cosmic neighbours

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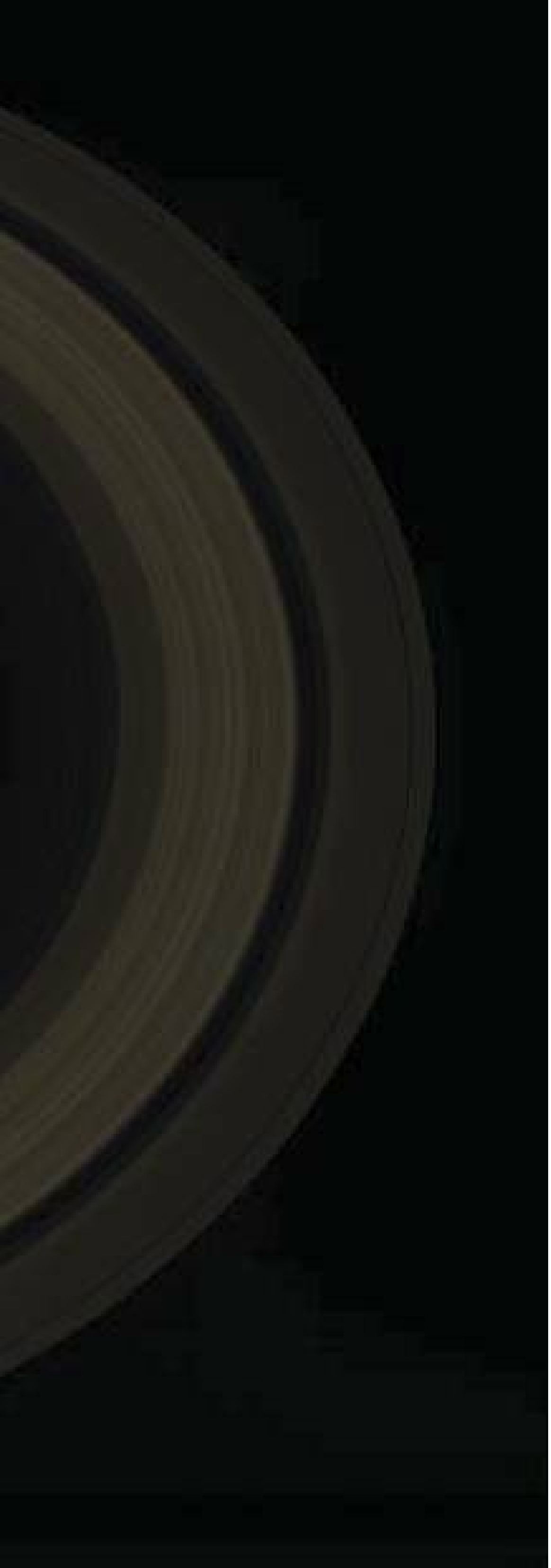


Introducción

The Sun and the planets have always been a part of human imagination. We cannot be sure of what was thought of them prehistorically when they were observed moving through the celestial sphere, but the most ancient civilizations thought them to be holy and considered them the incarnation of their gods.

Some of us (at least for the moment) will travel on spacecrafts that will take us through the Solar System, showing us not just what we already know but also what our species has never explored. Let us begin, then, a journey that will reveal to us the main features of the Solar System, a journey that can take us far in terms of understanding and exploration.

These few pages are a short travel guide through the Solar System. In them, we will find a description of the main characteristics, special features and some fun facts about our closest cosmic neighbours.

Figure. 1: Saturn and its rings, the most beautiful planet of the Solar System. (Source: NASA)

Formation of the planetary system

Stars are formed from huge clouds of gas and dust that collapses. The collapse causes the temperature and density to rise and leads to hydrogen fusion reactions; in that moment we can say a star is born.

The original cloud keeps spinning, and as it collapses, it spins swiftly, just like an ice skater drawing his or her arms close to the body. Then, the gas in the equatorial zone suffers a centrifugal force (like the car turning at a bend) that is counteracted to some extent by the collapse. This only happens close to the 'poles' of the cloud, while the gas at the centre spins at high velocity. Thus, the cloud ends up forming a protostar surrounded by an equatorial disc made out of gas (and some dust). In the disc, particles of dust and ice reunite to form small grains, pebbles and, eventually, planets. The greatest of them attract large quantities of gas (mainly hydrogen and helium) to form gaseous planets.

We cannot confirm that this process definitely occurred in the Solar System, because it happened more than 4500 million years ago. But this process has been confirmed by observing young stars close by, around which many discs of gas and dust have been discovered. Almost two thousand exoplanets have been already found, and it is believed that approximately half of the stars in the galaxy possess their own planetary system.

All the bodies in a planetary system spin around its star following elliptic orbits (except for the satellites that spin around a planet).

