

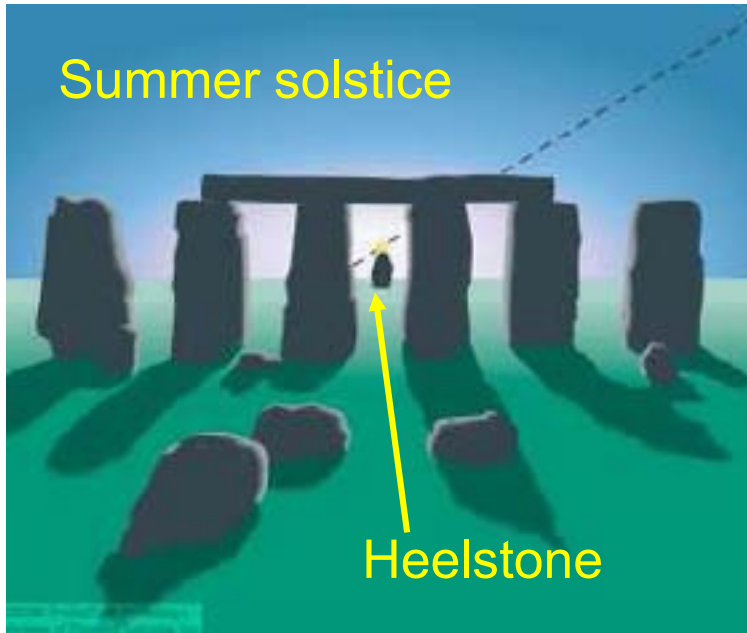


The Roots of Astronomy

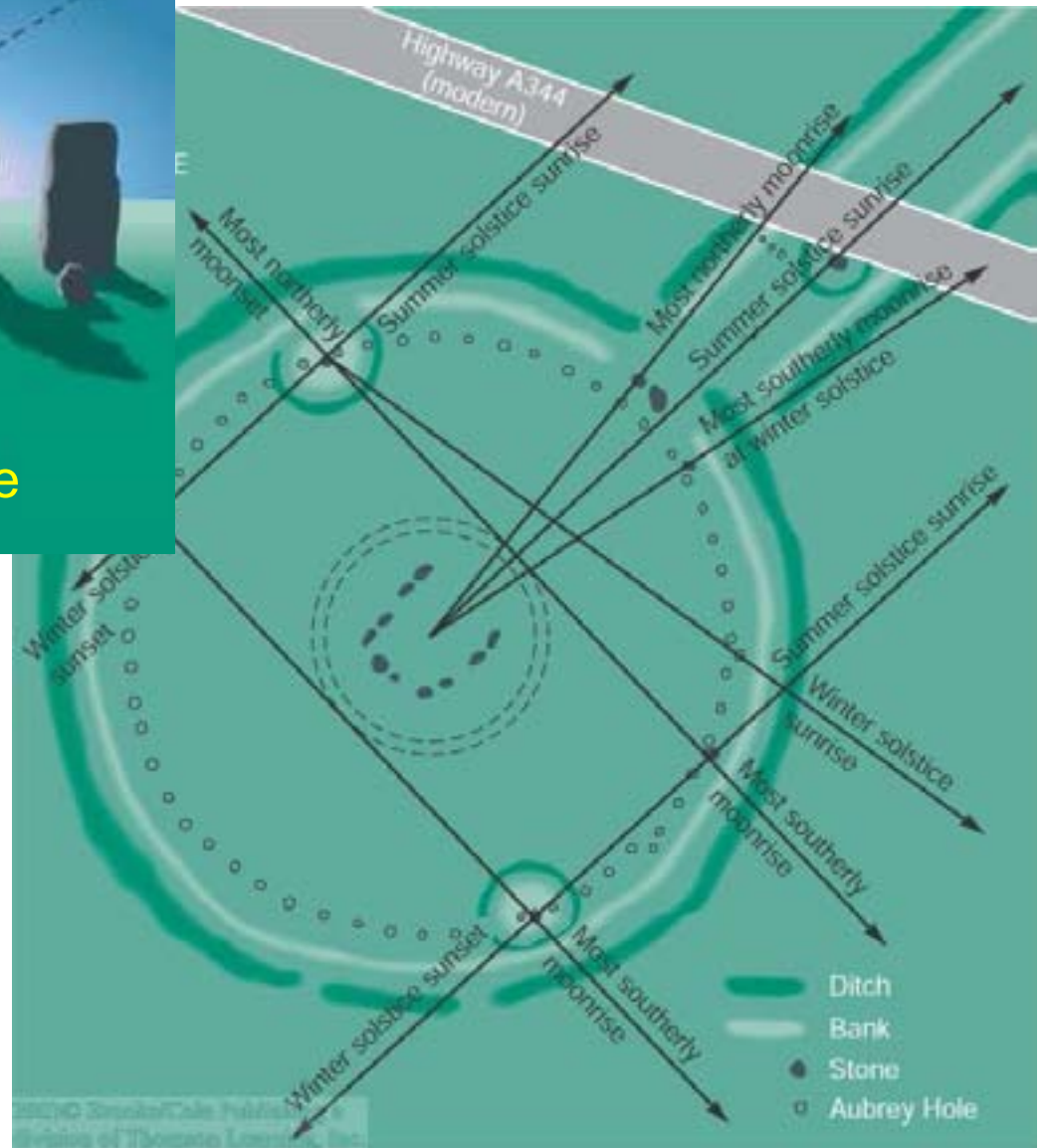
- Already in the stone and bronze ages, human cultures realized the cyclic nature of motions in the sky.
- Monuments dating back to ~ 3000 B.C. show alignments with astronomical significance.
- Those monuments were probably used as *calendars* or even to predict eclipses.

Stonehenge

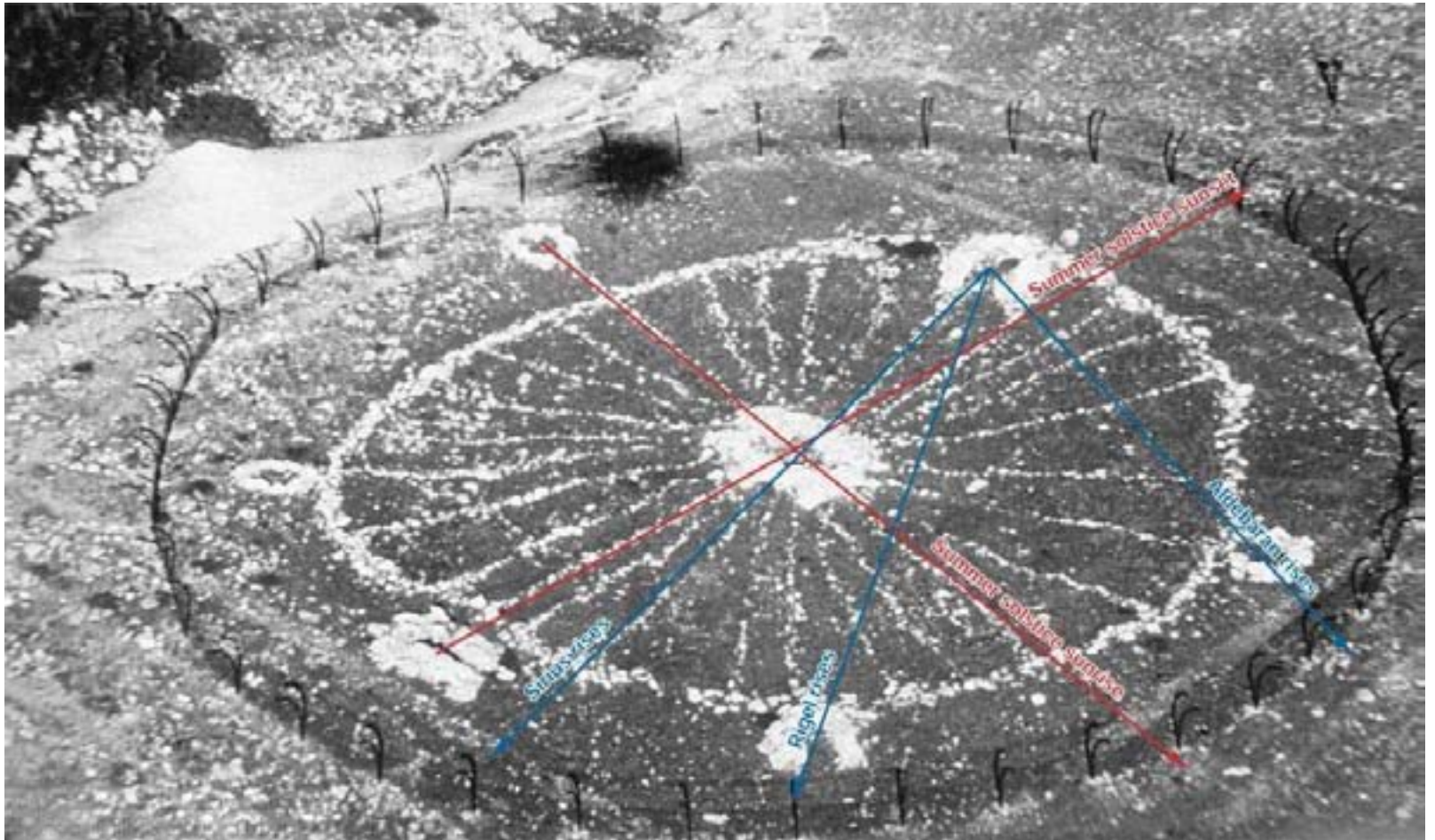
- Constructed: 3000 – 1800 B.C.



- Alignments with locations of sunset, sunrise, moonset and moonrise at summer and winter solstices
- Probably used as calendar.

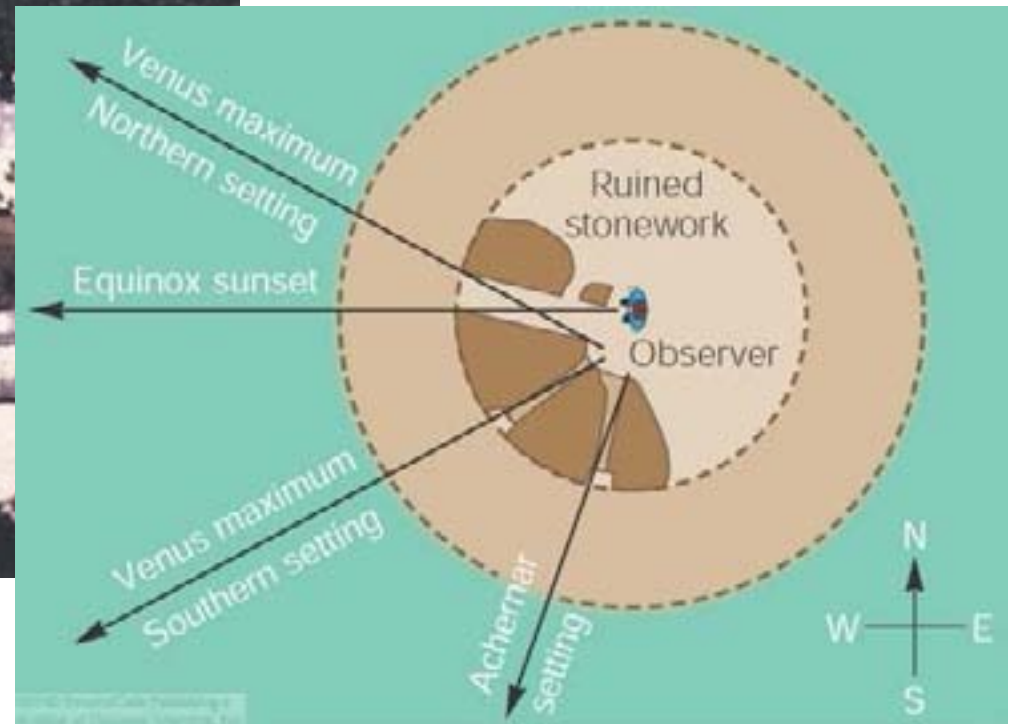
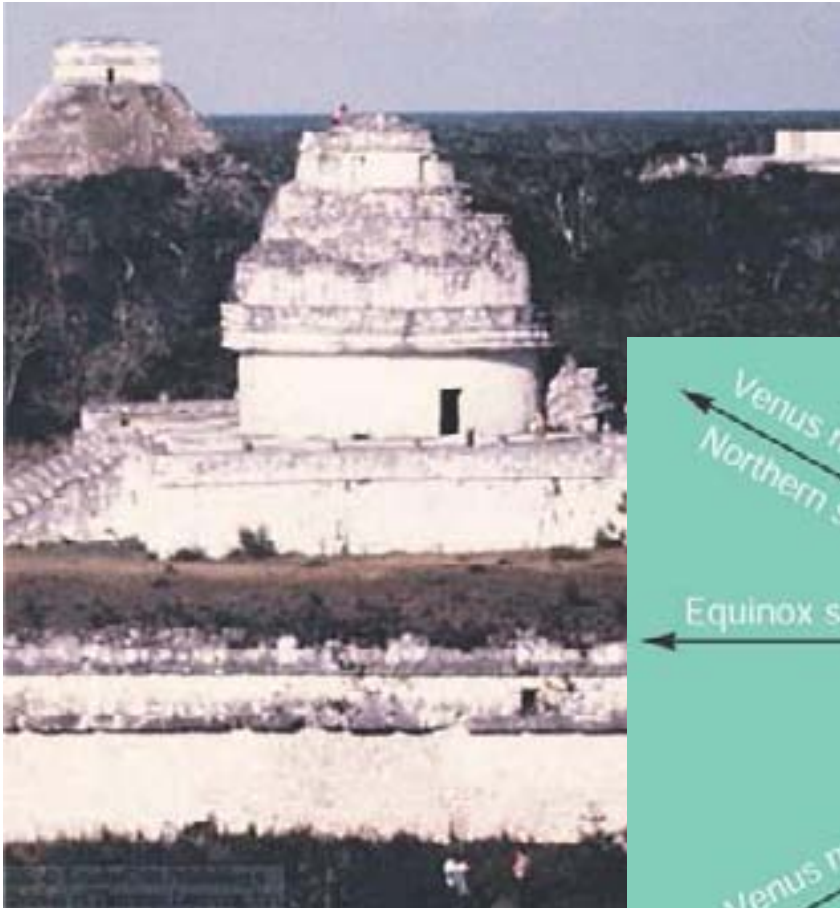


