Chapter 4

The Origin of Modern Astronomy

Guidepost

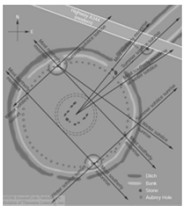
In the 16th and 17th centuries, astronomers tried to understand the motions they saw in the sky. In doing so, they invented a new way of understanding nature, what we now call ***science***. This chapter, then, is really about the birth of science.

To understand the chapters that follow, we must understand how scientists use evidence to test hypotheses and build theories to explain nature.

Although science has become a powerful force in shaping our society, it remains now as it was four centuries ago, nothing more than a logical way of thinking about nature – a way of understanding what we are and where we are.

Pre-Copernican Astronomy

- Unfortunately, there are no written documents about the significance of stone and bronze age monuments, like Stonehenge.



http://www.astro.virginia.edu/class/oconnell/astr121/eclipses-stonehenge.html

Pre-Copernican Astronomy

- First preserved written documents about ancient astronomy are from ancient Greek philosophy
- The Greeks tried to understand the motions of the sky and describe them in terms of mathematical (not physical!) models

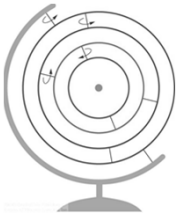
Ancient Greek Astronomers (1)

Models were generally wrong because they were based on wrong "first principles", believed to be "obvious" and not questioned:

1. Geocentric Universe: Earth at the center of the universe.
2. "Perfect Heavens": Motions of all celestial bodies described by motions involving objects of "perfect" shape, i.e., spheres or circles.

Ancient Greek Astronomers (2)

- **Eudoxus** (409 – 356 B.C.): Model of 27 nested spheres
- **Aristotle** (384 – 322 B.C.), major authority of philosophy until the late middle ages. Universe can be divided in 2 parts:
  1. Imperfect, changeable Earth,
  2. Perfect Heavens (described by spheres)
- He expanded Eudoxus' model to use 55 spheres.



Ancient Greek Astronomers (3)

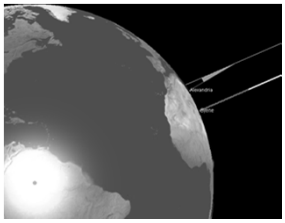
Aristotle also taught that Earth was at the center of the Universe (*Geocentrism*) and everything moved in perfect circular motion.

http://csep10.phys.utk.edu/astr161/lect/retrograde/aristotle.html

Ancient Greek Astronomers (4)

Eratosthenes (276 – 194 B.C.):

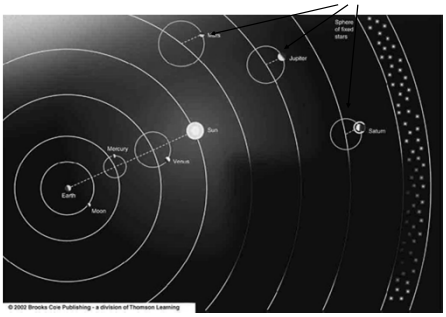
Determined the size of the Earth, assuming it was a sphere. His answer was only ~15% too large.



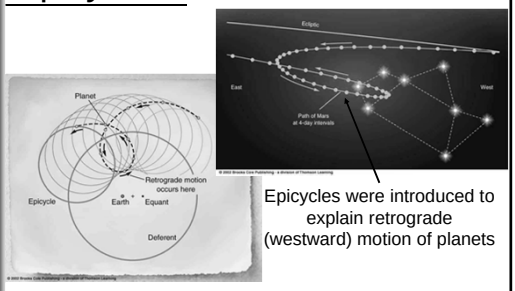
http://en.wikipedia.org/wiki/Eratosthenes

Later refinements (2nd century B.C.)

• **Ptolemy:** Further refinements, including epicycles



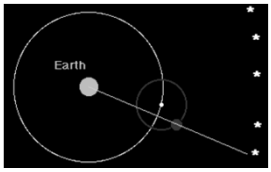
Epicycles



Epicycles were introduced to explain retrograde (westward) motion of planets

The Ptolemaic system was considered the "standard model" of the universe until the *Copernican Revolution*.

Epicycles



This illustration will show how epicycles work.

