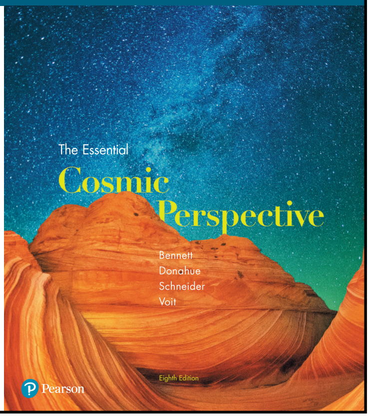
Lecture Outline

Chapter 3: The Science of Astronomy



1

An Assignment

We have now covered the first two chapters of the text:

- Now would be a good time to familiarize yourself with the Mastering Astronomy website
- Take the Chapter One on-line quizzes and evaluate how you are doing
- Find a friend to discuss/study with

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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?

3

In what ways do all humans employ scientific thinking?

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

4

How is modern science rooted in ancient astronomy?

- Astronomy is the oldest of the sciences.
- It was often practiced for practical reasons.
  - In keeping track of time and seasons
    - for practical purposes, including agriculture
    - for religious and ceremonial purposes
  - In aiding navigation

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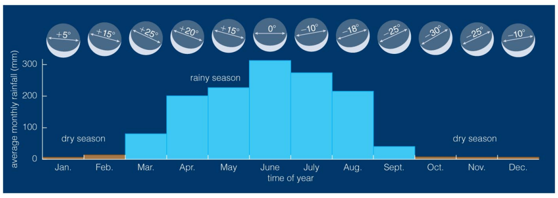

Ancient people of central Africa (6500 B.C.) could predict seasons from the orientation of the crescent moon.

6

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

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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…

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Egyptian obelisk: Shadows tell time of day.

9

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

10

Mexico: Model of the Templo Mayor

11

New Mexico: Anasazi kiva aligned north–south

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SW United States: "Sun Dagger" marks summer solstice

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Scotland: 4000-year-old stone circle; Moon rises as shown here every 18.6 years.

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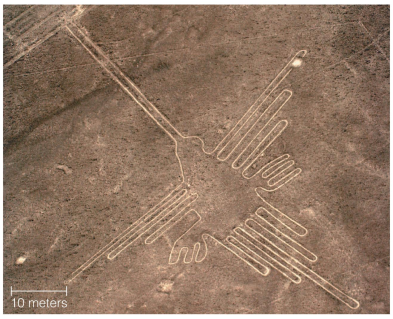

Peru: Lines and patterns, some aligned with stars

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Machu Picchu, Peru: Structures aligned with solstices

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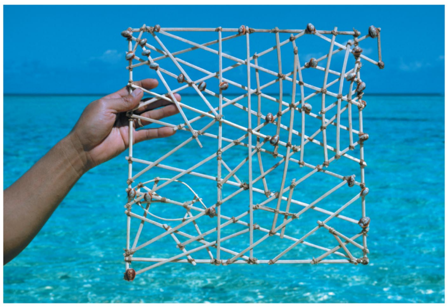

South Pacific: Polynesians were very skilled in the art of celestial navigation.

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

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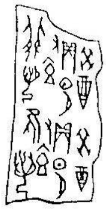

Bone or tortoiseshell inscription from the 14th century B.C.

China: Earliest known records of supernova explosions (1400 B.C.)

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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?

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Our mathematical and scientific heritage originated with the civilizations of the Middle East.

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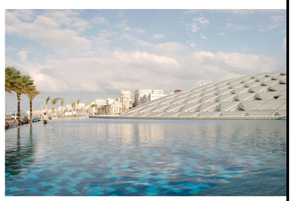
a This painting shows a courtyard of the ancient Library of Alexandria, as it may have looked shortly after its completion.



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

Artist's reconstruction of the Library of Alexandria, alongside the New Library of Alexandria, opened in 2003.

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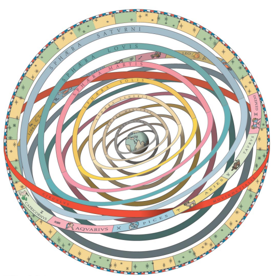
Why does modern science trace its roots to the Greeks?



- 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.)

