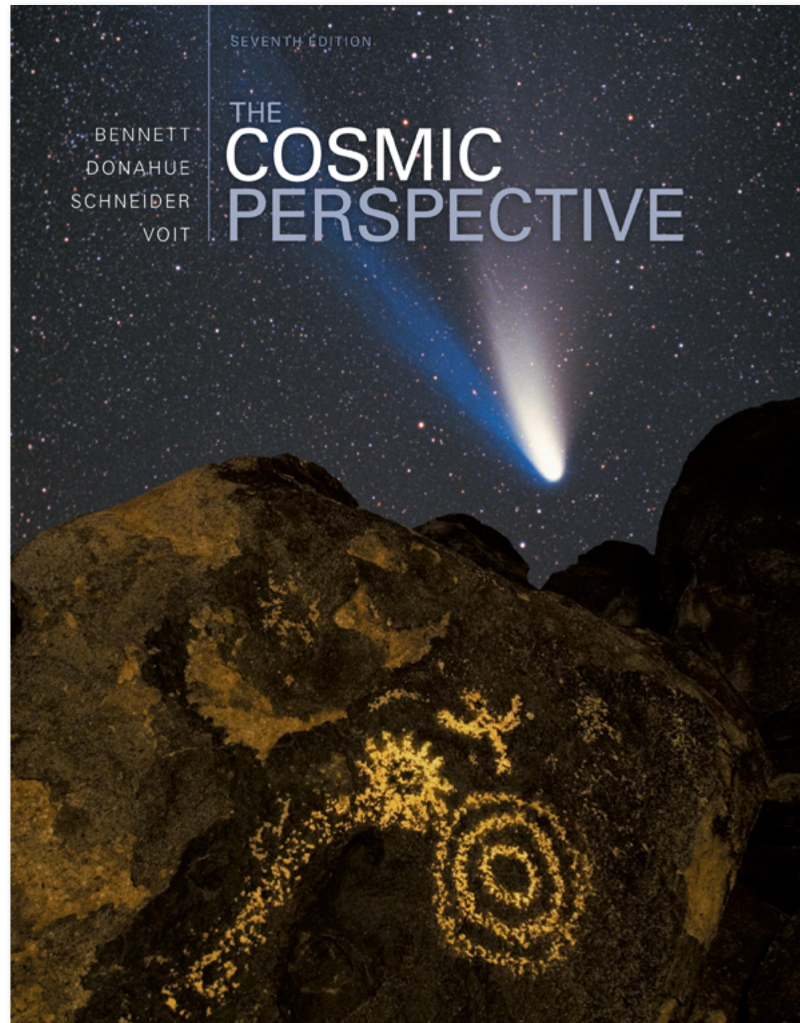
Chapter 3 Lecture

The Cosmic Perspective

Seventh Edition



The Science of Astronomy

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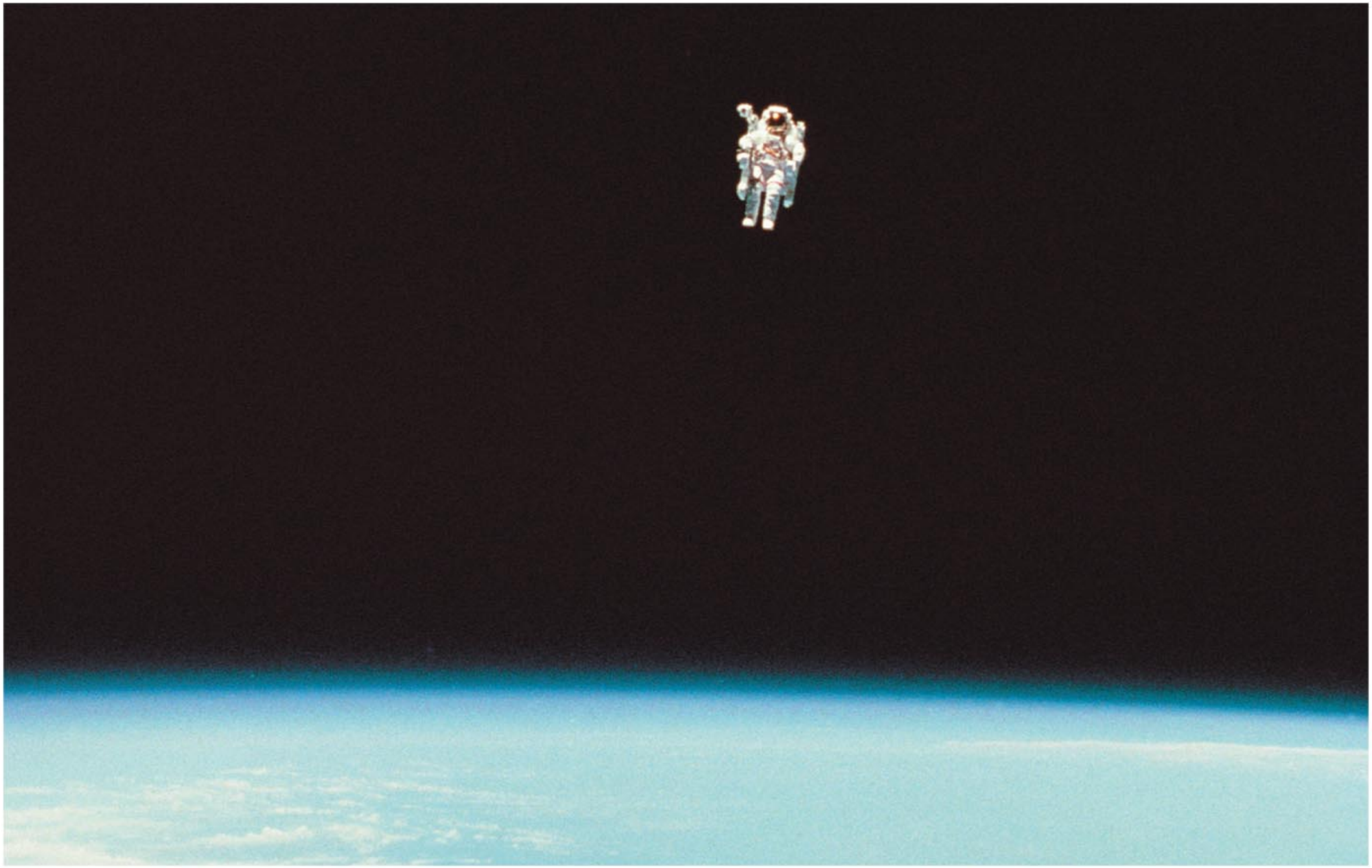


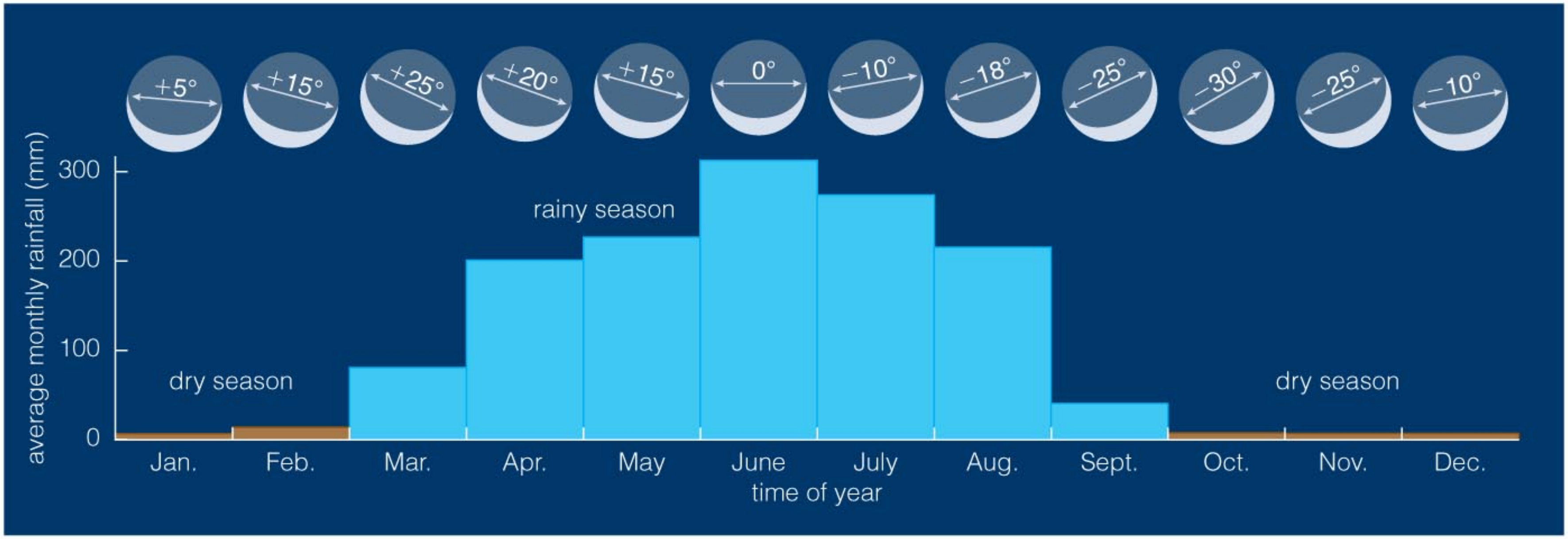
3.1 The Ancient Roots of Science

- Our goals for learning:
  - **How is modern science rooted in ancient astronomy?**

