

## Chapter 6 The Solar System

### An Inventory of the Solar System

The ancient Greeks knew of the Moon and the 5 planets; Mercury, Venus, Mars, Jupiter, and Saturn. They also knew of 2 other kinds of objects: comets and meteors. Our knowledge of the solar system remained pretty much unchanged until the 17<sup>th</sup> century. This was due to the invention of the telescope. Galileo was the first to turn it towards the heavens and see what was out there. His discovery of the phases of Venus (as predicted by Copernicus) and the 4 giant moons of Jupiter helped change our ideas of the heavens. Technology has been the reason for our better understanding of the cosmos. In 1659 we saw the rings of Saturn, in 1758 we discovered Uranus, and in 1846 we discovered Neptune. We discovered many *minor planets* (asteroids) orbiting the Sun. In the 20<sup>th</sup> century we saw the rise of nonoptical astronomy due to radio astronomy and the work in the infrared. We currently explore our *solar system*. It consists of 1 star, nine planets, 135 moons (and counting), 6 asteroids bigger than 300 km, thousands of others and a plethora of meteoroids.

We are going to use *comparative planetology*. We will look at the planets and compare them to the Earth and each other. The goal is to develop a model of our solar system that can explain why we are so diverse. We will also try to understand planetary systems around other stars. We have currently “discovered” over 100 *extrasolar planets*. We hope to use them to help explain why we are like we are and also to look for life. So far we have discovered no Earth sized planets, but that appears to be due to the need for better technology.

### Planetary Properties

On page 146 there is a table with properties of the planets. Here is how we have determined these:

- 1) The distance from the Sun is known from Kepler’s Laws once the scale of the solar system was set by radar ranging on Venus.
- 2) We can determine a planets orbital period (sidereal rate) by repeated observations of where it is in the sky, as long as we take into account the motion of the Earth.
- 3) Each planets radius is found by measuring the angular size of the planet and applying simple geometry.
- 4) The masses of planets with moons can be calculated by using Newton’s laws of motion and gravity by observing the moons orbits around the planet.
- 5) The mass of Mercury and Venus were harder to determine because they have no natural satellites. We were able to do it because they pulled on the other planets including the Earth. From this tug the masses were calculated.
- 6) The masses of these planets have been measured accurately through artificial satellites that we have sent out.
- 7) The rotation period should be easy to measure. You just watch the surface features. The problem is that the features may be hard to see (clouds on Venus) or there is no feature that can be seen easily from Earth. Also the atmospheres of the giant planets make it difficult. We’ll explain later how it is done.
- 8) Average density is fairly easy to compute. Density is unit mass / unit volume.

## The Overall Layout of the Solar System

The solar system is huge by our standards. Pluto is about 40 A.U. or 40 times the Earth-Sun distance from the Sun. The order of the planets is: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. The eccentricities of the planets orbits are *almost* circular. Mercury and Pluto have the largest eccentricities. As seen from above, the planets orbit counterclockwise around the Sun and they rotate counterclockwise on their axis (except Venus). Most of the planets lie on a flat plane that is less than  $7^\circ$  from perfect. Pluto lies  $17^\circ$  from the plane.

## Terrestrial and Jovian Planets

The solar system appears to be fairly ordered. The planets are on nearly a flat plane, on almost concentric elliptical orbits, orbit in the same direction at steadily increasing intervals. When you look at the planets you can see that there are 2 distinct groups: The *terrestrial planets* (Mercury, Venus, Earth, and Mars) and the *jovian planets* (Jupiter, Saturn, Uranus, and Neptune). Pluto seems to show characteristics of both groups. The terrestrial planets are small, dense, and rocky. They lie close to the Sun. The jovian planets are large, less dense, and made up of gases. They lie farther from the Sun. The 4 terrestrial worlds are very similar, but if you look up close, you find they are actually very different.

- 1) All 4 terrestrial worlds have atmospheres, but they are very different.
- 2) Earth alone has oxygen and liquid water.
- 3) The surface conditions are very different from barren, heavily cratered terrain to widespread volcanic activity on Venus.
- 4) Earth and Mars both rotate in about 24 hours, while Mercury and Venus take months to rotate.
- 5) Earth and Mars have moons, but Mercury and Venus don't.
- 6) Mercury and Earth both have measurable magnetic fields, although very different, while Venus and Mars don't.

