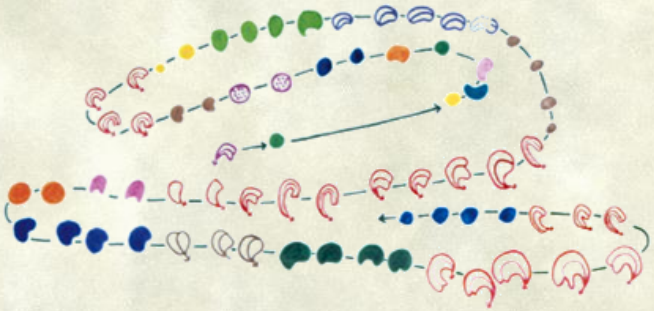
Astronomy Through the Ages 1
Early History and Greek Astronomy

ASTR 101

9/26/2018

Early History

- Astronomy is often described as the oldest of the natural sciences.
  - Humans attempts to understand and make sense of the sky predates antiquity.
  - Religious, mythological and astrological beliefs and practices of pre-historical societies related to celestial objects and events can be seen from many artifacts that have survived to date.



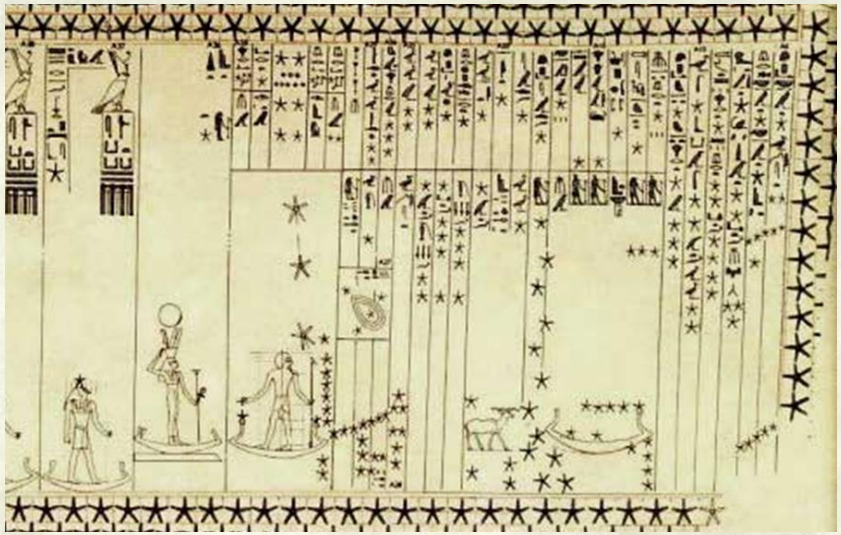
The Blanchard Bone, depicting a series of moon phases (France. 25,000 - 32,000 BCE)

Stonehenge

The Mayan observatory at Chichen Itza, seemed to have built to observe Venus and the Sun. The pyramid is aligned to solar equinox

Babylonian and ancient Egyptian astronomy

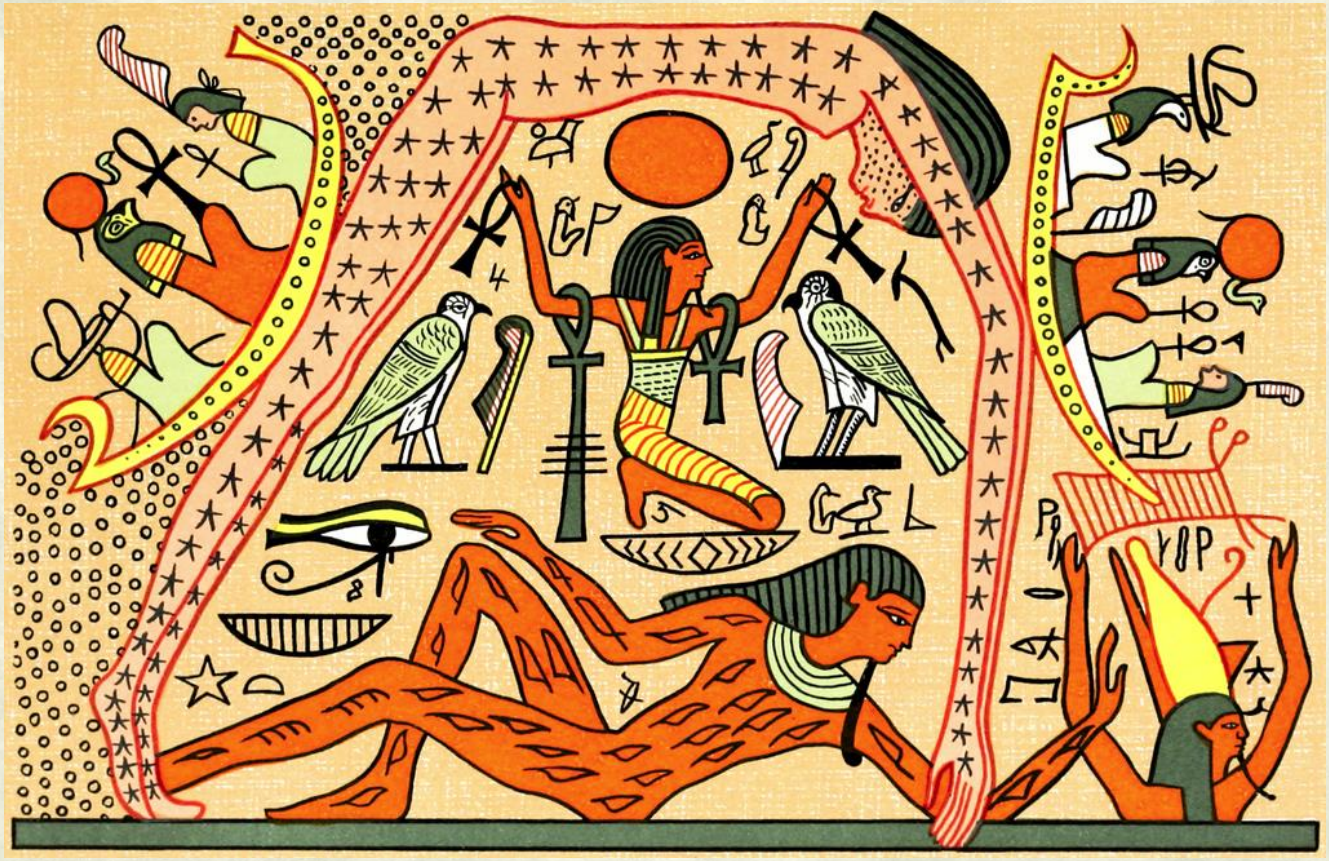
(left) Mul Apin tablet(1100 BCE): Describing the appearance of different constellations and stars:
(right) Babylonian clay tablets listing observation of Venus c. 7th century BCE. www.mesopotamia.co.uk/astronomer/explore/mulapin1.html



Astronomical ceiling. 1470BCE Egyptian tomb painting with constellations, planets, lunar cycle and stars depicted.

- Astronomy and mathematics were in an advance state in the Babylonian civilization:
  - They kept records of position of the stars and planets and eclipses Many constellations visible from the northern hemisphere, and the zodiac are of Babylonian/Sumerian origin.
  - They used a number system with base 60 (sexadesimal), and a year of 360 days.
    - Circle 360 degrees, 60 minutes and 60 seconds descend from the Babylonian sexadesimal number system.
- Egyptian astronomy mostly carried out by priest astronomers was largely concerned with time reckoning. Its main lasting contribution was the civil calendar of 365 days, with 12 months

- Unable to comprehend their underlying causes, early cultures resort to mysticism and religion for answers.
- They identified celestial objects with gods and spirits, with various powers and purposes attributed to them.



Universe according to Ancient Egyptians (from the Greenfield Papyrus, ca. 1025 BC):

- The air god (Shu) held and kept the sky goddess (Nut) above the Earth god (Seb).
- The sun god (Ra) traveled across the sky in his boat, and at night he passed through the underworld, among the dead to reborn again in the East at dawn

Greek Astronomy

when the Pleiades rise it is time to use the sickle, but the plough when they are setting; 40 days they stay away from heaven…
But when Orion and Sirius are come into mid-heaven, and rosy-fingered Dawn sees Arcturus, then cut off all the grape-clusters, Perses, and bring them home…
But if you plough the good ground at the solstice, you will reap sitting, grasping a thin crop in your hand…

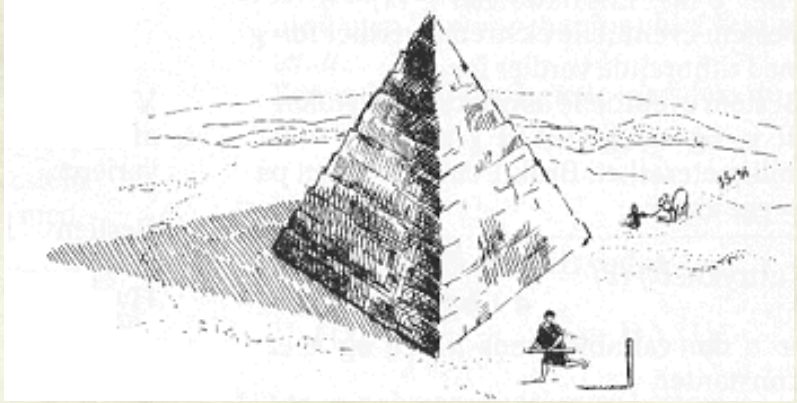
Life of the peasant, in the '*Works and Days*' by the Greek poet Hesiod (~700 BCE):
(ancienthistory.about.com/library/bl/bl_text_hesiod_worksanddays.htm

- Astronomy developed in some form or other in all ancient civilizations as an integral part of the culture, beliefs and religion, and serving their practical needs,
  - Farmers needed to know the seasons when to plant crops.
  - occurrence of celestial events like solstice equinox had to know in advance for ritualistic celebrations.
  - rulers needed astrologers to tell what lie ahead in the future for them and the regime
- Astronomy was primarily done by priestly astronomers (astrologers) in service of the rulers and the regime.
- For centuries they provided such needed celestial information for the people to carry out their daily routine.
- Most of their knowledge were rules of thumb, gained though long term observations and experience.
- The question why the things happened the way they did, seemed to had not bothered them.

