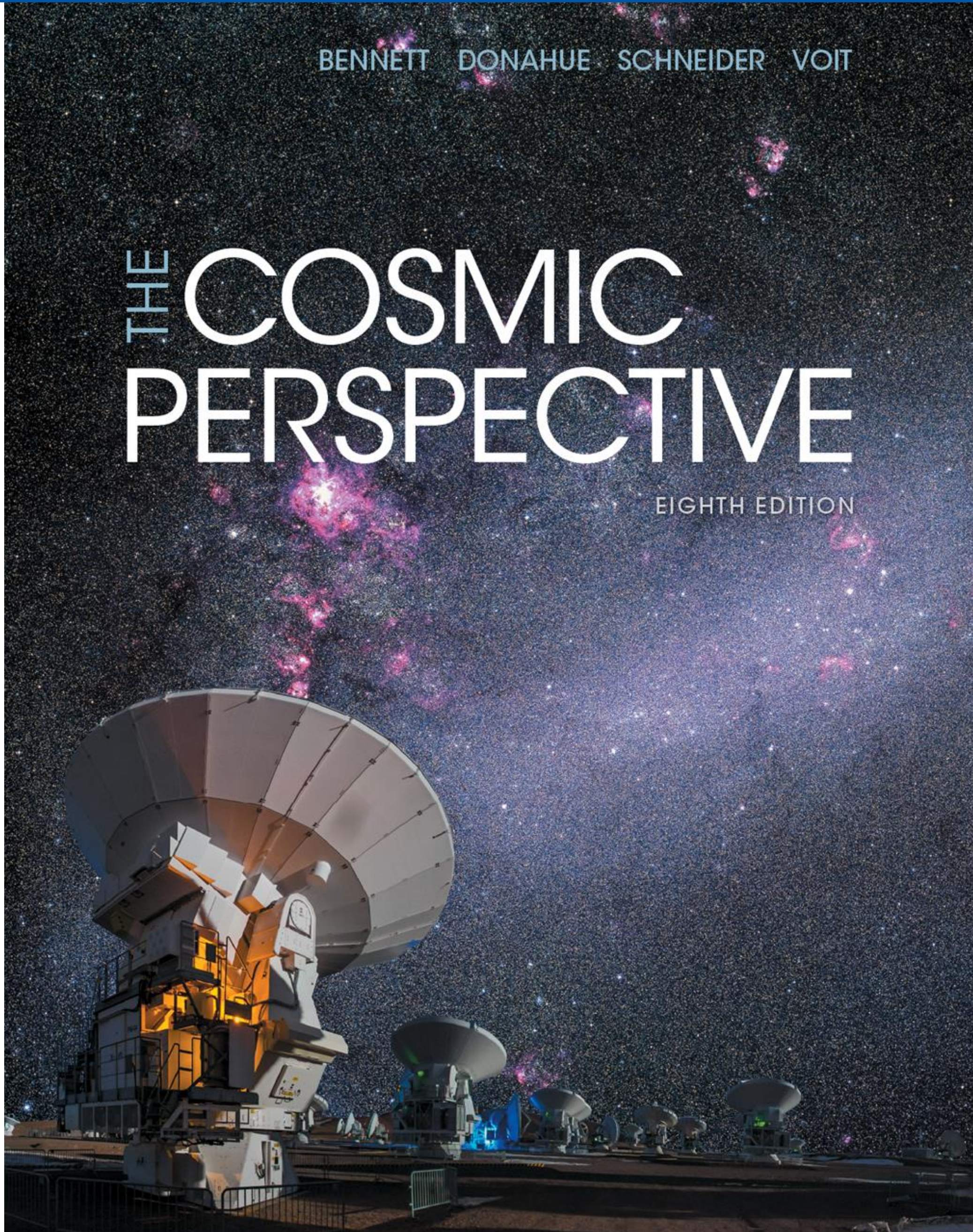
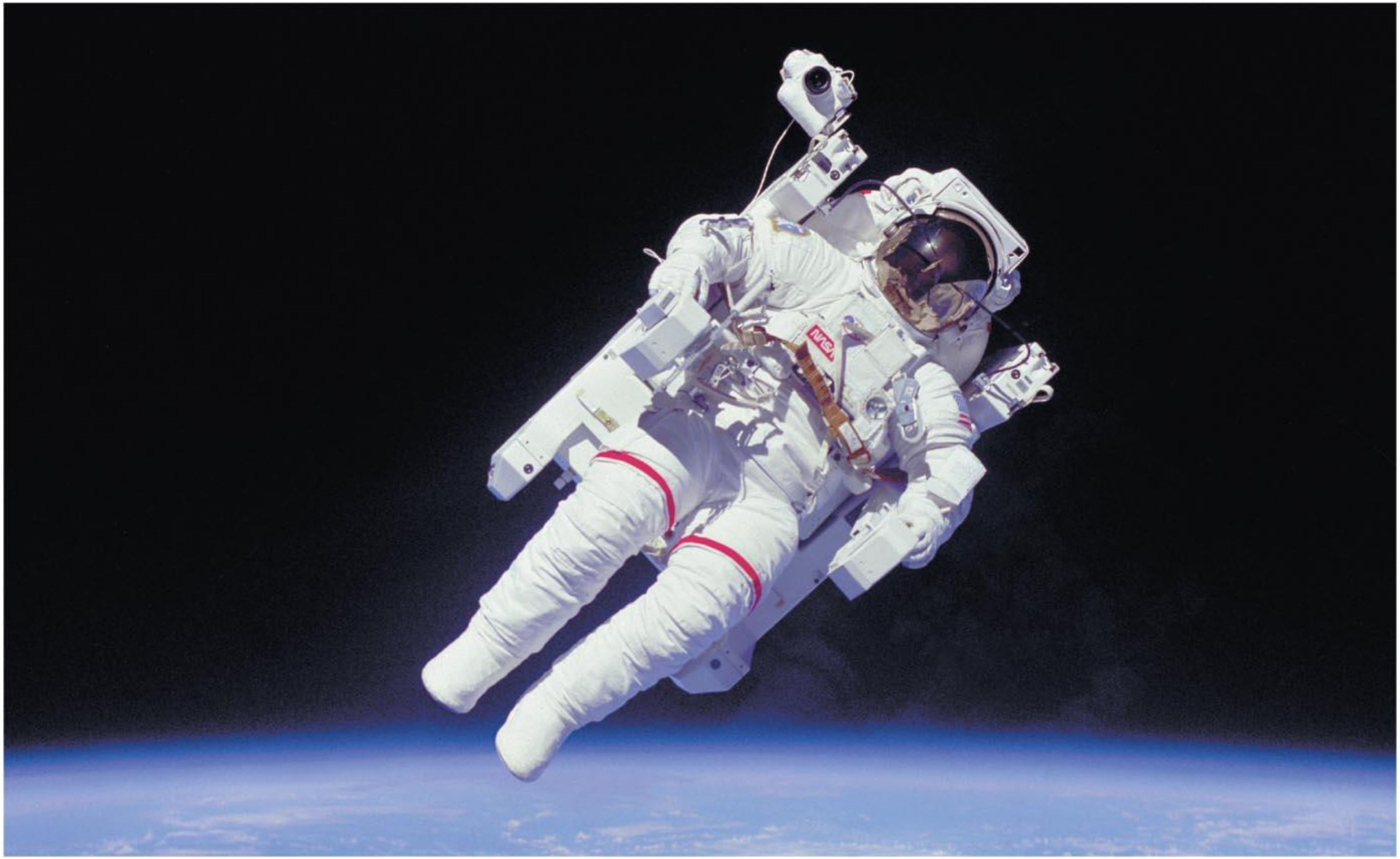
Chapter 3 Lecture



Chapter 3: The Science of Astronomy

The Science of Astronomy



3.1 The Ancient Roots of Science

- Our goals for learning:
  - **In what ways do all humans use scientific thinking?**
  - **How is modern science rooted in ancient astronomy?**

