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?
Early Hypotheses on the nature of the universe =roots of Astronomy

Myths, Fables, Legends and Folktales
In the beginning, before there was any land of Egypt, all was darkness, and there was nothing but a great waste of water called Nun. The power of Nun was such that there arose out of the darkness a great shining egg, and this was Re. Now Re was all-powerful, and he could take many forms. His power and the secret of it lay in his hidden name; but if he spoke other names, that which he named came into being. "I am Khepera at the dawn, and Re at noon, and Tem in the evening," he said. And the sun rose and passed across the sky and set for the first time.

Then he named Shu, and the first winds blew; he named Tefnut the spitter, and the first rain fell. Next he named Geb, and the earth came into being; he named the goddess Nut, and she was the sky arched over the earth with her feet on one horizon and her hands on the other; he named Hapi, and the great River Nile flowed through Egypt and made it fruitful.

After this Re named all things that are upon the earth, and they grew. Last of all he named mankind, and there were men and women in the land of Egypt. Then Re took on the shape of a man and became the first Pharaoh, ruling over the whole country for thousands and thousands of years, and giving such harvests that for ever afterwards the Egyptians spoke of the good things "which happened in the time of Re".
CREATION MYTHS  On the WEB

A report from a student on:
Iroquois , Australian Aborigine, African Bushmen,
Hebrew/Christian, Greek & Japanese Creation Myth

Check at:  Iraquois to Japanese Creation Myths

Creation Myths of  The World
Check at:  Creation Myths of the World

TRY a SEARCH ENGINE  “creation myths”—have fun.
Any common threads? EXTRA CREDIT report!
Archaeo-astronomy-astronomy of ancient people

27,000 year old Mammoth tusk from Ukraine
= four cycles of Lunar Phases???
In what ways do all humans employ scientific thinking?

- Scientific thinking is based on everyday ideas of observation and trial-and-error experiments.
- Ancient folks did just that, observe and make connections as we will now see!
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
Ancient people of central Africa (6500 BC) could predict seasons from the orientation of the crescent moon. The moon's angle changed because of the tilt of the earth changing with respect to the sun. Hence, the path of the sun and Moon change in the sky with the seasons. Like High noon in summer vs winter.
Days of week were named for Sun, Moon, and visible planets.

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

The correspondence between objects and days is easy to see in French and Spanish. In English, the correspondence becomes clear when we look at the names of the objects used by the Teutonic tribes who lived in the region of modern-day Germany.

<table>
<thead>
<tr>
<th>Object</th>
<th>Teutonic Name</th>
<th>English</th>
<th>French</th>
<th>Spanish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>Sun</td>
<td>Sunday</td>
<td>dimanche</td>
<td>domingo</td>
</tr>
<tr>
<td>Moon</td>
<td>Moon</td>
<td>Monday</td>
<td>lundi</td>
<td>lunes</td>
</tr>
<tr>
<td>Mars</td>
<td>Tiw</td>
<td>Tuesday</td>
<td>mardi</td>
<td>martes</td>
</tr>
<tr>
<td>Mercury</td>
<td>Woden</td>
<td>Wednesday</td>
<td>mercredi</td>
<td>miércoles</td>
</tr>
<tr>
<td>Jupiter</td>
<td>Thor</td>
<td>Thursday</td>
<td>jeudi</td>
<td>jueves</td>
</tr>
<tr>
<td>Venus</td>
<td>Fria</td>
<td>Friday</td>
<td>vendredi</td>
<td>viernes</td>
</tr>
<tr>
<td>Saturn</td>
<td>Saturn</td>
<td>Saturday</td>
<td>samedi</td>
<td>sábado</td>
</tr>
</tbody>
</table>

Days of week were named for Sun, Moon, and *visible* planets.
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…
• Egyptian obelisk: Shadows tell time of day.

Check out the one behind the
The metropolitan museum of Art
On 5\textsuperscript{th} ave.
England: Stonehenge (completed around 1550 B.C.)
England: Stonehenge (1550 B.C.)
Rising Sun at the Equinoxes
Let’s sacrifice a captive neighbor
Heart cutting is the best!

Mexico: model of the Templo Mayor of the Aztec city
Tenochtitlan = modern day Mexico city
Anasazi Kiva oriented N-S

Anasazi (navajo="enemy ancestors" =cliff dwellers=modern Hopi, Zuni and Rio Grande tribes of SW US

Kivas are religious structures built into the ground with a particular astronomic orientation. Different kivas are used at different times of year for different ceremonies. Nearly every Anasazi ruin has at least one kiva present somewhere in the building complex
Anasazi “Sun Dagger” marks summer solstice at Chaco canyon. Two daggers bracket spiral winter solstice, also a dagger at equinox.
Scotland: 4,000-year-old stone circle; Moon rises as shown here every 18.6 years.
Peru: Lines and patterns, some aligned with stars. UFO folks claim they were built for Alien ships to land. WHAT DO YOU THINK?
Macchu Pichu, Peru: Structures aligned with solstices.
1000 year old “Carocal” (snails shell) of Mayan City Chichen itza