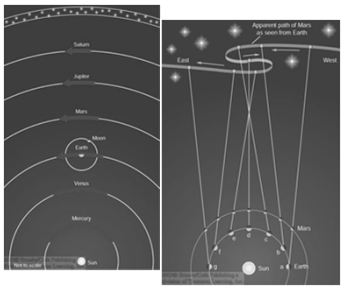
http://csep10.phys.utk.edu/astr161/lect/retrograde/aristotle.html

The Copernican Revolution

Nicolaus Copernicus (1473 – 1543):

Heliocentric universe (sun in the center)

Copernicus's new (and correct) explanation for retrograde motion of the planets



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

This made Ptolemy's epicycles unnecessary.

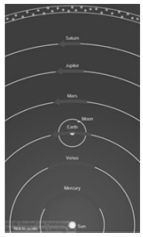
Copernicus's new (and correct) explanation for retrograde motion of the planets

Copernicus results were finally published shortly after his death in *De Revolutionibus Orbium Celestrium*.

http://csep10.phys.utk.edu/astr161/lect/retrograde/copernican.html

Copernicus's New Model

Copernicus' heliocentric model still did not predict the locations of the planets very well (circular orbits).



http://csep10.phys.utk.edu/astr161/lect/retrograde/copernican.html

Tycho Brahe (1546 – 1601)

- Tycho was the greatest astronomer of the pre-telescopic era.
- Tycho's observations of a supernova disproved Aristotle's "perfection".
- Although his own model of the solar system was still geocentric and circular, his precise observations of the orbits of the planets allowed others to determine a more correct model.

http://www.oglethorpe.edu/faculty/~m_rulison/Astronomy/Chap%2005/telescopes.htm

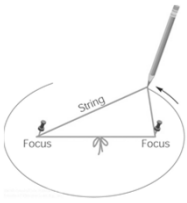
Johannes Kepler (1571 – 1630)

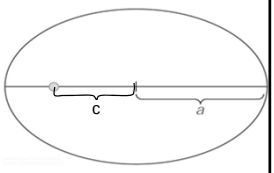
- Used the precise observational tables of Tycho Brahe to study planetary motion mathematically.
- Found a consistent description by abandoning *both*:
  1. Circular motion, and
  2. Uniform motion

Planets move around the sun on elliptical paths, with non-uniform velocities.

Kepler's Laws of Planetary Motion

1. The orbits of the planets are **ellipses** with the sun at one focus.





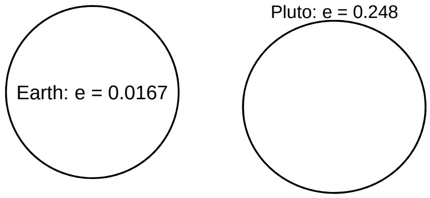
Eccentricity e = c/a

Eccentricities of Planetary Orbits

The orbits of planets and other large objects are virtually indistinguishable from circles:

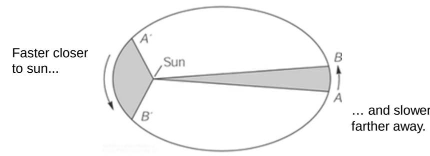
Most extreme example:

Pluto: e = 0.248



Kepler's Laws of Planetary Motion (2)

2. A line from a planet to the sun sweeps over equal areas in equal intervals of time.



Kepler's Laws of Planetary Motion (2)

3. A planet's orbital period (*P*) squared is proportional to its average distance from the sun (*a*) cubed:

$$P_y^2 = a_{AU}^3$$

(P_y = period in years; a_{AU} = distance in AU)

The Rudophine Tables

• Published by Kepler in 1627.

• Could predict planetary positions 10 to 100 times better than previous tables.


RUDOLPHINÆ
TYCHONE
IOANNES KEPLERUS

http://www.library.usyd.edu.au/libraries/rare/modernity/kepler.html

Galileo Galilei (1594 – 1642)

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

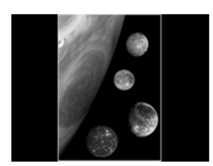
• Greatly improved on the newly invented telescope technology. (But Galileo did NOT invent the telescope!)

• Was the first to meticulously report telescope observations of the sky to support the Copernican model of the universe.

