A Short History of the Origin of Modern Astronomy

What is a "Theory"?

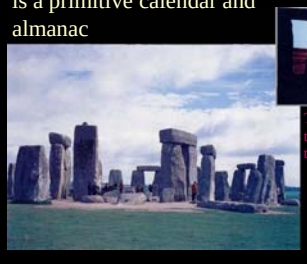
- …a concise model which explains an observed phenomenon
- Must be consistent with experiment or observation, thus…
  - macro-evolution is a theory
  - creationism is an issue of religious faith
- Aesthetically pleasing
- Occam's Razor (William of Occam)

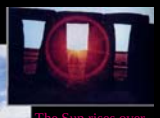
Other names worth knowing: Francis Bacon, Karl Popper

Some of the Players in Astronomical History

- Stone Age Europeans

The remarkable "Stonehenge" is a primitive calendar and almanac





The Sun rises over the "heel stone" at the summer solstice.

Some of the Players in Astronomical History

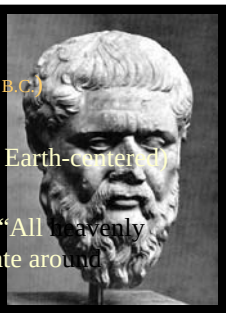
- 3000 B.C. (*e.g.*, Babylonians)

Cuneiform Tablet from ~870 B.C. depicting the sun god Samas.

Some of the Players in Astronomical History

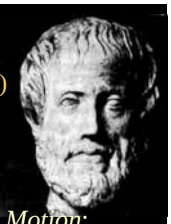
- Ancient Greeks (*e.g.*, Plato, Aristotle, Aristarchus, Hipparchus, Chinese, Persians, to name a few)
- Renaissance (*e.g.*, Copernicus, Tycho, Kepler, Galileo, Newton, etc.)
- Modern Astronomy (*e.g.*, Halley, Messier, Herschel, Fraunhofer, Einstein, Shapley, Jansky, Hubble, etc.)

Plato (427-347 B.C.)



- Homocentric (geocentric or Earth-centered) Universe
- *Uniform Circular Motion* - "All heavenly bodies move at a uniform rate around circles."
- "Perfection is found in spheres." (Credited to Pythagoras - followers coined phrase "music of the spheres")

Aristotle (384-322 B.C.)



(Student of Plato)

- Geocentric Universe
- Embraced the concept of *Natural Motion*: The universe is governed by two sets of rules to "...save the appearances of symmetry and perfection."
  - objects on Earth naturally seek the downward direction.
  - Heavenly objects naturally move in circles.

Aristotle's Universe

- Stars are on a crystalline sphere
- Sun is on a sphere closer to Earth than stars
- Planets are on their own spheres closer or farther from the sun's

"We are what we consistently do; excellence... therefore, it is not an act but a habit."
--Aristotle

Homocentric Universe Evidence:

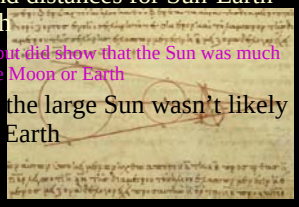
- All astronomical bodies appear to revolve around the Earth
  - Theory consistent with observation and appealingly simple
- No stellar parallax observed
  - Earth fixed in place relative to stars
- View of constellations relative to horizon changes as one travels north or south

Homocentricism: The Problem

Aristotle's homocentric model cannot explain observed retrograde motion of planets

Aristarchus (356-323 B.C.)

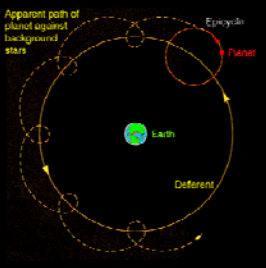
- ★Adopted a heliocentric (Sun-centered) model of the universe
  - 1700 years in advance of Copernicus!
- ★Estimated by geometric measurements the relative sizes and distances for Sun-Earth and Moon-Earth
  - ★Inaccurately but did show that the Sun was much larger than the Moon or Earth
- ★Concluded that the large Sun wasn't likely to orbit a small Earth



Aristarchus (356-323 B.C.)

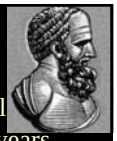
- ★Contradicted Aristotle's highly accepted model so was rejected by most
  - ★with some exception, there wasn't anything wrong with previous theory. So why change?
- ★Most of the history of Aristarchus lost in the fires at the library in Alexandria
- ★Geocentricism will survive until 18th century A.D.