How is modern science rooted in ancient astronomy?

- Many of our current systems had their roots in the achievements of ancient astronomy
  - Daily timekeeping
  - Tracking the seasons
  - Calendar
  - Monitoring lunar cycles
  - Monitoring planets and stars
  - Predicting eclipses
  - And more…

How is modern science rooted in ancient astronomy?



- Ancient people of central Africa (6500 BC) could predict seasons from the orientation of the crescent Moon.

How is modern science rooted in ancient astronomy?

TABLE 3.1 The Seven Days of the Week and the Astronomical Objects They Honor

The seven days were originally linked directly to the seven objects. The correspondence is no longer perfect, but the overall pattern is clear in many languages; some English names come from Germanic gods.

Object	Germanic God	English	French	Spanish
Sun	—	Sunday	dimanche	domingo
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	—	Saturday	samedi	sábado

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

How is modern science rooted in ancient astronomy?

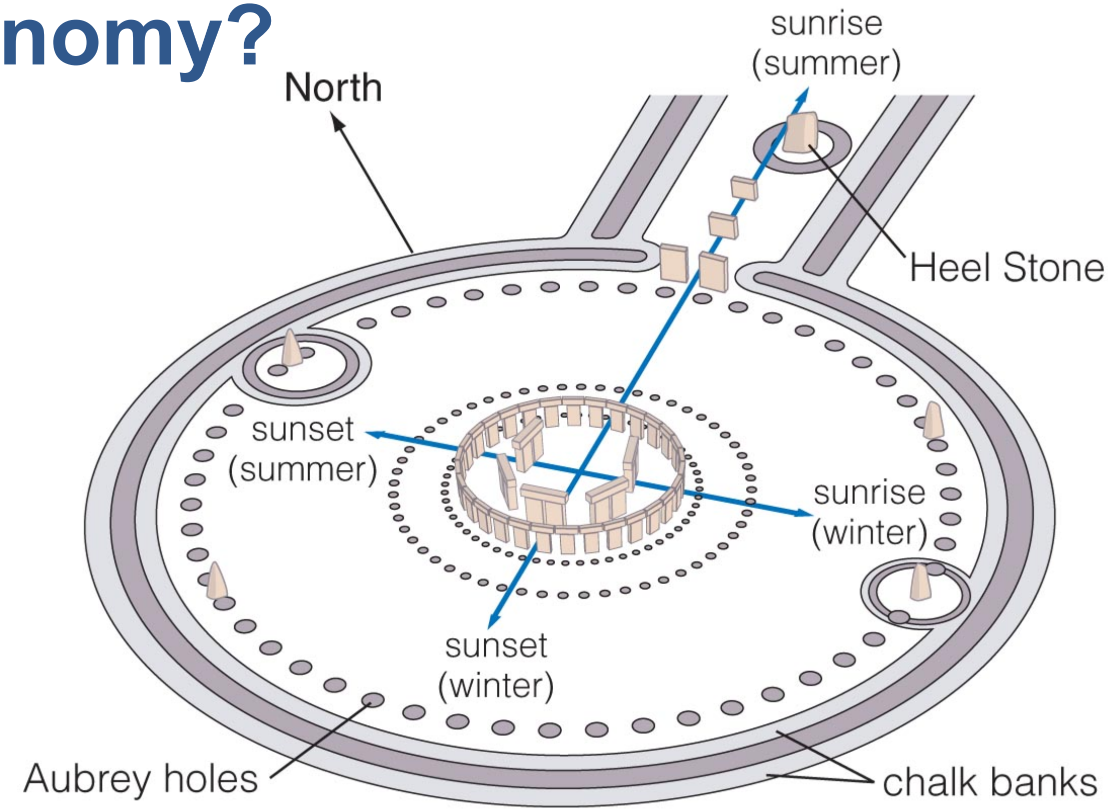
- Egyptian obelisk: Shadows tell time of day.

How is modern science rooted in ancient astronomy?

a The remains of Stonehenge today.

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

How is modern science rooted in ancient astronomy?



b This sketch shows how archaeologists believe Stonehenge looked upon its completion in about 1550 B.C. Several astronomical alignments are shown as they appear from the center. For example, the Sun rises directly over the Heel Stone on the summer solstice.

- England: Stonehenge (1550 B.C.)

How is modern science rooted in ancient astronomy?

- SW United States: "Sun Dagger" marks summer solstice

How is modern science rooted in ancient astronomy?

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

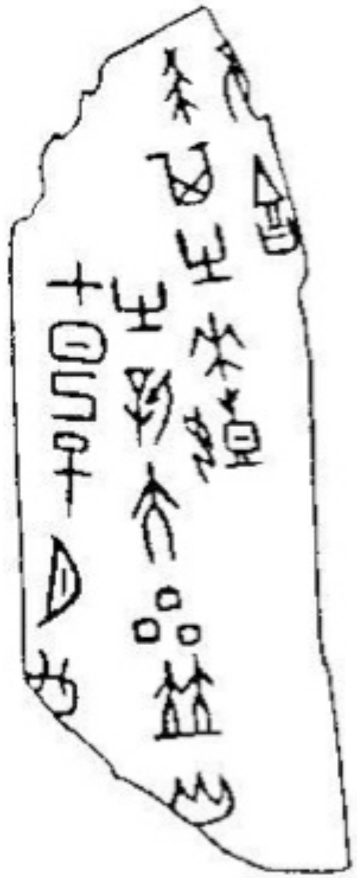
How is modern science rooted in ancient astronomy?

- Macchu Pichu, Peru: Structures aligned with solstices.

How is modern science rooted in ancient astronomy?

- France: Cave paintings from 18,000 B.C. may suggest knowledge of lunar phases (29 dots)

How is modern science rooted in ancient 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: Earliest known records of supernova explosions (1400 B.C.)

3.2 Ancient Greek Science

- Our goals for learning:
  - **Why does modern science trace its roots to the Greeks?**
  - **How did the Greeks explain planetary motion?**

Why does modern science trace its roots to the Greeks?