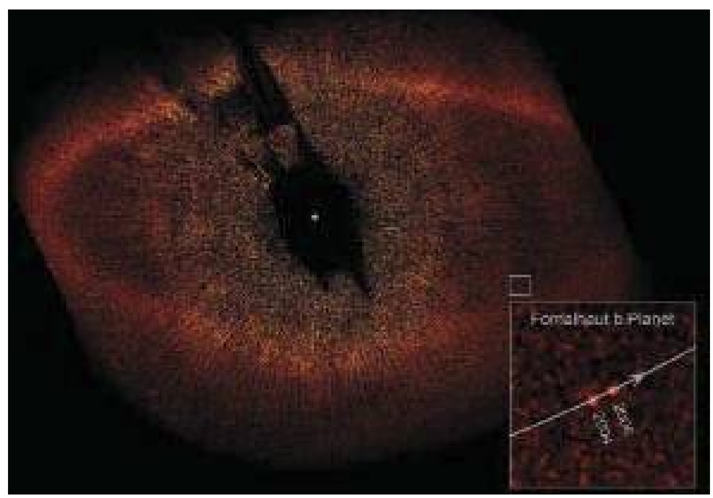


Figure 2. Disc of dust and planets surrounding Fomalhault (Source: NASA, ESA)

Drawing an ellipse

Cut a piece of thread and tie the ends to form a loop. Place a piece of paper on a cardboard and put two thumbtacks at a distance. The thumbtacks mark the focal points of your ellipse. Suspend the loop on the thumbtacks. With the tip of a pen we push the thread until it is tense and, keeping it that way, move the pen around, drawing a round on the paper. This is an ellipse: An ellipse is a set of points in an oval shape. The sum of the distance from any point in this set to the focal points (where the thumbtacks were fixed) is a constant value. This value is equal to the length of the thread.

It is a good idea to repeat this by increasing or decreasing the distance between the thumbtacks: increasing the distance will produce an elongated ellipse, and decreasing the distance will produce a round. Nailing the loop with a single thumbtack will produce a circumference. Planets spin in elliptic orbits with the Sun as the focus, but they are almost circumferences. Comets, on the other hand, follow very elongated elliptic orbits.

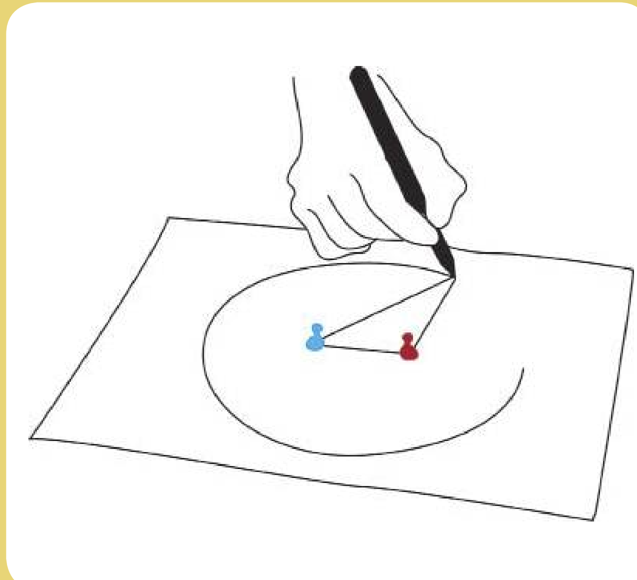


Figure. 3: Drawing an ellipse

What is the Solar System?

The Solar System consists of the Sun, eight planets with their satellites, dwarf planets, asteroids, objects in the Kuiper belt, smaller bodies such as comets and meteoroids and clouds of gas and dust between them. All these objects spin around the Sun, with the exception of the satellites, which spin around their planets following the elliptic orbits. For planets, satellites and many asteroids, the elliptic orbits are almost identical to their circumference. The gravitational force acts on all these objects.

The members of the Solar System are found in this order: Mercury, Venus, Earth, Mars, belt of asteroids (though asteroids are scattered all around the Solar System), Jupiter, Saturn, Uranus, Neptune, the Kuiper belt and, even further away, the Oort cloud and a huge frozen collection of thousands of millions of comets.

	Diameter (km)	Distance to the Sun (km)
Sun	1 392 000	
Mercury	4 878	57 900 000
Venus	12 180	108 300 000
Earth	12 756	149 700 000
Mars	6 760	228 100 000
Belt of Asteroids		300 000 000 – 500 000 000
Jupiter	142 800	778 700 000
Saturn	120 000	1 430 100 000
Uranus	50 000	2 876 500 000
Neptune	45 000	4 506 600 000
The Kuiper belt		4 500 000 000 - 15 000 000 000

Diameter size model

Basta considerar los diámetros reales It is enough to consider the real diameters of the objects in centimetres and divide them by 1,000,000,000 to obtain a scaled-to-size model.

On paper or yellow cloth, cut a circle with a diameter of 1.4 metres to represent the Sun. Inside this circle, paste the 8 planets of the Solar System, whose diameters should be

Mercury 0.5 cm
Venus 1.2 cm
Earth 1.3 cm
Mars 0.7 cm
Jupiter 14 cm
Saturn 12 cm
Uranus 5 cm
Neptune 4.5 cm

We can colour the planets by looking at their images available on the Internet.

Then, paste the planets on the surface of the Sun. It is important to note that the obtained effect is similar to the one visible when Venus or Mercury transit across the Sun. The only difference is that we would see a black disc, instead of a colourful planet, because the planet cannot reflect the light that reaches it from the Sun.

Figure. 4: Sun and the planets of the Solar System.

