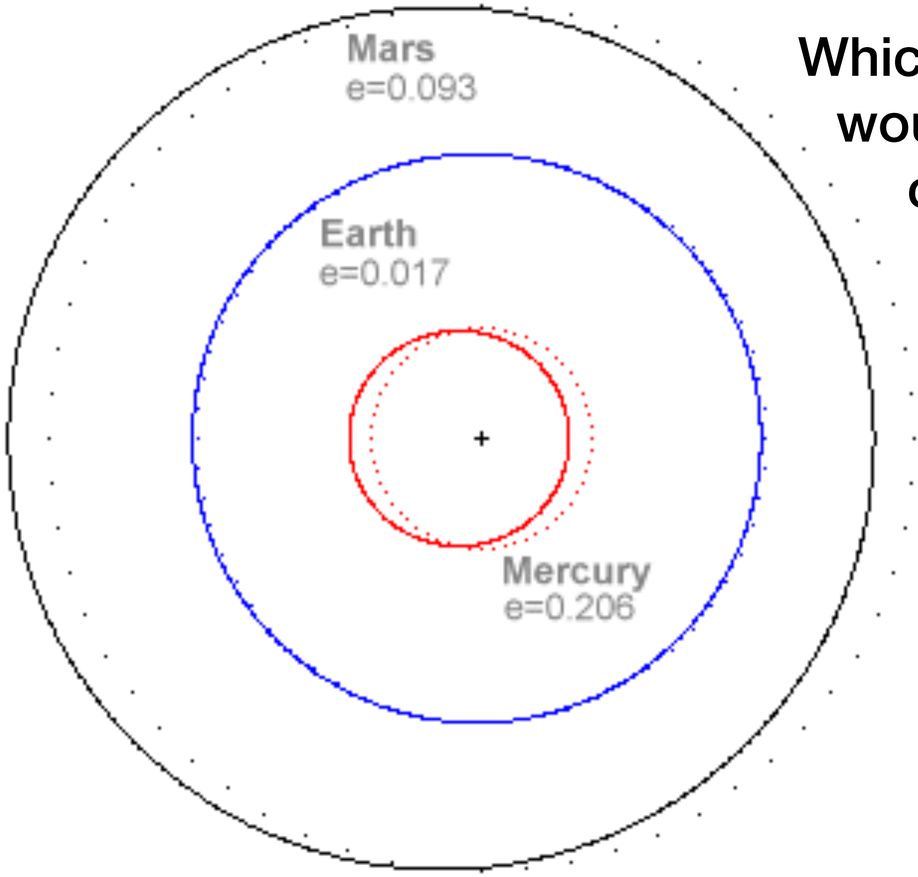
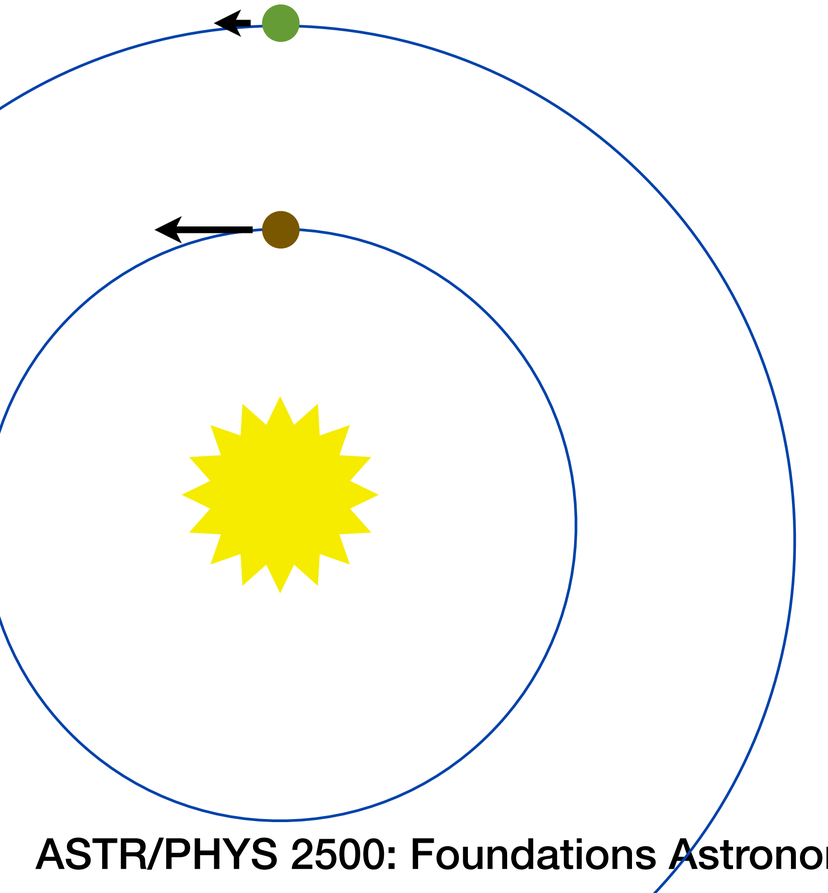




