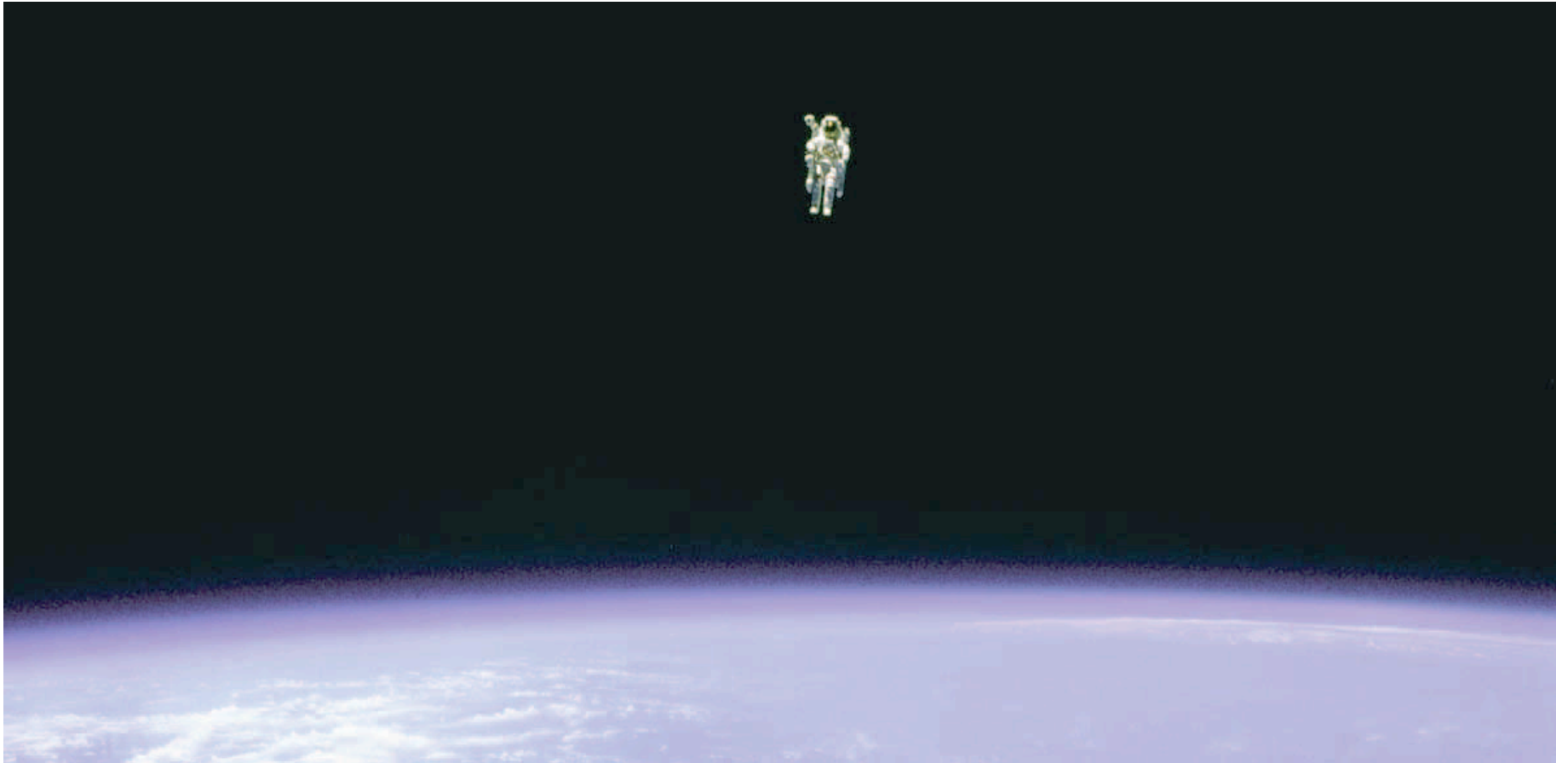


Chapter 3

The Science of Astronomy



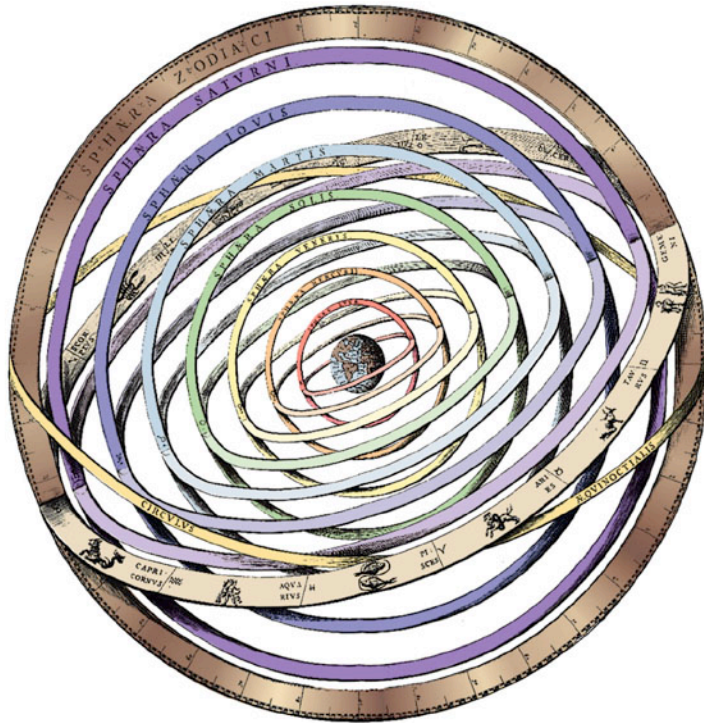
<i>Object</i>	<i>Teutonic Name</i>	<i>English</i>	<i>French</i>	<i>Spanish</i>
Sun	Sun	Sunday	dimanche	domingo
Moon	Moon	Monday	lundi	lunes
Mars	Tiw	Tuesday	mardi	martes
Mercury	Woden	Wednesday	mercredi	miércoles
Jupiter	Thor	Thursday	jeudi	jueves
Venus	Fria	Friday	vendredi	viernes
Saturn	Saturn	Saturday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

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

What did ancient civilizations achieve in astronomy?

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

Why does modern science trace its roots to the Greeks?



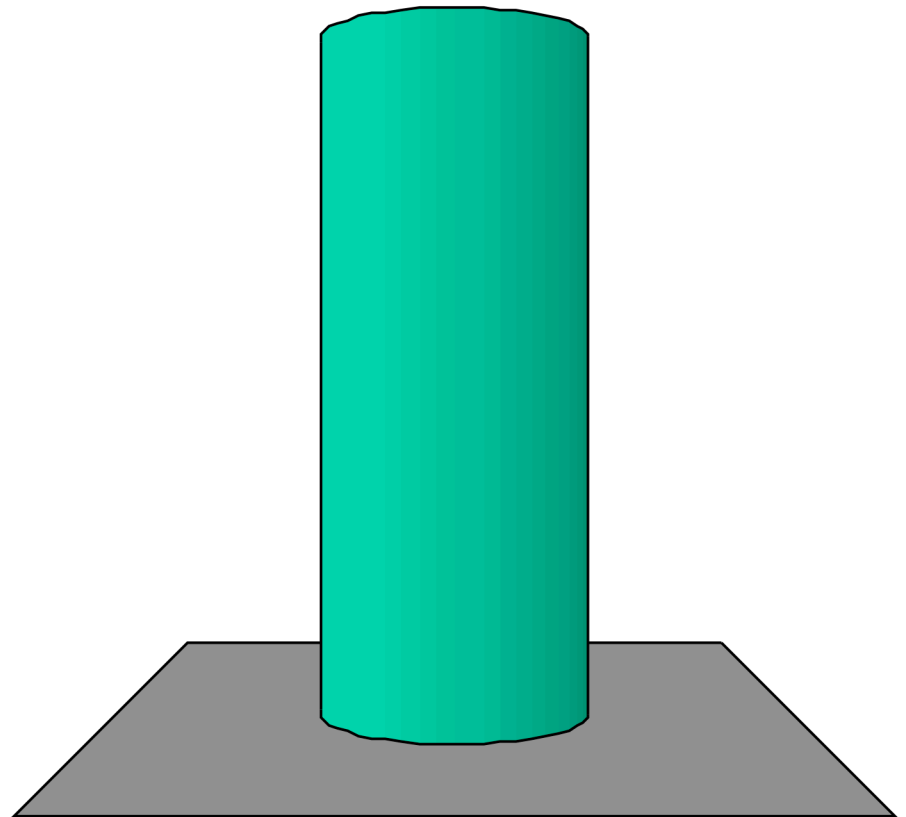
- Greeks were the first people known to make *models* of nature.
- They tried to explain patterns in nature without resorting to myth or the supernatural.

