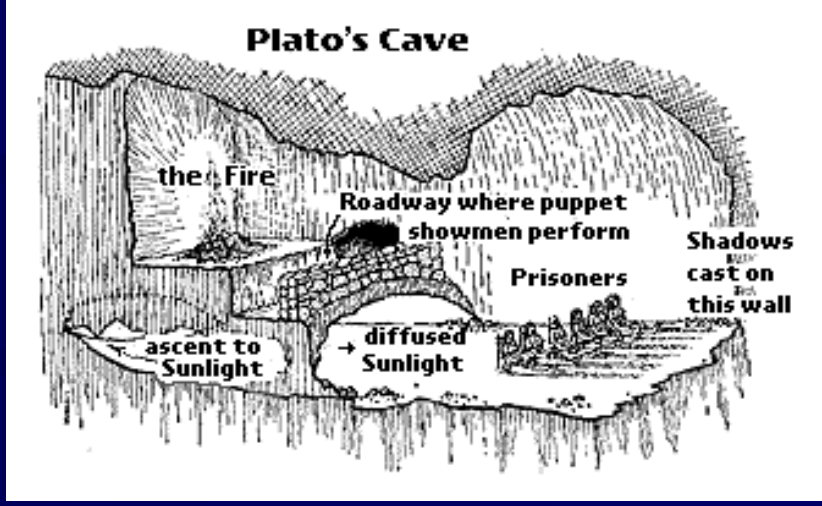
Greek Astronomy

Ancient Greeks Discover that the Universe can be Discovered

- Reasons: seafaring nation, open, geography, trading
- What "is" the universe?
  - Thales: Water! (liquid, solid, gas)
  - Empedocles: Fire, Earth, Water, Air → Substance!
  - Democritos: Atoms! (smallest, elementary particles)
  - Pythagoras: Math!
    - Find "harmonic" mathematical relations to explain patterns, e.g. vibrations of a violin string, perfect circles

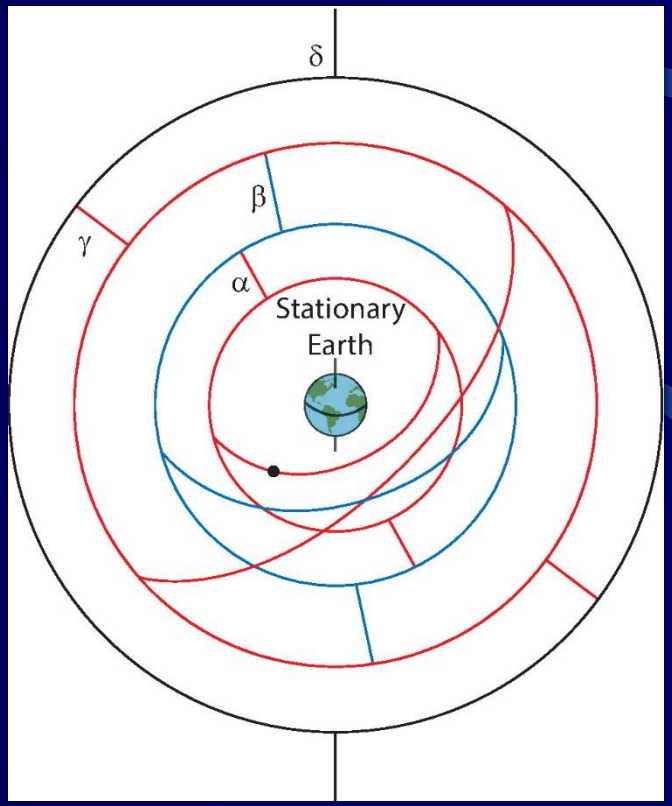
Plato: Senses are Suspicious, Circles are Perfect



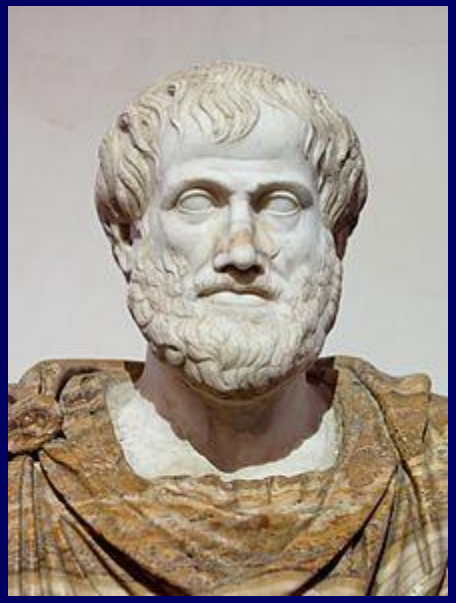
- We cannot always trust our senses
  - Cave analogy → we only know how things APPEAR, not how/what they really "are"
- Plato introduces the prejudice that all heavenly motion has to be uniform circular motion
  - Circles have no beginning nor end
  - Specified by just one number (radius)
- HW for astronomers: save the appearances while only using uniform circular motion

Eudoxus: Homocentic Spheres

- Planetary motions are explained by having the planet move on a set of 4 spheres, each inclined wrt to the others
  - Daily motion
  - Seasonal motion
  - Retrograde motion



Aristotle (384 – 322 BC)

