Jupiter and the Giant Planets in Our Solar System

Based on the material from the online Caltech course Science of the Solar System by Prof. Mike Brown and additional research

by Tihomir Dimitrov
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CREDITS

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CONTENTS

INTRODUCTION 4

The Upper Atmosphere and Weather on Jupiter / The Galileo Probe 5

Jupiter’s Density 7

Hydrostatic Equilibrium and Heat Transport 9

Theoretical Internal Structure of Jupiter 10

A Core from Gravity 11

The Juno Spacecraft 12

Jupiter’s Magnetic Field 13

Jupiter Picture Models 14

Saturn, Uranus and Neptune - the rest of the giant planets in our solar system 15

Jupiter through the eyes of an alien 16
INTRODUCTION

If you are an alien traveling through our solar system, you will not fail to notice the largest and most fascinating planet in our solar system - Jupiter! It was named in ancient times by the Romans after their king of gods, Jupiter, who was also the god of the sky and of thunder (known as Zeus in Greek mythology) (Image 1). Later, when the Germanic people adopted the Roman weekly calendar, they replaced the name Jupiter with Thor, which stems the modern name of the day Thursday.

If you are a human today and you look with a good pair of binoculars in the night sky, you will see Jupiter there - a magnificent planet, the most massive of all the planets. Actually, the original ancient Greek meaning of the word “planet” was simply “wanderer”, or something that moved across the night sky, as opposed to all the stars that stayed stationary. If you look carefully through your binoculars, you will see small white dots next to Jupiter. These are the 4 Galilean moons - named after the Italian astronomer Galileo Galilei (Image 2). When he first turned his telescope towards Jupiter in 1609, he observed that these moons were centered on Jupiter the same way the Moon is around Earth. Back then he didn’t know anything about orbits.

The Galilean moons became the first celestial bodies that are known to be going around another celestial object than Earth. Note that 400 years ago, the times were such that the Sun and Jupiter itself were going around Earth and everyone who thought otherwise was burnt on the pyre!

Years later, in 1666, people saw features on Jupiter - color bands that span across the whole planet and at one place a big orange oval that they called the Great Red Spot (Image 3), which was observed to move from east to west throughout half the diameter of the planet in 2 hours. It was then concluded that Jupiter makes one rotation around its own axis in just about 8 hours!

Today we know that the Renaissance calculations were pretty close - Jupiter makes a full rotation around its axis every 9 hours 55 minutes, which makes it the fastest rotating planet in our solar system! This rapid spin throws material in its equatorial region outwards which results in a slightly bulging equator (71,500km - ~ 4,400km larger than its polar radius). Its axis’ tilt is only 3.1 degrees and this means that neither of the planet’s hemispheres point towards or away from the Sun, as a consequence Jupiter has no seasons. Jupiter’s average distance from the Sun is ~ 780 million kilometers - this is more than 5 times the Earth - Sun distance. With a rotation period of just less than 10 hours and an orbital period around the Sun of nearly 12 Earth years, one Jovian year has ~ 10,500 Jovian days. If you
are a 24 year old youngster then you are about 2 Jovian years old! The four moons that Galileo first saw four centuries ago are the largest Jovian moons - **Io, Europa, Ganymede and Callisto (Image 4)**. They are only four of the *67 moons* orbiting Jupiter that we have discovered so far. Most of these moons have been discovered since 2000.

As the imagery of Jupiter became better and better with the years, we have discovered that it is engulfed in clouds. This raises interesting questions like *what is the atmosphere of Jupiter. Is it breathable? What’s the weather on Jupiter? Can a man walk on the planet? What is the Great Red Spot that helped Galileo determine the rotation period of Jupiter? And above all, what’s underneath those clouds on Jupiter?* We will give answers to these questions next.

**The Upper Atmosphere and Weather on Jupiter / The Galileo Probe**

Bad news if you would like to live on Jupiter - the gas giant has *no* firm surface to touch down to. Instead, its primary composition is hydrogen in gaseous and liquid form (if you go deeper) and a little helium. Jupiter’s upper atmosphere is composed of ~ *90% hydrogen* and ~ *10% helium by volume*. Since a helium atom has ~ *4 times* as much mass as a hydrogen atom (*Image 5*), by mass Jupiter’s atmosphere is ~ *75% hydrogen* and ~ *25% helium*.