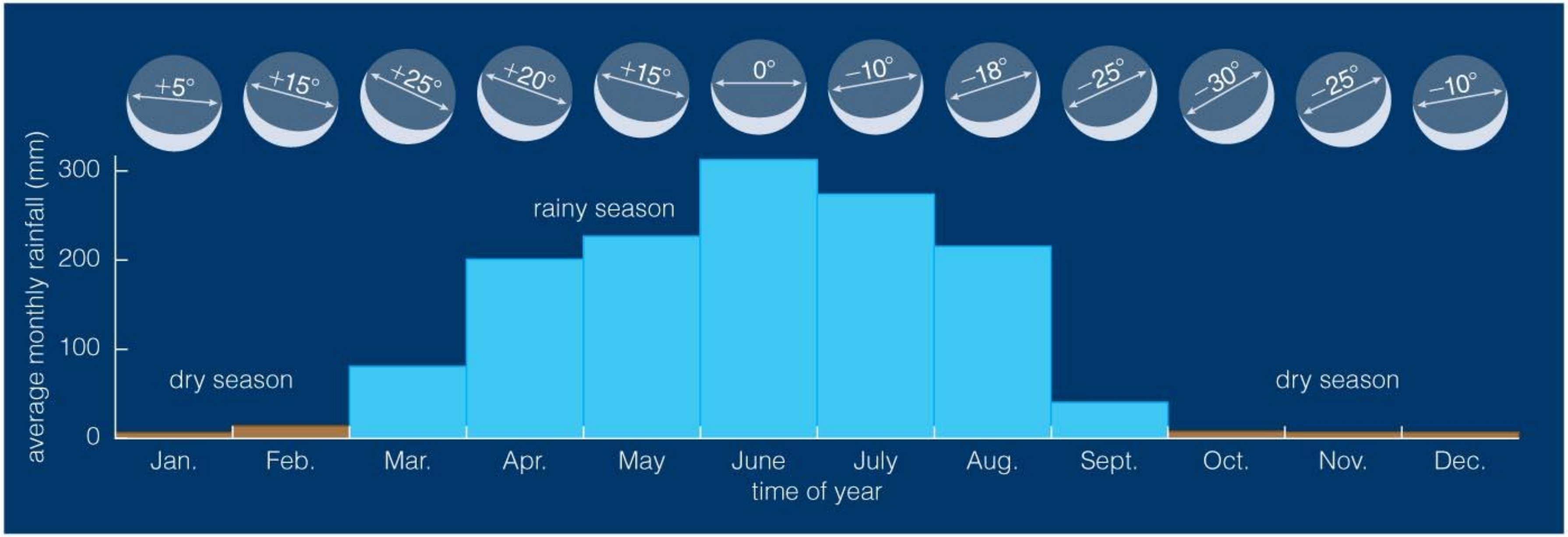
In what ways do all humans use scientific thinking?

- Scientific thinking is based on everyday ideas of observation and trial-and-error experiments.

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?

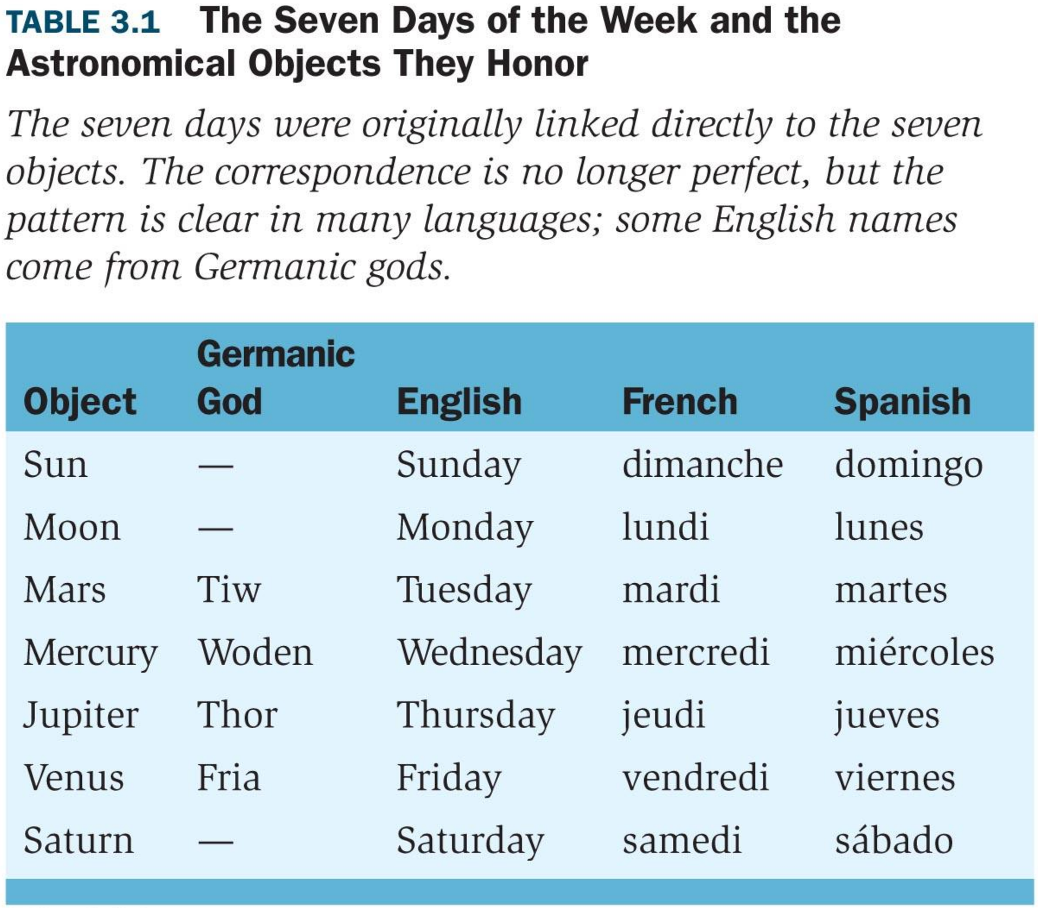


TABLE 3.1 **The Seven Days of the Week and the Astronomical Objects They Honor**

The seven days were originally linked directly to the seven objects. The correspondence is no longer perfect, but the 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.

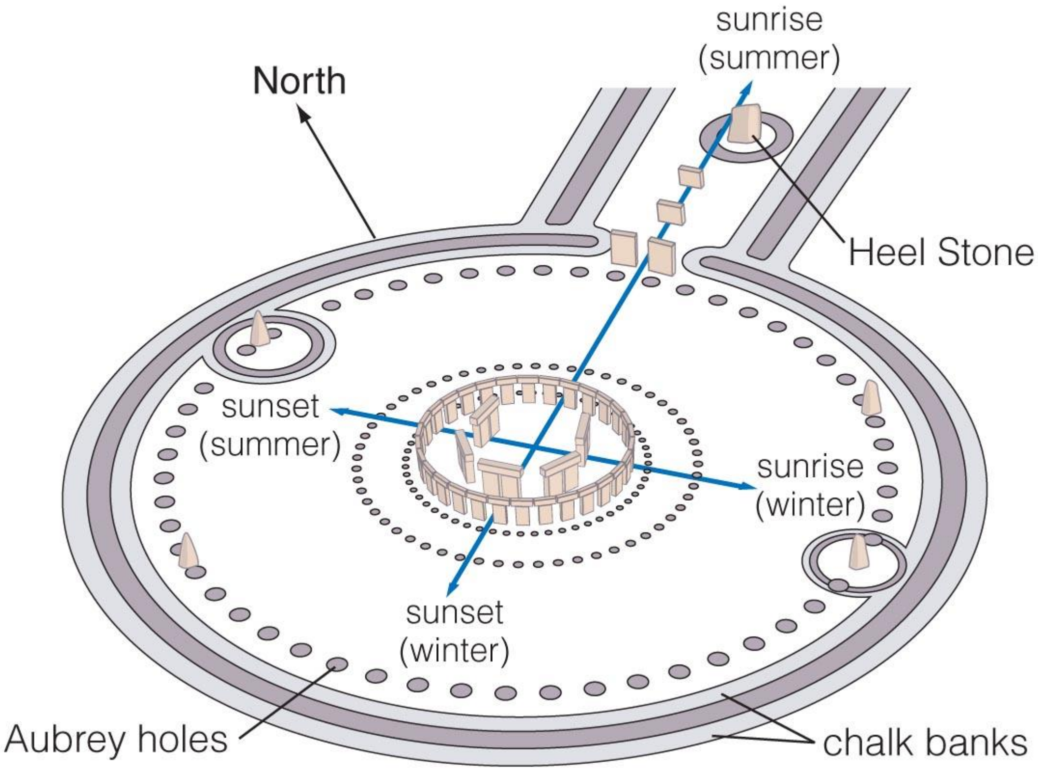
How is modern science rooted in ancient astronomy?

- Egyptian obelisk: Shadows tell time of day.

How is modern science rooted in ancient astronomy?

- 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?