Other Examples All Over the World



Big Horn Medicine Wheel (Wyoming)

Other Examples All Over the World (2)



Caracol (Maya culture, approx. A.D. 1000)



Ancient Greek Astronomers (1)

- Unfortunately, there are no written documents about the significance of stone and bronze age monuments.
- First preserved written documents about ancient astronomy are from ancient Greek philosophy.
- Greeks tried to understand the motions of the sky and describe them in terms of mathematical (not physical!) models.



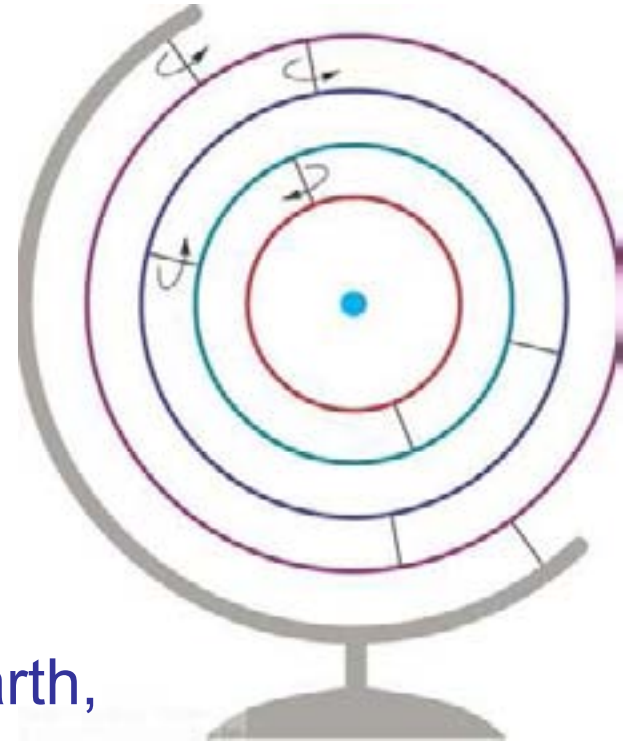
Ancient Greek Astronomers (2)

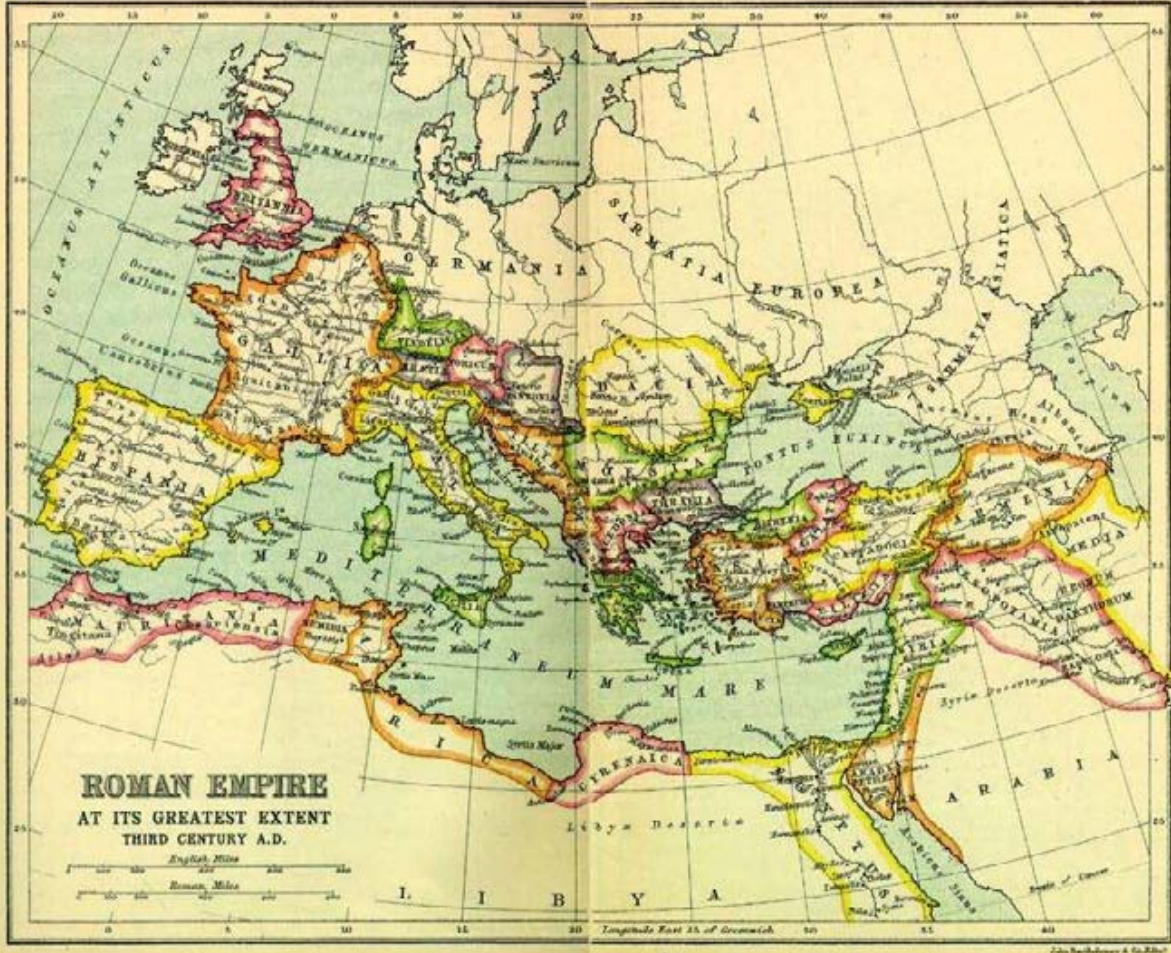
Models were generally wrong because they were based on wrong “first principles”, believed to be “obvious” and not questioned:

1. Geocentric Universe: Earth at the Center of the Universe.
2. “Perfect Heavens”: Motions of all celestial bodies described by motions involving objects of “perfect” shape, i.e., spheres or circles.

Ancient Greek Astronomers (3)

- Eudoxus (409 – 356 B.C.):
Model of 27 nested spheres
- **Aristotle** (384 – 322 B.C.),
major authority of philosophy
until the late middle ages:
Universe can be divided in 2
parts:
 1. Imperfect, changeable Earth,
 2. Perfect Heavens (described
by spheres)
- He expanded Eudoxus' Model to use 55 spheres.





Passage of astronomical knowledge



**Ancient
Babylon**



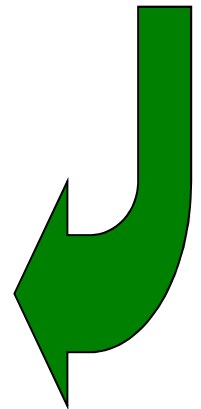
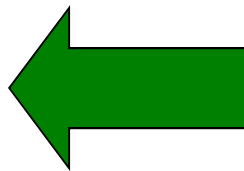
**Ancient
Egypt**

