A Brief History of Astronomy

Reading: Chapter 3.1-3.4

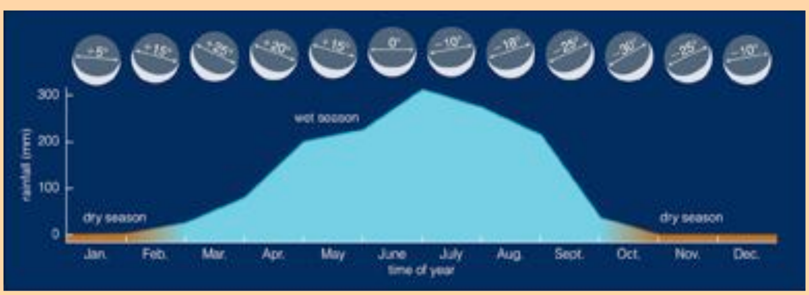
Development of Astronomy

The development of astronomy came about through careful observations and gradual application of the scientific method across the world and over thousands of years….

Development of Astronomy

France: Cave paintings from **15,000 B.C.** may suggest knowledge of lunar phases (29 dots) and some star patterns (Pliades cluster)

Development of Astronomy



Ancient people of central Africa (**6500 BC**) could predict seasons from the orientation of the crescent moon. A carved bone shows pictographs of the crescent moon

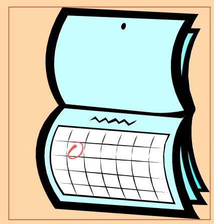
This allowed them to determine when to plant seeds and grow their crops

Development of Astronomy

4000BC: Egyptians institute the 365 day calendar based on the periodic rising of Sirius.

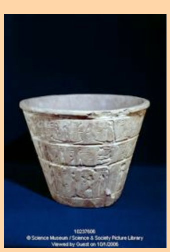
Sirius, the brightest star in the sky, which they identified with the fertility goddess Isis, first appeared in the predawn sky each year just as the Nile began its life-giving floods. While the rising of the Nile varied year to year, Sirius appeared with perfect regularity.

Once again this helped them predict planting season



Development of Astronomy

- The Egyptians were also the first to divide the night and day into **twelve hours**, using the rising of bright stars-later called decans-to mark the hours till dawn.



Water clock: water runs out of a small hole like sand in an hourglass

Egyptian obelisk acts as a sundial: Shadows tell time of day.

Development of Astronomy

Scotland: **4,000-year-old** stone circle; Moon rises as shown here every 18.6 years.

Development of Astronomy

England: Stonehenge (completed around **1550 B.C**.) Alignments of the stones at Stonehenge mark the rising and setting points of the Sun at the solstices

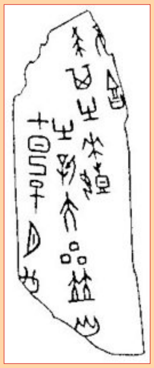
Development of Astronomy

2354 BC, Babylon: First female astronomer recorded in history. Her name was En Hedu' Anna
Her position: Astronomer priestess of the Moon Goddess

Development of Astronomy

2000 BC: Babylonian priests in Mesopotamia (Iraq) recorded the motions of planets on thousands of tablets.
763 BC: Solar eclipse observed and recorded by Babylonians
Constellations (asterisms) of the zodiac are based on ancient Babylonian names

Development of Astronomy



"On the Jisi day, the 7th day of the month, a big new star appeared in the company of the Ho star."

"On the Xinwei day the new star dwindled."

Bone or tortoise shell inscription from the 14th century BC.

China, 1400 BC : Earliest known records of supernova explosion of a dying star. Also recorded solar, lunar eclipses continuously from 4 BC !

Development of Astronomy

Astronomy in the Americas

SW United States: "Sun Dagger" marks summer solstice

Many ancient structures were built to mark and aid in astronomical observations

Development of Astronomy

Astronomy in the Americas

Mayan observatory at Chichen Itza.

Many ancient structures were built to mark and aid in astronomical observations

Development of Astronomy

Astronomy in the Americas

Inuit people used the stars to mark seasons and to find their way across the frozen land where there were no easy geographical landmarks

Development of Astronomy

1054 AD : Supernova explosion recorded by Anasazi tribes as well as in China.
It was brighter than Venus and visible during the day for 23 days!

Development of Astronomy

The crab nebula : This is what the supernova of 1054 AD looks like through powerful telescopes today!