- Mexico: Model of the Templo Mayor

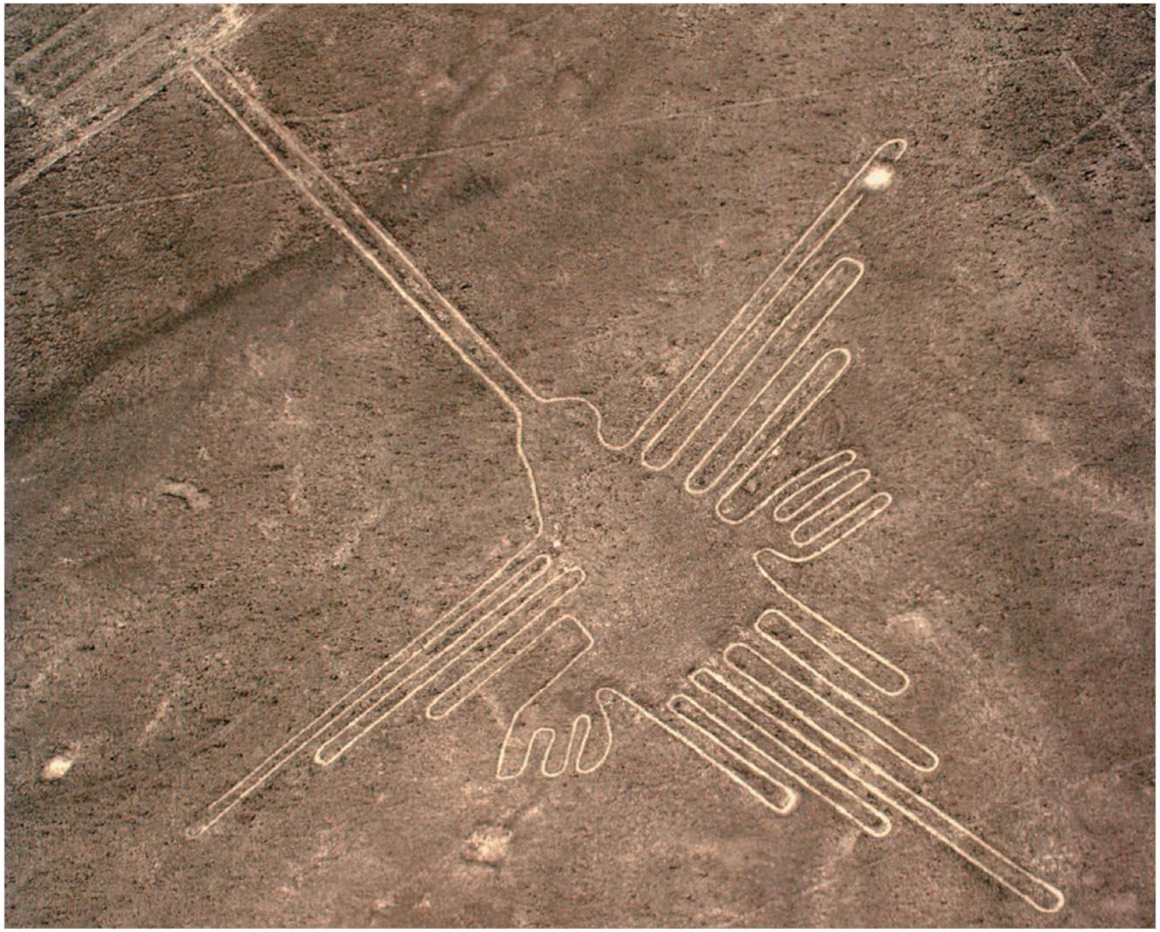
How is modern science rooted in ancient astronomy?

- New Mexico: Anasazi kiva aligned north-south

How is modern science rooted in ancient astronomy?

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

How is modern science rooted in ancient astronomy?

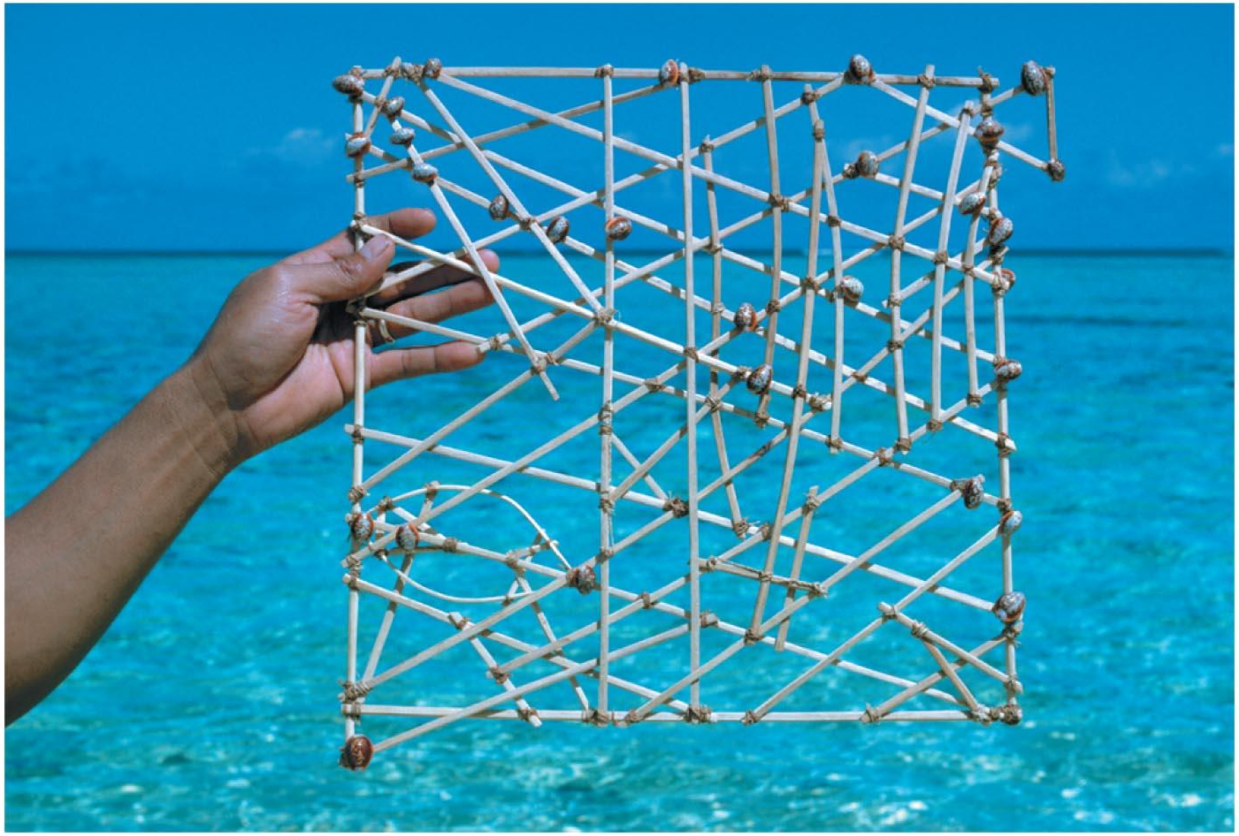


- Peru: Lines and patterns, some aligned with stars.

How is modern science rooted in ancient astronomy?

- Macchu Pichu, Peru: Structures aligned with solstices.

How is modern science rooted in ancient astronomy?



- South Pacific: Polynesians used a knowledge of astronomy alongside a detailed understanding of ocean currents to guide navigation.

What have we learned?

- **In what ways do all humans use scientific thinking?**
  - Scientific thinking involves the same type of trial and error thinking that we use in our everyday live, but in a carefully organized way.
- **How is modern science rooted in ancient astronomy?**
  - Many of our modern timekeeping systems have ancient roots

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?**

3.2 Ancient Greek Science

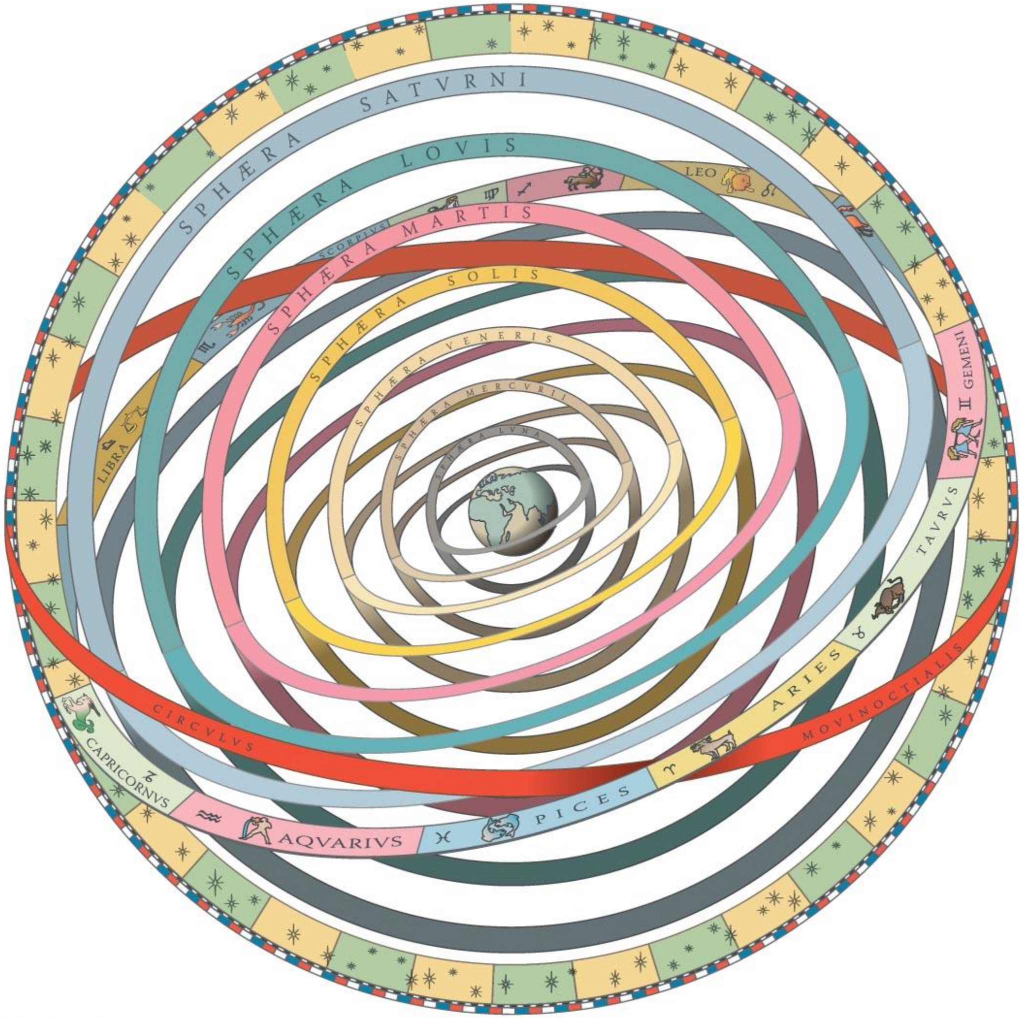
a This rendering shows an artist's reconstruction of the Great Hall of the ancient Library of Alexandria.

b A rendering similar to part a, showing a scroll room in the ancient library.

c The New Library of Alexandria in Egypt, which opened in 2003.