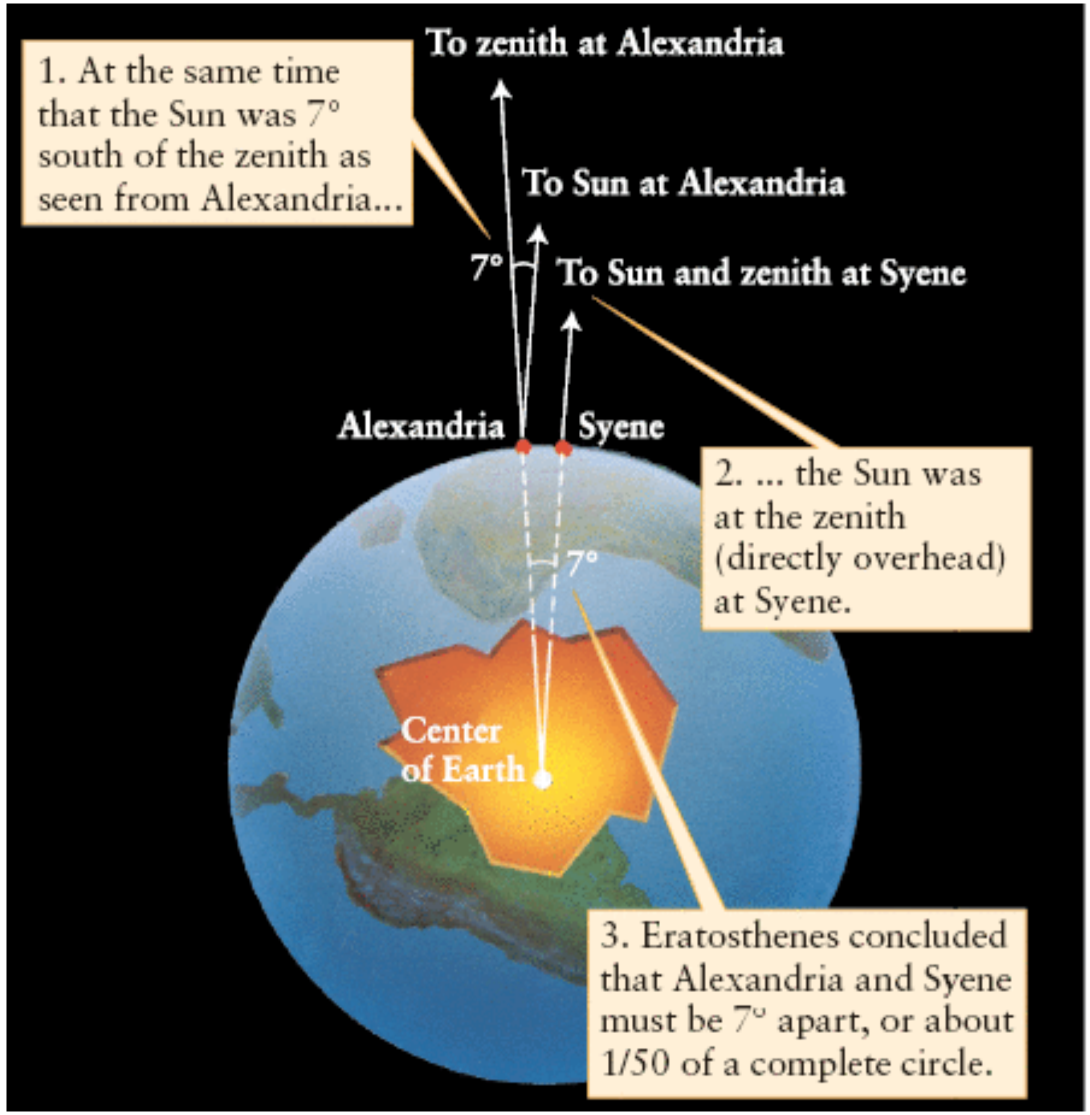
- Greeks were the first people known to make ***models*** of nature.
- They tried to explain patterns in nature without resorting to myth or the supernatural.

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

Eratosthenes: Estimate the radius of the Earth

$$\frac{360^\circ}{7^\circ} = \frac{2\pi R_{Earth}}{d}$$

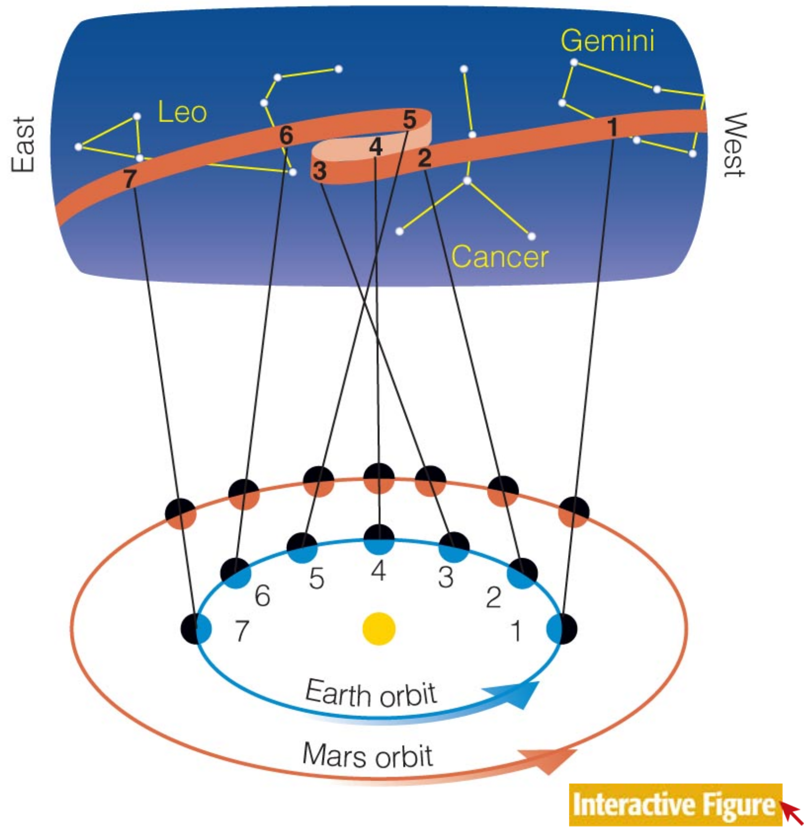
where d is the distance between Alexandria and Syene



How did the Greeks explain planetary motion?

- 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.

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.

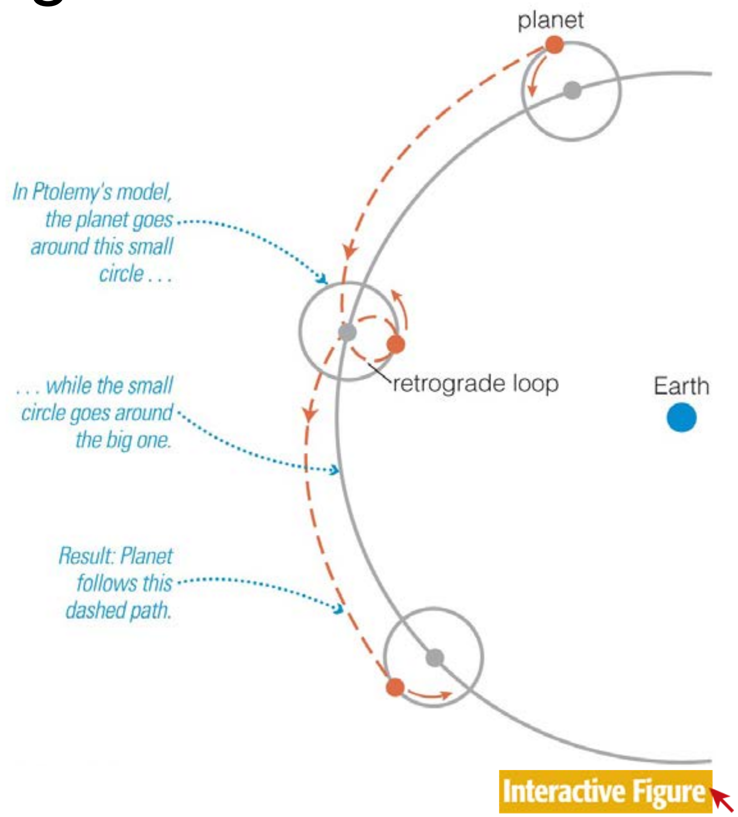
But this made it difficult to explain apparent retrograde motion of planets…

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")

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

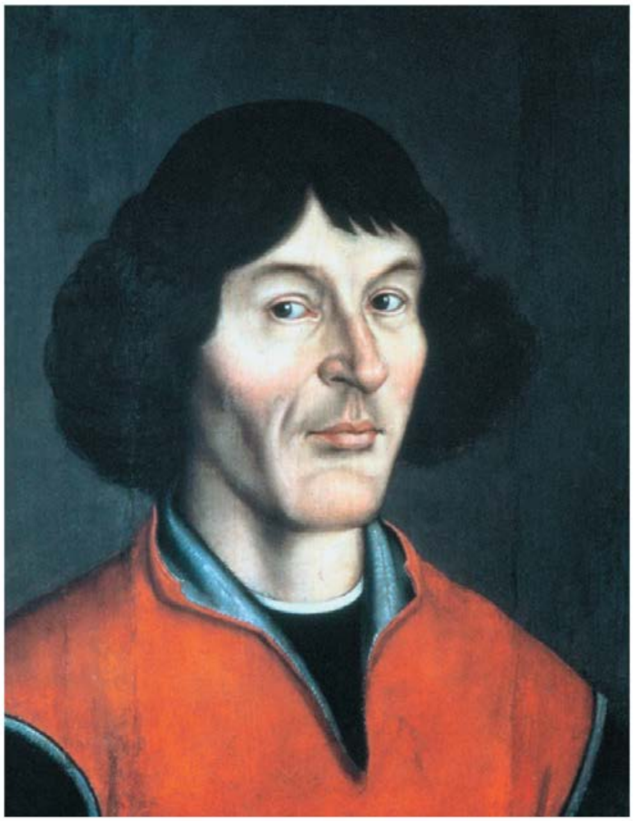
- So how does the Ptolemaic model explain retrograde motion?
  Planets *really do* go backward in this model..