Which of the three planets shown would experience the smallest change in orbital speed?

Kepler's 3 Laws

3) The farther from the Sun a planet orbits, the slower it moves (in addition to having farther to travel in order to complete a revolution around the Sun).



$$(\text{Period of Planet [in years]})^2$$

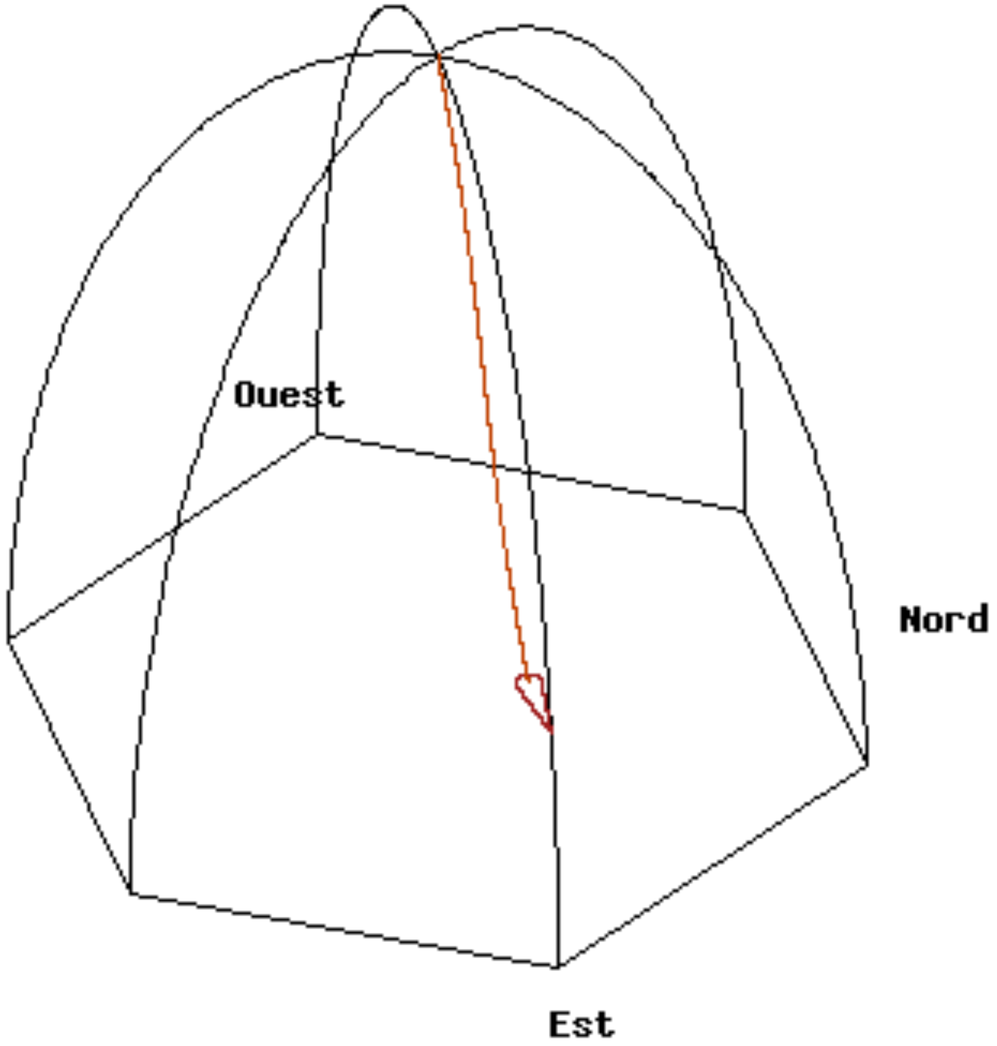
$$=$$

$$(\text{Semimajor Axis of its orbit [in AU]})^3$$

So the Earth IS moving, but why can't we tell?