Thales of Miletus (624 – 54BCE): From Myth to Reason

- Around 6th century BCE Greek scholars took a different turn.
  - starting from **Thales of Miletus,** Greek thinkers tried to use more rational, physical explanations for natural phenomena.

- Thales was the first philosopher in the Greek tradition and widely considered as the father of science.
  - He rejected the mythological explanations, belief that nature was under the control of supernatural gods and deities which were to be appeased rather than understood.
  - Instead he introduced the concept of investigation by basic physical principles to explain the world in terms of hypothesis based on observable facts.



Thales measuring the height of a pyramid

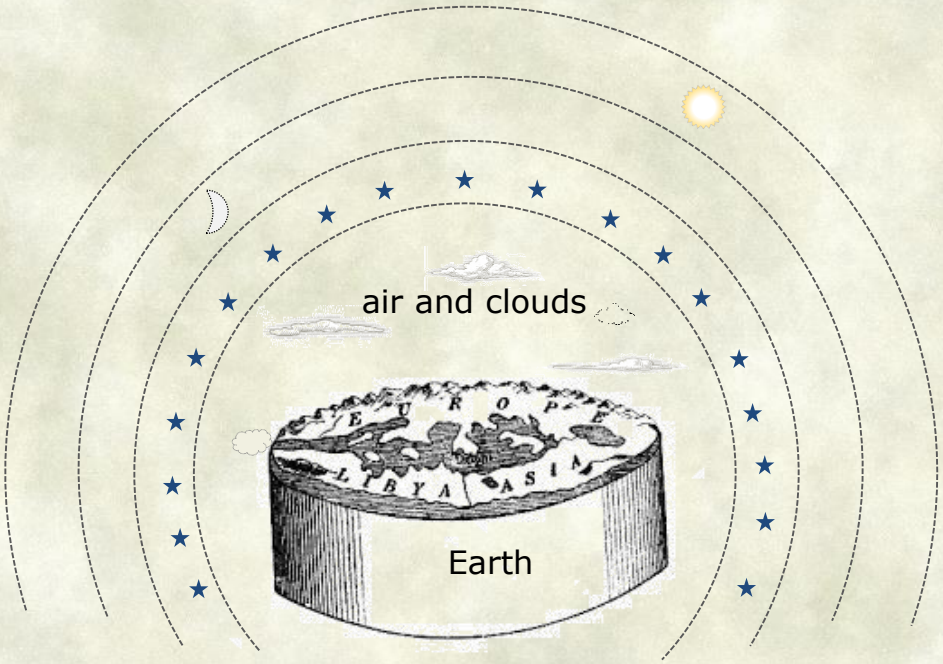
- According to Thales Earth is a flat disk floating on water. Earthquakes happen when the Earth is rocked by waves, like a boat in rough seas.
  - Although this was wrong, it was an attempt to explain the working of the world in terms of observable physical facts through reason, without invoking any deities or divine interventions
  - He is famous for many accomplishments in astronomy, geometry and engineering, but none of his writings has survived.
  - He may have obtained some of his knowledge and ideas from Egypt, where he had visited and studied.
- He founded the Ionian school of philosophy in Miletus.
- Subsequent Greek philosophers followed Thales's lead searching for explanations in nature by reason and inquiry, and laid the foundation of science and the western thought.

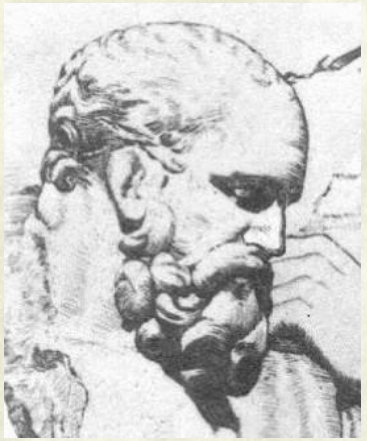
Why Greeks? extra credit topic

There may be many reasons:

- **Location:** City-state of Ionia where the earliest Greek rational thought developed was a trading post.
  - Ionians sailors and merchants traveled throughout the Eastern Mediterranean Sea, exposing them to the influence of then advanced civilizations (Egyptian, Babylonian and Persians of the time
  - That provided ample opportunity for them to be open to a diversity of ideas and knowledge from different cultures.
- **Freedom of thought and democracy:** In previous civilizations astronomy (and other sciences) was a part of the religion, managed by the priestly astronomers serving a King.
  - Whatever astronomy or mathematics developed were to serve practical needs, mostly rules of thumb, not a systematic study of nature. There was no room for inquiry for by average people.
- In Greek city states people had more freedom for their own thought and inquiry (leaders were elected, trials were done by jury) free of the authority of priesthood and religious doctrines.
  - Astronomy and other sciences were studied by ordinary people driven by the curiosity to understand the working of the nature.

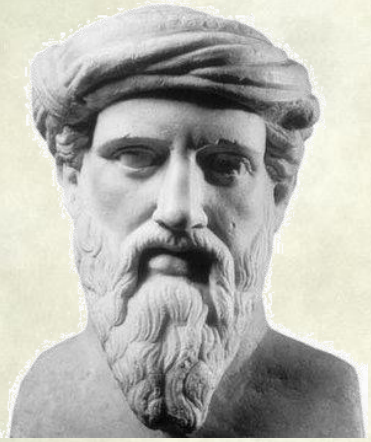
Anaximander (610 - 546 BCE): *Earth floats in space!*





- Student and successor of Thales at the Ionian school.
- According to him the Earth had a cylindrical shape. Flat top formed the inhabited world, surrounded by a circular oceanic mass.
- Earth floated at the center of the universe
  - Not supported by anything, as required by other views prevailing that time. **a revolutionary idea!**
  - That allowed celestial objects pass under the Earth (stars during the day, sun at night).

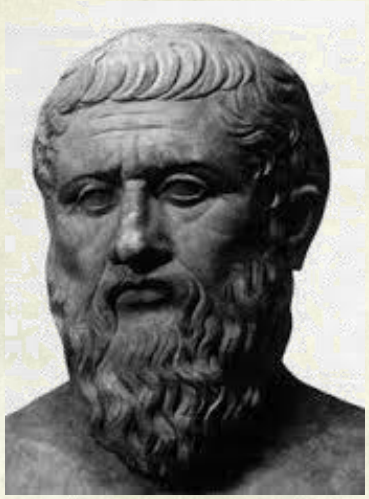
- Pythagoras of Samos: *Earth is Spherical.*
  (570BCE – 495 BCE)



Ionian Greek philosopher, mathematician, and founder of the movement 'Pythagoreanism'.

- He was the first to show that the morning star and the evening star were the same object.
- He believed that the Earth and other celestial objects were spherical.
  - mostly on aesthetic grounds rather than on any physical evidence, because sphere is the geometrically perfect shape.
- Pythagoras (and the Pythagoreans) ideas were a mix of reason, mathematics and mysticism.
  - They believed in a well-ordered, harmonious universe and placed great importance on the power and aesthetics of geometry and mathematics.
  - They view mathematical relationships as the unchanging principles of the nature and universe could be understood in terms of whole numbers.
- Pythagoras' successor Philolaus (470-385 BCE) was the first to suggest that the Earth rotates (which did not gain much acceptance by later Greek philosophers)

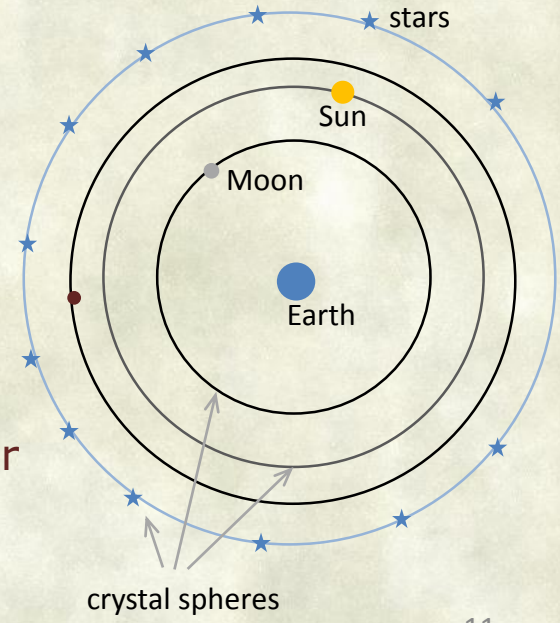
Plato (429–347 BCE): *perfection in the Heavens!*



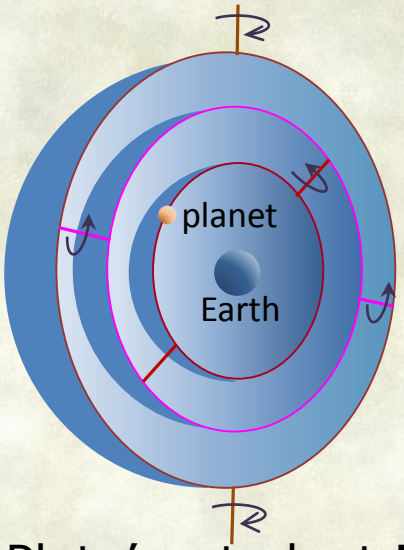
- Plato was the founder the school 'Academy' in Athens.
- He took Pythagoras' ideas of geometric beauty steps further.
- According to him Universe (sky) was constructed with geometric simplicity and perfection.
  - The Earth and all celestial objects had to be spherical
  - They moved in circular orbits at uniform speeds.
- **Influence of those ideas lasted over two millennia**.

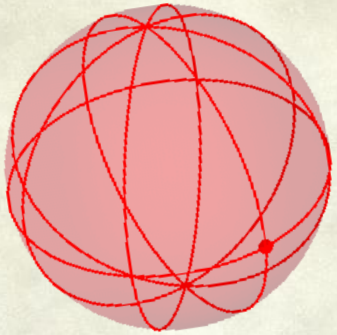
According to Plato:

- Spherical Earth was at the center (Geocentric).
- Celestial objects were located on nested, concentric crystal spheres that were rotating around the Earth at different rates.
  - Obviously this did not explain the complicated retrograde motions of planets. Plato left it as an exercise for his students to solve.
    - Plato's question: What uniform and ordered circular motions would result in the apparently irregular motions of planets?