The temperature of the atmosphere increases towards the planet’s interior and convection currents move the mixture of gas upwards. Water is the first to reach the altitude where it is cool enough to condense and form clouds. Higher up, where it is even cooler, red-brown ammonium hydrosulfide clouds form, and highest of all, where it is coolest, are the white ammonia clouds. The colder white bands are known as *zones*, while the darker red ones are called *belts* (*Image 8*). Gases within the zones rise and move eastwards, while within the belts they fall and move westwards. The rising warm air and descending cool air within the atmosphere produce winds that are channeled around the planet, both to the east and west, by Jupiter’s fast spin. These winds’ speed changes with latitude; winds within the equatorial region are particularly strong and reach speeds ~ *400 kph* (*Image 9*).

The solar and infrared heat, the wind, and Jupiter’s spin combine to produce regions of turbulent motion, forming
oval cloud structures. The smallest of these storms are like the largest hurricanes here on Earth. They can be relatively short-lived or to last for years, like the Great Red Spot - an enormous high-pressure storm that was observed from Earth even when Galileo first saw Jupiter.

Speaking of Galileo Galilei - the Italian astronomer who lived in the sixteenth and seventeenth century - in 1989 we sent a spacecraft to Jupiter that carries his name - the Galileo spacecraft that carried with it the Galileo probe. The Galileo probe had the sole purpose of going under the clouds of Jupiter as far as it could and make a detailed analysis of the composition of the planet, assuming that the distribution of materials is homogenous (Image 10). The probe was released 5 months before the spacecraft got to Jupiter and it plunged directly into the planet with a speed of 50 km/s and experiencing a force of 230g.

It survived that force because it had a thick 152kg heat shield that protected it for as long as it could while it entered the atmosphere, burning its way towards the depths of Jupiter. The heat shield lost 80kg of its mass during this dive, then it was released, the parachute was deployed and the spacecraft started collecting data with its instruments (Image 11). Its mission lasted for about an hour during which the probe passed through wispy clouds, then towards some thick clouds and its signal ended when the pressure reached 24 bars. That’s 24 times the pressure that we experience here on Earth - a human would be crushed under such pressure (Image 12)!

Homogenous distribution in the atmosphere means that if we inspect a tiny part of the surface area of Jupiter, it should be a good representation of the whole layer of atmosphere. The Galileo probe measured the composition of Jupiter and it found a lot of hydrogen (H), helium (He), some methane (CH₄), sulphur (S) and
some noble gases like neon (Ne), argon (Ar), krypton (Kr) and xenon (Xe). An interesting observation is that the quantities of water (H₂O) that the probe observed in the atmosphere were much less abundant than originally expected. People were interested in water on Jupiter not for the same reasons as on Mars where it has implications to habitability (If you are interested in the topic of where is the water on Mars, you can read The Human Adventures in Space Exploration article here), but because water contains oxygen and oxygen is one of the most abundant elements in our solar system.

However, just before the Galileo probe ended its mission, the water level started rising! Why water levels were calculated by the probe low and why did they rise just at the end of its mission? Scientists had been observing Jupiter before the probe entered its atmosphere and they knew that it will enter a small region in the atmosphere that is essentially a dry hole deprived of large amounts of water in it. This dry hole can be compared to the Sahara desert on Earth (Image 15).

![Image 15: The Sahara desert on Earth](image15)

One would have expected that if the Sun and Jupiter formed out of the same nebular disk, they would have the same composition unless something different happened to Jupiter to add all those additional chemical elements in its composition. Indeed, that is the case - what happened to Jupiter? To answer this question we need to delve even deeper into the planet to see what’s inside. We already know that it is a very hostile environment for humans and that you can’t set foot on Jupiter, but is the planet made only out of gas and if you pierce through it would you go from one end to the other? To answer this, let’s talk about the density of the planets in our solar system and where Jupiter does fit in!