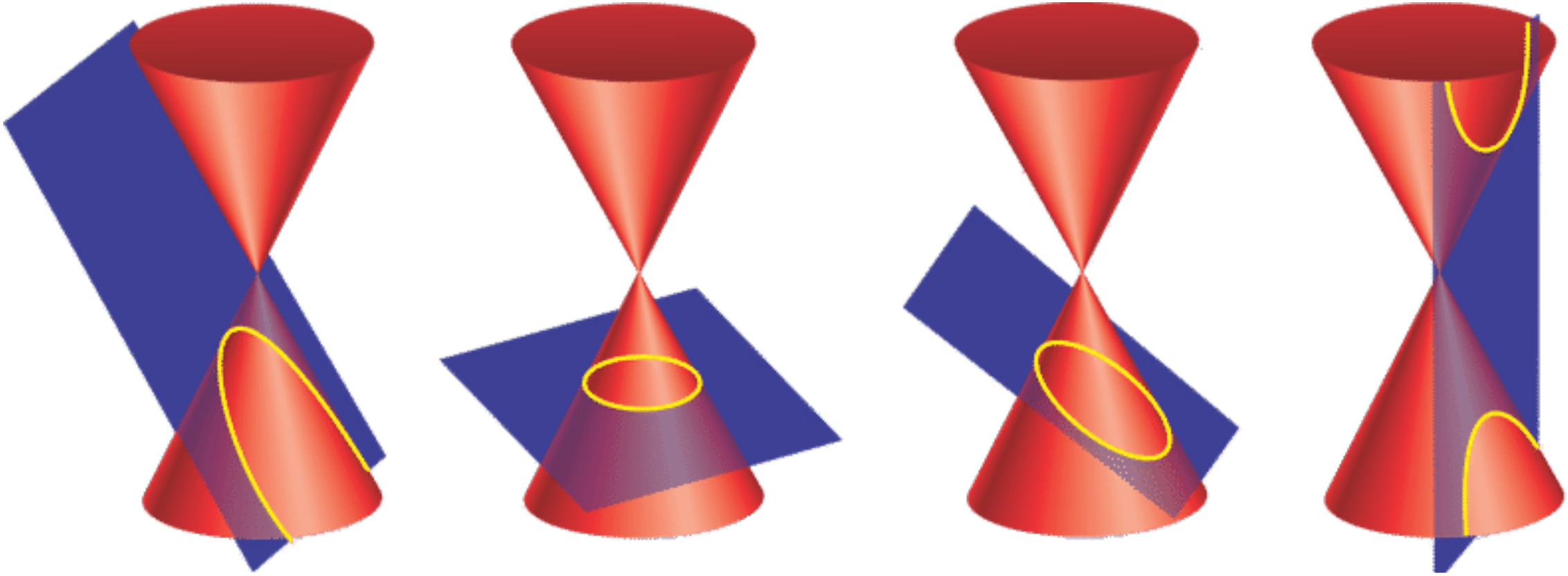
On the equator, Earth's surface is moving at ~10 m/s relative to the poles.
Creates a "centrifugal force" trying to fling things into space

This velocity depends on your latitude, so ballistic motion north or south is deflected.
(A cannonball shot due N at the equator has a 10 m/s velocity component to the E, but the Earth's surface rotates slower than this at higher latitudes, so it will be deflected eastward relative to the ground. Also why rockets are launched from Florida towards the Atlantic Ocean.)
This is the "Coriolis force".



To the board!