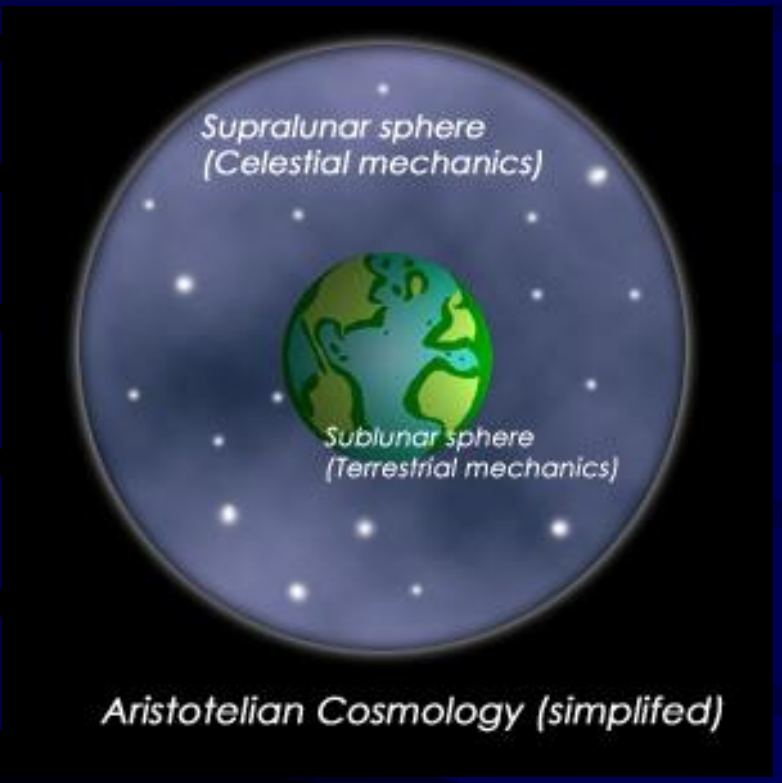


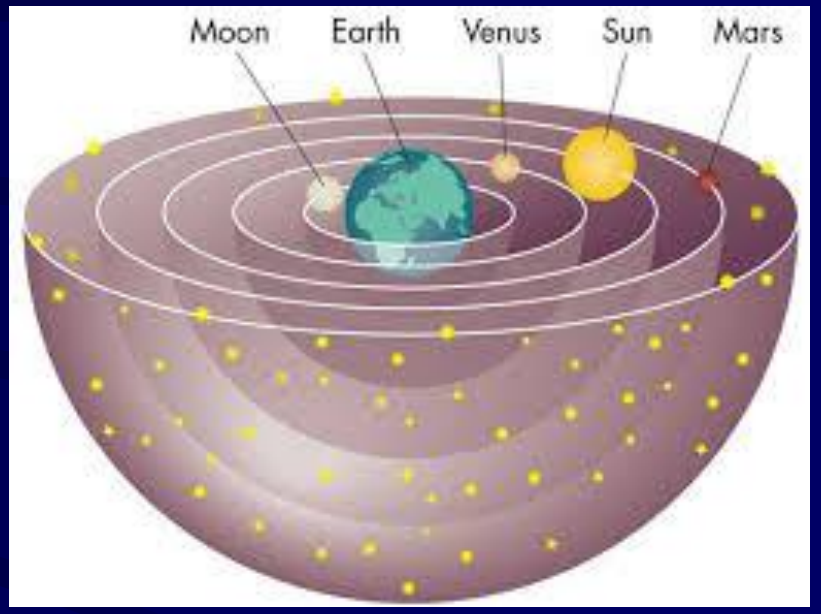
- Arguably the first genuine scientist in history
- Aristotle's views on physical science shaped medieval scholarship → Scholasticism
- His views on motion of the objects was deeply flawed but compelling
- Thomas Aquinas made Aristotle compatible with Christian beliefs

Aristotle: On the Heavens

- Aristotle on astronomy
- Improvement on Eudoxus: 55 homocentric spheres
- Plus: explain motion by "tendencies" of the elements: fire/air rise, earth sinks to center of the universe

Two realms – eternally separated





- Sublunar: ever changing, complicated, chaotic, human (i.e. lowly)
- Supralunar: eternal, no changes other than "perfect" (i.e. complete) circular motion, divine

Aristotle as a "physical" Astronomer

- Aristotle's model of the universe as 55 spheres is "physical"
- He describes "what is happening" (turning of hinged spheres due to a prime mover, etc.)
- Lacking both in practicality and accuracy
- Cements the belief in a central earth
  - Things "naturally" fall to the center of the universe
  - The planets rotate about the center of the universe
  - The 4 elements + quintessence "stack" to stabilize the cosmos

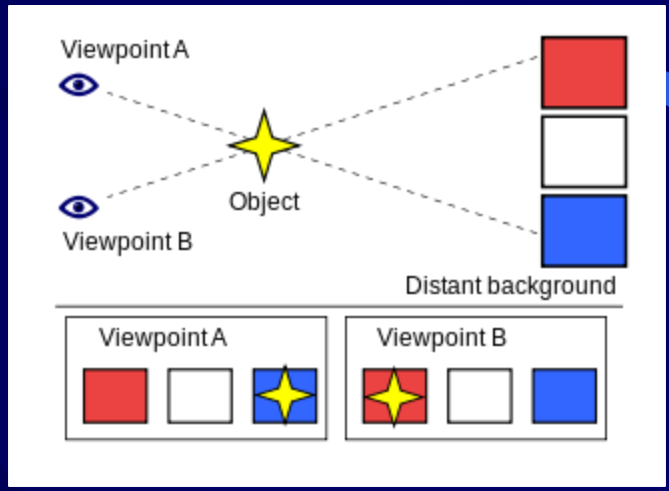
Progress in the Hellenistic Period

- Not classical antiquity, i.e. Hellenic
- Geographic shift from Athens, Greece to Alexandria, Egypt (at this point part of the Greek-speaking part of the Roman Empire)
  - Aristarchus (310 – 230 BC)
  - Archimedes (c. 287 BC – c. 212 BC)
  - Eratosthenes (276 – 194 BC)
  - Hipparchus (190 – 120 BC)
  - Ptolemy (90 – 168 AD)

Using the Parallax Effect to Measure Distances

- From different viewpoints, objects appear in front of a different background
- The closer they are, the larger this parallactic effect

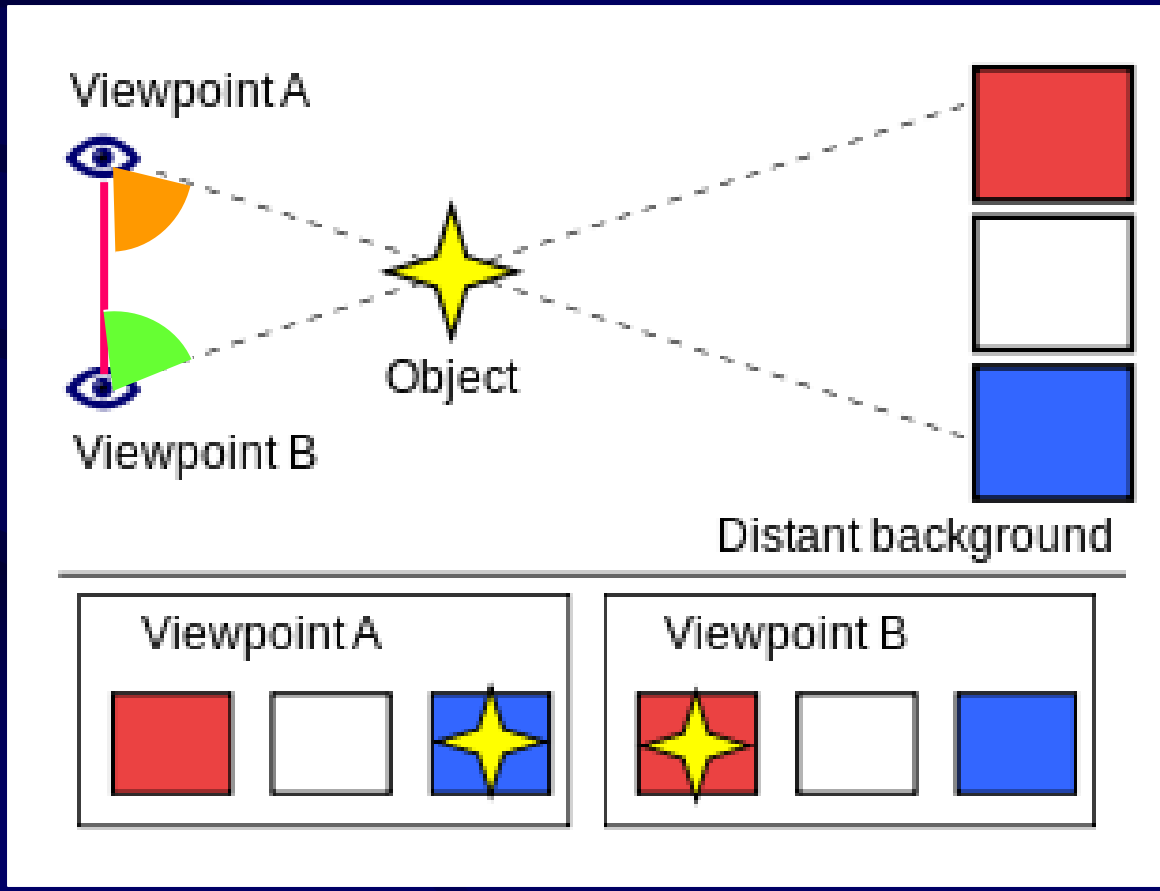
➔ We can use this to determine distance!