Orbit size model

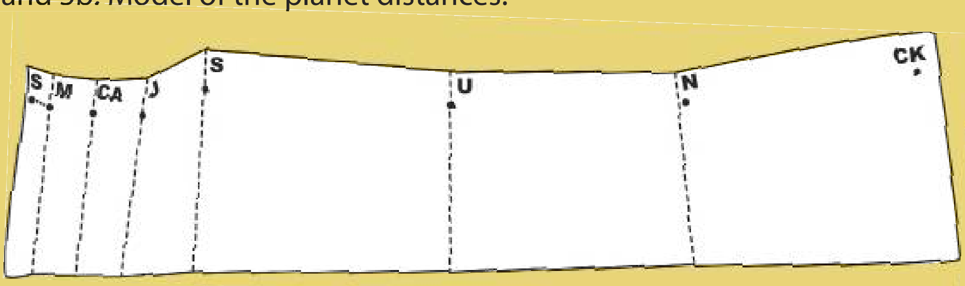
The distance of a planet to the Sun is, approximately, half of that of the next planet to the Sun; for example, the distance from Jupiter to the Sun is half of the distance from Saturn to the Sun.

This activity will allow us to perceive the relative distance between objects of the Solar System with the help of an A4 or A3 sheet of paper.

On the right border of the sheet, write an S to represent the Sun, and on the left border, write KB for the Kuiper belt. Fold the paper in half, and position Uranus along that fold, with a U. Fold the paper once again in the middle between U and KB, and write an N on the fold for Neptune. If we fold again along the middle between S and U, we have Saturn's position, which we represent with Sa. Fold the paper again between the Sun and Saturn, and in the same way, write J for Jupiter on the fold. Fold again between the Sun and Jupiter for positioning the belt of asteroids (BA). Fold in the middle between S and BA to position Mars, with an M.

Finally, divide the distance between the Sun and Mars into four parts for the positions of Mercury, Venus and Earth, represented by Me, V and E (Figure 5). Although this model does not give an exact picture of the real distances of the planets from the Sun, it is simple and shows in an intuitive way the relative distances, which is the intention of the activity.

Figures 5a and 5b: Model of the planet distances.



Comparing diameters and distances

It would be interesting to present a model in which we can have scaled distances along with scaled planet sizes. A balance between the distances must be achieved so that they are not too big and, at the same time, the diameters should be adjusted so that the planets are not rendered invisible. A good option is considering all the values in metres and dividing all the values by 5,000,000. The results of the scale are shown in the following table.

Start by placing the basketball, which represents the Sun, in a corner of the school's yard. Mercury, which is a pinhead, should be placed at distance of 12 m (a step is approximately a meter). Venus and Earth, two slightly bigger pinheads, should be placed at 22 m and 30 m from the Sun, but not directly behind Mercury. Place Mars, another pinhead like Mercury, at 46 m. Normally this is the extent of the Solar System that can lie inside a school yard.

	Diameters	Distance to the Sun
Sun	28.0 cm – basketball	
Mercury	0.1 cm – pinhead	12 m
Venus	0.2 cm – pinhead	22 m
Earth	0.2 cm – pinhead	30 m
Mars	0.1 cm – pinhead	46 m
Jupiter	3 cm – golf ball	155 m
Saturn	2.5 cm – ping-pong ball	285 m
Uranus	1.0 cm – marble	575 m
Neptune	1.0 cm – marble	900 m

We can build the whole system if we place the planets on a public park or on many streets, in different directions, provided the streets are long enough, as Neptune is 900 m away from the starting point.

We can use golf balls for Jupiter at 155 m, a ping-pong ball for Saturn at 285 m and two marbles for Uranus and Neptune at 575 m and 900 m, respectively.

Figure 6: Solar System model displayed across a city.

Sun

Being 4.6 billion years old, the Sun has lived half its lifetime. Every second the solar core transforms 4 million tons of matter into a huge amount of energy (that we partially perceive as visible radiation when it emerges from its surface) and some evasive particles called neutrinos*.

The Sun has quite an intense and complex magnetic field that constantly changes and that periodically gives rise to great activity. The magnetic field lines arise from the surface and create sunspots. These appear dark on the Sun's surface because they are colder that the rest of the surface: at 'just' 4,000ºC, when the average temperature is around 5,500ºC.

*For more details, look up the book 'Stars party' from the same collection.
**For more details, look up the book 'Looking for the north' from the same collection.

Given that, the Sun is a gas ball; its rotation distorts the magnetic fields, causing them to break up, which produces explosions of high energy particles (flashings) and expulsions of mass from the crown (Figure 7). The Sun continuously emits solar wind, a faint breeze made up mainly of protons, iron nucleus and electrons.

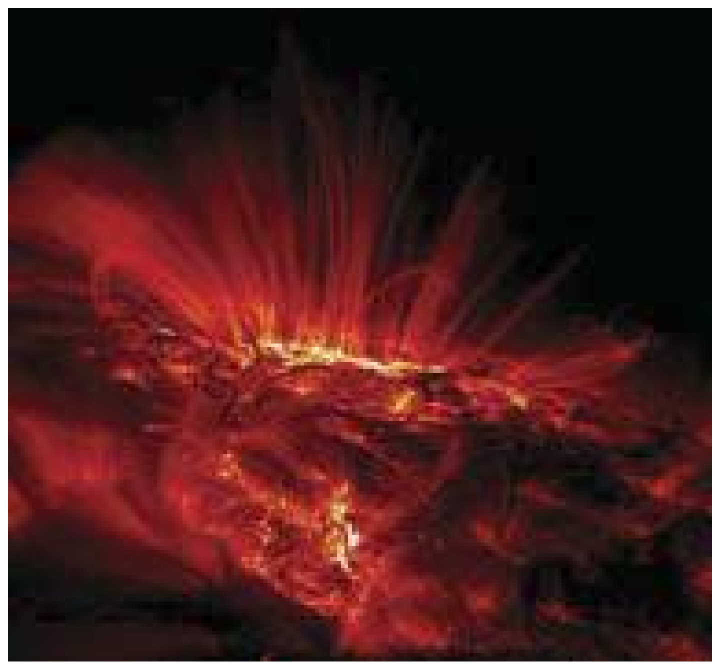


Figure 7: Details of the sunspots and the flashings that they produce. (Source: TRACE)

Observing the sunspots

Observing the Sun is dangerous because of its intense blaze and the ultraviolet rays emitted by the solar crown, which can cause serious ocular damage.