Orbits are Conic Sections



Parabola
$e = 1$
$E_{tot} = 0$

Circle
$e = 0$
$E_{tot} < 0$ (minimum for a given L)

Ellipse
$0 < e < 1$
$E_{tot} < 0$

Hyperbola
$e > 1$
$E_{tot} > 0$

Kepler's 3rd Law

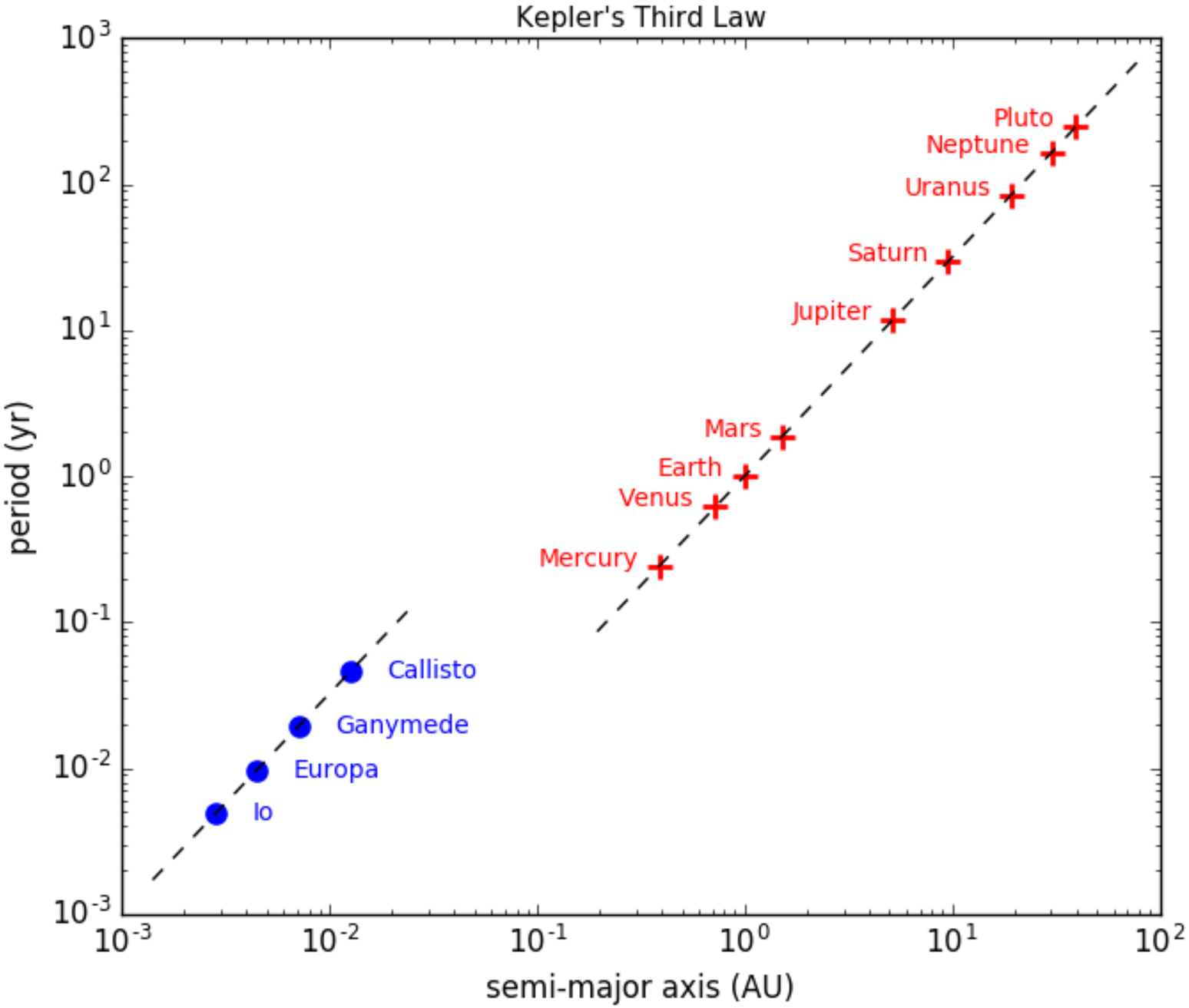
Log-log plot
Relations to some power (called power laws) appear as straight lines