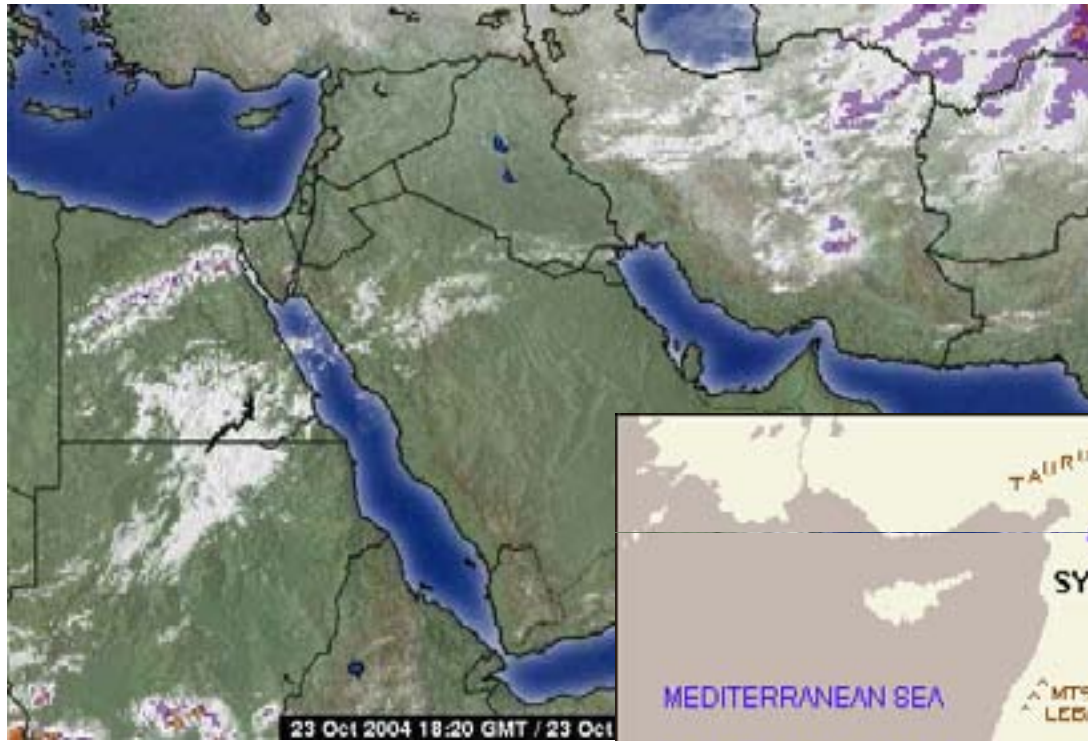


Ancient Roman Empire



**Ancient
Greece**

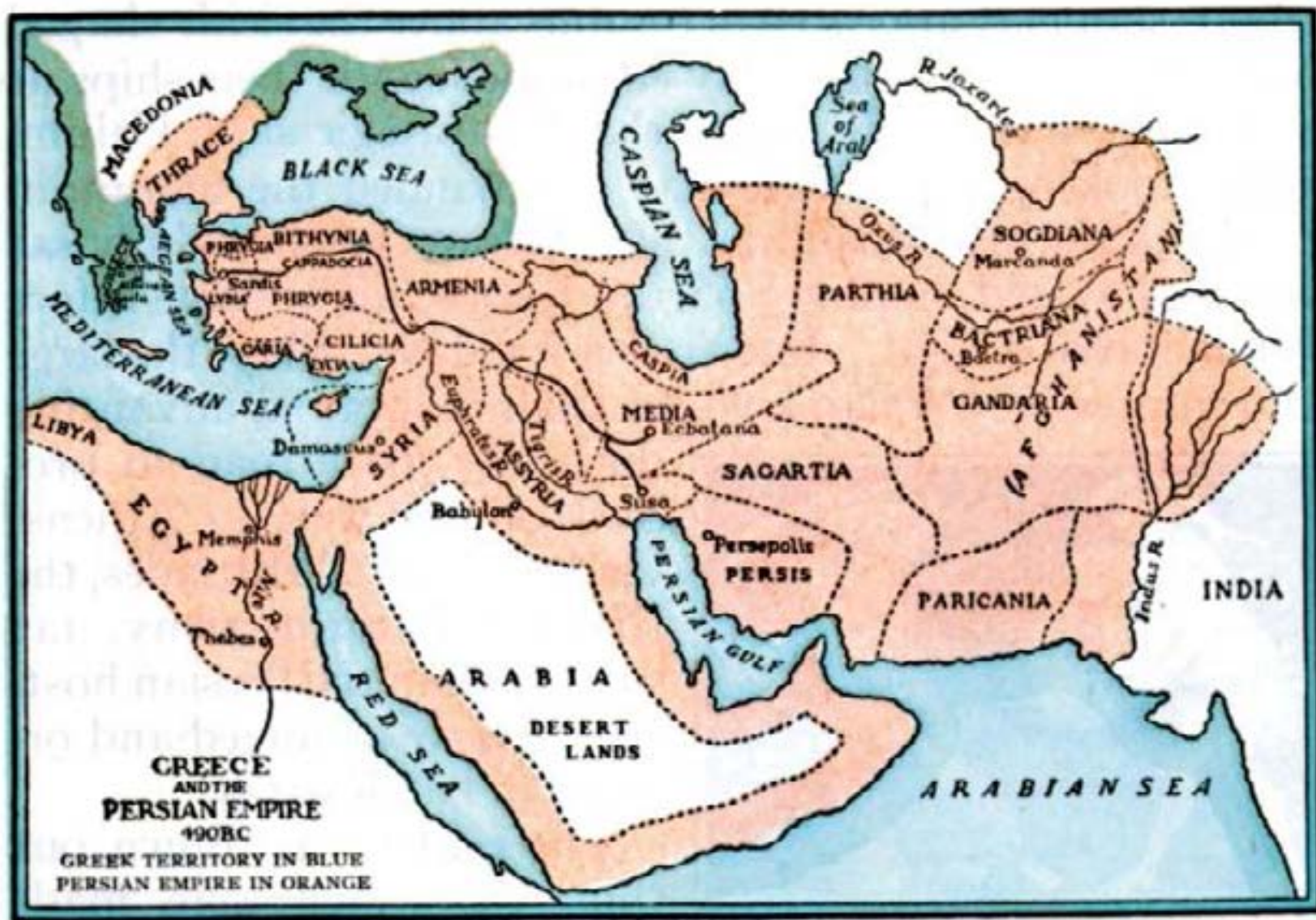




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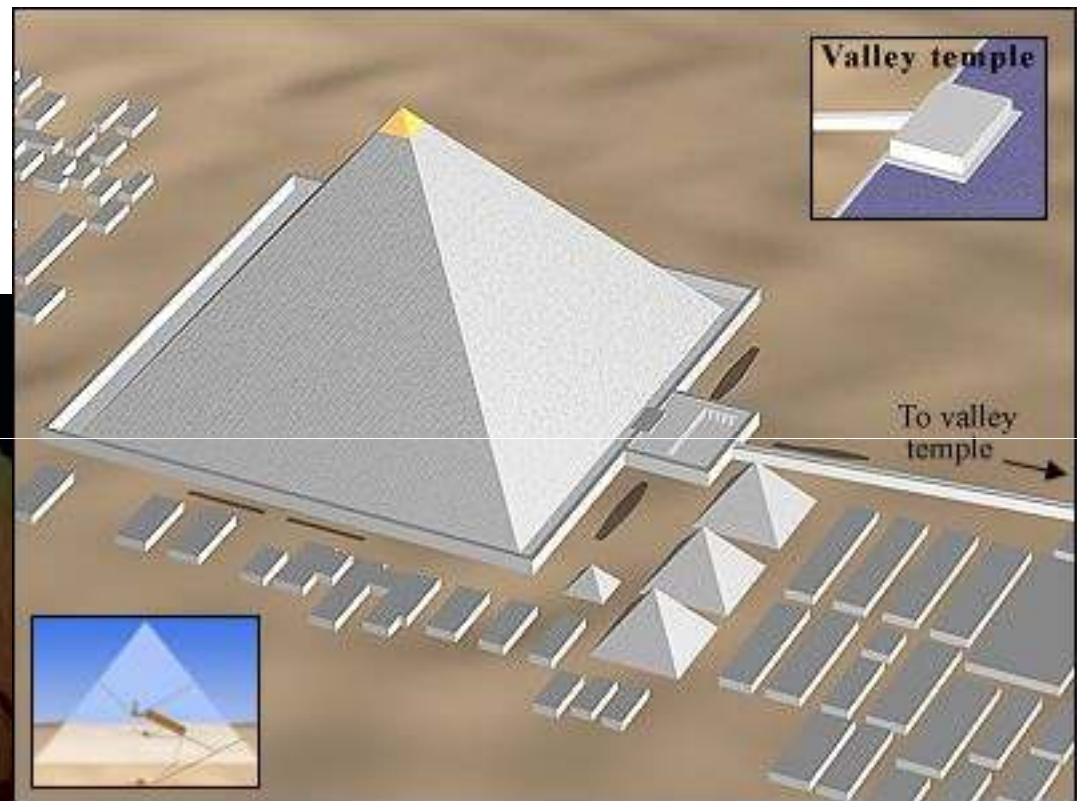
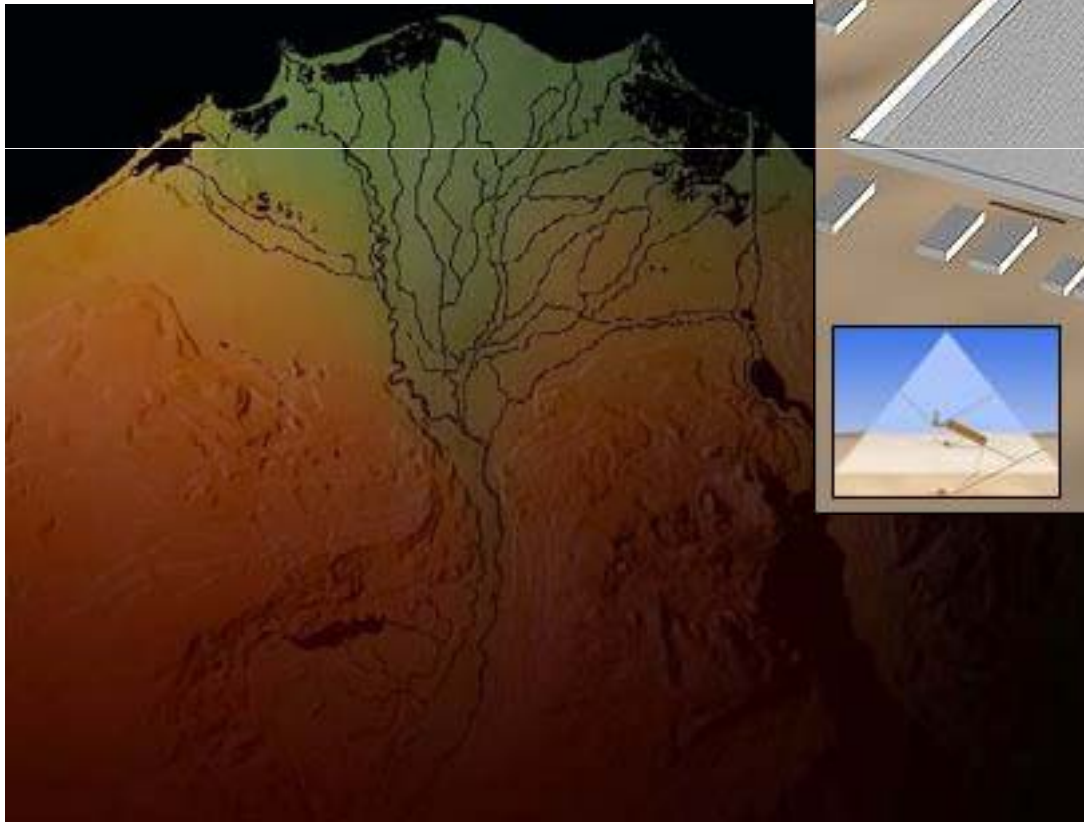


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Ancient Egypt

Nile River Valley



Great Pyramid of
Kufu



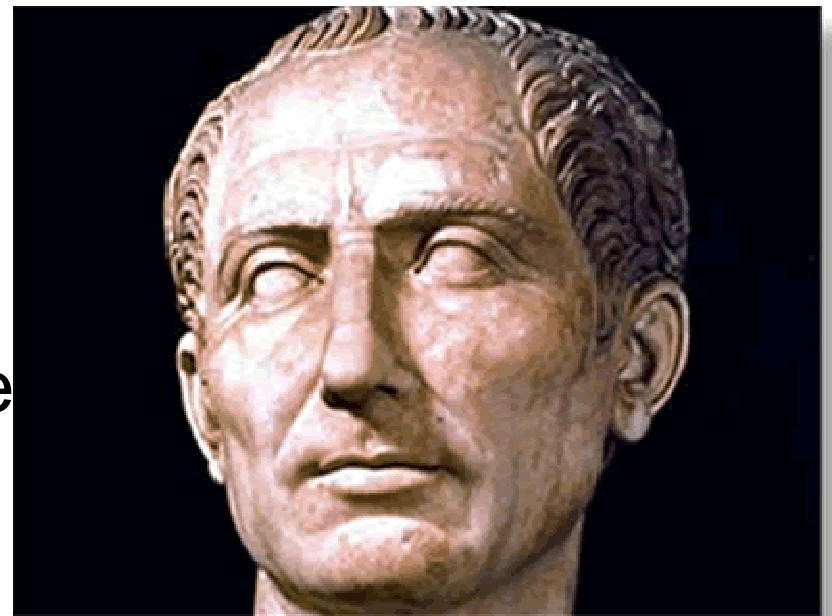
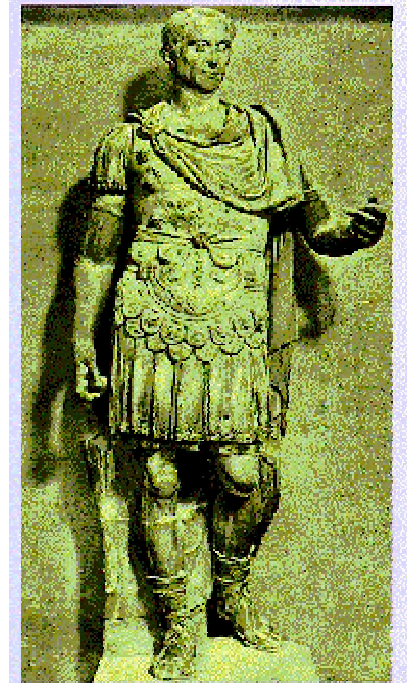