![Image 16: The Solar System and the densities of its planets](image16)

The first thing you want to do if you want to know what a planet looks like from the inside is to measure its density. What is density? It is how close the particles of a particular material are. In science, density is the mass divided by the volume! It is ~ 1 g/cm³ for water and ~ 8 g/cm³ for iron. Density is probably the most fundamental measurement that you can make about an object in our solar system. It is the first one that you make to get an idea what an object is made out of.

When you look at pictures of our solar system (Image 16), you can quickly distinguish between three types of planets. First are the terrestrial planets - they are small, but have high densities of ~ 5 g/cm³. If you pick up a rock on the surface of Earth, it will have a density of ~ 3 g/cm³. If you compress this rock, its density will go up a bit. However, the difference between the density of Earth (5 g/cm³) and the density of the rock (3 g/cm³) is so big that we can conclude that there is enough heavy material underneath the surface that this 3 g/cm³ can’t be just due to the compression of the surface rocks. (The deeper you go inside a planet, the more material is above you that presses the material underneath it and creates a higher density.)

![Image 17: Mass and density of the planets](image17)

Jupiter has a density of only 1.3 g/cm³ and it’s huge! Whatever it is made of, it must be highly compressed on the inside. If we compress even ice, it will give a higher than 1.3 g/cm³ density. This comes to tell us that Jupiter is made (almost) entirely out of gas! We know that the giant planet contains heavier elements than hydrogen and helium in its atmosphere, but this fact is not enough to account for its mass and size (Image Jupiter’s Density).
Jupiter is almost 2.5 times more massive than the other seven planets combined and it is ~ 320 times more massive than the Earth! Jupiter could fit ~ 1300 Earths inside it! No surprise that it is named after Zeus! Nevertheless, it looks like there should be extra material in the center of the planet to account for this extra mass.

How do we come to calculate what is the density of Jupiter?

Remember that the density is the mass divided by the volume.

The volume of a planet can be measured if we measure its radius when we look at it in the sky. The only way, however, to measure the mass of a planet is if it has a natural satellite orbiting it or if we send a spacecraft to orbit the planet. I won’t go into the detailed calculations that involve Kepler’s Third Law and Newton’s Universal Law of Gravitation (Image 19).

You can see the transit of Venus here on this YouTube video - it is a spectacular thing to watch! The idea here is that when Venus transits in front of the Sun, we can measure how much 1 AU is. How? A person on one side of Earth sees the transit of Venus 4 minutes earlier than a person on the other side. When you do the calculations, you find that 1 AU is 150 million kilometers. Once you know this, you can figure out how big Jupiter is when you look at it in the sky! That’s how we have precise calculations of Jupiter’s radius, mass and its density.

The same experiments can be done with the other giant planets too - Saturn, Uranus and Neptune. Mars has two moons of its own and that’s how we figured out its density. Mercury and Venus don’t have any moons and that’s why we figured out their densities when...
spacecrafts flew by and we calculated the perturbation of the spacecraft during the flyby. Saturn has an even lower density of 0.7 g/cm³ although it is smaller than Jupiter. What is worth noticing is that Uranus and Neptune are significantly smaller than Jupiter and Saturn, but they have higher densities and relatively similar densities besides that - 1.2 and 1.6 g/cm³ respectively. This means that they are composed of **much more dense material**. That’s why Uranus and Neptune are often called **ice giants**, in contrast with Jupiter and Saturn that are **gas giants**! We will talk more about this later in this article.

So, finally we know how to calculate the density of the massive planet Jupiter! Let’s see a couple more interesting concepts that are key to take into consideration in order to understand what the internal structure of the big planet Jupiter is. These concepts are **hydrostatic equilibrium** and **heat transport**.

