Chapter 3
The Science of Astronomy

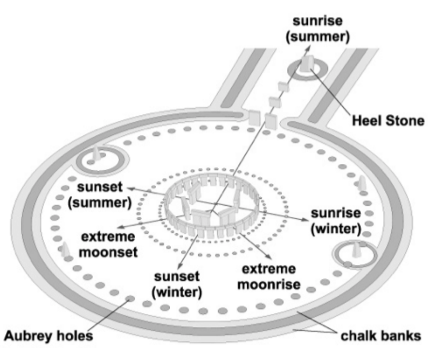
3.1 What did ancient civilizations achieve in astronomy?

- Daily timekeeping
- Tracking the seasons and calendar
- Monitoring lunar cycles
- Monitoring planets and stars
- Predicting eclipses
- Navigation

Object	*Teutonic Name*	*English*	*French*	*Spanish*
Sun	Sun	Sunday	dimanche	domingo
Moon	Moon	Monday	lundi	lunes
Mars	Tiw	Tuesday	mardi	martes
Mercury	Woden	Wednesday	mercredi	miércoles
Jupiter	Thor	Thursday	jeudi	jueves
Venus	Fria	Friday	vendredi	viernes
Saturn	Saturn	Saturday	samedi	sábado

Days of week were named for Sun, Moon, and *visible* planets

England: Stonehenge (completed around 1550 B.C.)



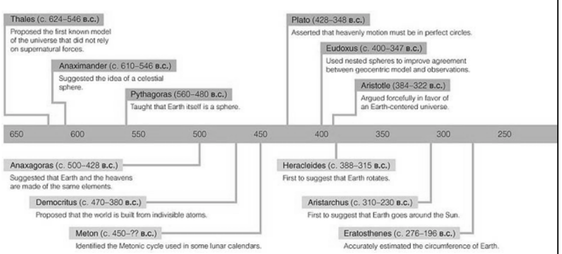
England: Stonehenge (1550 B.C.)

Macchu Pichu, Peru: Structures aligned with solstices.

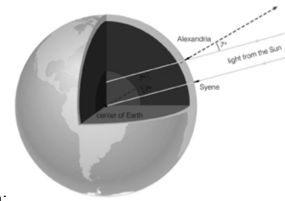
South Pacific: Polynesians were very skilled in art of celestial navigation

3.2 Ancient Greek Science

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



Special Topic: Eratosthenes measures the Earth (c. 240 BC)



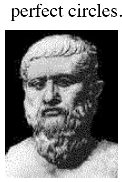
<u>Measurements:</u>
Syene to Alexandria
distance ≈ 5000 stadia
angle = 7°

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

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

How did the Greeks explain planetary motion?

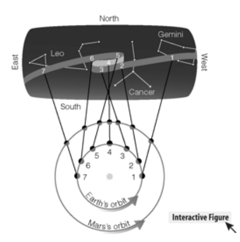
- Earth at the center of the universe: **geocentric model**
- Heavens must be "perfect": Objects moving on perfect spheres or in perfect circles.



Plato

Aristotle

But this made it difficult to explain apparent retrograde motion of planets…



Review: Over a period of 10 weeks, Mars appears to stop, back up, then go forward again.

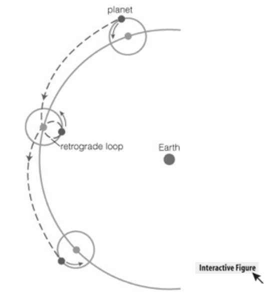
Ptolemy

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.

• Arabic translation of Ptolemy's work named *Almagest* ("the greatest compilation")

So how does the Ptolemaic model explain retrograde motion? Planets *really do* go backward in this model..



3.3 How did Copernicus, Tycho, and Kepler challenge the Earth-centered idea?

Copernicus (1473-1543):

• Proposed Sun-centered model (published 1543)
• Used model to determine layout of solar system (planetary distances in AU)

But . . .

• Model was no more accurate than Ptolemaic model in predicting planetary positions, because it still used perfect circles for orbits.

Tycho Brahe (1546-1601)

• Compiled the most accurate (one arcminute) naked eye measurements ever made of planetary positions.

• Still could not detect stellar parallax, and thus 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.

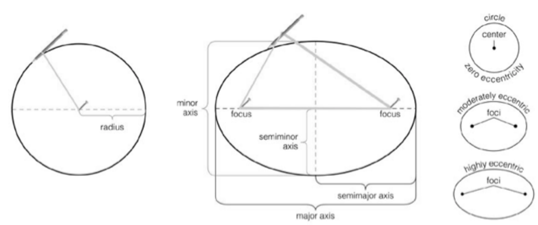
Johannes Kepler (1571-1630)

• 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."

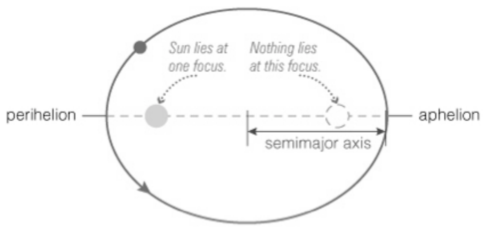
What is an ellipse?



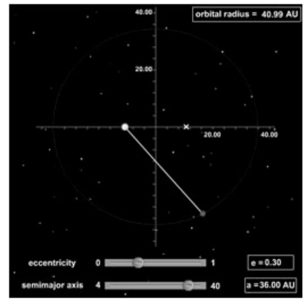
An ellipse looks like an elongated circle

What are Kepler’s three laws of planetary motion?