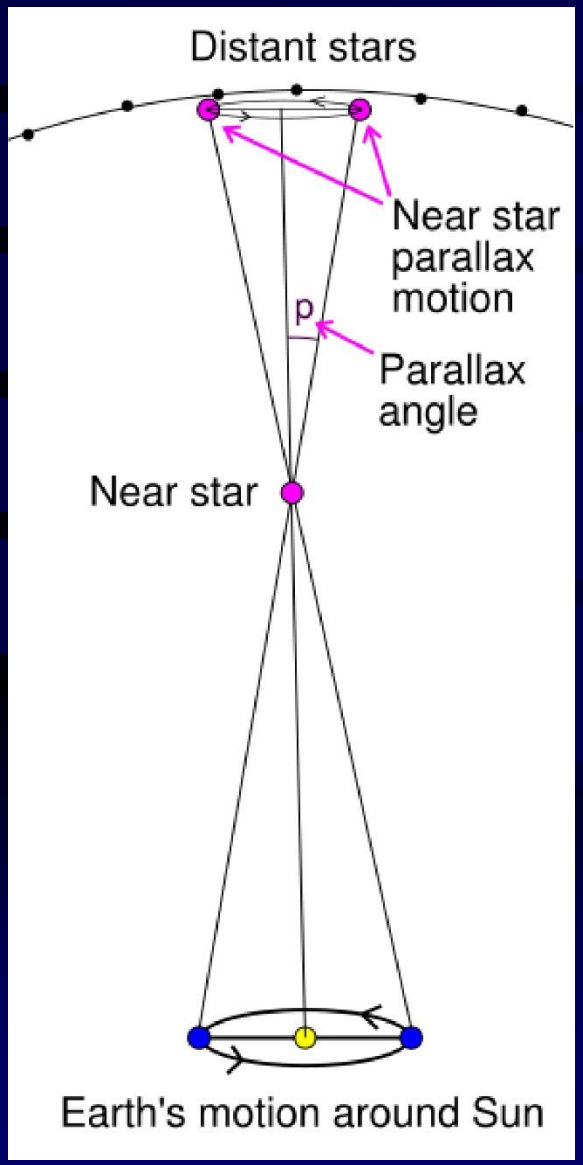
Using the Parallax Effect to Measure Distances

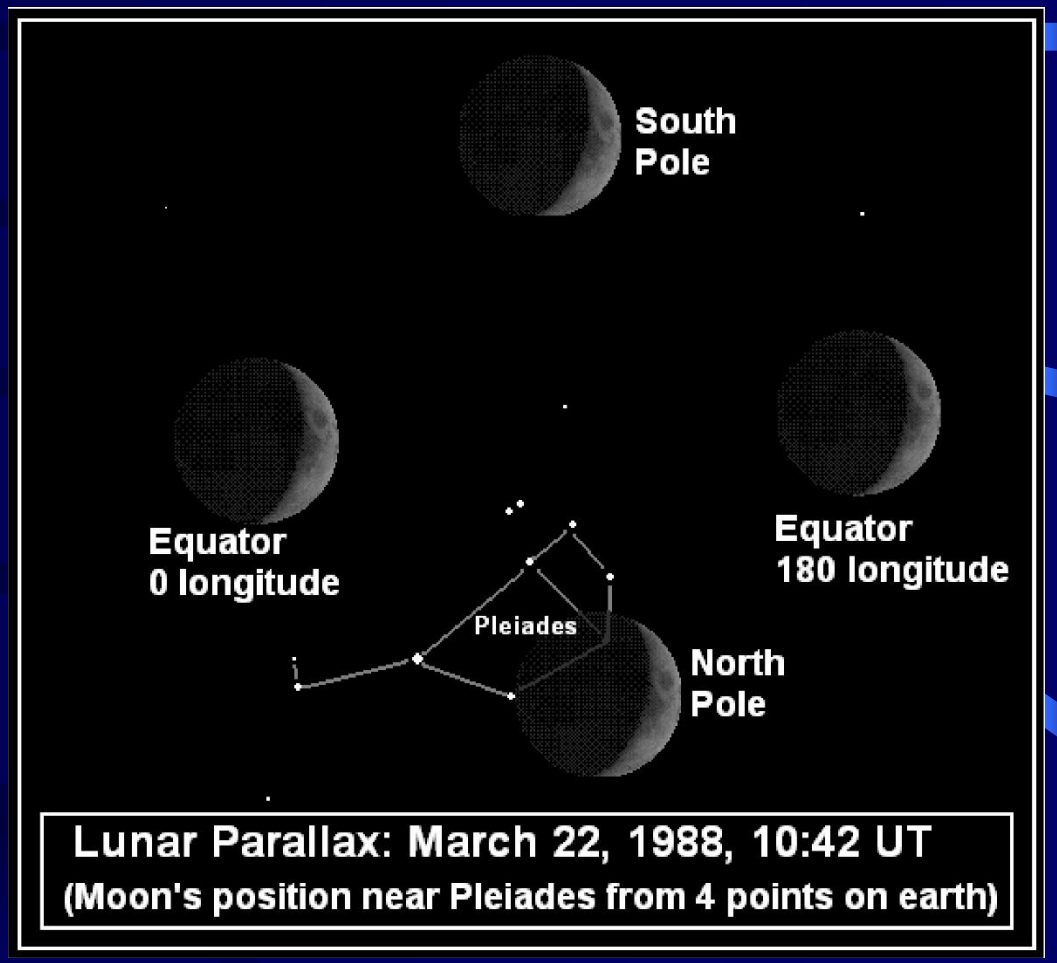
- Demo: look at you thumb with one eye closed

- Measure the baseline (distance A to B)
- Measure angle at B
- Measure angle at A
- Use geometry of triangles to determine distance to object:
  - If two angles plus one side of a triangle are known, everything else can be computed