To observe the sunspots we use a pair of binoculars, although not directly and always with the help of an adult. The Sun should not be looked at through them, but instead they are used to project the image of the Sun on a cardboard screen.

Uncover just one of the two lenses and cut a hole in a square cardboard such that it fits the lens. Now, hold another cardboard screen behind the binoculars so that the solar disc stands out in the shadowed zone. Point the lens to the Sun without looking through it, just feeling about its position and watch the shadows on the cardboard.

Figure 8: Observing the sunspots with a pair of binoculars

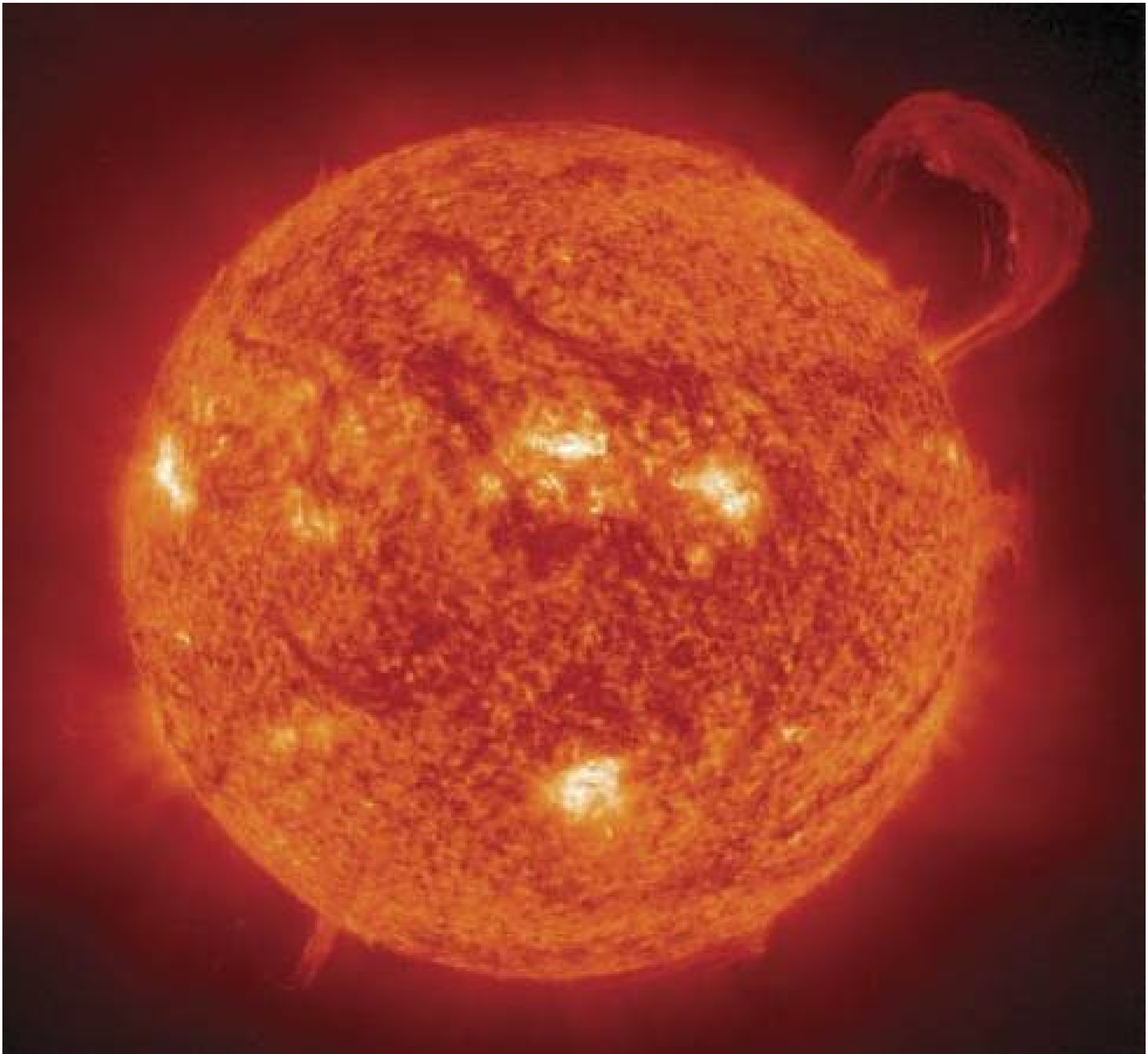


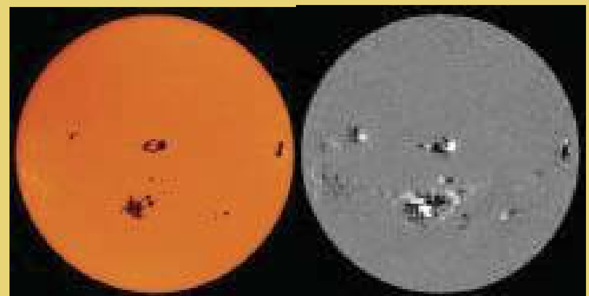
Figure. 9 Image of the Sun showing great activity as a consequence of its intense magnetic field. (Source: NASA)

Sunspots and magnetic field lines model

To visualize the magnetic field lines that produce the sunspots, we use some magnets over the Sun's picture (Figure 9).