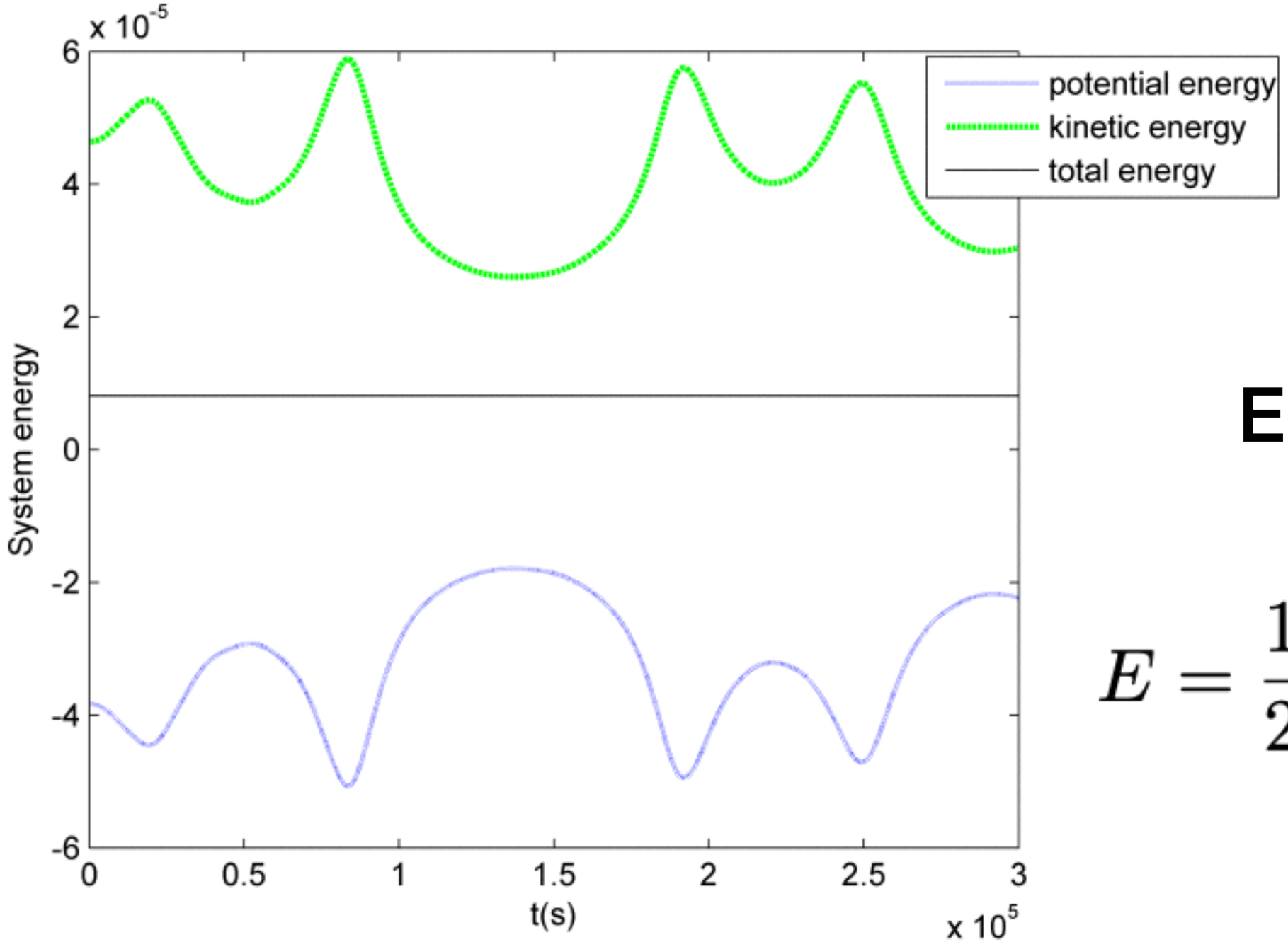
$$y = Ax^p$$

$$\log_{10}(y) = \log_{10}(Ax^p)$$

$$= \log_{10} A + p \log_{10} x$$

$$y' = B + Cx'$$