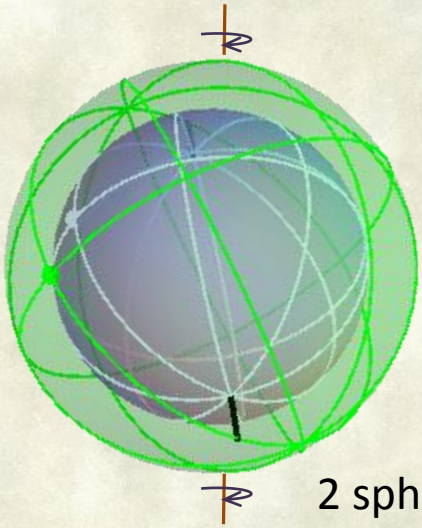


Eudoxus of Cnidus: *nested spheres* (408–355 BCE) (optional)





1 sphere

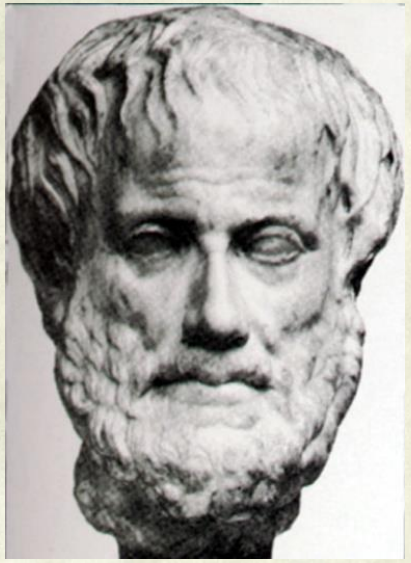


2 spheres

more details at: facultystaff.richmond.edu/~ebunn/homocentric

- Plato's student **Euxodos** came up with a solution to Plato's question.
- According to Eudoxus, each planet was located on a crystal sphere, but that sphere was not directly spinning about the Earth.
  - They are located on a system of (up to 4)nested spheres rotating about different axes.
  - Their combined motions could mimic the apparent complicated motions of planets.
  - Eudoxus model with a total of 27 spheres predicted the observable positions of the planets to the observational accuracy of the time.
    - (stars 1 sphere, each planets with 4 spheres , Sun and Moon each 3 spheres)

Aristotle (384-322 B.C.)

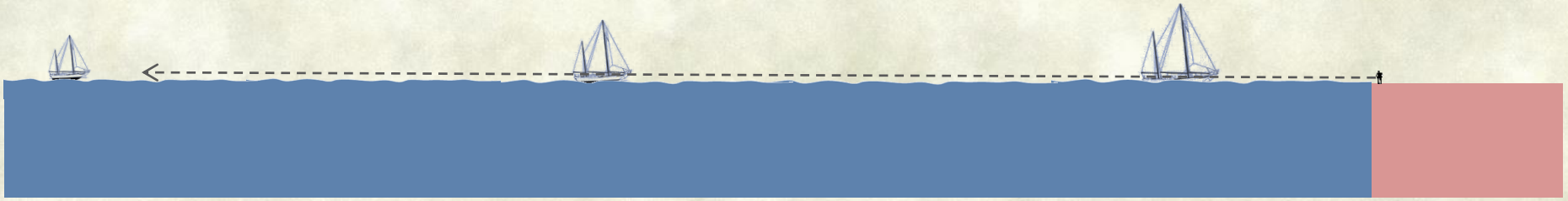


- Plato's student and the tutor of Alexander the Great.
- One of the greatest philosophers and thinkers of all time.
- He founded the school "The Lyceum" in Athens.

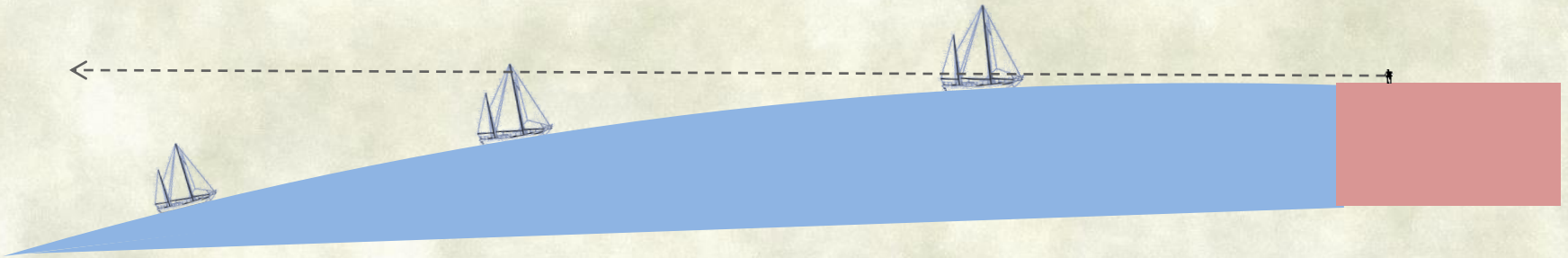
- His studies and written work covers all major areas of thought: politics, logic, ethics, biology, geology, physics, astronomy, music and poetry…
- He developed a comprehensive worldview to explain the physical world (matter, change, motion, time, and space) in a way consistent with logic and empirical experience which explained the working of his model of the universe.
- But his ideas about the physical world were mostly based on philosophical reasoning than experimental facts.
- No other Greek philosophers has had such a deep and long-standing impact on the development of physical science than Aristotle (although most of his ideas were wrong).
- His ideas dominated the western world until 16th century.

Aristotle gave observational evidence and physical arguments for the spherical shape of Earth:

- As ships sail off from a harbor, the hull disappears before the mast and sails, this could only happen if the Earth surface is curved.

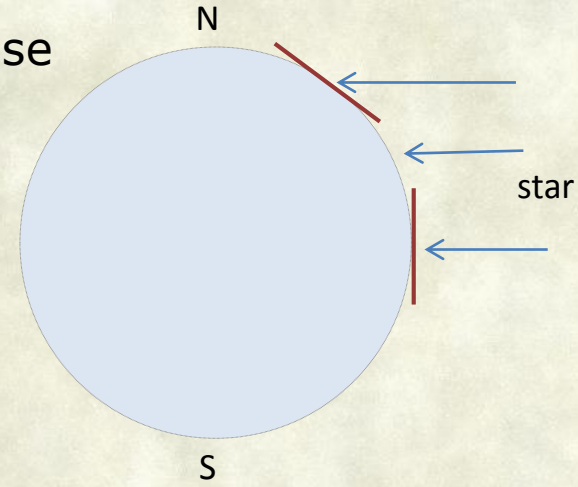


If the Earth is flat, ships would appear smaller as they sail farther away but always above water.

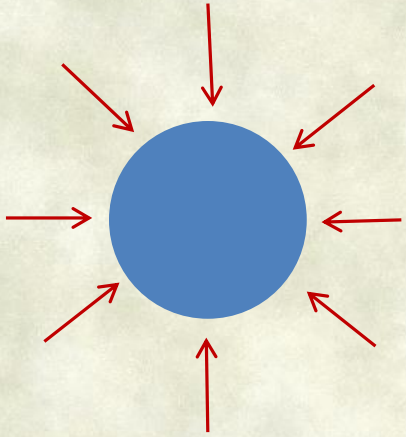


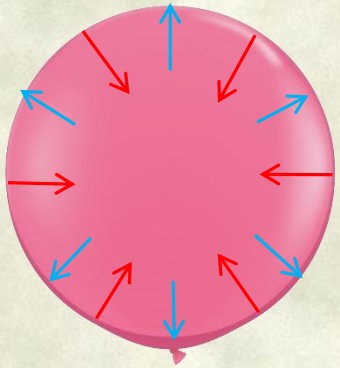
But on the spherical Earth they go below the line of sight due to curvature

- Travelers going south see southern constellations rise higher above the horizon, going north see northern stars higher up in the sky.



- During a lunar eclipse, Earth's shadow on the Moon is always circular. (A flat disc would cast an oval shadow.)

