CHAPTER I

PROPERTIES **OF THE PHYSICAL UNIVERSE**

Before we can discuss the evolution of the physical universe, we need to understand its current structure and other physical properties. We are going to present these things in conjunction with the history of how this knowledge was developed. But let us first define some basic concepts and terms that we will be using:

Physical Universe: ***Everything that can be sensed, observed, or measured in some way.*** If something cannot be measured, it does not belong to the realm of scientific scrutiny.

Laws of Physics: ***Approximate descriptions of what is observed in the physical world.***

They are anthropogenic inventions, not discoveries. That is, the laws of physics do not exist in any absolute sense. They have been constituted by humans based on experiments and observations.

The validity of any law is its ability to describe the phenomena to which it is applicable and to predict what will happen for a given set of conditions and only for those conditions.

Astronomical Unit (AU or au): ***the average or mean distance of the Earth from the Sun.*** It can also be thought of as the average radius of the Earth's orbit around the Sun and is a number like 150 million km. Recall that the Earth's orbit around the Sun is an **ellipse**, not a circle.

Light Year: ***The distance that light travels in a time of one year.*** This is about 63,000 AU.

Parsec: ***A unit of distance equivalent to 3.26 light years*.** This unit arises naturally from the method that astronomers use to measure stellar distances**.**

Satellite: ***An object or body moving in orbit around a more massive object***. For example, planets and comets are satellites of the Sun. The Moon is a satellite of the Earth.

Force: ***An interaction that produces an acceleration or change in velocity of an object.*** Only unbalanced or net forces produce accelerations. If an object is observed to be accelerating, we conclude that a net force is acting on the body.

Velocity: ***The speed of an object in a specified direction.***

THE HIERARCHICAL STRUCTURE OF THE UNIVERSE

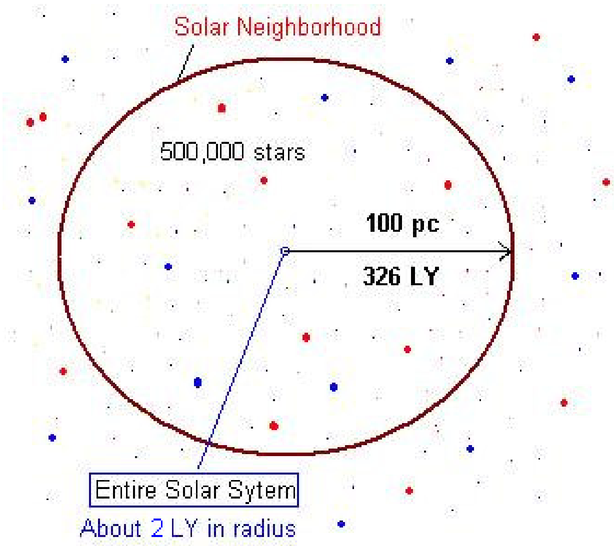
Historically, our knowledge of the universe has developed by making observations from the Earth. These observations were limited at first to what could be seen just by eye alone. This revealed only the immediate vicinity of the Earth, since more distant objects require a telescope to be observed.

For example, the Earth is one of many planetary and other types of bodies, collectively called solar satellites, that move in orbit around a star we call the Sun.

Slowly, our understanding of the universe grew outwards as technology developed. Today, we recognize the following **hierarchical** structure in the universe based on our historical perspective**:**

1. The **Solar System:** ***A gravitationally bound system consisting of the Sun and all of its satellites.*** The radius of the solar system is somewhere between 100,000 and 150,000 AU or, on the average, about 2 light years or 0.61 parsecs.

2. The **Solar Neighborhood:** ***All the stars within 100 parsecs from the Sun*** (or solar system). That is, the solar system is located at the center of the solar neighborhood and is very small in comparison. Below is a schematic of the solar neighborhood.



3. The **Milky Way Galaxy** or Our Galaxy**:** ***A gigantic, gravitationally bound system consisting of about 200 billion stars, including the Sun and the solar neighborhood***.

4. The **Local Group:** ***A gravitationally bound cluster of about 40 or so galaxies, including our galaxy.***

5. The **Local Supercluster:** ***A cluster of many smaller clusters of galaxies, including our local group***. It is often referred to as the Virgo Supercluster**.**

6. The **Universe or Cosmos:** ***The largest scale of physical reality, which consists of other clusters and superclusters of galaxies extending, in a frothy like distribution, to the limit of visibility***.

The photo to the right shows a normal spiral galaxy much like our Milky Way Galaxy. Notice the dust clouds in the disk of the spiral arms. The dust allows planets and people to form. Later we will discuss the origin of the dust. (Photo courtesy of NASA)

The structure of the universe that we have outlined above results from gravity. That is, the structure of the universe is what it is because of the nature of gravity or law of gravity. If the law of gravity were different, then the universe would have a different structure than the one we observe.

Because of the work of Edwin Hubble in 1929, we now know that the universe is in a state of expansion. Exactly what this means will be discussed later.

