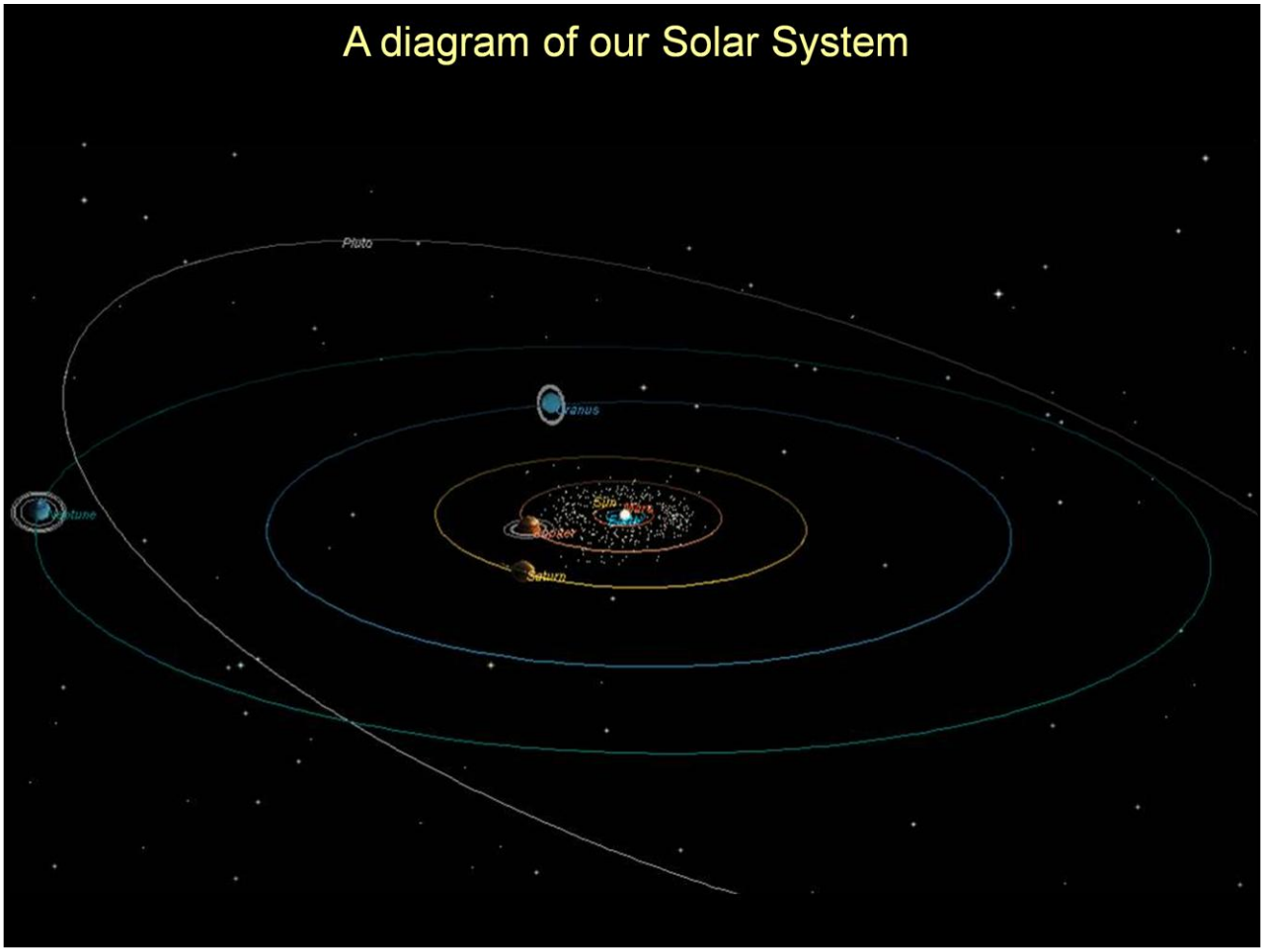
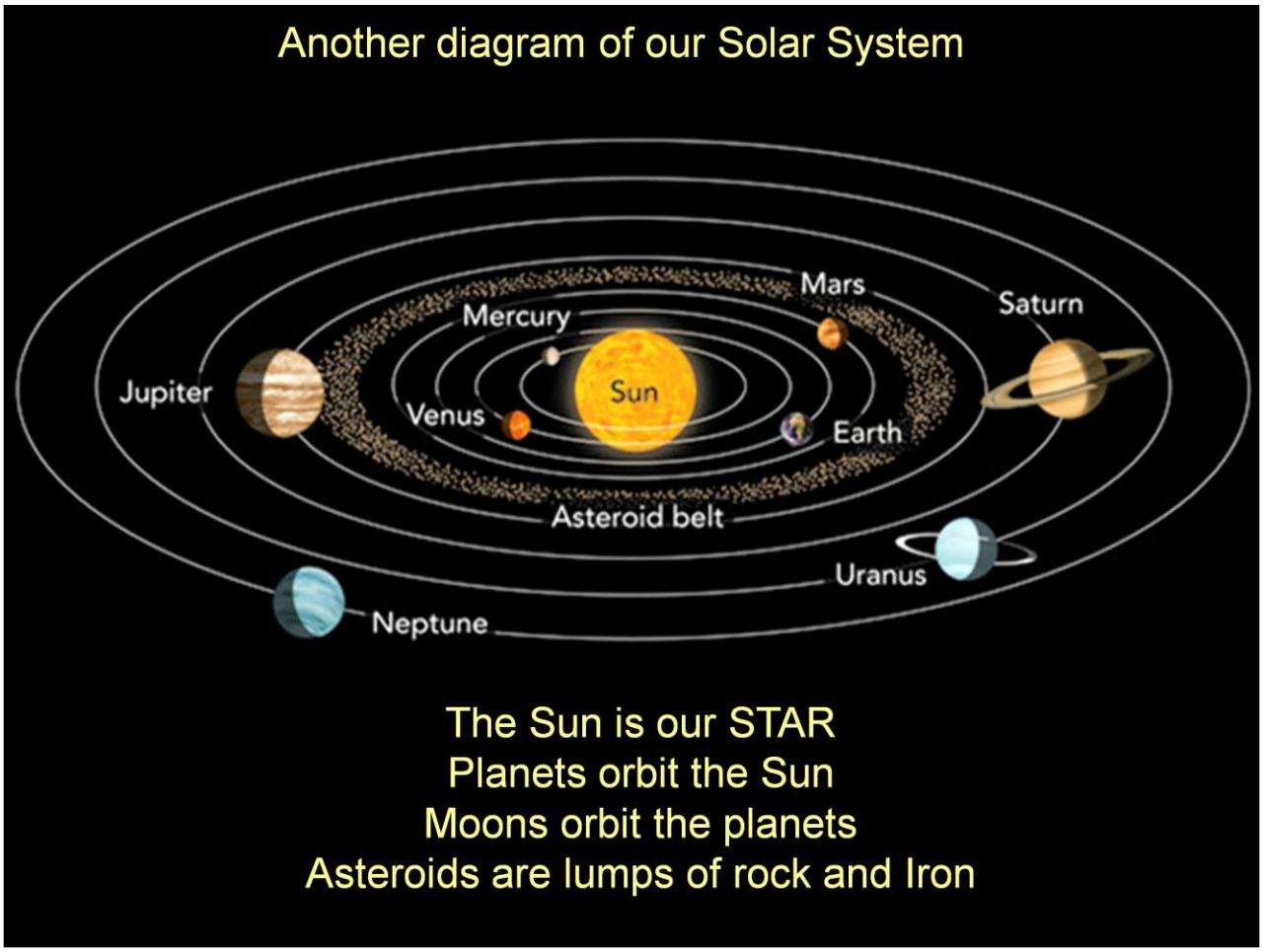
Our Solar System

Beginners 20th January 2021

Steve Harris



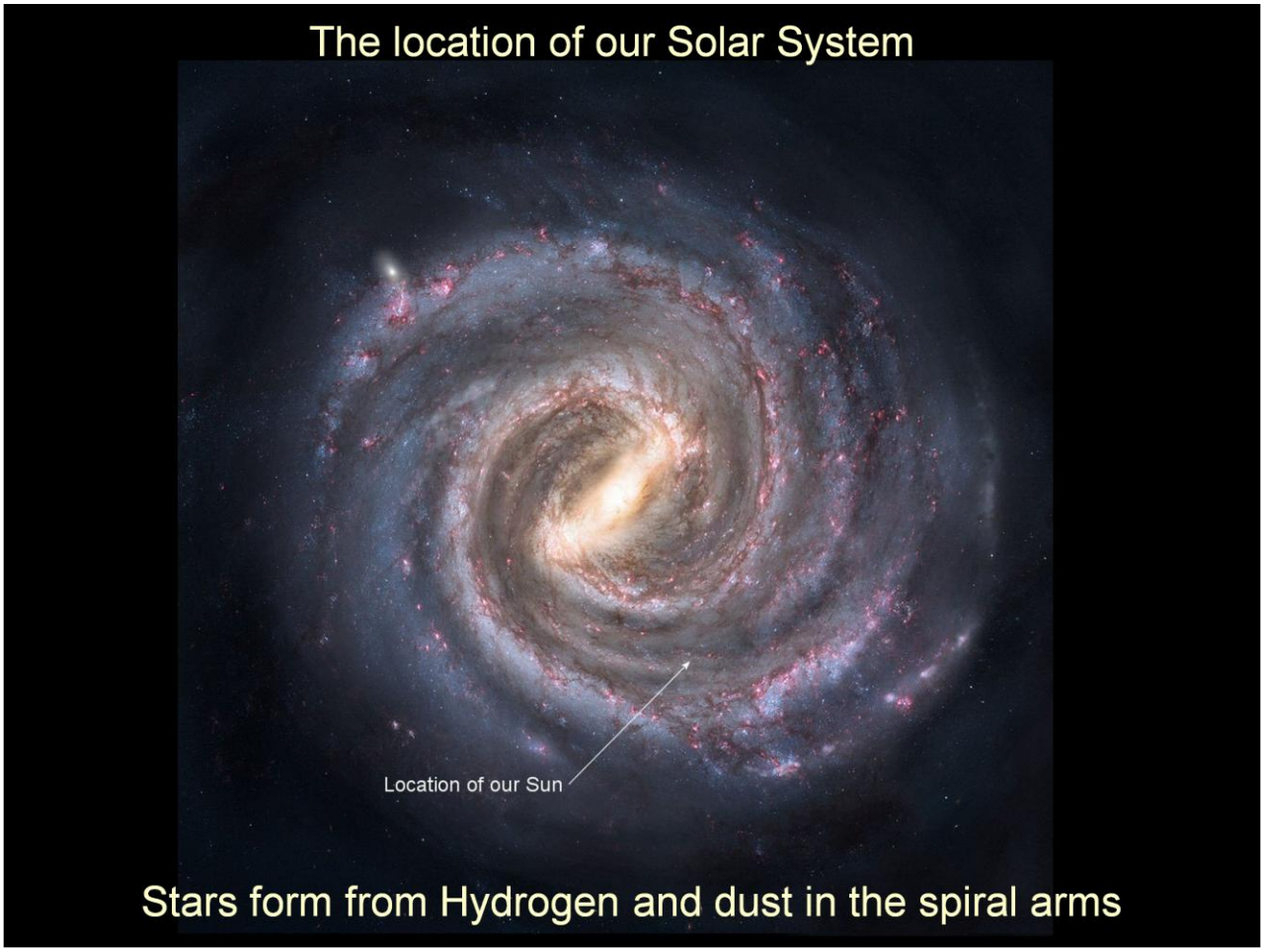
If we could see the orbits of the planets this is what the Solar System would kook like. However the planets would appear much smaller and the gaps between the orbit would be much wider.



Here is another diagram of our Solar System. The planets are named and the zones are shown. The chart above shows the Sun, main planets and minor planets that make up our Solar System. Let us first clarify the terms we use. Our Sun is a star and is in many ways a very ordinary star. A star is a vast cloud of mainly Hydrogen with about 11% Helium. This cloud has been compressed by gravity into its most compact shape which is a sphere. The enormous force of gravity produces Nuclear Fusion that powers the star and causes it to shine.

Planets are objects that orbit a star and have cleared paths from the original disc of material that formed around the developing star. Our Solar System has eight main planets that in order out from the Sun are called: Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune. See the diagram above.

There are also small objects orbiting the Sun that we have called Dwarf Planets or Minor Planets. These objects mainly orbit in specific zones around the Sun.



