

## Chapter 13 Uranus, Neptune, and Pluto

### The Discovery of Uranus

Uranus was discovered in 1781 by William Herschel when he came to an odd looking object that he described as a nebulous star or a comet. It was neither. He observed it for several nights and realized that it moved against the stars, although very slowly. He had discovered the 7<sup>th</sup> planet. He wanted to name it Sidus Georgium after King George, but cooler heads prevailed and it was named Uranus, Saturn's father. If you know where to look and are in dark skies you can see Uranus with the naked eye. It shines just above the threshold of visibility. In a telescope it appears as a greenish disk. Even when Voyager went by it showed almost no surface detail.

### The Discovery of Neptune

By 1790 the orbit of Uranus had been calculated using Kepler's Laws. Soon after the discovery a discrepancy showed up in Uranus' position. Fifty years after the discovery the discrepancy had grown to a quarter of an arcminute. This is far too big to be explained by observational error. The obvious conclusion was that there must be another body beyond Uranus pulling on Uranus, causing it to not be where it should be. In 1845 an Englishman named John Adams and a Frenchman named Urbain LeVerrier independently calculated where this body should be. In September, 1846 John Galle at the Berlin Observatory looked for and found the new planet within a degree of the prediction. For this work, Adams and LeVerrier were given co credit for the discovery. Neptune lays 30.1 AU from the Sun and takes 163.7 Earth years to go around the Sun. Neptune can't be seen with the naked eye. Through a telescope Neptune looks like a blue disk. Voyager 2 gave us some very detailed views of Neptune's surface as it passed.

### Physical Properties of Uranus and Neptune

These 2 planets are very similar in most ways. Uranus is 4x the size of the Earth while Neptune is 3.9x larger. Uranus is 14.5x the Earth's mass and Neptune is 17.1x the mass. Their densities are 1300 kg/m<sup>3</sup> and 1600 kg/m<sup>3</sup> respectively. The cores are probably similar to the other 2 giants.

Uranus rotates every 17.2 hours and it rotates differentially. It actually rotates faster at the poles than at the equator. One of the most bizarre features of Uranus is that it lies on its side. It tilts over at 98°. This means that the poles point towards the Sun for about 21 years during the summer and winter. It also means that the equinoxes last for 21 years. We really don't know positively why it tilts like this, but it is thought that a catastrophic event occurred and knocked Uranus over. Uranus shows almost no surface variation like the other giants do.

Neptune shows more variety and contrast than Uranus does. The average rotation rate is 17.3 hours as shown by the clouds, but the magnetic field shows that it rotates every 16.1 hours. This is unique because it the only Jovian world where the clouds rotate slower than the world itself.

### The Atmospheres of Uranus and Neptune

The atmospheres of these 2 worlds have been studied by looking at reflected sunlight. The upper atmosphere is very much like Jupiter and Saturn. The main element is

hydrogen (84%), helium (14%), and methane (3% on Neptune and 2% on Uranus). Ammonia is not really found with any significance on these 2 worlds. It appears that as we move out from the Sun the amount of ammonia goes down and the amount of methane increases in the Jovian worlds. Ammonia gas freezes out at 70 K and the temperature on Uranus is 58 K and on Neptune is 59 K. This means that there is no ammonia gas on these 2 planets. The methane is responsible for the blue color on Uranus and Neptune.

#### Weather

Voyager observed very few cloud features on Uranus. They only became visible after much computer enhancement. The color of the clouds tells us the depth we are looking on Uranus. Uranus apparently lacks any significant internal heat source. Due to this the clouds are much farther in the planet. It was found that the clouds move at between 200 and 500 km/hour. Wind speeds are greater near the North Pole. This may be due to the fact that the North Pole is facing the Sun.

Neptune has several storm systems on it. One such storm was called the Great Dark Spot. This was discovered by Voyager 2 in 1989 and it was about the size of the Earth. In many ways it was like the Great Red Spot on Jupiter. It rotates counterclockwise. In the mid 1990's the spot disappeared from view. Neptune has dynamic wind patterns. Winds blow at 1500 km/hour on Neptune. What drives the clouds? Apparently it is responding to the feeble sunlight that it receives.