**Hydrostatic Equilibrium and Heat Transport**

We already know how to calculate the mass and volume of Jupiter and we know that the surface composition of the planet is **gaseous** with ~ 75% hydrogen and ~ 25% helium composition. We also know that there are enormous pressures when you go deeper into the planet. A logical question that comes up is **how can we figure out what are the pressures inside Jupiter?**

Here we will make an assumption that Jupiter is in **hydrostatic equilibrium**. This means that its interior behaves like a stationary liquid that balances on itself. When we say that something is in hydrostatic equilibrium, we don’t mean that there is a lot of motion in its interior or that there is a lot of heat that makes everything boil, but we mean that it is simply a stationary fluid! This might seem counter-intuitive and strange at first reading since we said that Jupiter’s composition is mainly hydrogen and helium and they are gases, but hydrostatic equilibrium can be a pretty good assumption for all the planets, even for Earth, or the Earth’s atmosphere. Hydrostatic equilibrium is simply the balance between all the weight of all the material that is above you and the pressure of you (**Image 21**)! We also know that Jupiter’s surface temperature is **-143 degrees Celsius** as we said earlier. Nevertheless, it is not a cold dead place, but it has **a lot of heat in it** left over by its formation billions of years ago. Earth also has such a heat and it can be felt if you go inside of a mine that is a kilometer deep (**Image 22**). When you are inside the mine, you can feel the heat that is being conducted through the rocks to escape out into space. In fact, the removal of heat is the single most important task that a planet has and Earth does it very efficiently through **conduction, plate tectonics and volcanoes**.

![Image 22: Mines deep inside Earth](image22)

A material that has high conductivity can transfer heat very quickly and doesn’t need to be heated a lot, but a material that has low conductivity (wood) needs high temperature in order to conduct heat (**if any**, **Image 23**).

![Image 23: Metal - Wooden rod](image23)

Jupiter, as we said, is made primarily of molecular hydrogen and it has very low conductivity. In fact, to get heat flowing out of the surface of Jupiter its interior needs to be ~ 2 million degrees K hot! That’s insane, so something must be happening to hydrogen that makes it a more conductive material. It turns out that this is the part where **heat transport** plays a role! We know that
there is heat coming from within Jupiter, because we can measure the emission coming from its photosphere and we found out that there is **1.5 times** more energy than can be explained by only heating from sunlight. All this energy comes from the cooling of the planet’s interior. Through the adiabatic process of convection, the interior of Jupiter has been cooled down. *(You don’t need to know what an adiabatic is, except that generally it is the temperature change of a parcel of material when it goes up or down in a planet due to something like the ideal gas law.)* As the pressure increases when you go deeper into the planet, the temperature increases too and molecular hydrogen (**H₂**) turns into metallic hydrogen (**H⁺**) which is 100 times more conductive *(Image 24)*.

**Why are the temperature and pressure of Jupiter relevant?** Because they give us data about how this molecular hydrogen turns into metallic hydrogen when the temperature increases from -143 degrees Celsius on the surface to ~ 9700 degrees Celsius in the interior of the planet.

The same thing happens to hydrogen when under great pressure and at very high temperature - it becomes a **liquid substance**. This is why the interior of Jupiter has high conductivity and this is why Jupiter has a **powerful magnetic field**!

We know now that Jupiter is made out of gas, we made the correct assumption that the planet is in hydrostatic equilibrium, we know that it emits heat and we know that under high pressures and temperatures its molecular hydrogen turns into metallic hydrogen.

**How can we use all these to match two simple observations that we have done - the radius and mass of Jupiter?**

**Theoretical Internal Structure of Jupiter**

To start constructing Jupiter with all the concepts and knowledge that we have so far, **we start from the top layer** of material on the surface of Jupiter where we know what the temperature is, we know the phase of the material (**H₂**), we know the energy that is being dissipated from the surface and we go one layer down towards the center of the planet. We can calculate what the pressure and temperature are in this new layer. We do the same thing going layers down, at some point the molecular hydrogen turns into metallic hydrogen, we take that into consideration in our calculations and we continue to go down and calculate temperature, radius, mass and pressure **until we reach the center of the planet**.