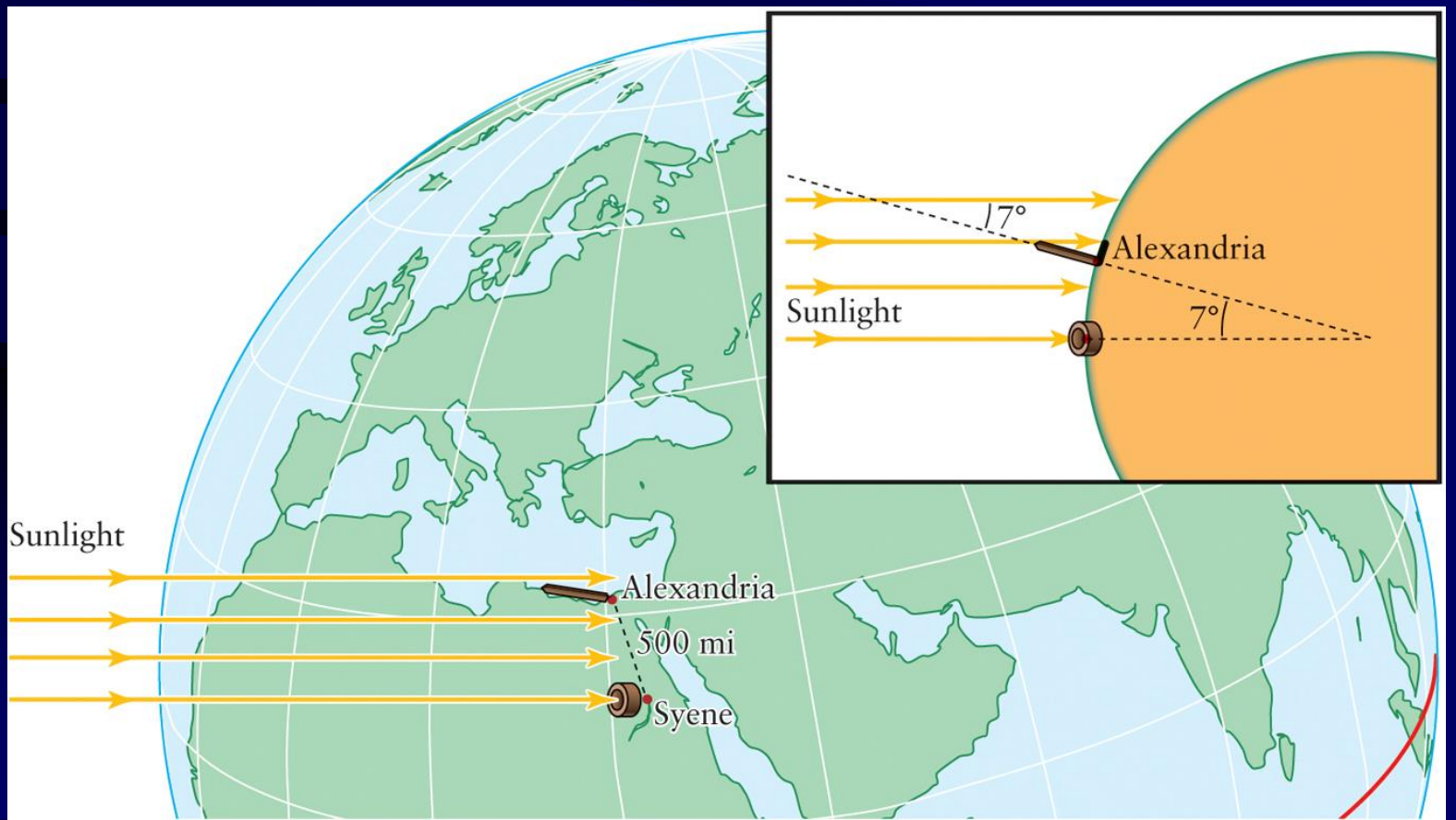
Triangulation and Parallax in Astronomy



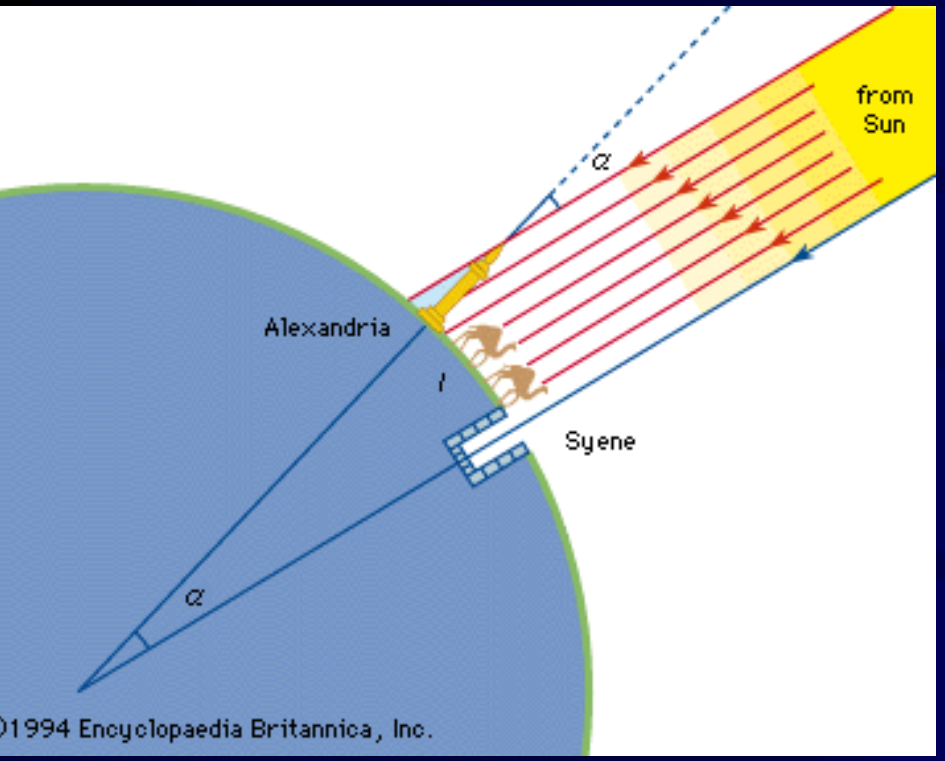


Triangulating the Size of the Earth

- Eratosthenes (ca. 276 BC)
  - Measures the radius of the earth to about 20%



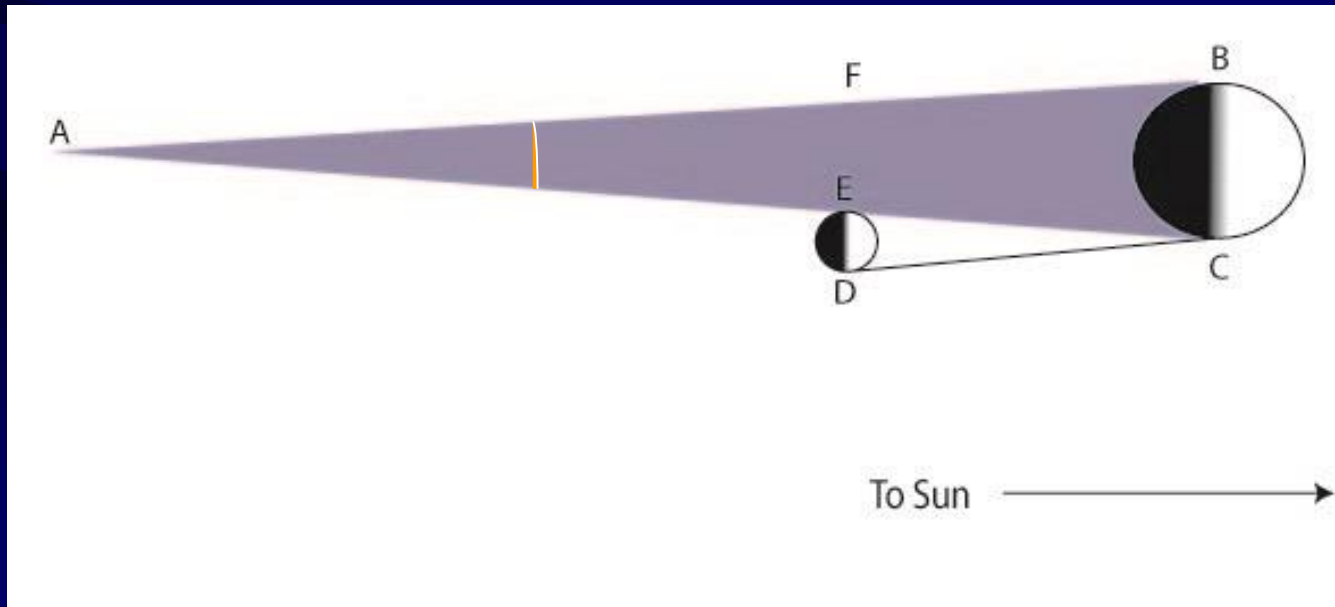
Calculation



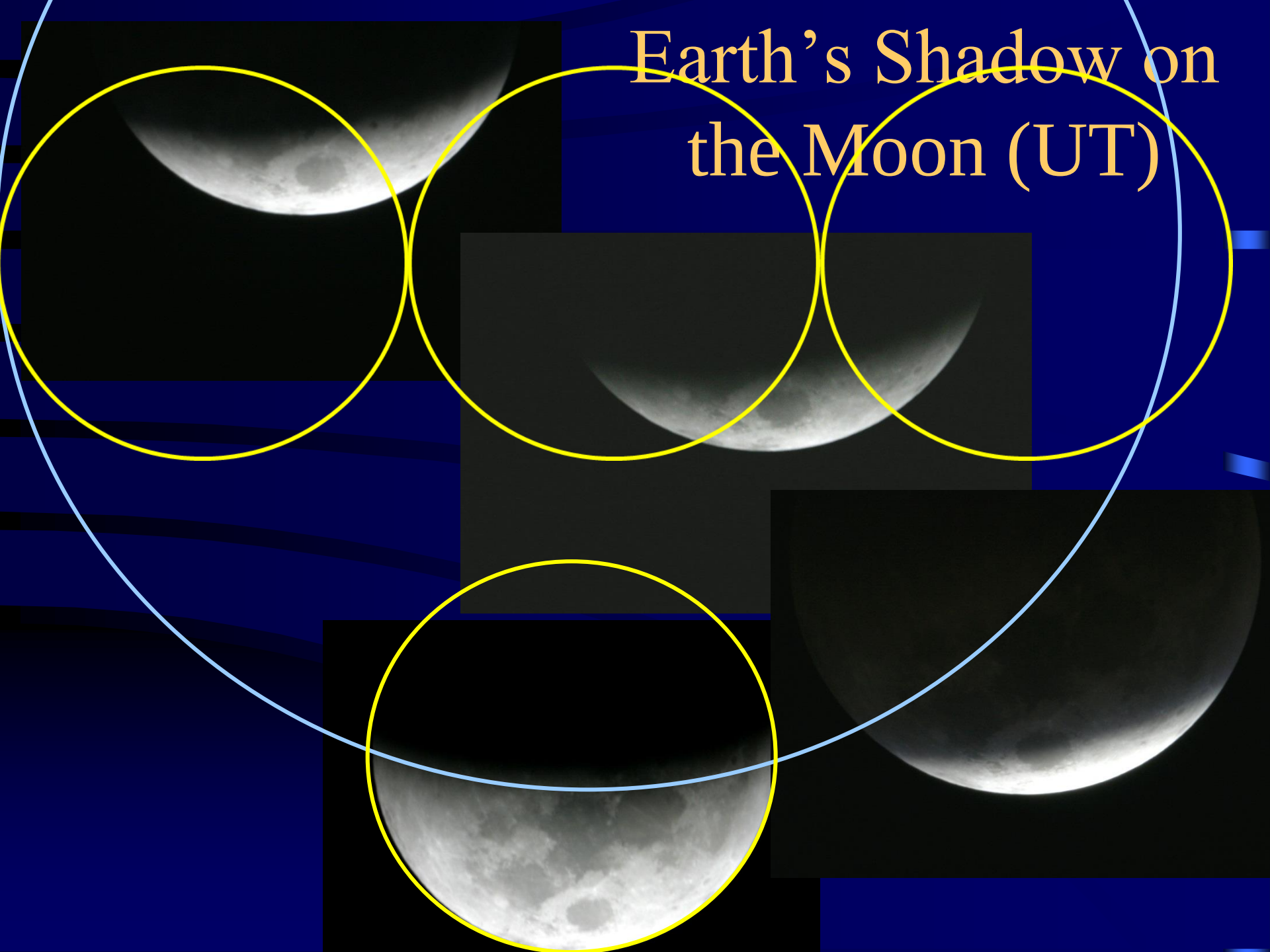
- Angle is measured to be 7.2 = 360/50
- So distance Alexandria-Syene is 1/50 of Earth's circumference
- Baseline can be measured: 5000 stades