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

What is the circumference of the Earth? (approximate)

1. Around 100 miles
2. Around 1000 miles
3. Around 5000 miles
4. Around 20,000 miles
5. Around 100,000 miles
6. Around 1 million miles

100%

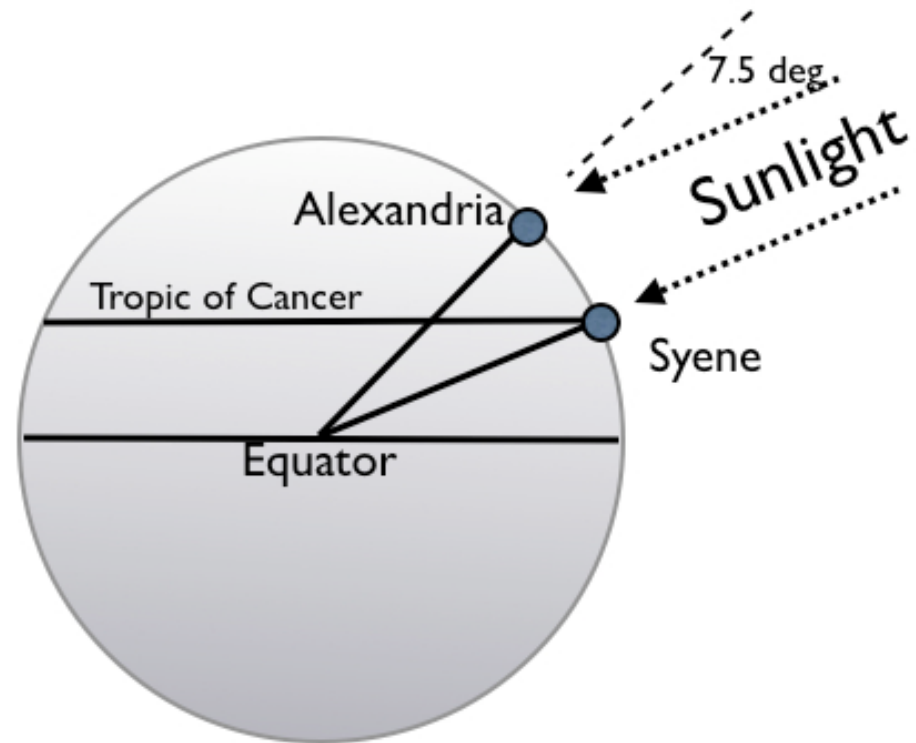


Shape of the Earth

- Greeks (500 BC)
- Pythagoras - round because sphere is perfect
- Aristotle because of shape of shadow on moon (eclipse)
- Also going South you see new stars

Eratosthenes 240 B.C.

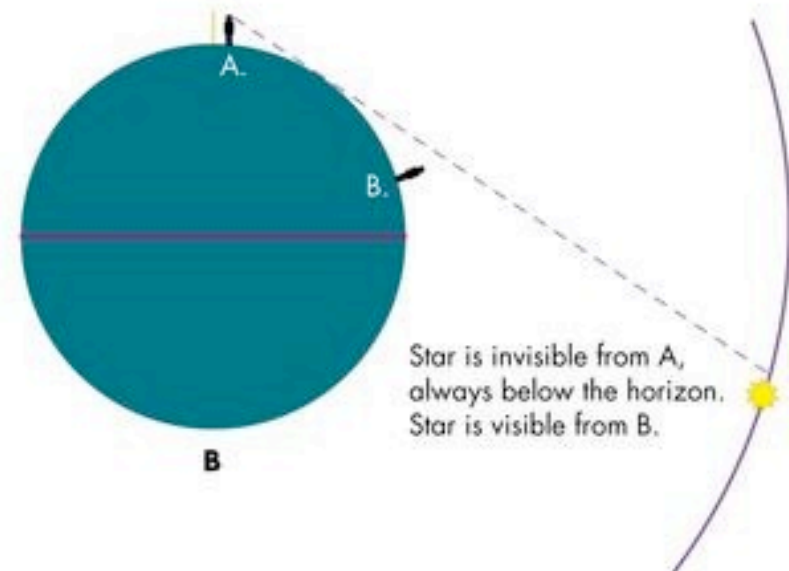
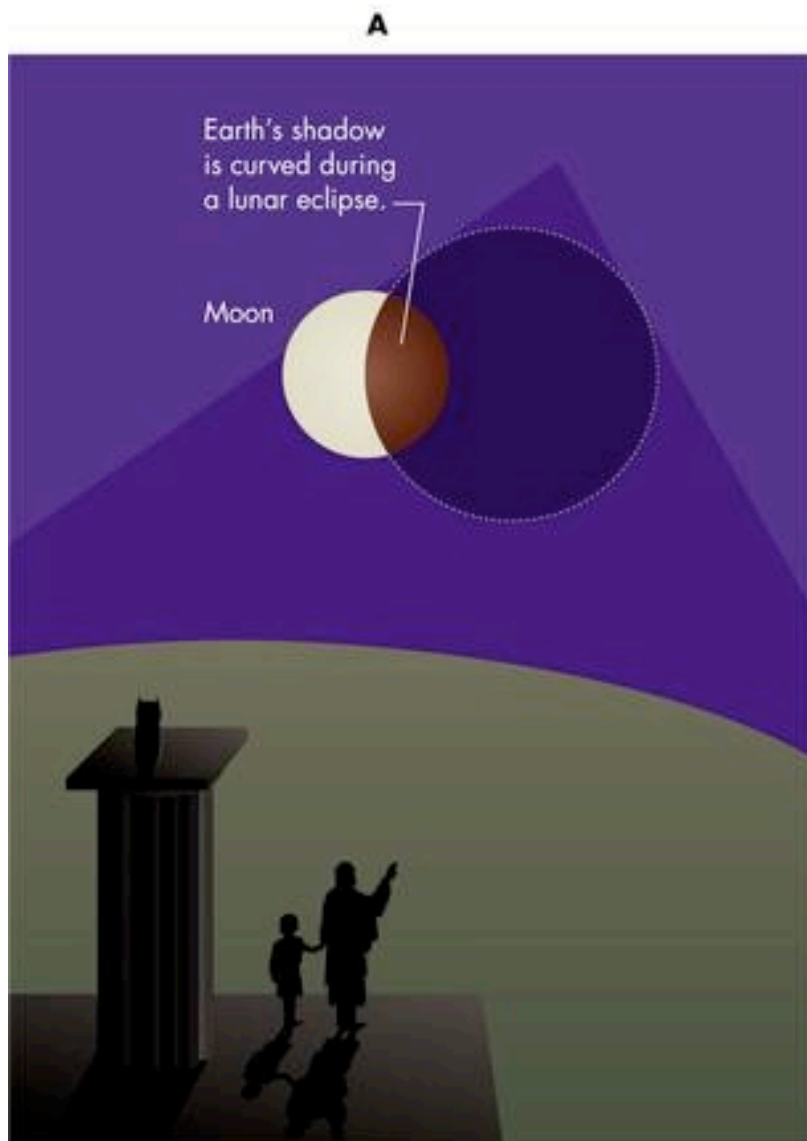
- Calc a circumference of 25,000 mi
- Ptolemy later - 18,000 mi