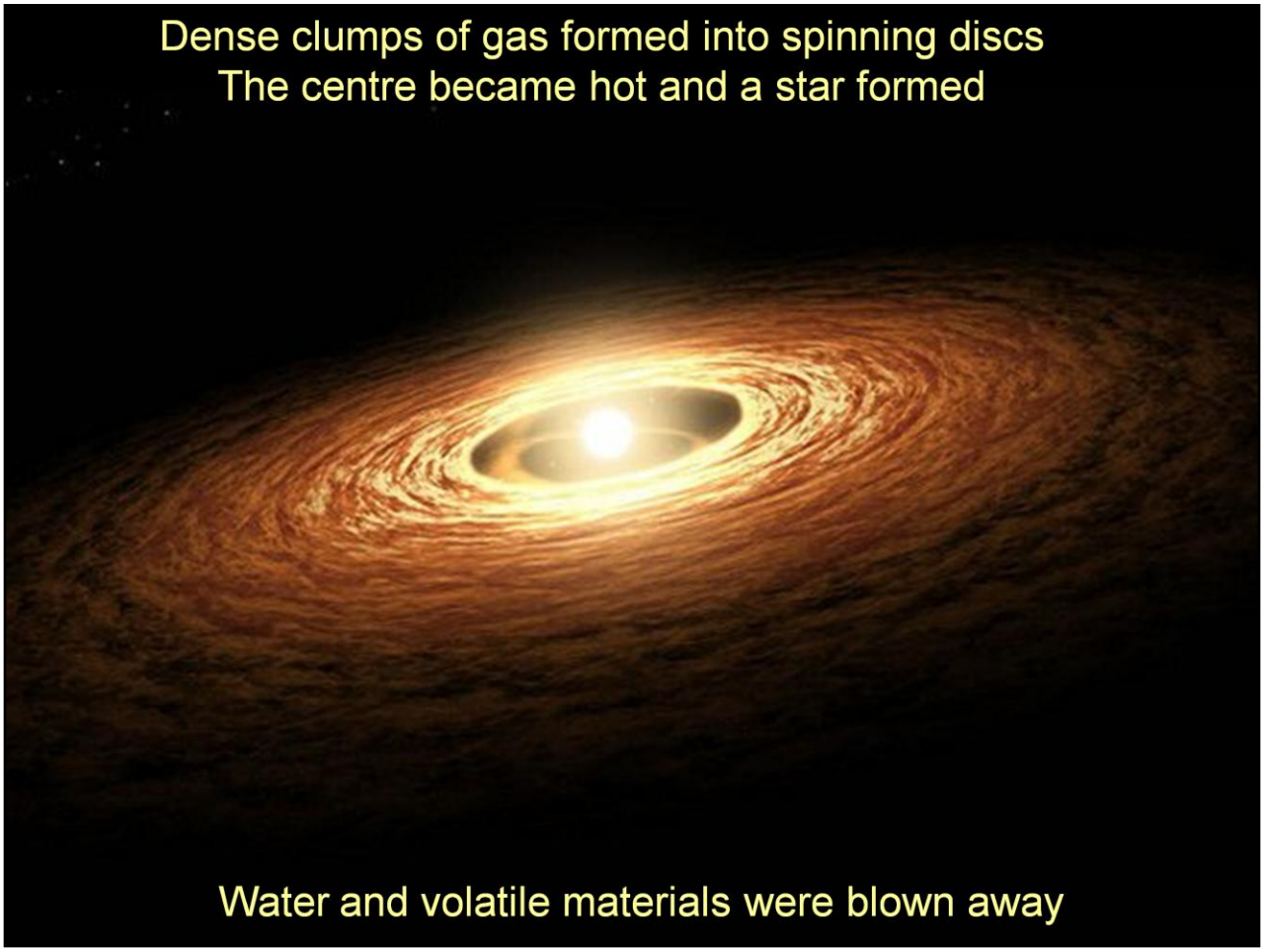
Stars form in vast clouds of gas and dust, called Nebulae located in the arms of Spiral Galaxies. Galaxies are huge rotating discs of stars, gas and dust where hundreds of billions of stars form. The spiral arms of these galaxies are created by shock waves of star formation moving through the nebulae. These shock waves stir up the gas and dust causing the atoms to swirl around and be drawn together by gravity.

Dense clumps of gas develop that pull in more gas and dust as they grow and their gravity increases. These dense clouds begin to spin and form into a flat disc of rotating gas and dust.

As more and more material is pulled in by the increasing gravity the centre of the disc is compressed and begins to heat up. This core becomes so compressed it is forced into its most compact shape, a ball or sphere. Eventually the pressure and temperature become so great that the Hydrogen atoms are pressed together until they fuse together to be transformed into a Helium atom.

The new Helium atom will have slightly less mass that the two Hydrogen atoms that it formed from. This lost mass is converted into energy in the form of a X-Ray or Gamma-Ray that heats the sphere so it begins to shine and a star is 'born'. This process is called Nuclear Fusion described by Albert Einstein in his famous equation $E = Mc^2$ where E = Energy, M = Mass and c^2 = the speed of light squared.

Other stars form in the Nebula creating a group of stars that blow away any remaining gas to reveal a new cluster of stars called an Open Custer. Our Sun was one star in a cluster of between 30 and up to about 1000 stars. Gradually the stars of the cluster drifted apart and were distributed around our Galaxy that we call the Milky Way.



As the early Solar System rotated, the gas and dust in the disc formed into larger and larger lumps under the force of gravity. These lumps developed into planets and gradually cleared paths around the star to establish a clear orbital path for each planet.

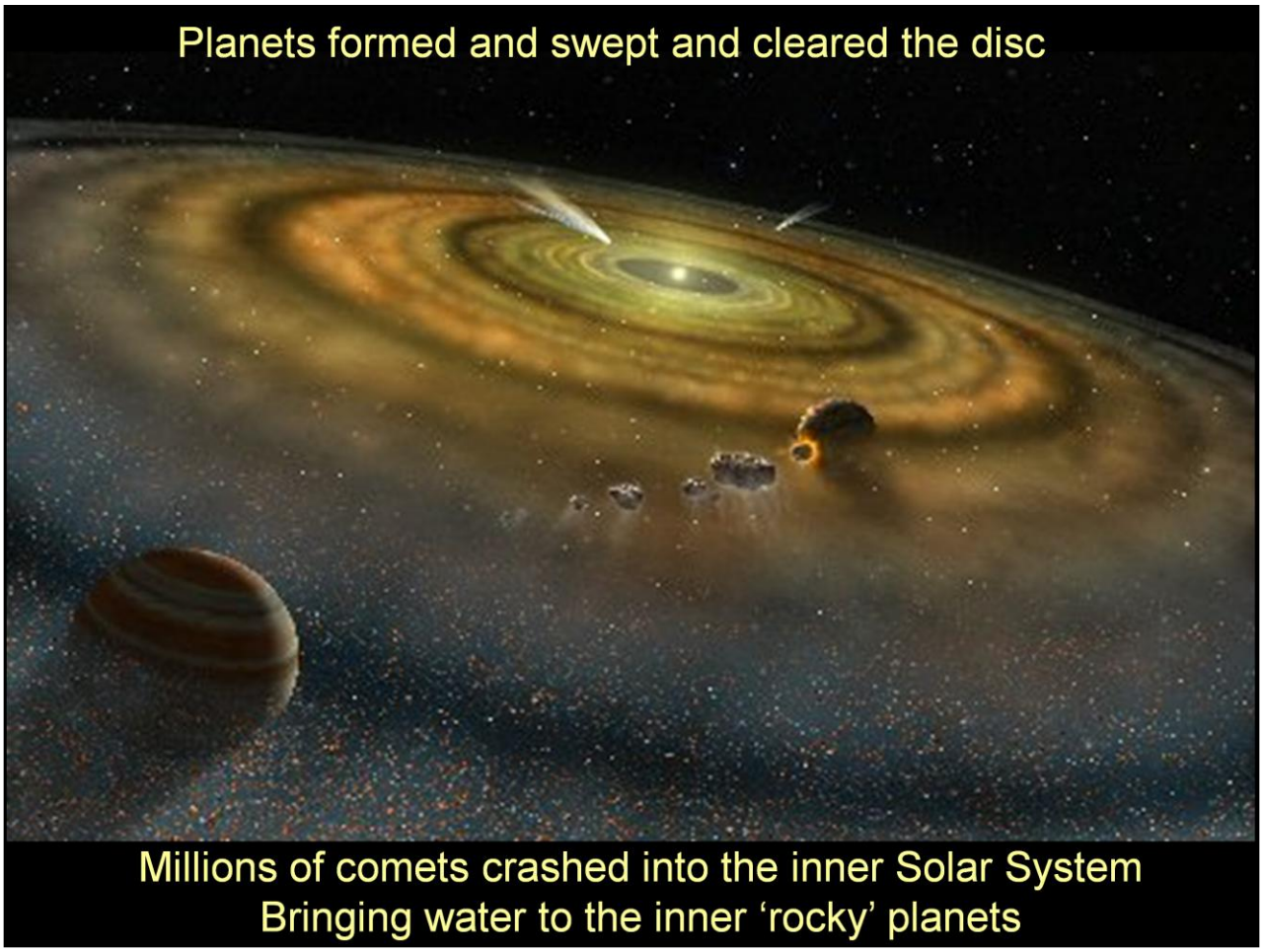
The charts shown on the previous slides how we think of our Solar System looks now but it was not always like this. It is thought there were originally many more planets. There may have been up to 80 planets but due to close encounters or collisions many planets were lost. Close encounters can change the orbits of planets and may cause them to be thrown out of the Solar System or sent crashing into the Sun.

When stars first form they are more active than later in their 'lives'. They are hotter, more active and produce powerful ultraviolet winds.

Volatile materials such as water, and gases would have been heated and blown of the surface of the planets closest to the Sun. The powerful ultraviolet winds would drive the volatile materials off the planets and push them further out from the Sun. There is a point where the radiation was reduced and the gases began to cool and eventually froze. The frozen gases coalesced into larger piece that grew to become fairly large bodies that we call Dwarf Planets in the outer reaches of the Solar System.

DWARF PLANETS are found beyond the orbit of the outermost main planet Neptune. These are composed mainly of water ice and frozen gases. When the Solar System first formed the Sun was more powerful than it is now and produced powerful ultraviolet radiation. Any volatile materials on the inner planets were vaporised by the radiation and blown away into the outer reaches of the developing Solar System. Here these volatile materials cooled and froze into ice and accumulated into objects up to a few thousands of kilometres in size. The object called Pluto was reclassified from being considered a main planet to being a Dwarf Planet.

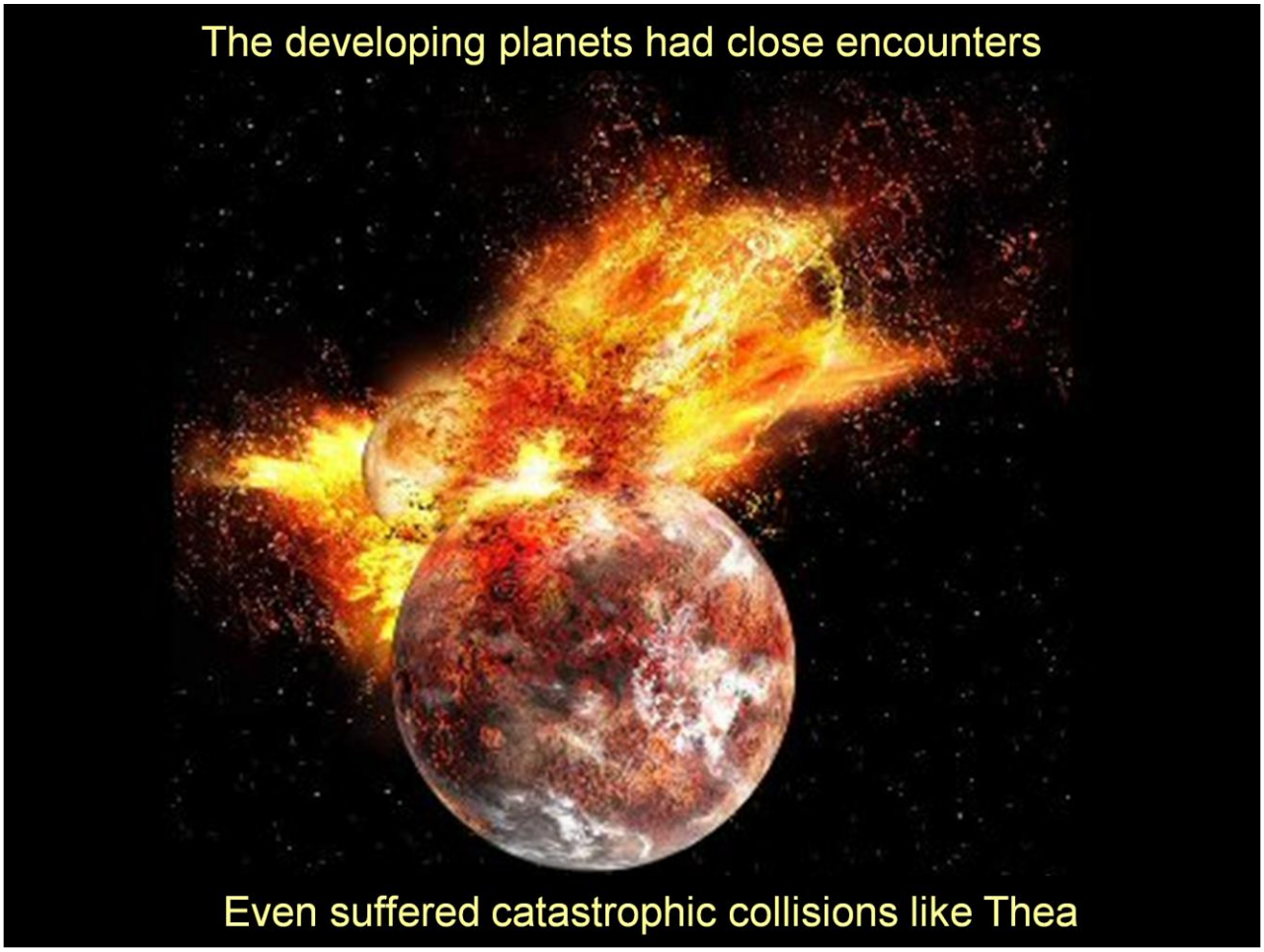
There are vast numbers of these Dwarf Planets orbiting the Sun beyond the orbit of the outermost main planet Neptune and Pluto is just the closest of these objects.



The dust and gas accumulated in a rotating disc around the developing Sun. Dust particles from the original Nebula were attracted to other particles and began to grow into larger accumulations. These accumulations grew larger as they attracted dust and boulders that were forming in the disc. Eventually most of the free dust was used up and cleared paths around the Sun. When the newly formed proto –planets reached a critical size and mass allowed the gravity to compact the material and they became spherical.