A BRIEF HISTORY OF THEORIES AND DISCOVERIES ABOUT THE SOLAR SYSTEM.

The ancients recognized 7 objects in the sky that moved relative to the "fixed" stars. These were the Sun, Moon, and 5 relatively bright stellar-like objects. The latter were called wandering stars or "planets" and were assigned the names of ancient gods. The Earth was not considered a planet but the center of the universe. This remained the situation up through the 16th century until the telescope became available as an instrument to study the sky.

The Geocentric Theory or Model of the universe has its origins in prehistoric time, that is, going back more than 3,000 years. The Geocentric Model assumes the Earth is the immobile center of the universe and everything else seen in the sky revolves around the Earth.

The Heliocentric Model assumes that the Sun is the center of the universe, that the Earth is a planet, and that the planets all revolve around the Sun. This is closer to what we recognize as the model of the Solar System today. It must be remembered that the ancients had no awareness of the universe other than what they could see with their eyes.

We proceed now to examine the written history of who did what and when. The dates quoted below are the time frames when the work was done.

Aristotle, circa 350 BC

Presented arguments for the geocentric theory of the universe, such as, there was no evidence for the parallactic displacement of nearby stars, which should result from the revolution of the Earth around the Sun. He also argued that diurnal motion (the daily movement of the Sun, stars, and planets in the sky) could not be explained by the Earth rotating, since the Earth would have to rotate so fast that it would break apart.

Aristarchus, c. 250 B

Rebutted Aristotle's arguments. He argued that parallax cannot be observed because all the stars are so far away that this angular displacement could not be detected, which is true. He promulgated and taught the validity of the heliocentric theory of the universe, which was commonly not accepted.

Hipparchus, c. 150 BC

One of the greatest of the ancient astronomers was the Greek philosopher and mathematician, Hipparchus. He lived and worked in Alexandria, Egypt. Apparently he made measurements of planetary positions without a telescope and developed a mathematical model for computing future positions of the planets. Unfortunately, he adopted the geocentric theory. As a result, the model did not predict things very well. Hipparchus also invented trigonometry, calculated the distance of the Moon, made the first known star chart, and classified stars on a scale of apparent brightness, by assigning them numbers that we now call magnitudes. For example, the brightest stars were classified as magnitude 1 and the faintest were magnitude 6.

Ptolemy, Claudius c. 120 AD

Ptolemy attempted to improve the geocentric theory by introducing epicycles into a planet's motion. He wrote a compendium of astronomy referred to by Arab scholars as the Almagest. Arab scholars had journeyed to the great library in Alexandria, Egypt and copied the original manuscript and translated the Greek into their native language. The original manuscript was destroyed in a fire that occurred during the battle between Julius Caesar and Queen Cleopatra Ptolemy.

Kopernik, Nicholas (aka Copernicus), 1543 AD

Nicholas Kopernik was a polish cleric of the Church and scholar. He resurrected and updated the heliocentric theory of the ancients, including the development of a mathematical model that predicted the positions of the planets more accurately than any of the geocentric theory models. The heliocentric model of the solar system was also able to explain the apparent retrograde motions of the planets, which the geocentric model was not able to do successfully. He published his results in 1543, shortly before his death.

Brahe, Tycho, 1580 – 1600

This Danish astronomer made the most precise measurements of the positions of the planets before the use of telescopes. He used sighting instruments that he designed and had constructed by skilled craftsmen. He was able to measure positions with an uncertainty of only 4 arcminutes, a precision never achieved before. An arcminute is one sixtieth of a degree. The apparent angular diameter of the full moon is 30 arcminutes or half of a degree.

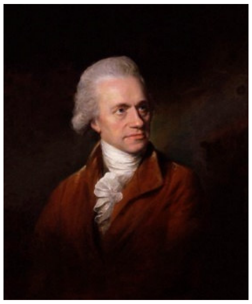
Kepler, Johannes, 1600 – 1620

Kepler was a German mathematician and colleague of Brahe. He mathematically analyzed the observations of Brahe and developed 3 laws of planetary motion.

Galileo Galilei, 1609 – 1620

Galileo built his own telescope base on information he garnered from colleagues in Holland. In 1609, he began to observe the planets telescopically. He saw that Jupiter had dark cloud bands. He also discovered 4 moons orbiting Jupiter, which are now called the Galilean satellites. He watched Venus go through a cycle of phases that is different than the Moon's cycle and that could only be explained if Venus were in orbit around the Sun, not the Earth. Galileo described Saturn as a planet with ears. His telescope could not separate Saturn from its rings. It was some years later, in 1659, that Huygens discovered that Saturn had rings. Galilei was convinced that his observations proved Kopernick to be correct. Galilei is considered the Father of Modern Physics because of the many experiments he did involving the motion of objects.