Syene - Alexandria = 500 miles

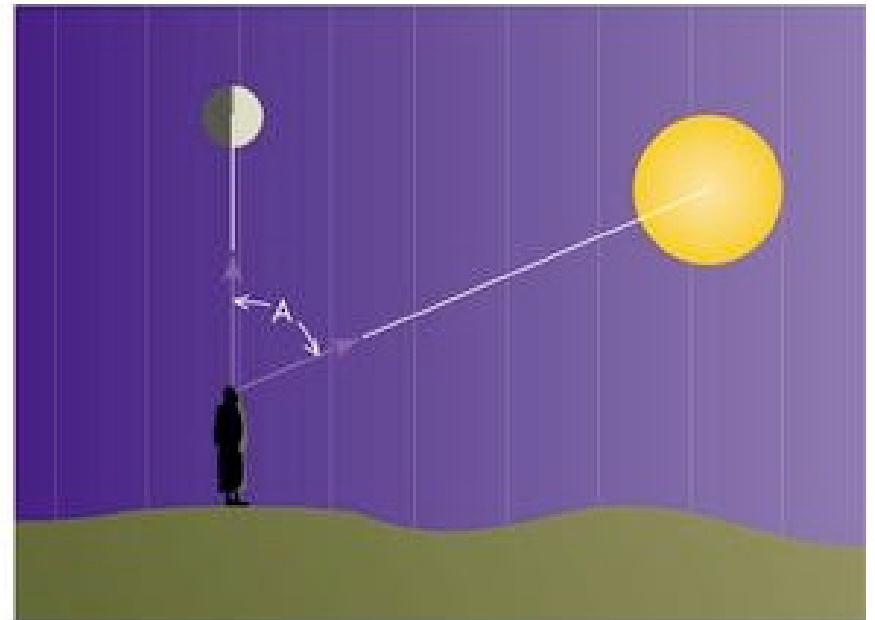
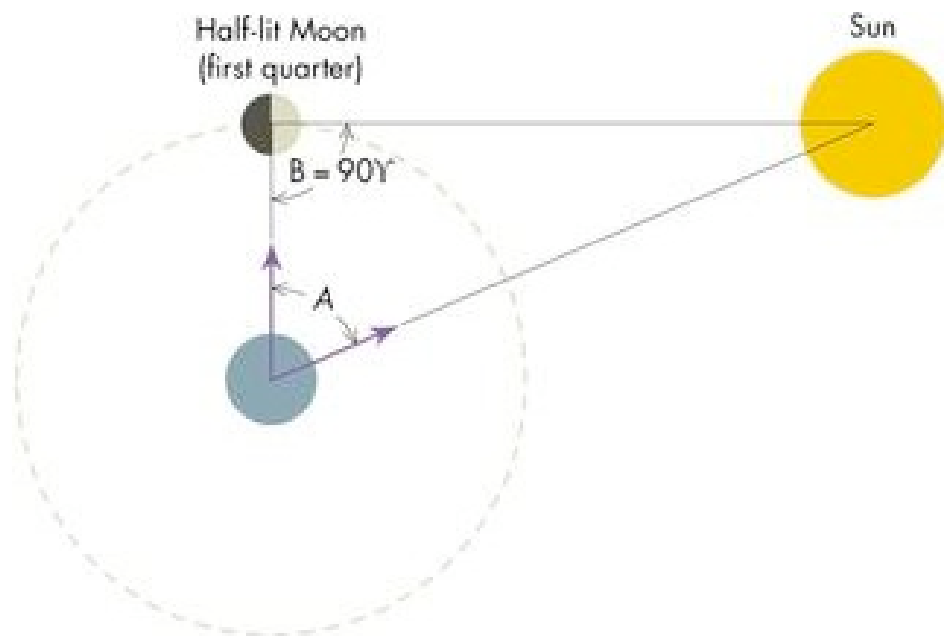
Distance to moon

- Hipparchus of Nicea (150 B.C.)
- Used Earth's shadow during eclipse
- Geometry to determine distance of moon in terms of Earth's diameter
- Answer: distance = 30 times Earth's diameter (about correct)



Aristarchus

- Distance to the Sun
- Used geometric method that was valid, but difficult to measure (small angles)
- Answer: Sun is 20 times as far as moon (wrong, it is 400 times as far)
- Anyway, this means the sun is very large
- Thus earth must revolve around sun
- No one listened to him



Development of Science

- Greeks: Deductive Reasoning is the way
- Start with the obvious and work to the specifics
- Logic is the authority
- Good for geometry
- The way of Aristotle

Inductive Reasoning

- Galileo Galilei, Francis Bacon, Tycho Brahe
- Starts with the specifics (observations) and generalizes upwards
- Data is the authority

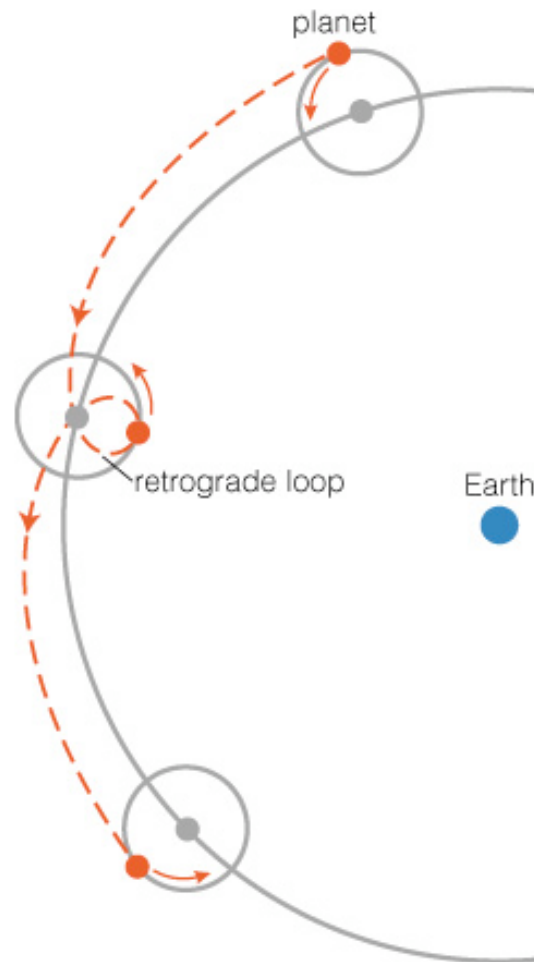


Ptolemy

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”)

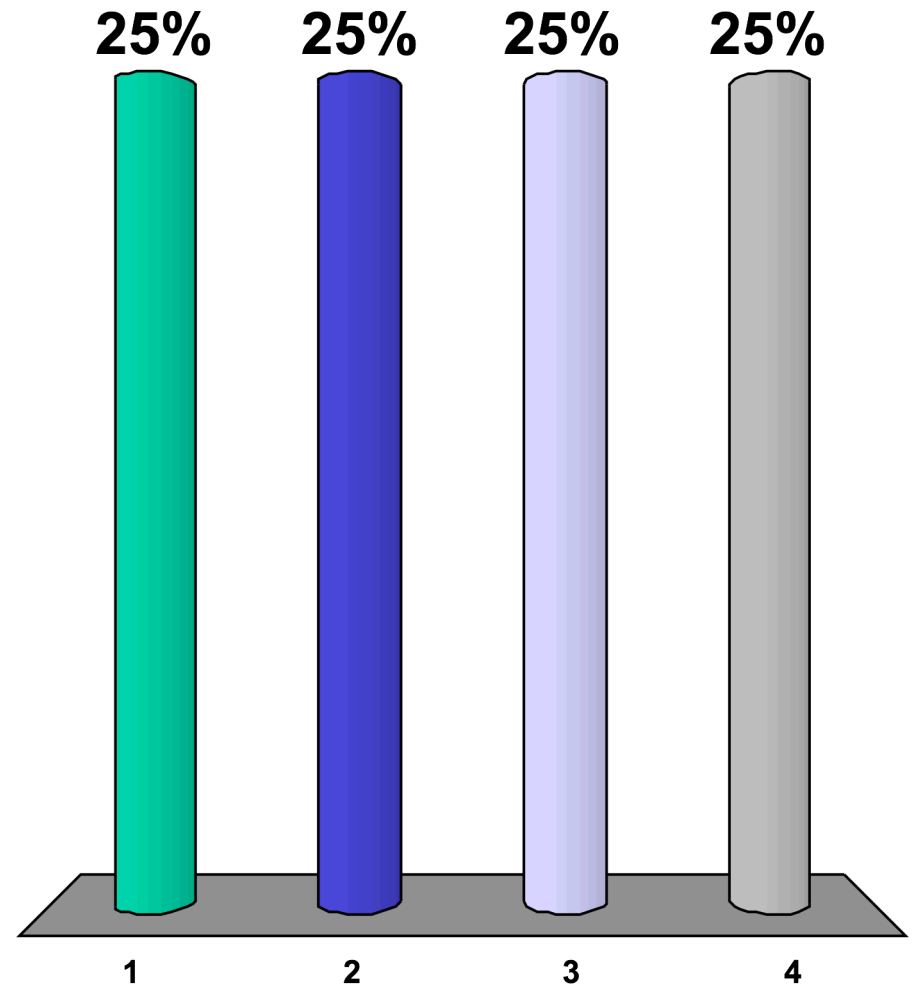
So how does the Ptolemaic model explain retrograde motion?
Planets *really do* go backward in this model.