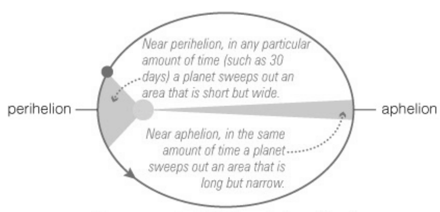
Kepler’s First Law: The orbit of each planet around the Sun is an ***ellipse*** with the Sun at one focus.



Eccentricity of an Ellipse



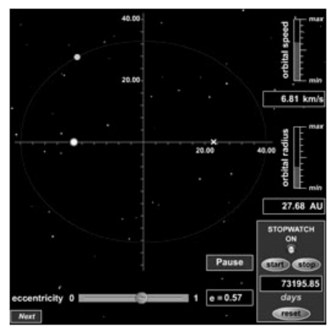
Kepler’s Second Law: As a planet moves around its orbit, it sweeps out equal areas in equal times.



The areas swept out in 30-day periods are all equal.

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

Kepler’s Second Law



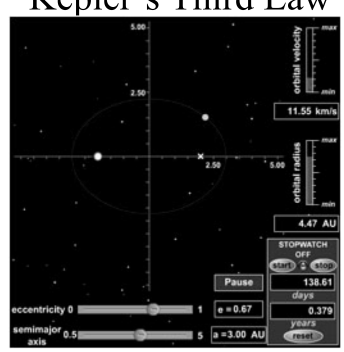
Kepler’s Third Law:

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

Kepler’s Third Law



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?

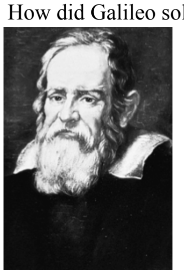
A. 4 years
B. 8 years
C. 16 years
D. 64 years

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

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

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

How did Galileo solidify the Copernican revolution?



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

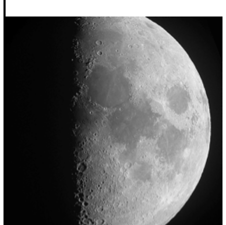
1. Earth could not be moving because objects in air would be left behind.
2. Non-circular orbits are not "perfect" as heavens should be.
3. If Earth were really orbiting Sun, we'd detect stellar parallax.

Overcoming the first objection (nature of motion):

Galileo's experiments 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).

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")

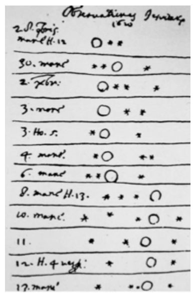
  • Mountains and valleys on the Moon (proving it is not a perfect sphere)

Overcoming the third objection (parallax):

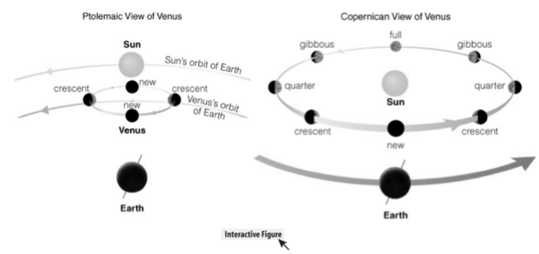
• Tycho *thought* he had measured stellar distances, so lack of parallax seemed to rule out an orbiting Earth.

• 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.

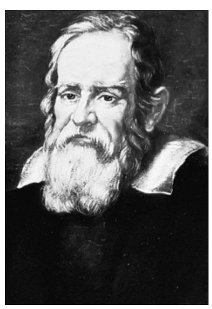
✓ If stars were much farther away, then lack of detectable parallax was no longer so troubling.



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



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



Galileo Galilei

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.

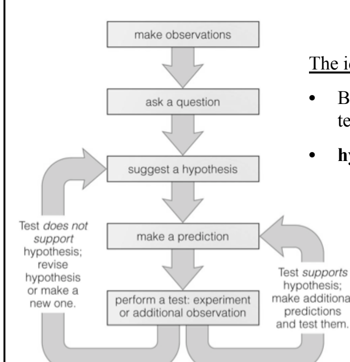
Galileo was formally vindicated by the Church in 1992.

What have we learned?

- How did Copernicus, Tycho and Kepler challenge the Earth-centered idea?
  - Copernicus created a sun-centered model; Tycho provided the data needed to improve this model; Kepler found a model that fit Tycho's data
- What are Kepler's three laws of planetary motion?
  - 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: $p^2 = a^3$

What have we learned?

- What was Galileo's role in solidifying the Copernican revolution?
  - His experiments and observations overcame the remaining objections to the Sun-centered solar system



<u>The idealized scientific method</u>

- Based on proposing and testing hypotheses
- **hypothesis** = educated guess

But science rarely proceeds in this idealized way. For example:

- Sometimes we start by “just looking” then coming up with possible explanations.
- Sometimes we follow our intuition rather than a particular line of evidence.

Hallmark of Science: #1

Modern science seeks explanations for observed phenomena that rely solely on natural causes.

(A scientific model cannot include divine intervention)

Hallmark of Science: #2

Science progresses through the creation and testing of models of nature that explain the observations as simply as possible.

(Simplicity = “Occam’s razor”)

Hallmark of Science: #3

A scientific model must make testable predictions about natural phenomena that would force us to revise or abandon the model if the predictions do not agree with observations.

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, 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.

Thought Question

Darwin’s theory of evolution meets all the criteria of a scientific theory. This means:

A. Scientific opinion is about evenly split as to whether evolution really happened.
B. Scientific opinion runs about 90% in favor of the theory of evolution and about 10% opposed.
C. After more than 100 years of testing, Darwin’s theory stands stronger than ever, having successfully met every scientific challenge to its validity.
D. There is no longer any doubt that the theory of evolution is absolutely true.

Next time:

- Chapter S1:
  Celestial Time Keeping and Navigation
  please read pages 84 – 103 in text.