- ➔ Circumference is 23,330 miles (modern value: 25,000 miles – only 7% off

Aristarchus: How far away is the Moon?

- The Greeks used a special configuration of Earth, Moon and Sun (link) in a lunar eclipse
- Can measure EF in units of Moon's diameter, then use geometry and same angular size of Earth and Moon to determine Earth-Moon distance
- See here for method

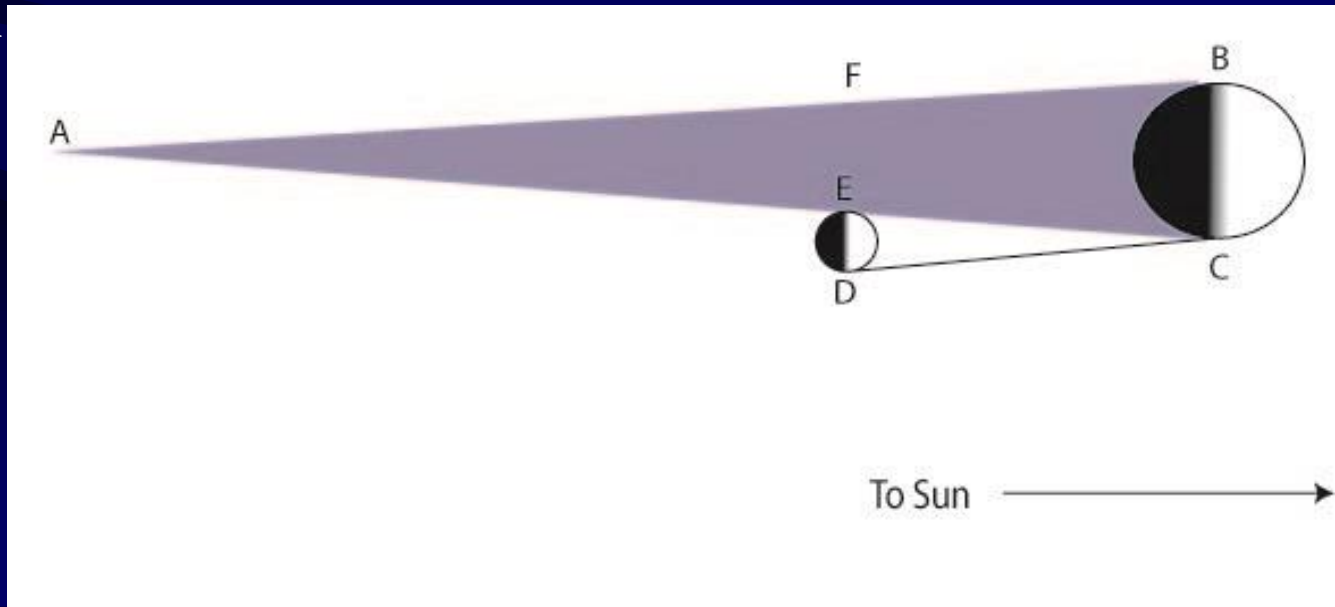


Earth's Shadow on the Moon (UT)