Ptolemaic Model

Which of the following is NOT a fundamental difference between the geocentric and Sun-centered models of the solar system?

1. Earth is stationary in the geocentric model but moves around Sun in Sun-centered model.
2. Retrograde motion is real (planets really go backward) in geocentric model but only apparent (planets don't really turn around) in Sun-centered model.
3. Stellar parallax is expected in the Sun-centered model but not in the Earth-centered model.
4. The geocentric model is useless for predicting planetary positions in the sky, while even the earliest Sun-centered models worked almost perfectly.



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

Copernicus (1473–1543):



- He proposed the Sun-centered model (published 1543).
- Modeled layout of Solar system

But . . .

- Still used circle

Tycho Brahe (1546–1601)



© 2005 Pearson Education, Inc., publishing as Addison Wesley

- Brahe compiled the most accurate (one arcminute) naked eye measurements ever made of planetary positions.
- No stellar parallax
- He hired Kepler - worked on data

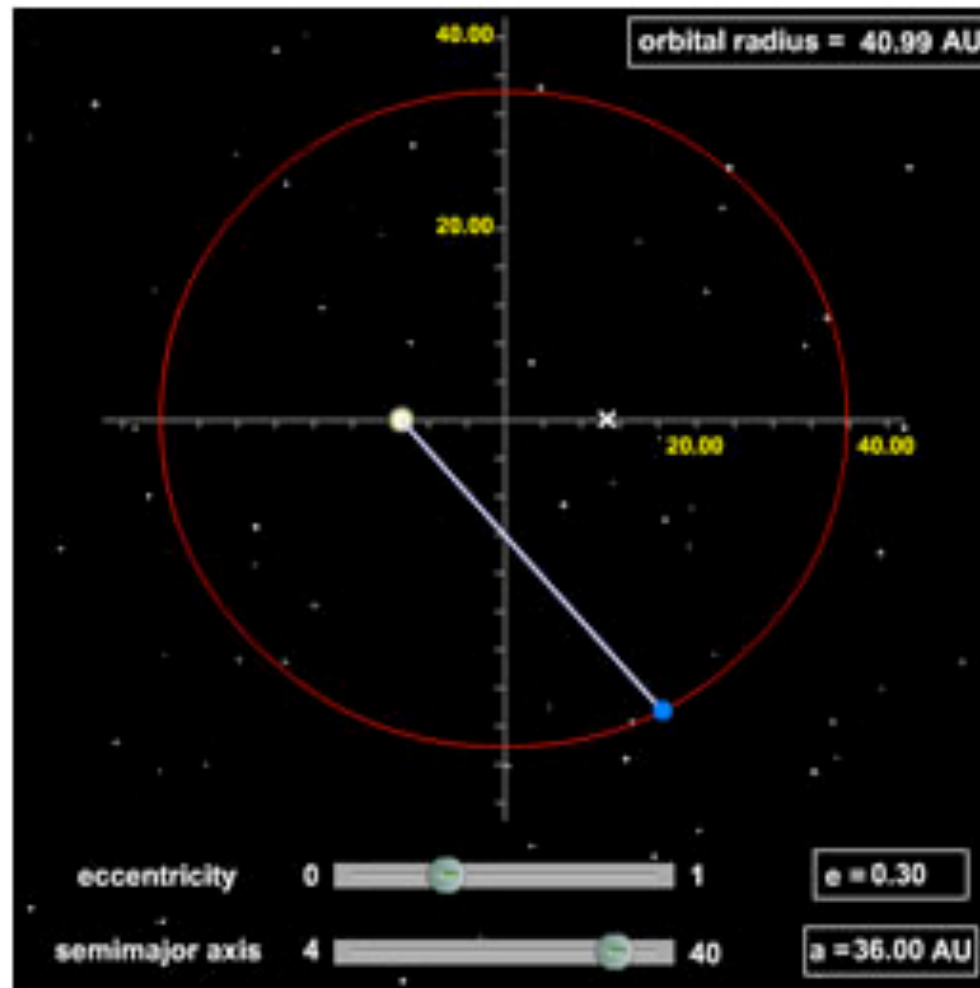


Johannes Kepler
(1571–1630)

- 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.”