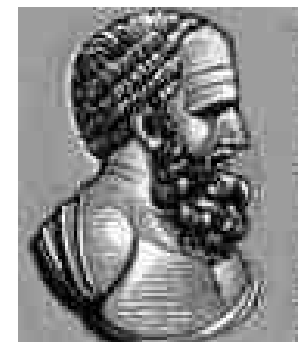
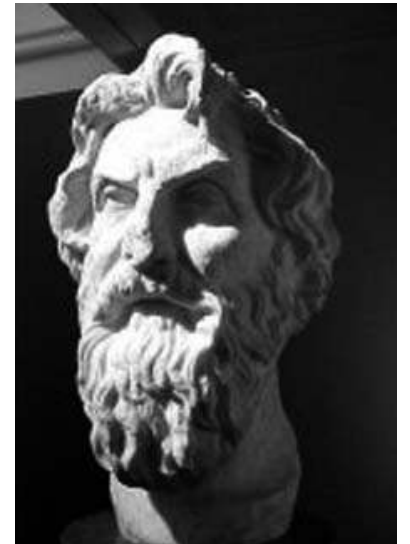
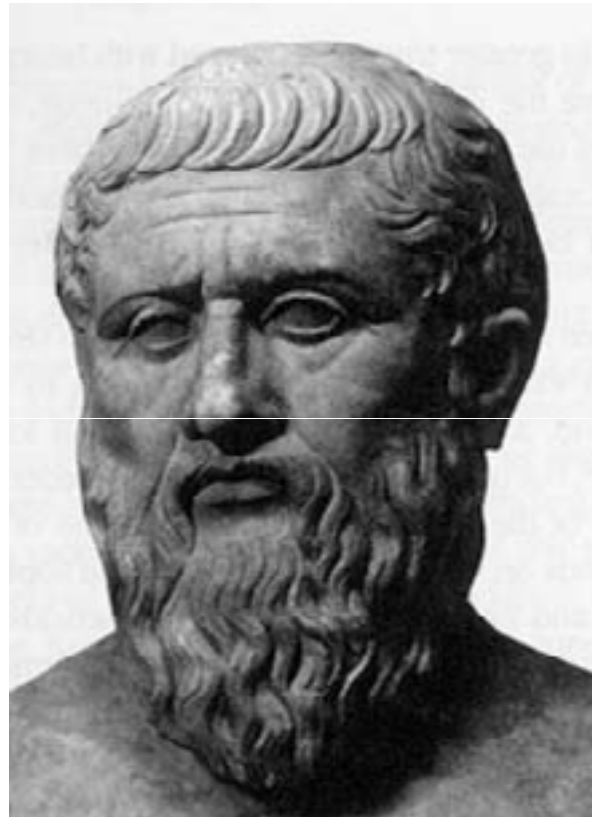
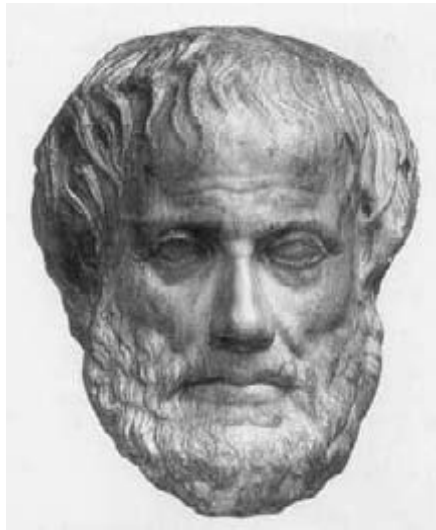
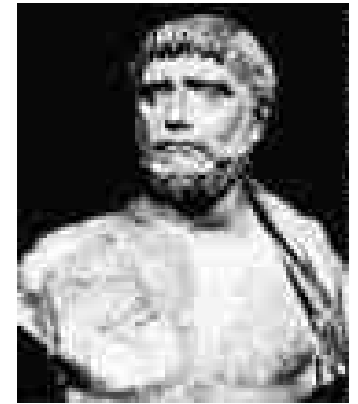
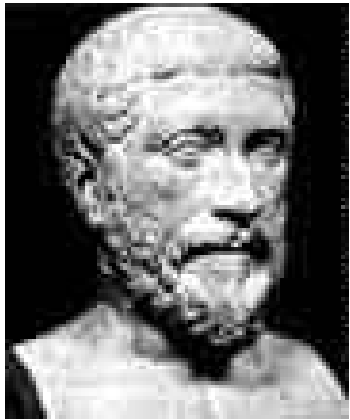
Ancient Rome



Ancient Rome

The Romans most important contribution to the field of astronomy is the enforcement of a systematic calendar that would account for fact that the year is about $\frac{1}{4}$ of a day more 365 days. The astronomers of Julius Caesar convinced him to create the Julian Calendar which adds one day to the calendar every 4 years to account for the time we had skipped. This is known as a “leap year”.

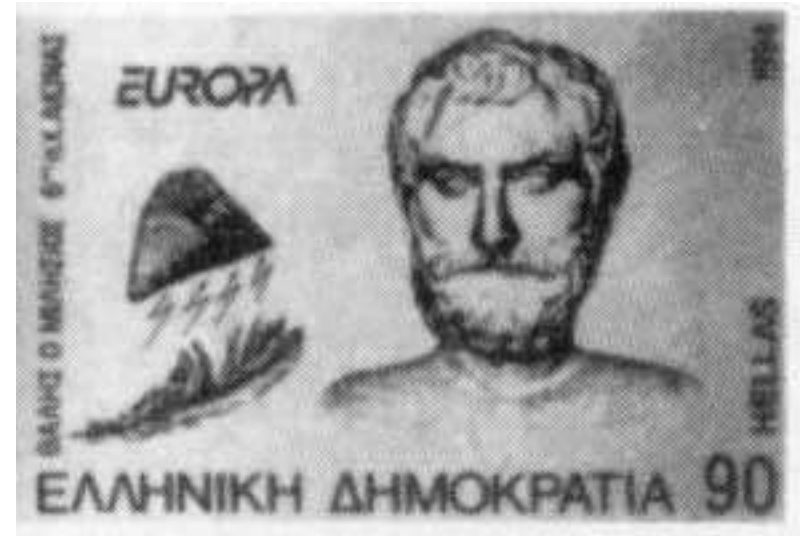
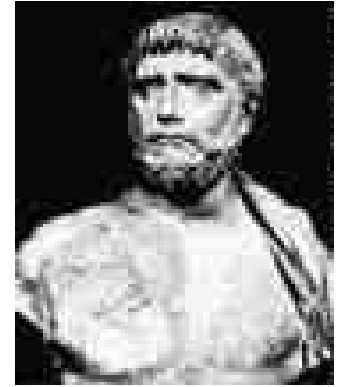




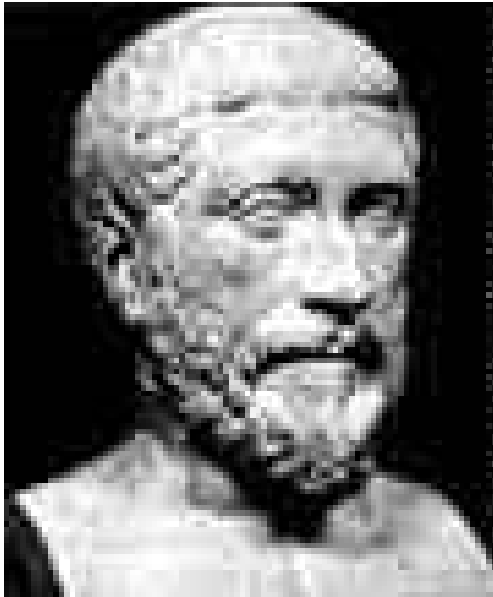
Greek Astronomy

- About 624 BC to 547 BC
- One of the earliest Greek philosophers.
- His areas of interest included geometry and astronomy.
- There are no books or writings that have survived from Thales.

Thales



Greek Astronomy



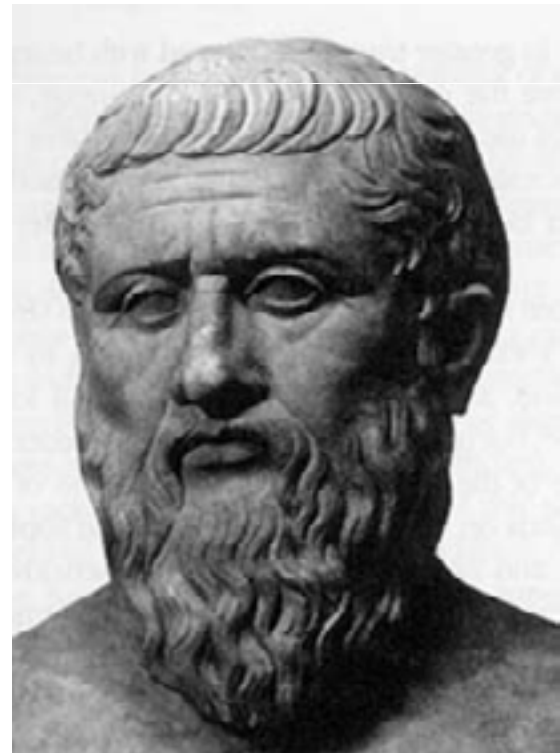
- About 569 BC to 475 BC
- One of the greatest mathematicians of all time.
- Founded secret society based on his mathematical discoveries and their religious implications.
- Since the society was extremely secretive, very little is known about his life or personal works.

Pythagoras

Greek Astronomy

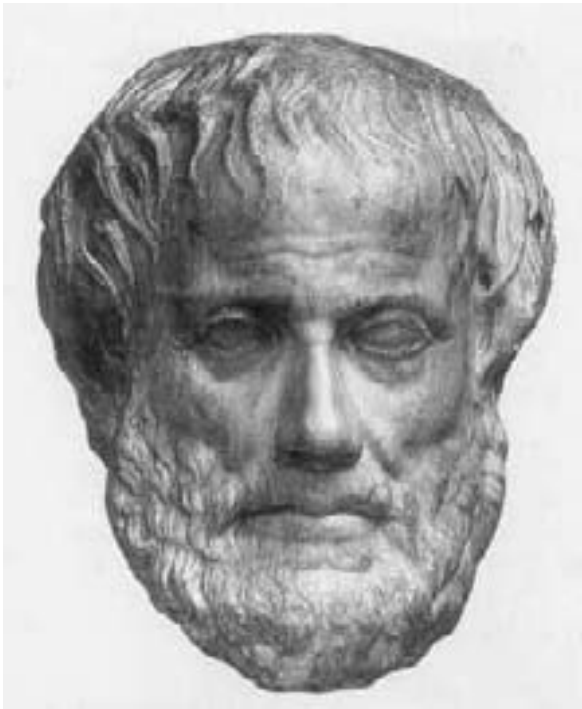
- 427 BC to 347 BC
- Well known for political and social philosophy but he also made contributions to astronomy.
- He was most noted for his belief in the perfect and unchanging nature of the heavens.
- Plato was the head of the School of Athens & was Aristotle's teacher.

Plato



Greek Astronomy

Aristotle



- 384 BC to 322 BC
- Founded his own school called the Lyceum in Athens
- Made contributions to all areas of philosophy but math was his weakness
- He did not believe that empirical evidence was necessary to prove ideas.

Greek Astronomy

Aristotle



- Aristotle is one the first to attempt to create a scientific model of the universe.
- This model has now become known as the “Geocentric Model” which places the “imperfect” Earth at the center and all of the “perfect” celestial objects go around us in perfect circular motion

Greek Astronomy

Euclid

- About 325 BC to 265 BC
- Great mathematician but so little is known about him that people question whether he was an actual person or a group of mathematicians.



