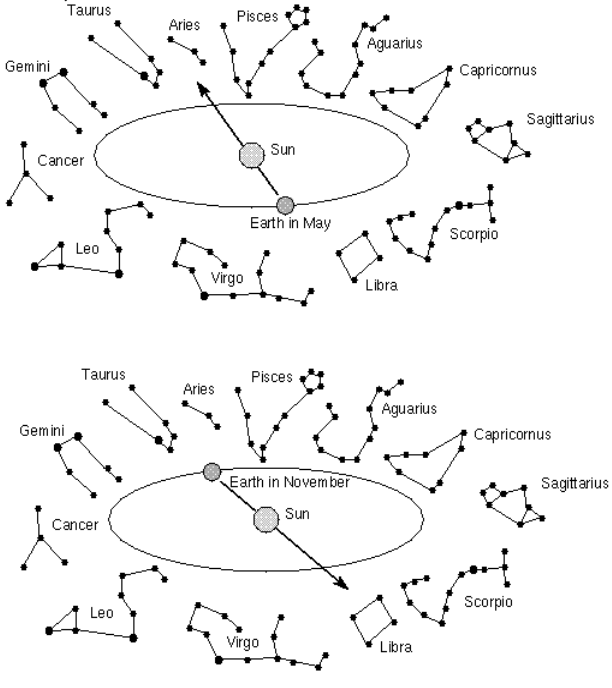
VI. Astronomy: It's Early History

A. The Sun has an extensive system of objects orbiting it.
1. There are eight recognized planets, including the Earth.
a. The terrestrial planets (Mercury, Venus, Earth, and Mars) are small, rocky and close to the Sun..
b. The giant planets (Jupiter, Saturn, Uranus, and Neptune) are large, gaseous/liquid, far from the Sun.
c. It takes sunlight nearly 6 hours to reach beyond Neptune, whose average distance is at least 40 A.U. (i.e. 40 X that of Earth).
2. The planets have a wide variety of moons and rings that provide additional clues to physical processes in the Solar System.
3. The asteroids are small chunks, probably material that failed to follow a planet.
a. Most of them are between Mars and Jupiter.
b. Some asteroids have orbits that cross Earth's orbit.
4. Meteoroids are interplanetary rocks with random orbits (i.e. not in families of asteroids).
5. Comets can be characterized as "dirty snowballs"--frozen primitive material.
a. They reside in reservoirs far from the Sun----one just beyond Pluto, and the other out to 50,000 A.U. (nearly 1 ly)
b. Occasionally they approach the Sun and develop reflective tails as they evaporate.
6. There is also interplanetary gas and dust, the supply of which is replenished by processes such as asteroid collisions and volcanism.

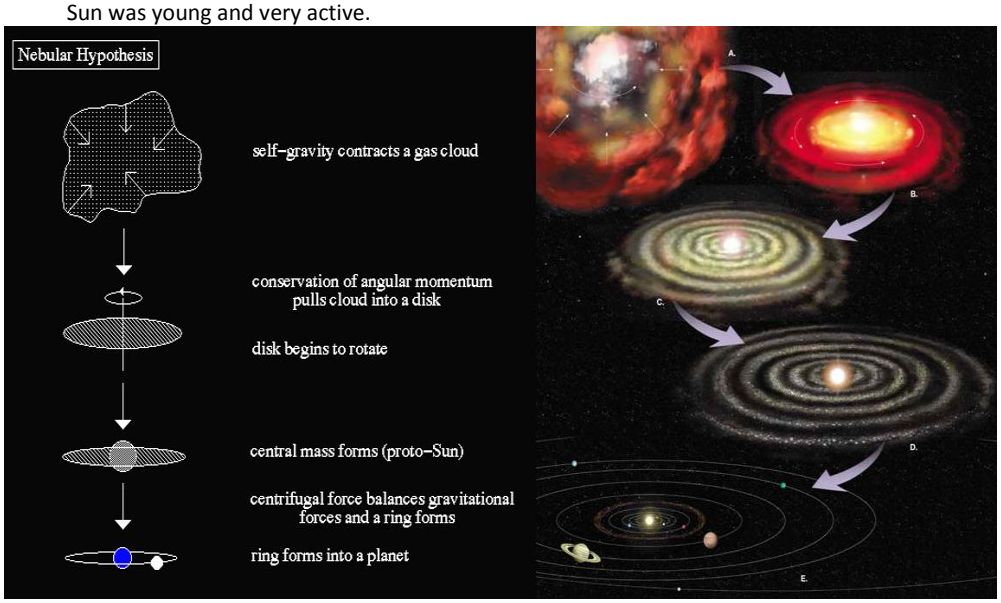
B. Models of the origin of the Solar System are based on several basic properties.
1. All of the planets orbit the Sun in nearly the same plane--their inclinations relative to Earth's orbital plane are small (at most 4^0). The Solar System looks like a thin disk.
a. The zodiac is the band of constellations, centered on Earth's orbital plane, through which planets move.
b. There are 12 zodiacal constellations (actually 13 but one barely intersects the zodiac).



