3. The Science of Astronomy

We especially need imagination in science. It is not all mathematics, nor all logic, but is somewhat beauty and poetry.

Maria Mitchell (1818 – 1889)
Astronomer and first woman
elected to American Academy of
Arts & Sciences

3.1 Everyday Science

Our goals for learning:

- How is scientific thinking similar to other everyday thinking?

Scientific Thinking

- It is a natural part of human behavior.
- We draw conclusions based on our experiences.
- Progress is made through “trial and error.”

3.2 The Ancient Roots of Science

Our goals for learning:

- How is modern science rooted in ancient astronomical observations?
- Describe several impressive ancient astronomical accomplishments.

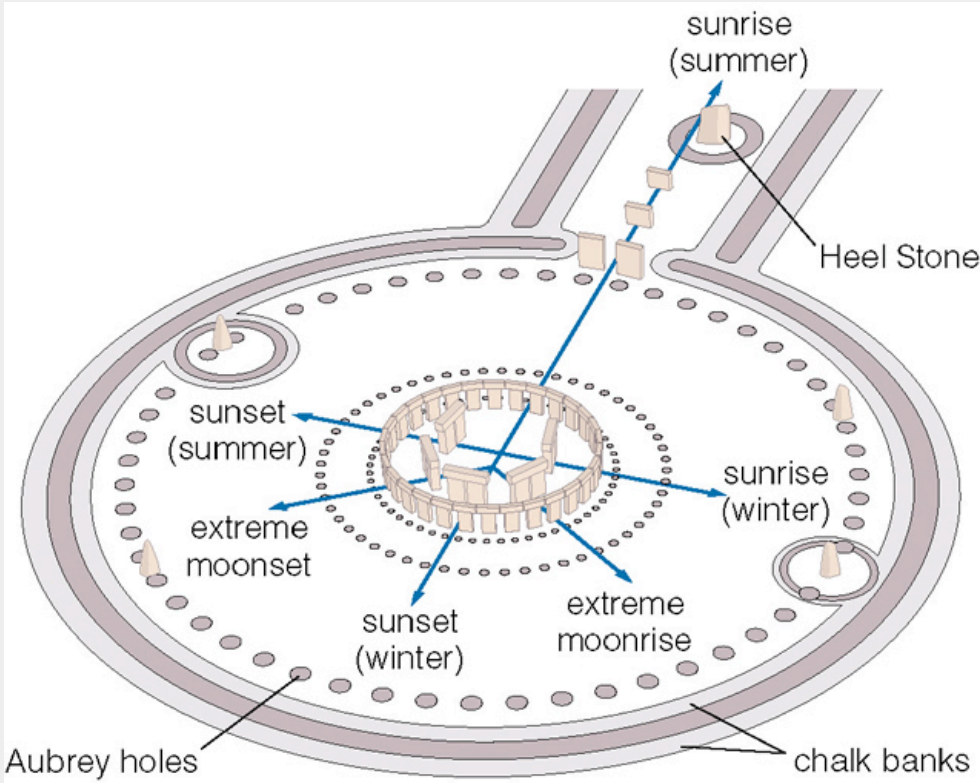
Ancient Astronomy

- Many cultures throughout the world practiced astronomy.
- They made careful observations of the sky.
- Over a period of time, they would notice the cyclic motions of:
  - Sun
  - Moon
  - planets
  - celestial sphere (stars)

Stonehenge (completed 1550 BC)

This famous structure in England was used as an observatory.

- If you stand in the middle:
  - the directions of sunrise & sunset on the solstices is marked.
  - the directions of extreme moon rise & set are marked.
- The Aubrey holes are believed to be an analog eclipse computer.



Stonehenge Pictures

Mayans (fl. A.D. 400 – 1200)

the Observatory at Chichén Itzá

- lived in central America
- accurately predicted eclipses
- Venus was very important
- marked zenial passages
- Mayan mathematics
  - base 20 system
  - invented the concept of "zero"

Anasazi (ca. A.D. 1000)

- lived in “four corners” area of SW USA
- built structures to mark solstices and equinoxes

Pueblo Bonita at Chaco Canyon, NM

Sun Dagger at Fajada Butte

Plains Tribes of N. America

Big Horn Medicine Wheel, WY

- star maps and sighting circles were drawn on the ground to mark:
  - solstice rising points of Sun
  - helical rising points of stars

Why did they do it?

- archeologists & anthropologists surmise:
  - to keep time
  - for agricultural purposes
  - for religious purposes
- As far as we can tell, none of these ancient cultures tried to build a physical model based on their observations.
- Instead, they created myths to explain the motions of the objects in the sky.