#### Magnetospheres and Internal Structures

Uranus and Neptune both have strong internal magnetic fields. They are probably 100 times stronger than ours, but at the cloud tops it is spread out so much that it is only as strong as ours. They both have substantial magnetospheres due to captured particles from the solar wind. Uranus has a magnetic field that is tipped  $60^\circ$  to the axis of rotation. The field lines offset from the center by about  $1/3^{\text{rd}}$  of the radius. Since the dynamo effect says that the magnetic field should be roughly aligned with its axis of rotation some scientists think that we may have caught Uranus in the middle of reversing the polarity. Another idea is that the large impact that tipped it over may have skewed both axes at the same time. When the same kind of thing was discovered at Neptune those ideas were thrown out. It now appears that the internal structure of Uranus and Neptune are very different from Jupiter and Saturn and this difference is why the magnetic fields are off. Models suggest that Uranus and Neptune have rocky cores like Jupiter and Saturn. They are thought to be about 10x the Earth's mass. They don't have the mass to produce liquid metallic hydrogen. One theory is that there is a water layer on the inside of these 2 and that the ammonia is dissolved in the water. This would form an electrically conducting solution. This would also explain the offset magnetic fields if they weren't at the centers. In reality we just don't know enough to make good predictions for what is really happening.

#### The Moon Systems of Uranus and Neptune

Both Uranus and Neptune have mini-solar systems around them. They are not as extensive as those of Jupiter and Saturn.

## Uranus's Moons

As of early 2004 there were 27 known moons of Uranus. By 1948 only 5 moons were known of at Uranus. Voyager 2 discovered 10 more moons when it went by. They all have orbits that are tipped just like the poles of Uranus and go around the equator. Eleven of the last 12 have been discovered by systematic searches since 1997. The other one was found after careful reanalysis of Voyager 2 data. Most of these small bodies orbit in retrograde, highly inclined orbits. It is thought to be interplanetary debris captured by Uranus. The 5 largest moons are thought to be like the 6 mid-sized moons of Saturn. These 5 moons are by size: Titania, Oberon, Ariel, Umbriel, and Miranda. The first 2 are about 1600 km across, the next 2 are about 1200 km and Miranda is about 480 km. Titania and Oberon are heavily cratered and show little evidence of geologic activity. They are also dark suggesting that their surfaces are quite dirty. One idea is that the whole area out with Uranus and Neptune is quite dirty because it contains a lot of small sooty particles. A more widely accepted idea now is that radiation and high energy particles have been breaking down material on the surface leading to the production of organic material. This is called *radiation darkening*. The darkest of Uranus's moons is Umbriel. It shows a light spot in the northern hemisphere about 30 km across. Ariel does appear to have undergone some activity in the past. Ariel is thought to have undergone internal stresses due to tidal forces between Uranus and the other moons. The most interesting moon is Miranda. It was guessed that Miranda would not be very interesting; craters and basically no other features. Boy, were they wrong. Miranda displays features such as ridges, valleys, oval faults, and many other tortuous geologic features. Why? Some scientists think that Miranda has been catastrophically disrupted several times and hasn't gone back exactly right.

## Neptune's Moons

Only 2 moons can be seen from Earth: Triton and Nereid. Voyager 2 found 6 other small bodies, all less than a few hundred kilometers across. Since 2002 we have found 5 more moons with wide, eccentric orbits. None of the moon fit the typical moons of the solar system. The largest moon Triton is 2700 km across, orbits retrograde and is inclined by 20° to the equatorial plane. Nereid is 340 km across and orbits prograde, but in an elongated orbit that takes it from 1.4 million km to 9.7 million km. All that we know about Triton came from Voyager 2. It is one of the 6 largest satellites in the solar system coming in at number 6. Triton has a surface temperature of 37 K. It has a thin nitrogen atmosphere and a surface of mainly water ice. Triton has a layer of nitrogen frost at the poles due to the temperature. There are very few craters. What does this say about Triton? It appears that Triton had a very active past. Triton has numerous lakes of water ice which may be volcanic in origin. These would be from water volcanoes. Voyager detected 2 great jets of nitrogen gas coming from the surface. It seems that liquid nitrogen is heated and becomes a gas and expands outward and comes blasting out through cracks in the surface to form these geysers. This may have led to the thin atmosphere on Triton. Why is Triton in such an inclined, eccentric, retrograde orbit? Most astronomers think it was a captured body. Others think that it is due to some catastrophic event. We just don't know.

