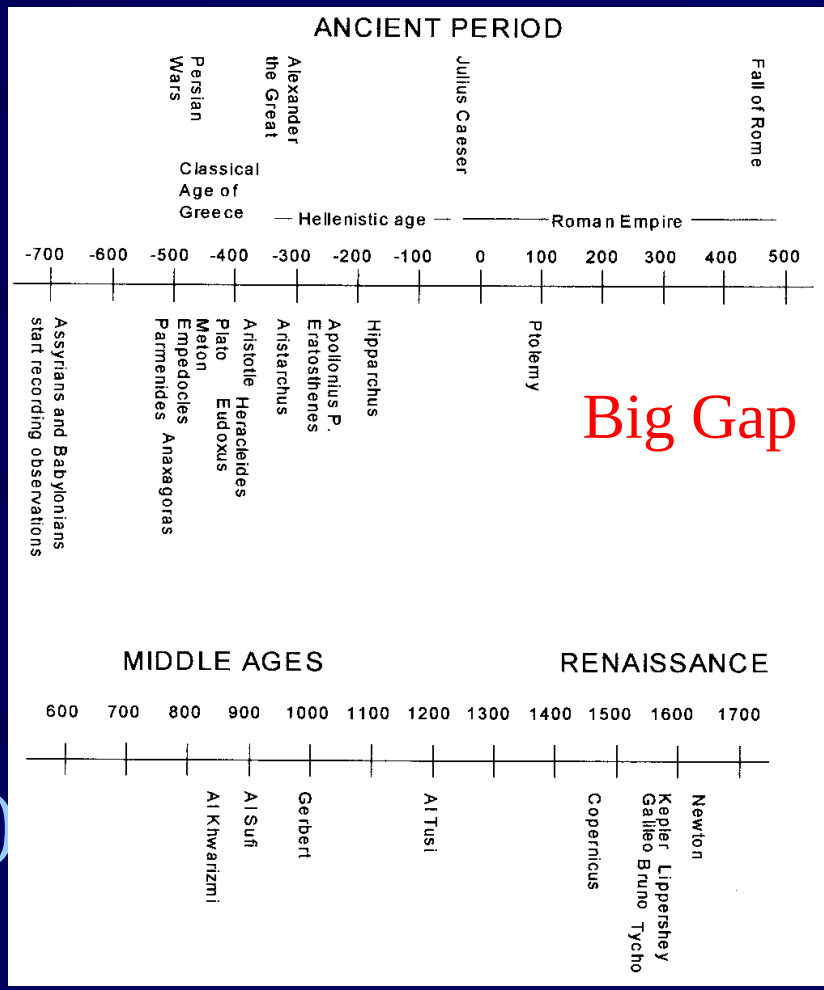
HISTORY OF ASTRONOMY

A Short History of Astronomy

- Ancient (before 500 BC)
  - Egyptians, Babylonians, Mayans, Incas, Chinese
- Classical Antiquity (500 BC-500 AD)
  - Greeks, Romans: **Plato, Aristotle, Ptolemy**
- Middle Ages (500-1450 AD)
  - Arabic astronomers
- Renaissance (1450-1550 AD)
  - **Copernicus**
- Baroque (1550-1700 AD)
  - **Brahe, Kepler, Galilei, Newton**



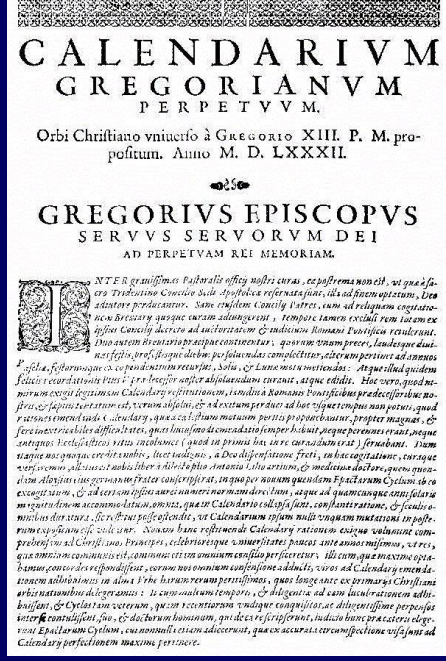
Ancient Astronomy

Stonehenge, England

Pyramids,
Gizeh near Cairo, Egypt

Early Cosmologies, Creation Myths

Early Uses of Astronomy: Calendars


CALENDARIVM
GREGORIANVM
PERPETVVM.

Orbi Christiano vniuerso à Gregorio XIII. P. M. propositum. Anno M. D. LXXXII.

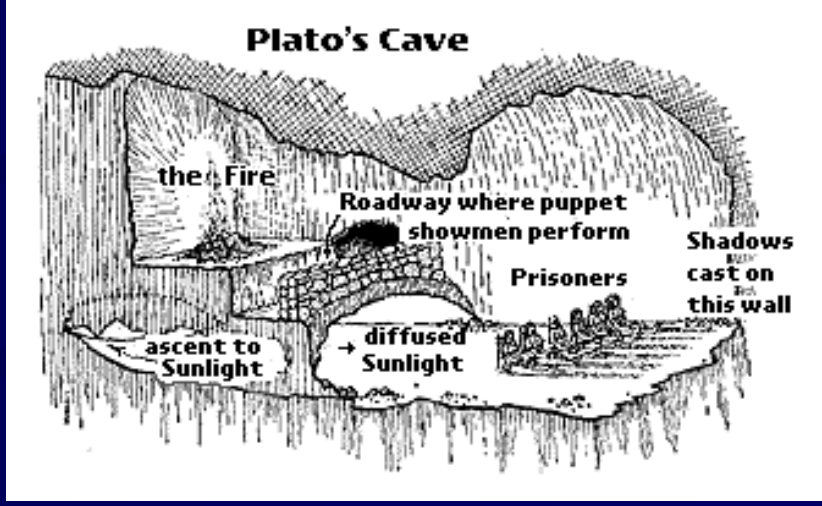
GREGORIVS EPISCOPVS
SERVVS SERVORVM DEI
AD PERPETVAM REI MEMORIAM.