Geometrical Argument

- Triangles AFE and EDC are congruent
- We know ratio FE/ED = f
- Therefore AE=f EC, and AC = (1+f)EC
- AC=108 R_{Earth}
- EC = distance to Moon



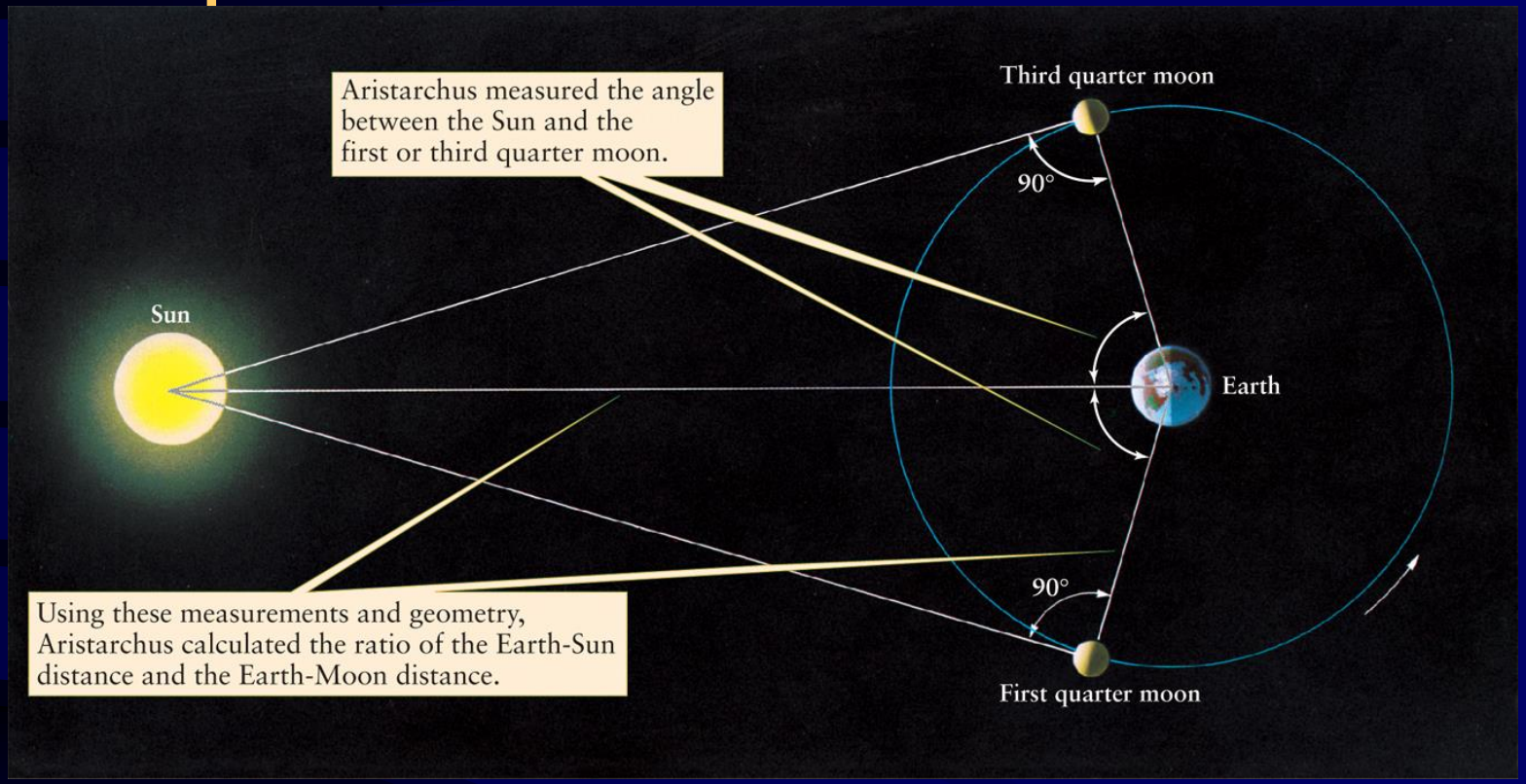
That means we can size it up!

- We can then take distance (384,000 km) and angular size (1/2 degree) to get the Moon's size
- D = 0.5/360*2π*384,000km = 3,350 km

How far away is the Sun?

- This is much harder to measure!
- The Greeks came up with a lower limit, showing that the Sun is much further away than the Moon
- Consequence: it is much bigger than the Moon
- We know from eclipses: if the Sun is X times bigger, it must be X times farther away

Simple idea – hard measurement

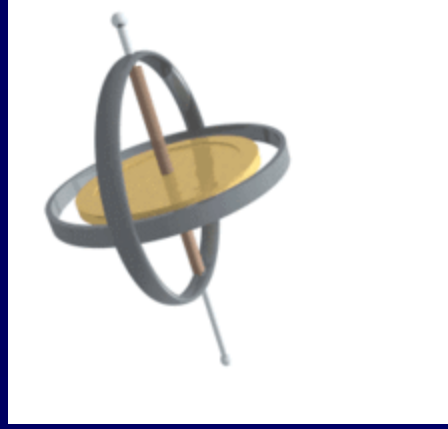


- The angle α is different from 90° by only 1/6 degree
- Very hard to measure such a small angle ☹