3.3 The Copernican Revolution

- Our goals for learning:
  - **How did Copernicus, Tycho, and Kepler challenge the Earth-centered model?**
  - **What are Kepler's three laws of planetary motion?**
  - **How did Galileo solidify the Copernican revolution?**

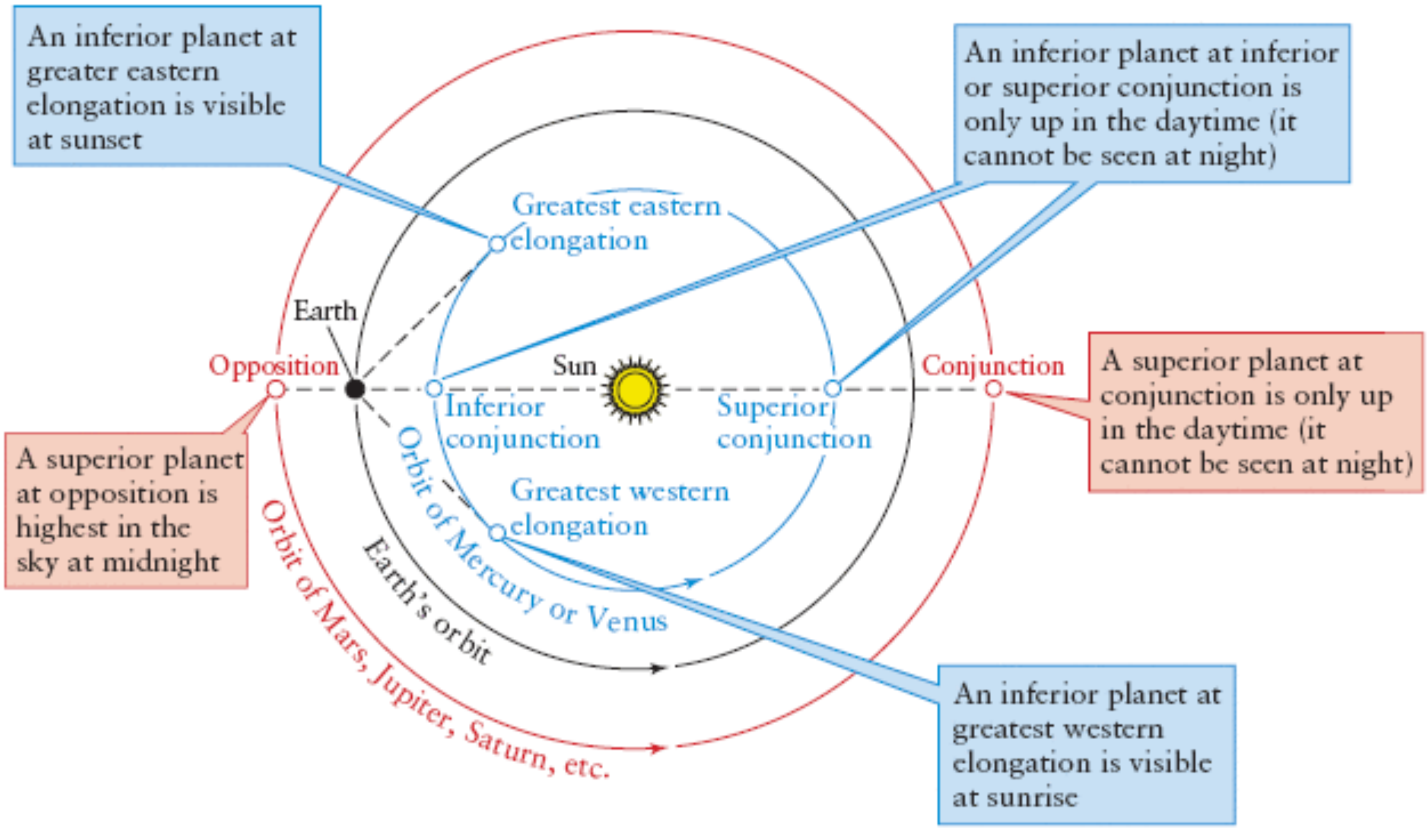
How did Copernicus, Tycho, and Kepler challenge the Earth-centered model?



Copernicus (1473-1543)

- Proposed a Sun-centered model (published 1543)
- Used model to determine layout of solar system (planetary distances in AU) But . . .
- The model was no more accurate than the Ptolemaic model in predicting planetary positions, because it still used perfect circles.

Copernicus: Inferior and Superior Planets

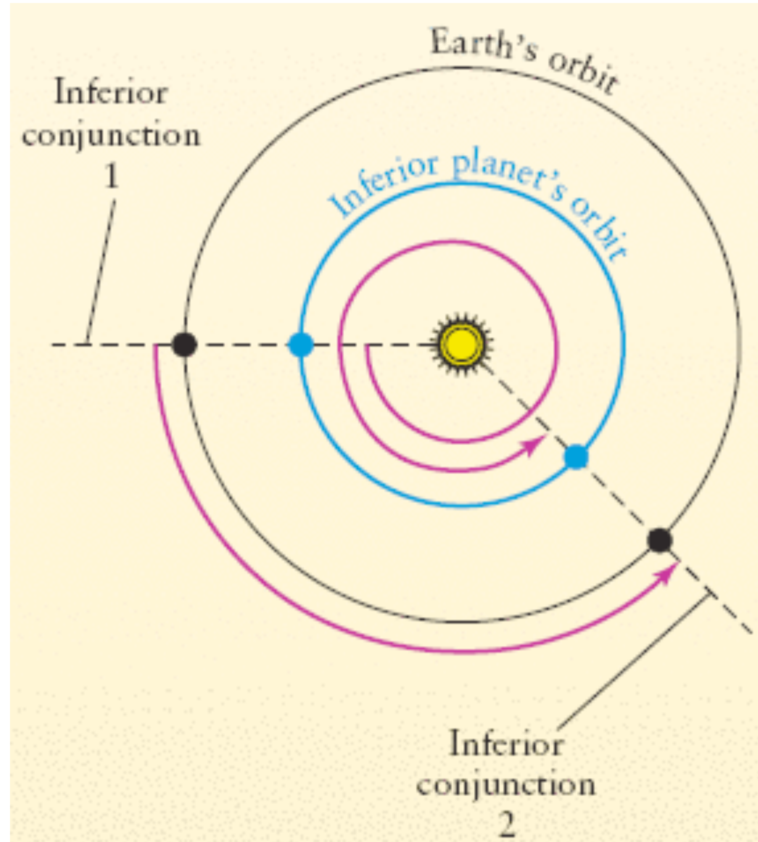


Inferior planets have orbits smaller than the Earth's, while superior planets have orbits larger than the Earth's. Synodic Period Animation

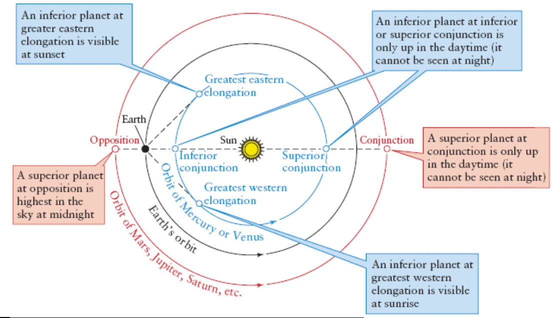
Synodic and Siderial Period

The **synodic** period is the time that elapses between two successive identical configurations as seen from Earth—
from one opposition to the next, for example, or from
one conjunction to the next.