Water that had been vaporised and had been driven out from the inner regions had frozen in the outer regions of the developing Solar System. In a period from 4.2 billion years to 3.8 billion years ago something perturbed the icy Dwarf Planets that had formed from the ice in the outer regions. Millions of these icy bodies were disturbed and redirected on a path spiralling in towards the centre.

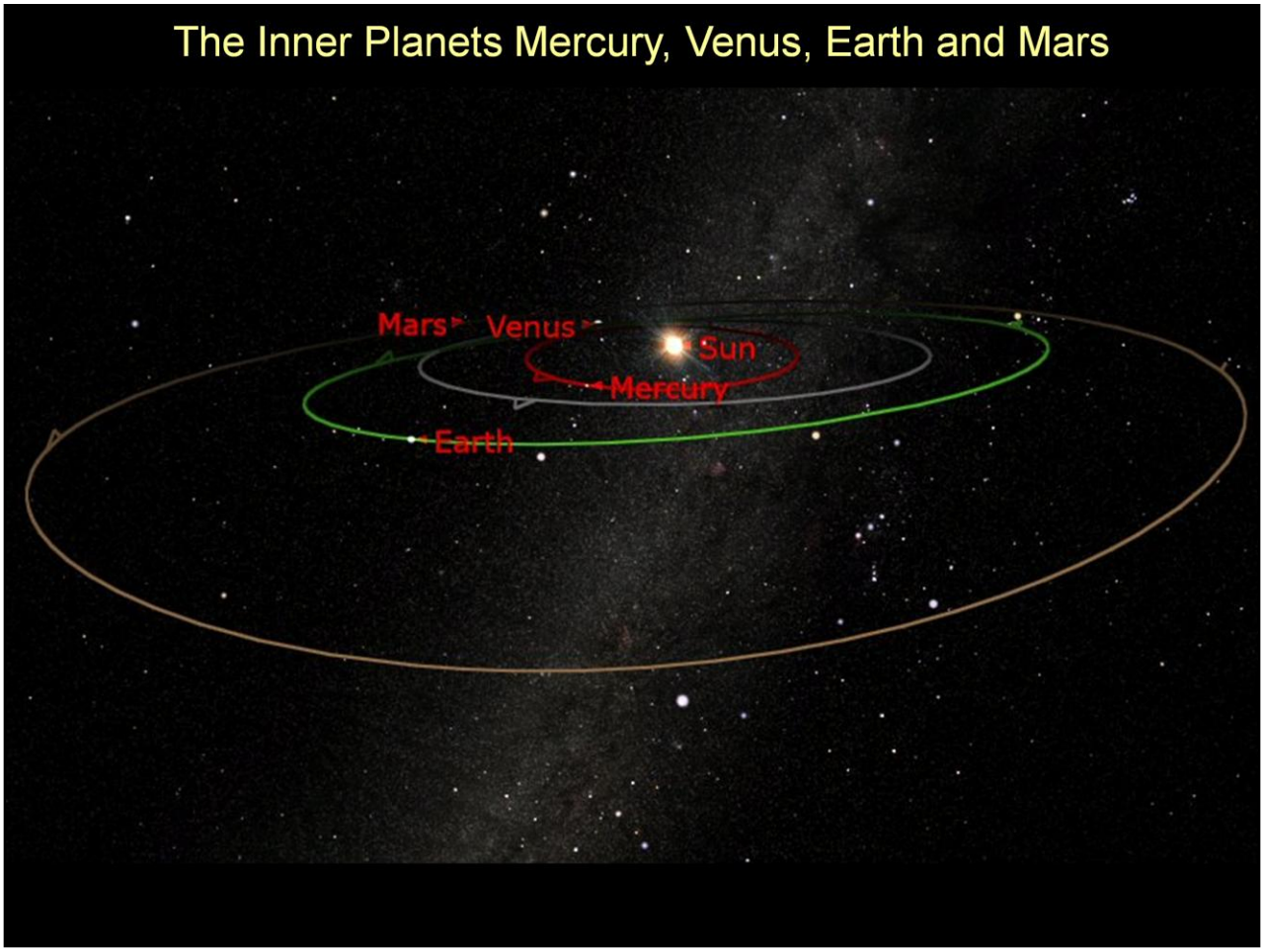
Many of these lumps of ice impacted on the dry rocky inner planets as comets and delivered the water back to the planets to produce oceans. This period is called the Late Heavy Bombardment.



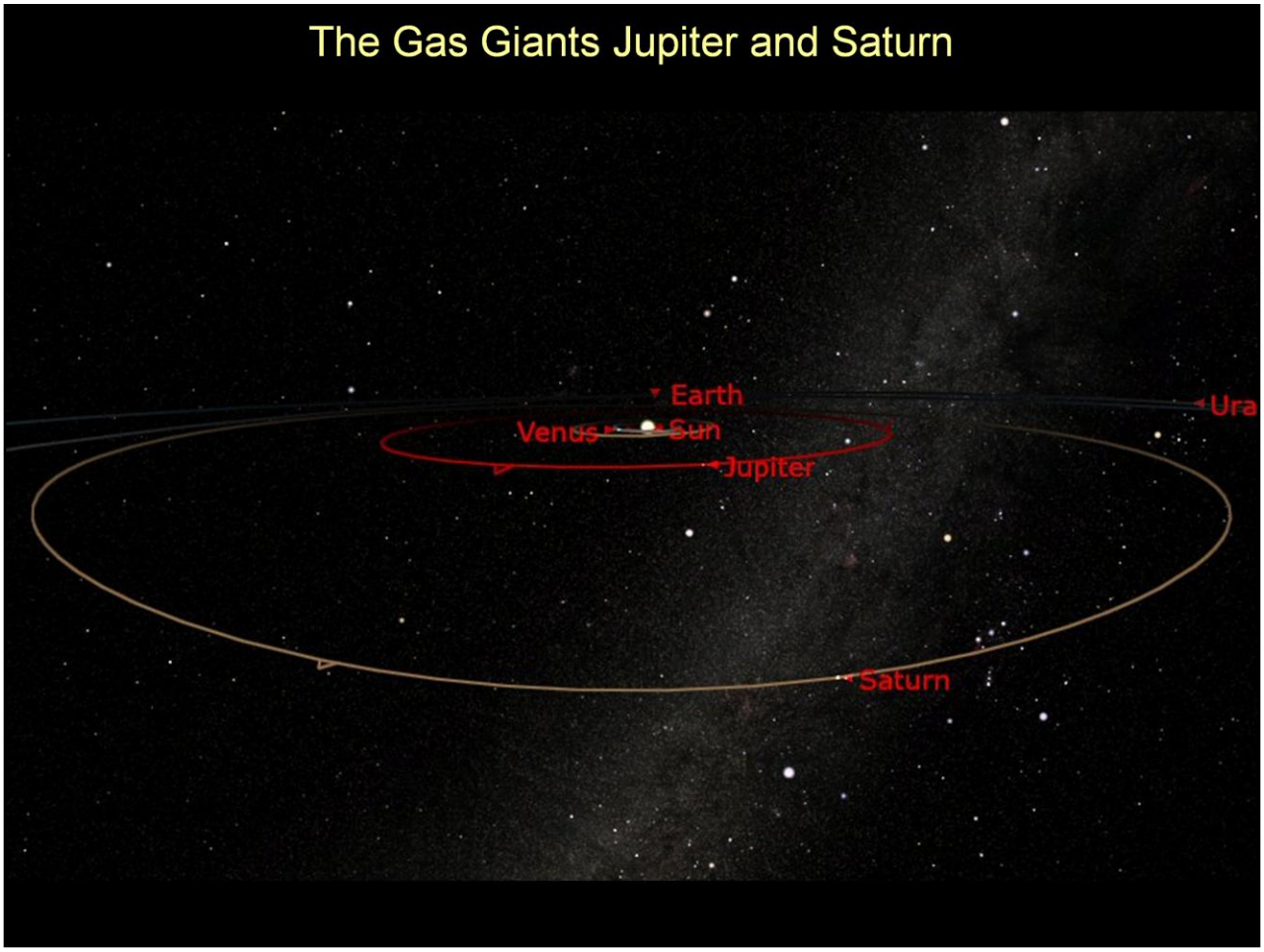
It is thought there were originally many more planets. There may have been up to 80 planets but due to their unstable orbits there were close encounters or collisions and many planets were lost. Close encounters can change the orbits of planets and may cause them to be thrown out of the Solar System or sent crashing into the Sun.

It is almost certain that the early Earth was hit by another planet that we call Thea. Thea was about the same size as Mars and is thought to have hit Earth off centre, crashed right through Earth knocking off a huge mass of rock and some of the Iron core. The debris was thrown into orbit around the molten remains of Earth. The Iron including the core of Thea soon crashed back on to the remains of Earth causing another massive impact.

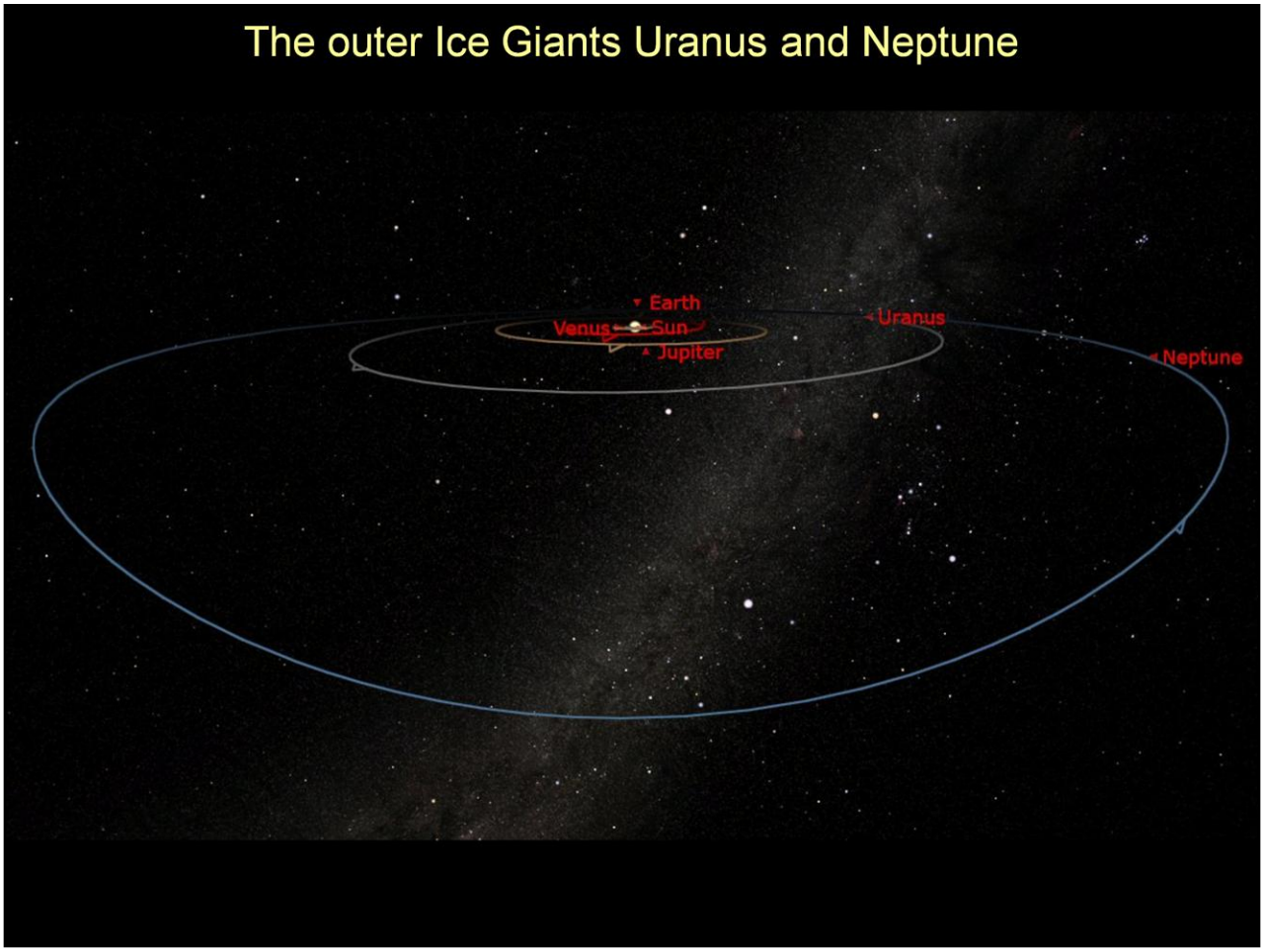
Much of the remaining mass of rock remained in orbit and formed into our Moon. The impact of Thea knocked Earth off its axis and caused the 23.4^{o} tilt of Earth's axis that we see today. Thea was completely destroyed and became part of Earth then our planet cooled and became the planet we live on today.