At this point either all the mass that we used in our calculations is used up and it **perfectly** matches with the mass of Jupiter or we end up with mass left over. This redundancy means that if a planet with the **mass** and **radius** of Jupiter (in other words a planet with the **density** of Jupiter) is constructed **only** of hydrogen and helium, it would fall on the **H+He line (Figure)**, but
Jupiter falls a little bit below that line, which means that it is a little smaller than it should be (Image 26). Why?

Because there should be heavier materials than hydrogen and helium in Jupiter, either nicely mixed up in the planet or in the form of a core in the center, these heavier elements contract Jupiter a little bit. The giant planet is composed of hydrogen and helium and has a core of heavier materials in the center. In fact the graph above shows a line that represents a planet that is mostly hydrogen and helium and has a core of 15 Earth masses!

Now we have a theoretical understanding of what is inside Jupiter, but there are still uncertainties as to what is the real ratio between the hydrogen and helium inside the planet, is there really anything else besides those two elements in larger quantities and if there is something more - is it distributed uniformly throughout the planet or is it in the form of a planetary core? (Image 27)

Let’s see how gravity on its own can help us reveal what’s inside Jupiter.

A Core from Gravity

We already know that Jupiter rotates very fast and that this motion makes the planet a little oblong along its equator due to the centrifugal force. This means that a spacecraft that orbits Jupiter would feel more gravitational pull over Jupiter’s equator than over its poles … unless Jupiter has a core of solid material! In this case the spacecraft will feel a proportionately more gravity on the poles than it experiences over the equator. These measurements are very subtle, but the tracking of the spacecrafts that we have sent to Jupiter is so good nowadays that we can measure such differences with great accuracy.

If a spacecraft is in an orbit far away from Jupiter, it won’t be able to differentiate the subtleties we are talking about here, but as it approaches the surface of the planet it will be able to measure the difference in the gravitational pull (Image 29). In real life, the material inside of Jupiter will be denser and denser the closer you get to the center of the planet. The closer the spacecraft gets to the planet, the more subtle those variations become between the elongation of these layers and the gravitational pull that they feel.

We don’t have such a spacecraft to make these measurements yet, but the Juno spacecraft is on its
way to Jupiter right now and its mission is to do exactly that! The Cassini spacecraft (Image 30) that orbits Saturn and its moons has managed to make some rough measurements, but as its mission approaches the end of its life, Cassini will be thrown into an orbit very close to Saturn’s surface and it will be able to make such measurements, not for Jupiter, but for Saturn and will be able to give an appropriate picture of what Saturn’s density structure is like.

With the moderate measurements that we have today, it is consistent to claim that Jupiter has a core made out of heavy materials. This 15 Earth masses core is a huge clue to how Jupiter assembled itself from the original material of the solar system. This theoretical core is probable, but not 100% certain! This is what Juno will find out (Image 32).

The Juno Spacecraft

The Juno spacecraft is part of the Juno mission to determine what is inside Jupiter. It won’t take fancy pictures of the planet and its moons, but it is specially equipped to measure what is on the inside. There are several key things about how Juno will make these measurements.

The spacecraft will be able to tell us if there is a core in the center of Jupiter by making very close flybys to its surface - a part of very elongated orbits passing by Jupiter’s north and south poles. Why are Juno’s orbits so elongated? (Image 33) The reason is that the spacecraft cannot spend much time very close to Jupiter, because it will get destroyed by the planet’s radiation and that’s why it will make these daring voyages near the surface and then screams back out at a distance from the planet. Juno will also measure the very small deviations of the magnetic field of Jupiter that are detectable when the spacecraft passes by on its closest approach. Juno’s instruments will also be able to probe at some (not a lot) distance beneath Jupiter’s clouds and to measure the abundance of water in the planet.
We touched briefly upon the fact that Jupiter has a huge magnetic field, but let’s explore it more now. Let me tell you an interesting story about the giant magnetic field of Jupiter!