- 7 day weeks (7 "planets")
- 30 day months (moon's synodic period)
- Julius Caesar (45 BC): 365 days + leap day
- Gregory XIII (1582): year divisible by 100 has no leap day, divisible by 400 does (1900 no, 2000 yes)
  - This approximates the length of the year very well (38 sec difference)

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

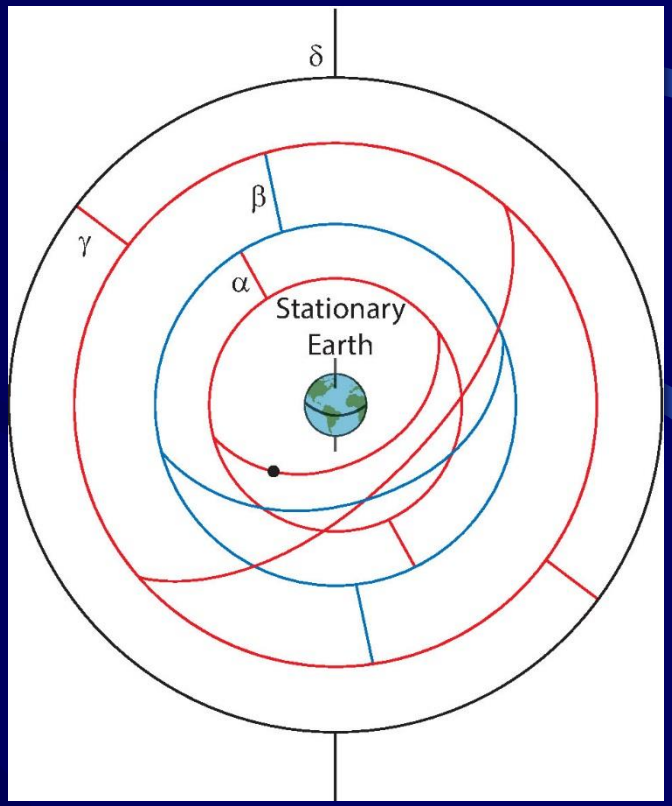
Plato: Senses are Suspicious, Circles are Perfect



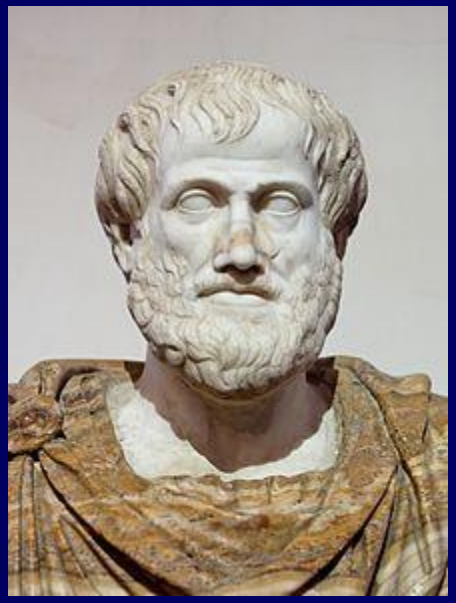
- We cannot always trust our senses
  - Cave analogy → we only know how things APPEAR, not how/what they really "are"
- Plato introduces the prejudice that all heavenly motion has to be uniform circular motion
  - Circles have no beginning nor end
  - Specified by just one number (radius)
- HW for astronomers: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



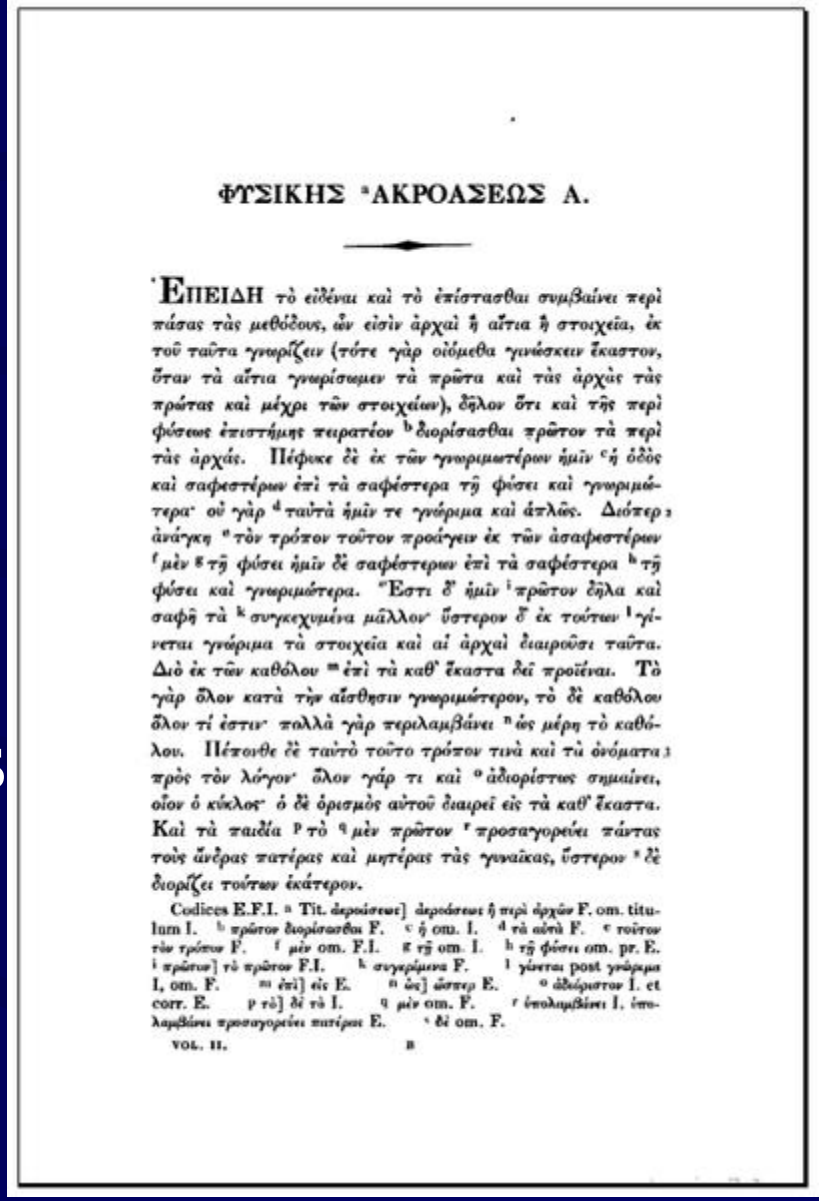
Aristotle (384 – 322 BC)



- 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

Physics and Metaphysics

- Aristotle's "***Physics***" (Greek: Φυσικὴ ἀκρόασις or *physikes akroasis*; Latin: *Physica*) is one of the foundational books of science and philosophy
- His book on philosophy is called ***Metaphysics*** (Greek: τὰ μετὰ τὰ φυσικά) – beyond physics



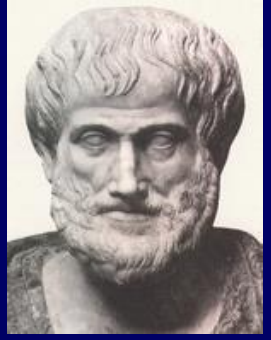
ΦΥΣΙΚΗΣ [a]ΑΚΡΟΑΣΕΩΣ Α.