The **sidereal** period is the true orbital period of a planet,
the time it takes the planet to complete one full orbit around the Sun relative to the stars.

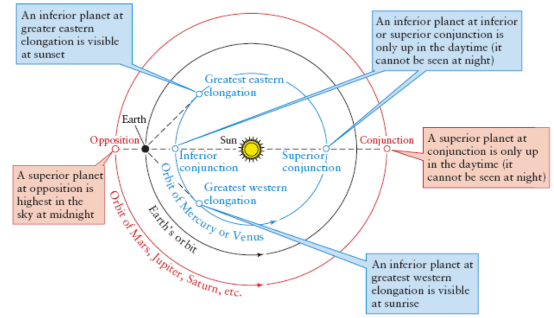


Venus before Sunrise



Facing East

Venus after Sunset



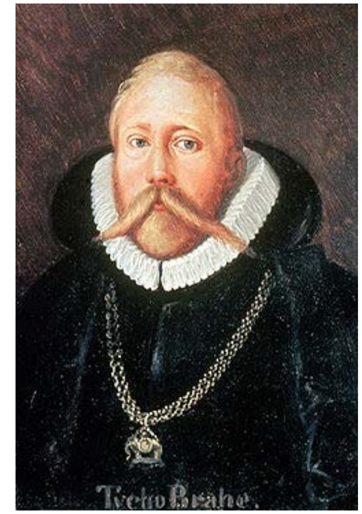
Facing West

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

Tycho Brahe (1546-1601)

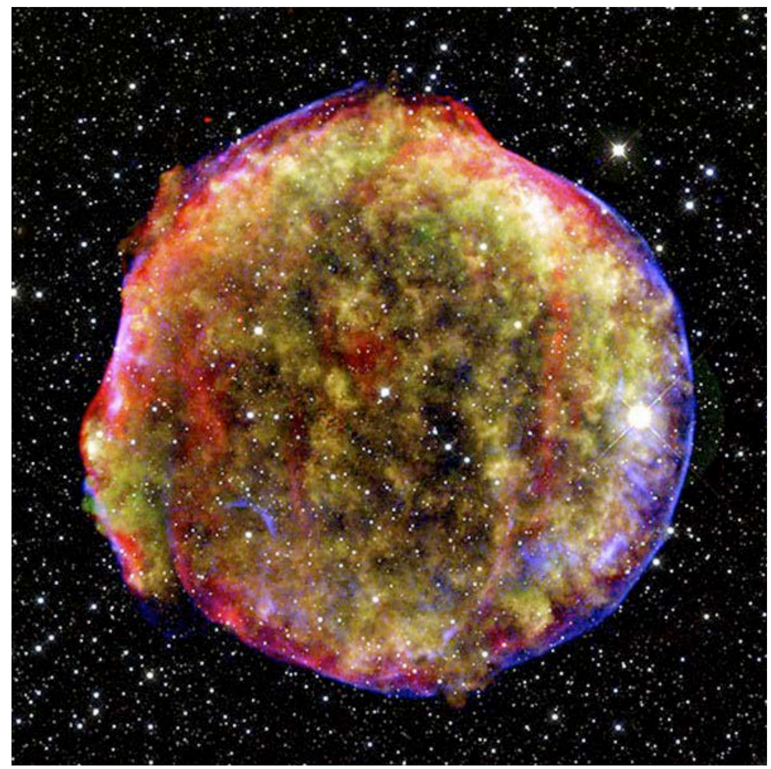
- Compiled the most accurate (one arcminute) naked eye measurements ever made of planetary positions.
- Still could not detect stellar parallax, and thus still thought Earth must be at center of solar system (but recognized that other planets go around Sun).
- Hired Kepler, who used Tycho's observations to discover the truth about planetary motion.

Tycho observes Tycho



SN 1572 was a supernova Type 1a in the constellation of Cassiopeia that burst forth in early November 1572.

Tycho's (1546-1601) observations showed that the heavens are by no means pristine and unchanging.

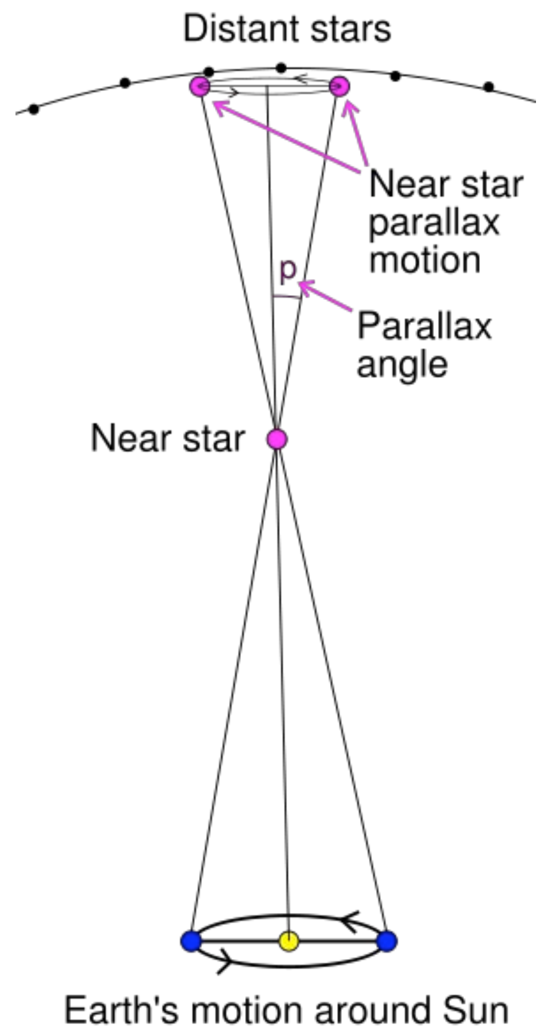


Parallax

Tycho used the **parallax method to measure the distances** of celestial objects.

The distance to an object (measured in parsecs) is the reciprocal of the parallax (measured in arcseconds):
d(pc) = 1 / p(arcsec).

Tycho Brahe found that the parallax angle of SN 1572 must be very small and concluded that **SN 1572 was a very distant object**.