- Artist's reconstruction of the Library of Alexandria.

Why does modern science trace its roots to the Greeks?

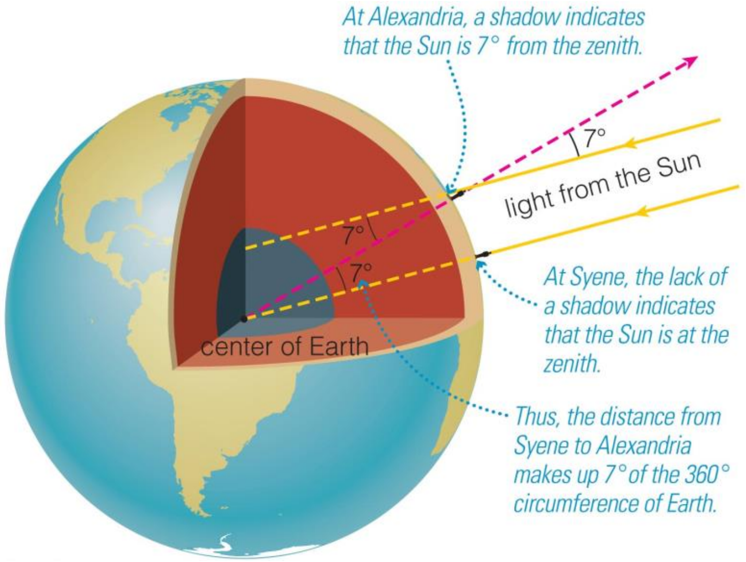


- Greeks were the first people known to make ***models*** of nature.
- They tried to explain patterns in nature without resorting to myth or the supernatural.

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

Special Topic: Eratosthenes Measures Earth (c. 240 B.C.)

- Measurements:
  - Syene to Alexandria
    distance ≈ 5000 stadia
    angle = 7º

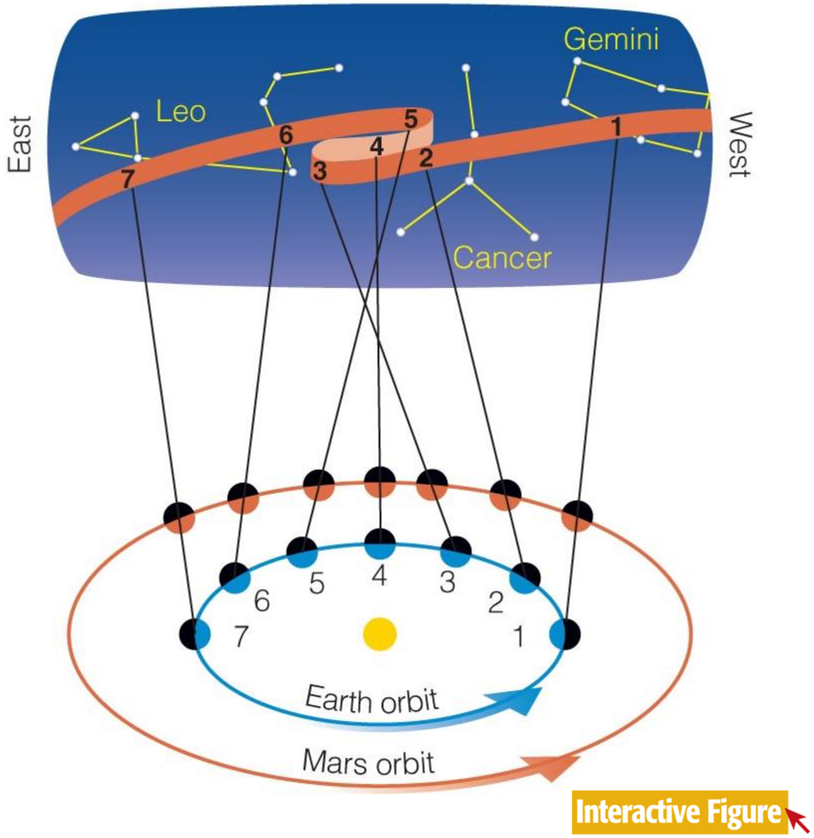


  - <u>Calculate circumference of Earth:</u>
    $7/360 \times$ (circum. Earth) = 5000 stadia
    $\Longrightarrow$ circum. Earth = $5000 \times 360/7$ stadia ≈ 250,000 stadia
  - <u>Compare to modern value (≈ 40,100 km):</u>
    Greek stadium ≈ 1/6 km $\Longrightarrow$ 250,000 stadia ≈ 42,000 km

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…



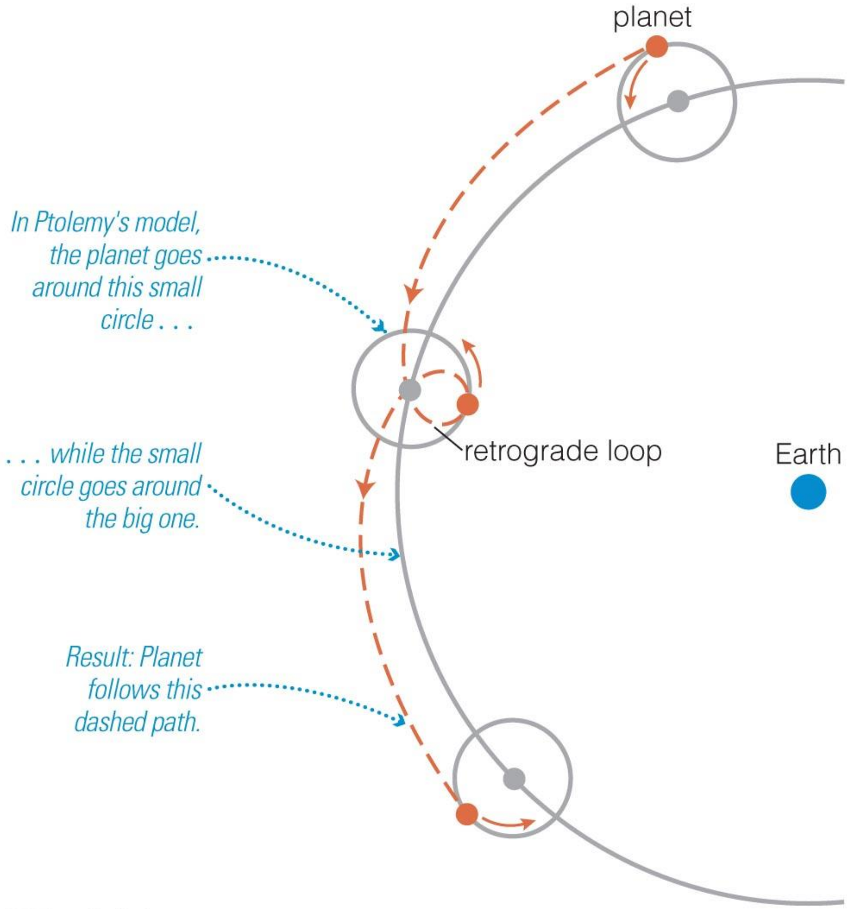
- Review: Over a period of 10 weeks, Mars appears to stop, back up, then go forward again.

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

- 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..



Thought Question

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

A. Earth is stationary in the geocentric model but moves around Sun in Sun-centered model.

B. Retrograde motion is real (planets really go backward) in geocentric model but only apparent (planets don't really turn around) in Sun-centered model.

C. Stellar parallax is expected in the Sun-centered model but not in the Earth-centered model.

D. The geocentric model is useless for predicting planetary positions in the sky, while even the earliest Sun-centered models worked almost perfectly.

Thought Question

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

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C. Stellar parallax is expected in the Sun-centered model but not in the Earth-centered model.

D. The geocentric model is useless for predicting planetary positions in the sky, while even the earliest Sun-centered models worked almost perfectly.