Ἐπειδὴ τὸ εἰδέναι καὶ τὸ ἐπίστασθαι συμβαίνει περὶ πάσας τὰς μεθόδους, ὧν εἰσὶν ἀρχαὶ ἢ αἴτια ἢ στοιχεῖα, ἐκ τοῦ ταῦτα γνωρίζειν (τότε γὰρ οἰόμεθα γινώσκειν ἕκαστον, ὅταν τὰ αἴτια γνωρίσωμεν τὰ πρῶτα καὶ τὰς ἀρχὰς τὰς πρώτας καὶ μέχρι τῶν στοιχείων), δῆλον ὅτι καὶ τῆς περὶ φύσεως ἐπιστήμης πειρατέον [b]διορίσασθαι πρῶτον τὰ περὶ τὰς ἀρχάς. Πέφυκε δὲ ἐκ τῶν γνωριμωτέρων ἡμῖν [c]ἡ ὁδὸς καὶ σαφεστέρων ἐπὶ τὰ σαφέστερα τῇ φύσει καὶ γνωριμώτερα· οὐ γὰρ [d]ταὐτὰ ἡμῖν τε γνώριμα καὶ ἁπλῶς. Διόπερ ἀνάγκη [e]τὸν τρόπον τοῦτον προάγειν ἐκ τῶν ἀσαφεστέρων [f]μὲν [g]τῇ φύσει ἡμῖν δὲ σαφεστέρων ἐπὶ τὰ σαφέστερα [h]τῇ φύσει καὶ γνωριμώτερα. Ἔστι δ' ἡμῖν [i]πρῶτον δῆλα καὶ σαφῆ τὰ [k]συγκεχυμένα μᾶλλον· ὕστερον δ' ἐκ τούτων [l]γίνεται γνώριμα τὰ στοιχεῖα καὶ αἱ ἀρχαὶ διαιροῦσι ταῦτα. Διὸ ἐκ τῶν καθόλου [m]ἐπὶ τὰ καθ' ἕκαστα δεῖ προϊέναι. Τὸ γὰρ ὅλον κατὰ τὴν αἴσθησιν γνωριμώτερον, τὸ δὲ καθόλου ὅλον τί ἐστιν· πολλὰ γὰρ περιλαμβάνει [n]ὡς μέρη τὸ καθόλου. Πέποιθε δὲ ταὐτὸ τοῦτο τρόπον τινὰ καὶ τὰ ὀνόματα πρὸς τὸν λόγον· ὅλον γάρ τι καὶ [o]ἀδιορίστως σημαίνει, οἷον ὁ κύκλος· ὁ δὲ ὁρισμὸς αὐτοῦ διαιρεῖ εἰς τὰ καθ' ἕκαστα. Καὶ τὰ παιδία [p]τὸ [q]μὲν πρῶτον [r]προσαγορεύει πάντας τοὺς ἄνδρας πατέρας καὶ μητέρας τὰς γυναῖκας, ὕστερον [s]δὲ διορίζει τούτων ἑκάτερον.

Codices E.F.I. [a] Tit. ἀκροάσεως] ἀκροάσεως ἡ περὶ ἀρχῶν F. om. titulum I. [b] πρῶτον διορίσασθαι F. [c] ἡ om. I. [d] τὰ αὐτὰ F. [e] τοῦτον τὸν τρόπον F. [f] μὲν om. F.I. [g] τῇ om. I. [h] τῇ φύσει om. pr. E. [i] πρῶτον] τὸ πρῶτον F.I. [k] συγκρίμενα F. [l] γίνεται post γνώριμα I, om. F. [m] ἐπὶ] εἰς E. [n] ὡς] ὥσπερ E. [o] ἀδιόριστον I. et corr. E. [p] τὸ] δὲ τὸ I. [q] μὲν om. F. [r] ὑπολαμβάνει I, ὑπολαμβάνει προσαγορεύει πατέρας E. [s] δὲ om. F.

How do things move?

Aristotle (c. 350 B.C.)



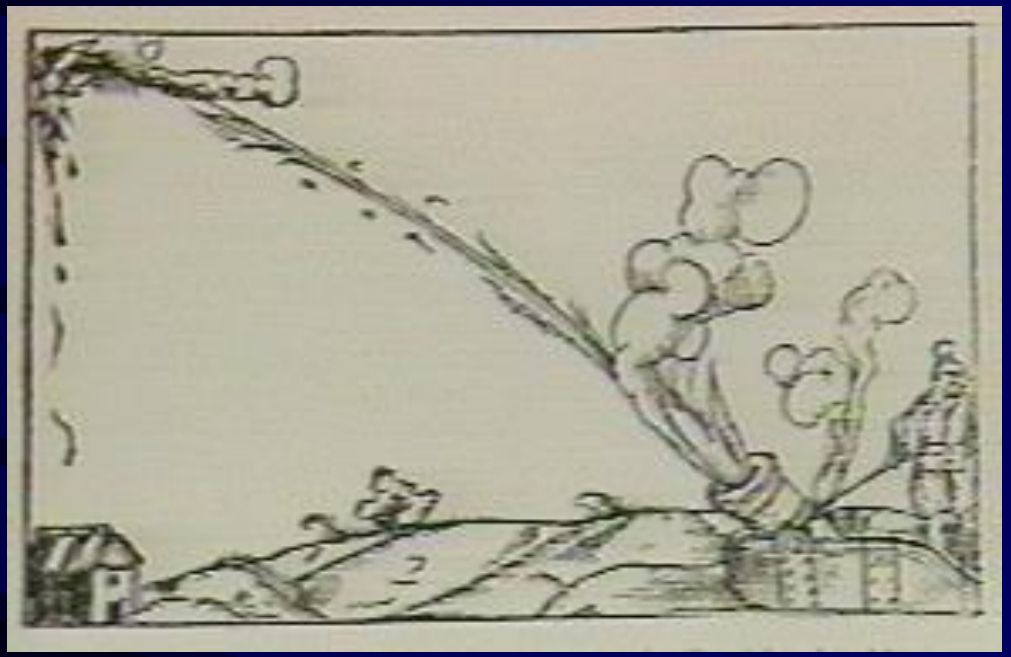
Aristotle **observed** how things move, and constructed the following **theory**:

- Things have a tendency to stay stationary.
- If you push something, it will move, then return to it's natural state: stationary.
  - Actually, it will try to return to it's natural place: smoke and gas will go up, rock and water will go down.
- If you fire an arrow from a bow, you give it *impetus*: it will travel until this impetus runs out, at which time it will fall to to ground and return to it's natural state.

Wrong, i.e. falsified by experiments!

This was stated in a series of books called 'Physics', and gives us the name of the science. This theory makes intuitive sense, and allows us to make a prediction: rocks won't move unless they are pushed. People took this as truth for ~1900 years.