As the Earth moves around the Sun, the Sun **appears** to drift among the zodiac constellations along the path called the **ecliptic.** The ecliptic is the projection of the Earth's orbit onto the sky.

c. These constellations, together with the positions of the Sun, Moon, and planets at the time of a person's birth, form the basis of astrology. Astronomy and astrology had common roots, but they are now very different subjects. There is no scientific basis for astrology, and it will not be further discussed in this course.

2. All of the planets orbit the Sun in the same direction.
3. The Sun and most of the planets rotate in roughly the same direction well.
4. These facts led to the "nebular hypothesis", first proposed by Immanuel Kant and Pierre Laplace in the 18th century.
   a. The Solar System formed from a contracting, spinning cloud of gas and dust.
   b. The spin rate increased as the cloud contracted, according to the conservation of "Angular Momentum" (essentially the product of mass, velocity, and radius). An example is an ice dancer who spins faster as her arms are brought in.
   c. A disk formed as the outward "centrifugal force" balanced the inward pull of gravity. Perpendicular to the disk, there were no forces to counteract gravity, so particles continued to collapse.
   d. The Sun formed in the center, and small "planetesimals" (little planets) formed in the disk.
   e. The planetesimals attracted each other and coalesced to form planets.
   f. Most of the unused gas and dust was blown away by a strong wind when the Sun was young and very active.



5. Such a process seems to be common in the Universe; disks of gas and dust are seen around many of the young or newly forming stars that have been detected in our Galaxy.

C. We will now consider some of the early history of studies of the Solar Systems.

1. Astronomy has roots in ancient civilization such as those of Mesopotamia, Babylon, India, Egypt, China and America.
   a. Much of the impetus was of a practical nature; people needed to know when to plant crops, when rivers (such as the Nile) would flood, and how to navigate.
   b. Some of the studies were astrological; the Sun, Moon, and planets were associated with gods, and their positions were thought to influence human traits.
   c. But surely the development of consciousness and curiosity also led to astronomical inquiry; people wondered about celestial objects, and they wanted to understand their origin in nature, as well as the relationship of the cosmos to humans.
2. (REFER TO POWER POINT ON ARCHEOASTRONOMY)
3. Over 2000 years ago, Democritus believed that substances are made of indivisible particles he called atoms.
4. Early Greek astronomers knew that the Earth is a sphere.
   a. The Earth's shadow on the Moon during a lunar eclipse is always circular.
   b. Lunar eclipses occur at any time of the day or night (as measured from a given location, not

necessarily one from which a specific eclipse is actually visible); thus, sunlight can strike the Earth from a wide range of angles.

c. A sphere is the only object whose shadow is always circular, regardless of the direction of illumination.

d. This seemed reasonable; after all, the Moon is a sphere (as deduced from the lunar phases), and the Sun is round and hence probably spherical.

e. Moreover, as one travels to the north or south, a given star's altitude (angular distance from the horizon) when crossing the meridian changes. This is most easily seen with stars very near the celestial poles; one doesn't have to observe near the time of meridian crossing.

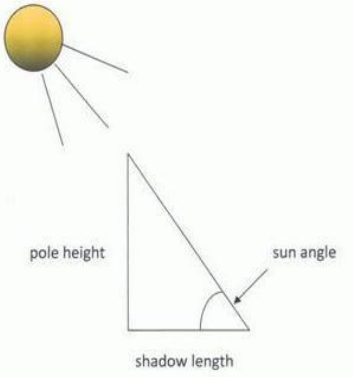
5. By measuring the angle formed by the Earth, the first-quarter Moon, and the Sun, Aristarchus of Samos Concluded around 250 B.C. that the Sun is much more distant than the Moon, and therefore much larger than Moon (since they have the same angular size).