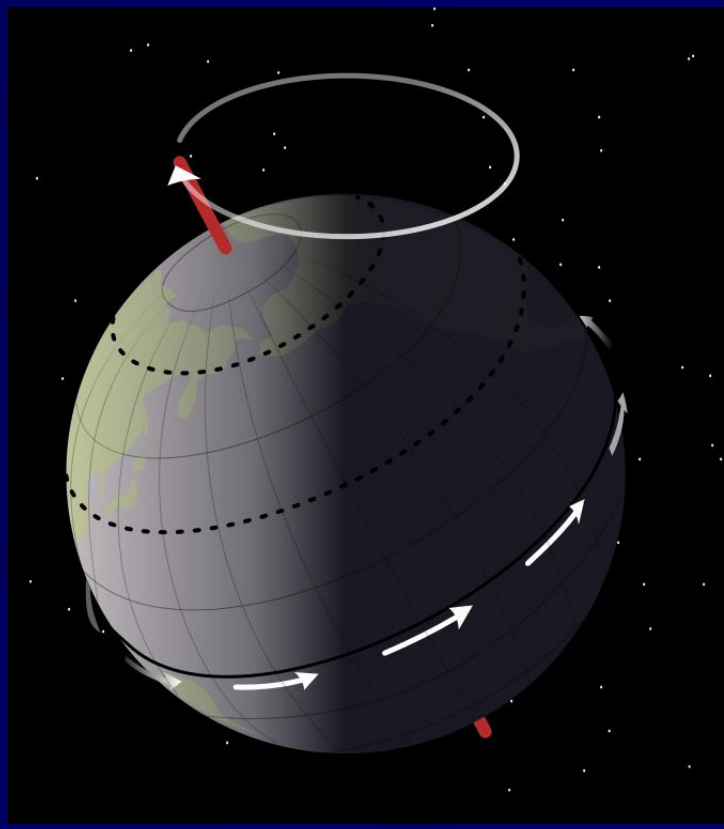
Hipparchus's (190-120 BCE) achievements

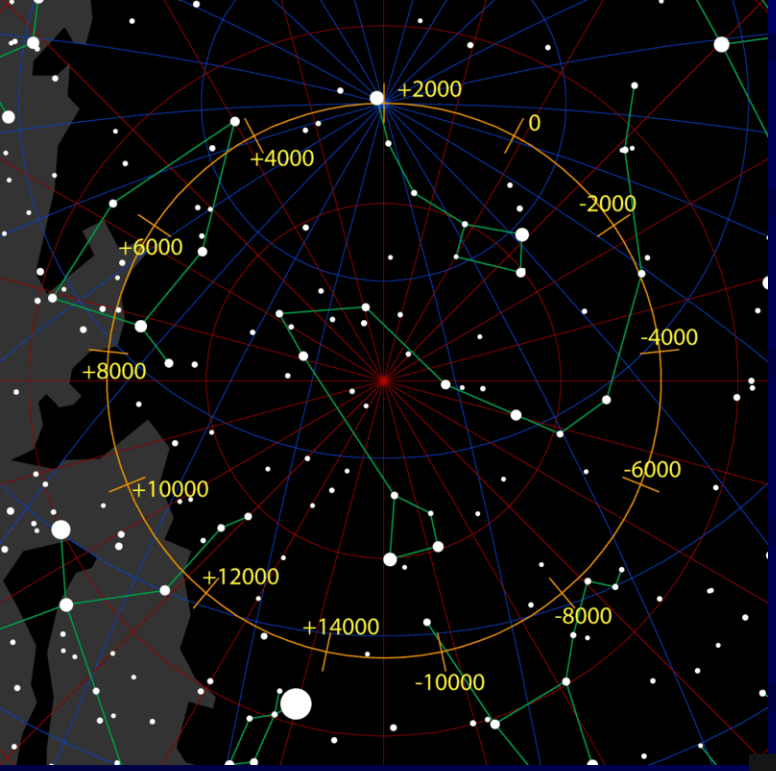
- Compiling an accurate Star Catalog in use for a milenium
- Discovery of Precession
  (Shift of the equinoxes)
- Invention of the
  Eccentric Circle

Precession of the Equinoxes



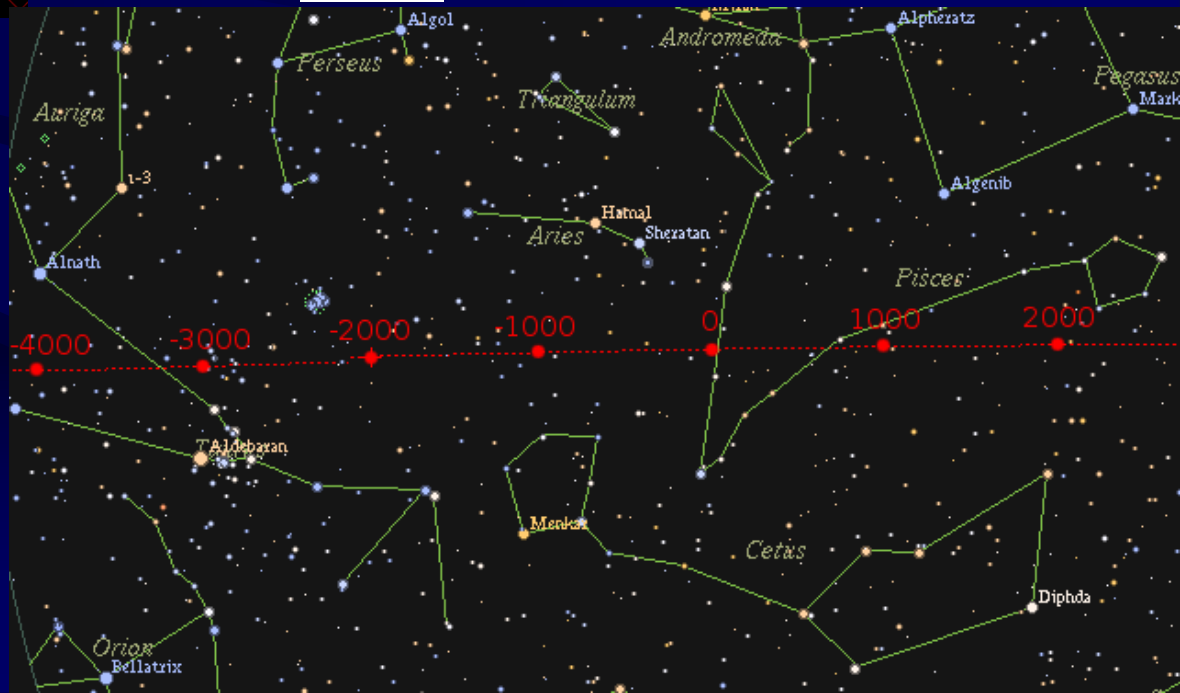
- Earth rotates around its axis
- The axis itself rotates very, very slowly (26,000 years) around the pole of the ecliptic
- This effect can only be discovered by meticulous recordkeeping, comparison with historic data → cumulative effect





When celestial coordinates were "invented" 2,000 years ago, the equinox was in Aries, hence the ram sign ♈