Jupiter’s Magnetic Field

In 1955 astronomers built a big radio telescope in the USA. When we think today about a huge radio telescope, we imagine one of those huge dishes that NASA Deep Space Network has that stare off into space. This telescope, however, consisted of an array of antennas that formed a big cross across a field (Image 34). These antennas were designed to scan and pick up very low frequency radio waves that come from intergalactic space. Such low frequency radio emissions come from electrons spinning around the magnetic field line of an object and giving off radiation as it goes. This radiation can be detected and mapped using these antennas.

Back in 1955, when these astronomers were doing this, every once in a while they got a little burst of energy coming in. This didn’t happen consistently, but from time to time. They thought that it might be from cars passing by on the nearby road, but with time they noticed that these bursts came each night 4 minutes earlier than the night before. This meant that this phenomenon is not something random, but something that happens periodically and is associated with space, and not with Earth.

It turned out that as Jupiter rose on the night sky 4 minutes earlier each night, they detected this burst of energy with their giant telescope. It probably would have been easier to make the connection if this burst was every night, but it was sporadic. What was happening? Why did these astronomers detect these bursts of energy only at those nights when Jupiter rose in the night sky? It was because Jupiter has a giant magnetic field! In fact, Jupiter has the strongest magnetic field of all the planets in the solar system. It also has a small moon called Io that is very close to it (a little farther than our Moon is from Earth) (Image 35). Io has active volcanoes on its surface that spew off material into space and if these materials get ionized (that is if the electrons are removed from the atoms of the molecules), those electrons spiral down and slam into Jupiter’s poles (Image 36).

This is the same process that creates the Auroras that we observe here on Earth, but our auroras are created by the solar wind (the Moon doesn’t have active volcanoes) (Image 37). This slamming of electrons on Jupiter’s poles is what creates those emissions, but they are directed in a certain direction like a lighthouse and astronomers on Earth can detect them with their telescopes only when those emissions point to Earth. That’s why the astronomers in 1955 got only sporadic emissions. They didn’t know about Io and its volcanoes but they knew the general picture.

Today we know that Jupiter has auroras and those auroras are a product of its magnetic field.
Let’s observe these images from the Hubble Space Telescope. You can see Jupiter’s auroras on them, but what you will notice by looking at them is that the auroras are a little tilted (about 10 degrees) and offset from the vertical line of Jupiter’s rotation. This is because Jupiter’s magnetic field is an offset tilted dipole (Image 38). This means that the rotation axis of the planet is a little offset and tilted from its magnetic field. It is amazing how much you can learn by looking at aurora images of a planet!

Magnetic fields around astrophysical objects are created by a dynamo. You need three conditions to create this dynamo. First, the planet must have a conducting liquid inside it. In the case of Earth, this conducting liquid is liquid iron; in the case of Jupiter it is the liquid metallic hydrogen we talked about, formed under the enormous pressures in the depths of the planet. Second, the planet must have a convection process inside as a way to get rid of its internal heat. This happens by rising and falling of the conductive liquid. Third, the planet must rotate! Even if a planet had a conducting liquid, without rotation there would not be any magnetic field.

In the case of Jupiter, in its center there is (most probably) this solid mass of 15 Earth masses, as we said, and then there is this moving metallic hydrogen that rises and falls inside the planet. This, combined with Jupiter’s fast rotation speed, creates a huge Coriolis force inside the planet and creates a dynamo that is responsible for the strong magnetic field that the planet has. The details of this process are not exactly known and once again, the Juno spacecraft that is on its way to Jupiter right now will be able to give us the answers to these questions: is there a core inside Jupiter and how exactly does its magnetic field work?

Jupiter Picture Models

We have gathered so much information about Jupiter. We learned about its density, we sent a probe into its atmosphere and we looked at its gravitational and magnetic fields. Let’s put all this together and see what we know about the biggest planet in our solar system.

Here is a picture of what we think Jupiter’s interior looks like (Image 39):

The outermost layer of Jupiter is made of molecular hydrogen (H₂) with ~ 23% helium and this is something that the Galileo probe measured when it dove into Jupiter’s atmosphere. It is expected that this upper envelope is homogeneous in nature. This means that whatever the Galileo probe measured in its spot, is expected to be everywhere in this upper layer. The only exception is the water (H₂O) deficiency that was due to the specific location - a dry hole - that the probe went into.

