Chapter 2 The Copernican Revolution

Ancient Astronomy

Many cultures learned the night sky for different reasons. The most basic reason was probably survival. Sailors learned how to navigate the seas; other cultures used the heavens to know when to plant and harvest. Most of this depended on them to recognize patterns of stars or constellations. Some cultures built monuments to the night sky. The most recognized structure is probably Stonehenge in England. It is believed to be an observatory of sorts. It was built between 2800B.C. and 1100 B.C. The stones seem to be aligned with many astronomical events. If you stand in the center on the summer solstice the Sun will rise over the Heel Stone . These stones were aligned to within about 1° of being perfect.

Other cultures such as the Native Americans made astronomical structures. In Big Horn, Wyoming a structure called a Medicine Wheel was constructed. The spokes of the wheel are aligned to the rising and setting of the Sun at different times of the year as well as being aligned to bright stars. The Mayans built a more elaborate structure than Stonehenge but had the same purpose. The only difference was that at the Mayan structure many sacrifices were held when Venus was up in the sky.

The Chinese were very good at recording events in the sky. Modern astronomers still go back into the records to determine when events occurred. One of the best known events was recorded by the Chinese. In 1054 A.D. a guest star appeared in the sky, for about 2 months it was seen in the day. We now know that it was a *supernova* or an exploded star.

The works of the ancient Greeks and the Europeans was linked by the Muslims. During the Dark Ages, knowledge flourished in Islam. For about 600 years the Muslim scholars were the only people doing any astronomy, up to the point of the Renaissance. No one culture was responsible for our knowledge in astronomy.

The Geocentric Universe

Observations of the Planets

As the ancients watched the skies they saw the Sun, Moon, and the stars move across the sky in relative ease. They all went from the east and moved across to the west. They also noticed the planets, but their movements were more complex that the others. Every once in a while the planets would slow down and start to move backwards for a short time and then go back to normal. This backwards motion is called *retrograde motion*. Normal motion is called *prograde motion*. Mercury and Venus are called inferior planets because they are inside the Earth's orbit and Mars, Jupiter, and Saturn are called *superior planets* because they are outside of the Earth's orbit. Several things were noticed: 1) inferior planets never strayed far from the Sun. These 2 planets are seen in *conjunction* twice with the Sun or they align with the Sun. 2) superior planets can be seen in conjunction with the Sun as well as in *opposition* with the Sun. Opposition means that the Sun is on one side of us and the planet is on the other side of us. 3)superior planets are brightest at opposition. Now the problem was to construct a model that explained the solar system.

A Theoretical Model

One of the earliest models of the universe came from Aristotle (384-322 B.C.). His model was a *geocentric model* or Earth centered. His model did a pretty good job of approximating the movement of the Sun and Moon, but couldn't explain retrograde motion. Around 140 A.D. a Greek named Ptolemy put together a model using Aristotle's ideas and he tried to explain retrograde motion. This model required over 80 circles. It wasn't pretty, but it did a better job of explaining the movements in the sky. Another Greek, Aristarchus of Samos (310-230 B.C.) argued that the Sun was in the center and the Earth went around it. Also he said that the Earth rotated on its axis. This would explain what we see. His ideas weren't taken too seriously due to Aristotle's widespread importance. Aristotle's followers said that if we moved you should be able to feel the movement. They also said that you should be able to see some *parallax*, which is the apparent movement of a body due to our changing positions.

The Heliocentric Model of the Universe

In the 16th century a man named Nicolas Copernicus brought forth the *heliocentric model*. This was a Sun centered model. Copernicus felt that the Earth went around the Sun and it spun on its axis. Only the Moon went around the Earth. This became known as the *Copernican revolution*. It explained why we see retrograde motion and the whole system was much cleaner that Ptolemy's model. One of his predictions was that if it was all true you should be able to see the phases of Venus. The problem was he couldn't prove it. Therefore he didn't find the following that Aristotle had. He wrote a book on the topic, but because he was afraid of the church he didn't have it published until he knew he was dying. He saw the first printed copy on May 25, 1643 and died on that day.