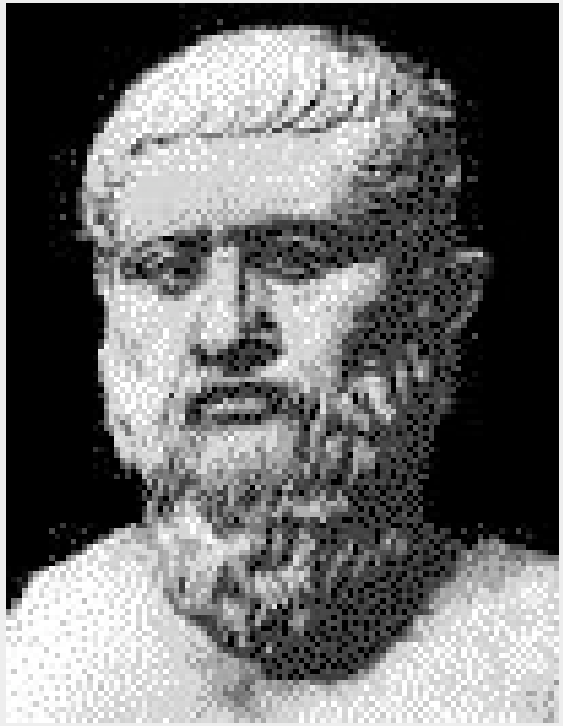
3.3 Ancient Greek Science

Our goals for learning:

- How did the Greeks lay the foundations for modern science?
- What was the Ptolemaic model?

Plato (428 - 348 BC)

- All natural motion is circular
- Reason is more important than observation



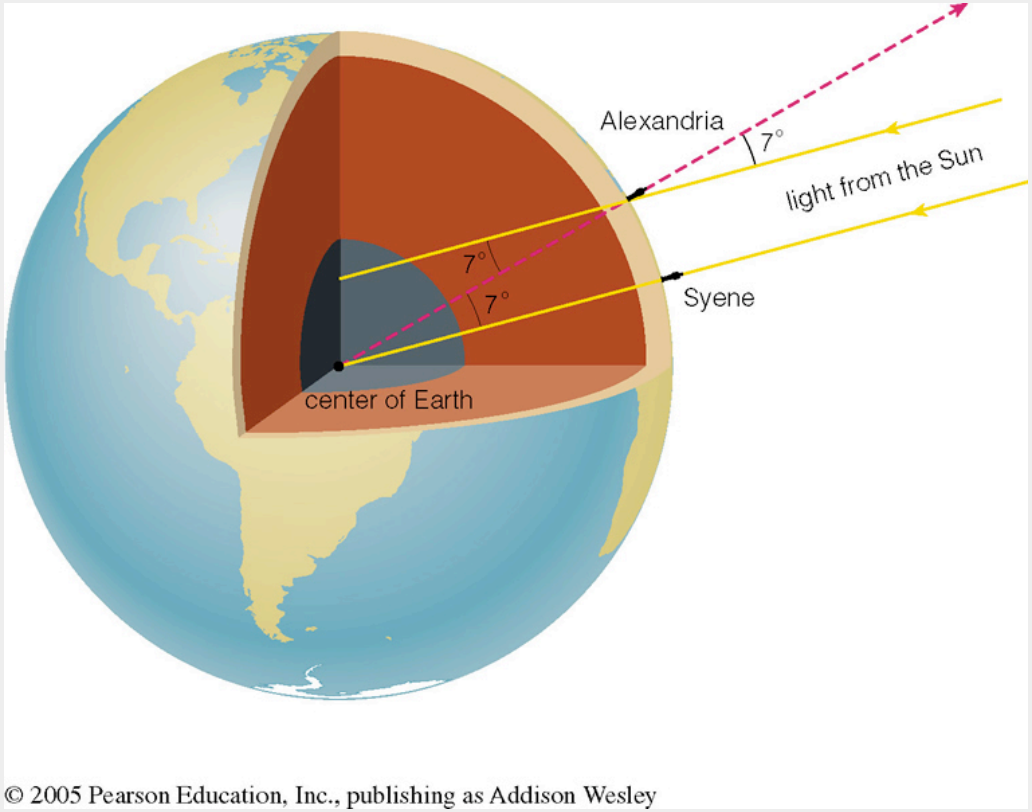
Aristotle (384 -322 BC)

- *Physics*
- elements
  - *earth*
  - *water*
  - *air*
  - *fire*
  - *quintessence*

- Earth at center of universe (geocentric)

Eratosthenes (276 - 195 BC)

- He measured the circumference of the Earth.
- The Sun is at the zenith in the city of Syene at noon on the summer solstice.
- But at the same time in Alexandria, it is 7° from the zenith.



- Eratosthenes inferred that Alexandria was 7° of latitude north of Syene.
- The distance between the two cities is 7/360 times the Earth's circumference.
- His result of 42,000 km is very close to the right number: 40,000 km.

