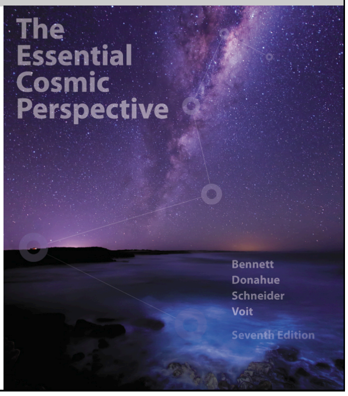
Lecture Outline

Chapter 3: 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 employ scientific thinking?

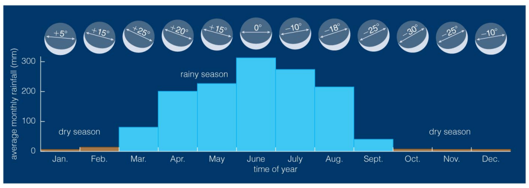
- Scientific thinking is based on everyday ideas of observation and trial-and-error experiments.
- Rather than thinking differently, scientist organize everyday thinking in a way that makes it easier to share discoveries

How is modern science rooted in ancient astronomy?

- Astronomy is the oldest of the sciences.

Why study it?

- Inherent curiosity
- Keeping track of time and seasons
  - for practical purposes, including agriculture
  - for religious and ceremonial purposes
- In aiding navigation



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

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…

Astronomy and Measures of Time

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; in English the correspondence is obvious for Sunday, "Moonday," and "Saturnday," while other day names come from Germanic gods.

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

Days of the week were named for the Sun, Moon, and *visible* planets (*wandering star*).

Determining the Time of Day

- Egyptian obelisk: Shadows tell time of day.
- am (ante meridiem) pm (post meridiem)

Astronomy and Measures of Time

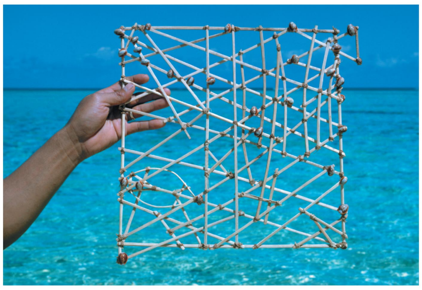
England: Stonehenge (completed around 1550 B.C.)

Aztec city of Tenochtitlan Templo Mayor (15th century)

New Mexico: Pueblo Bonito.
Anasazi kiva aligned north–south (1050 A.D.)

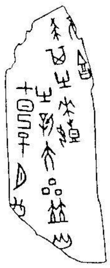
Scotland: 4000-year-old stone circle; Moon rises as shown here every 18.6 years.

Machu Picchu, Peru: Structures aligned with solstices

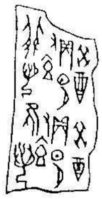


South Pacific: Polynesians were very skilled in the art of celestial navigation.

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



"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 tortoiseshell inscription from the 14th century B.C.

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

3.2 Ancient Greek Science

Our goals for learning:

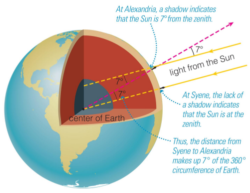
- Why does modern science trace its roots to the Greeks?
- How did the Greeks explain planetary motion?

Why does modern science trace its roots to the Greeks?

- Geographical location
- Rational ideas
- Conquest of Alexander the Great

Eratosthenes measures the Earth (c. 240 B.C.)

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



Calculate circumference of Earth:
Compare to modern value (≈ 40,100 km):
Greek stadium ≈ 1/6 km ⇒ 250,000 stadia ≈ 42,000 km

Three Philosophical Innovations

- ❑ Did not rely on supernatural explanations
- ❑ Used mathematics for precision of ideas
- ❑ Reasoning from observations

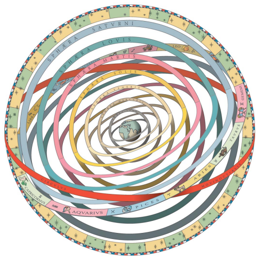
Our mathematical and scientific heritage traces back to these principle ideas

Scientific Method

axioms

- ❑ There is no absolute truth
- ❑ All things being equal the simpler explanation is better

Models of Nature



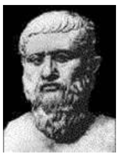
- ❑ Greeks were the first people known to make ***models*** of nature.
- ❑ A ***Model*** is a conceptual representation created to explain and predict observed phenomena

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

➢How did the Greeks explain planetary motion?

Underpinnings of the Greek geocentric model:

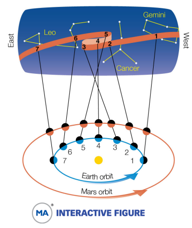
- Earth at the center of the universe
- Heavens must be "perfect"—objects move on perfect spheres or in perfect circles.



Plato

Aristotle

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



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

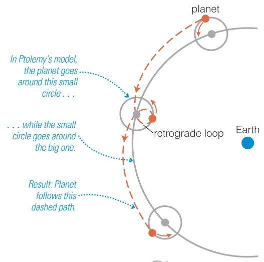
Ptolemy

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

- Sufficiently accurate to remain in use for 1500 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.