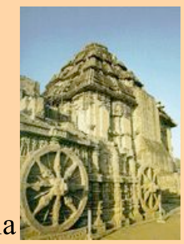
Development of Astronomy

Astronomy and Religion

The observed connection between the planting seasons and the position of celestial objects led to the rise of religions to attempt to understand these events.
Various ceremonies were designed to please celestial beings: priests became an important class

Egyptian sun god Ra

Sun temple: India



Development of Astronomy

Astronomy vs Astrology

- The association of celestial objects with one or more gods lead to the idea that these gods could affect human lives - the birth of Astrology
- Astrology is the search for influences on human lives based on the positions of planets and stars in the sky.

Development of Astronomy

Does astrology have any scientific validity?

- Scientific tests have shown that astrological predictions are no more accurate than we should expect from pure chance.

Development of Astronomy

Summary: Astronomical observations benefited ancient societies in many ways:

- Keeping track of time and seasons
  - for practical purposes, including agriculture
  - for religious and ceremonial purposes
- Aid to navigation (polaris, southern cross)

Development of Astronomy

Summary of achievements of ancient civilizations:

- Daily timekeeping
- Tracking the seasons and calendar
- Monitoring lunar cycles
- Monitoring planets and stars
- Predicting eclipses
- And more…

Development of Astronomy

BUT, so far astronomy only involved making observations, recognizing basic patterns and making rudimentary predictions.

A crucial part of the scientific method - **building models/hypotheses** that did not resort to supernatural or godly influence - was missing.

This was about to change in Greece….

Greek Astronomy

Greek geocentric model (c. 400 B.C.)

- Greeks were the first people known to make ***models*** of nature.
- They tried to explain patterns in nature without resorting to myth, gods or the supernatural.

Thales of Miletus first assumed that the world was understandable and proposed a model of the earth.
He successfully predicted a solar eclipse

Greek Astronomy

500BC: Pythagoras suggests that the Earth is a **sphere** and not flat, as had been previously assumed

What observations of the ancient Greek astronomers could you use to prove the spherical model of the earth to a member of the Flat Earth Society ?

Greek Astronomy

Earth as a sphere:

Ships disappear sailing away from shore by sinking below horizon with mast last visible; Earth's curvature visible over 13 mile distance

Greek Astronomy

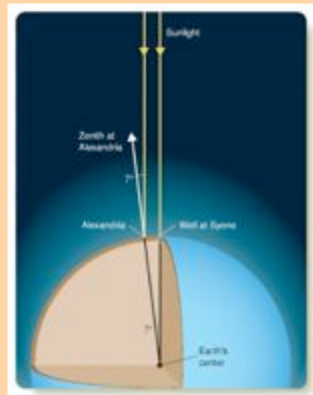
Earth as a sphere:

Circular shadow projected by Earth when it eclipses the Moon

When traveling north, new stars appeared above northern horizon, while stars previously seen along southern horizon no longer visible; reverse true traveling south

Greek Astronomy

240 BC: Eratosthenes measures the Earth's circumference



Measurements:
At noon on first day of summer,
Syene: sun directly overhead
Alexandria: sun at 7° from vertical
Syene to Alexandria
distance ≈ 5000 stadia

Calculate circumference of Earth:
7/360 × (circum. Earth) = 5000 stadia
⇒ circum. Earth = 5000 × 360/7 stadia ≈ 250,000 stadia

Compare to modern value (≈ 40,100 km):
Greek stadium ≈ 1/6 km ⇒ 250,000 stadia ≈ 42,000 km

Greek Astronomy

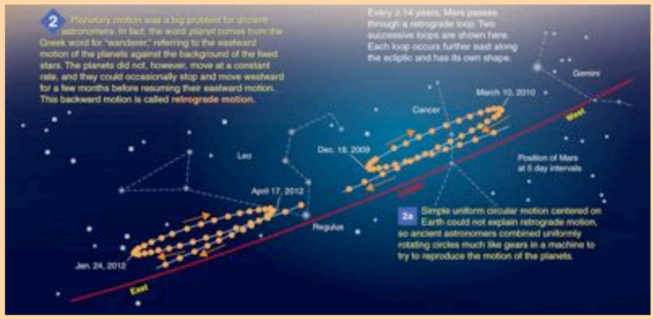
Underpinnings of the Greek **geocentric model**:

- Earth at the center of the universe
- Heavens must be "perfect": Objects moving on perfect spheres or in perfect circles.
- Aristotle supported this world view
- Hence this model lasted for 1500 years

http://topdocumentaryfilms.com/story-of-science/

Greek Astronomy

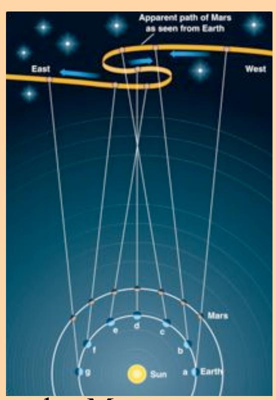
Simple geocentric models make it difficult to explain apparent **retrograde motion** of planets…



Over a period of 10 weeks, Mars appears to stop, back up, then go forward again (retrograde motion).