Greek Astronomy



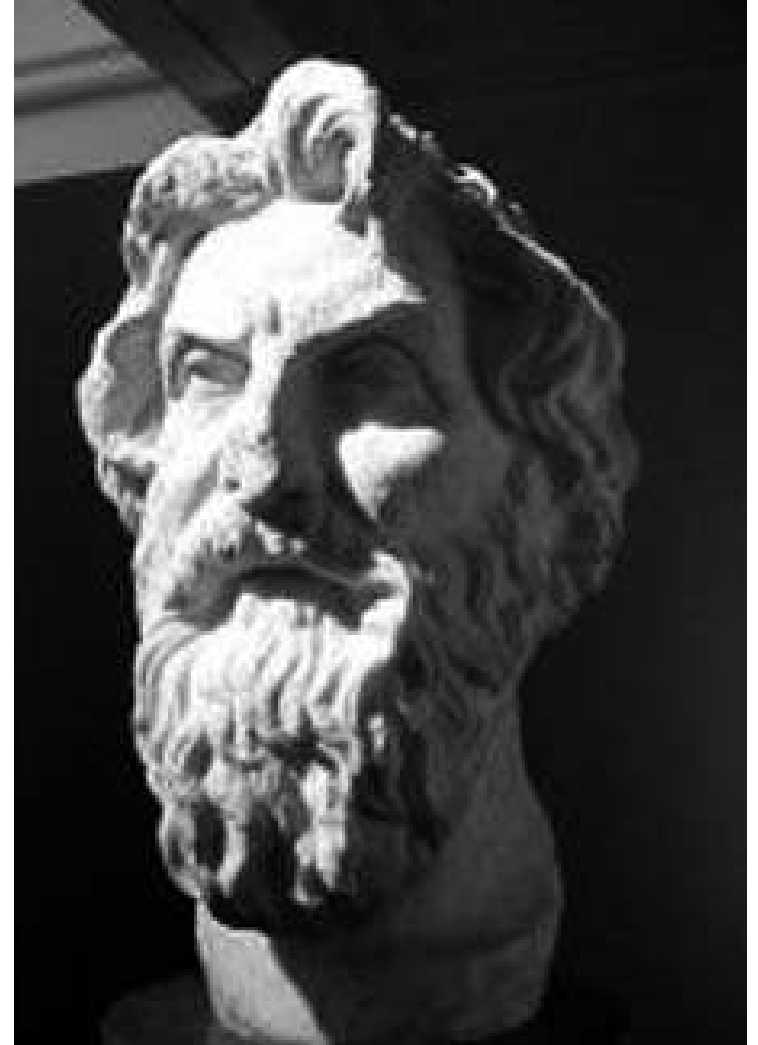
- The book “Elements” is possible the most famous and long lasting math text books in history.

Euclid

Greek Astronomy

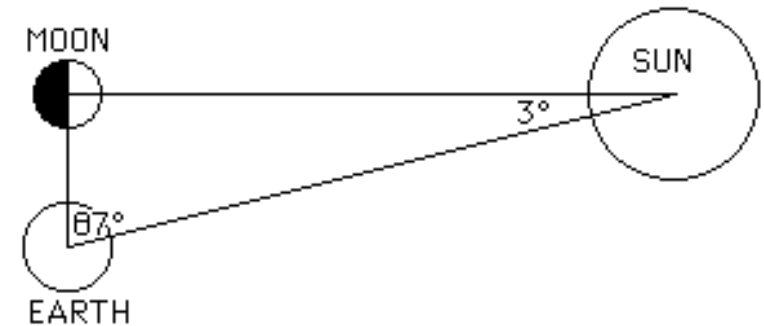
Aristarchus

- About 310 BC to 230 BC
- We have no writings that have survived but Aristarchus is referred to in the writings of other philosophers



Greek Astronomy

Aristarchus



- Most noted for proposing the idea of a heliocentric universe with the earth as one of the planets moving around the Sun.
- Aristarchus is the first to attempt to measure the relative distance between the Earth-Moon and the Earth-Sun without the aid of trigonometry.
- Actual angle = $89^\circ 50''$ not 87°

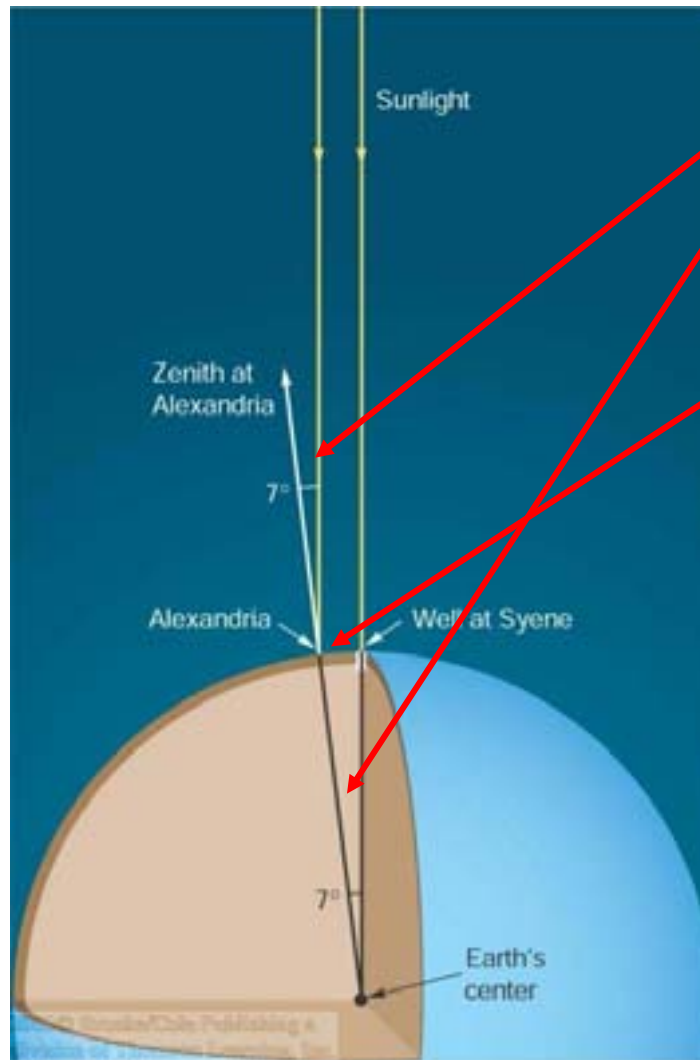
Greek Astronomy

Eratostrhenes



- 276 BC to 194 BC
- Librarian at the Great Library of Alexandria in Egypt.
- Developed a calendar with a leap year.
- Measured the circumference of the Earth in 325 BC !!
- Achieved an accuracy of about 90% of the actual number.

Eratosthenes (~ 200 B.C.): Calculation of the Earth's radius

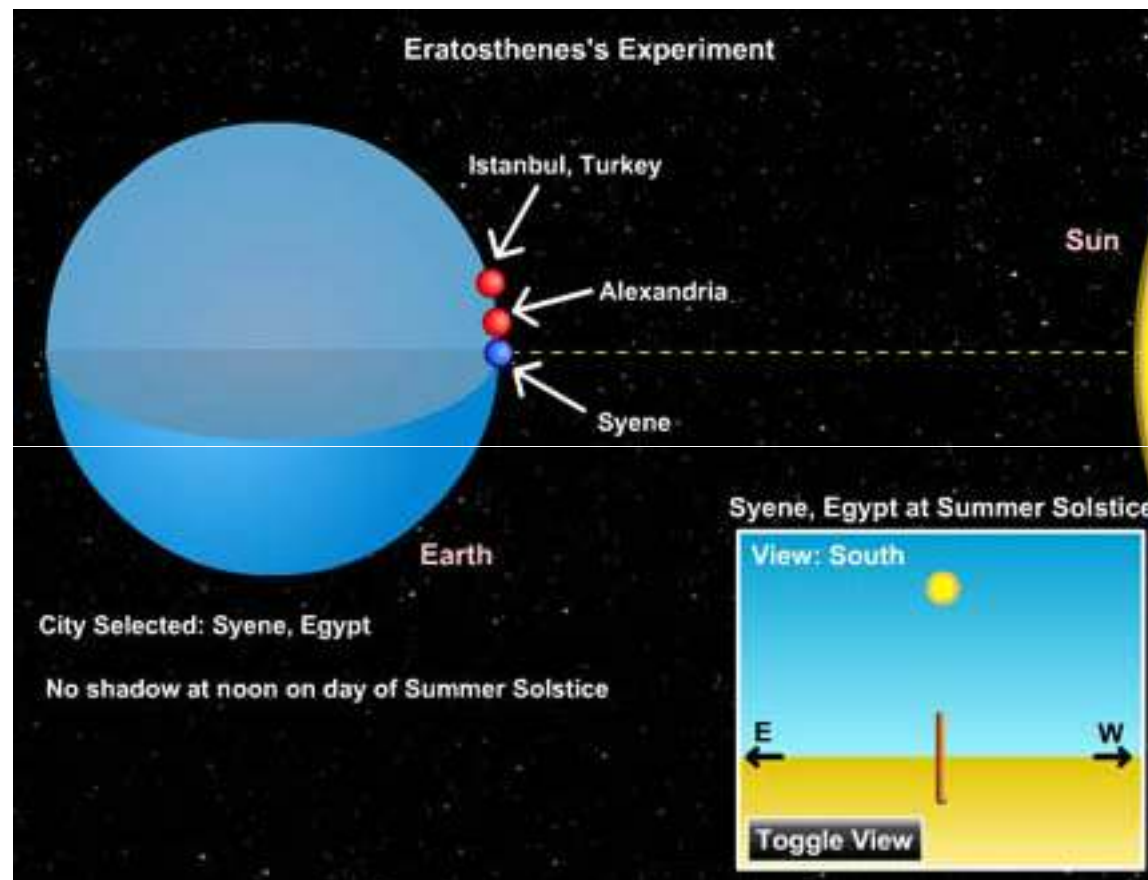


Angular distance between
Syene and Alexandria:
 $\sim 7^\circ$

Linear distance between
Syene and Alexandria:
 $\sim 5,000$ stadia

→ Earth Radius $\sim 40,000$
stadia (probably $\sim 14\%$
too large) – better than
any previous radius
estimate.

Eratosthenes's Experiment

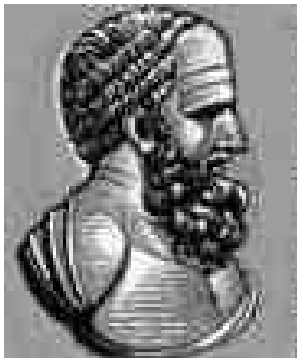


PLAY
ANIMATION

(SLIDESHOW MODE ONLY)

Greek Astronomy

- 190 BC to 120 BC
- Hipparchus is considered the first great astronomer and scientist
- Hipparchus is one of the first of the ancient philosophers to realize that ideas must be proven with empirical evidence.
- He realized that more data meant more certainty in the idea or model



Hipparchus

Greek Astronomy

Hipparchus



- Created highly accurate star atlases in an attempt to measure the length of the year more accurately.
- He measured the length of the year to within 6.5 minutes of the actual time.
- He discovered precession by examining ancient star position data (mostly Mesopotamian) and comparing them to his own measurements.

Greek Astronomy

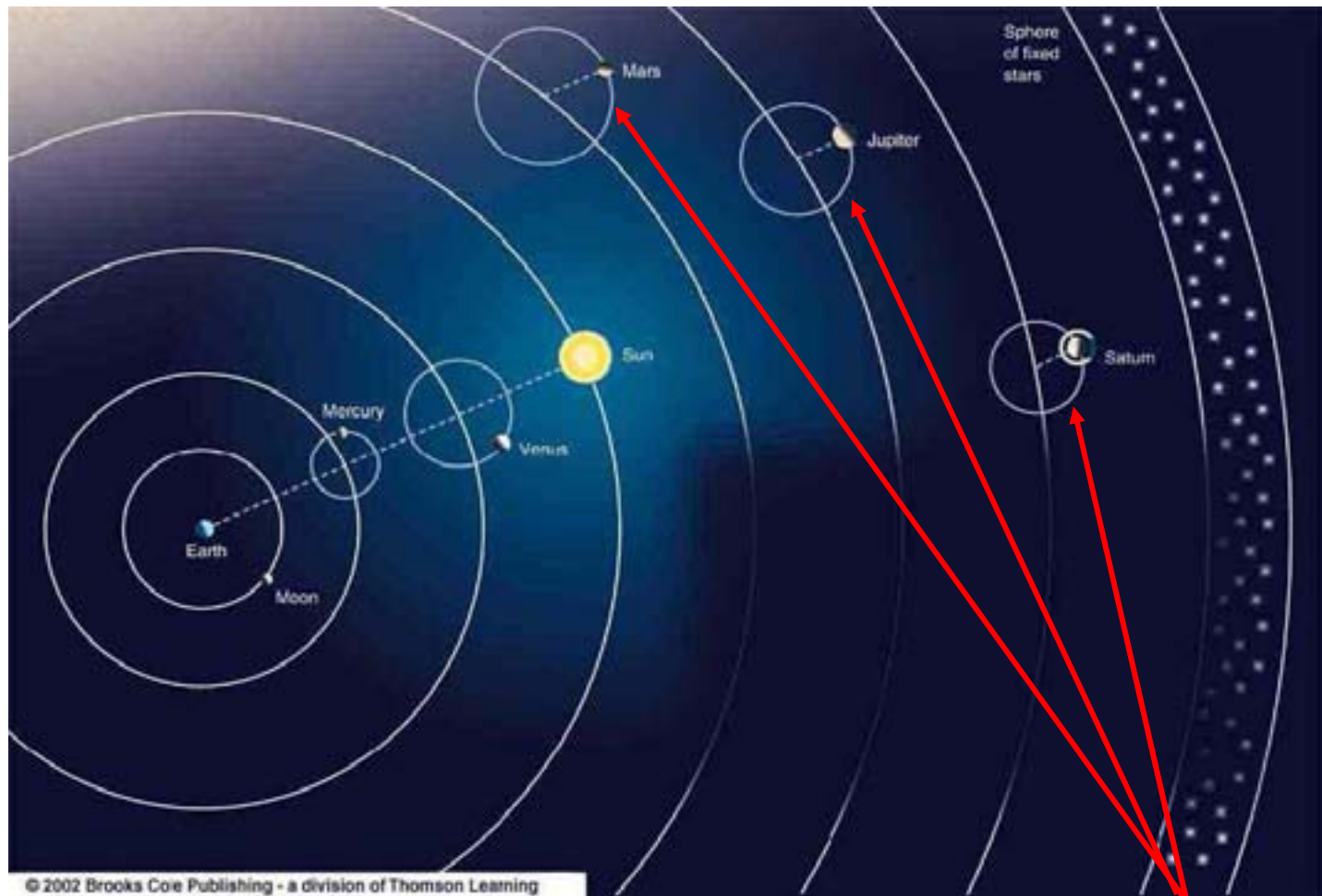
Hipparchus



- Based on measurements during an eclipse, he is able to place a range on the distance to the moon.
- He estimated it to be between 59 and 67 Earth diameters. The actual number is 60.
- He marks the first truly scientific astronomical mind and his influence is still felt today.