Aristotle easily falsified by experiment – but emphasis was not on observation



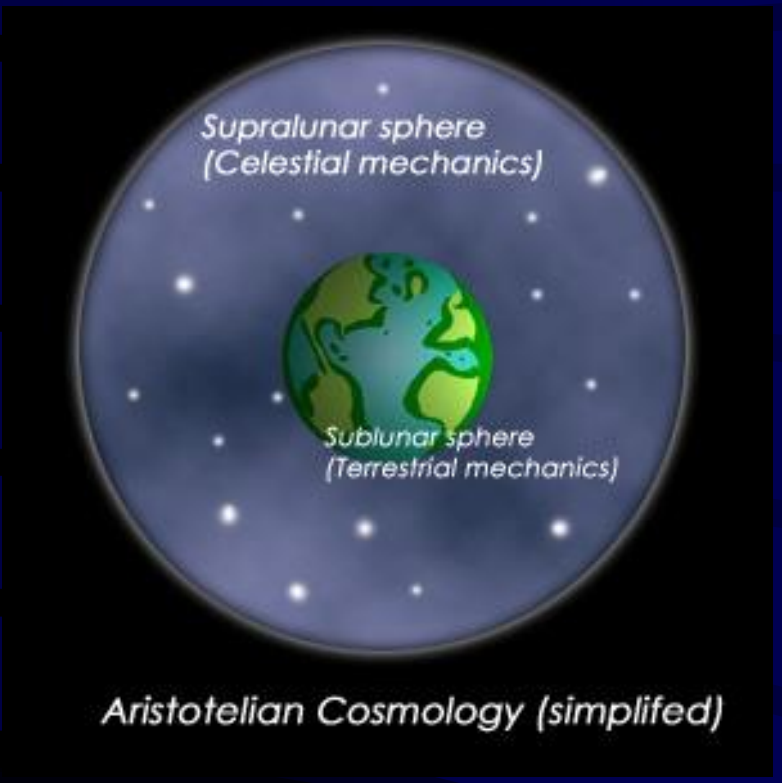
How people thought about projectiles up until the Renaissance: the cannonball moves in almost a straight line, until it runs out of impetus and falls on the house.

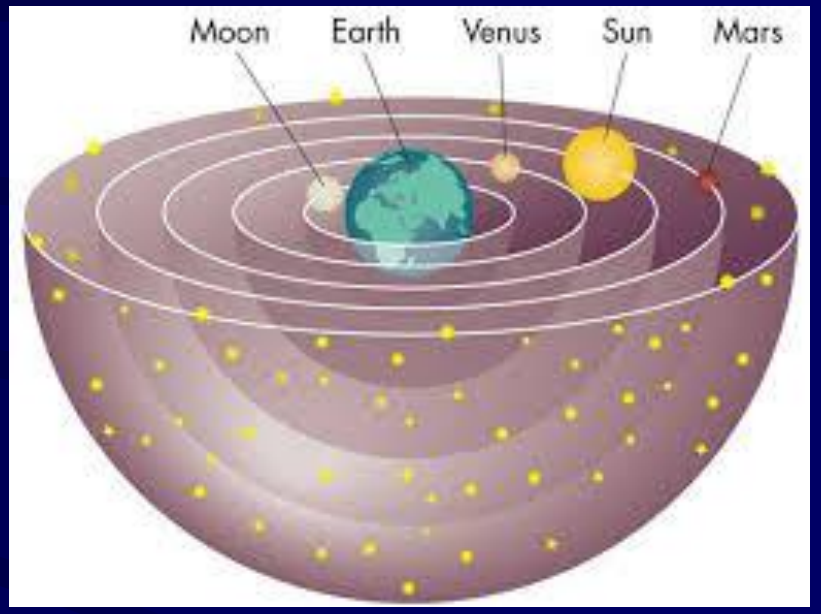
WRONG!

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

The Grand Mystification of the Cosmos

- Aristotle's thoughts ossified and prevented progress
- Disempowerment of the inquisitive mind
  - Trapped in a realm of chaos, what can we do?
  - There is no connection of what goes on on Earth and in the heavens, so how can we find out?
  - We are lowly, how can we ask divine questions or question the word of God?