Greek Astronomy

The modern heliocentric model easily explains apparent **retrograde motion** of planets…



Over a period of 10 weeks, Mars appears to stop, back up, then go forward again (retrograde motion).

Greek Astronomy

Ptolemy

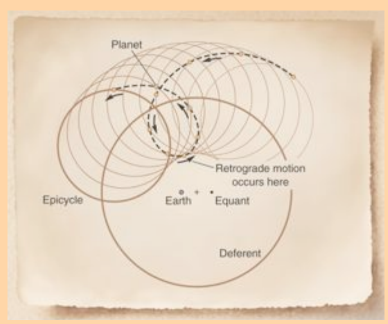
The most sophisticated geocentric model was that of Ptolemy (A.D. 100-170) — the **Ptolemaic model:**

- Sufficiently accurate to remain in use for 1,500 years.
- Ptolemy's model could handle retrograde motion

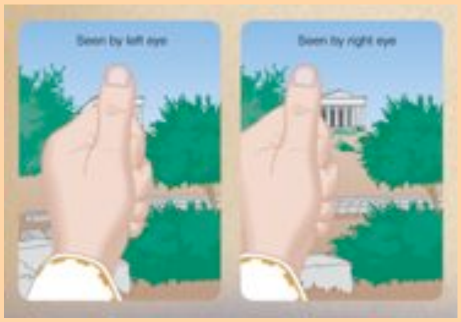
Greek Astronomy

Ptolemy's wheels within wheels: Planets move on small circles called epicycles, attached to a big circle

Planets *really do* go backward in this model..



Greek Astronomy



Ancient Greeks could not detect **parallax** which would have proved the earth's motion around the sun. Hence the geocentric model persisted for 1500 years.

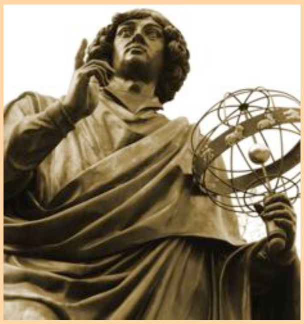
Greek Astronomy

Greek knowledge was preserved through the Middle Ages:

- Muslim world preserved and enhanced the knowledge they received from the Greeks
- Al-Mamun's House of Wisdom in Baghdad was a great center of learning around A.D. 800
- With the fall of Constantinople (Istanbul) in 1453, Eastern scholars headed west to Europe, carrying knowledge that helped ignite the European Renaissance.

The Copernican Revolution

Copernicus (1473-1543):



- Proposed Sun-centered model (published 1543)
- Used model to determine layout of solar system (planetary distances in AU)
- Driven by aesthetics rather than observations

But . . .

- Model was no more accurate than Ptolemaic model in predicting planetary positions, because it still used perfect circles.
- Not widely accepted

The Copernican Revolution

Possible influences on Copernicus

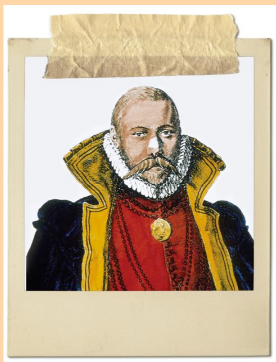
Aristarchus of Samos (Greece) in the 3rd century BC had developed the first serious model of a heliocentric solar system.
However his work did not catch on.

Aryabhatta of India anticipated Copernicus' discoveries by over 1,000 years and formulated a heliocentric model.
The 8th century Arabic edition of his work was translated into Latin.
It is likely that some of Aryabhata's results had an influence on European astronomy and on Copernicus' ideas.

Aryabhatta's description of eclipses

The Copernican Revolution

Tycho Brahe (1546-1601)



- Compiled the most accurate (one arcminute) naked eye measurements ever made of planetary positions.
- Still thought Earth must be at center of solar system (but recognized that other planets go around Sun)
- Hired Kepler, who used Tycho's observations to discover the truth about planetary motion.