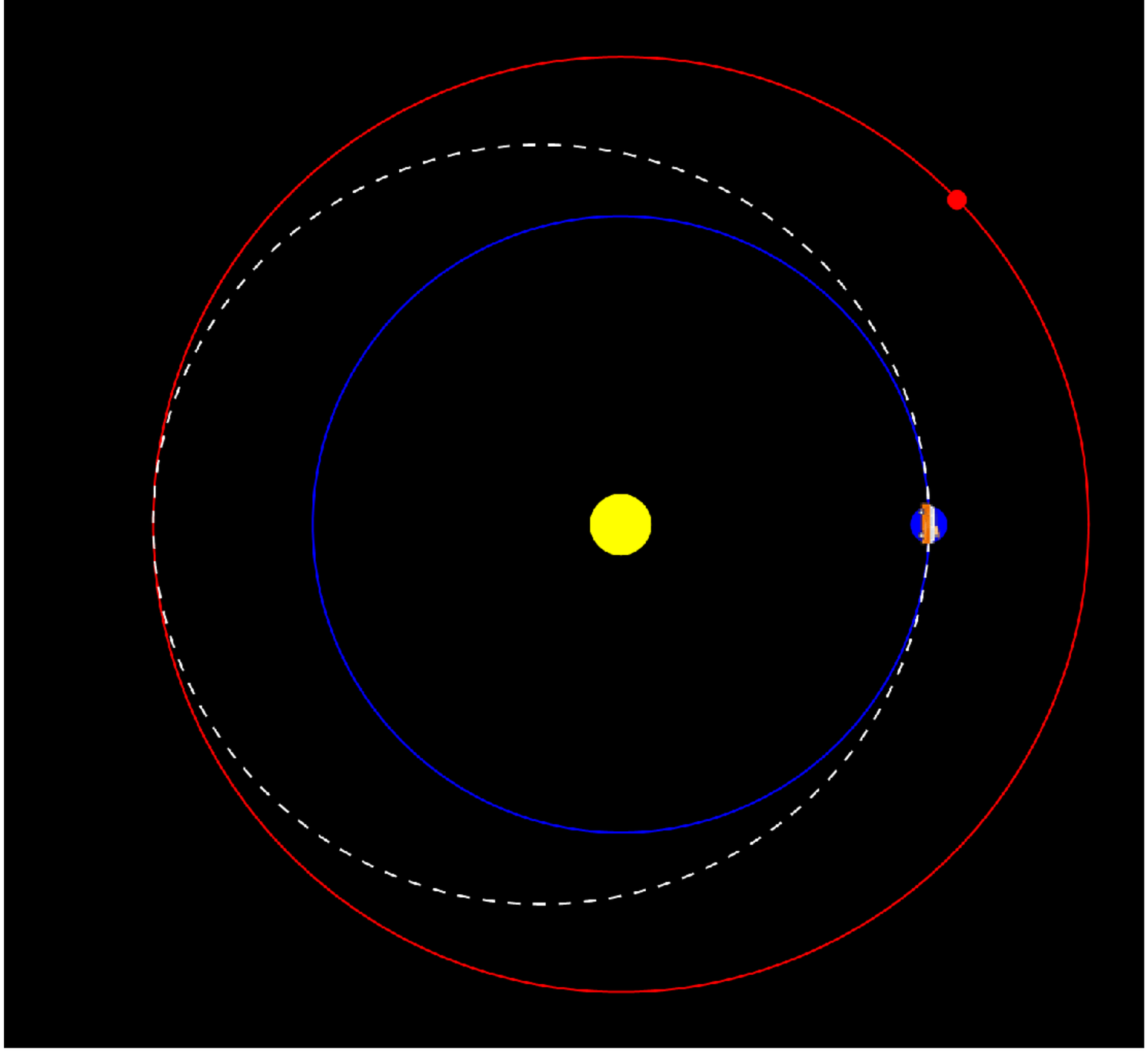




Orbital Energetics

$$E = \frac{1}{2}mv^2 - \frac{GMm}{r}$$

Hohmann Transfer Orbit



Virial Theorem

$$2\langle K\rangle = -\langle U\rangle$$