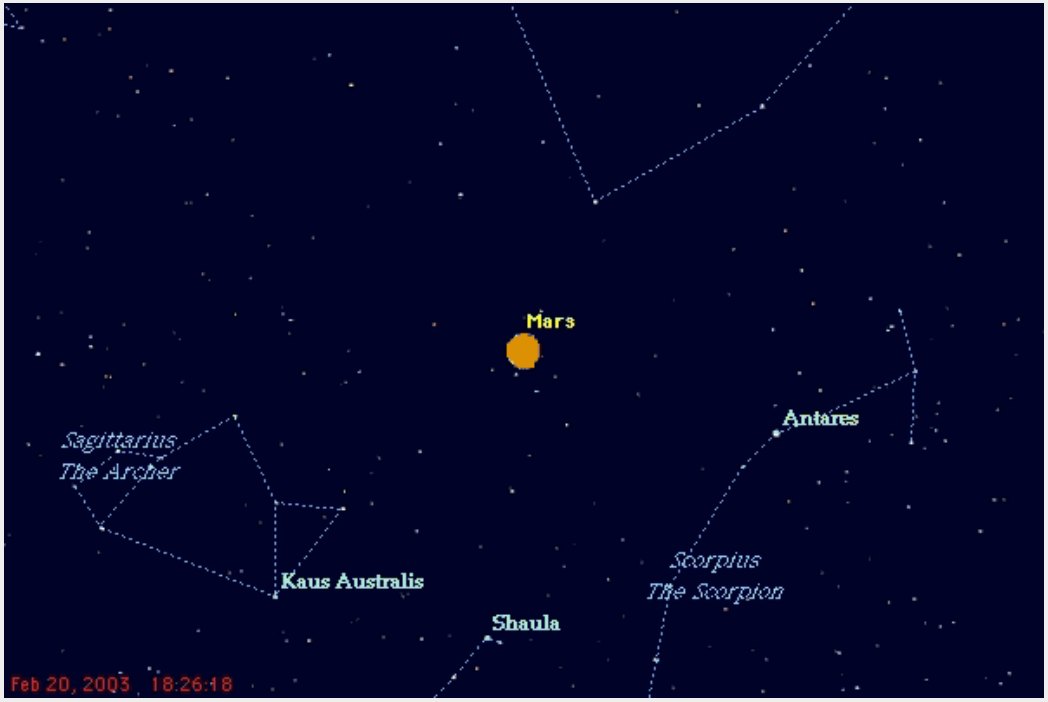
Claudius Ptolemy (AD 100-170)

Almagest

- star catalogue
- instruments
- motions & **model** of planets, Sun, Moon

His model fit the data, made accurate predictions, but was horribly contrived!

How does one explain *retrograde* motion?

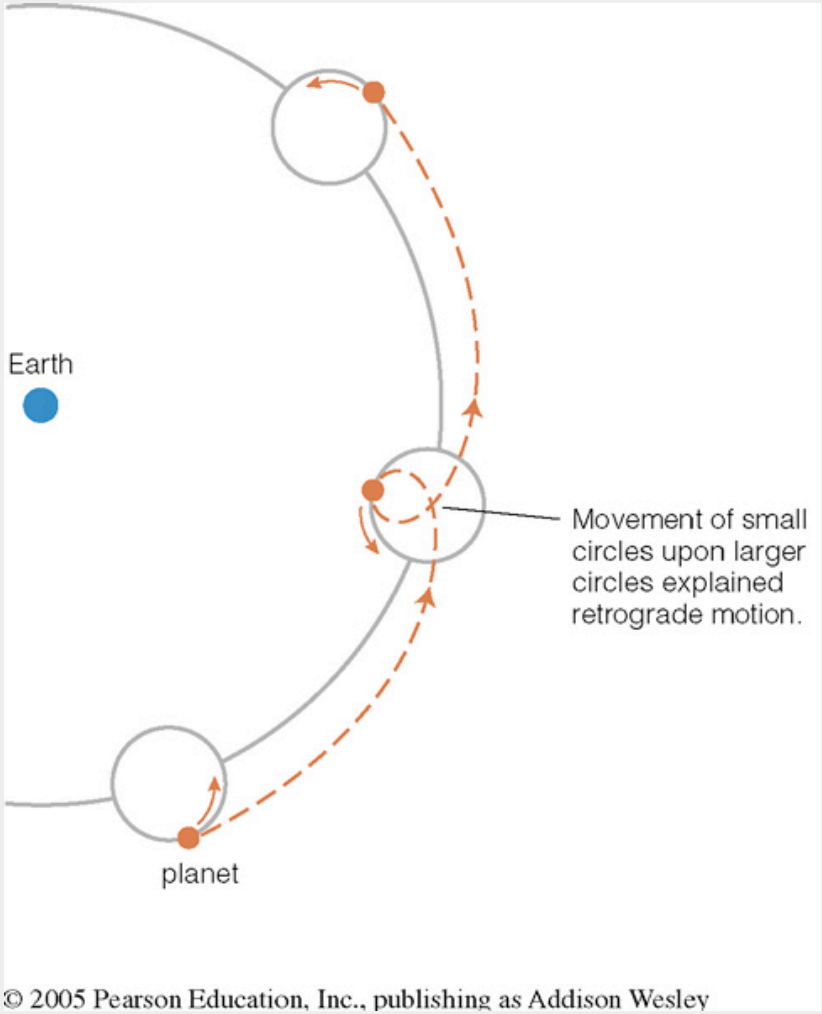


Movie. Click to play.

