Chapter 3
The Science of Astronomy

3.1 The Ancient Roots of Science

Our goals for learning:

- In what ways do all humans employ scientific thinking?
- How did astronomical observations benefit ancient societies?
- What did ancient civilizations achieve in astronomy?

How did astronomical observations benefit ancient societies?

- Keeping track of time and seasons
  - for practical purposes, including agriculture
  - for religious and ceremonial purposes
- Aid to navigation

What have we learned?

- In what ways do all humans employ 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 did astronomical observations benefit ancient societies?
  - Keeping track of time and seasons; navigation

What have we learned?

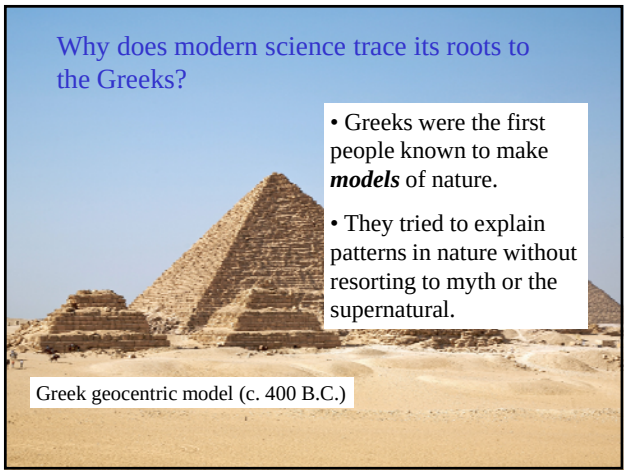
- What did ancient civilizations achieve in astronomy?
  - To tell the time of day and year, to track cycles of the Moon, to observe planets and stars. Many ancient structures aided in astronomical observations.

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?
- How was Greek knowledge preserved through history?

Why does modern science trace its roots to the Greeks?

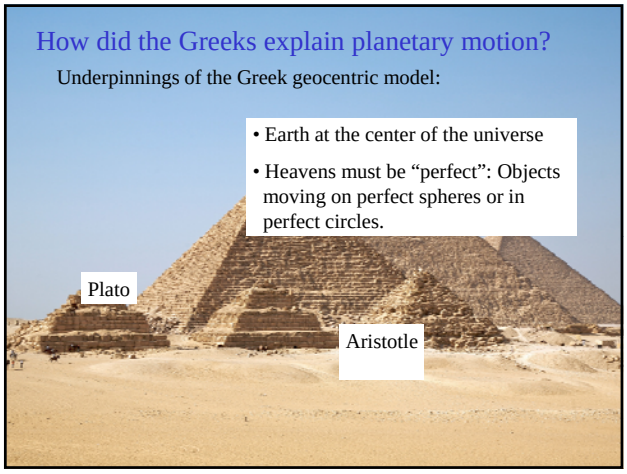


- Greeks were the first people known to make ***models*** of nature.
- They tried to explain patterns in nature without resorting to myth or the supernatural.

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

How did the Greeks explain planetary motion?

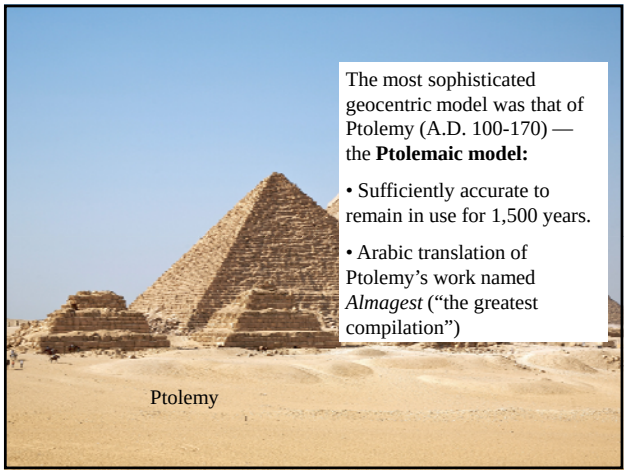
Underpinnings of the Greek geocentric model:



- Earth at the center of the universe
- Heavens must be "perfect": Objects moving on perfect spheres or in perfect circles.

Plato

Aristotle



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")

Ptolemy

How was Greek knowledge preserved through history?

• Muslim world preserved and enhanced the knowledge they received from the Greeks

• 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.

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

What have we learned?

- How was Greek knowledge preserved through history?
  - While Europe was in its Dark Ages, Islamic scientists preserved and extended Greek science, later helping to ignite the European Renaissance

3.3 The Copernican Revolution

Our goals for learning:

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

Copernicus (1473-1543):

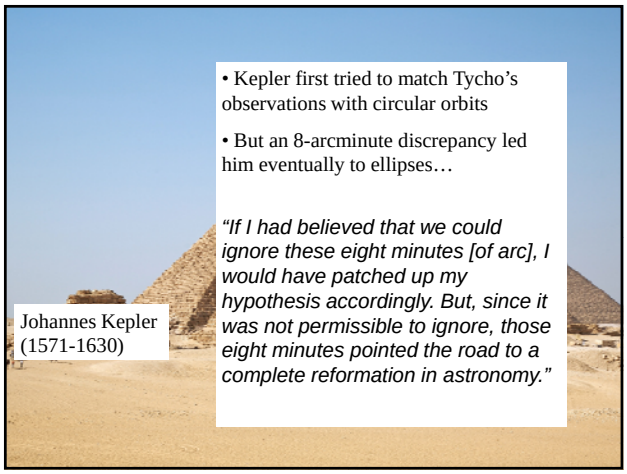
- Proposed Sun-centered model (published 1543)
- Used model to determine layout of solar system (planetary distances in AU)

But . . .