Comparing these 4 world should be easy, but they actually very different. If we look at their uncompressed densities (no compression due to own weight) as you go from the Sun you get 5300, 4400, 4400, and 3800 kg/m<sup>3</sup>. This means that Mercury must be made up of a very heavy material, such as iron or nickel.

You can compare the terrestrial and jovial worlds by saying this: the jovian worlds are everything that the terrestrial worlds are not.

The terrestrial planets are close together, near the Sun; the jovian planets are spread out far from the Sun. The terrestrial worlds are small, dense, and rocky; the jovian worlds are large, low density, and gaseous, mainly hydrogen and helium. We have solid surfaces while the jovian planets have none; the terrestrial worlds have weak magnetic fields if any while the jovian worlds have strong magnetic fields. The terrestrial worlds have 3 moons total and the jovian worlds have many moons between them, none the same. All of the jovian worlds have rings and we have none. The jovian worlds are thought to have cores that are 10 – 15 times the mass of the Earth.

Beyond Neptune is a world that like no other. It is Pluto. It doesn't fit well into either category. It is more like the icy moons of the outer solar system than anything else.

Right now, regardless of what is said, Pluto is still a planet.

### Interplanetary Debris

After looking at all of the different things that we find in the solar system the last component is the cosmic debris. It is called *interplanetary matter*. This is things like asteroids, small comets, even smaller meteoroids, and down to dust sized particles. This dust arises when larger particles collide in space making smaller ones. This material will eventually be swept away by the *solar wind*. This is a stream of high energy particles that stream away from the Sun. We can't really see it in the visible but it shows up in the infrared all over the place. Asteroids and meteoroids are distinguished by the fact that if it is larger than 100 m, it is an asteroid. The asteroids and meteoroids tell us much about what the early solar system was like. Much of it hasn't evolved since the beginning so astronomers are very interested in them. Sometimes they come to us in the form of meteorites. Comets are important because they are primordial. They most likely haven't changed at all since the beginning of time, so their make-up is very important.

### Spacecraft Exploration of the Solar System

Since the 1960's we have sent dozens of spacecraft out to the far reaches of the solar system to study things. We will look at some of these spacecraft and see what they learned at their planetary rendezvous.

#### The Mariner 10 Flybys of Mercury

In 1974 the *Mariner 10* spacecraft sent back almost 4,000 pictures of Mercury. The resolution was about 150 m. The satellite lasted from March 1974 to March 1975 when it ran out of maneuvering fuel. The pictures covered about 45% of the surface of Mercury. Around 2009 NASA is going back to Mercury.

#### Exploration of Venus

There have been at least 20 spacecraft to have visited Venus since the 1970's. The Soviets landed *Venera 4 – 12* on the surface. The first to return information was *Venera 7*. It sent back data for 23 minutes until the tremendous heat and pressure destroyed it. The longest any survived has been 54 minutes. In 1978 we sent *Pioneer Venus* to drop 5 probes onto Venus. It returned information on the temperature, pressure, and chemical composition of Venus. Between 1991 and 1994 the *Magellan* spacecraft was in orbit around Venus and it radar mapped most of Venus down to 120 m resolution.

#### Exploration of Mars

Both NASA and the Soviet space agency have been exploring Mars since the 1960's. The first satellite to reach Mars was the *Mariner 4* in 1965. It sent back pictures of craters instead of an Earth like surface. In 1969 *Mariner 6 & 7* did a flyby of Mars and confirmed these findings, leading to the idea that Mars was a dead world. In 1971 *Mariner 9* went into orbit around Mars and we soon reversed our idea of the dead world. The resolution was 1 km and we soon saw a very complex surface that was unexpected. It saw plains, volcanoes, drainage channels and canyons. This led to the actual landings on Mars. In 1976 *Viking 1 and 2* landed on Mars. There were orbiters going around Mars and landers on the surface. This mission was a complete success. We sent the *Mars Global Surveyor* to look at Mars and send back pictures. This has been going on since 1997 even though it was supposed to have ended in 2002.