6. The relative sizes of the Earth's shadow and the Moon, as seen during total lunar eclipses, showed that the Earth is only a few times larger than the Moon. The Earth was therefore small compared with the Sun. He correctly reasoned that the Sun is more likely than the Earth to be at the center of the Universe.

7. Eratosthenes, director of the great library of Alexandria around 250 B.C., was a geographer whose maps were among the best of their time.

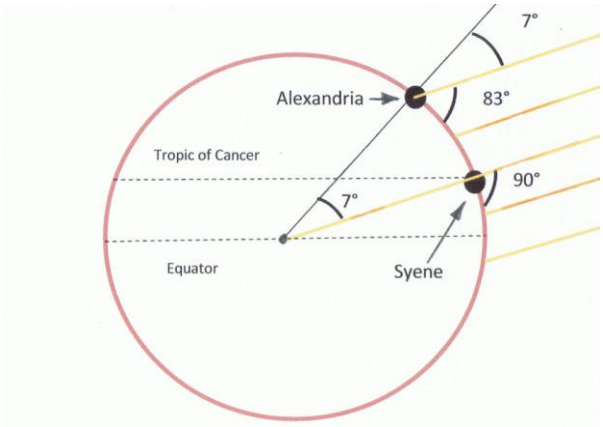
a. At local noon on the summer solstice (when the Sun is highest in the sky), he noticed that vertical sticks in the town of Syene (now called Aswan) do not cast a shadow, Hence, the Sun must be directly overhead.

b. He had also found that at the same date and time, vertical sticks in Alexandria, some distance due north of Syene, cast appreciable shadows; Hence, the Sun was not directly overhead.



c. Since, the Sun was known to be very far away (from the technique used by Aristarchus), Eratosthenes assumed that it's light rays reaching the Earth are nearly parallel.

d. He reasoned that the different apparent position of the Sun is a consequence of the curvature of Earth's surface.



e. He then deduced that the ratio of a shadow's angle (about 7^0 from the top of a stick) to 360^0 (a full circle) must equal the ratio of the Alexandria-Syrene distance to the Earth's circumference.

f. Knowing the Alexandria-Syrene distance in units of stadia (the length of a Greek stadium), he solved for the circumference of the Earth.

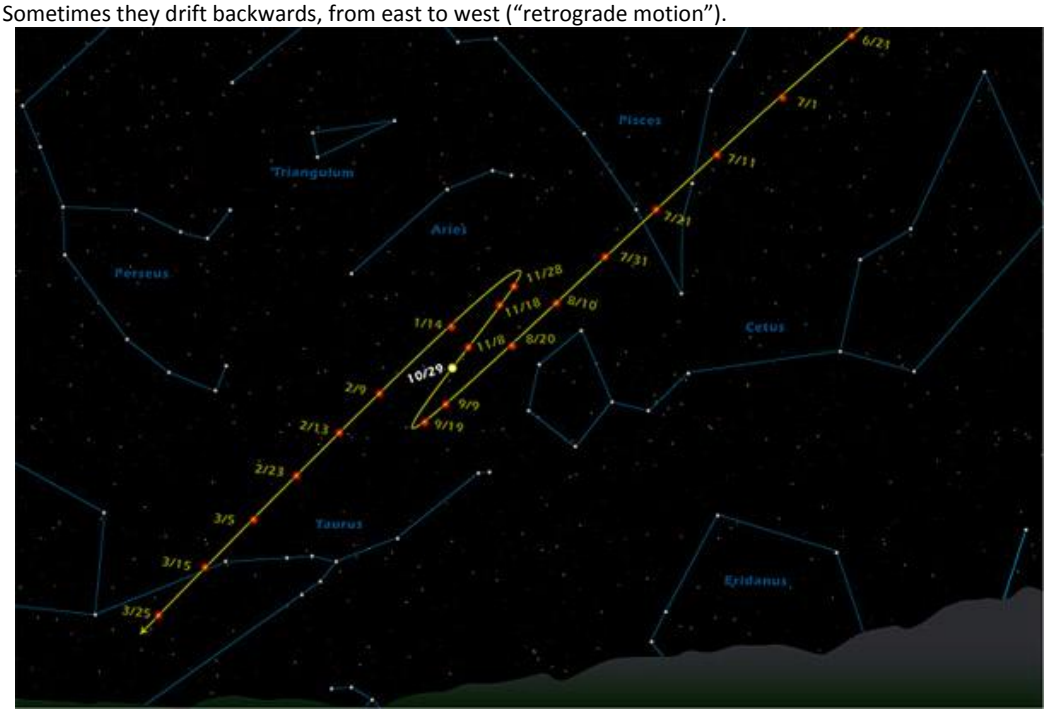
$$\frac{\text{angle of the sun}}{360^0} = \frac{\text{distance to Tropic of Cancer}}{Earth\ \ circumference}$$