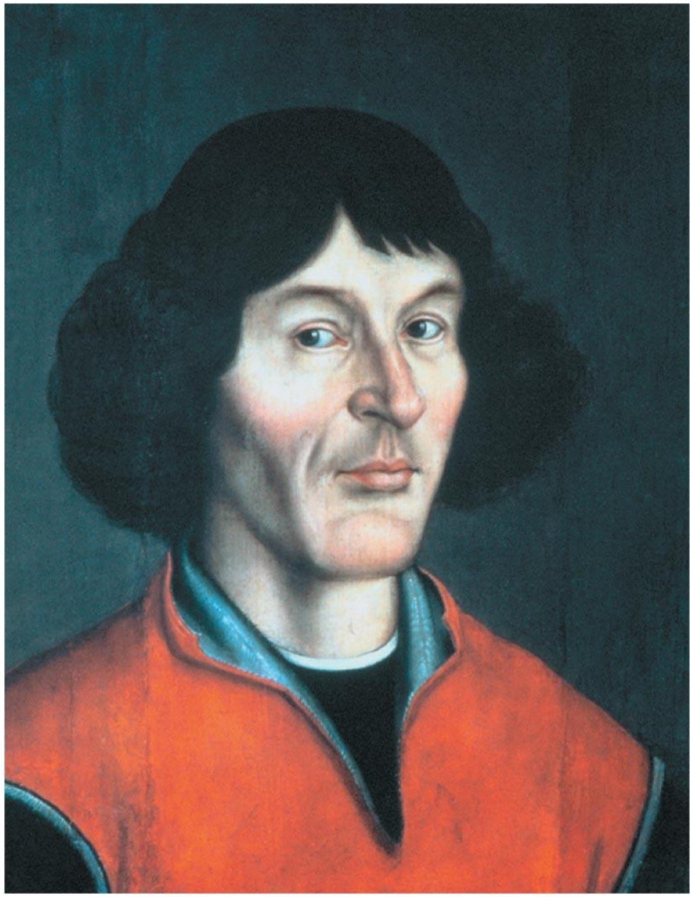
What have we learned?

- **Why does modern science trace its roots to the Greeks?**
  - They developed models of nature and emphasized that the predictions of models should agree with observations.
- **How did the Greeks explain planetary motion?**
  - The Ptolemaic model had each planet move on a small circle whose center moves around Earth on a larger circle.

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.

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

- Tycho Brahe (1546–1601)

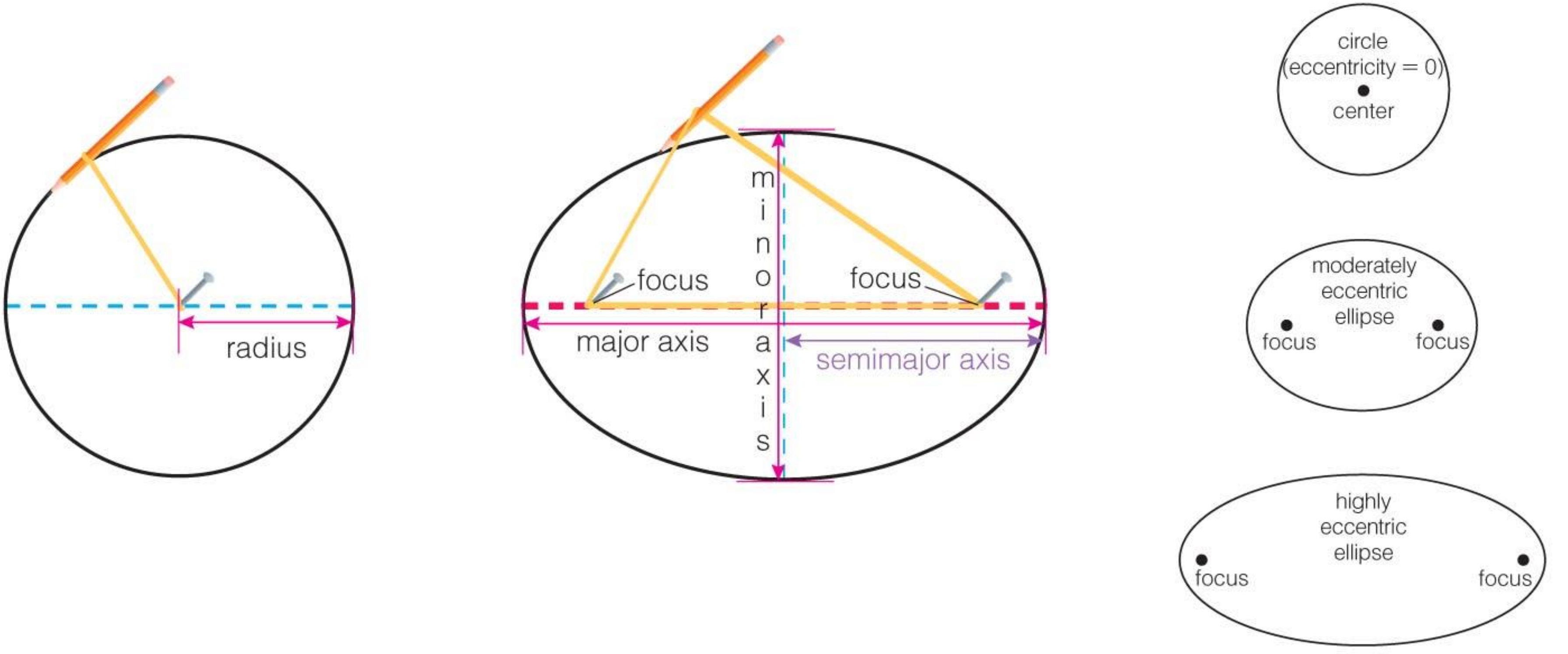
- Compiled the most accurate (one arcminute) naked eye measurements ever made of planetary positions.
- Still could not detect stellar parallax, and thus still thought Earth must be at center of solar system (but recognized that other planets go around Sun).
- Hired Kepler, who used Tycho's observations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

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.

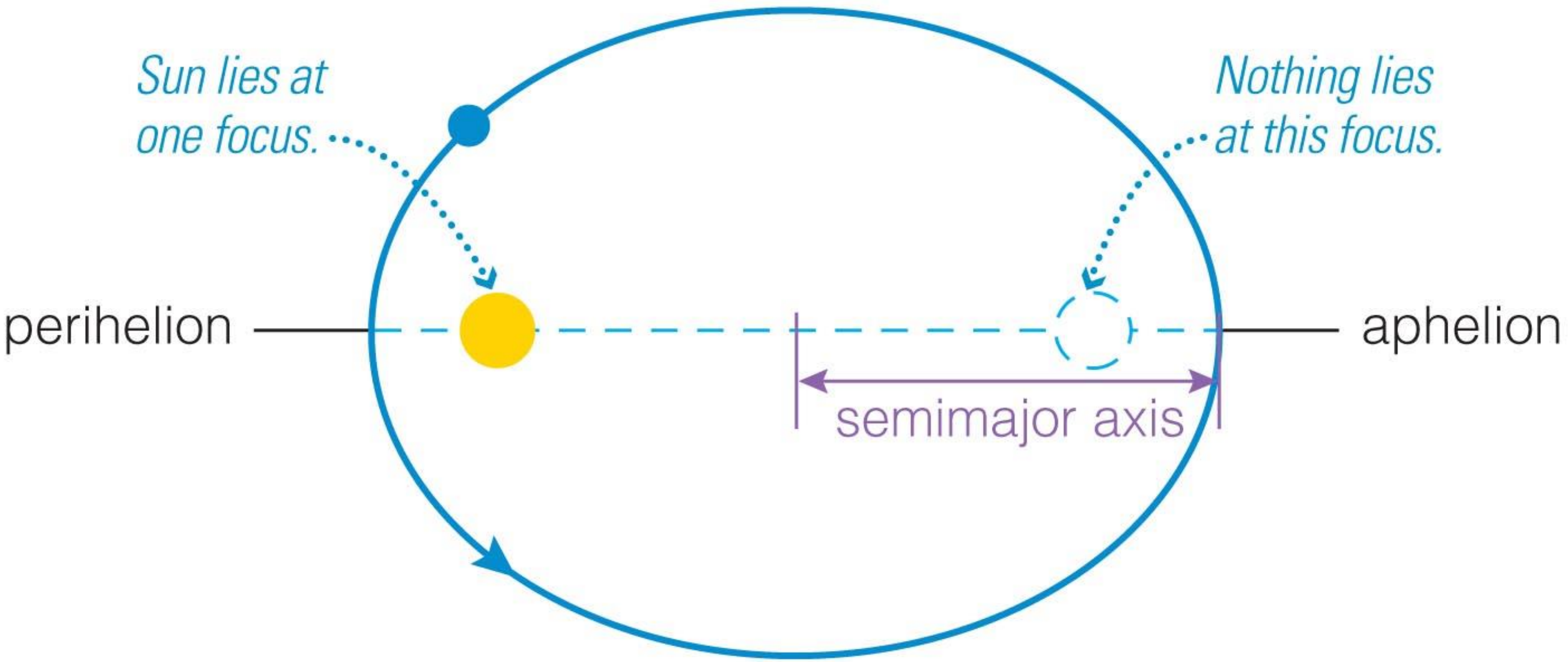
b Drawing an ellipse with a string of fixed length.