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

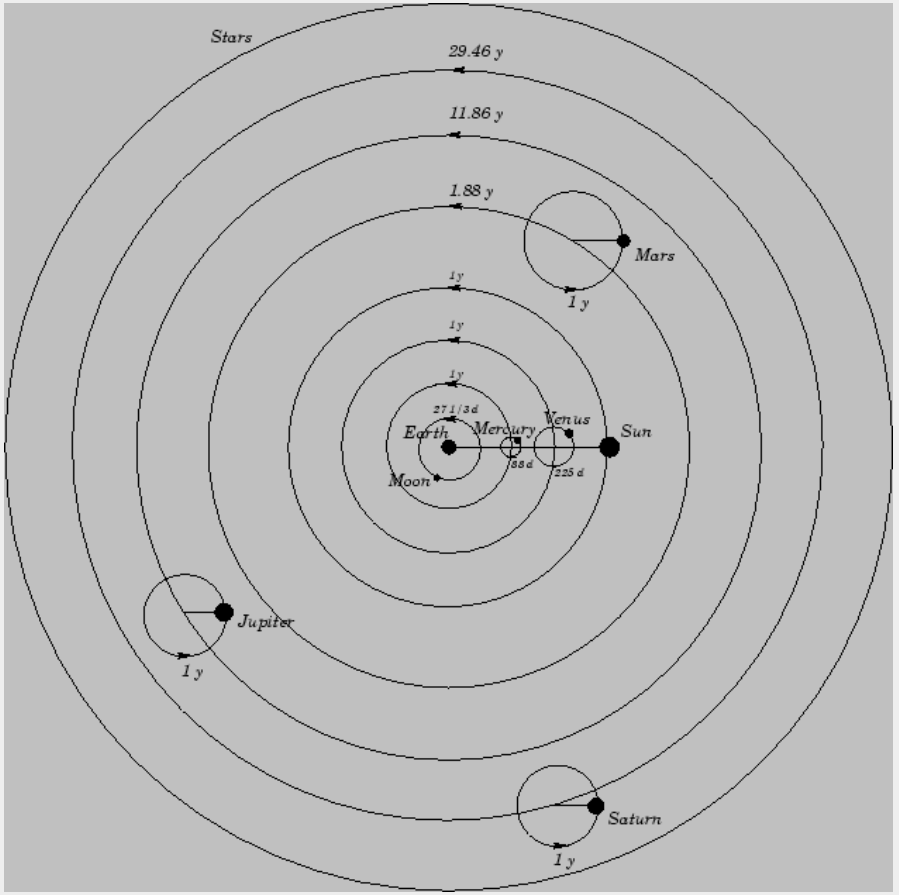
Ptolemy's Geocentric Model

- Earth is at center
- Sun orbits Earth
- Planets orbit on small circles whose centers orbit the Earth on larger circles
  - [the small circles are called **epicycles**]



Ptolemy's Geocentric Model

- This explained retrograde motion
- Inferior planet epicycles were fixed to the Earth-Sun line
- This explained why Mercury & Venus never strayed far from the Sun!



3.4 The Copernican Revolution

Our goals for learning:

- Briefly describe the roles of Copernicus, Tycho, Kepler, and Galileo.
- What are Kepler's three laws of planetary motion?

Nicolaus Copernicus (1473-1543)

He thought Ptolemy's model was contrived

Yet he believed in circular motion

De Revolutionibus Orbium Coelestium

Copernicus' Heliocentric Model

- Sun is at center
- Earth orbits like any other planet
- Inferior planet orbits are smaller
- Retrograde motion occurs when we "lap" Mars & the other superior planets

Did not predict better than Ptolemy's Model

Objections to Copernican view

- Earth could not be moving
  - Birds, falling stones, and clouds would be left behind
- Noncircular orbits contradicted claim of the heavens being perfect
- Stellar parallax not observed

Tycho Brahe (1546-1601)

- Greatest observer of his day

Uraniborg

- Charted accurate positions of planets

- Observed a nova in 1572

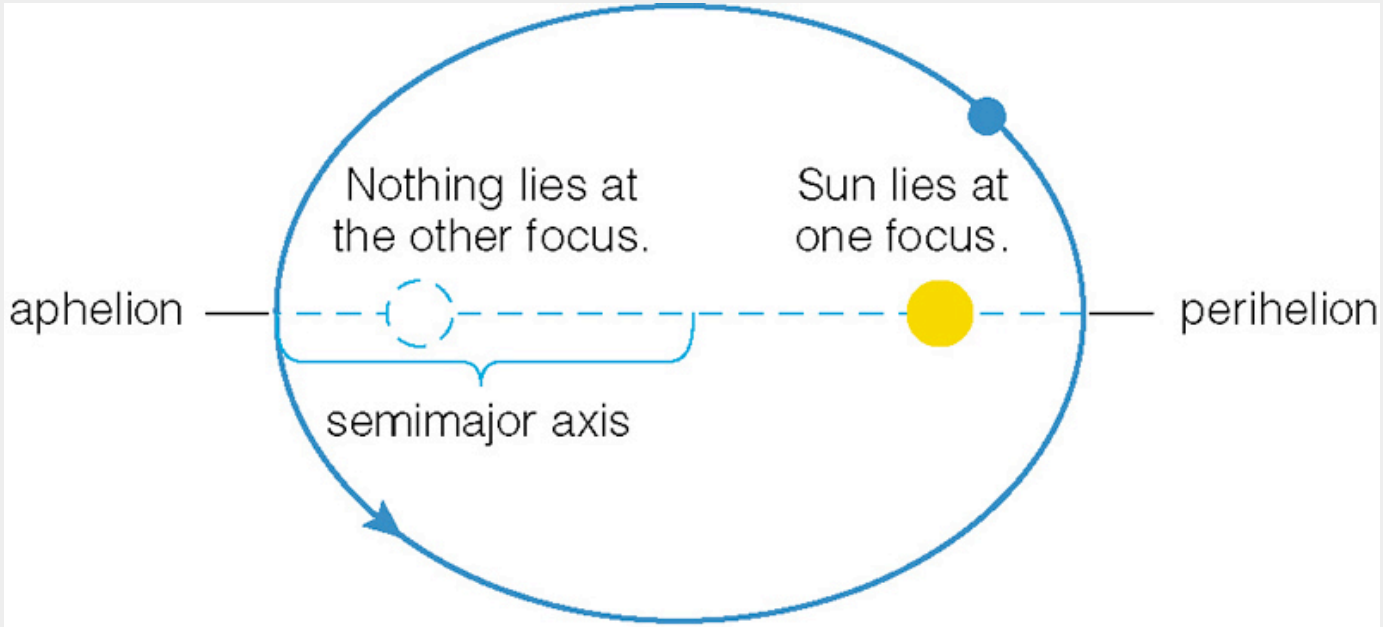
- Story about Nose

Johannes Kepler (1571-1630)

