Around 2500 years ago, **Pythagoras** began to use math to describe the world around him.

Around 200 years later, **Aristotle** stated that the Universe is understandable and is governed by regular laws.

Most of the Greeks felt that the Universe revolved around the earth.

This is called a **geocentric** cosmology.

This idea held on for about 2000 years, but evidence started to show up that perhaps it was wrong:

1) It was obvious that the planets moved against the background stars.

2) It was also obvious that the planets did not move through the sky at the same speed all of the time-- sometimes they moved faster than at other times.

3) The planets sometimes stopped their motion and moved backwards for a few weeks (**retrograde motion**) (fig 2-1)

These motions could not be easily explained if everything went around the earth.

**Aristarchus**, a Greek, proposed that everything orbited the sun and so was **heliocentric**.

What a foolish idea!

It was obviously wrong because your eyes show things moving around the earth.

During the Middle Ages, planetary motions were explained using **epicycles** and **deferents**.

This system actually worked-- it did predict very accurately how the planets behave, but it was very complex.

As time passed and measurements became more accurate and precise, the idea of epicycles no longer made sense.

**Occam's Razor** - when there are several possible solutions to a problem, the simplest one is usually the correct one.

**Nicholas Copernicus** started studying astronomy in the 1500's.

He found that if the sun was at the middle of the universe, then the motions of the planets could be easily explained.

Mercury and Venus must be inward from the earth, while the other planets were farther out.
Inferior Conjunction - occurs when a planet lies between the earth and the sun (Mercury, Venus).

Superior Conjunction occurs when a planet is on the far side of the sun (Mercury, Venus).

Greatest elongation occurs when a planet is at its maximum apparent distance from the sun (Mercury, Venus).

Planets whose orbits are outside of the earth's have different configurations.

When an outer planet is on the far side of the sun, it is in conjunction.

Planets have two different rotational periods as seen from the earth:

1) **sideral period** - the amount of time it takes the planet to travel 360 degrees around the sun (year).

2) **synodic period** - the length of time it takes a planet to return to a particular configuration (opposition to opposition, for example).
By using these periods, Copernicus was able to figure out how far the known planets were from the sun.

He did not know the actual distance, just the distances in terms of the earth-sun distance (fig 2-2, page 49).

**Astronomical unit** - the average distance from the earth to the sun (93,000,000 miles).

Copernicus published his ideas and their proofs in a book called *De Revolutionibus Orbium Coelestium* (On the Revolutions of the Celestial Spheres).

The book was published in the year of his death and he may never have seen it in print.

It did contain an error, though.

Copernicus felt that the planets moved in circular paths so his predictions were no more accurate than the old epicycles were.

Things soon changed, however.

In November, 1572, a new star (**nova**) appeared in the constellation of Cassiopeia.

It was thought that it couldn't really be a star (the heavens were, of course, unchanging) so it had to be something else-- something close to the earth.

**Tycho Brahe** felt that maybe he could find out how far away it was by measuring the object's **parallax**.

Tycho measured the location of the star in the sky from several different locations in Europe.

The star's location came out the same no matter where it was measured from.

This meant that the star had to be very far away-- it could not be something that was close to the earth.

Tycho was never able to determine the actual distance to the new star.
Tycho undertook to measure the positions of the planets in the sky for the next 21 years. His measurements were extremely accurate, considering that they were made with the naked eye. He attained high accuracy by using very large instruments, such as quadrants and cross-staffs. His project was funded by the King of Denmark, who had an observatory, Uraniborg, constructed for him on the island of Hven.

Tycho's records, which were very accurate, were given to his assistant when Tycho died. Johannes Kepler tried for many years to find an orbital shape that Tycho's observations would fit. He finally realized that the planets follow elliptical paths as they orbit the sun.
The shape of a planet's orbit around the sun is given by the eccentricity \(e\) of its ellipse.

Eccentricity can range from zero (circle) to beyond 1.

Kepler found that the planets do not orbit the sun at uniform speed.

When they are at **perihelion**, they move faster than when they are at **aphelion**.

Kepler also found that a line from a planet to the sun sweeps out equal areas of space in equal times.

He also discovered that the length of a planet's "year" depends on its distance from the sun—planets closer in orbit faster than those farther out.

He was able to describe this with a simple equation:

\[ p^2 = a^3 \]

where \(p\) is the period of the planet (in earth years) and \(a\) is the distance from the sun (in AU's).

An object is discovered orbiting the sun at a distance of 3.7 AU—what is the length of its year?

\[ P^2 = 50.7 \]
\[ P = 7.1 \text{ years} \]

An object is discovered orbiting the sun— it takes 0.58 years to make one complete orbit. How far is it from the sun?

\[ 0.336 = a^3 \]
\[ 0.7 = a \text{ AU} \]

Galileo Galilei is the first person known to have pointed a telescope at the sky.

He saw that the moon was rough and mountainous and it was blemished (craters).

He saw that Venus had phases just like the moon did.

Galileo saw that Jupiter was orbited by four tiny objects.

He saw blemishes on the face of the sun.

This meant that everything did not go around the earth and that the heavens were not perfect.

What Galileo saw was counter to the Church’s teachings and so Galileo was tried and convicted of heresy.

Since he was too famous to burn at the stake, he was sentenced to house arrest for the rest of his life.

While he publicly recanted, he did not actually change his mind— he still believed that the Universe was heliocentric.

He was finally pardoned by the Church in 1992.
Isaac Newton was born on Christmas Day, 1642.

Prior to Newton, astronomers worked by trial and error—they made observations and then adjusted their equations to match what they saw.

Newton was the first to use mathematics to accurately describe the motions of objects.

Newton's Laws of Motion

1) A body at rest will remain at rest, a body in motion will remain in motion unless they are acted on by an outside force.

This meant that there must be a force acting on the planets or they would fly off into space.

This force is now known as gravity.

Velocity - motion in a certain direction.

Acceleration - a change in velocity over time.

2) For every action, there is an opposite and equal reaction.

Why does a rocket move?

3) Bodies attract one another with a force that depends on their masses and on the distance between them.

This force decreases as the square of the distance.

If two objects are placed twice as far apart, then the force between them will be four times less ($2^2 = 4$).

This is the same as saying that the force will be 1/4 as strong.

Newton was the first person to discover why Kepler's Laws worked.

He also found that there are some objects that do not orbit in elliptical paths, but instead follow parabolic or hyperbolic orbits.

Conic Sections:
Because of Newton's work, Edmund Halley calculated that a particular comet returned every 76 years. The planet Uranus was discovered by accident in 1781 by William Herschel.

Uranus did not move like it should have—something was influencing it gravitationally. The position of the unknown object was calculated and Neptune was found to be near there.

Pluto—Clyde Tombaugh (1938)