The Birth of Modern Astronomy

Galileo's Historic Observations

Galileo was a well known scientist of his day. He was well respected and is now considered the father of experimental science. The telescope was invented in Holland and a year later he received a pair of lenses that he made into a telescope. What he saw conflicted with many of Aristotle's ideas. Aristotle said that the universe was perfect and unchanging. Galileo saw mountains and craters on the Moon as well as sunspots on the Sun. He looked at Jupiter and found 4 small objects that were going around Jupiter. This helped Galileo become an avid Copernican. He wrote a book that detailed his ideas and findings which challenged both the scientific orthodoxy and the religious dogma of the Church. He was instructed by Rome to desist in his teachings. One of the things that Galileo saw with his telescope was the phases of Venus that was predicted by Copernicus. Eventually he was questioned by the Inquisition 3 times before he recanted his ideas. He lived out his life under house arrest.

The Ascendancy of the Copernican Revolution

The heliocentric idea wasn't well received because there was no evidence. In 1728 James Bradley discovered the *aberration of starlight*. This is the slight shift in position of a star as we move perpendicular to the stars line of sight. This was shown with many stars and in 1838 stellar parallax was observed by Friedrich Bessel. Now there was evidence for the motion of the Earth.

The Laws of Planetary Motion

Brahe's Complex Data

Tycho Brahe was one the finest naked eye astronomers that ever lived. His work caught the eye of the king of Denmark and he gave him an island and money to build an observatory. He spent almost 30 years watching the planets and keeping very accurate records of where they were. The old king dies and his son takes over and Tycho is thrown out. He moves to Prague and takes on a young mathematician named Johannes Kepler to help him. Tycho died in Nov., 1601 and Kepler ended up with everything. Using the observations of Tycho, Kepler was able to determine that the orbits of the planets were *ellipses*. He used the planet Mars for this work. Here are the three laws:

1) the orbits of the planets are ellipses with the Sun at one focus. The ellipse is a flattened circle and the *semi major* axis is ½ the distance across the wide part of the ellipse. The *eccentricity* of the ellipse is just a measure of how flattened it is.
2) A line from a planet to the Sun sweeps out equal area in equal time.
3) $P^2_{yr} = a^3_{au}$

The Dimensions of the Solar System

We can determine the relative positions of the planets, but we can't determine the actual size because we are using the Earth-Sun distance for this measurement. We need to know what 1 AU is in km. The earliest methods used the transit of Mercury or Venus. A transit is where they cross the face of the Sun as seen from Earth. By watching this event from different points on the Earth we could us geometry to calculate the AU. Now we use things like radar. We can't use it on the Sun directly because it absorbs radar, but we can use it on the planets and use it to determine an AU.

Newton's Laws

Isaac Newton was born on Christmas day 1642. He went to college but was sent home along with everybody else in 1665. Why? It was at home that he did his best work in optics, mathematics, and mechanics (physics). He developed 3 laws of motion:

1) Every body continues at rest or in motion in a straight line unless acted on by an outside force. This tendency to keep doing what it is doing is called *inertia*. In other words the object has a constant velocity, which is a combination of speed and direction.
2) When a force acts on a body it produces acceleration equal to the force divided by the mass. $F = ma$
3) For every action there is an equal and opposite reaction.

Gravity

Another of Newton' work was done on the force of gravity. He brought forth the idea of gravity as to why things fall and why planets stay in orbit. $F_g = G\ (mm)/d^2$ This says that the product of the 2 masses times a gravitational constant divided by the distance squared gives you the force of gravity between the 2 objects. It is referred to as the inverse square law.

Planetary Motion

As time has gone on we have reevaluated many of the laws that have been brought forth and we have refined them. This is due to a better understanding of the concept or better measurements that have been made.

Kepler's Law Reconsidered

Using Newtonian mechanics we now realize that in Kepler's first law the planet doesn't orbit the Sun, but rather the center of mass of the planet-Sun pair. Thus if we rewrite Kepler's first law it would say: The orbit of a planet around the Sun is an ellipse, with the center of mass of the planet-Sun system at one focus.
We would also take into consideration the mass in his third law. $P^2_{yrs} = a^3_{au}/mass_{total}$ in solar units.

Escaping Forever

Kepler's laws explain the motions of the planets around the Sun. They also explain the motions of satellites around the Earth. To put a satellite in orbit, we must reach *escape velocity*. For the Earth it is about 25,000 miles per hour. Once a satellite is put into orbit, if we wish to send that satellite to another planet it must reach escape speed to escape the Earth's gravity. The space shuttle orbits at about 18,000 mph. If they exceed that they will head off somewhere. When they were in orbit around the Earth they were said to have had a *bound orbit*. When they break free their orbit is said to be **unbound**.