g. We are not certain of the accuracy of his result because the lengths of stadia were not uniform (they varied between about 160 and 210 m), but he was close in any case, and the method was correct and elegant.

8. Early Greek scientists deserve great credit for their careful observations and experiments, and for their logical deductions from the data. Those of the so-called "Ionian school", in particular, believed that the properties of the real Universe can be deduced through observations and experiments.
9. Unfortunately, many influential philosophers, such as Pythagoras (570-495 B.C.) and Plato (428-348 B.C.), generally discouraged such work and impeded the progress of science. These "Pythagoreans" believed such ideas as:
   a. The nature of the Universe can be learned through pure thought.
   b. The observed world is simply an imperfect reflection (or shadow) of an underlying "perfect reality".
   c. Grand insights should not be made known to common people (i.e., those untrained in geometry).

D. Most ancient Greek astronomers felt that the Earth is the center of the Universe. Even many Ionians believed this "geocentric" hypothesis, despite their other correct conclusions.

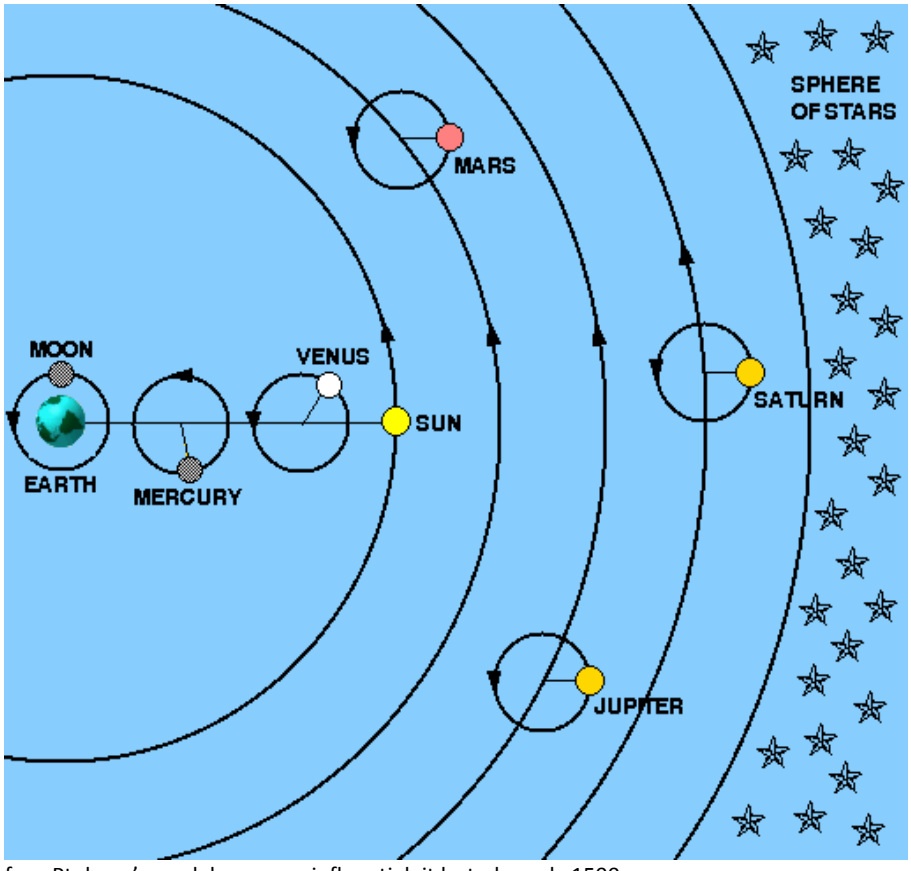
1. The "fixed stars" appear to be embedded in a celestial sphere that rotates around us, yet the Earth itself doesn't seem to rotate. (Otherwise, it was argued, people would fly off ---the concept of inertia had not yet been developed).
2. Similarly, the Sun rotates around the Earth, but at a different rate.
   a. It seemed unreasonable to think that the Earth orbits the Sun; once again, objects would fly off of the Earth's surface.
   b. Moreover, the relative positions of stars do not change at different times of the year, yet they would if the Earth orbited the Sun, unless stars were exceedingly distant.
3. The Moon rotates around the Earth in about a month.
4. A few stars drift slowly among the fixed stars from night to night, usually from west to east ("prograde motion").
   a. These were called planets (the "wanderers"), with periods of months to years.
   b. Sometimes they drift backwards, from east to west ("retrograde motion").