Print a picture of the Sun (Figure 9) and stick little circular magnets on a pair of sunspots such that the north pole of one magnet is on the top and the north pole of the other is on the bottom. Then place a horseshoe-shaped magnet on them so that we can visualize the magnetic field lines associated with a pair of sunspots on the solar surface, which in some cases generates huge flashings. The horseshoe magnet can be replaced by a piece of pipe cleaner that can be placed on top of the circular magnets (Figure 11).

These ejections, thanks to the solar winds, are carried to the magnetic fields of other planets, including our own, and produce auroras. In fact, auroras have been observed on Jupiter, Saturn and Neptune, in addition to Earth.



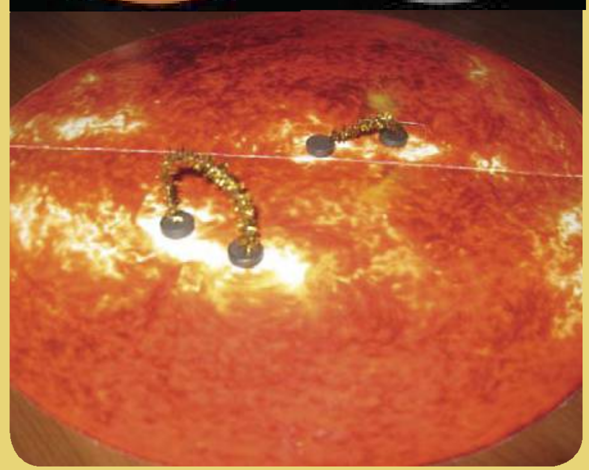


Figure 10a: Image of the Sun on the visible spectrum (out of tune colour). Figure 10b: Black and white magnetic image of the Sun to show the polarity of the sunspots. White corresponds to the south pole and black to the north pole of the spot. Figure 11: Pipe cleaner model.

Mercury

Figure 12: Mercury, the messenger of the Gods.

Mercury is the smallest planet on the Solar System (though not much smaller than Mars) and the closest to the Sun. That is why it rotates at a fast pace. The Greeks believed it was the messenger of the Gods, because of the swiftness of its movement through the celestial vault (Figure 12).

Because of its proximity to the Sun, Mercury is unable to maintain a perceptible atmosphere. Its surface resembles that of the Moon, since it's riddled with impact craters of all sizes (including the huge Carolis Basin, which resulted from an impact with an object that was hundreds of kilometres in diameter).

Mercurio posee otra peculiaridad: su Mercury has another peculiarity: its day lasts for 59 Earth days, its year for 88 Earth years and the time between two consecutive sunrises is 176 days: two Mercury years! The illuminated zone reaches terrible temperatures, even more than 600ºC, while in the night time it drops down to –150ºC!

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Figure 13: Mercury's surface

Impact crater model

We can create an impact crater model using flour and cocoa powder. To begin with, the floor must be covered with newspapers so as not to make it dirty and to simplify the cleaning process once the activity is over. In fact, it also allows us to reuse the material the next time the activity is repeated.

Spread a flat layer of flour, about 1 or 2 cm high, with a strainer to avoid lumps. Next, spread a thin layer (a few millimetres) of cocoa powder over the flour with the strainer. Then, from height of about 2 m (achieved by raising our arms over our heads), drop a soupspoon of cocoa power that will leave stains similar to the craters seen on the surface of Mercury and on many other bodies on the Solar System.

To continue the experiment, we can throw different balls or little stones of different sizes on the flour surface. They can be thrown in a straight line from the top or with some inclination. We can create these experiments with a flour surface or with a clay surface, but it is important to remember that the material layer that will receive the impact should be thick, otherwise the thrown object will bounce on the surface under the flour or clay.

Figure 14: Flower and cocoa craters

Venus

Figure 15: Roman goddess of beauty.

In its brightest moments, it is the brightest object in the sky after the Sun and the Moon. Although a planet, it is known as the 'morning star' (when it is seen before sunrise) or as the 'evening star' (when seen after sunset). The Romans named it after the goddess of love and beauty (Figure 15).

It is a rocky planet with a dense atmosphere: its pressure is ninety times that of Earth. The air is basically made up of carbon dioxide (CO_2), and it produces the biggest greenhouse effect in the whole Solar System, with an average surface temperature of 460ºC (greater that the average temperature of Mercury, and much greater, fortunately, than that of the Earth) (Figure 16).

A perpetual layer of clouds crowns the dense atmosphere. In more than 400 years of observation, no clearing has allowed us to observe the surface of Venus. The clouds, among other components, contain sulphuric acid, and it is believed that acid rains occur on Venus.

Figure 16: The layer of clouds on Venus is so thick that it does not allow us to see its surface.