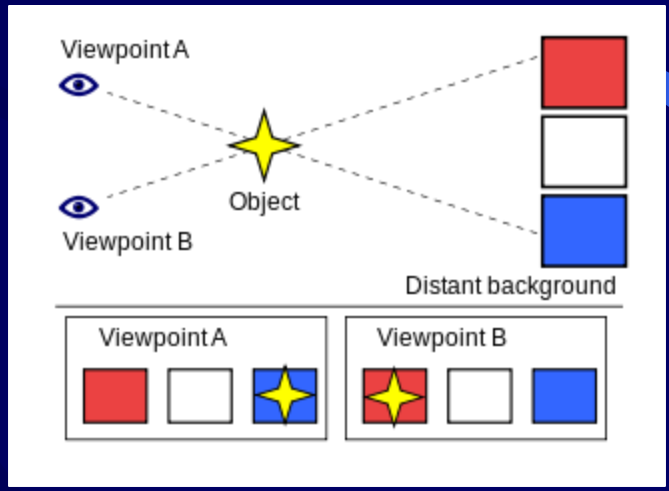
Progress in the Hellenistic Period

- 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

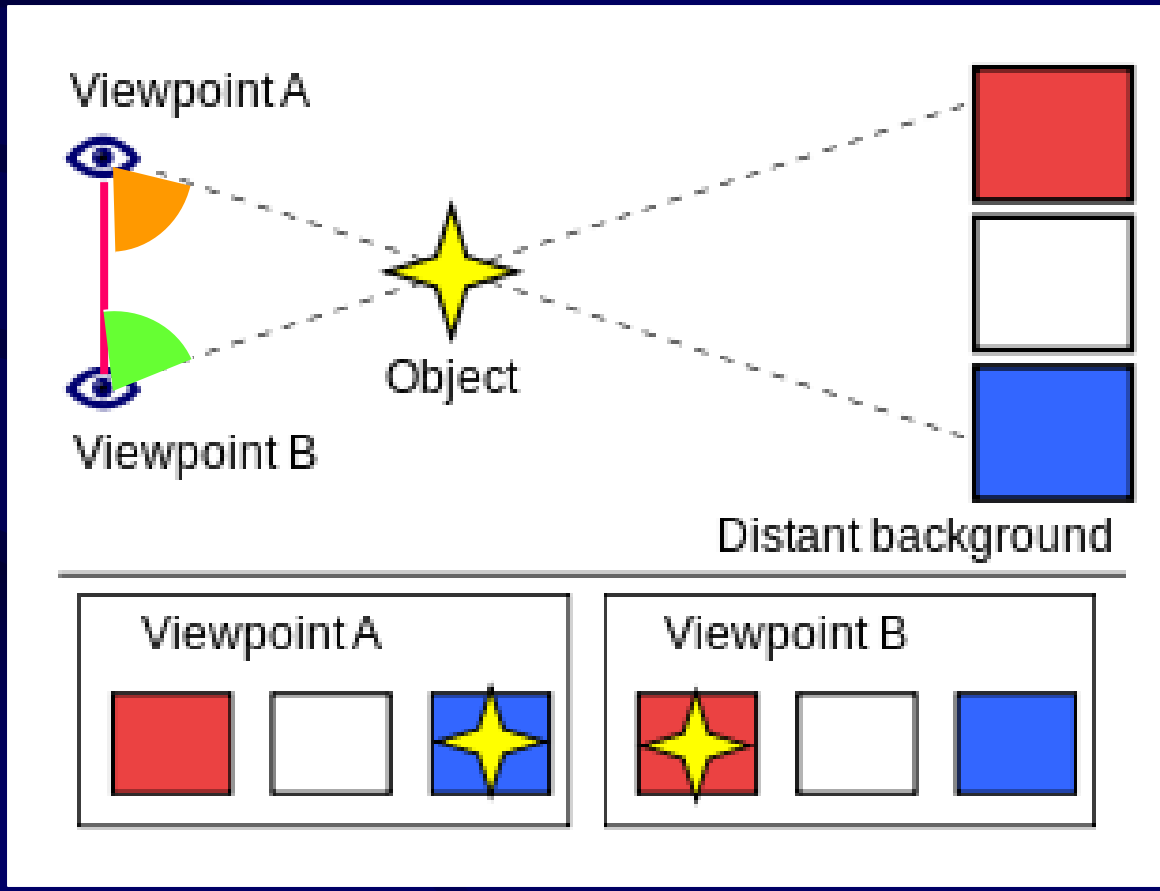
➔ We can use this to determine distance!



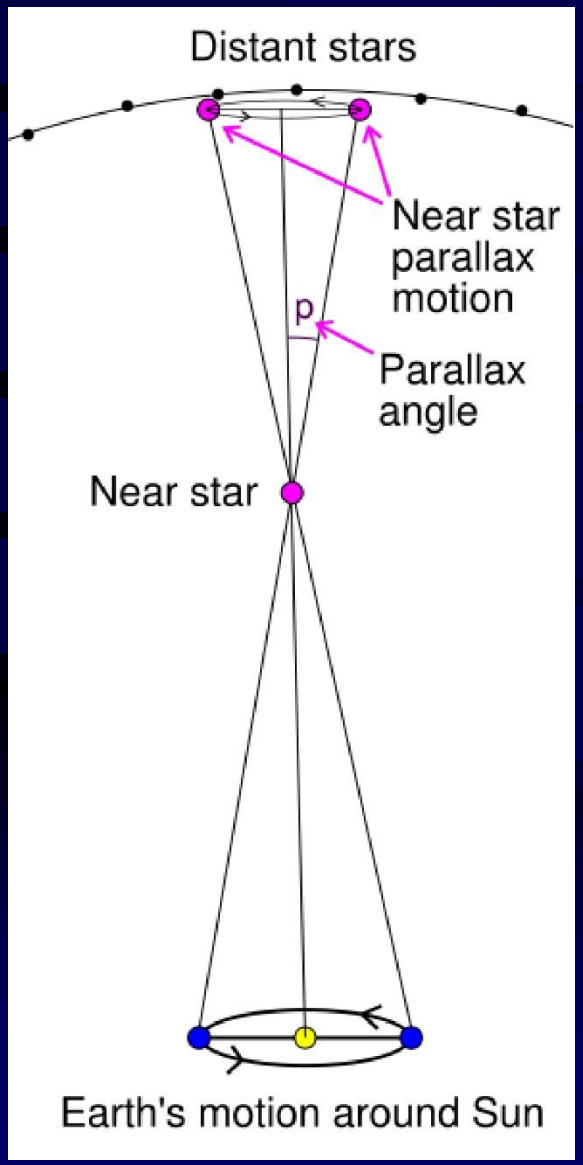
Using the Parallax Effect to Measure Distances

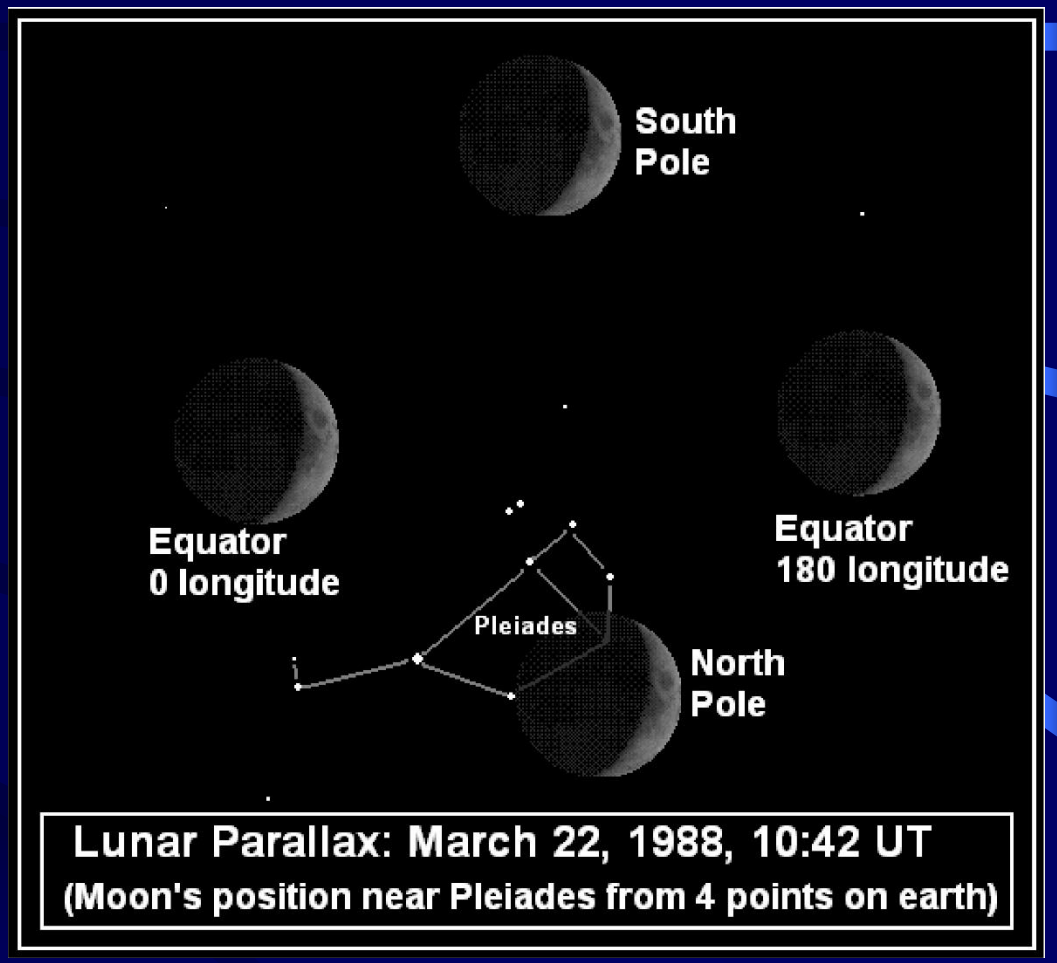
- Demo: look at you thumb with one eye closed