Later refinements (2nd century B.C.)

- Hipparchus: Placing the Earth away from the centers of the “perfect spheres”



- **Ptolemy:** Further refinements, including epicycles

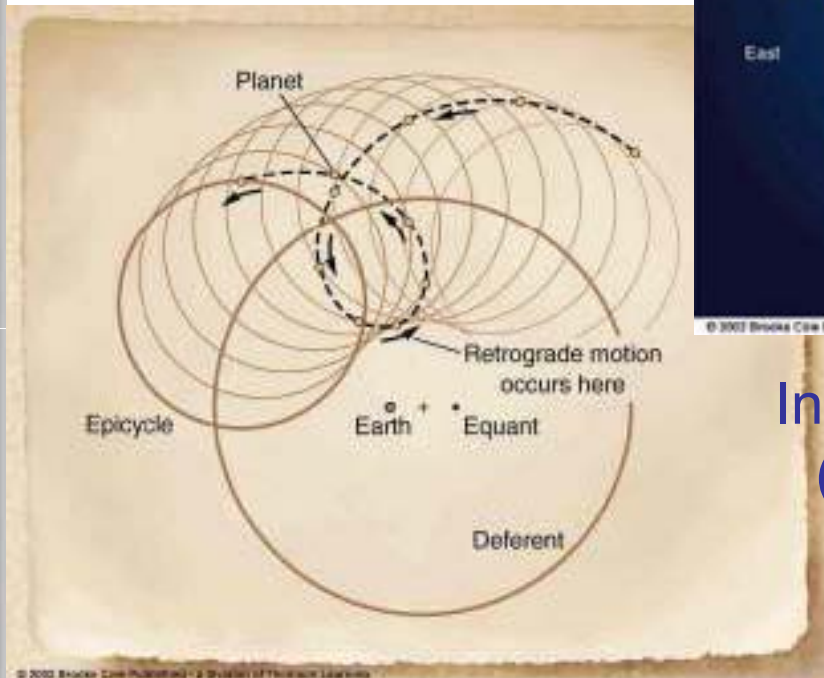
Greek Astronomy

Ptolemy



- About 85 AD to 165 AD
- Ptolemy is the most influential astronomer in his day and his models of the universe will prevail for the next 1400 years
- He is a great admirer of Hipparchus and his rigorous method of verifying ideas with empirical data.
- Ptolemy is also accused of stealing ideas without crediting his source.

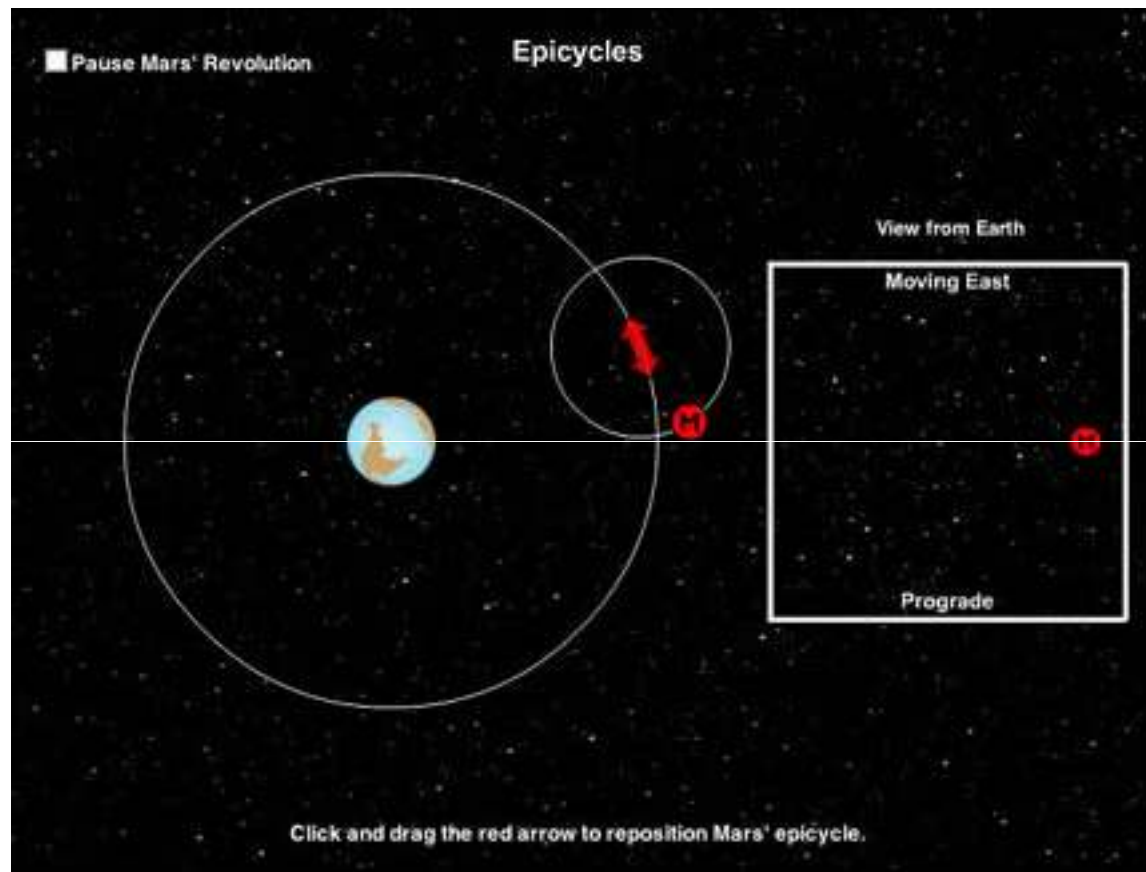
Epicycles



Introduced to explain retrograde (westward) motion of planets

The Ptolemaic system was considered the “standard model” of the Universe until the *Copernican Revolution*.

Epicycles



PLAY
ANIMATION

(SLIDESHOW MODE ONLY)

Greek Astronomy

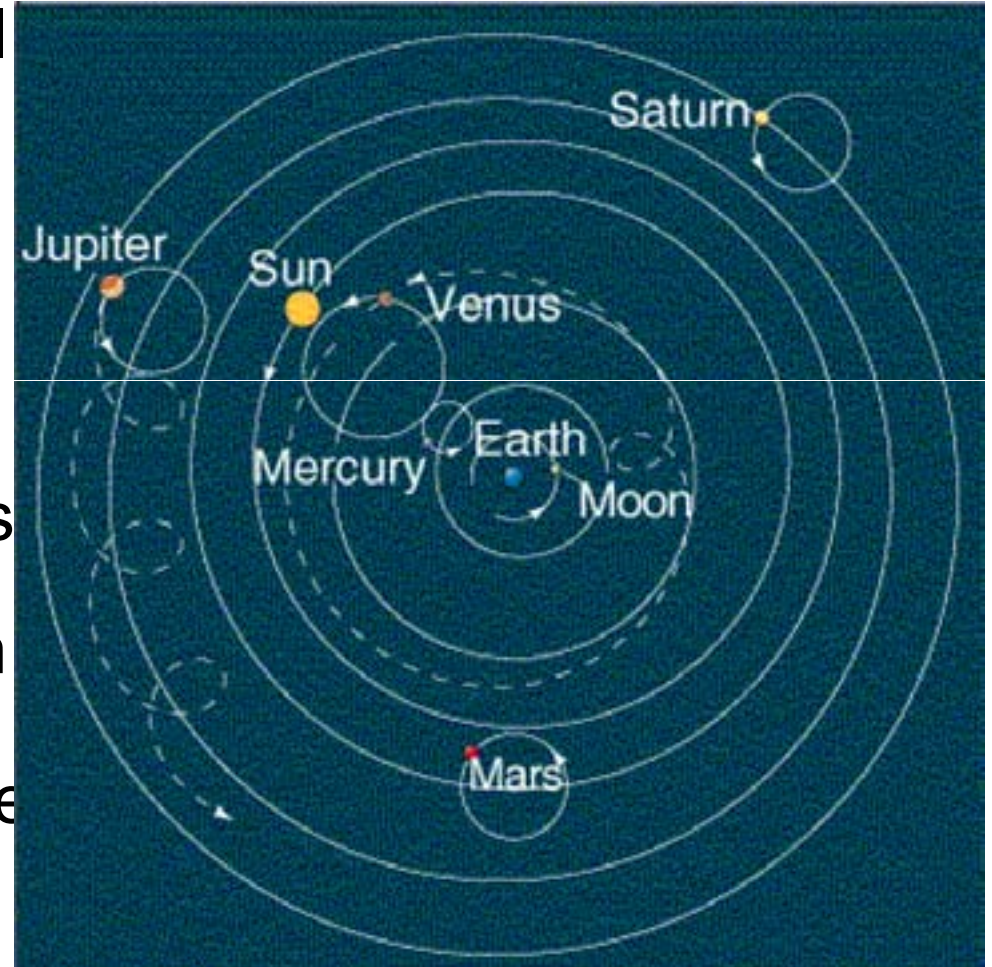
- Ptolemy is a great proponent of the geocentric model.
- He saw that there were problems with Aristotle's simplistic idea of a geocentric model.
- Ptolemy employed an old idea of epicycles to help explain the discrepancies in the evidence for geocentrism.
- Although he was able to make more accurate predictions than previous astronomers, his model still failed to be completely accurate.



Ptolemy

Ptolemy (140 A.D.)

- A more complex model of the Universe/Solar System was needed to explain Retrograde Motion.
- Ptolemy suggests that planets orbit the Earth in a large circular orbits but also follow a small circular orbit around an imaginary point.
- These small orbits were known as Epicycles



Geocentric or Heliocentric?

- Of the early philosophers, only Hipparchus favored the heliocentric model
- Most philosophers thought that the evidence supported the Geo model more than the Helio model
- What was the evidence? Let's Look....

Geocentric Evidence

- Everything appears to revolve around the Earth each day (diurnal motion).
- There is no observable parallax of the stars, planets, Moon, or Sun.
- The motions of the stars and heavens are perfect circles.
- The heavens were unchanging but the Earth was not.

Problems With the Geocentric Model

- The planets appear to change brightness, implying a change of distance.
- The planets undergo retrograde motion (they move backwards compared to the direction the Sun moves).
- The Sun, Moon, and Planets do not move at the same speed all the time.
- Mercury and Venus are never seen at opposition (they always appear close to the Sun).

Evidence of the Heliocentric Model

- The changing brightness of the planets is explained by the Earth getting closer and farther from the planets during our orbit of the Sun.
- Our passing planets explain the retrograde motion of the outer planets.
- Mercury and Venus are not seen at opposition because they orbit the sun, just as we do.