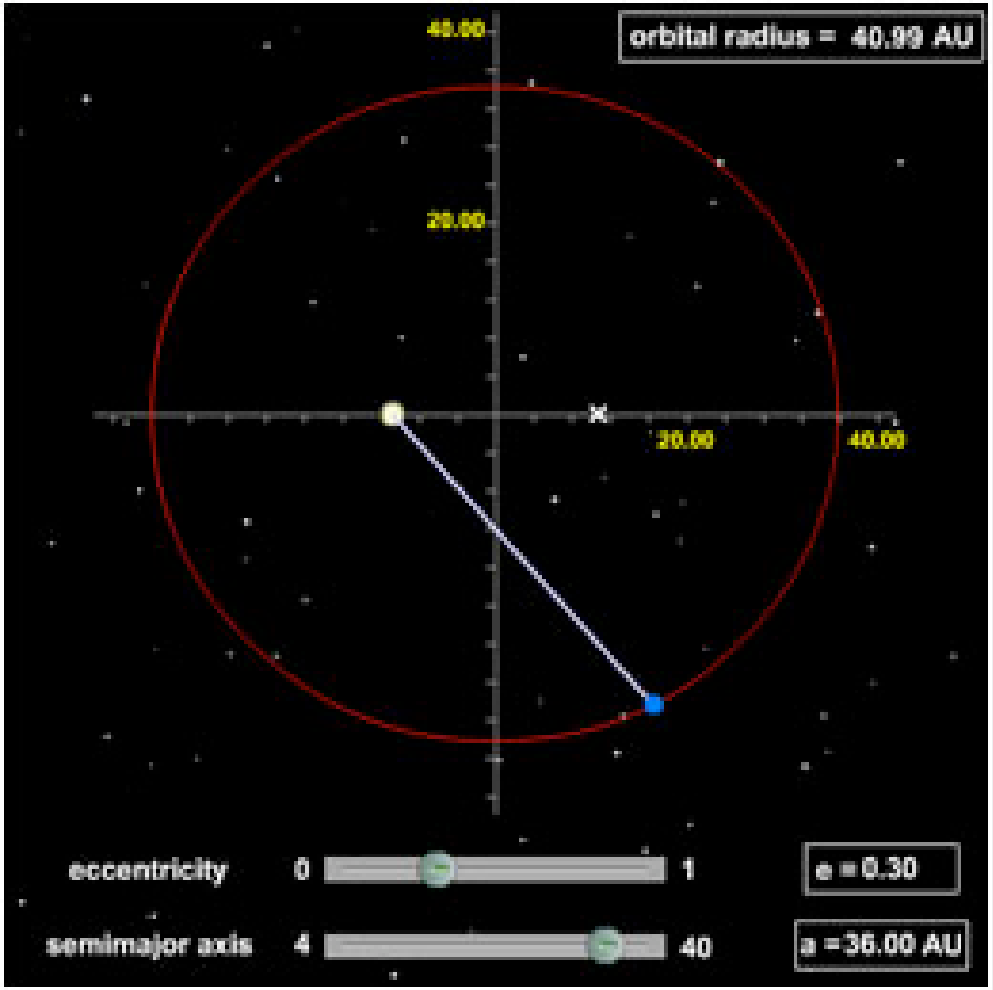
- Greatest theorist of his day
- a mystic
- there were no heavenly spheres
- *forces* made the planets move
- 8 arcminutes!