- 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



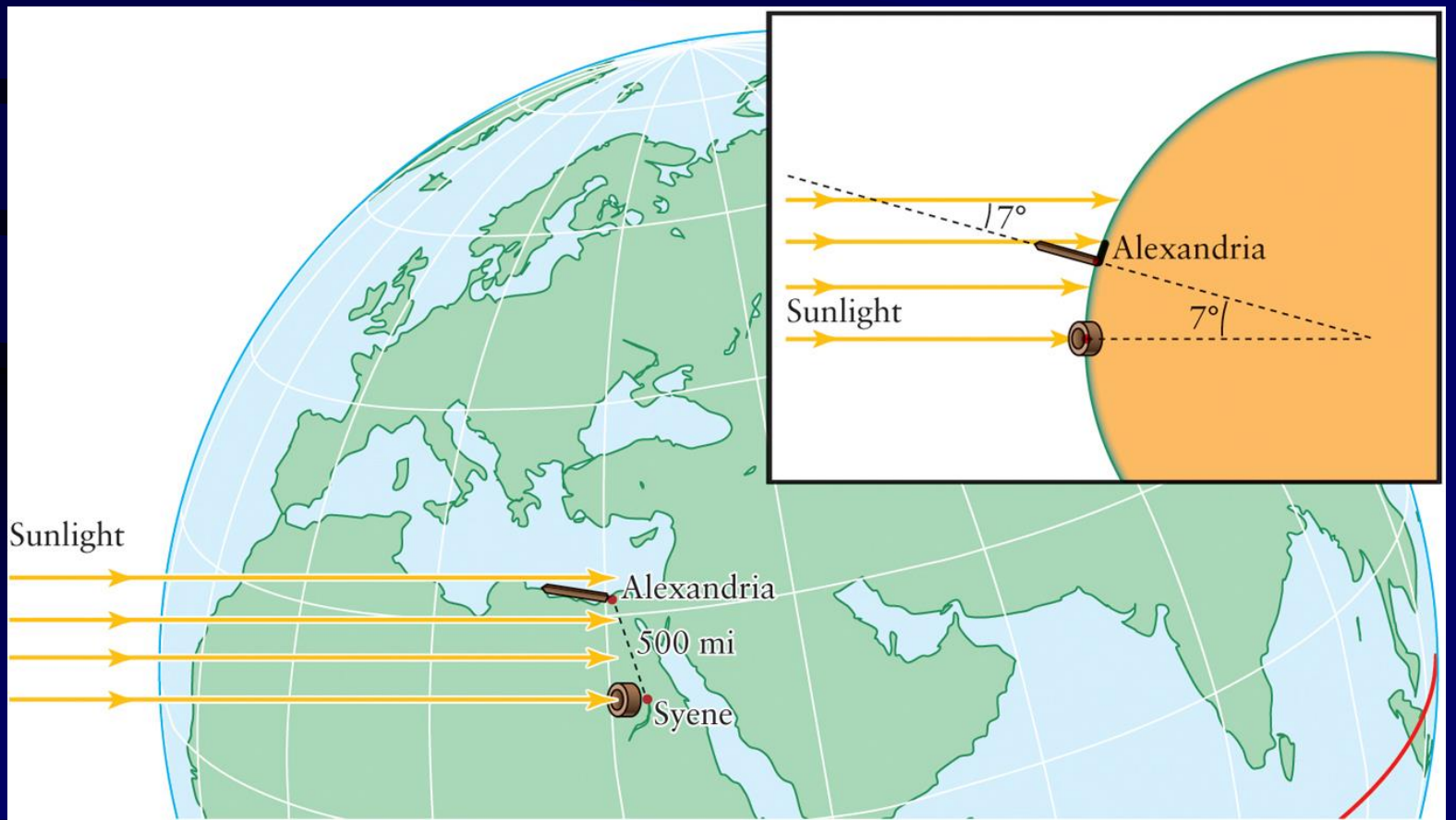
Triangulation and Parallax in Astronomy



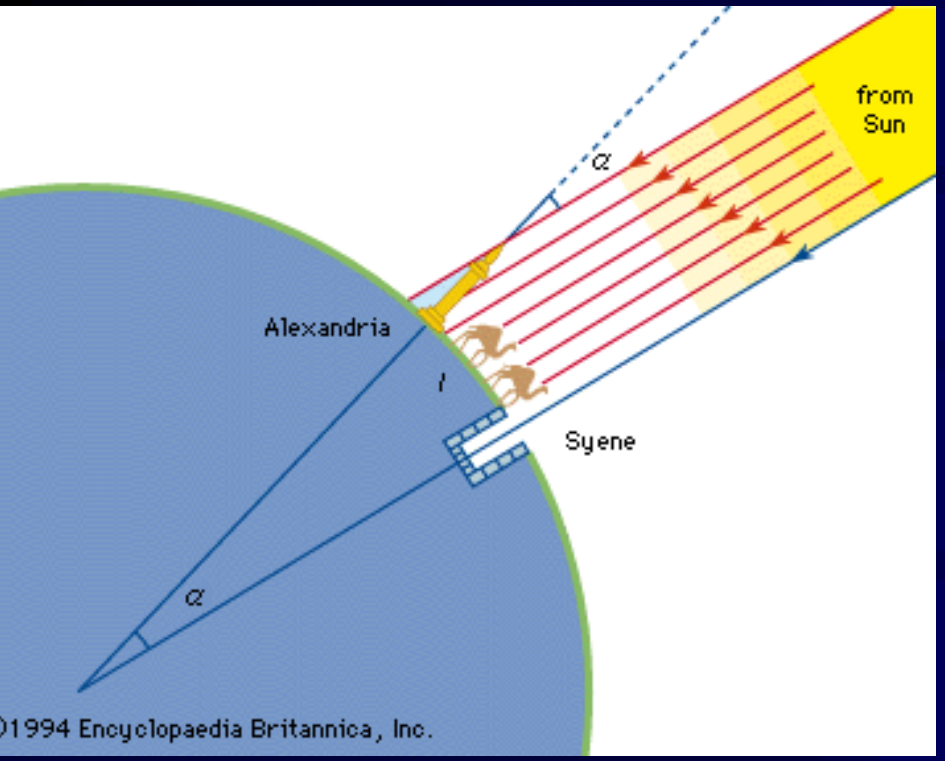


Triangulating the Size of the Earth

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