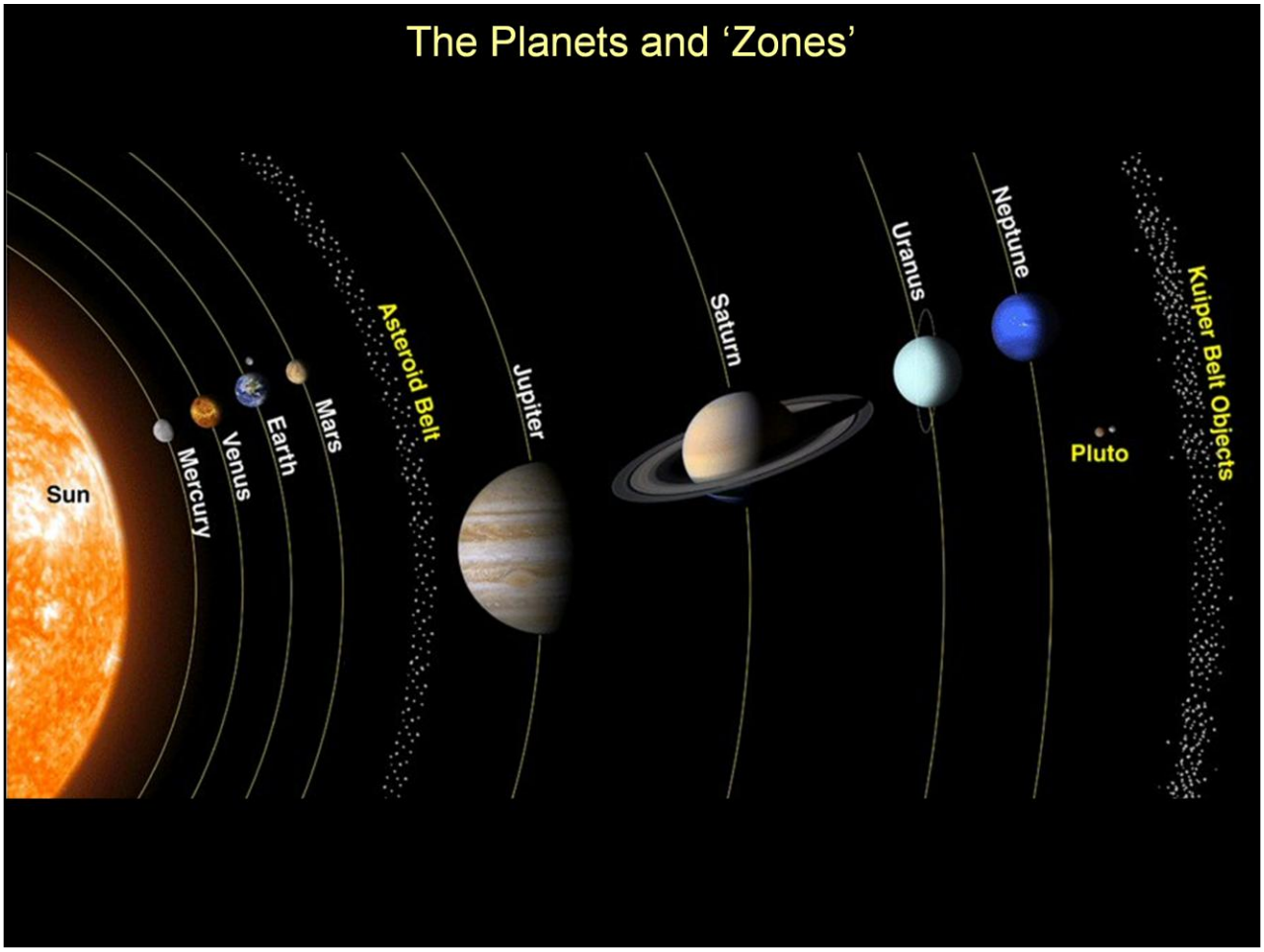
The chart above shows the inner four planets Mars, Earth, Venus and Mercury clustered around the Sun. These inner planets are called the Terrestrial (or rocky) planets. They are composed of rock and Iron and are kept warm by the heat from the Sun.



Beyond the realm of the inner planets we see the orbits of the Gas Giant planets Saturn and Jupiter. These two planets are about ten times the diameter of Earth and their orbit are much further apart. The four inner planets are gathered close to the Sun in the chart above.



Beyond the Gas Giant Planets are the orbits of the outer icy frozen planets Neptune and Uranus are widely spaced and occupy most of the chart. These planets are almost the same size and about four times the diameter of Earth. Their orbits are spaced even further apart.



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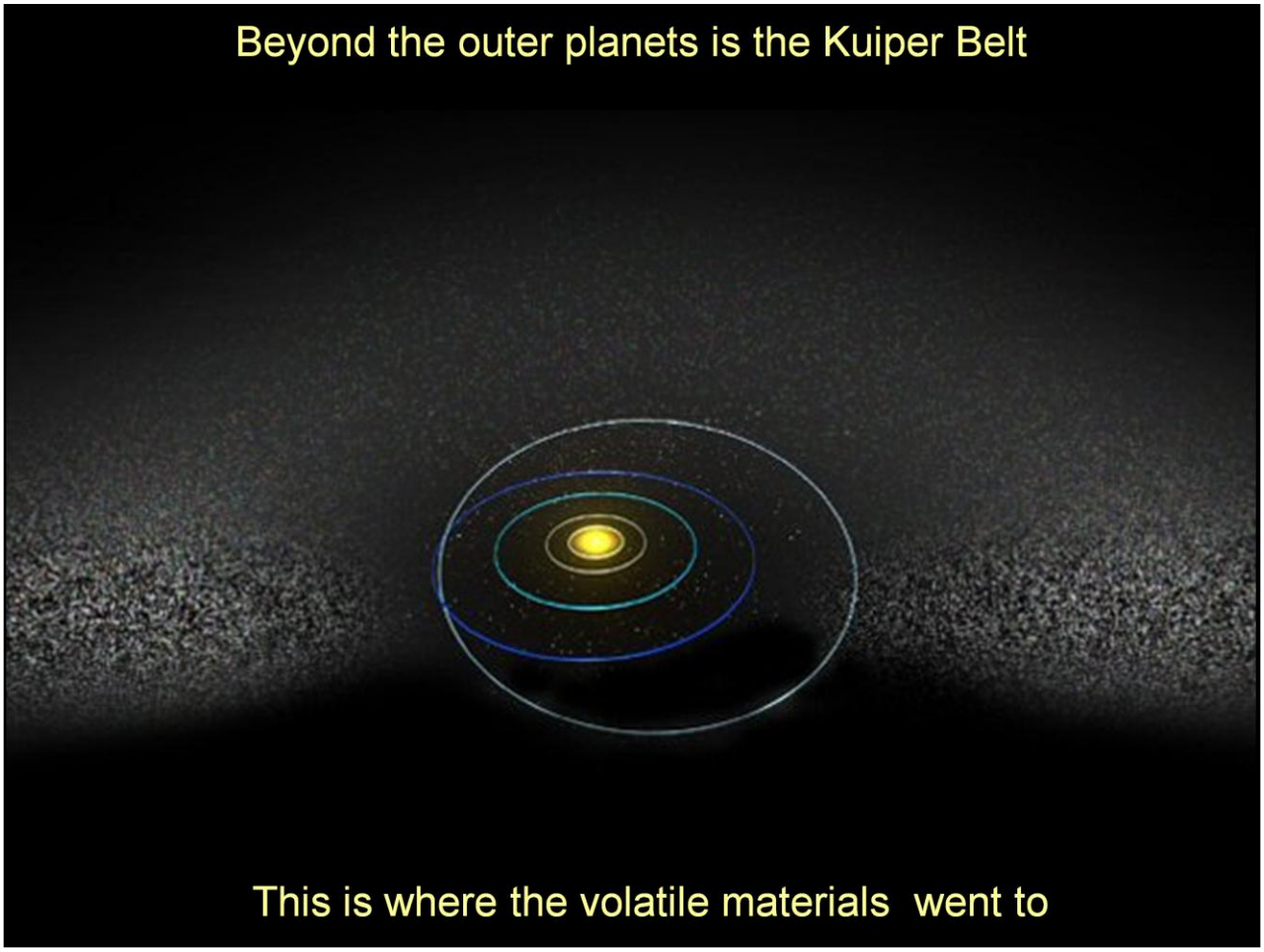
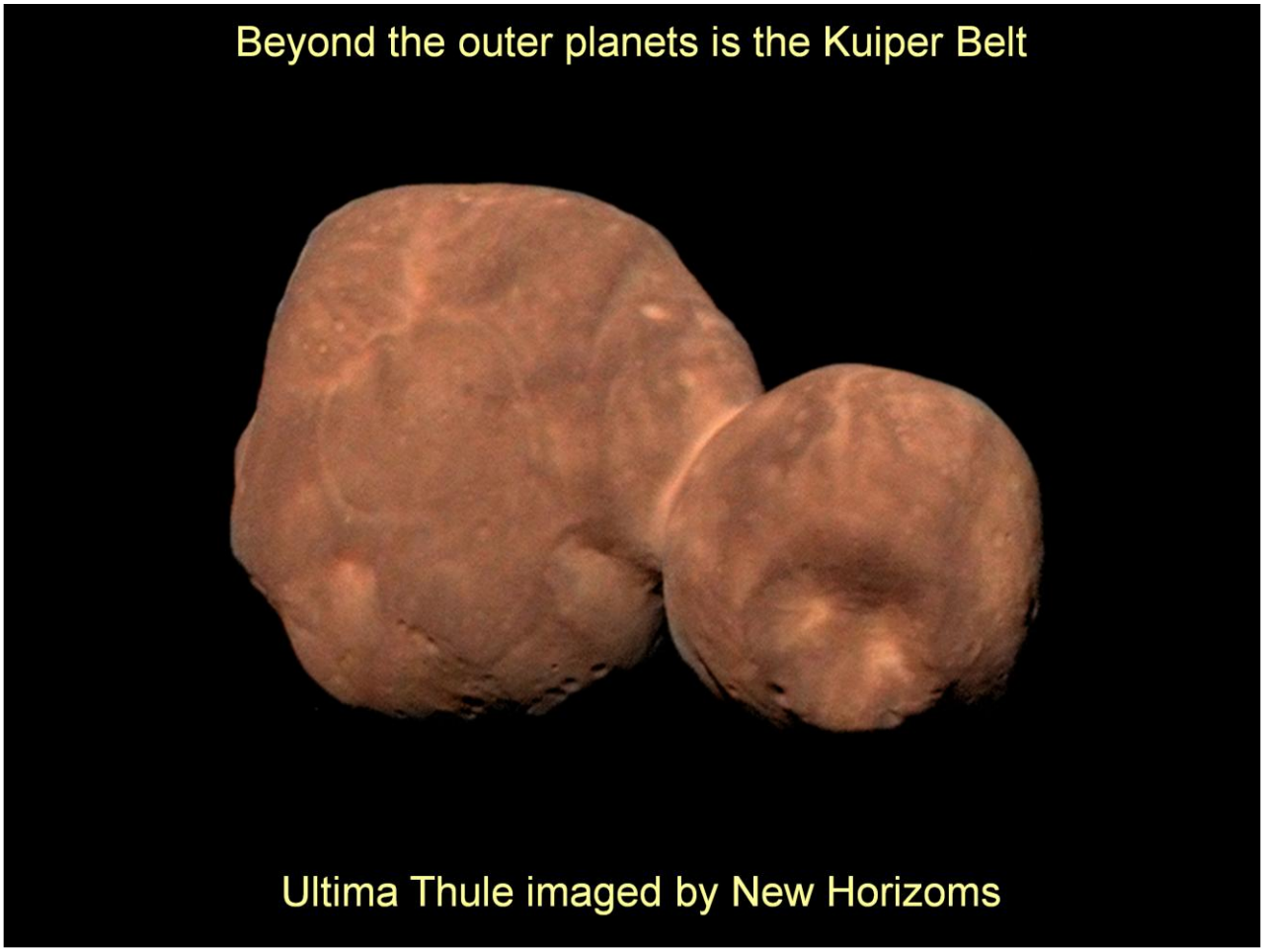
ASTEROIDS are mostly found between the orbits of Mars and Jupiter in what is known as the Asteroid Belt but there are some special groups of asteroids that orbit outside the zone. These sizes of these objects are from a few metres to a few hundred kilometres. They are mainly comprised of rock and Iron.



DWARF PLANETS are found beyond the orbit of the outermost main planet Neptune. These are composed mainly of water ice and frozen gases that were driven off the inner planets. When the Solar System first formed the Sun was more powerful than it is now and produced powerful ultraviolet radiation. Any volatile materials on the inner planets were vaporised by the radiation and blown away into the outer reaches of the developing Solar System. Here these volatile materials cooled and froze into ice and accumulated into objects up to a few thousands of kilometres in size. The object called Pluto was reclassified from being considered a main planet to being a Dwarf Planet.