Kepler's Laws

1 Each planet's orbit around the Sun is an ellipse, with the Sun at one focus.

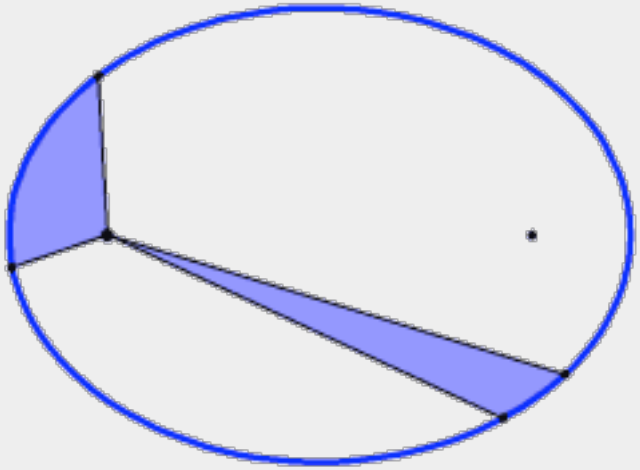


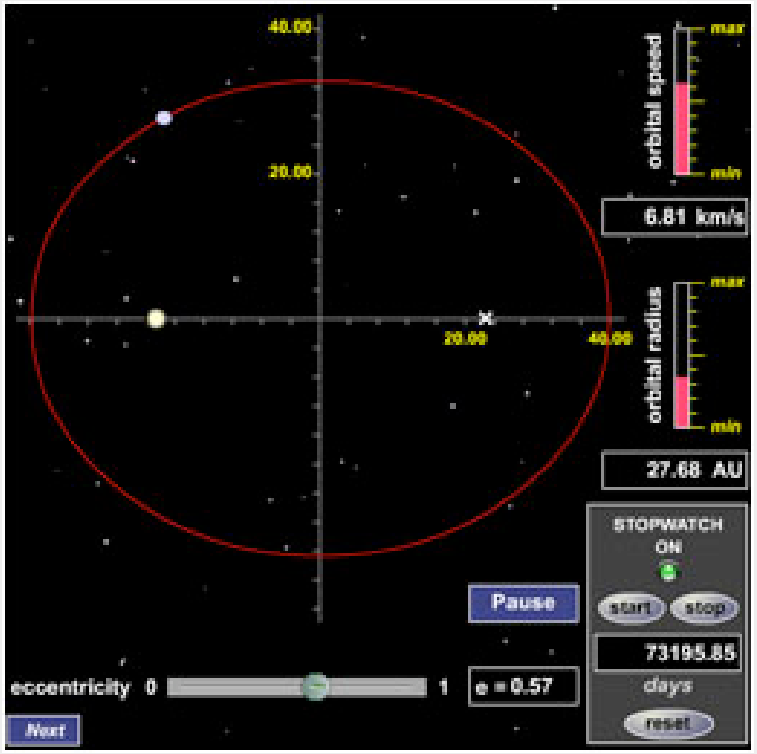
Eccentricity of an Ellipse



Kepler's Laws

2 A planet moves along its orbit with a speed that changes in such a way that a line from the planet to the Sun sweeps out equal areas in equal intervals of time.





Kepler's Laws

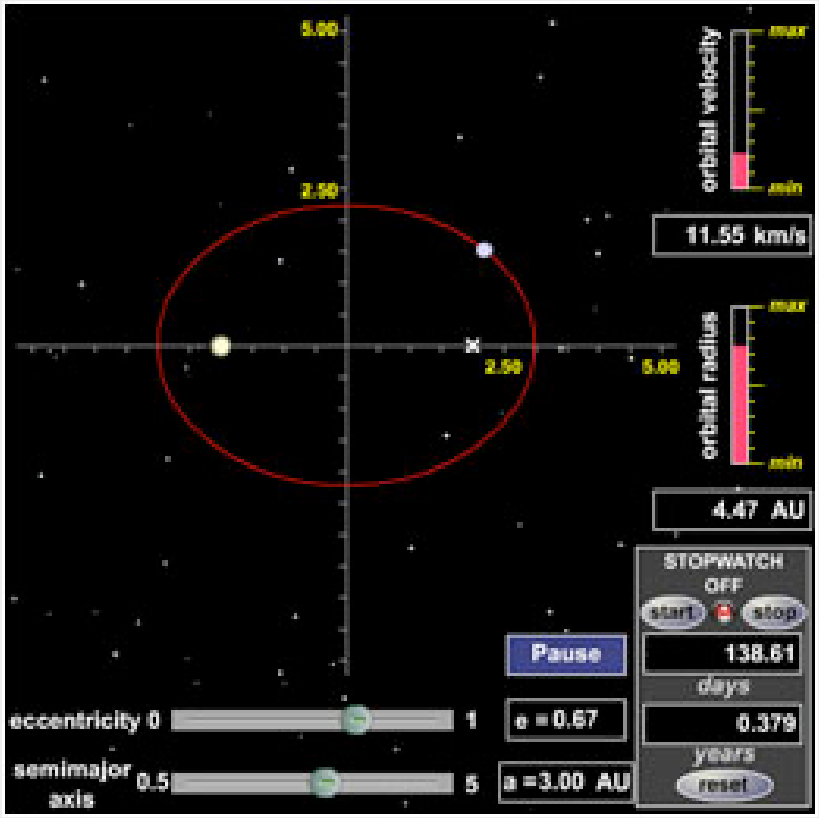
3 The ratio of the cube of a planet's average distance from the Sun to the square of its orbital period is the same for each planet.