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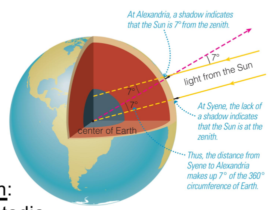
Special Topic: Eratosthenes measures the Earth (c. 240 B.C.)



<u>Measurements:</u>
Syene to Alexandria

- distance ≈ 5000 stadia
- angle = 7°

<u>Calculate circumference of Earth</u>:
7/360 x (circum. Earth) = 5000 stadia
⇒ circum. Earth = 5000 x 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

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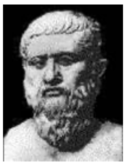
How did the Greeks explain planetary motion?

Underpinnings of the Greek geocentric model:



Plato

- Earth at the center of the universe
- Heavens must be "perfect"—objects move on perfect spheres or in perfect circles.

Aristotle

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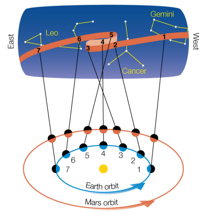
But this made it difficult to explain the apparent retrograde motion of planets…



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

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Ptolemy

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

- Sufficiently accurate to remain in use for 1500 years
- Arabic translation of Ptolemy's work named *Almagest* ("the greatest compilation")

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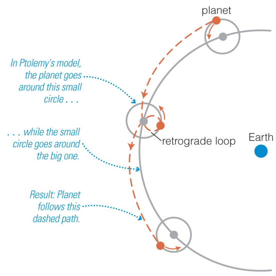
So how does the Ptolemaic model explain retrograde motion?

Planets *really* do go backward in this model.



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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 the Sun in Sun-centered model.
B. Retrograde motion is real (planets really go backward) in the geocentric model but only apparent (planets don't really turn around) in the 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, whereas even the earliest Sun-centered models worked almost perfectly.

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Thought Question

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

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Preserving the ideas of the Greeks

- The Muslim world preserved and enhanced the knowledge they received from the Greeks while Europe was in its Dark Ages.
- 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.

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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?

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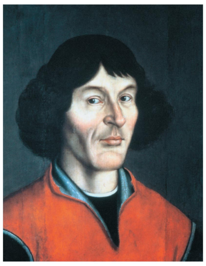
How did Copernicus, Tycho, and Kepler challenge the Earth-centered model?

Copernicus (1473–1543)



- Copernicus proposed the Sun-centered model (published 1543).
- He used the model to determine the layout of the 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.

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Tycho Brahe (1546–1601)

- Brahe compiled the most accurate (1 arcminute) naked eye measurements ever made of planetary positions.
- He still could not detect stellar parallax, and thus still thought Earth must be at the center of the solar system (but recognized that other planets go around the Sun).
- He hired Kepler, who used Tycho's observations to discover the truth about planetary motion.

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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."

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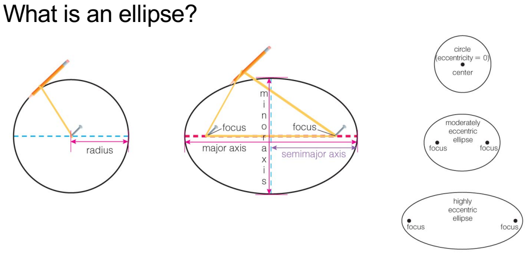
What is an ellipse?



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.

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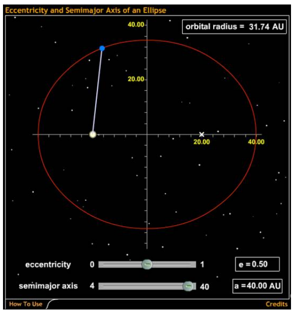
Eccentricity of an Ellipse



PLAY Eccentricity and Semimajor Axis of an Ellipse

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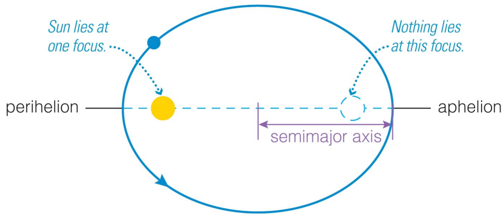
What are Kepler's three laws of planetary motion?