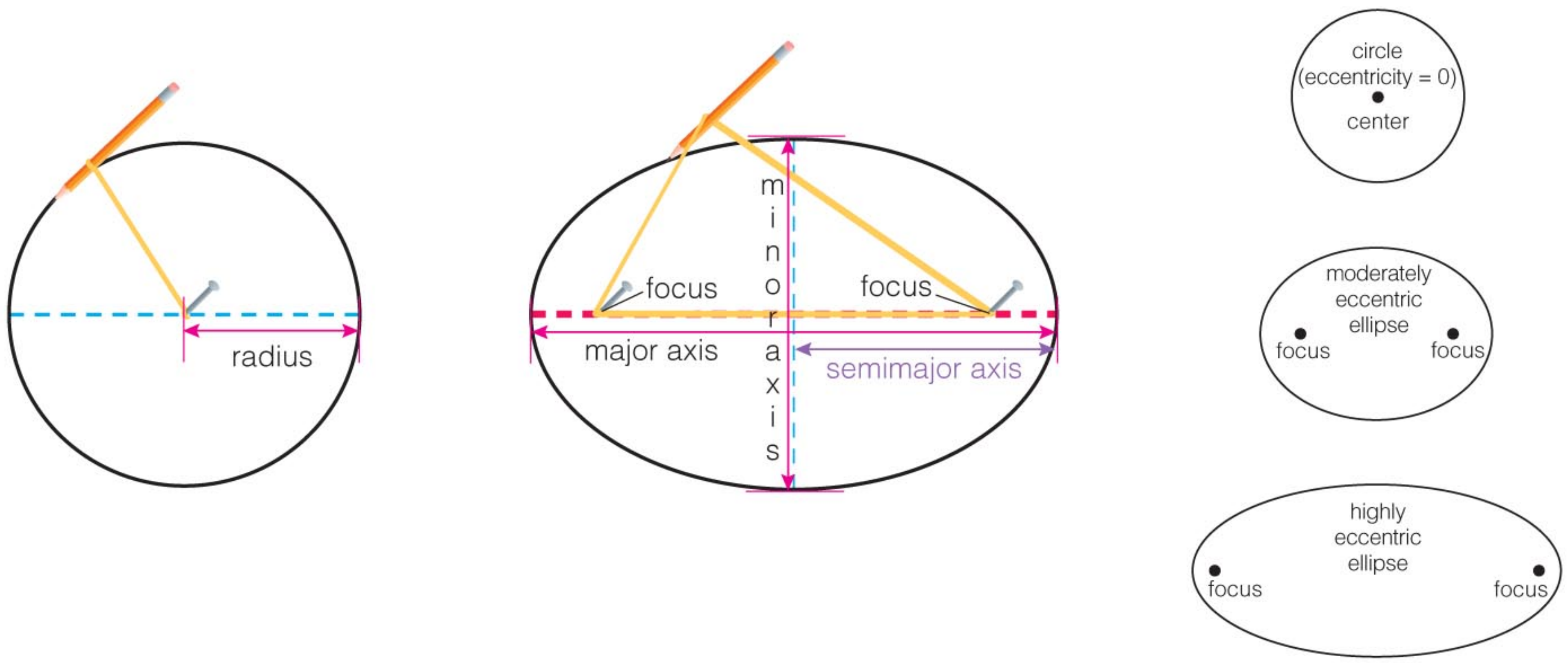


How did Copernicus, Tycho, and Kepler challenge the Earth-centered model?

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?



a Drawing a circle with a string of fixed length.

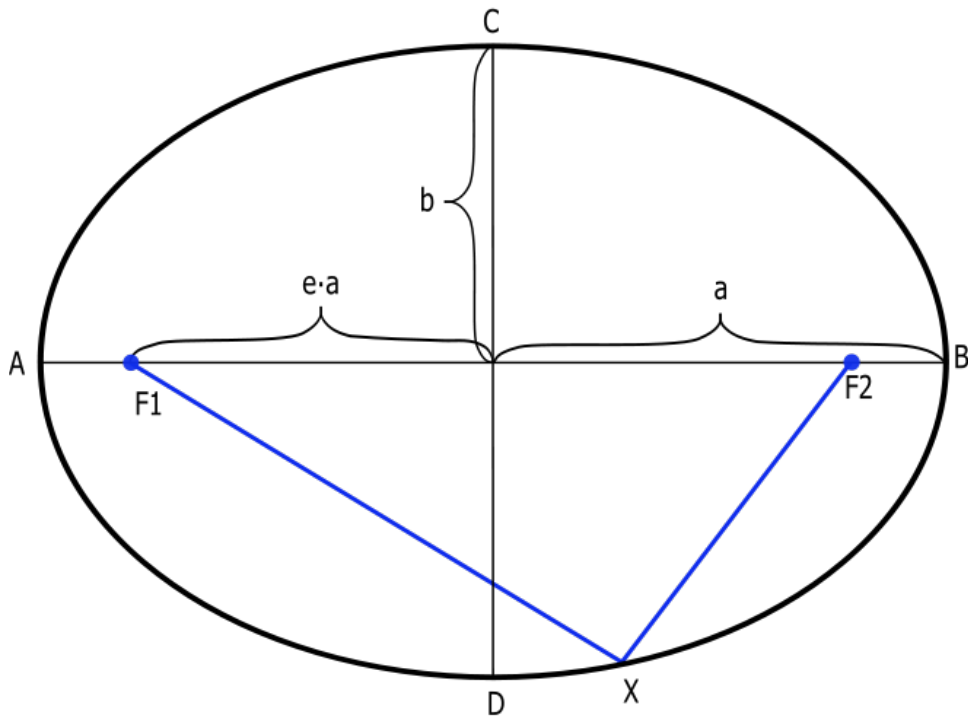
b Drawing an ellipse with a string of fixed length.

c Eccentricity describes how much an ellipse deviates from a perfect circle.

Interactive Figure

An ellipse looks like an elongated circle.