Greenhouse effect model

Take two glass pots covered with lids and two thermometers. Make a hole in the lids of a diameter slightly bigger than that of the thermometers. One of these pots should have Earth's atmosphere (easy to do, since we are performing the experiment on Earth), and the other one should have a composition more similar to that of Venus, i.e., it should have an abundance of CO_2.

To achieve that, insert a straw through the hole and blow into the pot. The air we exhale is full of CO_2. Next, introduce the thermometers into the pots through the holes and use clay to seal the holes so that the outside air does not enter the pots. The bottom end of the thermometers should not touch the walls or the bottom of the pot. Place a piece of paper on the bottom of the pots so that the papers shield the thermometers from direct sunlight. Once this is done, place the pots under sunlight and, after some time, compare the temperature readings on both the thermometers. You will see that the reading for the pot with CO_2 is higher, which is what happens on Venus.

Figure 17: Greenhouse effect model

The experiment can also be repeated with the pots painted in white or black or wrapped in aluminium paper. The results can then be compared.

Earth

It is the only planet in the Universe that is known to host life. Formed 4570 million years ago, it is covered mostly by water (71%), and only 29% of its surface is solid and dry. In reality, the amount of water on Earth is much less than the total amount of rock. Its superficial temperature is very variable, but the average is 15ºC, neither too high nor too low, which provides the necessary conditions for liquid water to exist on its surface and for life to develop.

Terrestrial life has greatly influenced the properties of the planet (or, at least, of the part of the planet accessible to us). Thus, our atmosphere is composed of an extraordinary 21% of free oxygen (different from that of Venus and Mars), which indicates the presence of photosynthetic organisms, who release free oxygen. If we were to eliminate all life on Earth, the oxygen in the air would quickly combine with the materials on the crust and would lose its free status.

The inside of the planet, which is inaccessible directly, has been studied by means of seismic waves. These techniques have helped us discover that under a thin hard crust (a few tenths of kilometres thick) exists a layer, the mantle, where rocks flow as if they were a very viscous liquid. Deeper within the mantle is the core, formed only by iron, nickel and other melted metals, where our Earth's magnetic field originates. Surprisingly, the inner core is solid, since the immense pressure that it bears overpowers the temperature conditions (which are higher than that of the surface of the Sun).

Figure 18: Planet Earth as seen from outer space (Source: NASA)

Sprouting chickpea model

Take four equal-sized glasses. In three of them, place a wet cotton ball and add a single chickpea. In the fourth glass, place a dry cotton ball and again add a chickpea.

Keep each glass in a different place with different light, temperature and moisture conditions. One of them should be placed under direct sunlight, another one in a semi-dark place with little light, and the third one inside the fridge. Place the glass with the dry cotton ball next to the one exposed to the sunlight.

After about 10 days, you will see that the chickpeas in the dry glass and in the glass in the fridge have not sprouted. The chickpea placed in the semi-dark spot will have sprouted a thin and long stalk. The one placed under direct sunlight will have the sprouted the best: to sprout and grow, the chickpea needs medium temperature, moisture and sunlight.

It is a good idea to repeat this experiment with different seeds stored in different places and examine the results.

Take four equal-sized glasses. In three of them, place a wet cotton ball and add a single chickpea. In the fourth glass, place a dry cotton ball and again add a chickpea.

Mars

Figure 20: Mars: Roman god of war.

It is an easily observable planet: usually, it tends to be brighter than Jupiter, though less bright than Venus. It gets its name from the Roman god of war, Mars, because of its reddish colour, which evokes image of blood (Figure 20). Its characteristic ochre colour is the result of the iron compounds on its surface.

Its diameter is approximately half of that of Earth. It is home to the highest mountain in the Solar System – the volcano Olympus Mons – with a height of 25 km and to an expansive cannon – Marineris Valley – that is about 5000 km long and up to 6 km deep (Figure 21). It is so broad that in many places it is impossible to see one side from the opposite side, since it lies under the horizon. There are observable signs of flowing water on its surface, even though the signs are very old. Currently, water can only be found as ice on the polar caps (the extent of which varies depending on the seasons, as on Earth) and possibly underground.

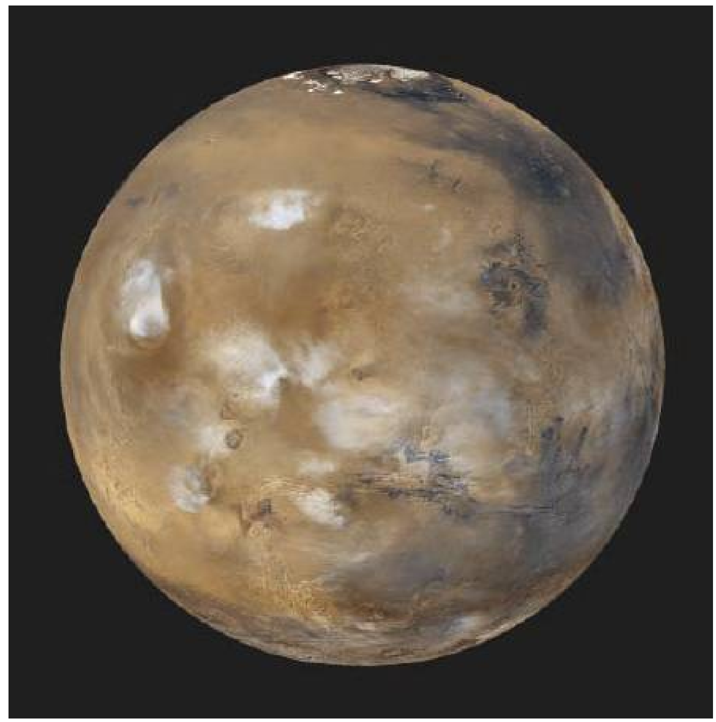

Figure 21: Surface of the planet Mars (Source: NASA).