Eccentricity of an Ellipse

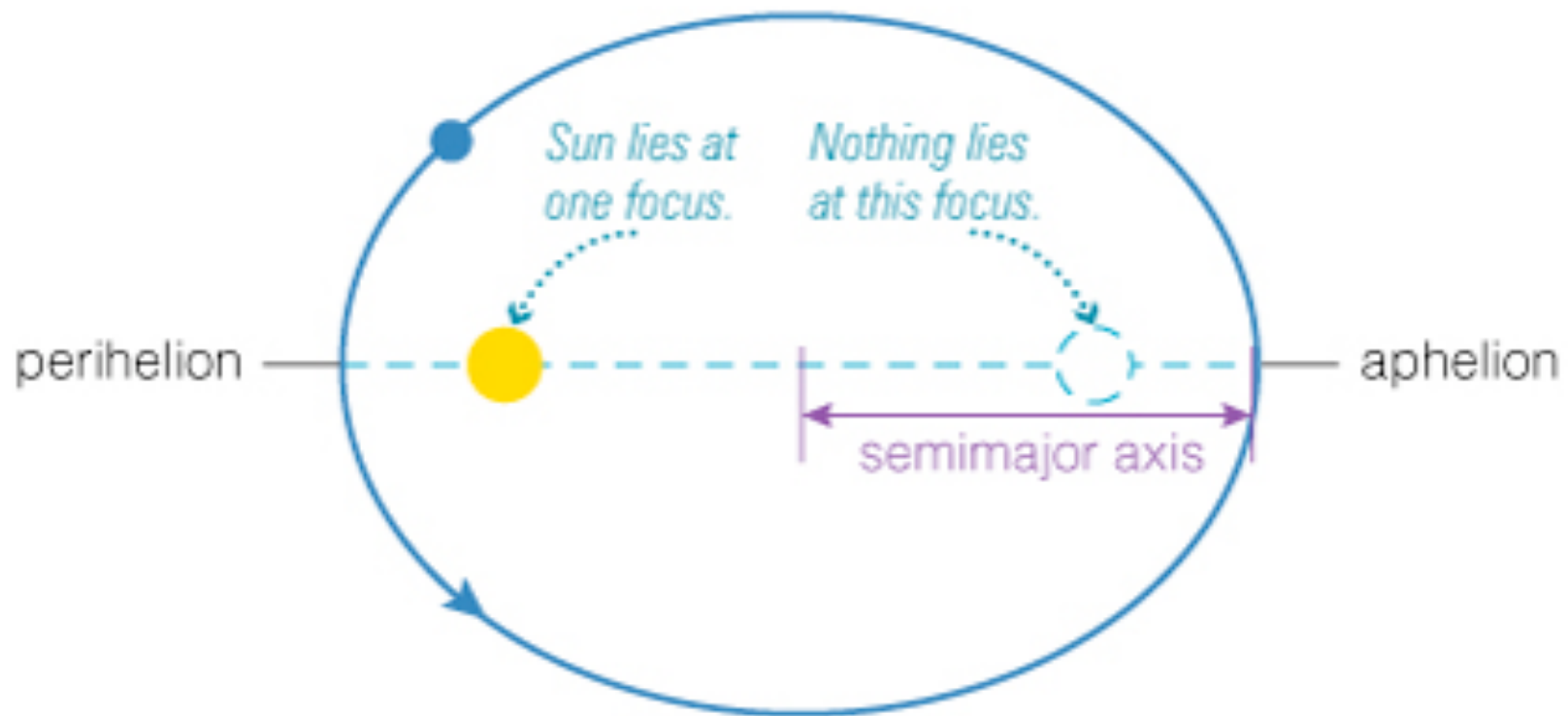


PLAY

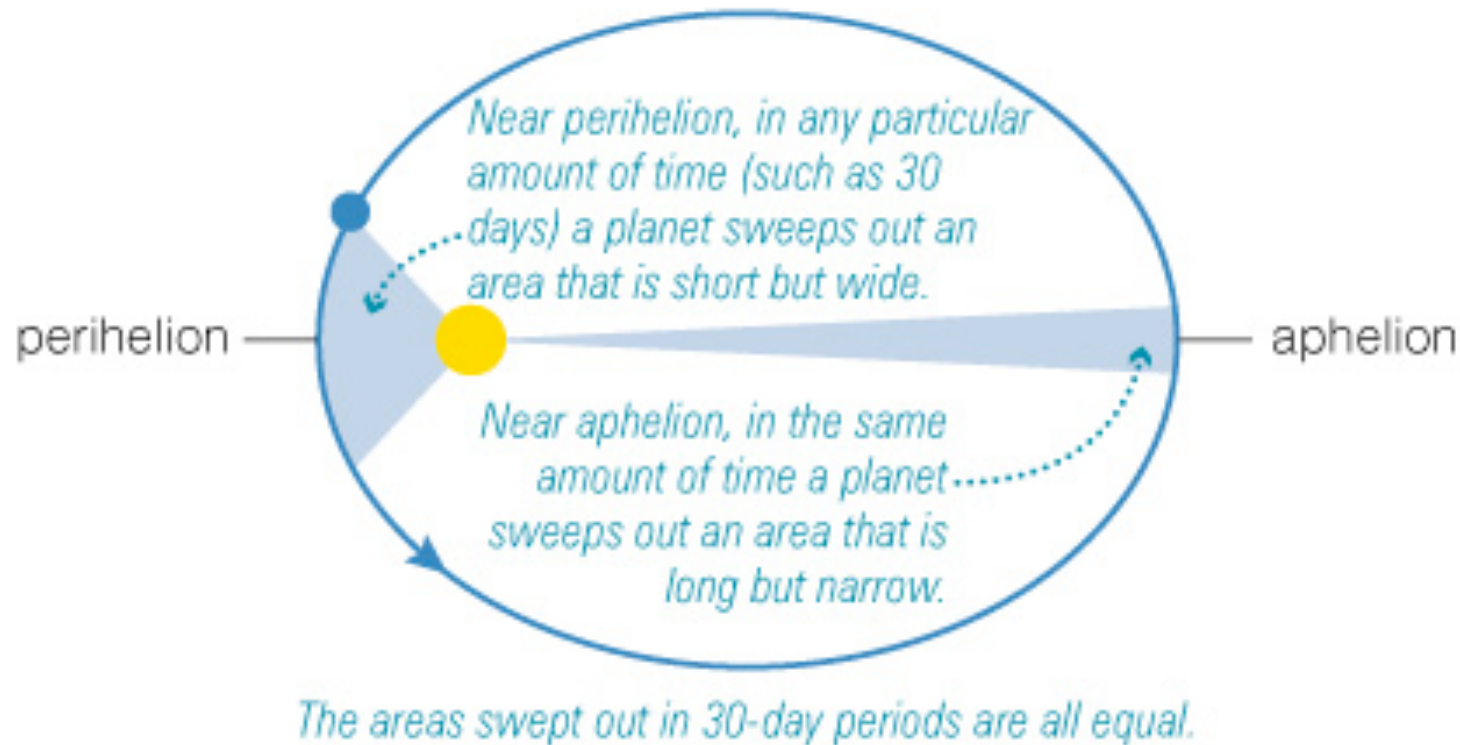
Eccentricity and Semimajor Axis of an Ellipse

What are Kepler's three laws of planetary motion?

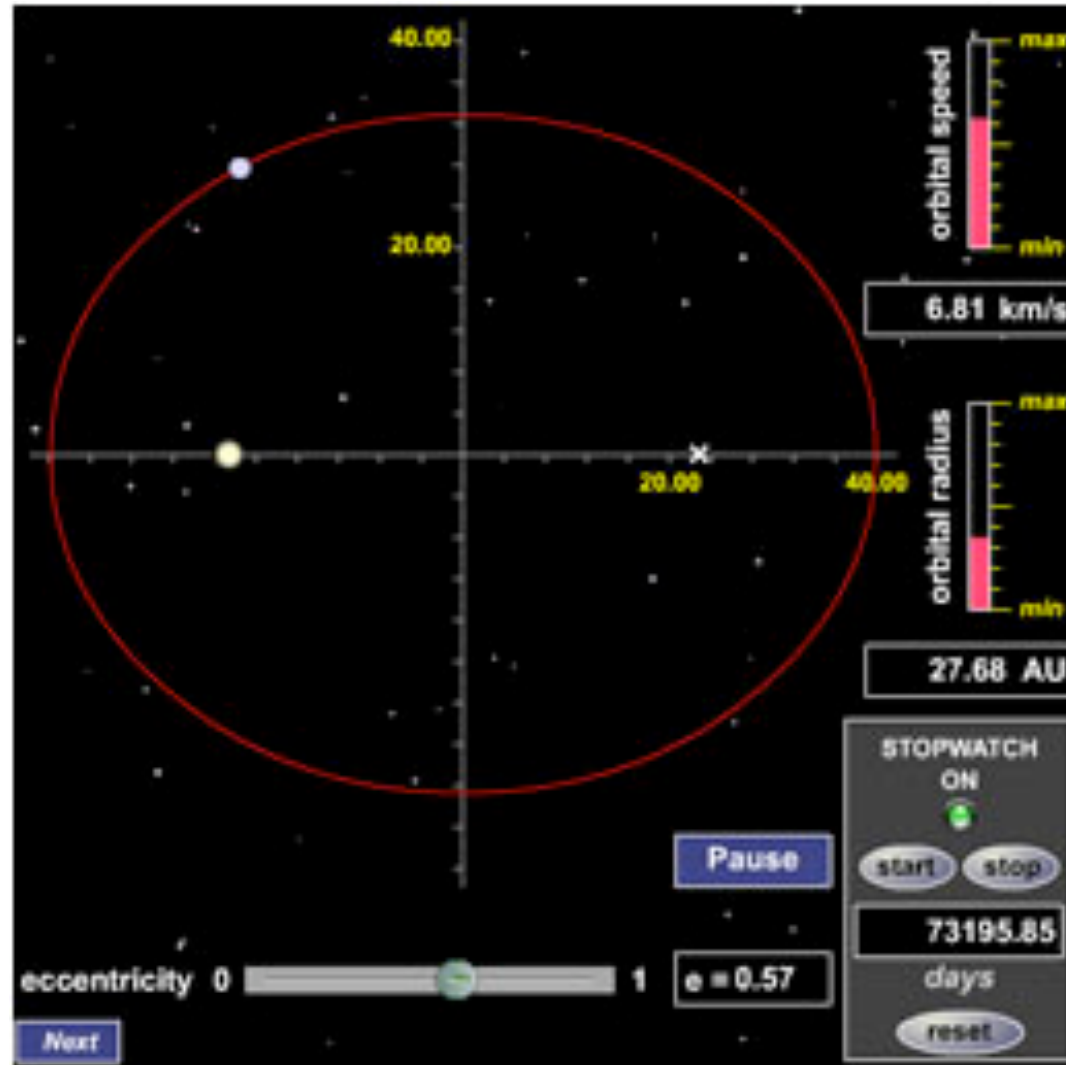
Kepler's First Law: The orbit of each planet around the Sun is an *ellipse* with the Sun at one focus.