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



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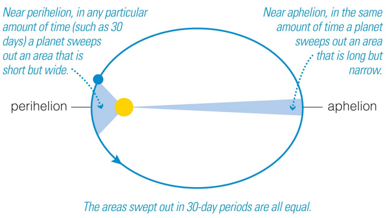
Kepler's Second Law: As a planet moves around its orbit, it sweeps out equal areas in equal times.



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

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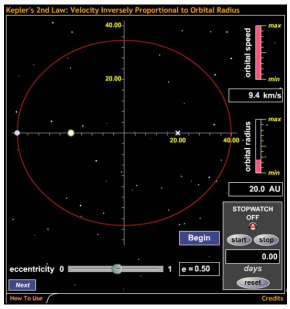

PLAY Kepler's 2nd Law

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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

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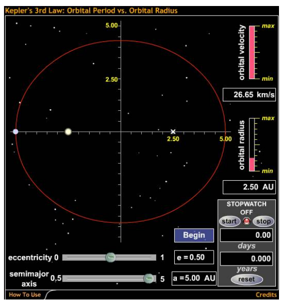
Kepler's Third Law



PLAY Kepler's Third Law

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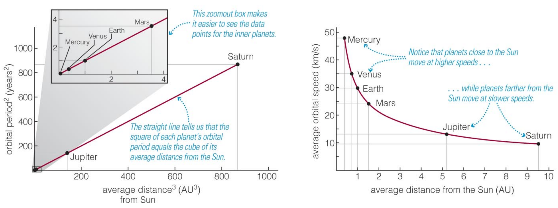
Graphical version of Kepler's third law



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.

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.

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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 $p^2 = a^3$.)

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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 $p^2 = a^3$.
Because a = 4, $a^3 = 4^3 = 64$.
Therefore, p = 8, $p^2 = 8^2 = 64$.

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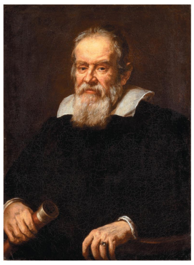
How did Galileo solidify the Copernican revolution?



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

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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).

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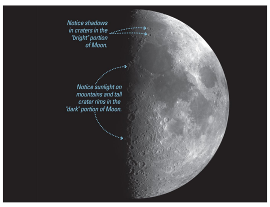
Overcoming the second objection (heavenly perfection):



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

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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.

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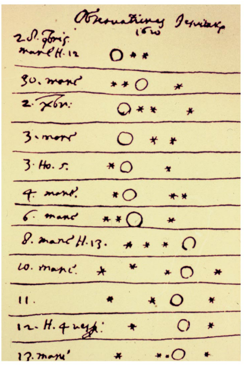

- Galileo also saw four moons orbiting Jupiter, proving that not all objects orbit Earth.

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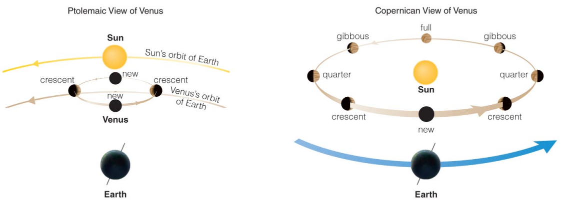

a In the Ptolemaic model, Venus orbits Earth, moving around a smaller circle on its larger orbital circle; the center of the smaller circle lies on the Earth–Sun line. If this view were correct, Venus's phases would range only from new to crescent.

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 proved that it orbits the Sun and not Earth.

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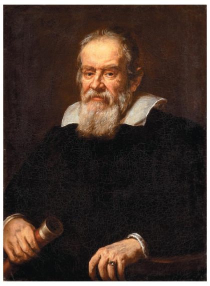

Galileo Galilei

- In 1633 the Catholic Church ordered Galileo to recant his claim that Earth orbits the Sun.
- 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.

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3.4 The Nature of Science

Our goals for learning:

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

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How can we distinguish science from nonscience?

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

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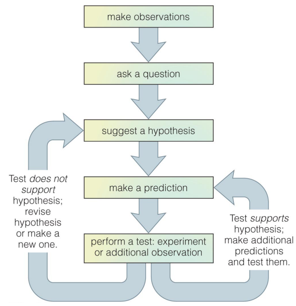

The idealized scientific method:

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

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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.

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Hallmarks of Science: #1

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

(A scientific model cannot include divine intervention.)

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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")

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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.

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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

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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.

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