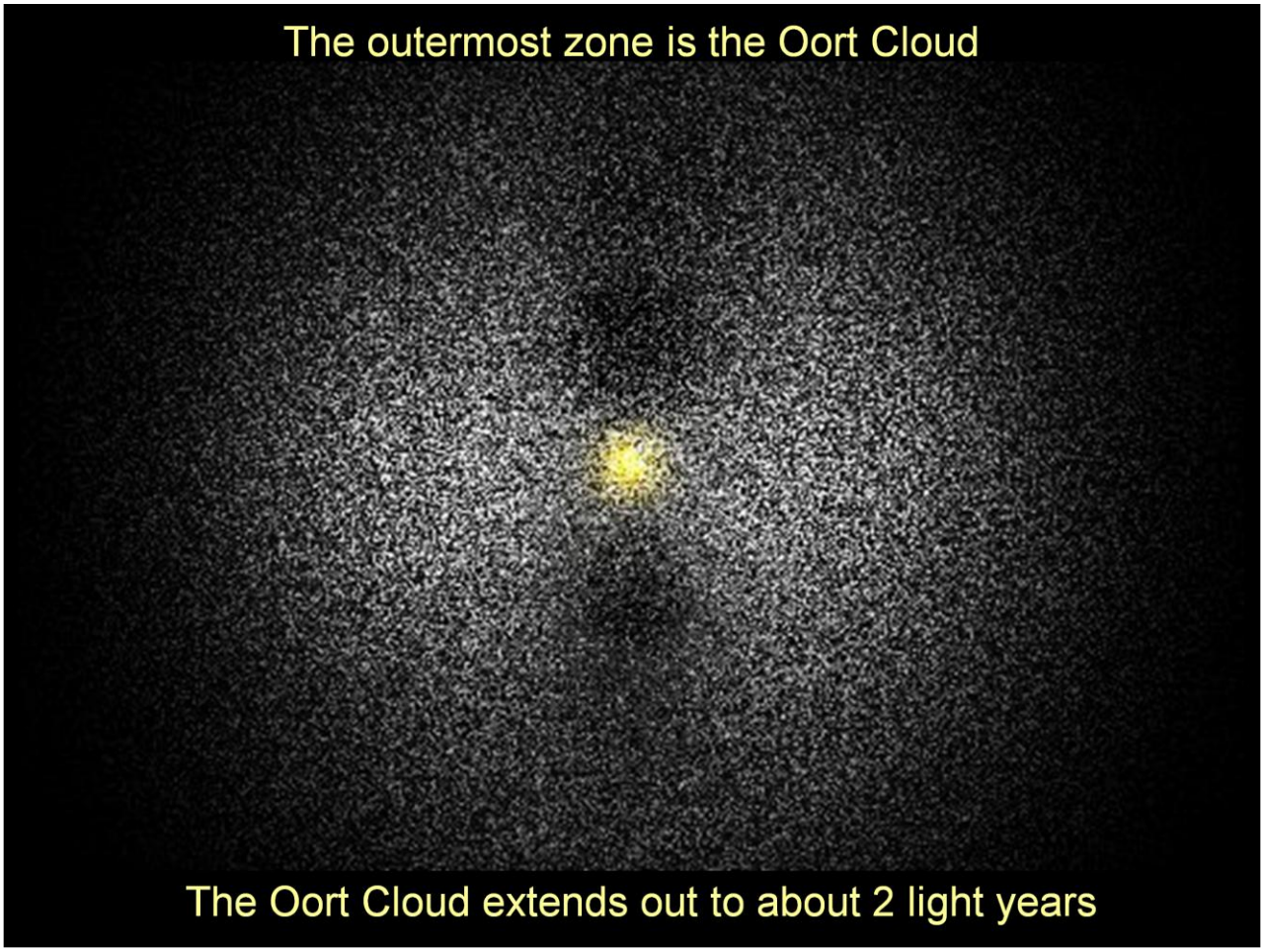
This Dwarf Planet Zone beyond the orbit of Neptune is called the Kuiper Belt and may contain millions of icy objects with many around the size of Pluto. This is why the decision was made to reclassify Pluto. So far there have been over 1000 objects, like Pluto and around the size that have been found, identified and named.



The object shown above was visited by the NASA probe New Horizons after its close fly-by of Pluto. There are vast numbers of these Minor Planets orbiting the Sun beyond the orbit of the outermost main planet Neptune and Pluto is just the closest of these objects. Ultima Thule (the furthest place) is thought to be two objects that are loosely pulled together by their very weak gravity.

New Horizons was launched on 19th January 2006 and swung past Jupiter for a gravity boost and scientific studies in February 2007. It conducted a six month long reconnaissance flyby study of Pluto and its moons in summer 2015, culminating with its closest approach to Pluto on 14th July 2015. As part of an extended mission the spacecraft was directed further into the Kuiper Belt to examine another of these ancient, icy mini-worlds. The object selected was a small Kuiper belt object designated (486958) 2014 MU.

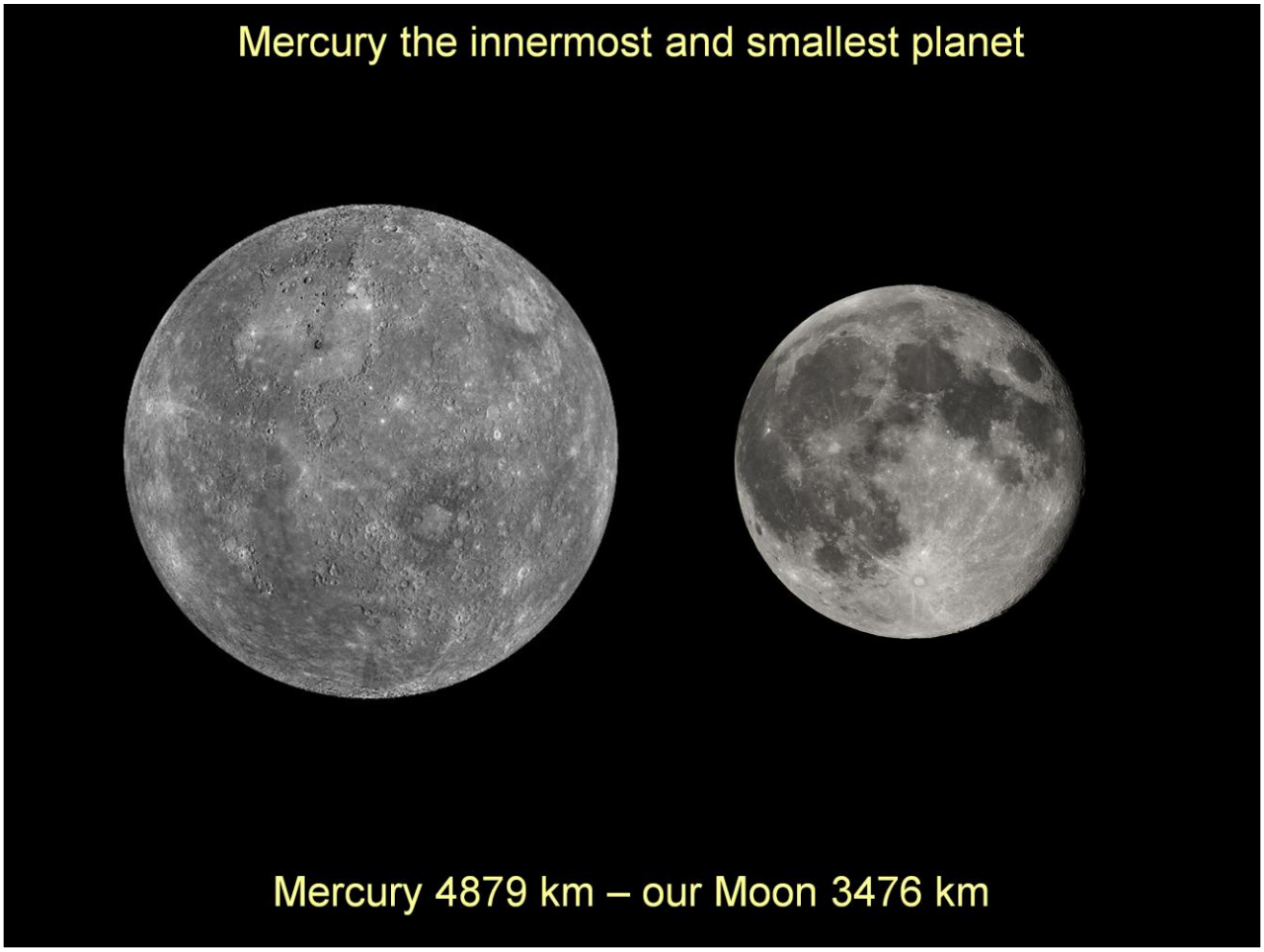
'Thule' is the farthest north location mentioned in ancient Greek and Roman literature and cartography. Modern interpretations have included Orkney, Shetland, the island of Saaremaa in Estonia and the Norwegian island of Smøla. In classical and medieval literature, Ultima Thule acquired a metaphorical meaning of any distant place located beyond the "borders of the known world". By the late middle ages and early modern era, the Greco-Roman Thule was often identified with the real Iceland or Norway. It is a very apt name for this the most distant Dwarf Planet ever to be seen up close.



There is also thought to be a halo of icy objects beyond the Kuiper Belt and surrounding the Sun this is called the Oort Cloud but these objects are too far away to detect. These mainly icy bodies surround the Sun in all directions and may extend out 1.5 billion (or more) from the Sun.

These objects are thought to be where some Comets originate. If the orbits of these distant objects are disturbed by the other bodies or even a star passing our solar system they may be redirected in towards the Sun or out of the Solar System.

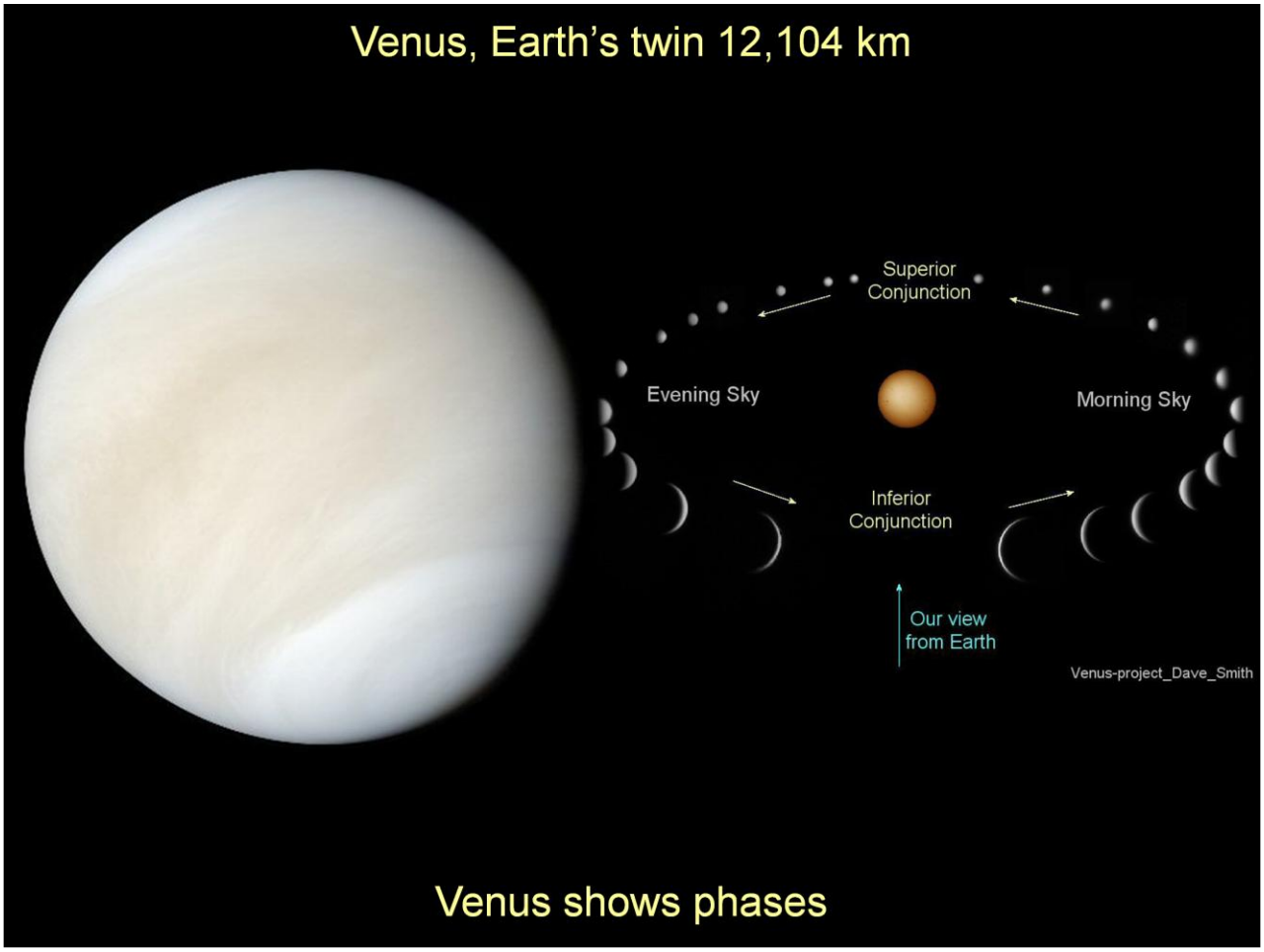
Those redirected into a spiralling path towards the Sun can become comets as their ice begins to be melted by the warmth of the Sun.



We have looked at our Solar System as our star, the Sun, being the dominating central object of the system with the Planets, Dwarf Planets, Asteroids and Comets having primary orbits around the Sun. Now we can consider those objects that have secondary orbits within the Solar System. We call these Moons that orbit around planets that in turn orbit the Sun.

The two inner planets do not have moons these are MERCURY and VENUS and they are closest to the Sun.

Mercury is the smallest of all the planets and is not a lot bigger than our Moon.



Venus is the second planet out from the Sun and is almost the same size as Earth and it does not have any moons.