Superficial gravities model

Mars and Mercury are the smallest planets on the Solar System, which suggests that they have the smallest superficial gravities of all the planets: Mars has approximately one-third the superficial gravitation force of Earth. This means that launching a rocket from Mars would be much easier than from Earth, and jumping on Mars, with the same effort as on Earth, will allow one to go much higher (almost three times higher) than on our planet. Something similar happens on the Moon, which, because it is smaller than these planets, intensifies our jumps by six times as that on Earth.

To visualize this effect, ask a student to jump over a shoebox. Measure the size of that box with a tape. Multiply the result by 3 or 6 and check the height on the tape. This will give you an idea of what that jump would lead feel like on Mars or the Moon, with the same musculature and effort.

Additionally, search the Internet for videos of the Apollo 11 astronauts walking on the surface of the Moon and observe their jumps. This is not exactly accurate, as they wore very heavy space suits. But what we can see is how slowly they hit the ground, as if in 'slow motion'.

Asteroid belt

Asteroids are rocky bodies orbiting the Sun between Mars and Jupiter. They are of varying sizes, from hundreds of kilometres in diameter to small flecks of dust. It is difficult to confirm their number, because if they are very small in size, then are not considered asteroids (these would then be meteoroids, those passing through the atmosphere are meteors and those that hit the ground are called meteorites). It is possible to pick up microscopic metallic meteorites with a magnet*.

The biggest asteroid is Ceres. It was considered a planet since its discovery in 1801 until 1850, when it was downgraded to an asteroid after many such objects were found in that region. Ceres has a diameter of 1000 km, and its gravitational force has lent it a spherical shape, though not a clear orbit. For all this reasons, Ceres was classified as a dwarf planet in 2006.

Typical asteroids are much smaller than Ceres. Their gravitational fields are not intense enough to produce a smooth shape, so they usually look like a potato. Their surfaces are riddled with craters, effects of violent impacts. It has been discovered that many of them possess small satellites.

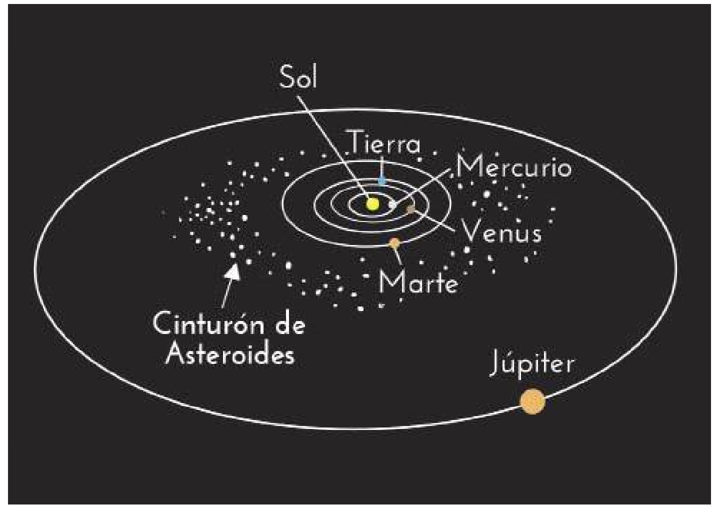

Figure 22: Asteroid belt.

Figure 23: Gaspra asteroid (Source: Galileo sounding line)

*For more details, look up the book 'Looking for the north' from the same collection.

Sky police

At the end of the XVIII century, astronomers where convinced that there should be another planet between Mars and Jupiter, a lost planet that was yet to be discovered. A group of them decided to study the sky until they found it. These planet hunters called themselves the 'sky police'.

Curiously, the Italian astronomer Giuseppe Piazzi discovered Ceres a few weeks before he received an invitation to become part of the group.

As an activity, do something similar and study the sky. While it is not easy to discover a new body in our Solar System, it is quite simple to observe the passing of the space station ISS. It can be spotted easily (and it is surprisingly bright) if you know the correct area and the time for observation. You can find these details on the website http://spotthestation.nasa.gov/

Figure 24: Ceres.

Figure 25: The ISS as seen from Earth (Source: Jürgen Michelberger)

Jupiter

Figure 26: The Roman god Jupiter

Jupiter is the biggest planet on the Solar System. Its diameter is 11 times that of the Earth, and its mass almost 318 times that of our planet. Because it very bright and moves with a majestic slowness, the ancient Greeks named it after the father of the gods: Jupiter.

This planet is a huge gas ball (basically hydrogen and helium) with a rock core that is many times heavier than the Earth. We can observe the cloudy structures that form and disappear on Jupiter, influenced greatly by the rapid rotation of the planet (it goes around its axis in a little over nine hours). In particular, there is an immensely large spot on Jupiter (a cyclone the size of two Earths) that has been observed continuously for 400 years (Figure 27). However, its size has been decreasing considerably over the last few years.

Also, because of its high-speed rotation, Jupiter has an intense magnetic field, which is by far the most powerful of all the planets.

Figure 27: Jupiter and its great spot

There are many satellites around it, four of which are so big that they could be planets: Io, Europe, Ganymede and Calisto. It is believed that a liquid water ocean covered with an ice layer exists on Europe, which is very promising from a biological point of view.