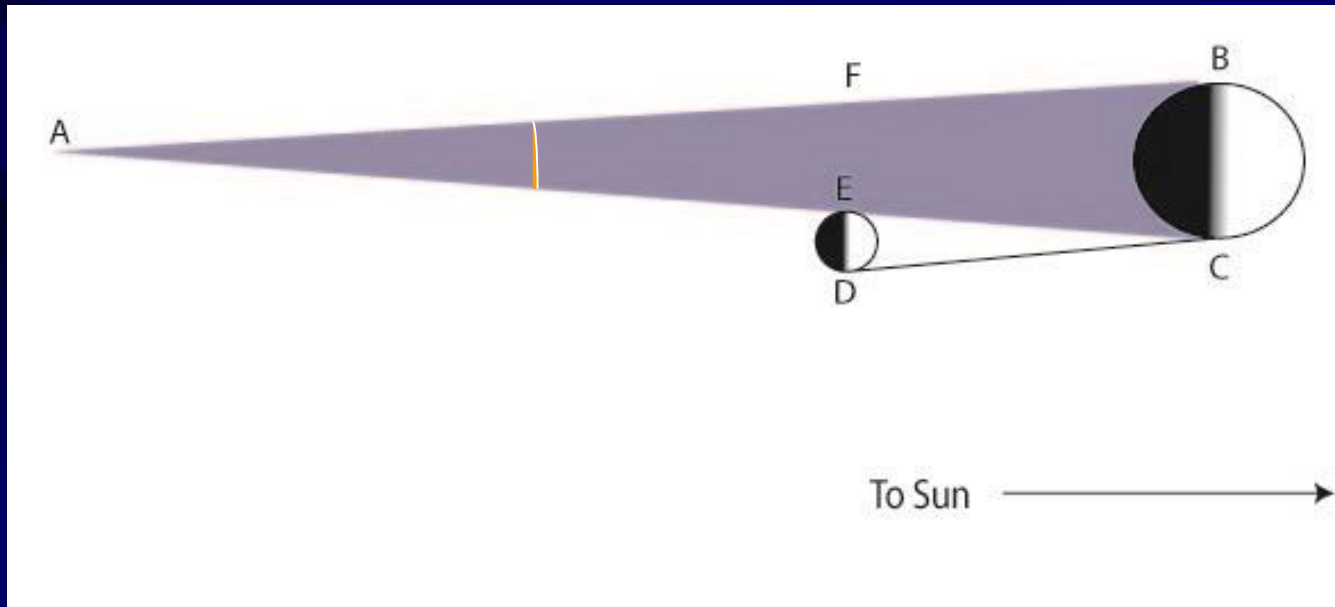
Calculation



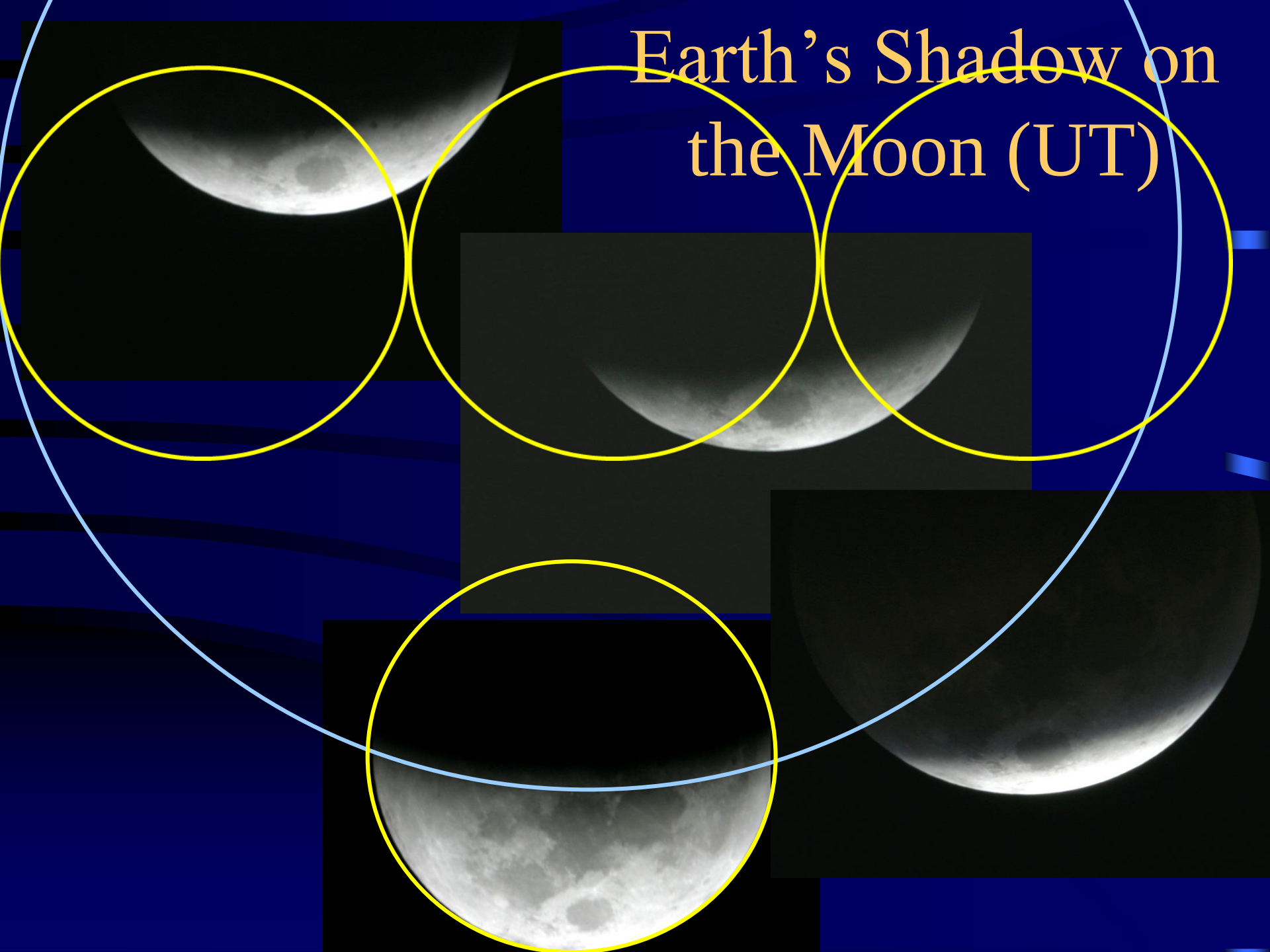
- Angle is measured to be 7.2 = 360/50
- So distance Alexandria-Syene is 1/50 of Earth's circumference
- Baseline can be measured: 5000 stades
- ➔ Circumference is 23,330 miles (modern value: 25,000 miles – only 7% off