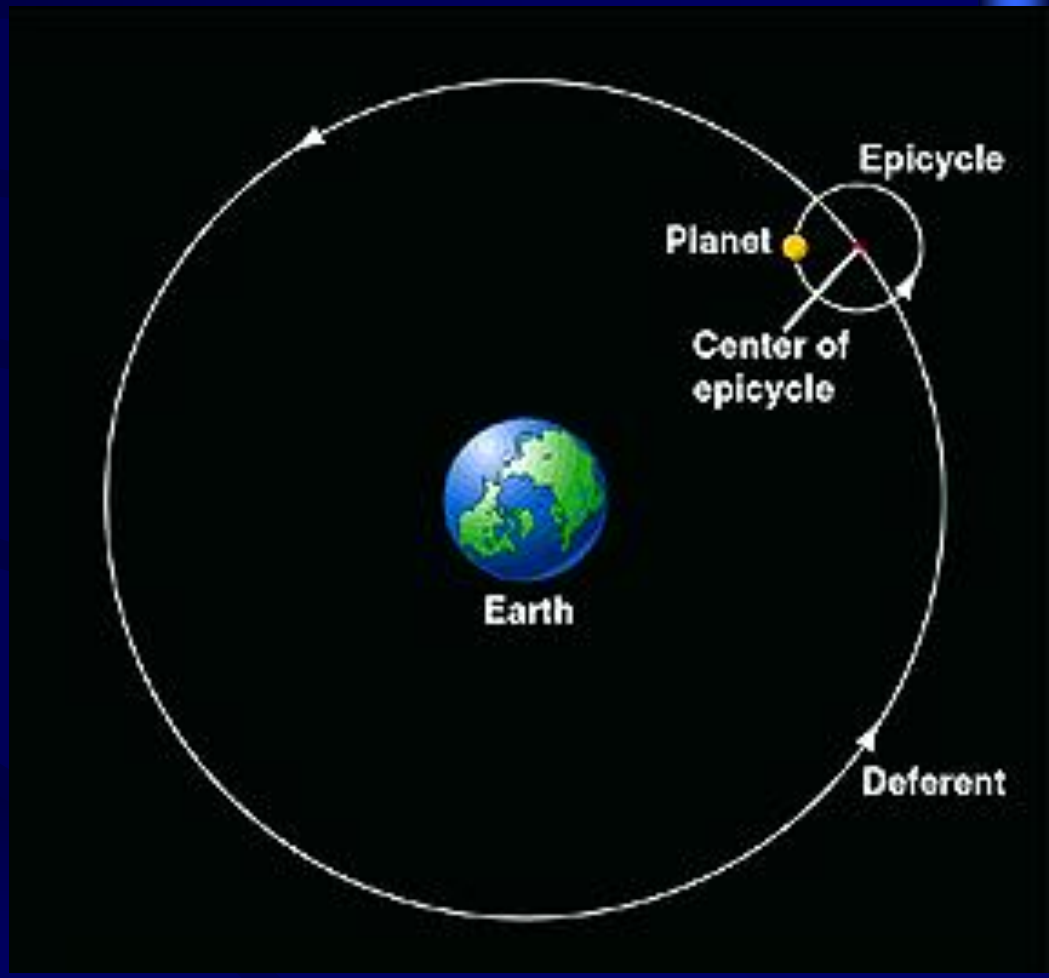
Path of CNP and Equinox due to Precession



Ptolemy (~140 AD)

- Puts forth a complete geocentric model
- dominates scientific thought during the Middle Ages
- Longest lasting (wrong) theory ever: 1000yrs

Major Work: **Almagest**

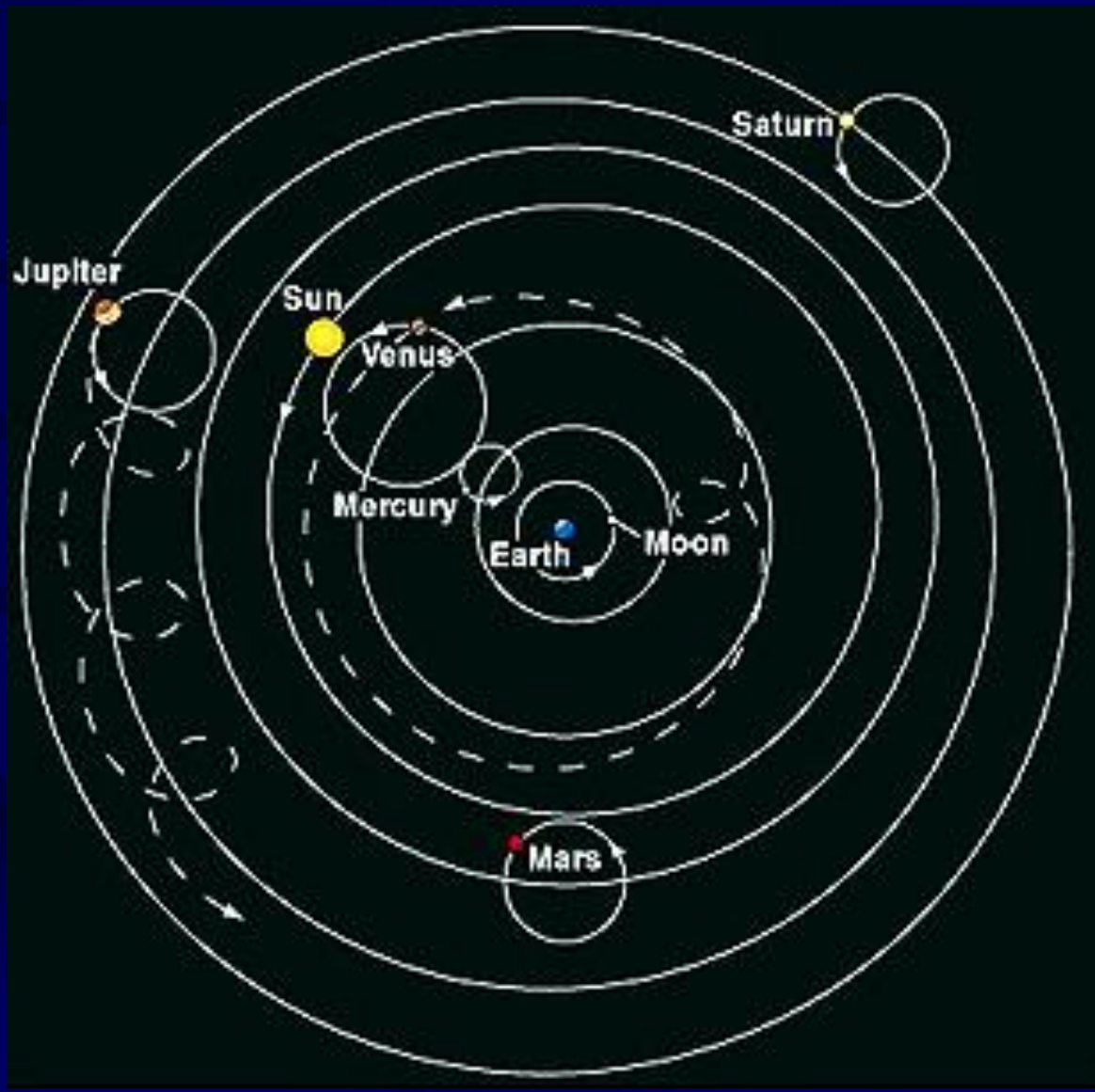


Epicycles

- **Ptolemy's** explanation of **retrograde motion**
- Ptolemy Simulator

(Sun can be simulated as an inferior planet with no epicycle)

- Several epicycles necessary to explain all observations
  ➔complicated theory
- Saves the appearances!



Ptolemy as a mathematical Astronomer

- Ptolemy employs a set of geometrical tools (epicycles, equants, eccentric circles) to describe the cosmos (planetary motion) mathematically
- He is concerned more with saving the appearances, less with explaining what is physically going on
- Is this wrong? No, because you can describe ANYTHING with epicycles!
- But it doesn't lead anywhere: it is sterile and not useful – at least if you want to understand the cosmos