$$a^3 / P^2 = 1$$

$$a^3 = P^2$$

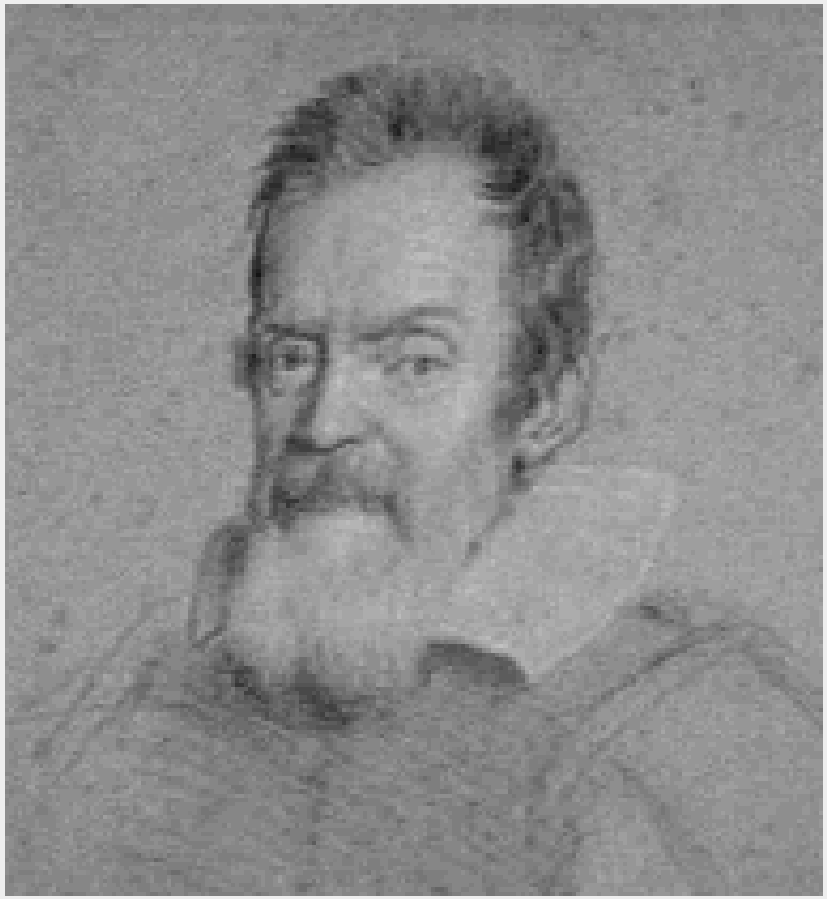
$$\left(\frac{P}{2\pi}\right)^2 = \frac{a^3}{G(M+m)}$$

$$T^2 = \frac{4\pi^2}{G(M+m)} \cdot a^3$$



Galileo Galilei (1564-1642)

- First man to point a telescope at the sky
- wanted to connect physics on earth with the heavens
- *Dialogue Concerning the Two Chief World Systems* [written in Italian]



This book got him in trouble with the Church!

Physics on Earth

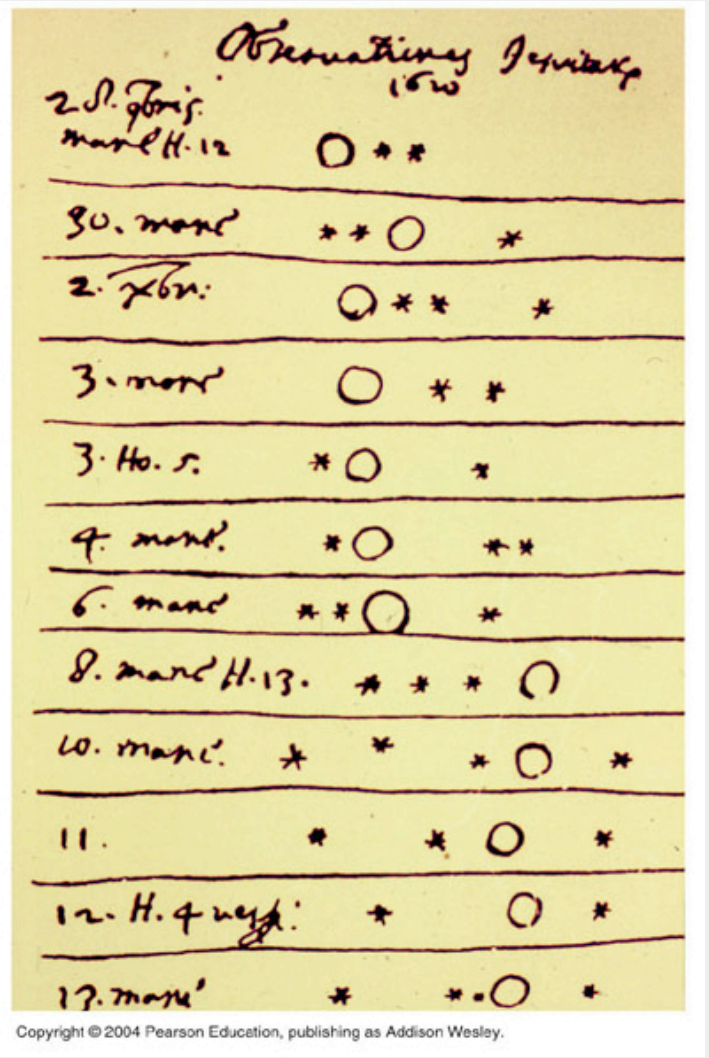
- Demonstrated that object remains in motion unless a force acts to stop it
  - Birds, stones, and and clouds stay with earth unless something was to knock it away
  - Also known as Newton's first law

Galileo's Observations

- Galileo saw shadows cast by the mountains on the Moon.
- He observed craters.
- The Moon had a landscape; it was a "place", not a perfect heavenly body.