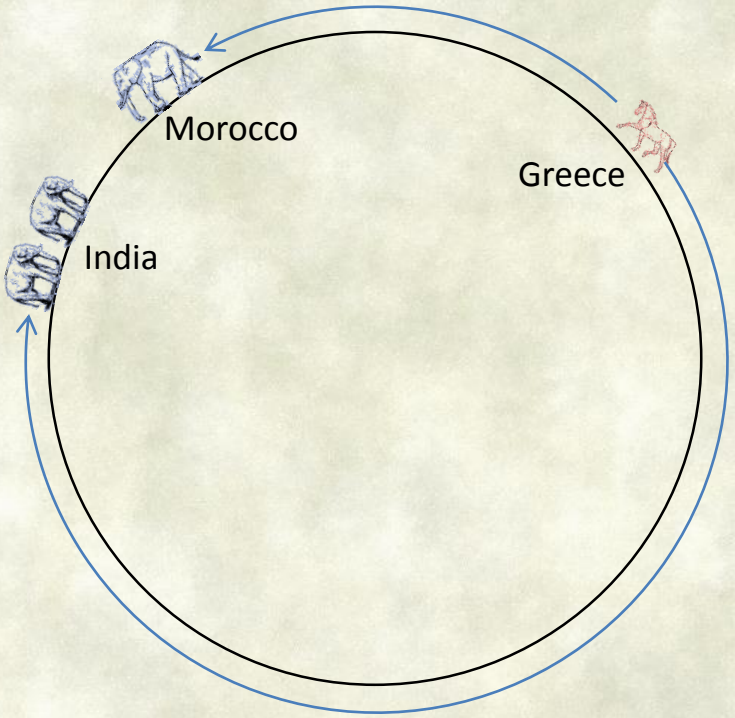


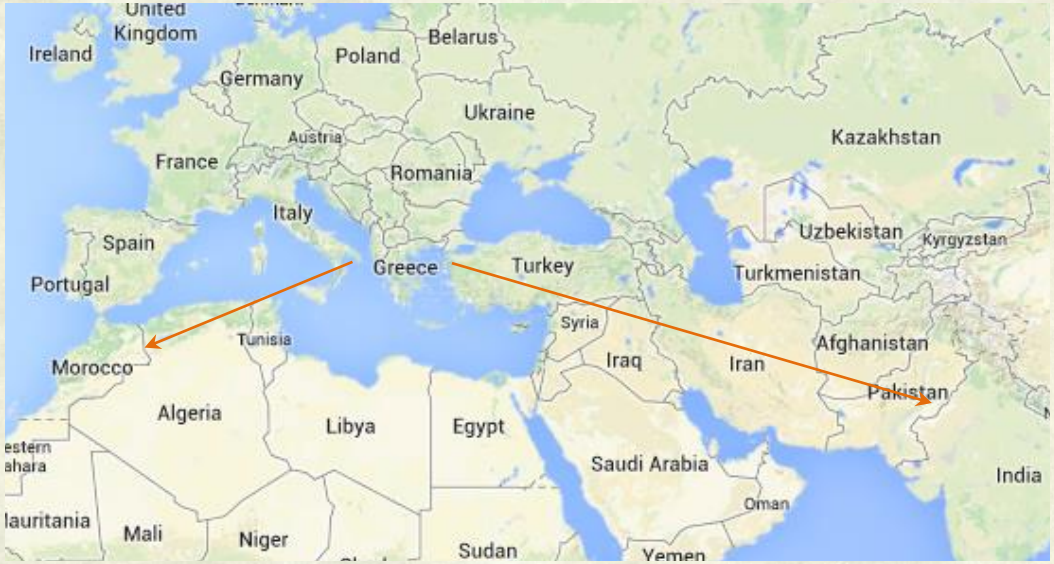


Just like a balloon is round because the rubber membrane pulls inward in all directions against air pressure

- Aristotle argued that everything fell to the Earth because the Earth was at the center of the universe.
- So by compression and convergence they form a sphere.

(as we know now things fall due to gravitation, not because earth is at the center of universe. Otherwise it is a valid argument)

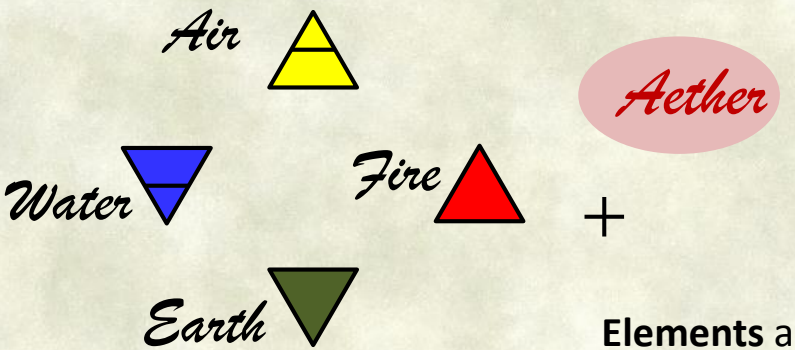




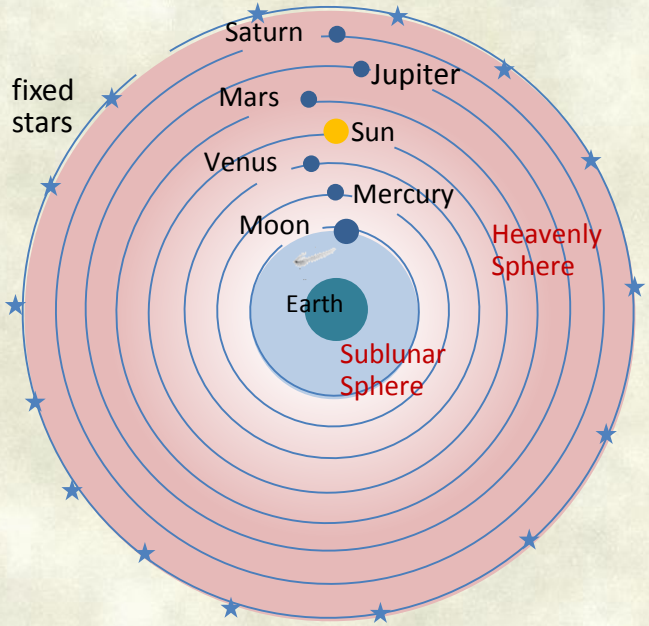
- When Alexander the Great's army marched to India they had seen elephants in India.
- Greeks had also seen elephants in Morocco (as far as the Greeks could go west on land).
- But there were no elephants in Greece. So Aristotle argued, Alexander must have come close to circling the Earth when he reached India.

(This is incorrect. Here Aristotle hugely underestimated the size of the Earth. Besides those were two different species of elephants)

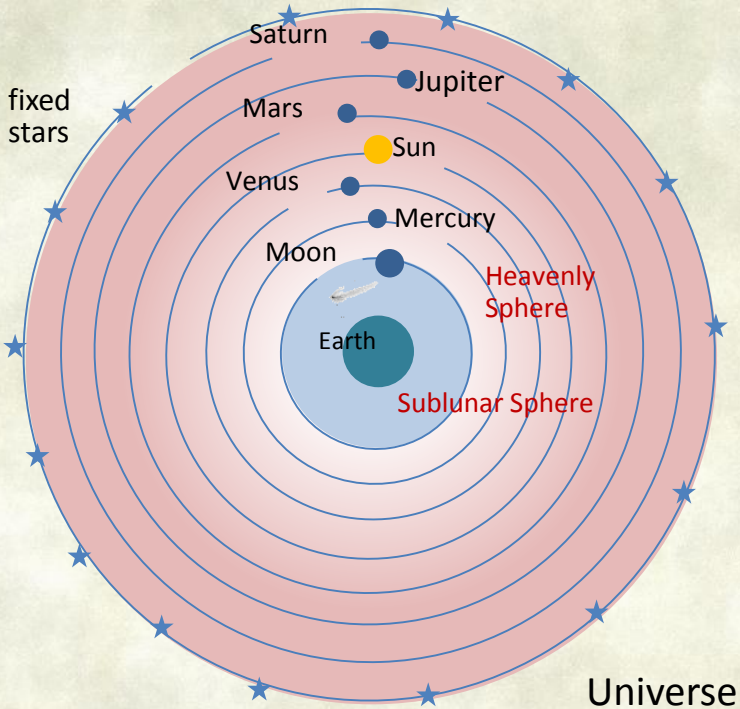
Aristotle's Universe



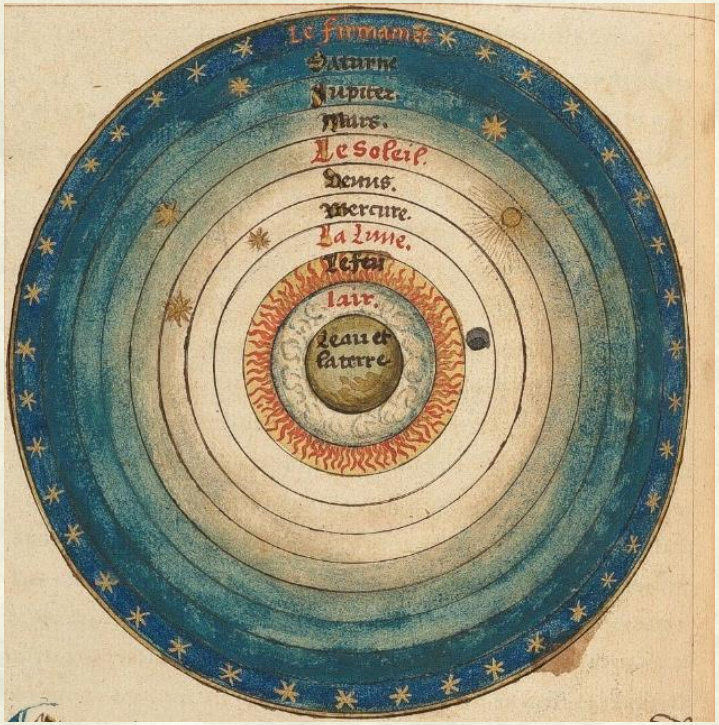
Elements according to Aristotle



- Aristotle's view of the universe was a further evolution of Eudoxus' and Plato's ideas, integrated with his philosophical system and his 'physics'.
  - Aristotle accepted the prevailing Greek view of four basic elements *Earth, Water, Air,* and *Fire*
  - However, in addition to them, Aristotle introduced a fifth element *Aether* which he believed to be the main constituent of celestial bodies.
  - Earthly substances made of 4 elements were subjected to change and decay.
  - Heavenly regions are unchanging and permanent, so they had be made of a different substance '*Aeither*' he argued.



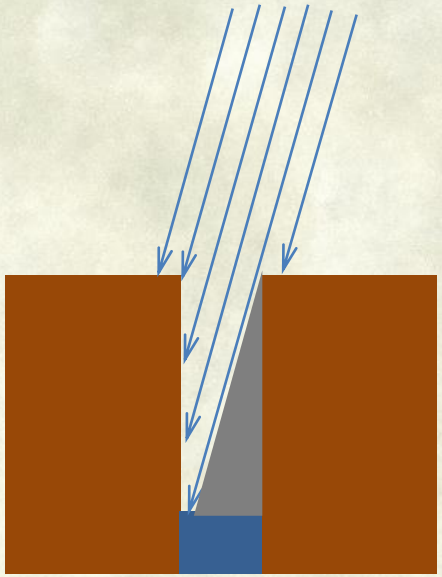
Universe according to Aristotle



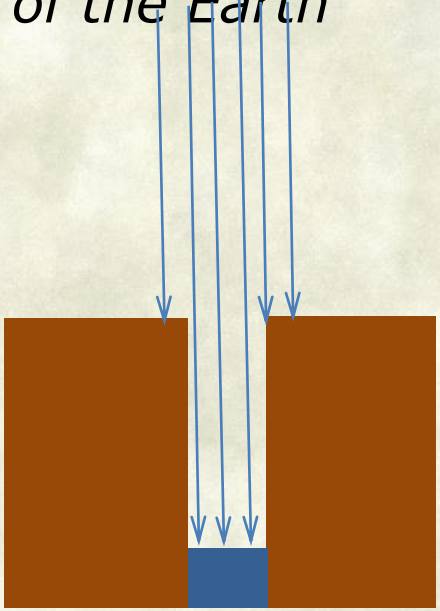
- Earth was at rest at the center. Celestial bodies were located on concentric crystal spheres and rotated around the Earth (center of the universe).
  - Made of *aeither* they were perfect in form, unchanging and permanent in nature. (**Heavens were perfect unchanging and eternal**)
  - Earth and everything under the Moon (sublunary), made of earthly elements were subjected to change, decay and death.
- Phenomena such as rainbows, lightning, meteors, comets which were of changing nature were thought to be atmospheric phenomena occurred closer to the Earth.
- This model, with some refinements, remained as the basic description of the nature and structure of the universe for nearly 2,000 years.