In 1997 we also had the Pathfinder and Sojourner on Mars. WE have had several setbacks since then with failed missions. Right now we have the 2 rovers, Opportunity and Spirit, on the surface. They have lasted much longer than was planned and have sent back numerous photos containing so much information that it will keep astronomers busy for a while. In 2007 a mission is planned for a lander to go to Mars and pick up a soil sample and return it to the Earth for study.

#### Missions to the Outer Planets

Pioneer 10 and 11 were launched in 1972 and 1973 and reached Jupiter in 1973 and 1974. This was important because it showed that spacecraft could travel for a long period and reach the outer planets and send back information. The 2 Voyager spacecraft left Earth in 1977 and reached Jupiter in 1979. Both visited Saturn also, but Voyager 1 was programmed to visit Titan and didn't get a gravity assist that Voyager 2 did that sent it on the Grand tour. It went from Saturn to Uranus and Neptune. The data is still being analyzed today.

Most recently we had Galileo go to Jupiter in 1995. It dropped a probe into the clouds of Jupiter to understand the composition of the clouds. Galileo went on to finally study the Galilean Moons up close. It was supposed to last until 1997, but it continued until 2003 when it was dropped into the atmosphere to be burned up. NASA plans to send another satellite to Jupiter in 2010. In 1997 we sent the Cassini mission to Saturn. It reached Saturn in July of this year (2004) and is sending back pictures of Saturn. In Dec. it will drop a probe made by the European Space Agency onto the moon Titan to study the details.

#### How did the Solar System Form?

For over 4 decades we have been collecting data from our probes into space.

Astronomers have tried to explain the formation of our solar system and think they are on the right track. Some of the ideas came before the space age, so it is nothing new.

#### Nebular Contraction

One of the earliest heliocentric models of our solar system came in the 17<sup>th</sup> century from Rene' Decartes. He said that a large cloud of dust and gas (nebula) started to collapse for some reason. As gravity took over and the center got hotter and denser the Sun formed. While this happened, the planets and moons formed from the cooler material in the outer regions of the cloud. In 1796 Pierre Simon de Laplace used the idea of angular momentum to show that as it collapses the cloud should spin faster. This causes a flattened disk of material to form, from which we came to be. This swirling cloud of material has come to be known as the *solar nebula*. This idea of formation is known as the *nebular theory*. WE feel fairly confident about this model because we have now seen several other proto-solar systems forming up and we can see the bulge that will become the star as well as the disk on material that we predicted would have been there.

#### The Condensation Theory

Theories are constantly being improved upon and this is no different. Laplace's model has been pushed aside for the *condensation theory*. The big difference here is that we believe that there was *interstellar dust* present. This would have done 2 things: 1) it

would have radiated away heat so that the solar system cooled down and the material would have slowed down. This would allow the nebula to collapse more easily. 2) These dust grains would have acted like *condensation nuclei*, or seeds for larger molecules to form. You would have formed larger and larger balls of matter that would eventually someday become a planet. Matter would have accreted into bigger and bigger objects. *Accretion* is just the sticking together of material. They would have eventually become protoplanets, which would have evolved into planets.

#### The Role of Heat

As we have seen, there are 2 very different types of planets and they are found in very different parts of the solar system. Why has this happened? The answer is temperature. As the nebula flattened, it has been calculated that near the center it would have been several thousand K while out in the flattened disk it would have been about 100 K. As it radiated away the heat the dust grains began to condense out. The closer to the center you were, the hotter the temperature and this determined what could condense. At about Mercury's distance, only iron could condense out. At a distance of 1 A.U. silicates were condensing out and so on. Beyond about 4 A.U. the gases could condense out. This explains why the planets formed like they did.

#### Terrestrial and Jovian Planets

The inner 4 planets called the terrestrial planets are rocky and contain metals. These materials were able to condense at fairly high temperatures while the lighter materials couldn't. Out beyond the asteroid belt at a distance of 5 A.U. and greater the gases such as hydrogen and helium were able to condense out. Thus you had the formation of the Jovian planets.