Hipparchus (160?-127? B.C.)



- Aristotle's geocentric model saved by putting the planets on *epicycles*
  - addition generally attributed to Apollonius (265-190 B.C.)
- Epicycles helped explain observed motion, but...

Hipparchus (160?-127? B.C.)



- …epicycles alone did not help the model predict planetary positions over several years accurately.
- Hipparchus added *eccentrics* and *equants* to the model
  - eccentric: circle offset by small amount from center of Earth (explains why planet appears to move faster through zodiac when closer to Earth
  - equant: point offset from Earth about which a planet orbits

Hipparchus' Modification to Homocentricism

With this modification, planetary positions could be predicted fairly accurately over many years.

Claudius Ptolemy (A.D. 140)

- Homocentric Universe
- Published the 13 volume *Mathmematike Syntaxis*
  - first astronomical textbook
  - Hipparchus' star catalog
  - observed motions of stars and planets
  - translated into Arabic (*Almagest*) in the Dark Ages
- Refined the geocentric model to match observation even better than Hipparchus
- Detailed model so accurate that it predicted planetary positions for the next 1000 years

THE DARK AGES

The end of Greek astronomy

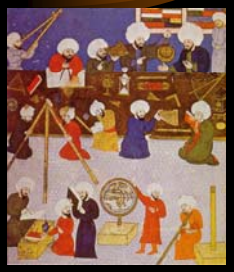
But…

Astronomy continues in…

- China: timekeeping, observing, astrology
  - By the end of the first few centuries A.D., little in literature distinguishes Chinese astronomy from western (although astronomy continues in China throughout the Dark Ages)
- India: Astronomy flourished after 961 B.C.
  - By A.D 500 western influence dominated Hindu astronomy

Astronomy continues in…

- Arab World:
  - Preservation of much scientific knowledge
  - New scientific and astronomical discoveries
  - Translated the *Syntaxis* into Arabic (*Almagest*)



From a midieval manuscript in the *Granger Collection*

Astronomy continues in…

- Americas: Modern appreciation difficult and slow in coming
  - Complete destruction of Mayan writings by Spanish conquest
  - The Caracol temple (Mexico) has many windows that are aligned with astronomical events.

Astronomy continues in…

- Americas: Modern appreciation difficult and slow in coming
  - Most Native American cultures had no written language (so dating petroglyphs and landmarks is difficult)
  - Big Horn Medicine Wheel (~500 B.C.?): Wyoming, 78' in diameter, astronomically oriented, of unknown cultural significance

So why does the geocentric model survive well into the 15th century?

Nicolaus Copernicus (1514)

- Heliocentric universe - Sun-centered cosmos
- Published *De revolutionibus Orbium coelestium*
  - By this time, the Catholic Church had accepted the Ptolemaic view as a part of church dogma making homocentricism the officially accepted theory of the universe
  - Placed on the Index of Prohibited Books, 1616

5 Basic Tenets of Heliocentricism

1. All celestial objects revolve around the Sun and the Sun is at the center of the cosmos.
2. The distance from the Earth to the stars is much greater than the distance of the Earth to the Sun.
3. The daily motion of the heavenly bodies relative to the horizon is due to the Earth's rotation on its axis.
4. The apparent motion of the Sun through the zodiac is a result of the annual revolution of the Earth around the Sun.
5. A planet's retrograde motion is due to the motion of the Earth relative to the other planets with respect to the "fixed" stars.

Observational Results of Heliocentricism

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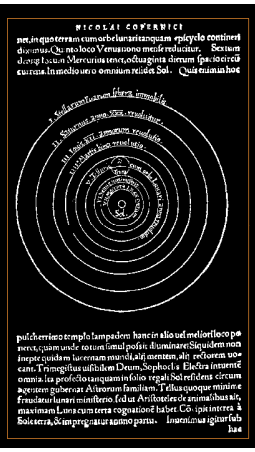
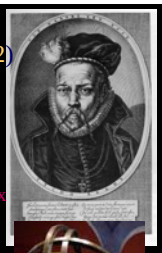


Keep in mind that this new model differs from the homocentric model only by geometry

The Copernican model doesn't predict planetary positions all that well.

Tycho Brahe (1572)



- Rejected both heliocentricism...
  - he couldn't measure a stellar parallax
- ...and geocentricism...
  - poorly predicted planetary positions
- … and developed a complicated new model.
  - with features of both

Armillary Sphere

Tycho Brahe

- His model isn't all that good but he was an excellent observer and took exquisite data with equipment of his own design.
  - Amassed the best and most systematic precision data on the planets known for the time.
- Observed a *nova* for nearly 2 years.
  - That a new star was formed in the heavens led Tycho to reject the Aristotelian/Ptolemaic view of a perfect universe.