Eratosthenes of Cyrene : *measuring the size of the Earth*

(276-194 BCE)

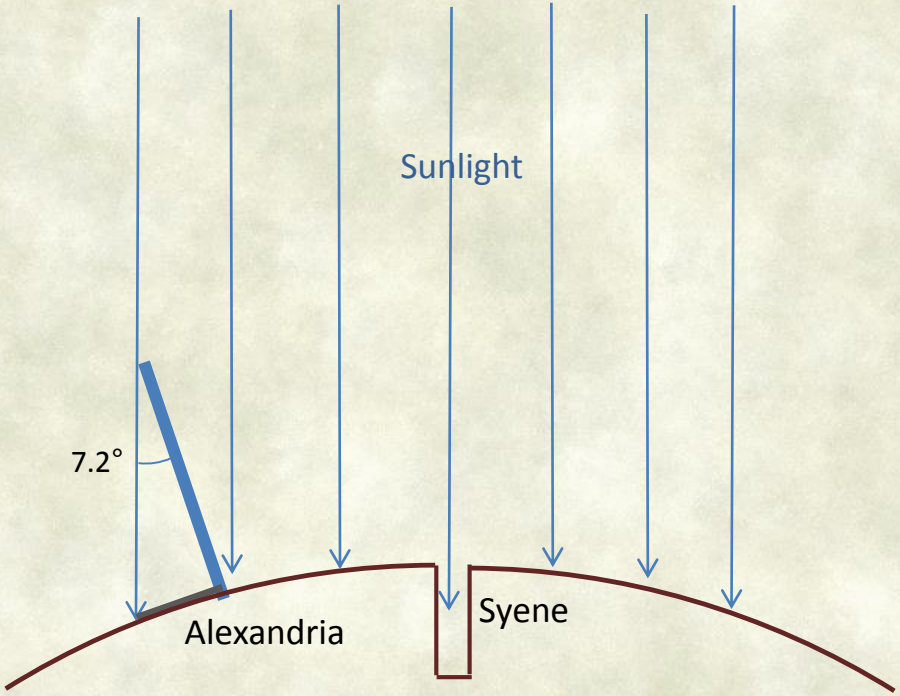


In Syene, the Sun usually cast a shadow along one side of the well



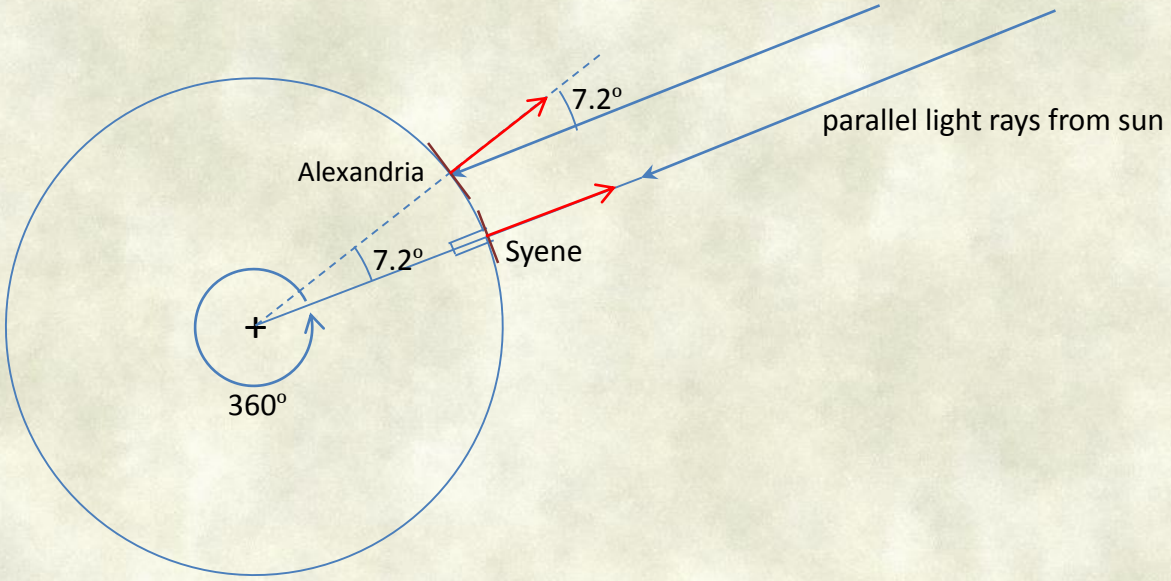
But on one day of the year, there was no shadow at noon, sun was shining straight down the well

- Eratosthenes, the head librarian at the library of Alexandria in Egypt, was a mathematician, poet, philosopher, astronomer, and a geographer.
- He is best known as the first person to measure the size of the Earth.
  - From travelers, Eratosthenes had learned about a strange thing happening on the day of summer solstice, in the southern city of Syane (present day Aswan).
  - At noon on the day of summer solstice, the sun illuminated the entire bottom of a deep well, without casting any shadow. One could see the Sun's reflection in the well. (ie. the Sun was directly overhead).



On the day at noon in Alexandria, Sun cast a shadow of a vertical stick

- Something like that never happened in Alexandria!
- On the day of Sumer solstice he measured the angle of a shadow cast by a stick at noon in Alexandria.
  - He found that sunlight fell at an angle of about 7.2° from the vertical.
- Assuming that rays of sunlight were parallel (Sun was far away), it showed that the vertical direction in Alexandria was different from the vertical direction in Syene.
- So he reasoned:
  - Vertical direction in Alexandria was different from Syene due to the spherical shape of the Earth.



- Thus according to geometry, locations of Alexandria and Syene should make the same angle, 7.2º at the center of earth.
- The whole circumference of the earth makes 360º angle at the center of Earth.

  Since 7.2º/360º = 1/50, Eratosthene reasoned that the distance between Alexandria and Syene had to be 1/50 the circumference of the Earth.
- Thus using the distance from Alexandria and Syene (790km) Eratosthenes was able to estimate the circumference of the Earth as 50x790 = 39500km

  so the diameter of Earth = $39{,}500/\pi = 12580$ km
- This is very close to the modern value of 12756 km. A remarkable achievement!

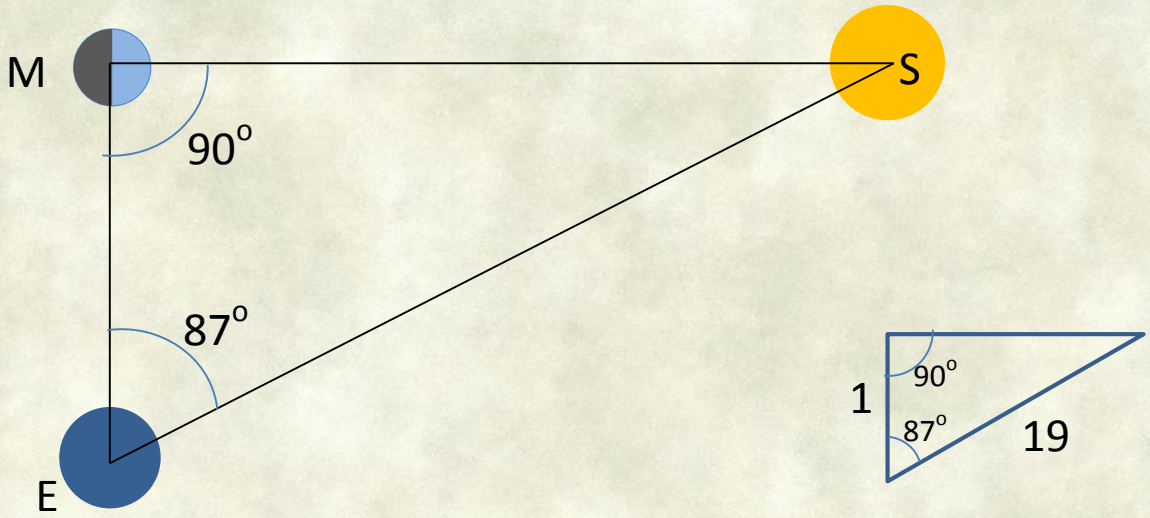
Eratosthenes www.youtube.com/watch?v=8On7yCU1EjQ

Aristarchus of Samos : *measuring the universe*

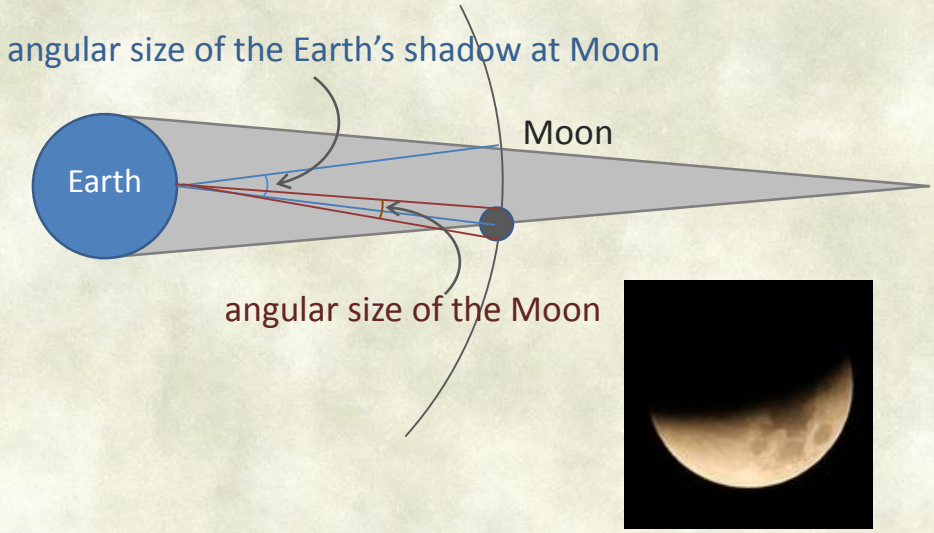
(310-230 BCE)