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



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



Kepler's 2nd Law

Kepler's Third Law

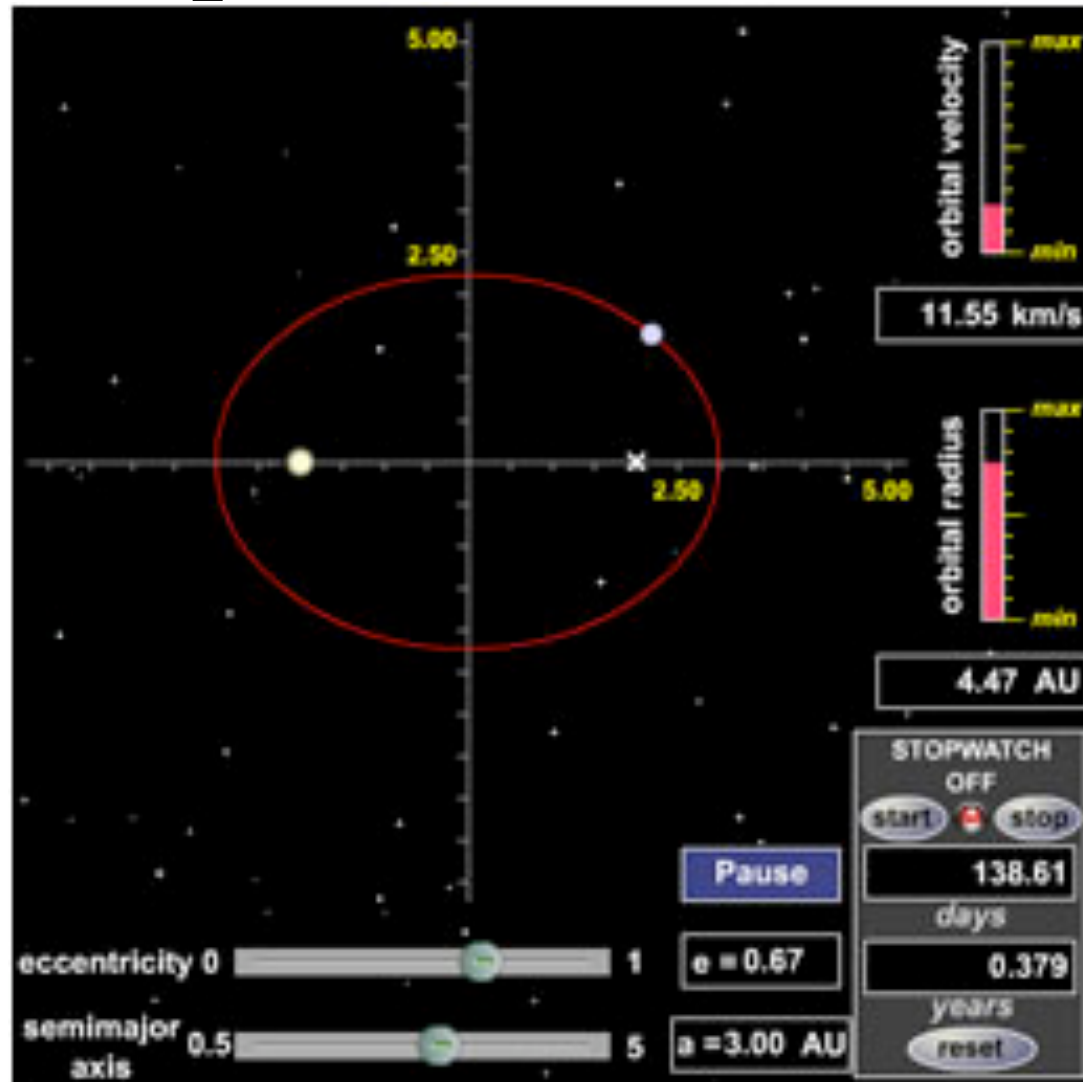
More distant planets orbit the Sun at slower average speeds, obeying the relationship

$$p^2 = a^3$$

p = orbital period in years

a = average distance from Sun in AU

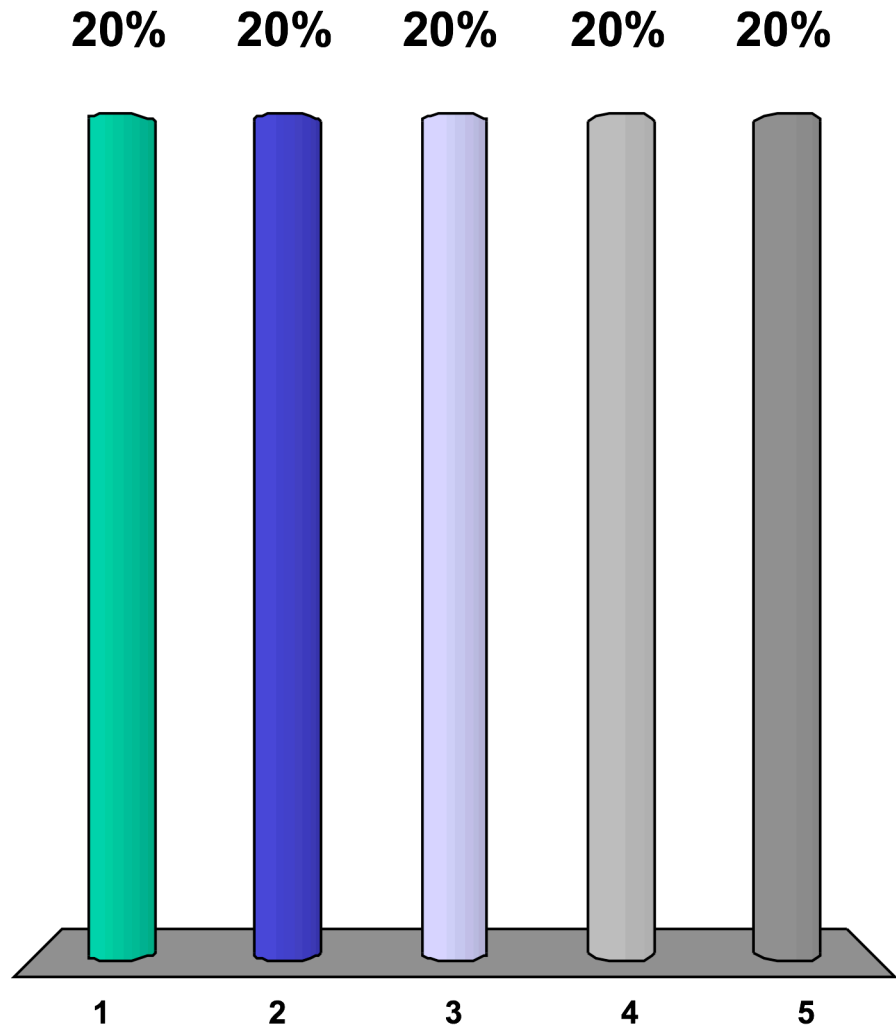
Kepler's Third Law



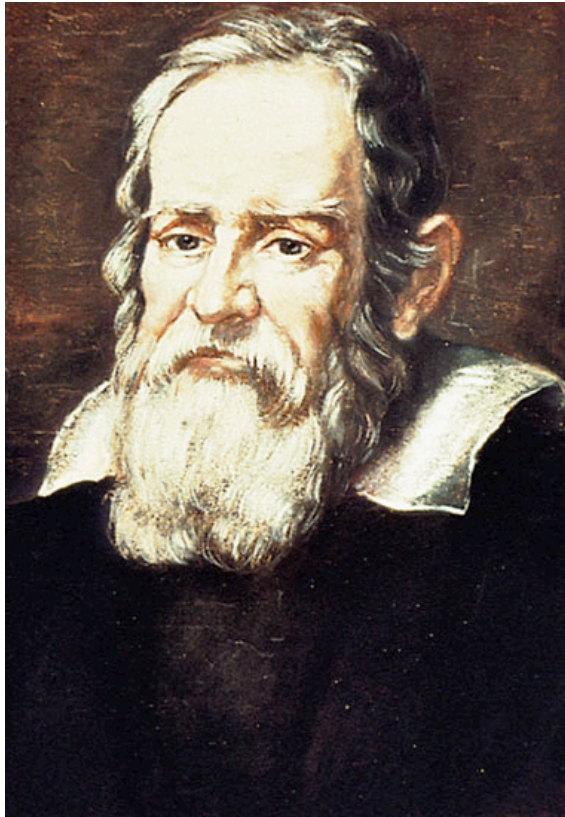
Kepler's 3rd Law

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

1. 4 years
2. 8 years
3. 16 years
4. 64 years
5. (Hint: Remember that $p^2 = a^3$.)



How did Galileo solidify the Copernican revolution?