INTERACTIVE FIGURE

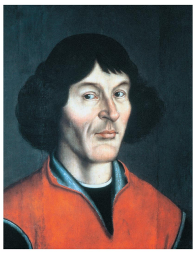
3.3 The Copernican Revolution

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)



- 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.

Tycho Brahe (1546–1601)

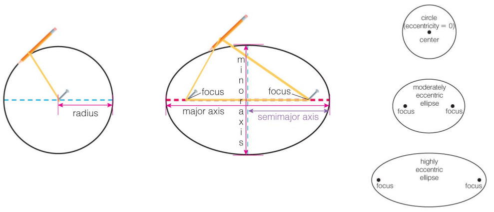
- Brahe compiled the most accurate (1 arcminute) naked eye measurements ever made of planetary positions.
- He still could not detect stellar parallax, and thus still thought Earth must be at the center of the solar system (but recognized that other planets go around the Sun).
- He hired Kepler, who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

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?



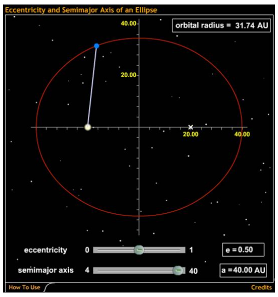
a Drawing a circle with a string of fixed length.

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.

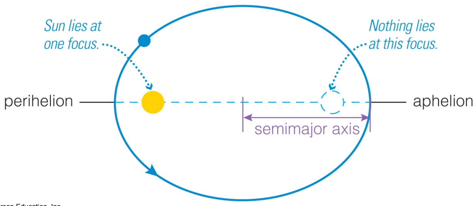
Eccentricity of an Ellipse



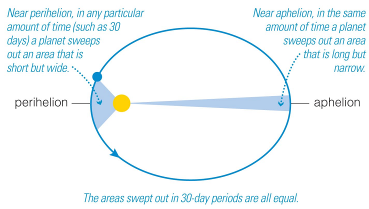
PLAY Eccentricity and Semimajor Axis of an Ellipse

➢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.



A planet travels faster when it is nearer to 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

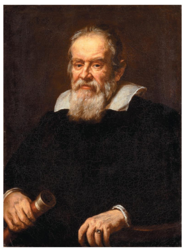
Thought Question

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 $p^2 = a^3$.)

➢How did Galileo solidify the Copernican revolution?



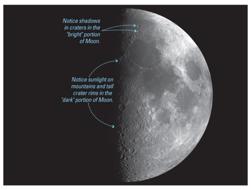
- ❑ Galileo (1564–1642) overcame major objections to the Copernican view.
- ❑ Aristotle's views:
  1. Earth could not be moving because objects in air would be left behind.
  2. Noncircular orbits are not "perfect" as heavens should be.
  3. If Earth were really orbiting Sun, we'd detect stellar parallax.

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).

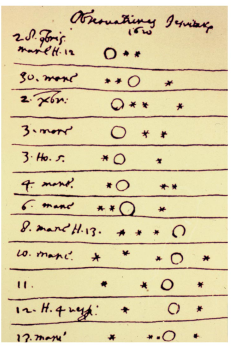
Overcoming the second objection (heavenly perfection):



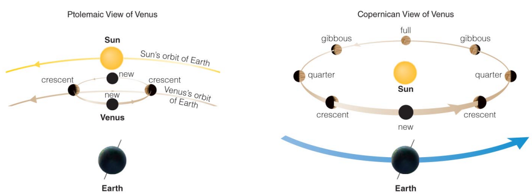
- ❑ Tycho's observations of comet and supernova already challenged this idea.
- ❑ Using his telescope, Galileo saw:
  - Sunspots on the Sun ("imperfections")
  - Mountains and valleys on the Moon (proving it is not a perfect sphere)

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 has 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.

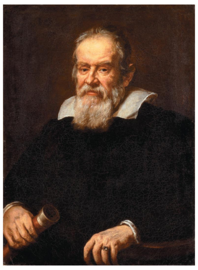


a In the Ptolemaic model, Venus orbits Earth, moving around a smaller circle on its larger orbital circle; the center of the smaller circle lies on the Earth–Sun line. If this view were correct, Venus's phases would range only from new to crescent.

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.

MA INTERACTIVE FIGURE

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



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.

3.4 The Nature of Science

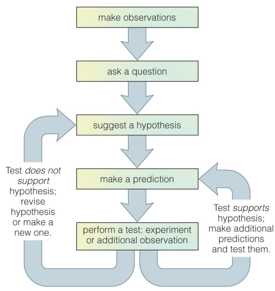
Our goals for learning:

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

How can we distinguish science from nonscience?

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

Approaches to Science



The idealized scientific method:

- 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.

Hallmarks of Science

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

  (A scientific model cannot include divine intervention.)

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

  (Simplicity = "Occam's razor")

- 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.

  (There is no absolute truth)

➢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
- 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

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.