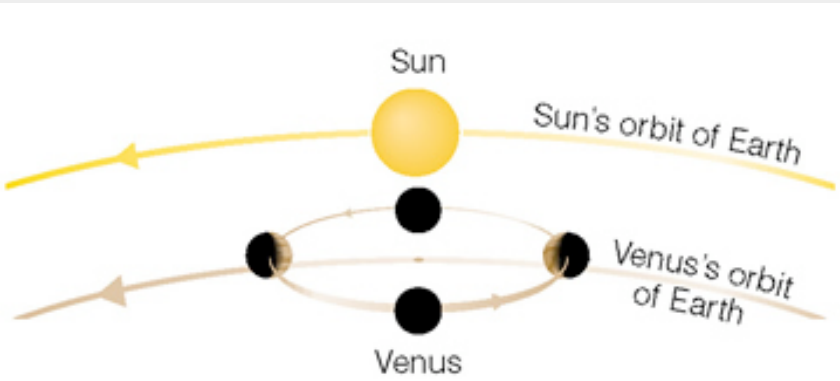
Galileo's Observations

- Galileo discovered that Jupiter had four moons of its own.
- Jupiter was the center of its own system.
- Heavenly bodies existed which did not orbit the earth.
- Parallax is not observed because stars to far away

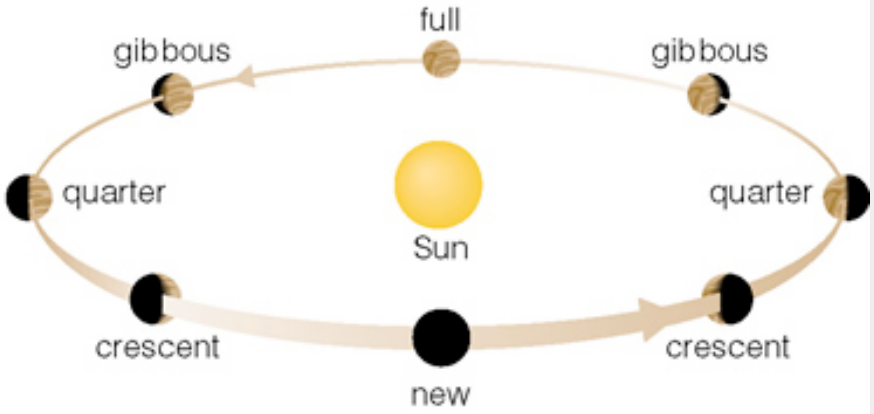


Galileo's observation of the phases of Venus was the final evidence which buried the geocentric model.

Geocentric



Heliocentric



No gibbous or full phases!

All phases are seen!

Galileo observed **all** phases!

3.5 The Nature of Science

Our goals for learning:

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

The Scientific Method

1 Question
2 Hypothesis
   – a tentative explanation
3 Prediction
4 Test
5 Result
   – confirm, reject, or modify

should be the same no matter who conducts the test

Hallmarks of Good Science

- Science seeks explanations for *observed* phenomena that rely solely on natural causes.
- Science progresses through the creation and testing of models of nature that explain the observations as simply as possible.

  ! Occam's Razor
- A scientific model must make testable predictions that could force us to revise or abandon the model.

Theory -- a model which survives repeated testing

Bad Scientific Practice

- **pseudoscience** – masquerades as science, but does not follow the scientific rules of evidence
- **nonscience** – establishes "truths" through belief

3.6 Astrology

Our goals for learning:

- How were astronomy and astrology related in the past, and are they still related today?

Astrology

- claims to study how the positions of the Sun, Moon, & planets among the stars influence human behavior
- was the driving force which advanced ancient astronomy
- Kepler & Galileo were the last astronomers to cast horoscopes… since then astronomy grew apart from astrology into a modern science
- modern scientific tests of astrology fail …it is a *pseudoscience*

What have we learned?

- How is scientific thinking similar to other everyday thinking?
  - Scientific thinking involves trial and error like much other everyday thinking, but in a carefully organized way.
- How is modern science rooted in ancient astronomical observations?
  - Ancient cultures observed the motions in the sky for religious and practical reasons. Science took root as they eventually sought to understand the patterns they had discovered.

What have we learned?

- Describe several impressive ancient astronomical accomplishments.
  - Structures for observation, such as Templo Mayor, the Sun Dagger, Mayan observatories, and medicine wheels. Eclipse predictions; time keeping.
- How did the Greeks lay the foundations for modern science?
  - By developing the notion of models and putting emphasis on the importance of having models agree with observed reality.

What have we learned?

- What was the Ptolemaic model?
  - Ptolemy's synthesis of earlier Greek ideas about the geocentric universe, which was a sophisticated model that allowed prediction of planetary positions.
- 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, following a precise mathematical relationship ($p^2 = a^3$).

What have we learned?

- Briefly describe the roles of Copernicus, Tycho, Kepler, and Galileo.
  - Copernicus created a Sun-centered model of the solar system designed to replace the Ptolemaic model, but it was no more accurate because he still used perfect circles. Tycho provided observations used by Kepler to refine the model by introducing orbits with the correct characteristics. Galileo's experiments and telescopic observations overcame remaining objections to the Copernican idea of the Earth is a planet orbiting the Sun.

What have we learned?

- How can we distinguish science from nonscience?
  - It's not always easy, but science generally exhibits at least three hallmarks. (1) Modern science seeks explanations for observed phenomena that rely solely on natural causes. (2) Science progresses through the creation and testing of models of nature that explain the observations as simply as possible. (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 have we learned?

- What is a theory in science?
  - A model that explains a wide variety of observations in terms of just a few general principles, which has survived numerous tests to verify its predictions and explanations.
- How were astronomy and astrology related in the past, and are they still related today?
  - Astronomy and astrology both grew out of ancient observations of the sky. Astronomy grew into a modern science. Astrology has never passed scientific tests and does not qualify as science.