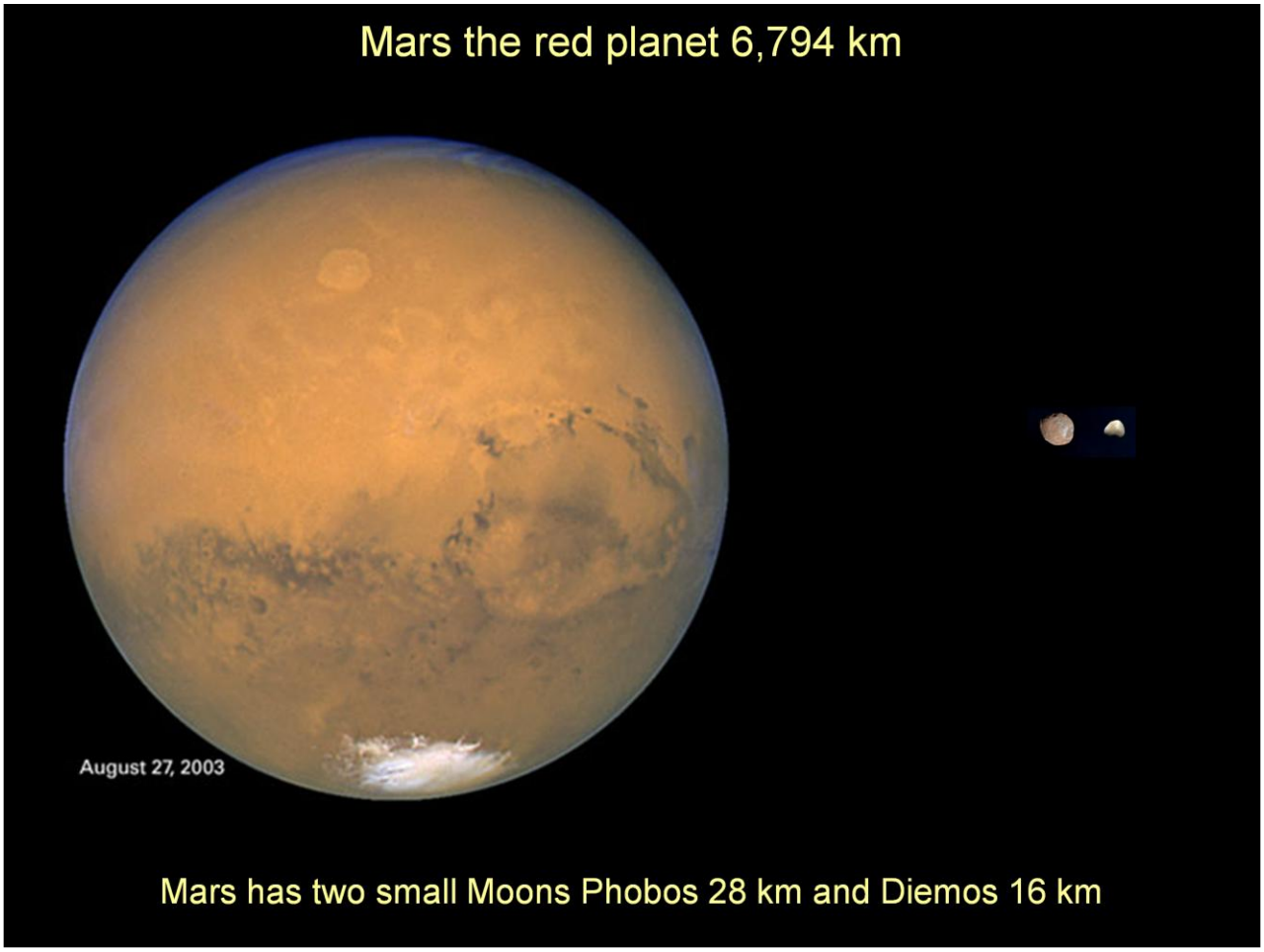
Venus is 12,104 kilometres in diameter compared to the 12,756 kilometres of Earth.

Venus is completely covered in thick white clouds and appears featureless when viewed using a telescope. However as it is an 'inferior' planet (orbiting inside Earth's orbit) we can see it has phases like our Moon. As Venus orbits the Sun we see the planet illuminated from different directions as it passes in front and behind the Sun. It also appears to change size as it moves closer and further away from us, as shown in the diagram on the right.

Our planet Earth has just one Moon but it is the biggest moon compared the size of its parent planet of all the planets and is sometimes said to be almost a double planet system.

It is almost certain that the early Earth was hit by another planet that we call Thea. Thea was about the same size as Mars and is thought to have hit Earth off centre, crashed right through Earth knocking off a huge mass of rock and some of the Iron core. The debris was thrown into orbit around the molten remains of Earth. The heavy Iron including the core of Thea soon crashed back on to the remains of Earth causing another massive impact.

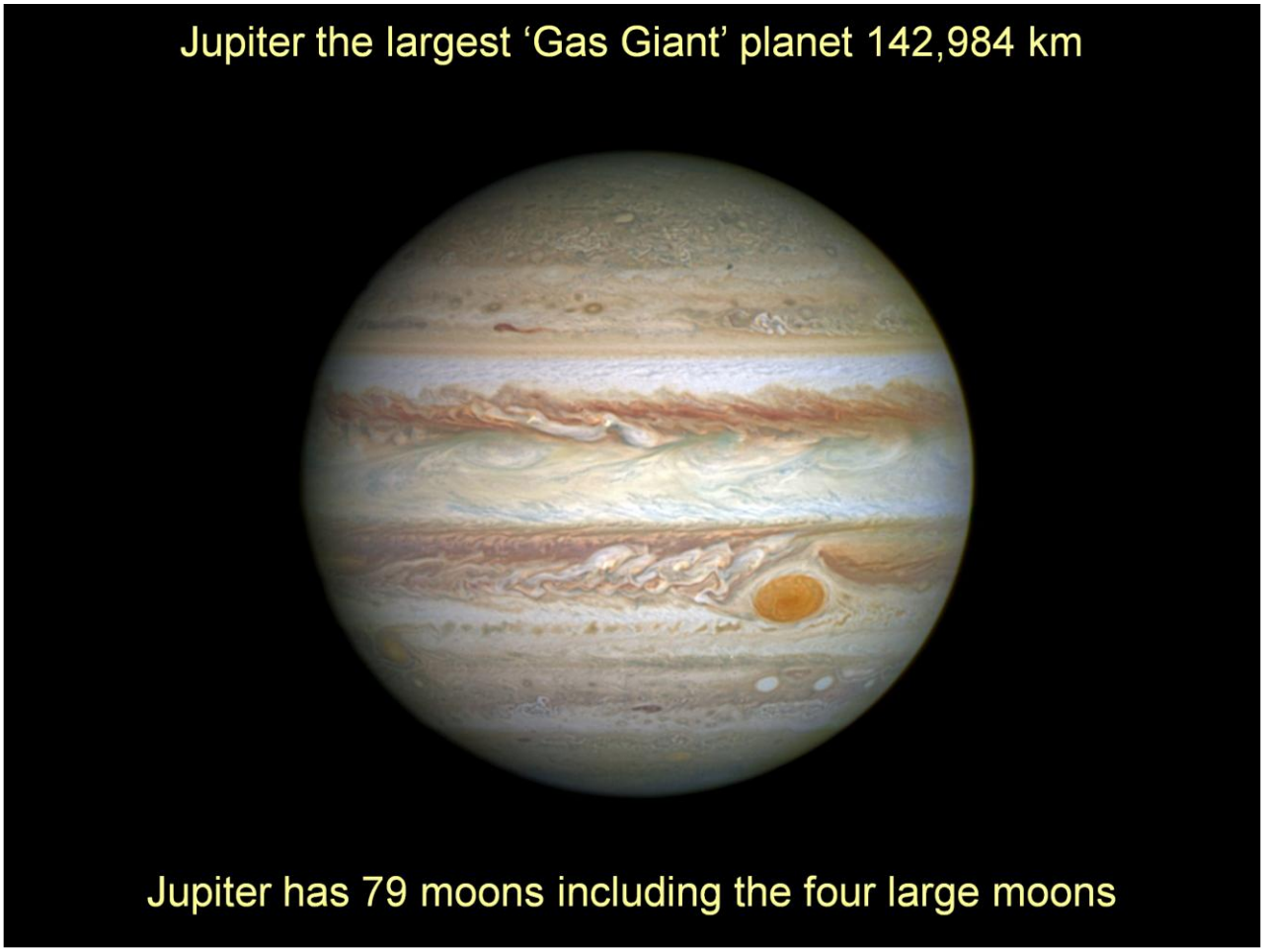
Much of the remaining mass comprised of lighter rock remained in orbit and formed into our Moon. The impact of Thea knocked Earth off its axis and caused the 23.4^{o} tilt of Earth's axis that we see today. Thea was completely destroyed and became part of Earth as our planet cooled and became the planet we live on today.



MARS has two moons but they are very small and are thought to be asteroids that have been captured by the gravity of Mars and are now in orbit around the planet. Phobos is 22.2 km wide and Deimos is 12.6 km wide. The moons have been enlarged in the picture above, they are really much smaller when compared to Mars. The two small moons look just like lumps of rock.

Mars is the 4th Planet out from the Sun, the next out from Earth and the second smallest planet in our Solar System after Mercury. It is approximately half the diameter of Earth at 6780 km (Earth 12,600 km). Earth orbits the Sun at an average distance of 146.6 million km and Mars orbits at an average distance of 229.9 million km. Due to the eccentricity of their orbits the distance between Earth and Mars can vary, at their closest approach (Opposition), from about 55 million km to about 100 million km.

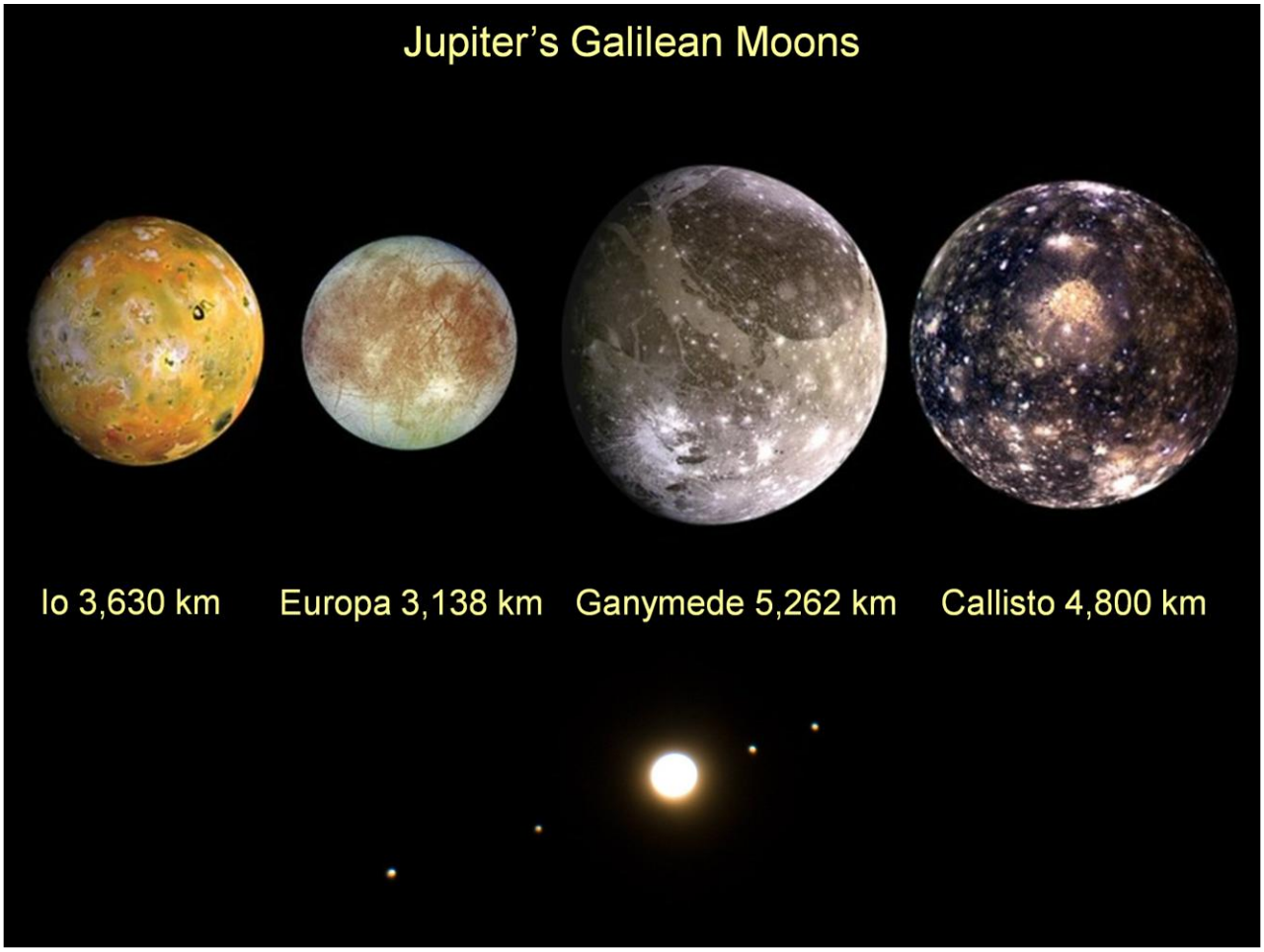
A telescope is required to see Mars as a disc. A small telescope even with an aperture of just 75mm will do because Mars is so bright. It will however require a magnification of at least 100 times. This means a telescope with a focal length of 1000mm will require a 10mm eyepiece to be used (1000 ÷ 10 = 100x).



JUPITER is the largest planet and is a Gas Giant. It has about 79 moons but only four are large and about the same size as our Moon. They are called Io, Europa, Ganymede and Callisto. These four largest moons are known as the Galilean moons and were discovered in 1610 by Galileo Galilei. Ganymede is the largest moon in the Solar System at 5262km in diameter. The Galilean moons can be seen in any telescope and even using binoculars.

Jupiter’s Galilean moons are very different to each other in size and appearance. Io is the inner moon and is covered in active volcanoes. Europa is the smallest and mainly water ice. Ganymede is the largest moon and Callisto has the oldest surface in the Solar System.

Jupiter and its four largest moons is easy to see using a telescope. The moons can even be glimpsed using a good pair of 9 x 50 binoculars or larger. A telescope is required to see the cloud markings on Jupiter.



Io is the innermost and smallest of the four Galilean moons in an orbit that takes just 1,77 (Earth) days to complete and because it is just 421,600 km from Jupiter it is possibly the weirdest of them all. During the first 'fly-by' space mission strange plumes were seen on the edge of Io. The plumes were found to be active volcanoes, this was a great surprise. Later probes showed that the volcano eruptions were of liquid rock like the volcanoes on Earth.