The Copernican Revolution

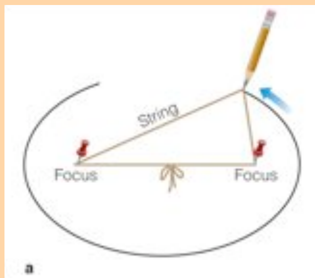
Johannes Kepler (1571-1630)

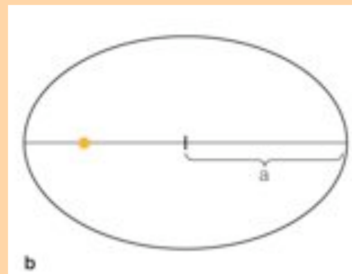
- Kepler first tried to match Tycho's observations with circular orbits
- But an 8-arcminute discrepancy led him eventually to ellipses…

"If I had believed that we could ignore these eight minutes [of arc], I would have patched up my hypothesis accordingly. But, since it was not permissible to ignore, those eight minutes pointed the road to a complete reformation in astronomy."

The Copernican Revolution

What is an ellipse?

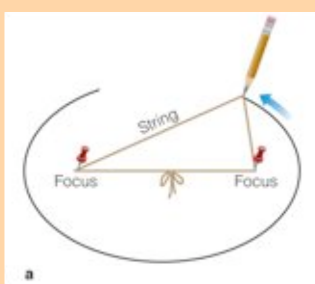


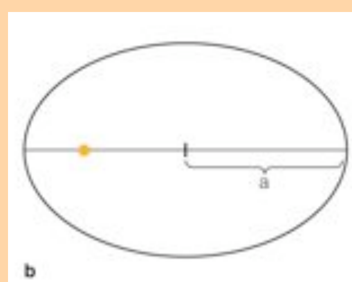


An ellipse looks like an elongated circle
Eccentricity quantifies the deviation from a perfect circle

The Copernican Revolution

What is an ellipse?



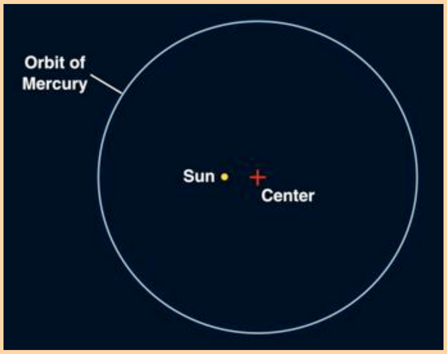


Eccentricity: e = distance between foci/major axis
Perihelion distance = (1-e) x semimajor axis
Aphelion distance = (1+e) x semimajor axis

The Copernican Revolution

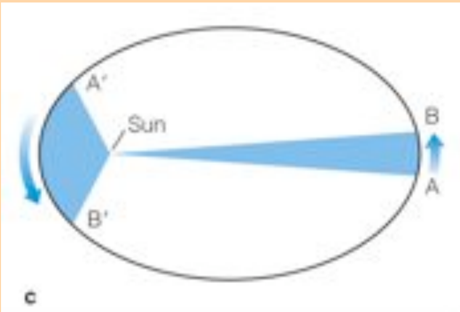
Kepler's three laws of planetary motion

Kepler's First Law: The orbit of each planet around the Sun is an ***ellipse*** with the Sun at one focus.



The Copernican Revolution

Kepler's Second Law: As a planet moves around its orbit, it sweeps out equal areas in equal times.



⇒ means that a planet travels faster when it is nearer to the Sun and slower when it is farther from the Sun.

The Copernican Revolution

Kepler's Third Law

More distant planets orbit the Sun at slower average speeds, obeying the relationship

$$p^2 = a^3$$

p = orbital period in years
a = avg. distance from Sun in AU

Thought Question:

An asteroid orbits the Sun at an average distance a = 4 AU. How long does it take to orbit the Sun?

A. 4 years
B. 8 years
C. 16 years
D. 64 years

Hint: Remember that $p^2 = a^3$

An asteroid orbits the Sun at an average distance $a = 4$ AU. How long does it take to orbit the Sun?

A. 4 years
B. 8 years
C. 16 years
D. 64 years

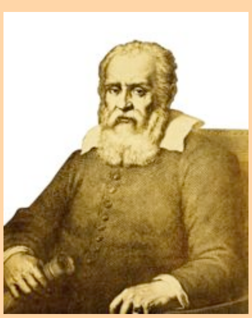
We need to find p so that $p^2 = a^3$

Since $a = 4$, $a^3 = 4^3 = 64$

Therefore $p = 8$, $p^2 = 8^2 = 64$

The Copernican Revolution

Galileo solidified the Copernican revolution



Galileo (1564-1642) overcame major objections to Copernican view. Three key objections rooted in Aristotelian view were:

1. Earth could not be moving because objects in air would be left behind.
2. Non-circular orbits are not "perfect" as heavens should be.
3. If Earth were really orbiting Sun, we'd detect stellar parallax.