Quetzalcoatl=Venus as a God
Windows aligned to Venus and special stars

Many written records have been lost. Mayan Manuscripts were burned by Spanish missionaries as “books of the Devil”
South Pacific: Polynesians were very skilled in art of celestial navigation. Image is wave patterns around islands. They used stars and knowledge of currents etc to navigate amongst pacific islands. Navigator held a very high position in their society!
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 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?
• How was Greek knowledge preserved through history?
Our mathematical and scientific heritage originated with the civilizations of the Middle East.
For example, a brief history of our calendar!
Artist’s reconstruction of Library of Alexandria - note the scrolls!

The new library built today
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 the Earth (c. 240 BC)

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

Calculate circumference of Earth:
\[
\frac{7}{360} \times (\text{circum. Earth}) = 5000 \text{ stadia}
\]
\[
≈ \frac{1}{50} \times (\text{circum. Earth}) = 5000 \text{ stadia}
\]

⇒ circum. Earth = 5000 × 50 stadia ≈ 250,000 stadia

Compare to modern value (≈ 40,100 km):
Greek stadium ≈ 1/6 km ⇒ 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.
Jupiter and Saturn in Retrograde motion
Nature’s way of driving astrologers crazy!

animated sequence combining 23 pictures taken at approximately 2 week intervals from June 2000 through May 2001
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”)
One way the Ancients got Angles used to position objects on the Celestial Sphere is that they used the “Cross-staff”

For angular distance & angular diameters note: surveying also!

Can be made easily:

Use a meter-stick;
and a pencil or pen

Slide pen
Ptolemaic Geocentric Model worked well at first but errors accumulated As the centuries past. He did well for 1500 years!

Note: centers of Mercury & Venus Epicycles lie on Earth-sun line Not Mars, Jupiter or Saturn. WHY?
Note Moon and Sun have no Epicycles.
Jupiter and Saturn in Retrograde motion
Nature’s way of driving astrologers crazy!

animated sequence combining 23 pictures taken at approximately 2 week intervals from June 2000 through May 2001
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.
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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

• While Europe was in its Dark Ages, Islamic scientists preserved and extended Greek science, later helping to ignite the European Renaissance when at the fall of Constantinople (Istanbul) in 1453, Eastern scholars headed west to Europe.
Islamic Astronomy
In the period
From the Dark Ages
(end classical era 500 AD)
To the Renaissance
(14th Century Italy)
Islam Preserved and
Augmented Ancient
Greek texts (Golden era
500 BC)
Motive-precise dates of
Holy Days and direction
of Mecca from any
location on Earth
Derived from arabic-
ZENITH, AZIMUTH,
RIGEL, Betelgeuse, Vega
Altar, Aldeberan Algebra
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.
The Copernican Revolution

Nicolaus Copernicus (1473 – 1543):
Heliocentric Universe (Sun in the Center)
Copernicus’ New (and Correct) Explanation for the Retrograde Motion of the Planets

Retrograde (westward) motion of a planet occurs when the Earth passes the planet.

This made Ptolemy’s epicycles unnecessary.
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 Brahe

- Measurement of a “new star” (a supernova) and comet showed no parallax. Hence they must be very far and not in our atmosphere as the ancients thought!

If they were in the atmosphere, then parallax would be seen. →
Kepler first tried to match Tycho’s observations with circular orbits.

But an 8-arcminute discrepancy led him eventually to ellipses... He had great faith that Tycho’s measurements were accurate!

“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.”
Kepler was also a mystic and constructed a geometrical model, as well as the treatise “Music of the Spheres”
What is an ellipse?

An ellipse looks like an elongated circle.
Eccentricity 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.

⇒ 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
Kepler’s Third Law
Graphical version of Kepler’s Third Law
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 \( p^2 = a^3 \)
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 \( p = 8 \), \( p^2 = 8^2 = 64 \)
Galileo Galilei (1594 – 1642)

• Invented the modern view of science: Transition from a faith-based “science” to an observation-based science.

• Greatly improved on the newly invented telescope technology. (But Galileo did NOT invent the telescope!)

• Was the first to meticulously report telescope observations of the sky to support the Copernican Model of the Universe.
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).
Aristotle said you need a force to stay in motion.

No that is incorrect... says Galileo. he experiments as above and Discovers a law of motion.

G.G. explores idea = Newton’s First Law!
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, first to estimate their heights, 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.

- Rings of Saturn

(What he really saw)
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.
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.
Hallmarks of Science: #1

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

(A scientific model cannot include divine intervention)
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”)
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.
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 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.

Let's try a test

**TEST ASTROLOGY**