   c. The five planets known to the ancients were Mercury, Venus, Mars, Jupiter and Saturn.
   d. The days of the week are name after the five planets, the Sun, and the Moon.
5. Aristotle, one of the greatest early philosophers, expanded and summarized the state of Greek astronomical belief in 350 B.C..
   a. The seven distinct objects are attached to perfect, concentric spheres that rotate around the the Earth with different periods.

b. The motions of the spheres affect each other to produce phenomena such as retrograde
c. The outermost sphere is that of the fixed stars.
d. Beyond this is the "prime mover" that causes the celestial sphere to rotate.
e. Below the closest sphere (that of the Moon), everything is made of four "essences": earth, air, fire, and water.
f. The spheres consist of a perfect, transparent, fifth essence (the "quintessence").

6. Aristotelian astronomy and most of physics (e.g., "the natural state of a body is to be at rest; everything that moves is moved by something else") were wrong, but they dominated Western science for nearly 2000 years, until the Renaissance.
7. Around 140 A.D., the Greek astronomer Claudius Ptolemy developed an elaborate model that could be used to accurately predict the positions of planets.
   a. He expanded on Aristotle's geocentric theory by borrowing ideas developed earlier by Hipparchus and others.
   b. Planets move along **circular epicycles**, the centers of which move around Earth along circular **deferents**.
   c. This basic structure allows planets to undergo retrograde motion.
   d. To explain observed planetary positions in detail, there were many complexities: the deferent is not centered on the Earth, the epicycle moves at a constant angular speed relative to a point called the equant, epicycles can be superposed on epicycles, etc.
   e. Moreover, by inserting additional epicycles, Ptolemy's model could reproduce the observed motions of the planets to arbitrary precision. This is actually similar to what is now done in the function of arbitrary shape can be represented as the sum of a large number of sine and cosine waves.



   f. Ptolemy's model was very influential; it lasted nearly 1500 years.
   g. Nevertheless, Ptolemy and others considered this to be only a mathematical tool; "perfect reality" was still Aristotle's set of nested spheres.
8. Ptolemy summarized his work and that of his predecessors in the *Almagest*.
   a. The *Almagest* provides most of our knowledge of ancient Greek astronomy.
   b. Unfortunately, it eradicated (sometimes by ommission) many correct ideas of the Ionian school.

E. Questions:

1. List the main constituents of the Solar System and the basic properties of planetary orbits.

2. Describe how the Solar System is thought to have formed from a cloud of gas and dust.

3. Explain how ancient Greek astronomers deduced that the Earth is spherical and measured it's Approximate size.

4. Summarize the Aristotelian view of the Universe.

5. Define what is meant by "retrograde motion" of planets.

6. Describe Ptolemy's geocentric model of planetary orbits, showing how it accounted for Retrograde motion.

7. Had you been alive 2000 years ago, do you think you would have believed in a geocentric model of the Universe, or a heliocentric model as did Aristarchus? Why?

8. Discuss the importance of assuming that the Sun is very distant, if the method of Eratosthenes is used to determine the circumference of the Earth.

9. . Can you find any good scientific evidence that astrology makes correct predictions?