Europa is the second moon out from Jupiter and the smallest of the four Galilean moons its orbit takes 3.55 (Earth) days. It is also quite close to Jupiter with an orbit 670,900km from the centre of Jupiter.

Europa is also affected by Jupiter's enormous gravity but its effect is manifested in a very different way. This small moon (3,138km diameter compared to our Moon's 3,476km) is primarily composed of water ice and Carbon Di-oxide ice. The very strong gravitational force from Jupiter produces powerful tidal forces and heat in a similar way to those on Io. Heat produced from the friction causes the ice to melt and seems to have produced a liquid ocean of what is thought to be salty water, similar to the seas on Earth, beneath a ~50km thick crust of ice.

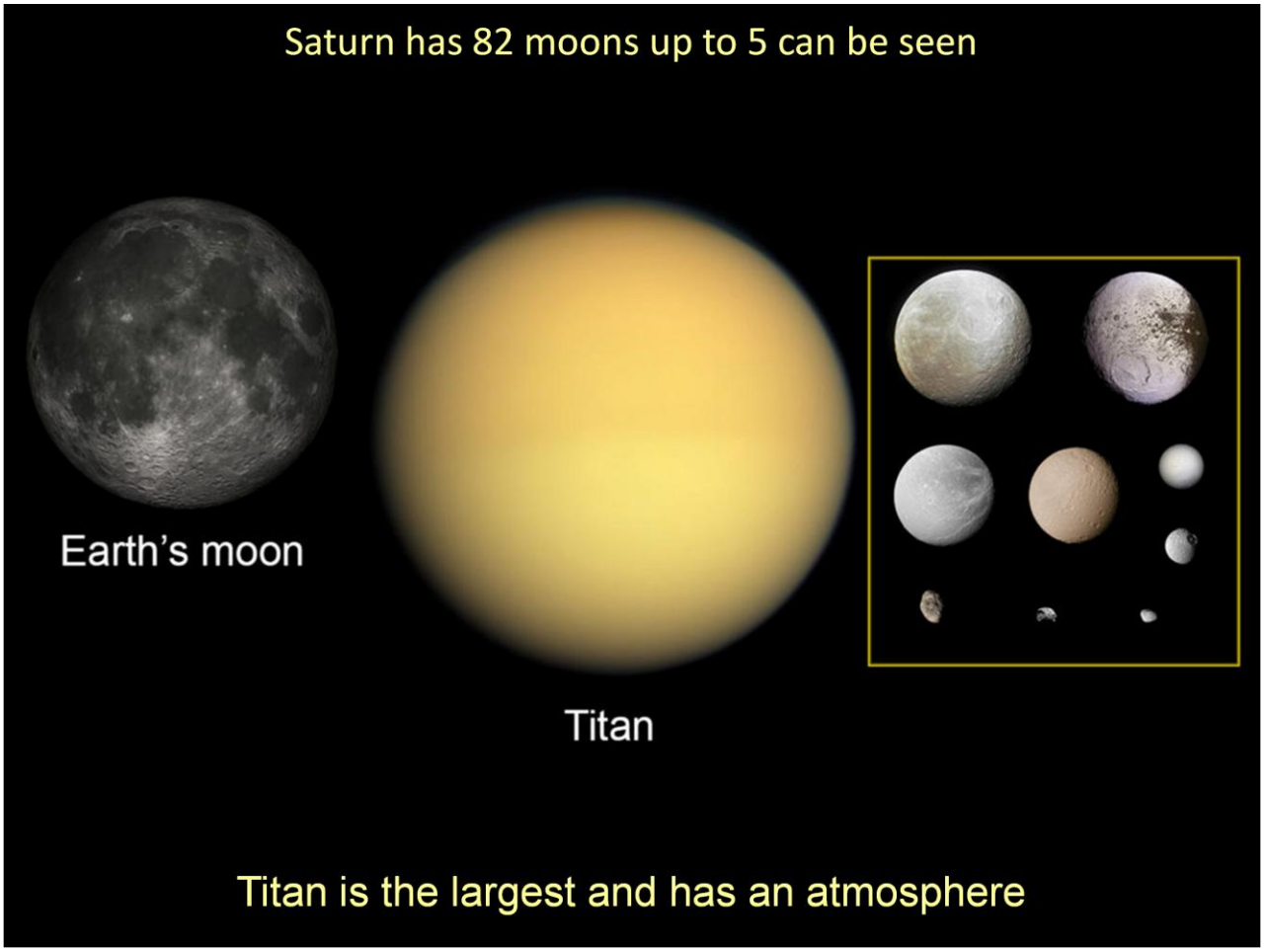
Ganymede is the largest moon in the solar system (5,263km in diameter). It orbits Jupiter in about 7.16 (Earth) days at just over 1 million km from Jupiter.

Callisto, unlike the other three Galilean moons, appears not to have had any noticeable internal activity or source of heat. Consequently the surface is old and has one of the most heavily cratered surfaces in the Solar System. It is a large moon with a diameter of 4,800km orbiting Jupiter at 1.8 million km and takes just 16.69 (Earth) days to complete each orbit.

Saturn, with its magnificent ring system, is surely the easiest planet to recognise. Any poster or cartoon depicting a space scene will almost certainly have a planet with a ring system looking somewhat like Saturn. All the large outer planets also have ring systems but those are all feeble compared to Saturn's.

Saturn is the second largest planet in our Solar System after Jupiter. The planet itself is 120,000 km in diameter at the equator but is flattened to 108,000 km at the poles due to its rapid rotation. Although Saturn is 10 times the diameter of Earth it rotates on its axis (1 day) in only 10 hours 14 minutes. The rings are 275,000 km (170,000 miles) across but may be less than a hundred metres thick. To put this in perspective, the ring diameter is almost the same as the distance from Earth to the Moon.

A 100mm telescope will show the ring system but a larger telescope is required to see the detail. On a really good clear night it is possible to see the Cassini Division in the ring. This is shown as the dark division in the rings in the image above. A smaller telescope will probably be able to show the division to the right and left of the planet but the portion to the front of the planet may be difficult to see.

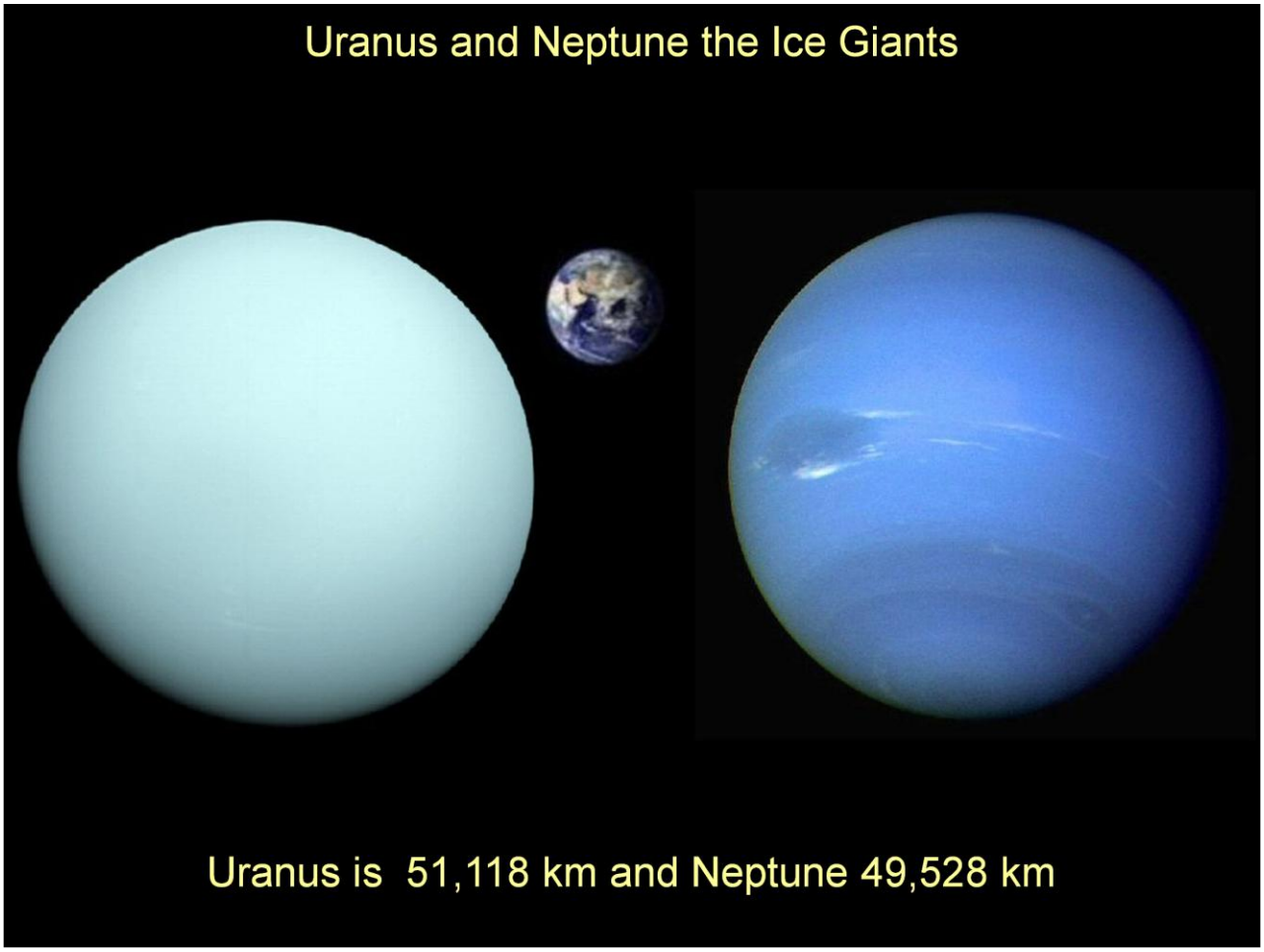


Saturn's largest moon is called Titan and is the second largest moon in the Solar System (5,105 km) after Jupiter's Ganymede (5,262 km). Titan has a thick atmosphere .

Titan is primarily composed of ice and rocky material, which is likely differentiated into a rocky core surrounded by various layers of ice, including a crust of ice of and a subsurface layer of ammonia-rich liquid water.

The atmosphere of Titan is largely Nitrogen; minor components lead to the formation of Methane and Ethane clouds. The climate including wind and rain creates surface features similar to those of Earth, such as dunes, rivers, lakes, seas (probably of liquid methane and ethane) and deltas and is dominated by seasonal weather patterns as on Earth. With its liquids (both surface and subsurface) and robust nitrogen atmosphere, Titan's methane cycle bears a striking similarity to Earth's water cycle albeit at the much lower temperature of about −179.2^{o} C (−290.5^{o} F).

Titan is visible along side Saturn using 100mm plus telescopes and up to four of the other moons are visible using larger telescopes.

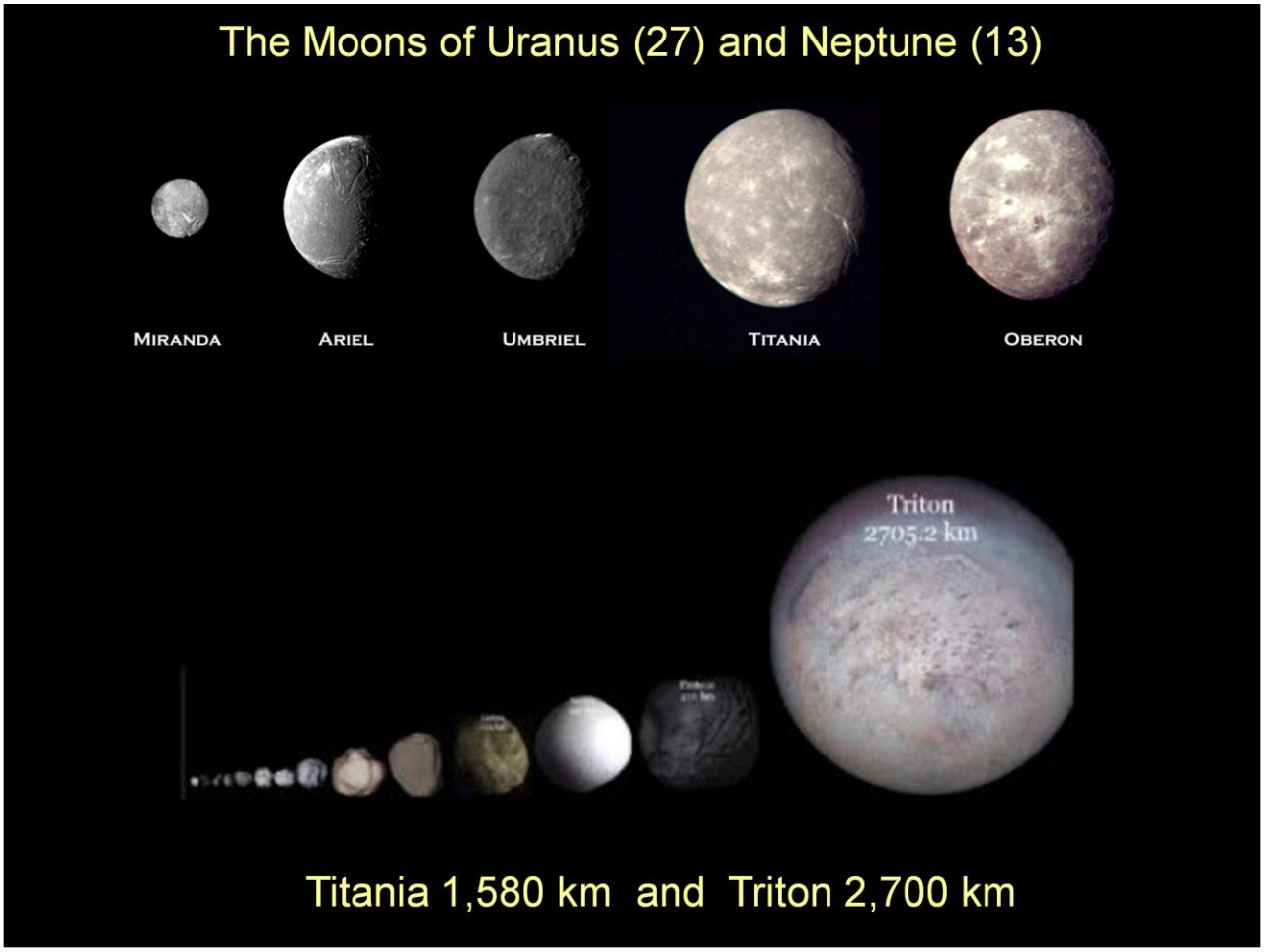


Beyond the Gas Giant Planets are the orbits of the outer icy frozen planets Uranus and Neptune that have their orbits much further apart. These planets are almost the same size and about four times the diameter of Earth. They are very far from the Sun and are therefore very cold.