The Copernican Revolution

Overcoming the first objection (nature of motion):

Galileo's experiments with rolling balls showed that objects in air would stay with a moving Earth.

- Aristotle thought that all objects naturally come to rest.
- Galileo showed that objects will stay in motion unless a force acts to slow them down (**Newton's first law of motion**).
- Hence objects moving with the earth would stay with the earth

The Copernican Revolution

Overcoming the second objection (heavenly perfection):

- Tycho's observations of comet and supernova already challenged this idea.
- Using his telescope, Galileo saw:
    - Sunspots on Sun ("imperfections")
    - Mountains and valleys on the Moon (proving it is not a perfect sphere)

The Copernican Revolution

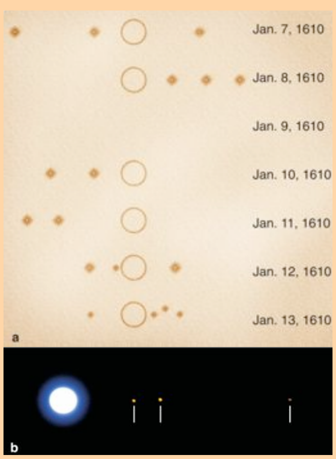
<u>Overcoming the third objection (parallax):</u>

• Tycho *thought* he had measured stellar distances, so lack of parallax seemed to rule out an orbiting Earth.

• Galileo showed stars must be much farther than Tycho thought — in part by using his telescope to see the Milky Way is countless individual stars.

✓ If stars were much farther away, then lack of detectable parallax was no longer so troubling.

The Copernican Revolution

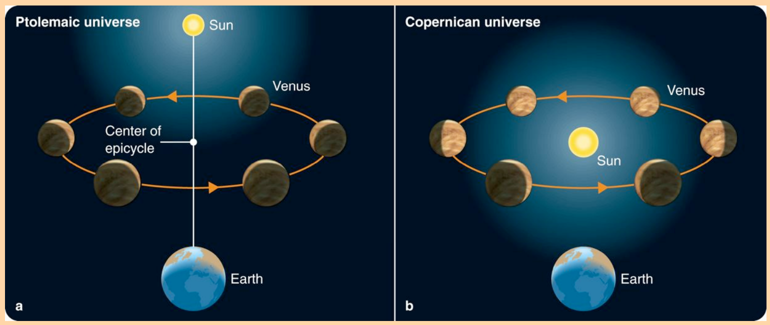


The moons of Jupiter

Galileo also saw four moons orbiting Jupiter, proving that not all objects orbit the Earth

The Copernican Revolution

Galileo's observations of phases of Venus proved that it orbits the Sun and not Earth.



Geocentric model: Only full and crescent phases of Venus observable
Heliocentric model: All phases of Venus observable as confirmed by Galileo

The Copernican Revolution

The Catholic Church ordered Galileo to recant his claim that Earth orbits the Sun in 1633

His book on the subject was removed from the Church's index of banned books in 1824

Galileo was formally vindicated by the Church in 1992

The Beginning of Modern Astronomy

Copernicus created a sun-centered model of the solar system

Tycho Brahe provided the data needed to improve this model

Kepler found a model that fit Tycho's data

- 1. The orbit of each planet is an ellipse with the Sun at one focus
- 2. As a planet moves around its orbit it sweeps our equal areas in equal times
- 3. More distant planets orbit the Sun at slower average speeds: $p^2 = a^3$

Galileo's experiments and observations overcame the remaining objections to the Sun-centered solar system

What is a scientific theory?

- The word theory has a different meaning in science than in everyday life.
- In science, a theory is NOT the same as a hypothesis or opinion, rather:
- A ***scientific theory*** must:
  - Explain a wide variety of observations with a few simple principles, AND
  - Must be supported by a large, compelling body of evidence.
  - Must NOT have failed any crucial test of its validity.

Summary

- What did ancient civilizations achieve in astronomy?
  - Daily timekeeping
  - Tracking the seasons and calendar
  - Monitoring lunar cycles
  - Monitoring planets and stars
  - Predicting eclipses
  - Ancient astronomers observations were useful
    - for practical purposes, including agriculture
    - for religious and ceremonial purposes
  - Aid to navigation

Summary

- What is the Copernican Revolution ?

Copernicus created a sun-centered model of the solar system

Tycho Brahe provided the data needed to improve this model

Kepler found a model that fit Tycho's data

- 1. The orbit of each planet is an ellipse with the Sun at one focus
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