Problems with the Heliocentric Model

- The changing speeds of the Sun, Moon, and planets is not explained by simply placing the Sun at the center of the universe.
- We do not feel the Earth moving or the atmosphere being pulled away as we fly around the Sun.
- If the Earth were spinning, wouldn't we be thrown off into space?
- Why is there no parallax due to our spin or our orbit?

So Which is Right?

- The ancients favored the geocentric model because it seemed impossible to believe that the Earth was moving.
- During ancient times, the mathematical and scientific tools were not available to answer the question without dispute.

Planets

- Greek astronomers observed that certain celestial objects do not follow a predictable path like the moon, sun, and stars.
 - Called these objects Planets (Greek word planetes means wanderer)
 - The observable motion of Planets is that they change speed and even loop back and forth relative to the stars.

Retrograde Motion

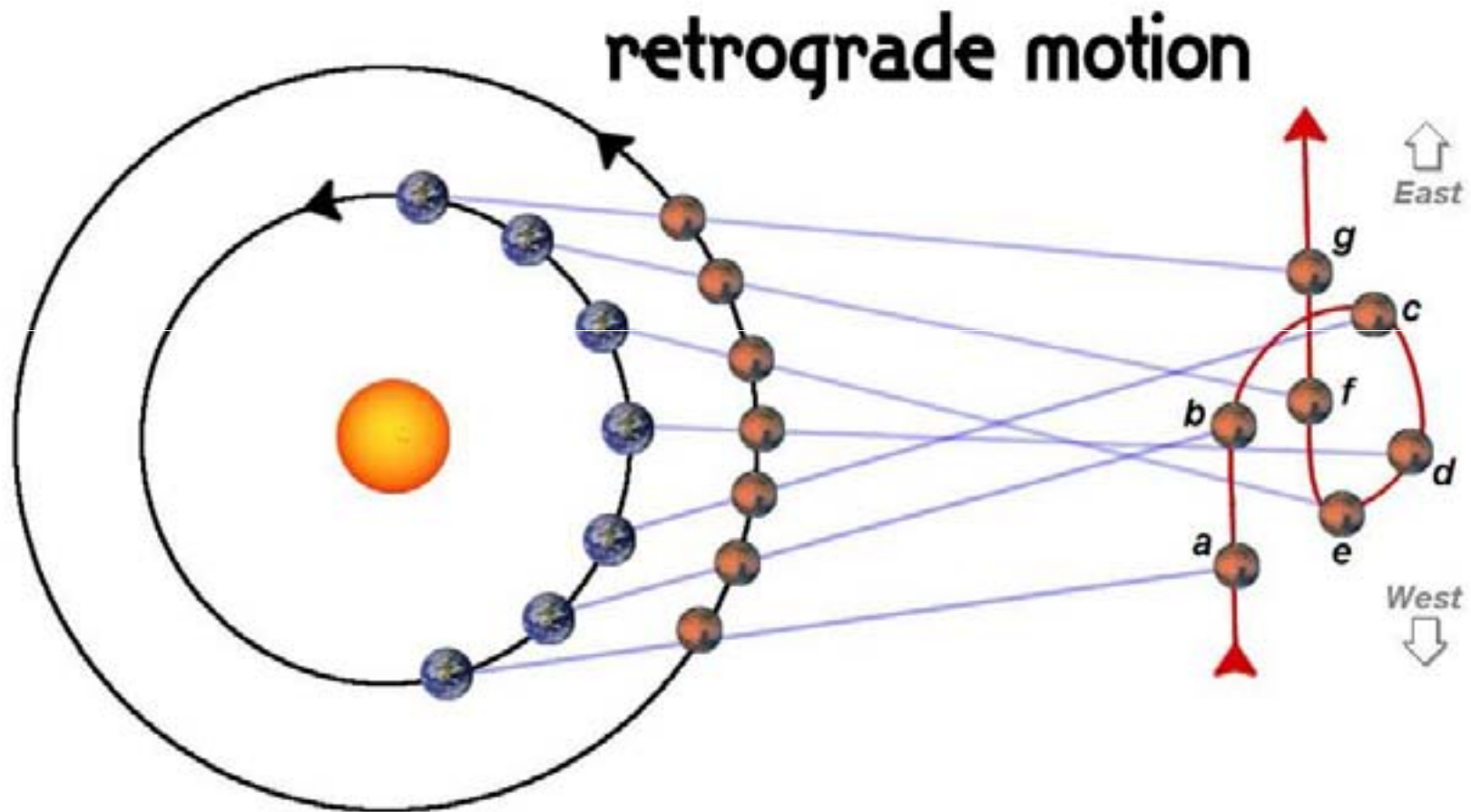
- Motion of planets in “backwards” or westward loops is known as Retrograde Motion.



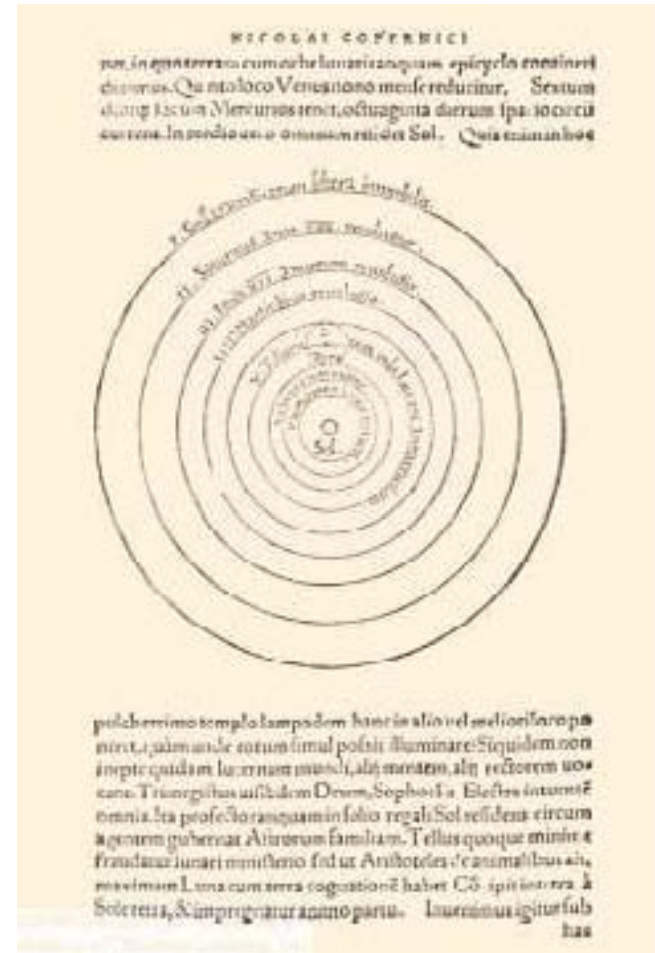
The Copernican Revolution: Heliocentric Model

- Ptolemaic Model survived for 13 centuries
- Copernicus suggested that the Earth is a planet and spins on its axis and orbits the Sun.
- Heliocentric- Sun Centered
 - This accounts for the apparent motion of the sun and stars.
- The realization that Earth is not at the center of the universe is now known as the Copernican Revolution.
 - What about Retrograde motion of the planets?

Just like when you pass another car on the highway.

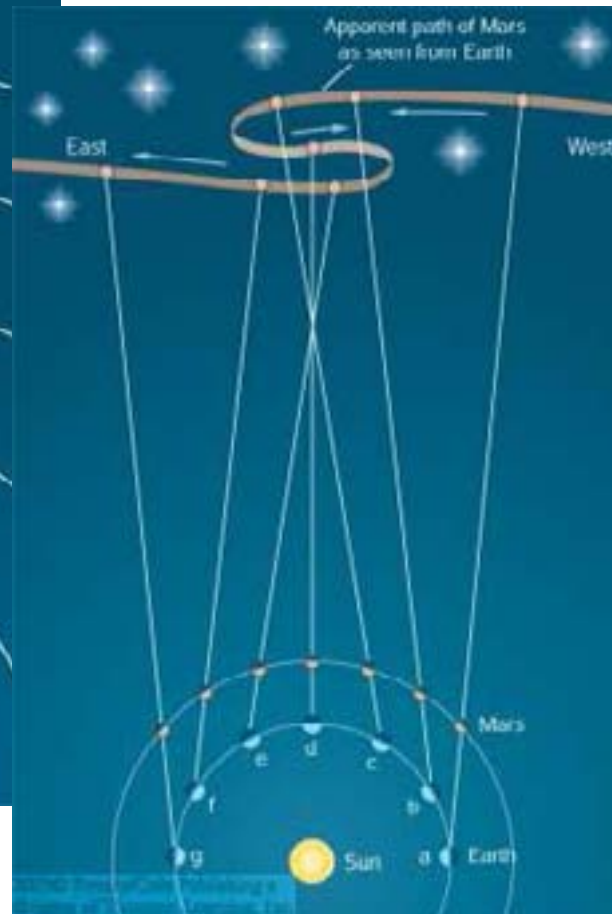
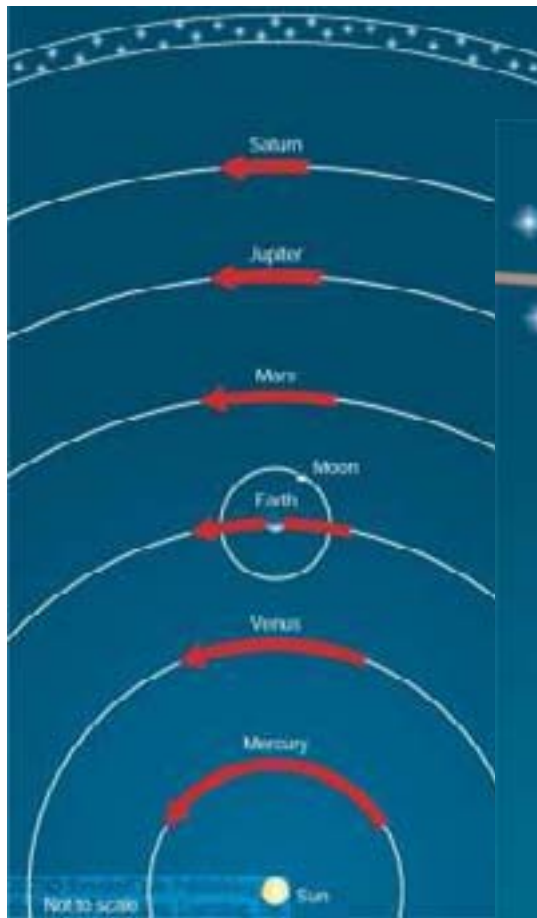


The Copernican Revolution



Nicolaus Copernicus (1473 – 1543):
Heliocentric Universe (Sun in the Center)

Copernicus' new (and correct) explanation for retrograde motion of the planets



Retrograde (westward) motion of a planet occurs when the Earth passes the planet.

This made Ptolemy's epicycles unnecessary.

Galileo Galilei (1594 – 1642)

- Invented the modern view of science: Transition from a faith-based “science” to an observation-based science.
- Greatly improved on the newly invented telescope technology. (But Galileo did NOT invent the telescope!)
- Was the first to meticulously report telescope observations of the sky to support the Copernican Model of the Universe.