As we go deeper into Jupiter, the molecular hydrogen turns into metallic hydrogen due to the enormous pressures. An interesting phenomenon is that the amount of helium grows when we go deeper. This is due to the fact that when hydrogen and helium are mixed under enormous pressures, the helium forms its own droplets and it doesn’t dissolve in hydrogen particularly well - the same way as water and oil don’t mix up very well. As this happens - these islands of helium that are formed in the otherwise hydrogen atmosphere - helium becomes denser and heavier than hydrogen and starts falling down deeper - helium rain from the upper envelope into the deeper sections of Jupiter (look at the diagram above) (Image 40). These deeper sections are where the metallic hydrogen is
formed. This metallic hydrogen and its convective properties are responsible for the magnetic field generation. Way down into Jupiter’s center where the pressure is ~ 40 Mbars and the temperature is ~ 20,000K, we speculate with a big amount of certainty that there is this solid core, made out of ice and rocks with a mass of ~ 15 Earth masses.

Is this solid core in the center of Jupiter actually solid or is it a mushy mixture of heavier materials that are stirred up by the convection in the metallic hydrogen layer like a piece of sugar at the bottom of a cup of coffee?
Is there a clear borderline between the solid material and the metallic hydrogen?
Did this core form first when the planet formed or did the material for it appear later from little Earth-like pieces or comets falling into the already formed gas giant Jupiter?
We don’t have exact answers to these questions at this moment.

Understanding the structure of this core interior of Jupiter and particularly the heavy materials in it is really one of the keys to try to understand the formation of Jupiter and the giant planets like it.

Saturn, Uranus and Neptune - the rest of the giant planets in our solar system

We have spent all this time talking about Jupiter and its interior and we concluded that there is no solid ground where you can set foot on Jupiter, but there is most probably a rocky core in its center under enormous pressure and high temperature. So, if you are an alien who holds this manual and you want to conquer new space territories, Jupiter is certainly a very interesting celestial object, but let’s have a brief look at the other giant planets in our solar system. Saturn is the sixth planet away from the Sun and the most distant planet normally visible to the naked eye. It is a magnificent gas giant with a composition dominated by hydrogen and helium and it has a bulging equator and an internal energy source. Saturn is the least dense planet in our solar system. It falls even lower than Jupiter on the H+He line which means that if we are not a hundred percent sure if Jupiter has a rocky core, that is certainly the case for Saturn! (look again at Image 18) Saturn’s central core is ~ 10 - 20 times the mass of Earth! This gas giant, with its spectacular system of rings and a large family of moons, has no excuses and is ready to be conquered by alien feet.

Saturn’s mass is only 95 times that of Earth and yet ~ 760 Earths could fit inside it. This second largest giant in our solar system has many similarities to Jupiter and yet it looks so unique. As we said earlier in the article, Saturn’s density is only 0.7 g/cm³ and is so light that if put in an ocean of water, it would float (Image 41). The planet has no discernable surface: its outer layer is gaseous atmosphere, so it can delude you at first sight.

Inside the planet, though, pressure and temperature increase with depth and the hydrogen and helium molecules are forced closer and closer together until they become fluid. Deeper still, the atoms are stripped of their electrons and act as a liquid metal. Electric currents within this region generate a magnetic field ~ 70 percent the strength of Earth’s. This is very similar to Jupiter!
Let’s go beyond Saturn to the farther parts of our solar system where there are 2 more planets - Uranus and Neptune (Image 43) (Yes, Pluto is not a planet, but a dwarf planet - sorry!).