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

1. Earth could not be moving because objects in air would be left behind.
2. Noncircular 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):



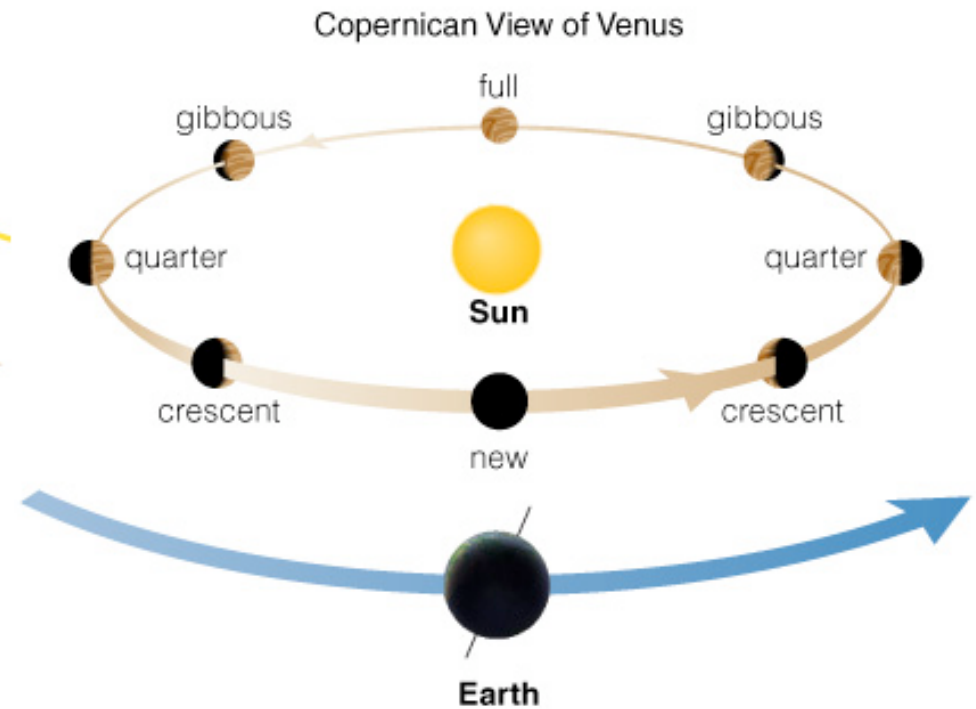
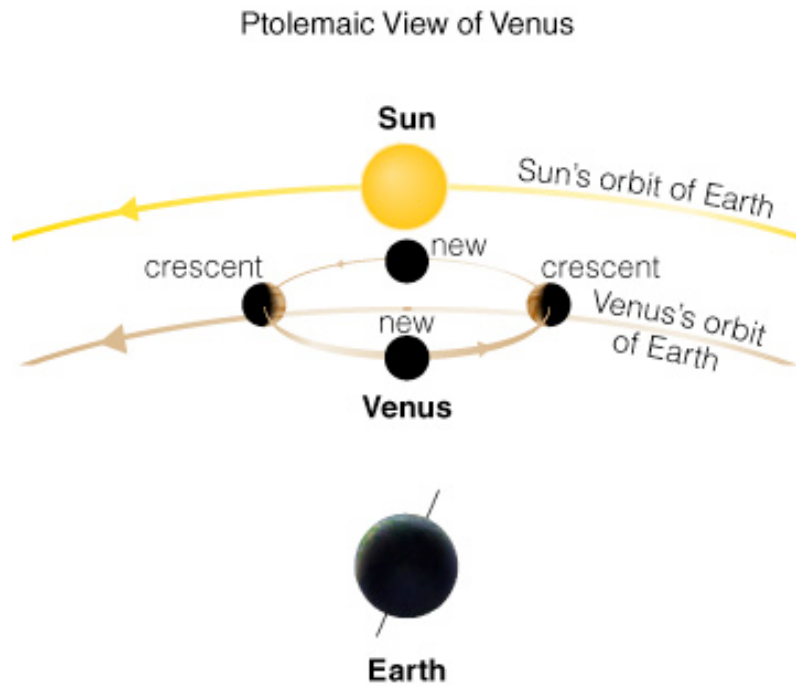
- Tycho's observations of comet and supernova already challenged this idea.
- Using his telescope, Galileo saw:
 - Sunspots on Sun (“imperfections”)
 - Mountains and valleys on the Moon (proving it is not a perfect sphere)

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 that the Milky Way is countless individual stars.
- ✓ If stars were much farther away, then lack of detectable parallax was no longer so troubling.

Observations Jupiter 1610				
2. J. Jovis. marc H. 12	○	*	*	
30. marc	*	*	○	*
2. J. Jovis.	○	*	*	*
3. marc	○	*	*	
3. Ho. s.	*	○	*	
4. marc	*	○	*	*
6. marc	*	*	○	*
8. marc H. 13.	*	*	*	○
10. marc.	*	*	*	○
11.	*	*	○	*
12. H. 4. ugh.	*		○	*
13. marc	*	*	○	*

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



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



Phases of Venus

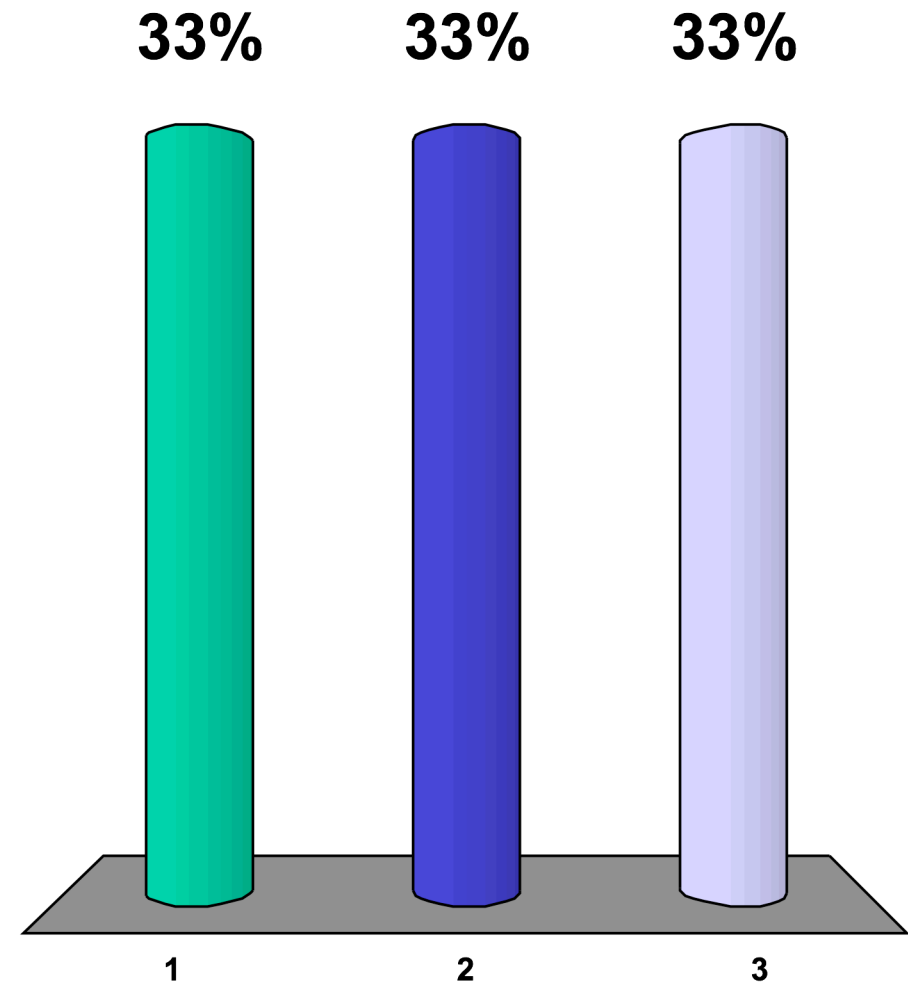


Which planet moves faster?