Ellipse

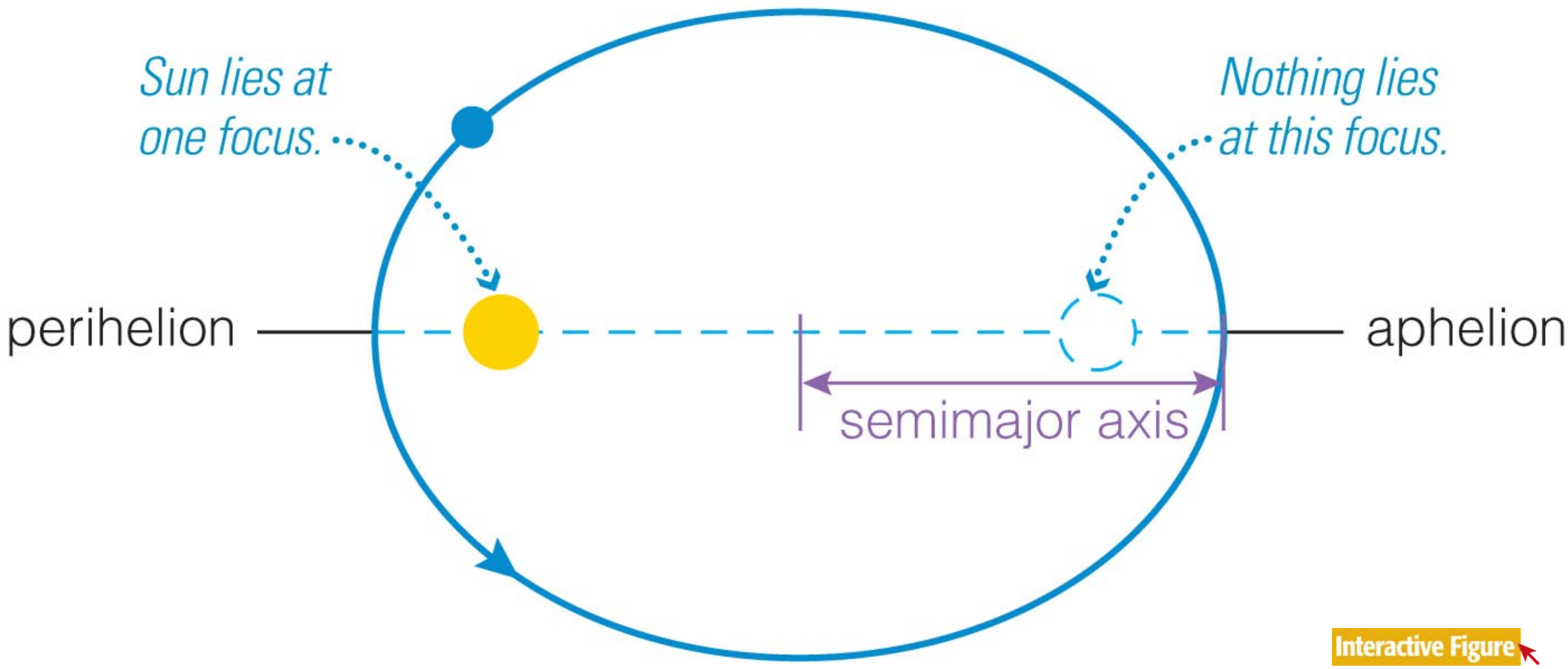


$$e = \sqrt{\frac{a^2 - b^2}{a^2}}$$

e = eccentricity
a = semimajor axis
b = seminor axis

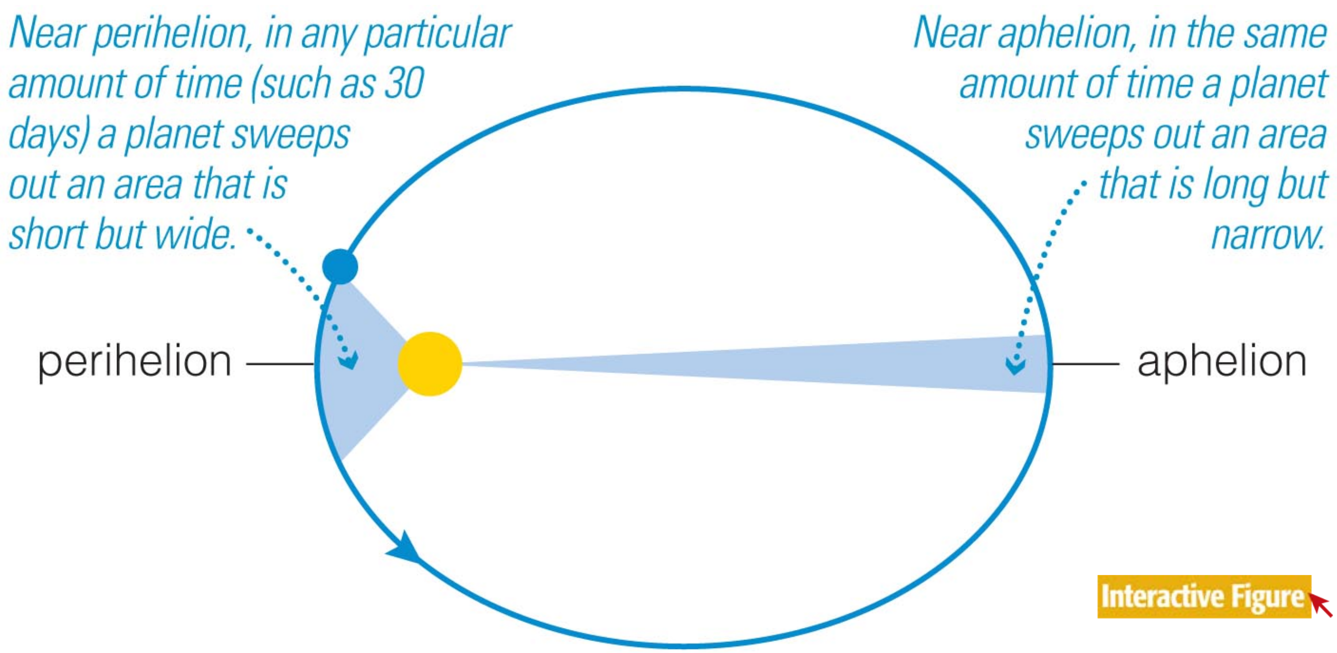
What are Kepler's three laws of planetary motion?

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



What are Kepler's three laws of planetary motion?

- **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 Third Law

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

$$P^2 = a^3$$

P = Planets Siderial Period in years

a = Planets semimajor axis in AU

This equation is valid only for objects that orbit the Sun.

Kepler's Third law: The square of the sidereal period of a planet is directly proportional to the cube of the semimajor axis of the orbit.

Question 1

$$P^2 = a^3$$

P = planets Siderial Period in (years)

a = planets semimajor axis in (AU)

This equation is valid only for objects that orbit the Sun.

Example 1: The orbit of a spacecraft about the Sun has a perihelion distance of 0.1 AU and an aphelion distance of 0.4 AU.

What is the semimajor axis of the spacecraft's orbit?

What is its orbital period?

Question 2

$$P^2 = a^3$$

P = planets Siderial Period in (years)

a = planets semimajor axis in (AU)

This equation is valid only for objects that orbit the Sun.

Example 2: A comet with a period of 125 years moves in a highly elongated orbit about the Sun. At perihelion, the comet comes very close to the Sun's surface.

What is the comet's average distance from the Sun?

What is the farthest it can get from the Sun?

Question 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

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

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

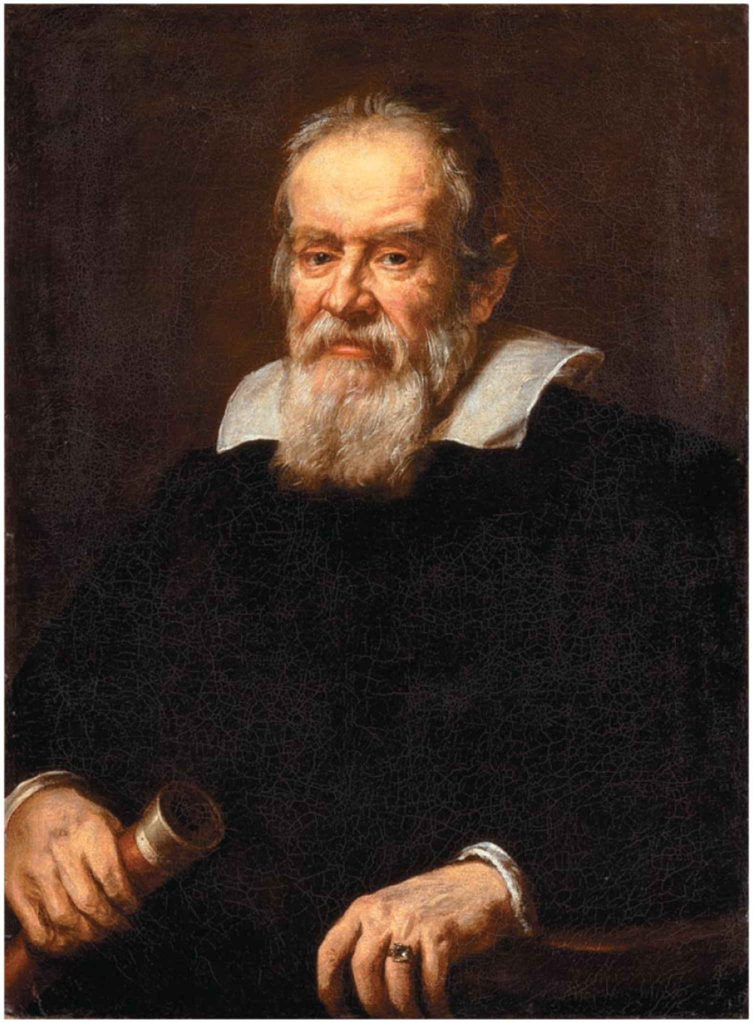
D. 64 years

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)

Galileo overcame major objections to the 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 the Sun, we'd detect stellar parallax.

Overcoming the first objection (nature of motion):

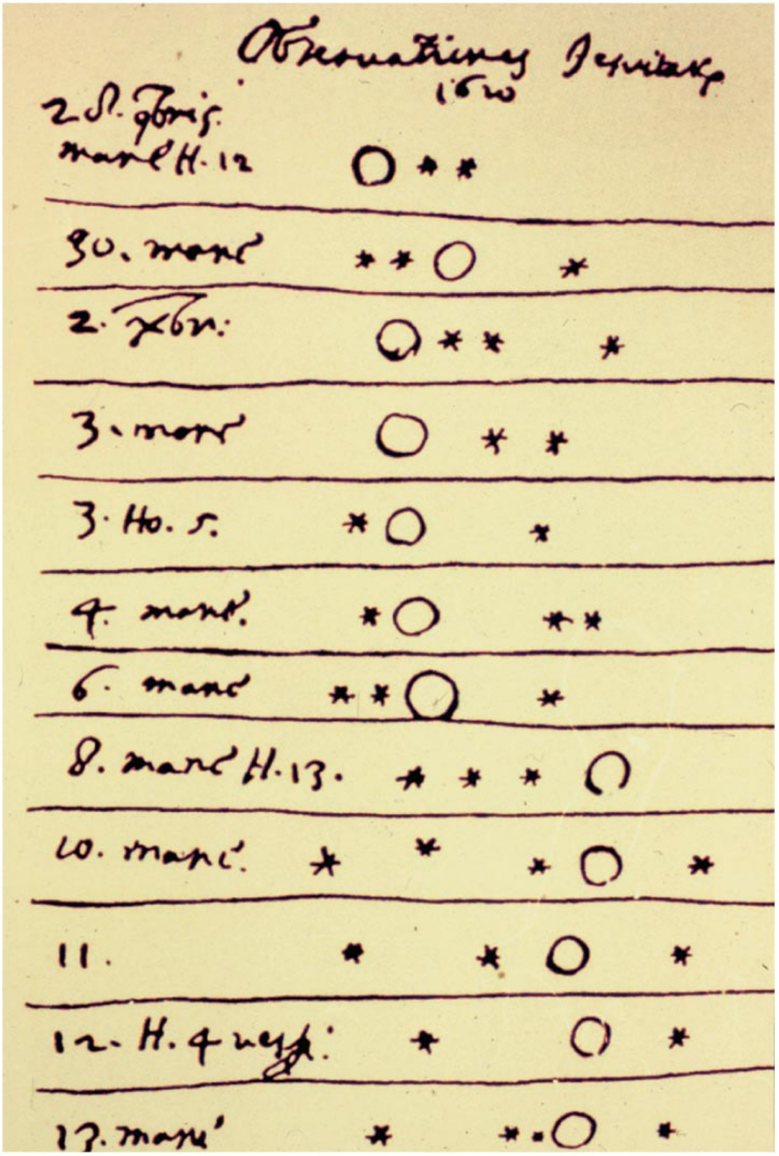
- Galileo's experiments showed that objects in air would stay with Earth as it moves.
  - Aristotle thought that all objects naturally come to rest.
  - Galileo showed that objects will stay in motion unless a force acts to slow them down (Newton's first law of motion).