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

- An ellipse looks like an elongated circle.

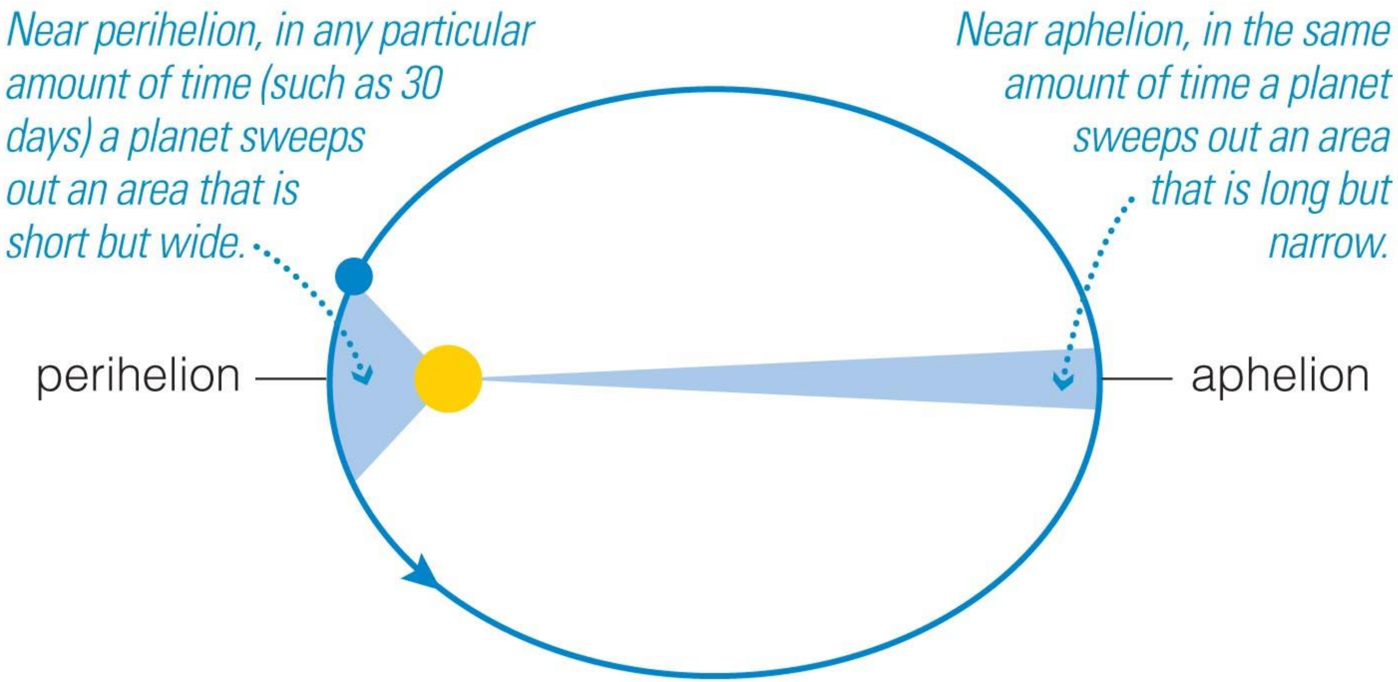
What are Kepler's three laws of planetary motion?

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



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.



Near perihelion, in any particular amount of time (such as 30 days) a planet sweeps out an area that is short but wide.

Near aphelion, in the same amount of time a planet sweeps out an area that is long but narrow.

- 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

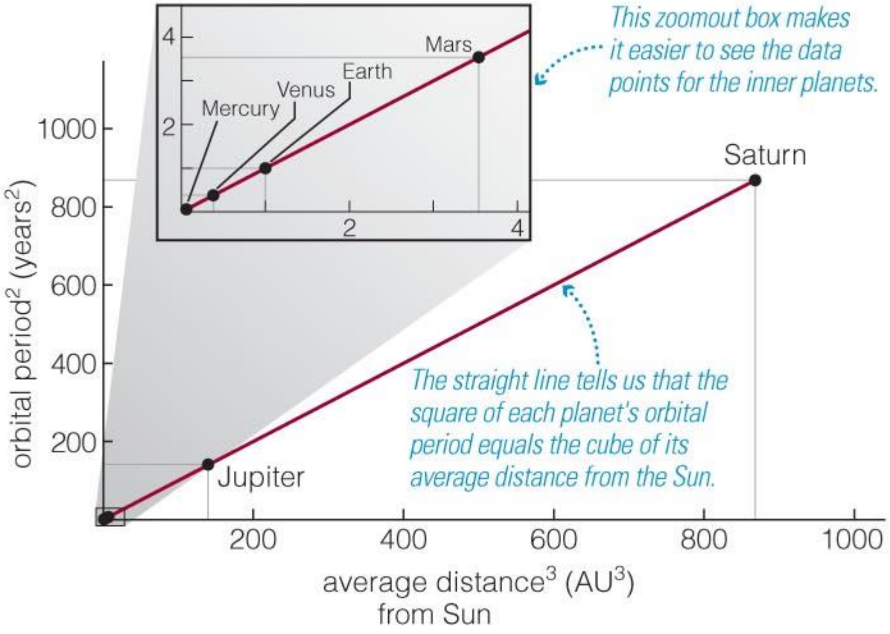
- More distant planets orbit the Sun at slower average speeds, obeying the relationship

$$p^2 = a^3$$

- p = orbital period in years
- a = average distance from Sun in AU

Kepler's Third Law

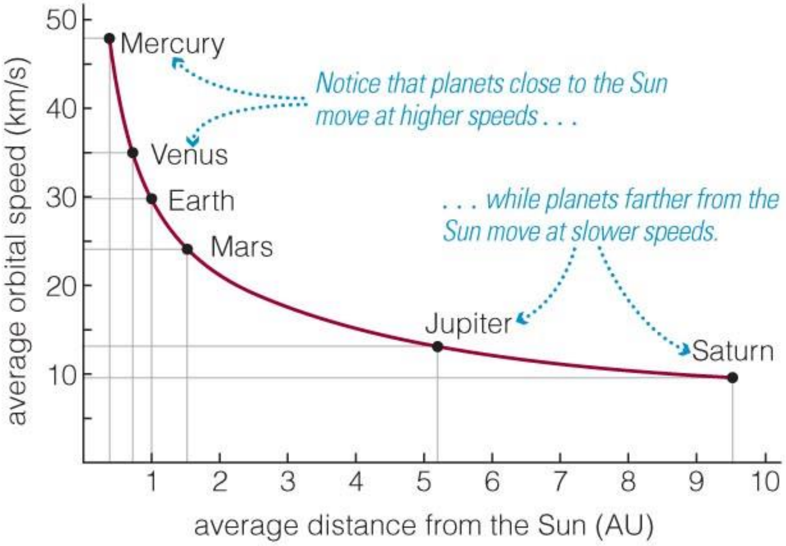
- Graphical version of Kepler's Third Law



This zoomout box makes it easier to see the data points for the inner planets.

The straight line tells us that the square of each planet's orbital period equals the cube of its average distance from the Sun.

a This graph shows that Kepler's third law ($p^2 = a^3$) holds true; the graph shows only the planets known in Kepler's time.



Notice that planets close to the Sun move at higher speeds . . .

. . . while planets farther from the Sun move at slower speeds.

b This graph, based on Kepler's third law and modern values of planetary distances, shows that more distant planets orbit the Sun more slowly.

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 $p^2 = a^3$

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

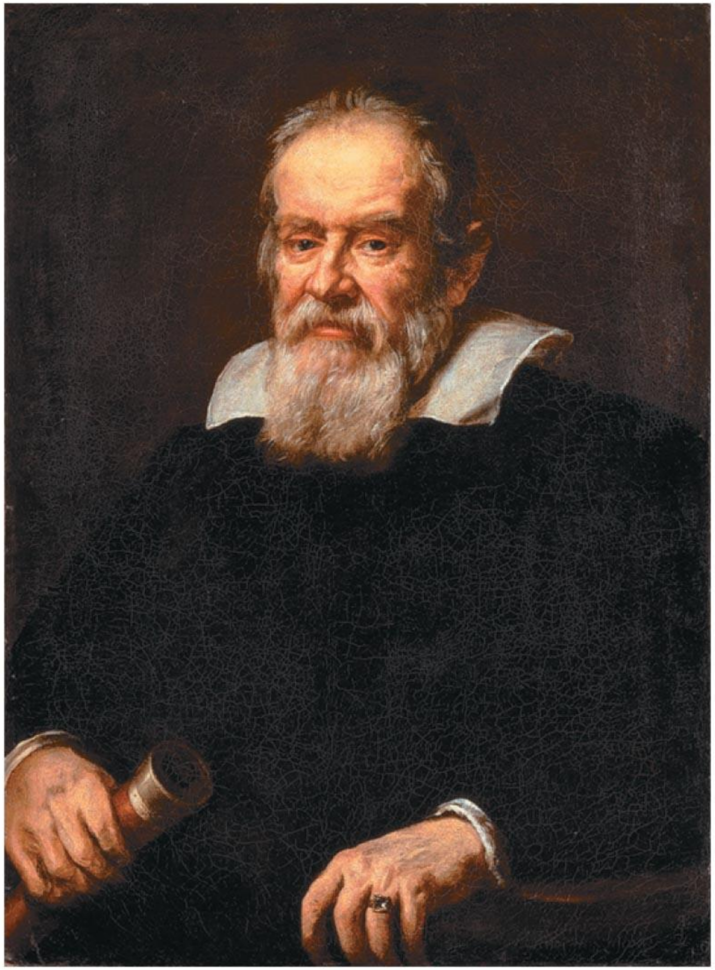
D. 64 years

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 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).