1. Earth
2. Venus
3. Neither, they both move at the same rate.



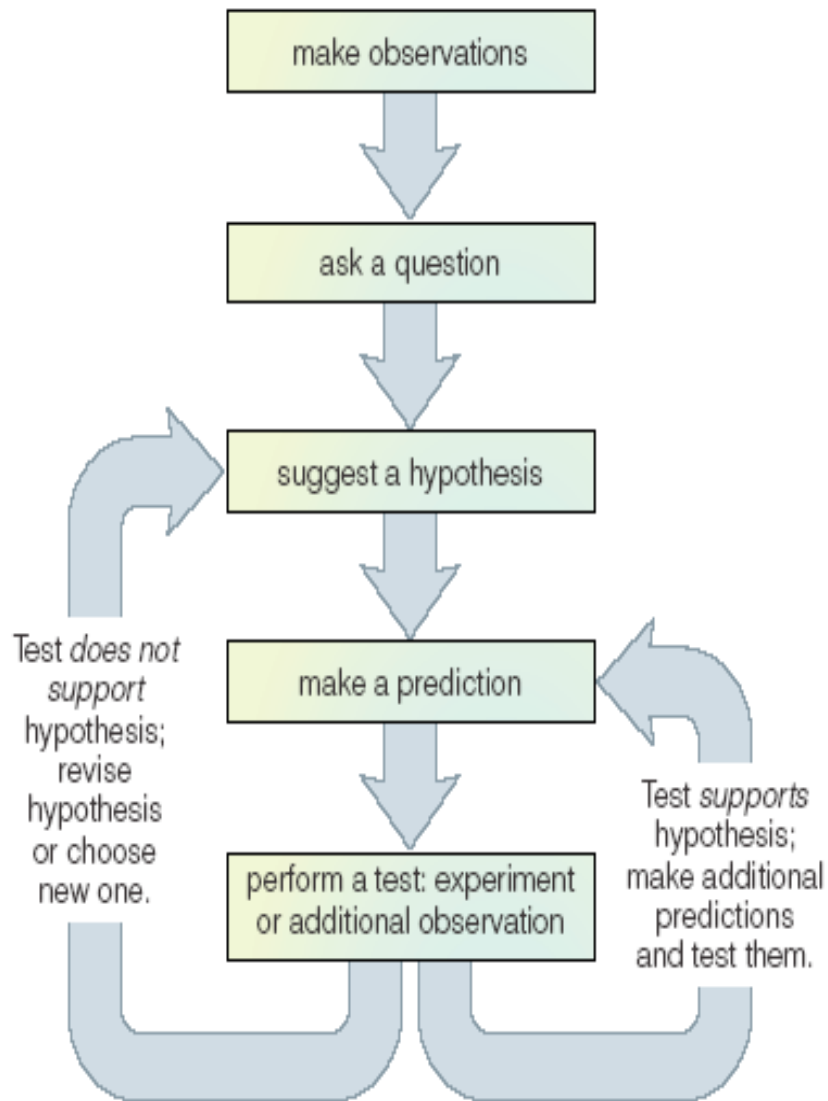
Phases Venus



3.4 The Nature of Science

Our goals for learning:

- How can we distinguish science from nonscience?
- What is a scientific theory?



The idealized scientific method:

- Based on proposing and testing hypotheses
- **hypothesis** = model

Hallmarks of Science: #1

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

(A scientific model cannot include divine intervention.)

Hallmarks 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”)

Hallmarks of Science: #3

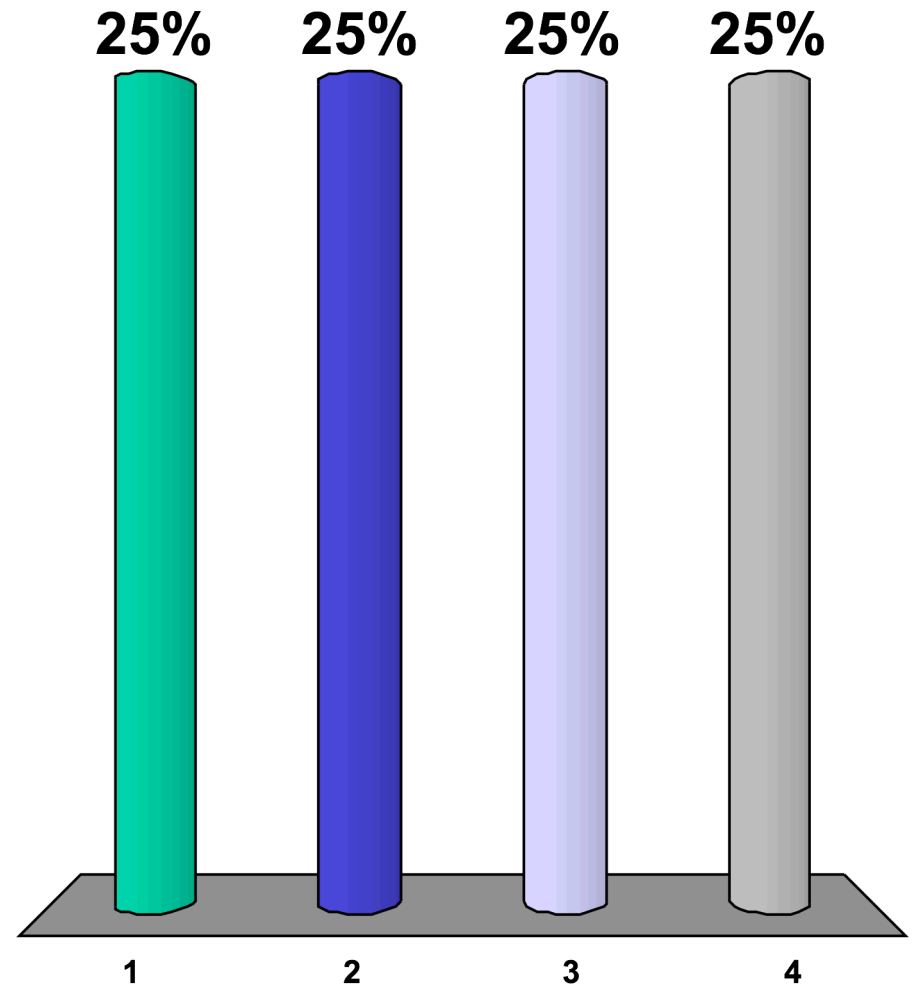
A scientific model must make testable predictions about natural phenomena that would force us to revise or abandon the model if the predictions do not agree with observations.

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.
- A ***scientific theory*** must:
 - Explain a wide variety of observations with a few simple principles
 - Be supported by a large, compelling body of evidence
 - NOT have failed any crucial test of its validity

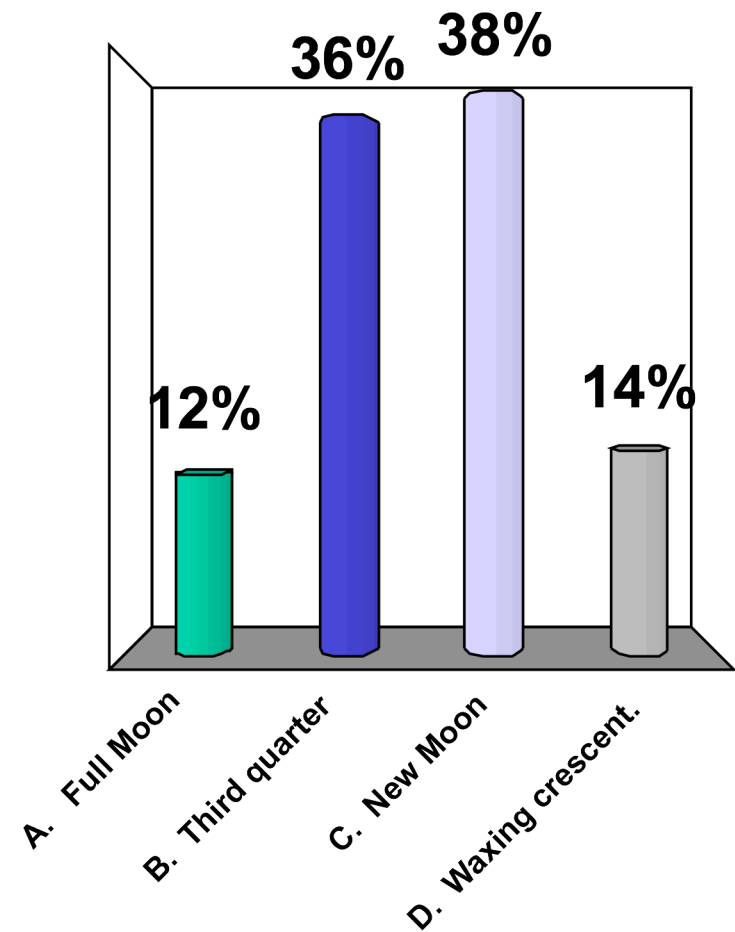
Darwin's theory of evolution meets all the criteria of a scientific theory.
This means:

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



Which phase of the Moon do you expect to see setting at sunset?

1. A. Full Moon
2. B. Third quarter
3. C. New Moon
4. D. Waxing crescent.



Which of the following statements describes the ecliptic?

1. The line of the solar and lunar eclipses on the celestial sphere **37%**
2. The elliptical shape of the Earth's orbit around the Sun
3. The extension of the Earth's path on the celestial sphere **26%**
4. The apparent path of the Sun across the celestial sphere
5. Both C and D are correct.