Major Discoveries of Galileo

- Moons of Jupiter
(4 Galilean moons)



(What he really saw)



- Rings of Saturn



(What he really saw)



Major Discoveries of Galileo (2)

- Surface structures on the moon; first estimates of the height of mountains on the moon



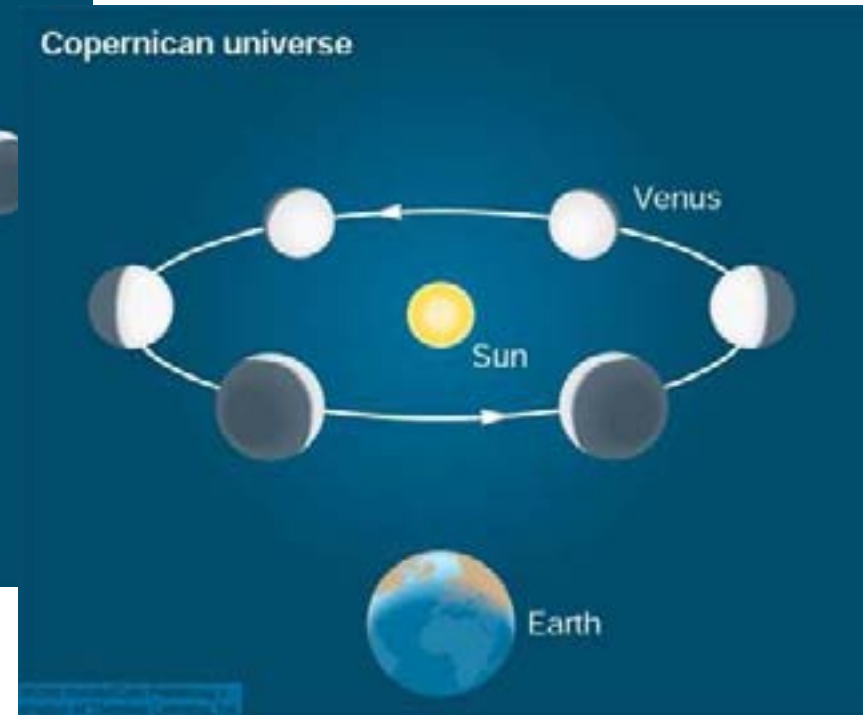
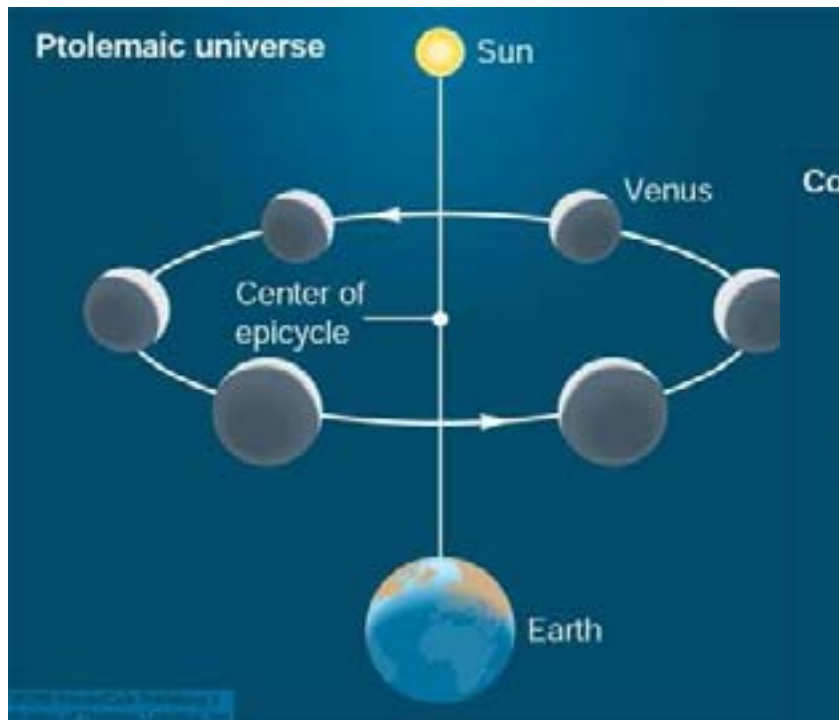
Major Discoveries of Galileo (3)



- *Sun spots* (proving that the sun is not perfect!)

Major Discoveries of Galileo (4)

- Phases of Venus (including “full Venus”), proving that Venus orbits the sun, not the Earth!

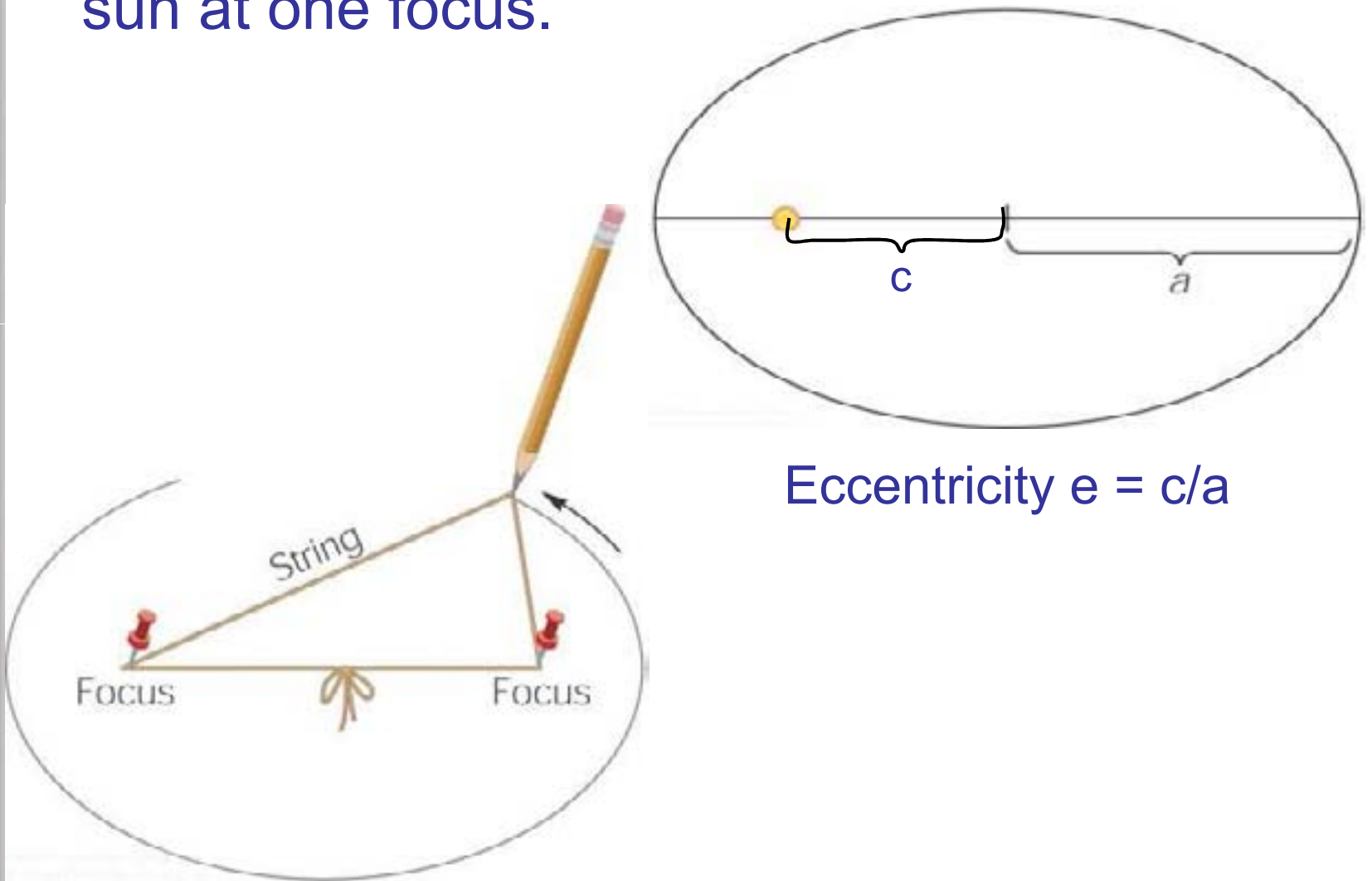


Johannes Kepler (1571 – 1630)

- Used the precise observational tables of Tycho Brahe (1546 – 1601) to study planetary motion mathematically.
- Found a consistent description by abandoning both
 1. Circular motion and
 2. Uniform motion.
- Planets move around the sun on elliptical paths, with non-uniform velocities.

Kepler's Laws of Planetary Motion

1. The orbits of the planets are **ellipses** with the sun at one focus.



Eccentricities of Ellipses

1)

$$e = 0.02$$

2)

$$e = 0.1$$

3)

$$e = 0.2$$

4)

$$e = 0.4$$

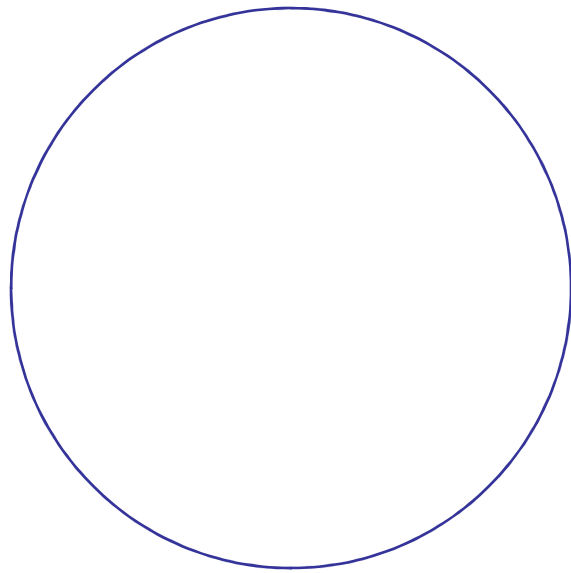
5)

$$e = 0.6$$

Eccentricities of Planetary Orbits

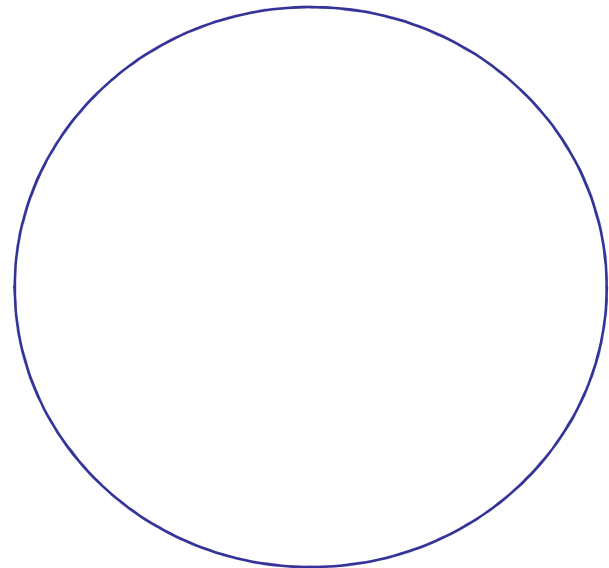
Orbits of planets are virtually indistinguishable from circles:

Earth: $e = 0.0167$



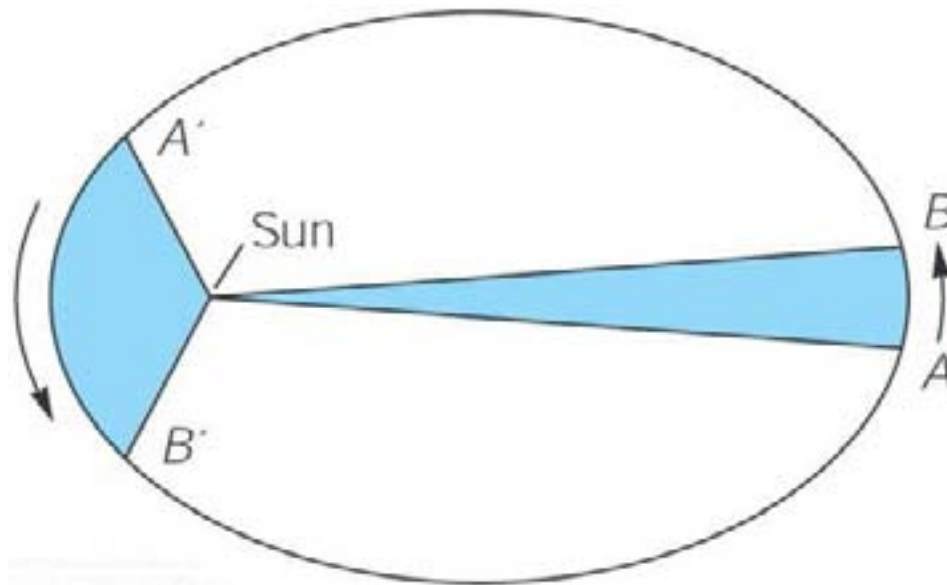
Most extreme example:

Pluto: $e = 0.248$



Planetary Orbits (2)

- A line from a planet to the sun sweeps over equal areas in equal intervals of time.



- A planet's orbital period (P) squared is proportional to its average distance from the sun (a) cubed:

$$P_y^2 = a_{AU}^3$$

(P_y = period in years;
 a_{AU} = distance in AU)