## The Rings of the Outermost Planets

### The Rings of Uranus

The rings of Uranus were discovered from Earth by accident. We were watching a *stellar occultation* which is where one object goes in front of another object. In this case Uranus was going in front of a star and while we watched the light from the star got dim then bright, then dim, and so on before the planet got to the star. What they finally realized was that the star dimmed when it passed through a thin ring. We now know that Uranus has 9 thin rings. All of the rings lie within the Roche limit of Uranus. Unlike Saturn, the rings of Uranus are dark, narrow, and widely spaced. Most of the rings are less than 10 km wide and the gaps between them are a few hundred to a few thousand km. They are only a few tens of meters thick. The rings are similar to Saturn's rings in density and size. The rings of Uranus are not smaller than about a centimeter. Like the rings of Saturn, these rings have shepherd moons helping to keep them together.

### The Rings of Neptune

Neptune has 5 dark rings. Three are quite narrow and the other 2 are broad and diffuse. All of the rings lie within the Roche limit of Neptune. From the Earth we only see parts of the outer ring because of its clumpiness. The rest is too thin to be seen. Many astronomers think that the clumpiness is caused by small shepherd moons. All 4 of the ring systems are different from one another. But there must be a common method of formation. If, as it appears, the rings are relatively short lived, then their formation must be a fairly common event. It also appears that the rings are controlled by the planetary environment.

### The Discovery of Pluto

By the 19<sup>th</sup> century it was thought that the influences on Uranus couldn't be accounted for by Neptune only. On top of that it was thought that Neptune was being influenced by another object. One of the people who was looking for this planet was Percival Lowell. Lowell started to calculate the position of the planet he called Planet X using the same technique that was used to find Neptune. He searched in vain for the planet and died in 1914. A young man named Clyde Tombaugh was hired later on to continue the search and in 1930 he found a body that turned out to be Pluto. It was found 6° away from the predicted position of Lowell. It was announced on March 13, 1930 which was Lowell's birthday. It was thought to be another success for celestial mechanics, but we now know that Pluto couldn't have affected Uranus and Neptune. We also realize that those discrepancies weren't real. The mass of Pluto wasn't accurately measured until the 1980's. The eccentricity of Pluto's orbit is .25 which is quite high. This means that at perihelion it is 29.7 AU from the Sun and at aphelion it is 49.3 AU. That is a difference of almost 20 AU! Because of this orbit, Pluto was inside Neptune's orbit for 20 years, Feb. 1979 to Feb. 1999. The period of Pluto is 248 years. This is 1.5 times the period of Neptune. That is a 3:2 resonance and as a result there is no danger of collision. Because of the resonance and the tilted orbit of Pluto, the closest they come to each other is about 17 AU.

### Physical Properties of Pluto

Due to its great distance, it has been hard to study Pluto. But in 1978 James Christie discovered a moon of Pluto. It is called Charon who is the boatman across the river Styx. This discovery allowed for more accurate measurements of the mass which we now know is only .0021 Earths. The moon's orbital period is 6.4 days. From 1985 to 1991 Pluto and Charon had a series of eclipses occur. It occurred while Pluto was at perihelion so it was easier to see. This allowed for very accurate measurements of the size of Pluto. It has been calculated to be 2270 km in diameter. The planet and moon are tidally locked so that Charon remains over only one place on Pluto. This also means that the rotation of Pluto is 6.4 days. Charon is about 1300 km in diameter. This is the largest planet-moon ratio in the solar system. With an estimated density of  $2100 \text{ kg/m}^3$ , it is more like one of the outer moons that a terrestrial or Jovian planet. Spectra of the planet show that methane ice is a major part of the surface. The surface temperature is about 50 K.

### The Origin of Pluto

Since Pluto is unlike any of the other planets, what is it? As theories came and went, we now believe that Pluto and Charon are members of a group of objects beyond Neptune called the Kuiper Belt Objects. The first of these was discovered in 1992. Many astronomers think that there may have been thousands of Pluto sized objects out there. Most of these were probably kicked out to great distances by Uranus and Neptune. These bodies could also explain why we have some strange moons such as Triton out there. NASA has plans to launch a mission to Pluto in 2006 with an arrival in 2015 to study this system.