Uranus was the first planet discovered by a telescope by Sir William Herschel who observed it in 1781 from the garden of his house in England. Nevertheless, Uranus had been observed on many occasions before him, but it was never recognized as a planet, because of its dimness and slow orbit - 84 years! (so, the lucky ones of us on Earth who live up to 84 years, are only 1 Uranus year old!) Something that is not necessarily recognizable at first sight (because we often see pictures of our solar system off-scale in books) is that Uranus and Neptune are much smaller than Jupiter and Saturn and are approximately the same size. In fact, these two most distant planets are much closer to Earth in size - only 4 times bigger in diameter than Earth. If you are the same alien traveling through our solar system, you will observe that Uranus is a planet with very interesting properties. It has a retrograde motion around its axis, meaning that it rotates in a direction opposite of its orbit around the Sun. Uranus is also unusually tilted more than 90 degrees according to the celestial plane, which means that its axial tilt almost aligns with the celestial plane (Image 44). This can be explained with a huge impact with an Earth-sized protoplanet during its early formation.

We don’t really know that much about the interiors of Uranus and Neptune, because only one spacecraft - Voyager 2 - has passed by them on its way out of the solar system, but what we observe is that the outer layer of these two distant planets is molecular hydrogen, but underneath it there is a lot of compressed ice that increases their densities (Image 42) and maybe little rock cores in their centers. In some regions near the top of the compressed ice layers there may be a convection layer of salty material that is causing a dynamo and it helps to explain why the magnetic fields of Uranus and Neptune are not dipolar.

Overall we can say that Jupiter and Saturn are exceedingly similar planets which main composition is hydrogen and helium and that’s why they can be called gas giants! Uranus and Neptune, in contrast, are ice giants, because they are really giant ice balls with a little bit of hydrogen atmosphere on their tops.

One might ask the question why the gas giants have so much gas and the ice giants have so little.

One possible explanation is that by looking at the giant planets, we are looking at the history of gas in our solar system. Jupiter was the first planet that formed in our solar system and it started feeding itself with all the gas around the middle of the solar system. Shortly after that Saturn did the same with most of the rest of the gas and by the time when Uranus and Neptune formed their cores, which took longer, because they are so far away, there was simply very little gas left for them, because all the gas that was left was slowly being blown away from the solar system and lost into space. Uranus and Neptune really had the last gasp of gas they could grab onto and they didn’t get much of it.

Jupiter through the eyes of an alien

So, if you are an alien visiting our solar system, Jupiter will definitely be the first celestial object that attracts your attention. That is not surprising - Jupiter is a spectacular sight - a giant, massive planet, full of interesting features. If you are close to Jupiter, dear
alien, I must congratulate you, because you definitely have mastered the radiation shielding technology. Your spaceship must be very well protected from the radiation and magnetic field with which Jupiter blasts the whole cosmic neighborhood around it. As mighty as you are, though, dear alien, you will be surprised to notice, when you go closer to Jupiter that you have nowhere to land, because this planet is made primarily out of hydrogen. Don't worry, though, you might visit one of its moons - Europa! We, humans, think that this wonderful moon has more water than we have here on Earth and might be a place in our solar system that harbors extraterrestrial life! You might go check it out for us, or not! No, don't tell us what you found there, because we want to explore and learn by ourselves. We are explorers! We live and thrive through exploration!

Not so long ago in cosmic terms we discovered the fire, then the wheel and how we can go from here to there faster than walking. After that we discovered that we can save our thoughts and memories on paper by writing and we noticed that it is better if we stay together in cities. We started exploring our planet and reached new continents and we thought we had reached the end of the world! Then we realized that it is not the end of the world, but that our planet is actually round! Then we looked up at the stars and saw the universe in its glory. We discovered that we are not in shackles on our planet and that we can actually fly in space! How cool is that?! We built the eighth wonder of the World - an orbital complex circling around our beautiful planet every hour and a half. So, don't spoil it for us, alien friend, because we want to know. We already know so much about our solar system and its planets that we decided that we don't need nine of them and threw one away from the list - the farthest one from the Sun, because it doesn't have a high enough status among other things. But we know so much about our giant planets - so much! So, you, little alien, yes, you - the one that is here on Earth and is about to make the next giant leap in exploration and conquer Mars and Jupiter - pick up your binoculars and look at Jupiter and the Galilean moons tonight (Image 47), because this is what separates us from the animals - we stand straight so that we can look at the stars!
Put on Your Stereo Glasses

by Tihomir Dimitrov
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