- Model was no more accurate than Ptolemaic model in predicting planetary positions, because it still used perfect circles.

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.



Johannes Kepler (1571-1630)

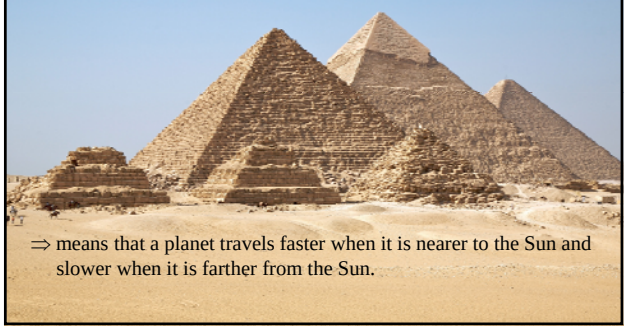
- Kepler first tried to match Tycho's observations with circular orbits
- But an 8-arcminute discrepancy led him eventually to ellipses…

"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 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.



⇒ 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 = avg. distance from Sun in AU

How did Galileo solidify the Copernican revolution?

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

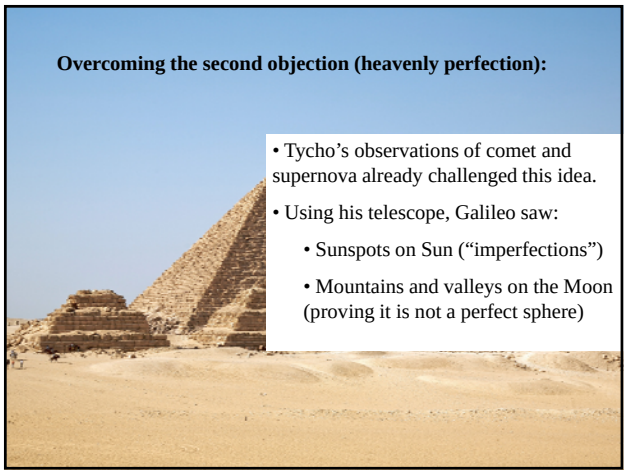
1. Earth could not be moving because objects in air would be left behind.
2. Non-circular orbits are not "perfect" as heavens should be.
3. If Earth were really orbiting Sun, we'd detect stellar parallax.

Overcoming the first objection (nature of motion):

Galileo's experiments showed that objects in air would stay with a moving Earth.

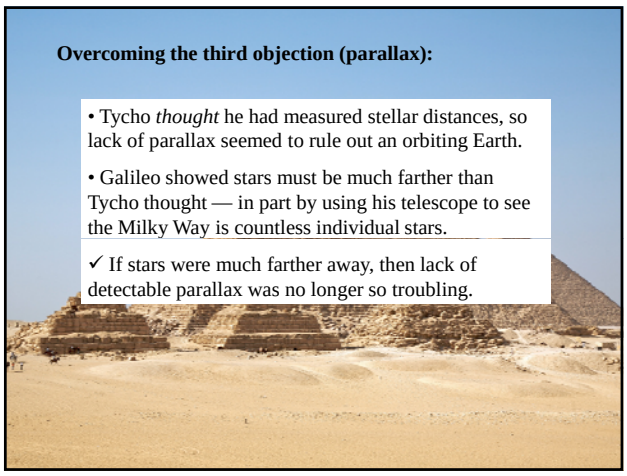
- Aristotle thought that all objects naturally come to rest.
- Galileo showed that objects will stay in motion unless a force acts to slow them down (Newton's first law of motion).

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)

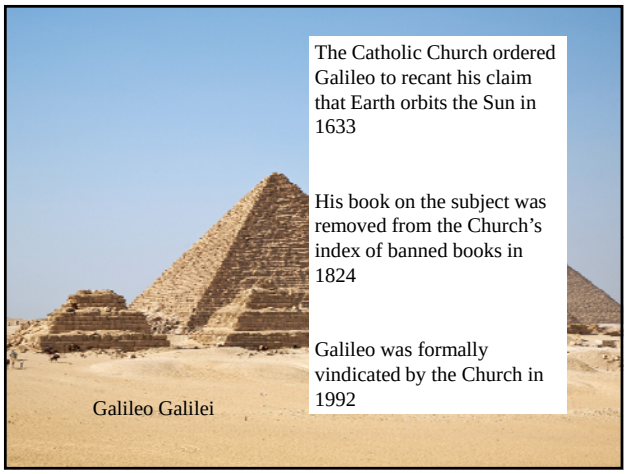
Overcoming the third objection (parallax):



- 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 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 the Earth



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 our 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

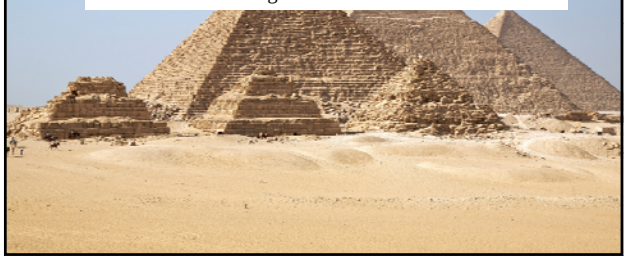
3.4 The Nature of Science

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…



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.

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.

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