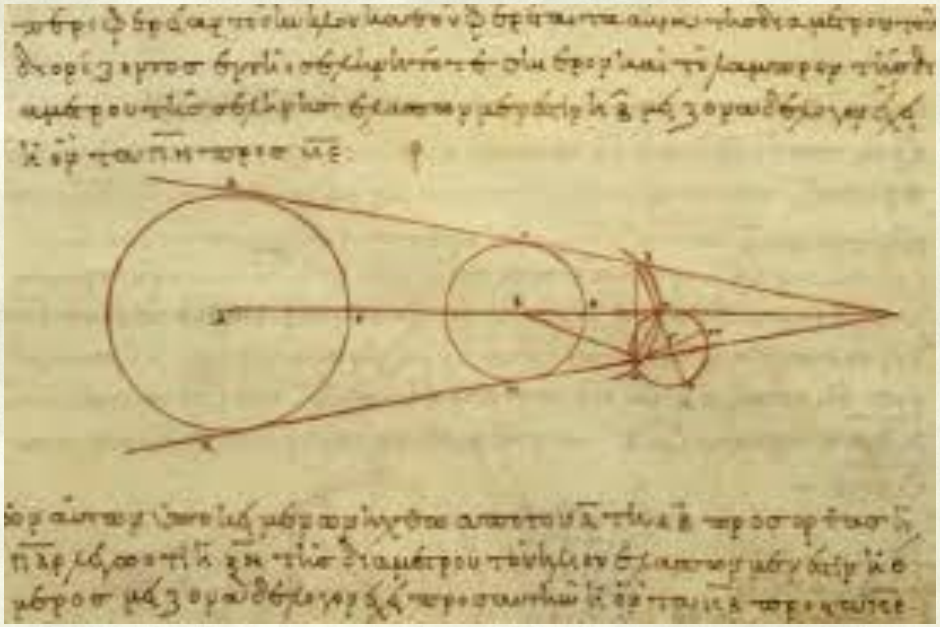
- Aristarchus measured the distance to the Sun and the Moon even before Eratosthenes measured the size of the Earth.
- He put forward the idea that the Sun was at the center of universe and Earth moved around it while rotating on its axis.

Relative distances to the Sun and the Moon



- When Moon is exactly in the first quarter, the angle E-M-S must be exactly 90°.
  - Measuring the Moon-Earth-Sun angle (M-E-S) when the Moon is a quarter phase will give the ratio of the Earth-Moon distance to the Earth-Sun distance.
- Aristarchus measured this angle to be 87° ,
- Right angled triangle with one angle 87° had a ratio of base to diagonal =1/19
- ie. $\frac{EM}{ES} = \frac{1}{19}$
- Therefore distance to the Sun was 19 times the distance to Moon according to Ariscartus.
- This is smaller than the modern value (~400), but still tells the Sun is much far away than the moon.



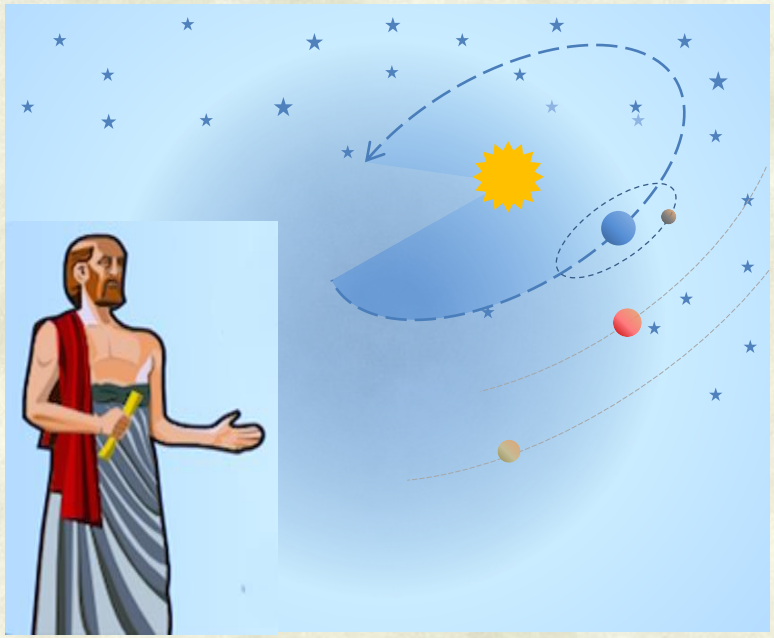


Aristarchus' calculations on the relative sizes of the Sun, Earth and Moon, from a 10th-century Greek copy

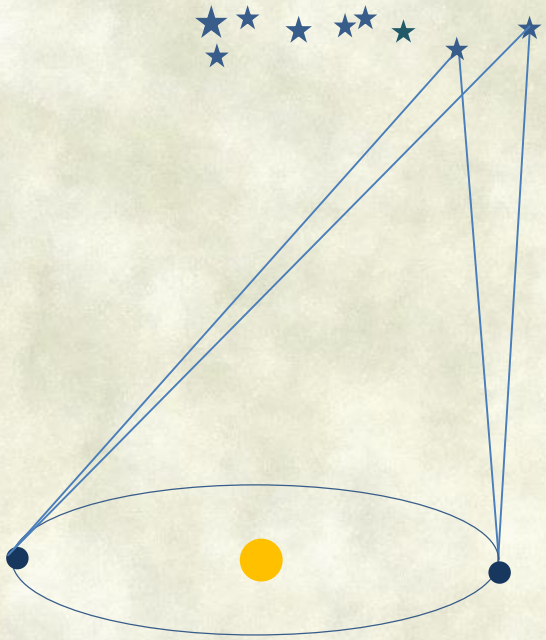
en.wikipedia.org/wiki/Aristarchus_of_Samos

- Then Aristarchus used size of the Earth's shadow on the Moon during a lunar eclipse to estimate relative sizes of the Sun and the Moon and their distances.
- He estimated:
  - the size moon is 1/3 the size of the Earth. (modern value 1/4)
  - Sun is 7 times the size of Earth. (110)
  - distance from Earth to the moon 20 times the diameter of the Earth (30)
  - distance from Earth to the Sun 380 times the diameter of the Earth (1200)

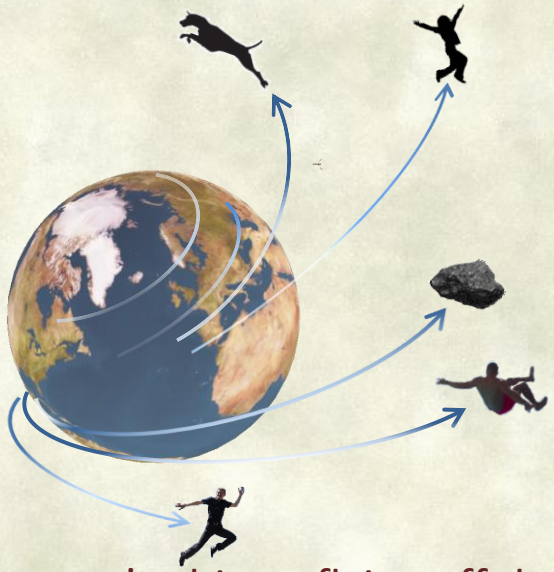
Aristarchus' Sun centered universe



- Although crude and inaccurate, it is remarkable that more than 2000 years ago he was measuring across the solar system using simple observations and mathematical reasoning.
  - His results were only limited by the accuracy of the measurements he could do.
- His measurements had shown that the Sun was 7 times larger than the Earth:
  - So naturally he came to the conclusion that the Earth moved around the Sun, not the other way around.

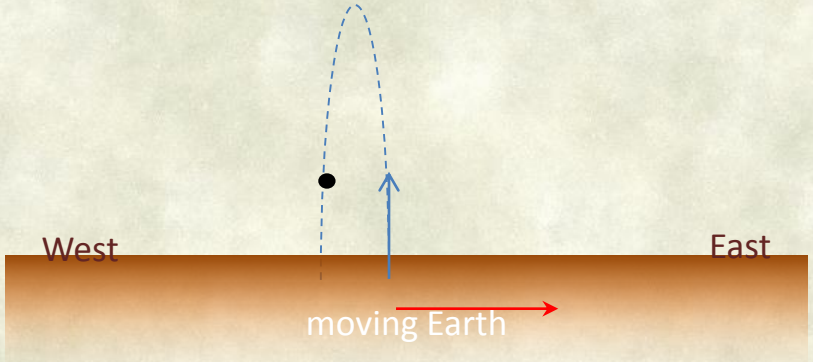


parallax



Why aren't objects flying off the spinning Earth?

- Aristarchus' Sun centered universe (heliocentric) did not become popular in his time.
- Most scholars rejected it, some on religious grounds, others on observable facts:
  - If the earth going around the Sun why don't stars show parallax movement over the year (shape or size of constellations don't change over the year)
  - Why does the movement/rotation of the Earth not generate a very strong wind?
  - If the Earth is spinning, why don't objects fly off the Earth? (like water from a spinning wheel or umbrella)



According to Aristotle, if the Earth was moving, an object hurled vertically upright should fall on the ground at a point to east, because Earth was moving underneath while it was in flight.