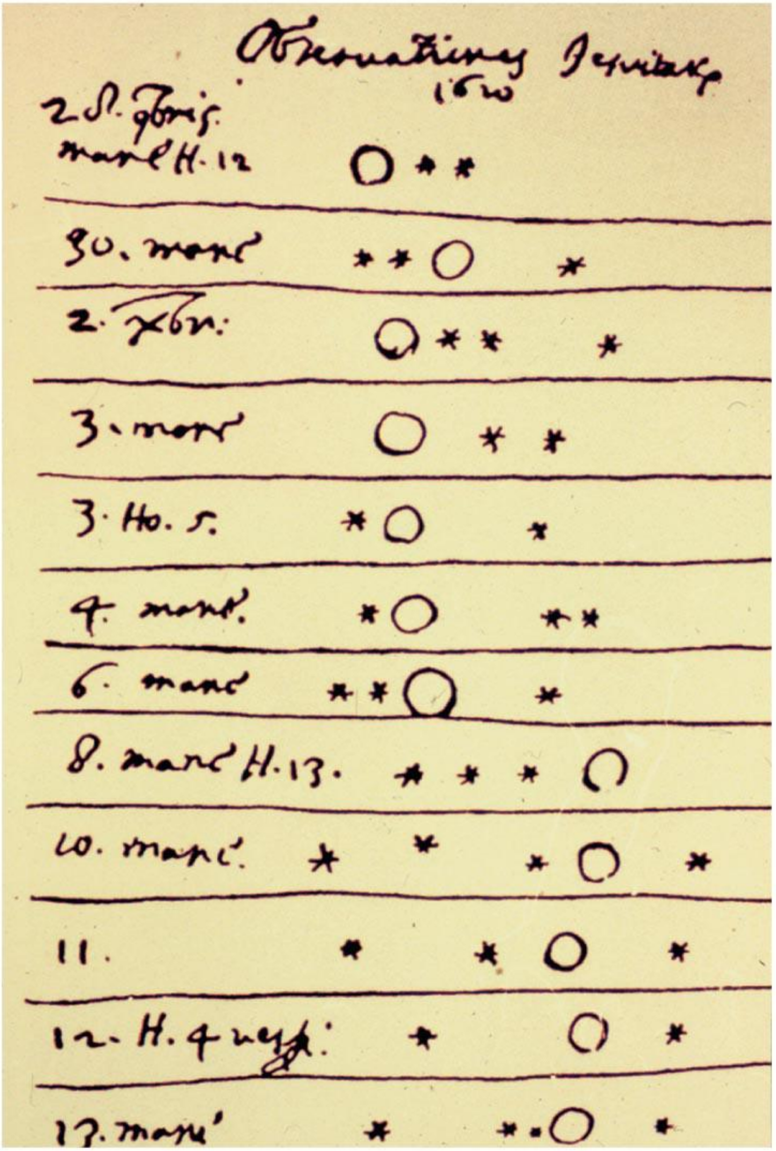
Overcoming the Second Objection (Heavenly Perfection)

- 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)

- 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.

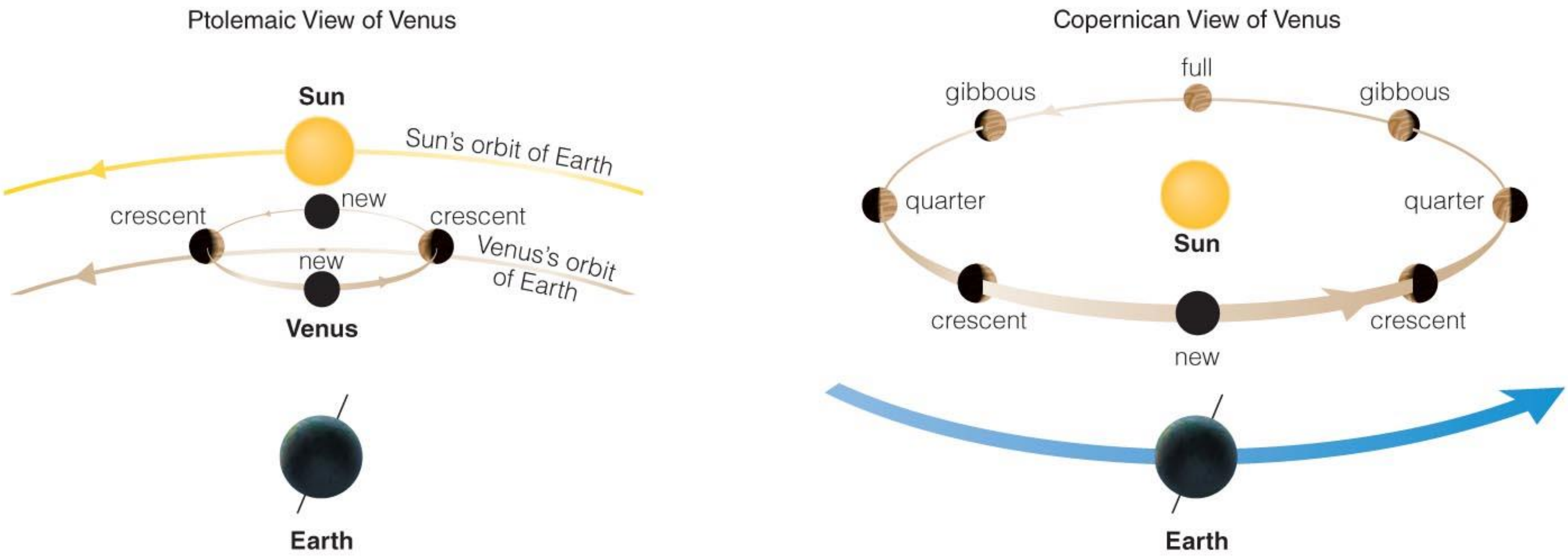
Overcoming the Third Objection (Parallax)



Observationi Jesuitae
1610
29. 9bris.
mane H. 12
30. mane
2. xbris:
3. mane
3. Ho. 5.
4. mane.
6. mane
8. mane H. 13.
10. mane.
11.
12. H. 4 vesp:
13. mane'

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

Overcoming the Third Objection (Parallax)

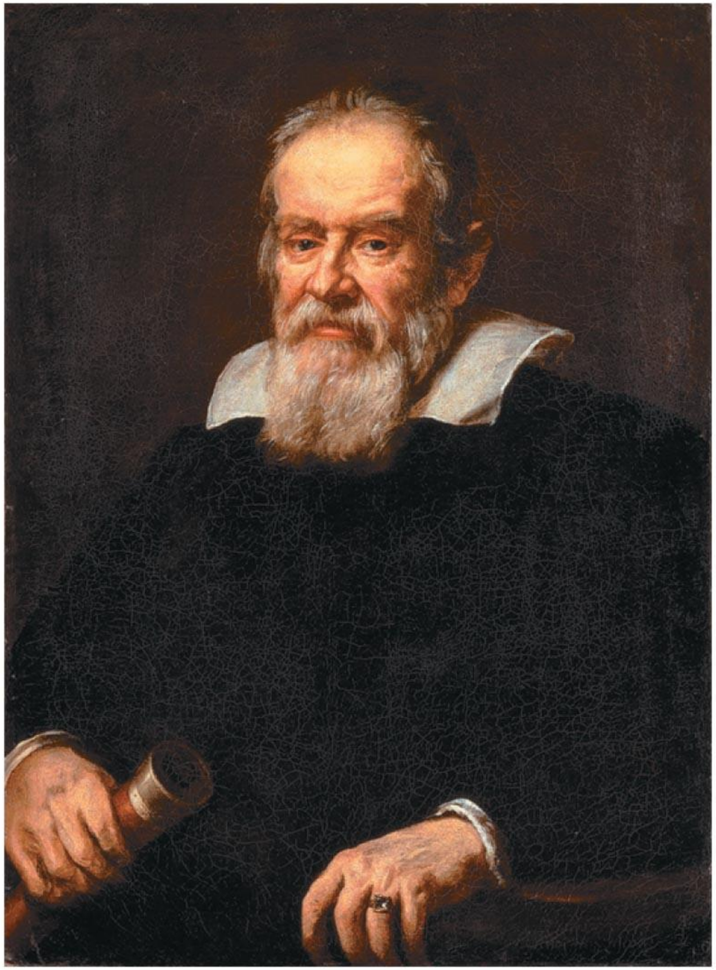


a In the Ptolemaic system, Venus orbits Earth, moving around a smaller circle on its larger orbital circle; the center of the smaller circle lies on the Earth-Sun line. If this view were correct, Venus's phases would range only from new to crescent.