Uranus is 51,118 kilometres in diameter and Neptune is slightly smaller at 49,528 km. This is about four times the diameter of Earth. The two most distant planets are very cold with most materials frozen. Strangely Neptune has a dynamic atmosphere and cloud system but the source that provide the power for this system is unknown.

Both planets are observable as small blue discs using most amateur telescopes but it is not possible to see an detail.

Uranus has 27 moons and Neptune has 13.



Uranus has 27 moons but these are quite small with Titania the largest at 1,580 km and 3 of the others just over 1000 km in diameter.

Neptune has 13 moons with Triton 2,700 km in diameter and the rest less than 400 km. Triton is mysterious because it has erupting geysers on its surface. These send a plume into the tenuous atmosphere generally in one direction. This leaves a dark stain across the surface due to a prevailing wind.

The moons of the Ice Giants are not visible in amateur astronomers telescopes.

Comets and Meteors

Comet Hale Bopp 1998

A comet is a lump of ice mainly comprised of water ice with Carbon Dioxide (CO^2) as the second largest constituent. When a comet is in the outer reaches of the Solar System it does not have a tail and resembles our much closer neighbours the Asteroids. The solid lump of material that has the close encounter with the Sun is called the Nucleus and is typically around 3 to 30 km across.

It is likely that there are still close encounters and even collisions of the Dwarf Planets in the Oort Cloud and the Kuiper Belt. Any close encounters are likely to disturb the fragile orbits of these icy bodies. The effect of the gravity of the Sun is extremely week at these vast distances. Just a tiny change to the path of one of the objects could send it on a course towards the Sun and its planets. These journeys in towards the Sun may take many thousands or even millions of years.

As the comet nucleus approaches the Sun the frozen gases begin to sublime (melt directly into gas) and form a cloud around the nucleus called the 'Coma'. Some comets develop two very distinct tails. The white curved tail is the Dust and Particle Tail. It is formed by particles of dust that in most cases have the consistency of cigarette ash. These particles are pushed away from the coma by the Solar Wind (radiation from the Sun) and normally form an arc behind the coma. A second straight blue tail is produced by ionised gas.

Comets and Meteors

The Chelyabinsk fireball 15th February 2013

There are two types of Meteor, the first is thought to originate from the large lumps of rock and iron left over when the planets formed, known as ASTEROIDS. Most asteroids orbit the Sun in a belt between Mars and Jupiter. The huge gravitational forces exerted by Jupiter may have pulled the rocks apart before they could accumulate into a planet.

Very rarely two asteroids may collide but when they do, chips of rock and Iron are thrown off and occasionally may head towards Earth. These can be a few millimetres across or up to tens or even hundreds of metres across. They are quite rare and are seen as individual 'fireballs'. Large ones can sometimes impact the ground as METEORITES and may even cause craters.

The second type of meteor originates from a comet and is much more common. Comets are large lumps of ice, typically between three and thirty kilometres across that reside beyond the orbits of the outer planets. When they approach the Sun the 'dirty' ice melts and leaves a trail behind it. Once or twice a year Earth may pass through this stream of particles that then collide with the atmosphere as Meteors. Meteoroid dust particles are usually small and very light and generally have the consistency of cigarette ash but are travelling very fast (~50 km/sec.).

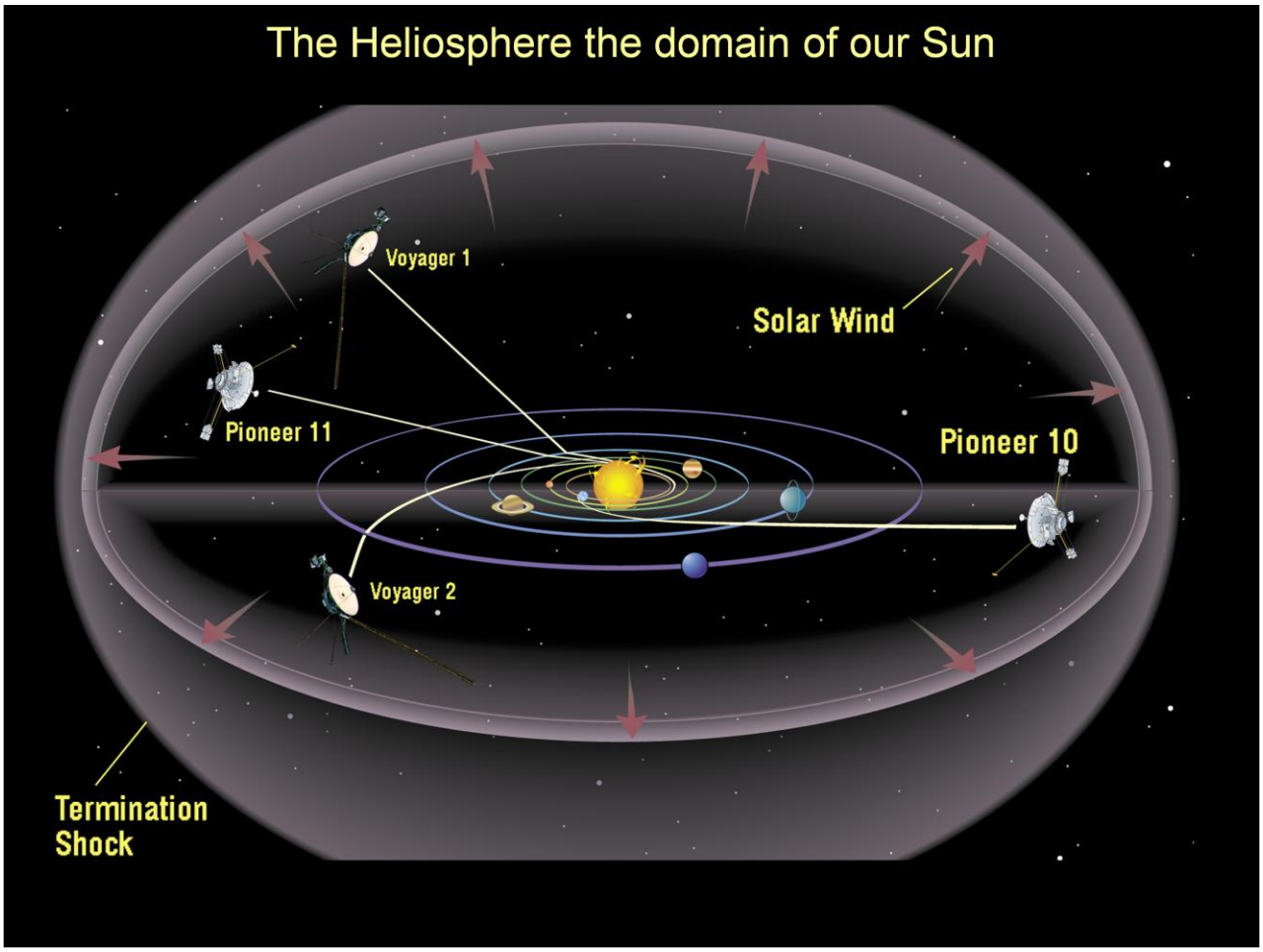
Where does the Solar System end?
and
Where does Deep Space begin?

Solar System ends where the Sun's influence stops

and

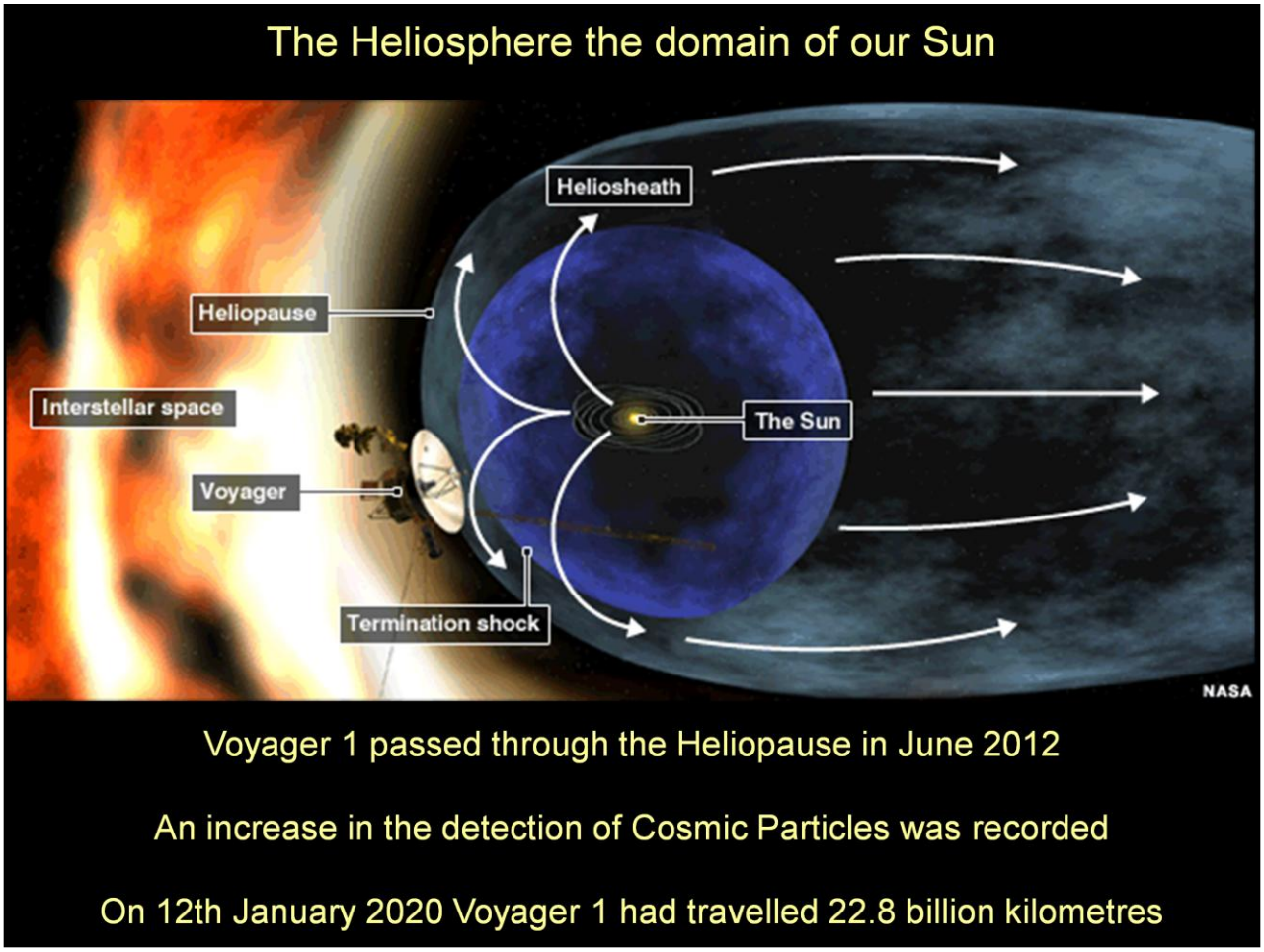
All the rest is Deep Space

We need to ask the questions: How big is our Solar System? and Where does it end and where does Deep Space begin? We describe the limits of our Solar System as being the furthest reach of the influence of our Sun. So this is the distance where the radiation from the Sun no longer affects the structure of deep space. We refer to the volume of space influenced by our Sun as the Heliosphere and the boundary as the Heliopause.



The diagram above shows the trajectories of the NASA's Voyager probes 1 and 2 along with Pioneer 11 and 12. These probes have reached the greatest distances of human made machines. On 12th January 2020 Voyager 1 had reached a distance of 152.2 AU (22.8 billion kilometres) from Earth.

NASA announced in June 2012 that the probe Voyager 1 that was launched on 5th September 1977 was detecting changes in the environment that were suspected to correlate with arrival at the Heliopause. Voyager 1 had reported a marked increase in its detection of charged Cosmic Particles from interstellar space which is normally deflected by the solar winds produced by the Sun within the Heliosphere. The craft had began to leave the Solar System and enter the interstellar medium at the edge of the Solar System.



The diagram above shows in dynamic detail how we perceive the Heliopause and how it creates a 'bow wave' where it is interacting with energetic deep space 'Cosmic' particles. In reality the Voyager experience as it entered deep space was less dramatic and amounted to counting an increase in the Cosmic Particles that pervade deep space.

The Heliopause pushes the cosmic particles around the Heliosphere as shown by the white arrows. These particles are then directed around the outside of the Heliosphere and therefore are not detected inside. So when the Voyager probes started to detect these particles it indicated the probes had left the Solar System and had entered Interstellar Space (Deep Space).

Beginner's Website:

naasbeginners.co.uk