The Great Quadrant

Johannes Kepler (1594)

- Accepted and promoted heliocentricism
- Invoked magnetism as the force holding the planets in orbit.
  - The arbitrary concept of *natural motion* given a physical existence.
- Placed planets in elliptical orbits around the Sun
  - circular orbits just a special case of elliptical orbits

Kepler's Three Laws

1. Law of Ellipses:
   The orbit of each planet is an ellipse with the sun at one focus.
2. Law of Equal Area:
   A planet sweeps out equal areas in equal times. The further a planet is from the sun, the slower it moves.
3. Harmonic Law:
   The square of the orbital period is directly proportional to the cube the semimajor axis. If *P* is in years and *a* is in AU then $P^2/a^3 = 1$.

Galileo Galilei (1619)

- Accepted and promoted heliocentricism
- Attempted to put celestial physics on a firm experimental, mathematical, and theoretical basis.
- Worked towards establishing what would be known later as *physics*.
- Still held that the stars were in a spherical shell well beyond the orbit of the planets.

- Galileo did not invent the telescope… but
  - Saw that the moon was not perfectly smooth but had mountains, rilles, and craters.
  - Showed that there were stars in the heavens that could not be seen with the naked eye.
  - Discovered the moons of Jupiter and that they revolve around the planet
    - thus there was a second center of motion in the universe which flies in the face of Aristotelian doctrine (still firmly held by many).
  - Observed sunspots - defects in the sun's surface.
  - Showed that Venus goes through phases the same as the moon and that Venus moves faster than the Earth in its orbit.
    - The issue of Venus strongly supports the Copernican model of the cosmos.

Galileo was critical of Aristotelian philosophy in print (in Italian, no less, so everyone could read his works) and a self-proclaimed Copernican (1613). Because of his "heresy", he was placed under house-arrest by the Catholic Church, a situation in which he would stay for the rest of his life.

He was acquitted of his crimes by the Church in 1992.

Isaac Newton (1642-1727)

- Born the year Galileo died
- Mathematician and physicist
- Invented the *calculus*
- Studied the nature of gravity, light, optics
- Developed the three laws of motion
- Published *Principia* (1687) placing science on a firm physical and mathematical base

The Three Laws of Motion

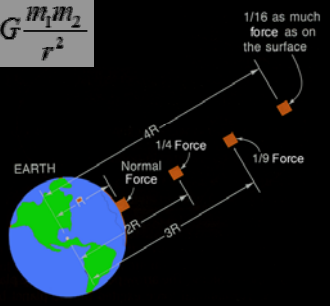
1. A body at rest tends to stay at rest and a body in motion tends to stay in motion unless it is acted upon by an external force.
2. A body's change of motion is proportional to the force acting upon it and it in the direction of the force.
3. When one body exerts a force on another body, the second body must exert an equal and opposite force back on the first body.

Newton was first to publish that the same force must be acting on the moon (gravity) that acts on objects when dropped.

He also realized that the gravitational attraction force on two objects is determined by the masses of each object and the distance between the objects.

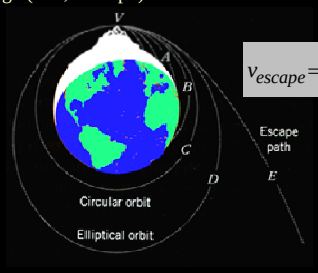
The Inverse-Square Law

$$F = -G\frac{m_1 m_2}{r^2}$$



Baseball Example

Throw a baseball off the top of a mountain and it will eventually drop to the ground… unless you throw it hard enough (~18,000 mph).



$$v_{escape} = \sqrt{\frac{2GM}{r}}$$

Newton's Laws describe...

- the difference between weight and mass
- why astronauts are weightless in orbit
- centripetal force

Newton also split sunlight into the rainbow with a prism...

That got him into a little trouble with the religious authorities.

This observation will become among the most important discoveries for astronomers!

What's next?

Our discussion stops here for now.

Physics remade astronomy into an analytical science in which scientists could take reliable measurements on celestial bodies and calculate the forces acting upon them and, furthermore, make accurate predictions of future motion.

The beginning of the 18th century would usher in an era of unprecedented discovery which has yet to slow.