Overcoming the second objection (heavenly perfection):

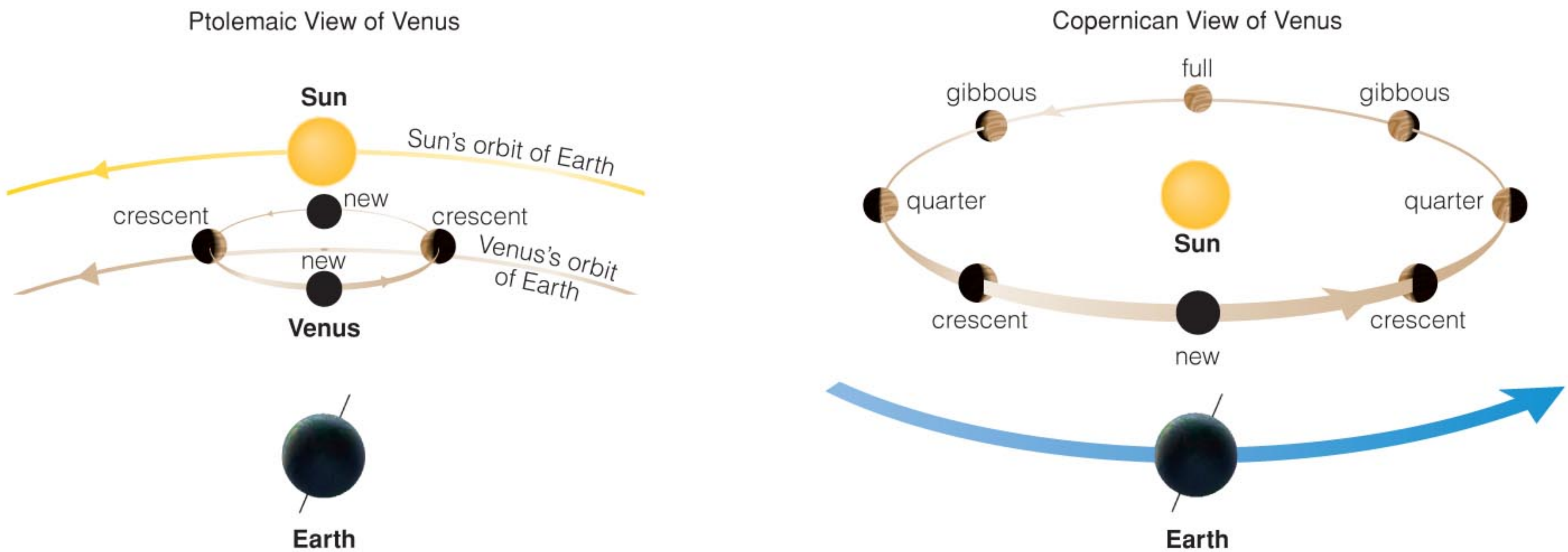
- Tycho's observations of comet and supernova already challenged this idea.
- Using his telescope, Galileo saw:
  - Sunspots on Sun ("imperfections")
  - Mountains and valleys on the Moon (proving it is not a perfect sphere)

Overcoming the third objection (parallax):

- 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 Earth.



a In the Ptolemaic system, Venus orbits Earth, moving around a smaller circle on its larger orbital circle; the center of the smaller circle lies on the Earth-Sun line. If this view were correct, Venus's phases would range only from new to crescent.

b In reality, Venus orbits the Sun, so from Earth we can see it in many different phases. This is just what Galileo observed, allowing him to prove that Venus orbits the Sun.

Interactive Figure

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

- 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 out 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 model.

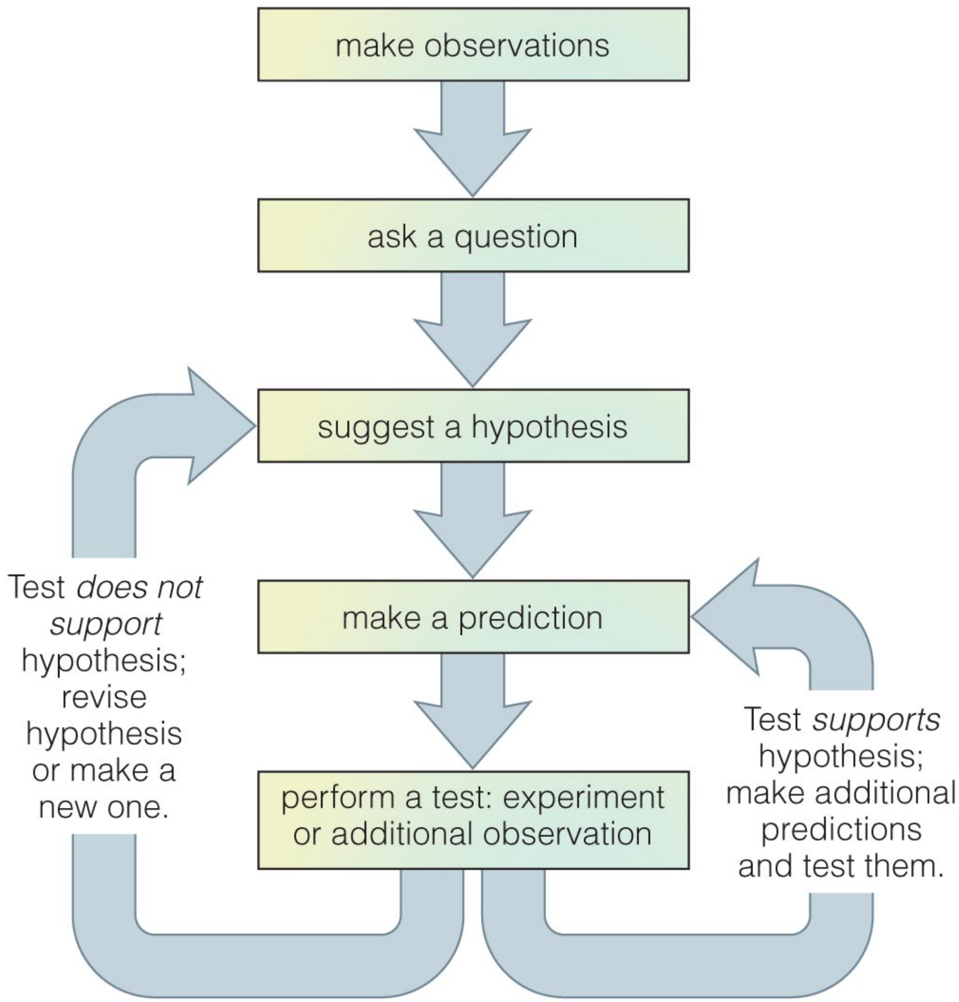
3.4 The Nature of Science

- Our goals for learning:
  - **How can we distinguish science from nonscience?**
  - **What is a scientific theory?**

What is science?

- Science is the systematic enterprise of gathering knowledge about the universe and organizing and condensing that knowledge into testable laws and theories.

How can we distinguish science from non-science?



<u>The idealized scientific method</u>

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

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 by natural selection 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.

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3.5 Astrology

- Our goals for learning:
  - **How is astrology different from astronomy?**
  - **Does astrology have any scientific validity?**

How is astrology different from astronomy?

- Astronomy is a science focused on learning about how stars, planets, and other celestial objects work.
- Astrology is a search for hidden influences on human lives based on the positions of planets and stars in the sky.

Does astrology have any scientific validity?

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