In 1671, Sir Issac Newton developed 3 laws of motion and the universal Law of Gravity. To accomplish the latter, he invented calculus. Newton also did experiments in optics and spectroscopy. He also invented the reflecting telescope which uses a mirror to collect light and bring it to a focus to be examined with an eyepiece. Newton is considered by many to be the most brilliant person of recorded history. His mathematical prowess has never been matched.

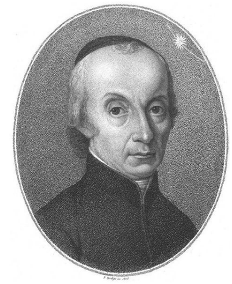


On March 13, 1781, Sir William Herschel (a professional musician and amateur astronomer) came across and object which he first believed was a new comet. After observing this object for some time, he noticed that it did not move like a comet, nor was it changing its appearance like comets usually do. He finally announced that he had discovered a new planet orbiting the Sun! This news astonished the entire world and made him instantly famous, for no one had ever thought there was another planet in the Solar System. Herschel named his new planet "Georgium Sidus" (George's Star in Latin) out of gratitude to King George III of England, because Herschel had migrated from Germany to England. This name was not accepted by many other astronomers, especially the French. An international body of astronomers decided that the naming of new planets should follow the tradition of using names of the ancient gods. Therefore, it was decided that the new planet should be called Uranus, the grandfather of Saturn and the god of the universe.

Urbain Jean Leverrier

In the meantime, all was not well with Uranus. It was not following the predicted orbit that had been calculated for it, based on observations and Newton's laws of motion. It was concluded that there must be another distant, large planet that was disturbing the orbit of Uranus. Two young mathematicians, Jean Leverrier in France and John Adams in England, working unaware and independently of one another, set about to analyze mathematically the observed departures of Uranus from its predicted path in order to calculate where this other planet might be located in the sky. Adams sent his results to George Airy at the Royal

Greenwich Observatory, but Airy did not bother to look for the planet. Leverrier was more successful in getting an astronomer at the Berlin Observatory to look for the planet. And so on the night of September 23, 1846, the eighth planet was discovered within 1 degree of where Leverrier had calculated it should be. Later Airy realized that Adams had also calculated the location of the new planet correctly. Adams and Leverrier are now both credited with having discovered the new planet which was named Neptune. Of course, all of this would not have been possible without Newton's Laws.



In 1801, the Italian astronomer Giuseppe Piazzi serendipitously discovered what was thought to be another planet. It was named Ceres and found to move in orbit around the Sun between the orbits of Mars and Jupiter. Shortly thereafter two other smaller bodies were found to be orbiting the Sun at approximately the same distance. Hence it was decided to classify these objects as minor planets or "asteroids." The number of asteroids has now grown to about 400,000, all of which are rather small. **Piazzi** (1746 - 1826) was an Italian Theatine monk, mathematician, and astronomer. He established an observatory at Palermo, now the *Osservatorio Astronomico di Palermo – Giuseppe S. Vaiana.*

Astronomers were convinced that there could still be other undiscovered planets and so the search for new planets continued for a long time without success. In 1930, Clyde Tombaugh, an assistant at the Lowell Observatory in Arizona, succeeded in finding another planet by photographic means. It was named Pluto and was considered to be another major planet because its orbit was found to be larger than that of Neptune. Pluto was later found to be a rather small planet both in size and mass and had a relatively large amount of ice its structure. It also had a strange orbit that departed from the orbital characteristics of the major planets. This has led to debates as to whether it should be classified as a major planet.


Gerard Kuiper

In 1950, Gerard Kuiper, a Dutch-American astronomer working at the Yerkes Observatory of the University of Chicago hypothesized that there was a toroidal shaped region of comet nuclei and other icy bodies just beyond the orbit of Neptune, moving in orbit around the Sun. Kuiper's hypothesis has since been verified. Since 1992, hundreds of smaller bodies have been discovered beyond the orbit of Neptune. These bodies are called Trans-Neptunian Objects (TNOs) or Kuiper Belt Objects (KBOs). They appear to be made of a lot of ice, like Pluto. The names given to some TNOs are Eris, Orcus, Sedna, Quaoar, Varuna, and Ixion. Eris is somewhat larger than Pluto, but twice as far from the Sun.

In 1994, the first solid evidence for the existence of a very massive planet orbiting another star (51 Pegasi) was obtained by Swiss astronomers. Such planets are called **exoplanets**. Exoplanets are discovered by applying the Doppler Effect to an analysis of a star's spectrum, thereby measuring the changing speed of the star as a result of its motion around the barycenter or center of gravity of the star and its planets.

In 2005, a body was discovered moving in orbit about the Sun at a distance of about 110 AU . It was given the designation 2005 UB313 and was nicknamed Xena by its discoverer. However, the IAU has now officially named this body to be Eris. Eris has a small moon called Dysnomia. Estimates of the size of Eris indicate it is 1.5 times larger than Pluto.

In August 2006, the ***IAU*** (International Astronomical Union) voted to demote Pluto as a major planet and placed it in a new category called "dwarf planets" along with the largest asteroid Ceres, and Eris.