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

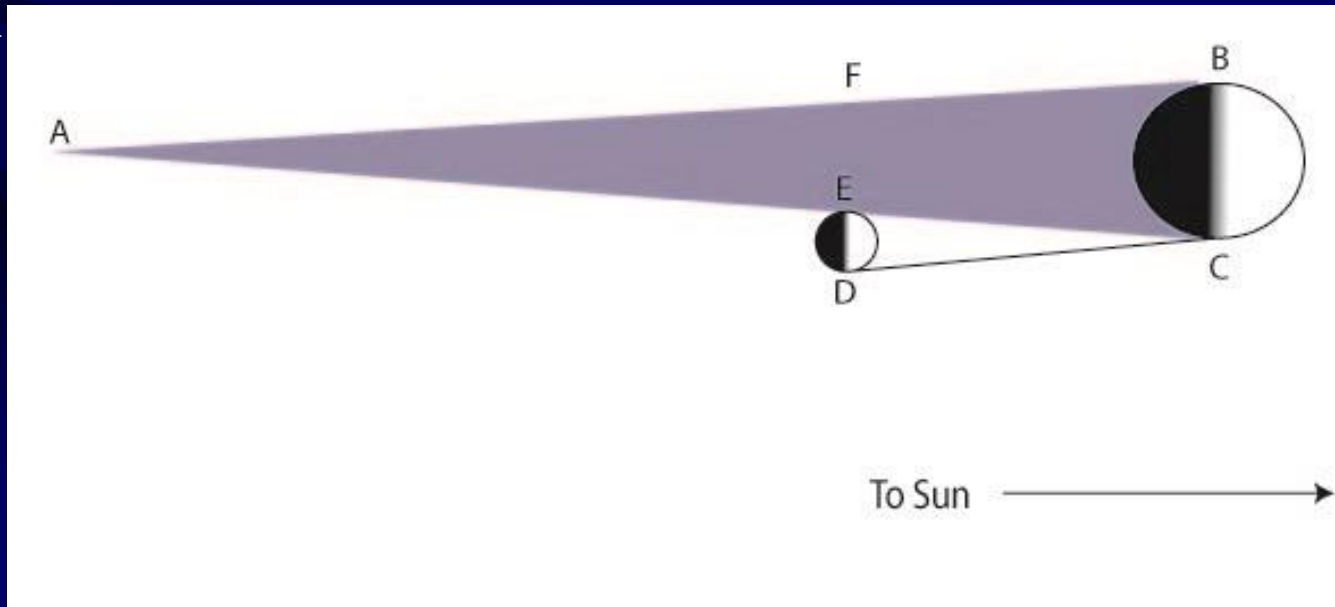


Earth's Shadow on the Moon (UT)



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



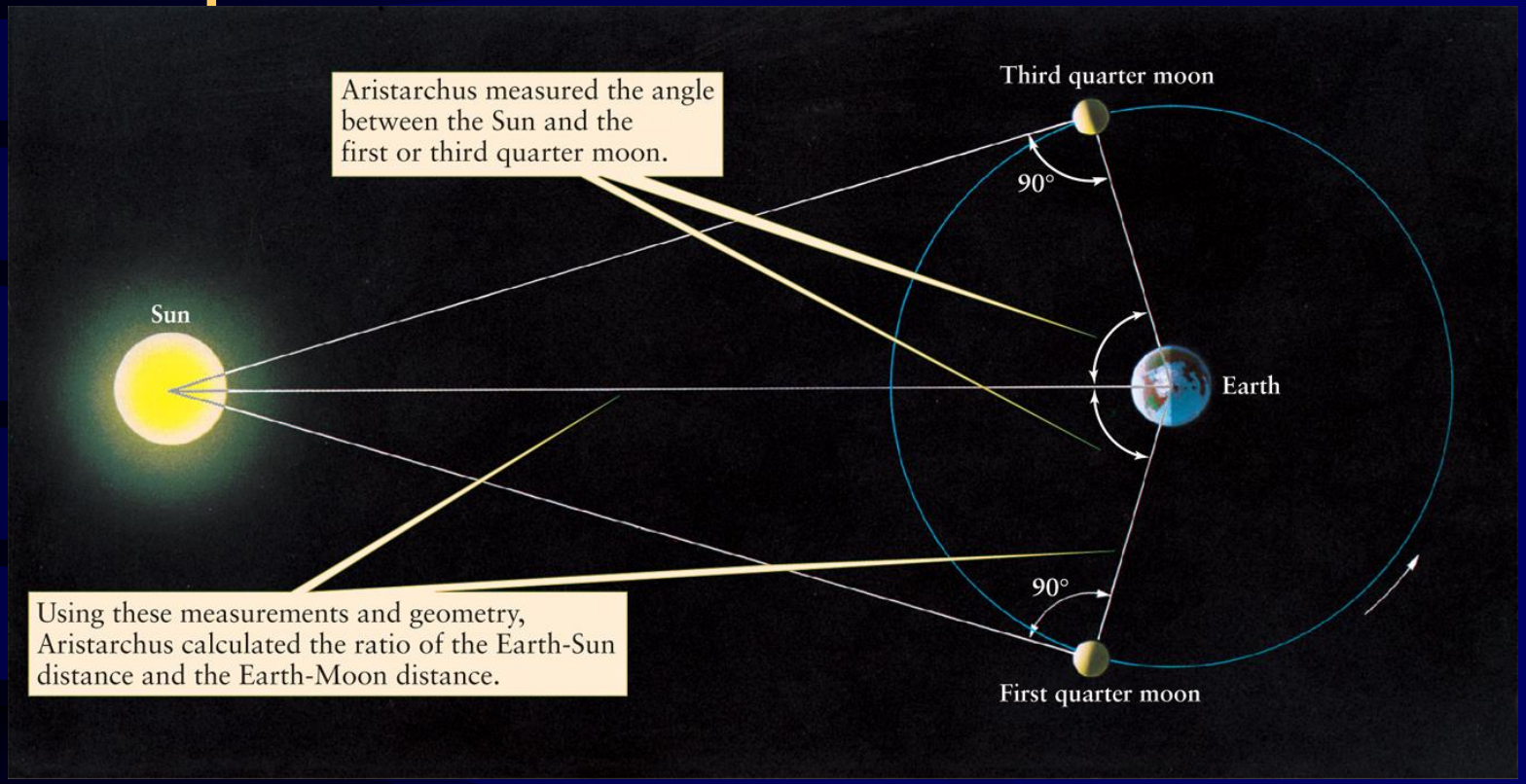
That means we can size it up!

- 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 achievements

- Star Catalog
- Precession (Shift of the equinoxes)
- Eccentric Circle