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.

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

Overcoming the Third Objection (Parallax)



- 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.

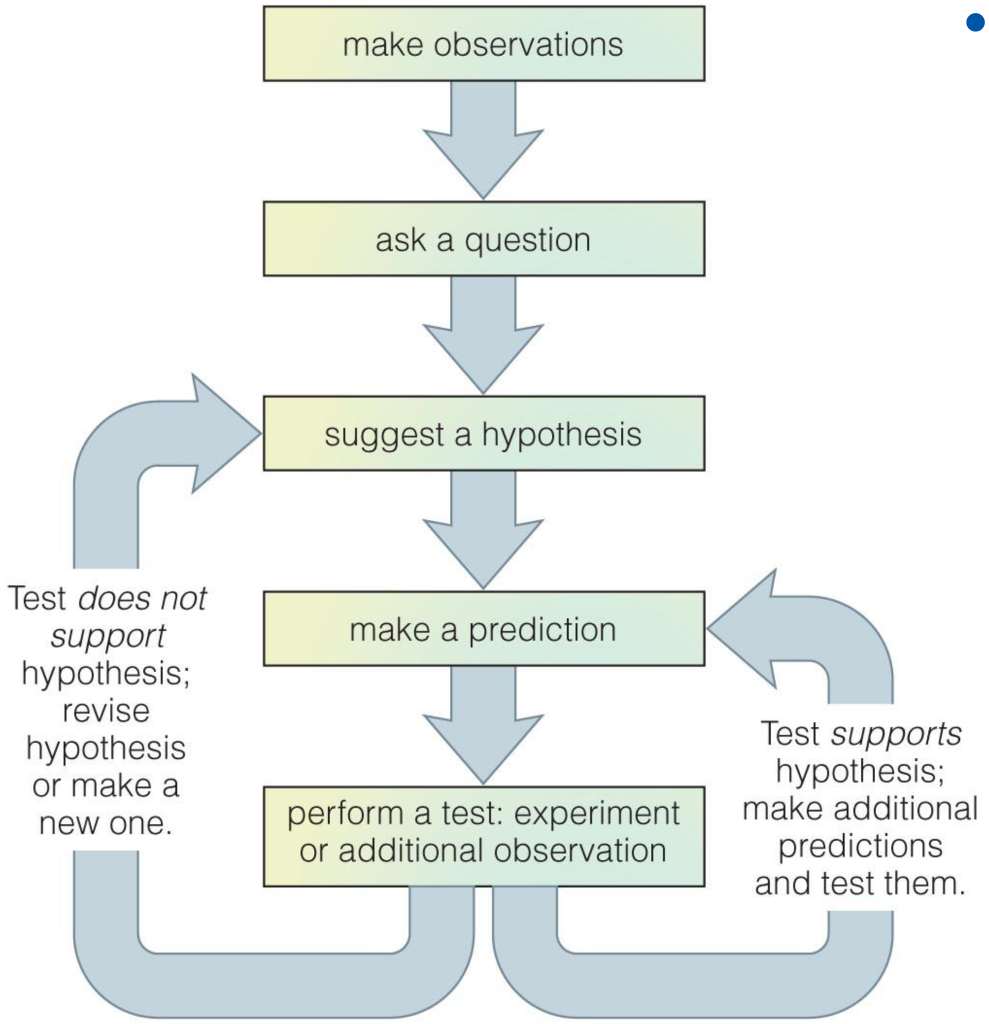
3.4 The Nature of Science

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

How can we distinguish science from non-science?

- Defining science can be surprisingly difficult.
- *Science* from the Latin *scientia*, meaning "knowledge."
- But not all knowledge comes from science.

How can we distinguish science from non-science?


make observations

ask a question

suggest a hypothesis

make a prediction

perform a test: experiment or additional observation

Test *does not support* hypothesis; revise hypothesis or make a new one.

Test *supports* hypothesis; make additional predictions and test them.

- <u>The idealized scientific method</u>
  - Based on proposing and testing hypotheses
  - **hypothesis** = educated guess

How can we distinguish science from non-science?

- 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.

Scientific vs. Everyday Usage

- Many terms used in science have different or more specific meaning than they do in everyday speech.
- Examples: model, hypothesis, theory, bias, critical, deviation, enhance, enrich, error, feedback, state, uncertainty, values.

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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What have we learned?

- **How can we distinguish science from non-science?**
  - Science: seeks explanations that rely solely on natural causes; progresses through the creation and testing of models of nature; models must make testable predictions
- **What is a scientific theory?**
  - A model that explains a wide variety of observations in terms of a few general principles and that has survived repeated and varied testing

3.5 Astrology

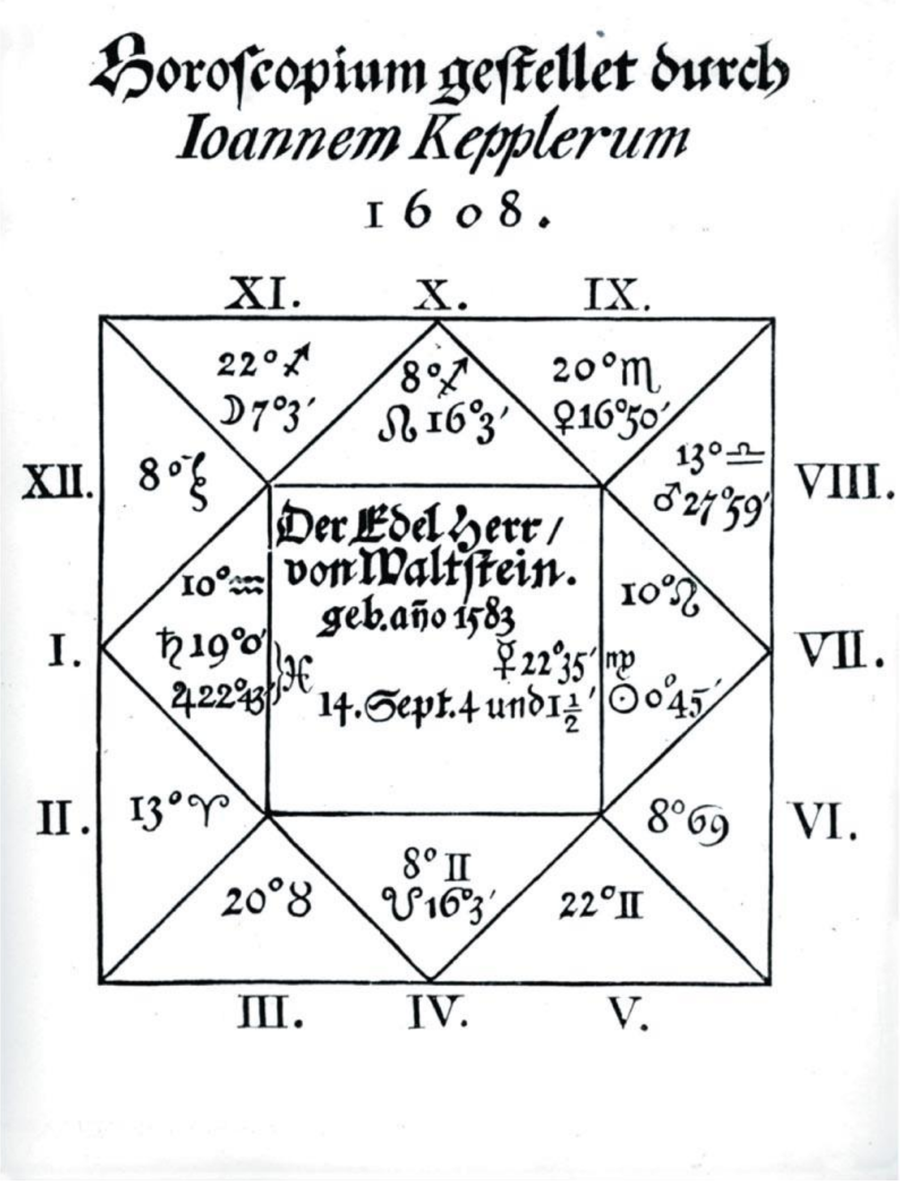
- Our goals for learning:
  - **How is astrology different from astronomy?**
  - **Does astrology have any scientific validity?**

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.



What have we learned?

- **How is astrology different from astronomy?**
  - Astronomy is the scientific study of the universe and the celestial objects within it.
  - Astrology assumes that the positions of celestial objects influence human events.
- **Does astrology have any scientific validity?**
  - Scientific tests show that the predictions of astrology are no more accurate than pure chance.