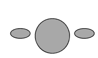
Major Discoveries of Galileo

• Moons of Jupiter (4 Galilean moons)

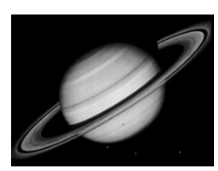
(What he really saw)



• Rings of Saturn



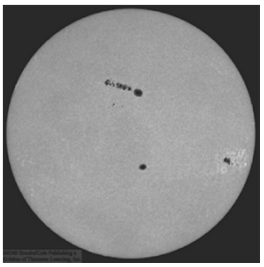
(What he really saw)



Major Discoveries of Galileo (2)

• Surface structures on the moon; first estimates of the height of mountains on the moon

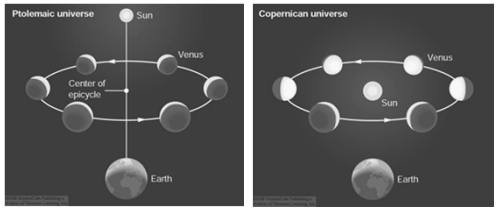
Major Discoveries of Galileo (3)



Sun spots (proving that the sun is not perfect!)

Major Discoveries of Galileo (4)

• Phases of Venus (including "full Venus"), proving that Venus orbits the sun, not Earth!



Dialogo and Trial

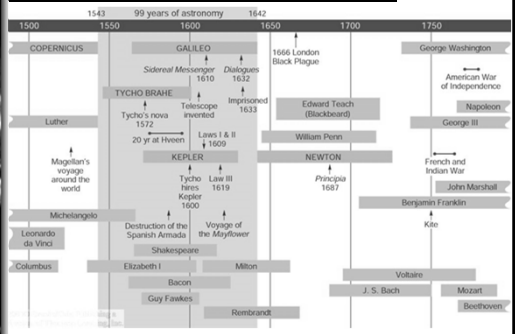
• Published a book (*Dialogue Concerning the Two Chief World Systems*) in 1632 supporting Copernican view of the Universe.

• Book sold out in spite of sales being stopped by Inquisition.

• Galileo was condemned for not adhering to an agreement from 1616 to "not hold, teach or defend" Copernicus' views in any way. Confined to his home for the rest of his life.

• Galileo was the first modern scientist, in that he used observation in order to understand the universe around him.

The Birth of Modern Science



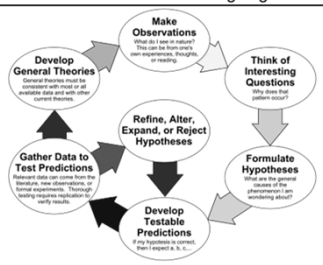
Science and the Scientific Method

The scientific method is "a method or procedure that has characterized natural science since the 17th century, consisting in systematic observation, measurement, and experiment, and the formulation, testing, and modification of hypotheses." (Oxford English Dictionary).

To be termed scientific, a method of inquiry is commonly based on empirical or measurable evidence subject to specific principles of reasoning

Science and the Scientific Method

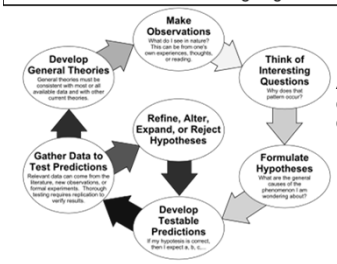
The Scientific Method as an Ongoing Process



https://en.wikipedia.org/wiki/Scientific_method

Science and the Scientific Method

The Scientific Method as an Ongoing Process

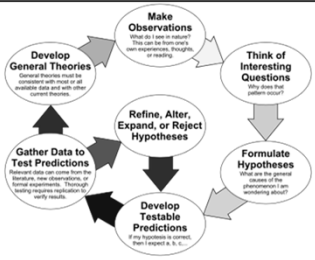


A hypothesis is a conjecture, based on knowledge

- Can be very specific or broad;
- Must be falsifiable.

Science and the Scientific Method

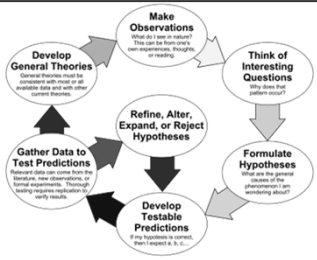
The Scientific Method as an Ongoing Process



A hypothesis is used to make predictions that can be tested.

Science and the Scientific Method

The Scientific Method as an Ongoing Process



The method is very general, and the steps need not be in order.