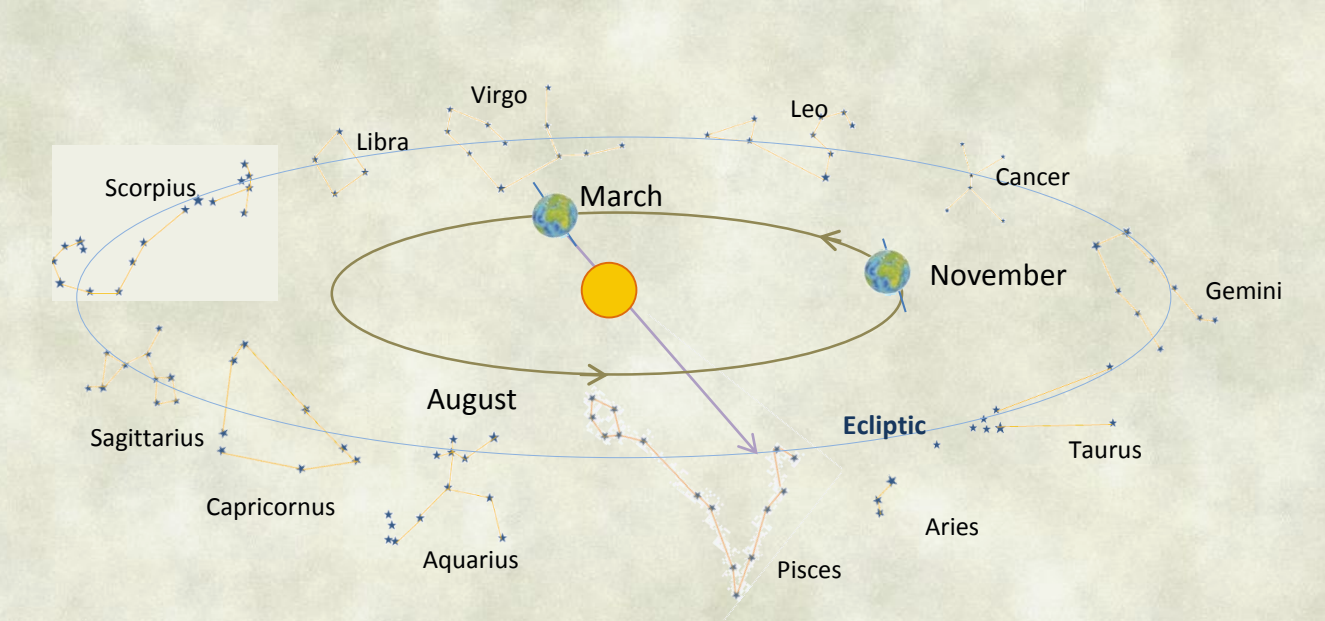
- If the Earth is moving why do projectiles thrown upward return to the same place from where they were hurled.
- Those objections were mainly due to lack of understanding of physical principals (nature of motion, gravitation…), which were understood only in the 17th century after the work of Galileo and Newton.
- Universe is much larger and stars are located farther away than they were willing to accept
  - star parallaxes are tiny. Astronomers were able to measure them only in late 19th century.
- Besides, geocentric models with elaborate mechanisms (epicycles) explained the movement of planets adequately!

Hipparchus of Nicaea: (190–120 BCE)

Astronomer, mathematician and geographer, last in the line of great Greek astronomers.

- He made precise measurements of the orbits of Sun and Moon
- calculated the length of the tropical year (time from one equinox to same equinox next year) to within 6.5 minutes.
- He is best known for discovering the Precession of Equinoxes and the star brightness magnitude system he introduced.

Precession of the Equinox



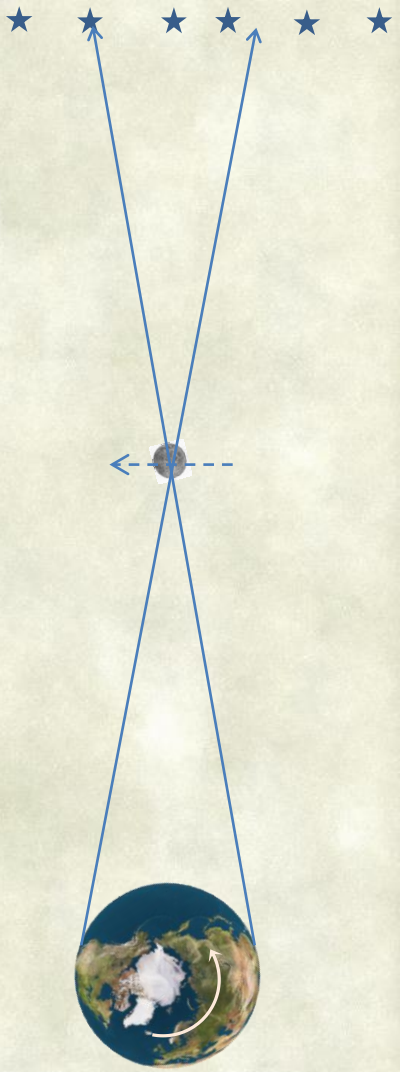
- Comparing positions of stars recorded by his predecessors, Hipparchus noticed that the position of Equinoxes (location of the Sun in the sky at the Equinox) were changing.
  - Hipparchus concluded that the equinoxes were moving ("precessng") at a rate about 1° in a century.
  - Since he believed in the geocentric system he could not have understood what causing it.

- Later on he started recoding precise locations of stars and completed a catalog in 129 BCE, containing 850 stars.
  - He seemed to have motivated to do so by seeing a new bright star in the sky (probably a nova).
  - According to then prevailing Aristotelian ideas, sky was unchanging, so such new stars were not expected.
  - In preparing his catalog, he also introduced the magnitude system of star brightness, which is still in use.

- Hipparchus measured the Moon's parallax, and estimated the distance to the moon to be between 59-67 Earth radii.

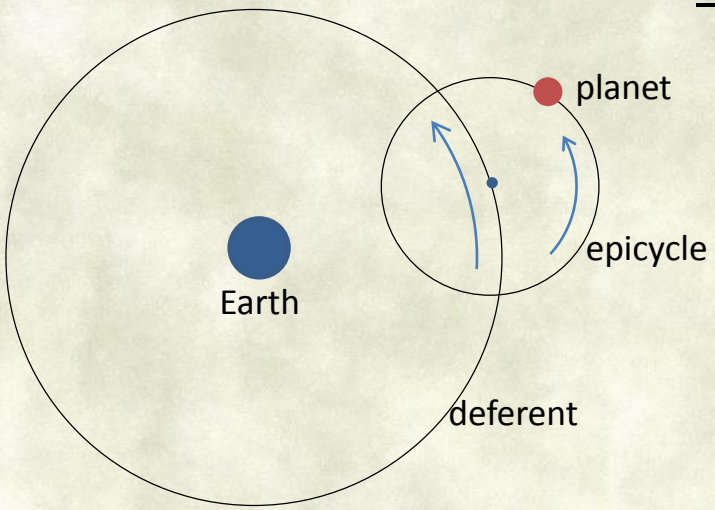
  (actual value 30)

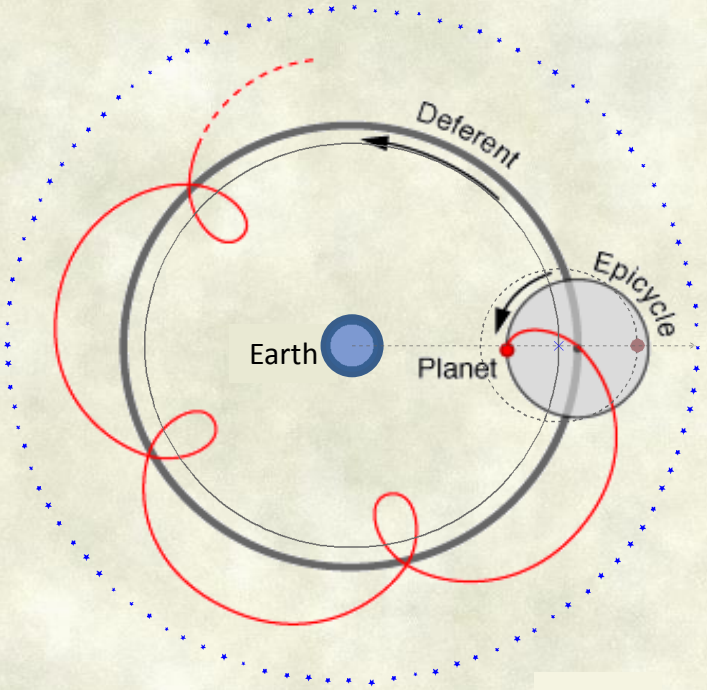
- His attempts to measure the parallax of the Sun did not succeed, so he determined that the Sun was too far away.



parallax of the Moon, between moonrise and moonset

Epicycles





www.phy.olemiss.edu/~perera/animations/epicycle.gif

Hipparchus rejected Aristarchus heliocentric model. He promoted a geo-centric model based on epicyclical motion of planets (first proposed by Apollonius)

- In the epicycle model, planets are located on a smaller crystal sphere, (called epicycle) and rotates at a uniform rate.
- Center of that sphere is located on another sphere (called deferent) which rotates around the Earth.
- Combined motion of the different and the epicycle produces a motion similar to retrograde motion of planets.
- It also explained changes in the apparent distances (brightness) of planets.

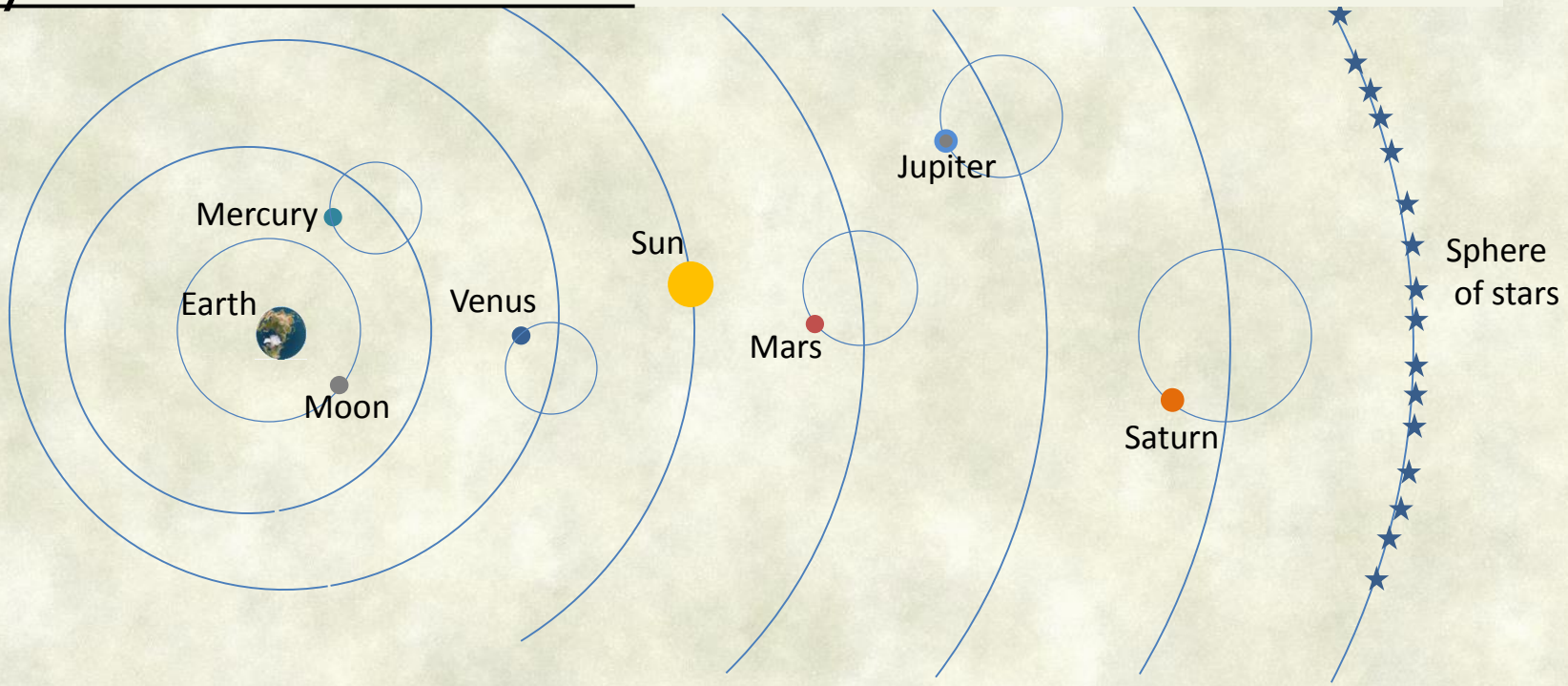
Claudius Ptolemy (90–168CE)

"I know that I am mortal by nature, and ephemeral; but when I trace at my pleasure the windings to and fro of the heavenly bodies I no longer touch the earth with my feet: I stand in the presence of Zeus himself and take my fill of ambrosia"

— Ptolemy, in Almagest

- Greek-Roman mathematician, astronomer, geographer, astrologer, and poet.
- One of the great synthesizers of history. His writings represent the culminating achievement of Greco-Roman astronomy.
- Ptolemy compiled his astronomical work into thirteen books.
  - They were translated into Arabic during the Middle Ages and named '*al-majisṭi*' (*The Great Treatise*) which became *Almagest* in English.
- Most of the writing by earlier Greek scholars were lost during the middle ages in Europe, but Ptolemy's work survived in Arabic. We know some of the earlier Greek achievements only through his work.

Ptolemy's Geocentric model



- Ptolemy further refined the epicycle model, and suggested a geocentric theory which was remarkably successful in accounting for the motion of the planets, and was in use for next 1400 years:
  - It proved adequate for everyday purposes of the time (predictions of planetary positions <2º)
- It was only when Arabian astronomers had accumulated more accurate observations of planets in the middle ages that the validity of the Ptolemaic model began to be questioned.
- Subsequent astronomers tried to modify the Ptolemaic model by adding more epicycles (epicycles on epicycles) to explain the latest observations.

Key figures and achievements in Greek astronomy

Thales (c624-546BC)

Introduced idea of rational (physical) reasoning to explain the nature instead of supernatural forces

Anaximander (c 610-546BC)

Suggested that the earth floats in space, the idea of the celestial sphere.

Pythagoras (560-480BC)

Suggested that the Earth was spherical

Aristarchus (310-230BC)

Measured sizes and distances to moon and Sun
First one to suggest that the Earth goes around the Sun.

Eratosthenes (276-196BC)

Measured the size of the Earth

Apollonius (240-190BC)

Introduced epicycles to explain retrograde motion

Ptolemy (100-170AD)

Refined the geocentric model of the universe that lasted 1400 years.
Wrote *Almagest*.

600BCE 500 400 300 200 100 0 100 200CE

Plato (428-348BC)

Suggested that the heavens were perfect so heavenly bodies must be spherical in shape and move in perfect circles.

Eudoxus (400-348BC)

Introduced nested spheres to explain retrograde motion of planets

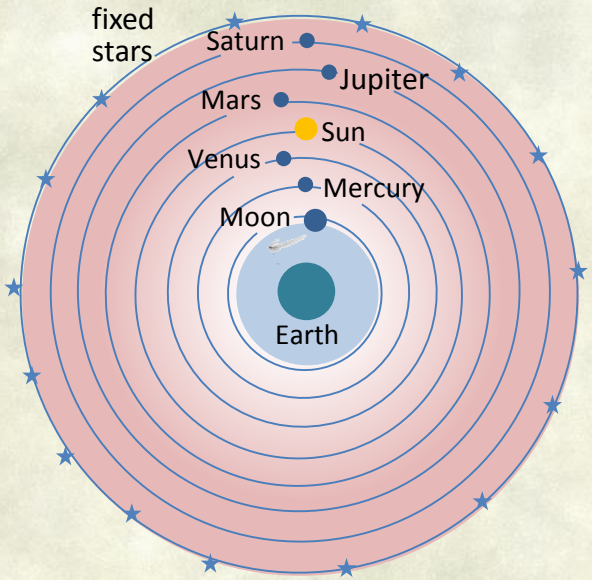
Aristotle (384-322BC)

Gave observational evidence for spherical earth.
Refined the geocentric universe and justified it with his view of the nature of matter and motion

Hipparchus(190-120BC)

Discovered precession
Introduced the magnitude system for star brightness
Measured the parallax of Moon
Improved epicycle model

Summary of Greek view of the Universe



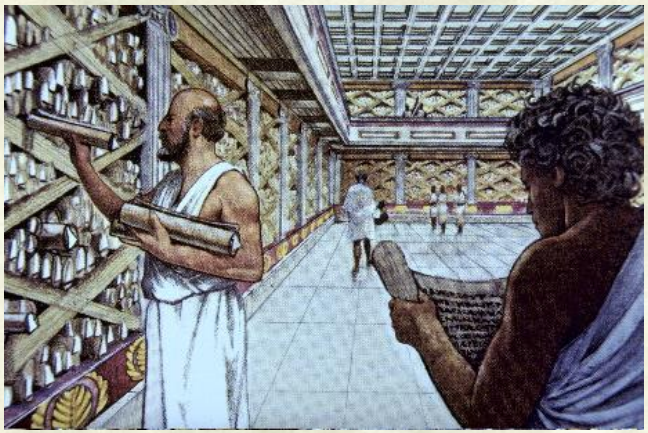
- The Earth, spherical in shape was at the center of universe, fixed and unmoving.
- Entire Universe (Sun, Moon, 5 planets and the sphere of stars) moved around the Earth in perfect circles at constant speed.
- Retrograde motion of the planets was described by epicycles.
- Ideas about the universe (heavens) were thoroughly integrated with Aristotelian physics (his vision of the nature and motion) and philosophy .
  - Earth and everything under the Moon (sublunary), made of four earthly elements (earth, water, air, fire) were subjected to change, decay and death
  - Heavens (Moon and beyond) were made of a*ether,* were perfect in form, unchanging, permanent and eternal moving in circles.
  - Various phenomena such as rainbows, lightning, meteors and comets which were of changing nature were atmospheric phenomena occurred closer to the Earth.

en.wikipedia.org/wiki/The_School_of_Athens

The School of Athens, a fresco by the Italian artist Raphael in 1511CE, represents all the greatest Greek scholars gathered together discussing ideas. The central figures are Plato (in red, hand pointed up - towards the heaven) and Aristotle (in blue, hand level to the Earth).

End of Greek Astronomy/Science

- The highly innovative period of Greek science which lasted from about 5th century BC to about 3rd century BC, and began to decline with the fall of the Greek civilization. (note: Ptolemy came 3 centuries after Hipparchus.)



Library of Alexandria (artist recreations)

- By this time most active intellectual and cultural center was Alexandria, the Egyptian city foundered by Alexander the Great.
  - Its library clamed to had over 400,000 manuscripts.
- After about 1st century BCE, the Greek Science started to lose its originality.
  - Many subjects seemed to have reached their natural endings, nothing new was found to take their place. Most of the effort was on commenting on and preserving the earlier results.
- Romans came after the Greeks were more interested in practical matters like agriculture, technology and engineering than pure sciences and abstract thinking.
- Still under Roman rule, Greek intellectual curiosity and freedom remained essentially unchanged, though the progress was stagnating.

- That changed with decline of the Roman empire, the changing world order, recurring political and social upheavals, declining economy and the advent of Christianity and the religious doctrine in the following centuries.

•The great library of Alexandria was burned in 642 CE by conquering Muslim army of Amr ibn al`As.

•Hundreds of thousands of manuscripts with centuries of Greek knowledge were destroyed.

Burning the library of Alexandria (from en.wikipedia.org/wiki/Library_of_Alexandria)

- Some Greek knowledge and traditions survived in the East Roman (Byzantine) empire, but hardly made any progress.
- Over the next millennia progress in scientific knowledge and astronomy was mostly stagnating in Europe, if not declining.
- While Europe was going through 'Dark Ages', astronomy and science flourished in the Islamic empire and eastern cultures.
  - Medieval Islamic scholars not only assimilated and saved classical Greek knowledge, but developed them in the following centuries.

Review Questions

- Why did Pythagoras think the Earth had to be Spherical in shape.
- What are the evidence Aristotle gave to show that the Earth is spherical.
- Why did Aristotle think celestial objects had to made of different material than the ordinary substance.
- How did Eratosthenes measured the size of the Earth?
- What are the flaws in the Eratosthenes estimate of the size of the Earth?
- Can you use stars instead of the Sun to measure the size of the Earth using Eratosthenes technique? Which star would be the best?
- Why did Aristarchus think that the Sun was at the center of the cosmos, not the Earth?
- Why did astronomers of the time did not accept Aristarchus' heliocentric theory?
- Why did Ptolemy used epicycles in his model of the solar system?
- What was the most significant discovery by Hipparchus?
- What motivated Hipparchus to prepare a star catalog with brightness magnitudes? Why?
- What makes the Almagest, the book by Ptolemy so important?