A model for comparing Jupiter and Earth's volumes

Jupiter's radius is 11 times that of the Earth. The formula for calculating the volume of a sphere is 4/3 of pi pmultiplied by the square of the radius. Thus, the volume of Jupiter is more than 1300 times the volume of Earth (11 × 11 × 11 = 1331).

Let us use a chickpea to simulate the Earth. The diameter of a chickpea is about 1 cm. To simulate the diameter of Jupiter (that ought to be 11 times bigger), take two semi-spherical salad bowls with a diameter of 11 cm. We can fill about 2 kg of chickpeas in each of the semi-spheres or salad bowls.

To make it simpler, it is better to use some measuring cup that once filled contains 100 chickpeas. This way, we can easily count the number of times we re-fill the measuring cup to fill up the salad bowl (Figure 28). The total number of chickpeas in the bowl should be about 1300 (or 1331 as seen above).

Other planet volumes can also be compared in this fashion. It is a good exercise for understanding proportions

Figure 28: Comparing the volumes of Jupiter and Earth.

Saturn

Figure 29: Saturn as painted for Rubens in 1636 after learning of its existence from Galileo as a triple body (upper part of the painting).

Saturn was the fifth planet discovered by the Greeks and Romans. It can be identified by its rings, which can be seen from Earth. All the gaseous planets have rings, but those of Jupiter, Uranus and Neptune are far less impressive (and difficult to spot from Earth). The rings spin on the equatorial plane of the planet, showing the position of its equator. Saturn's rings are very bright and made up of dust, rocks and ice. Its diameter is about 300,000 km; its inner layer is at a distance of about 67,000 km from the centre of Saturn.

As a planet, Saturn is similar to Jupiter, but smaller. Its average density is lower than that of water. Its rotation is swift, and many satellites surround it: Titan is the most prominent, with an atmosphere thicker than the terrestrial one and lakes of liquid ethanol and methane (and possibly butane) on its surface.

Saturn's rings

Take an old DVD and a styrofoam ball of 5 cm in diameter (it should be 4.8 cm for a scale model). Cut the styrofoam ball in half and stick it on the transparent centre of the DVD. The DVD represents the rings of Saturn and the ball represents the planet. If we hold the ball or the shiny ring on opposite ends and change the position of the model, we will be able to see the ring more or less tilted (Figures 30a, b and c).

Figures 30a, b and c: Pictures of the model.

In early 1600s, when Galileo observed Saturn through his telescope, he sometimes drew it as a simple sphere but at other times as three close spheres (Figure 31). As the planet was not clearly visible, he thought the rings were spheres.

Figure 31: Drawings of Galileo in a letter addressed to Belisarius Vinta, dated 30 July 1610.

Density model: Saturn floats

The density of Saturn is lower than that of water. In a pond large enough to contain it, the planet would float (if we do not take into account the fact that it would instantly freeze in the water because of its low temperature).

The planets of the Solar System are classified as terrestrial (Mercury, Venus, the Earth and Mars) or gaseous (Jupiter, Saturn, Uranus and Neptune). We can compare the planets using pieces of minerals of similar volume. It is easy to check this by immersing these pieces in a glass full of water – the one that sinks is dense. If we compare the weight of each piece of mineral using our hands, we will see that some are much lighter than others. For Saturn, it is not easy to find a mineral of its density; therefore, we can use wood to emphasize that it 'floats'.

If we compare the density of pyrite with any stone on the terrestrial surface, we will see that pyrite is much denser as the terrestrial core is much denser than the crust.

Planet	Density	Mineral
Mercury	5,41 g/cm^3	Pyrite (5.0–5.2)
Venus	5,25 g/cm^3	Pyrite (5.0–5.2)
Earth	5,52 g/cm^3	Pyrite (5.0–5.2)
Mars	3,90 g/cm^3	Chalcopyrite (3.5–4.3)
Jupiter	1,33 g/cm^3	Jet (1.2–1.3)
Saturn	0,71 g/cm^3	Olive wood (0.8 –1.0)
Uranus	1,30 g/cm^3	Jet (1.2–1.3)
Neptune	1,70 g/cm^3	Opal (1.8–2.3)

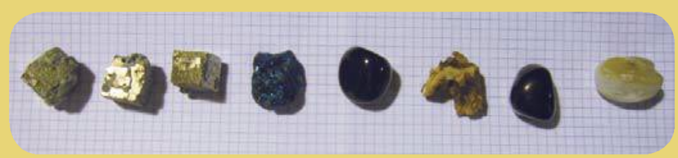

Figure 32: Minerals of different densities resembling the densities of planets on the Solar System.

Uranus

The ancient Greeks knew the five planets that were visible to the naked eye and named them after their gods: Mercury, Venus, Mars, Jupiter and Saturn (they also considered the Moon a planet and, sometimes, the Sun). The first planet discovered during the modern times was Uranus. In 1781, William Herschel (with the help of her sister Caroline) discovered it using the telescope that he constructed and after steady observation of the sky.

The rotation axis of Uranus is almost on its translation plane around the Sun, i.e., its rotation axis is horizontal (Figure 33). This inclination is believed to the result of a past impact. Its poles are approximately where other planets have their equator; therefore, those areas have more solar radiation, and the nights last for around 42 years (the equivalent of half a 'Uranian year').

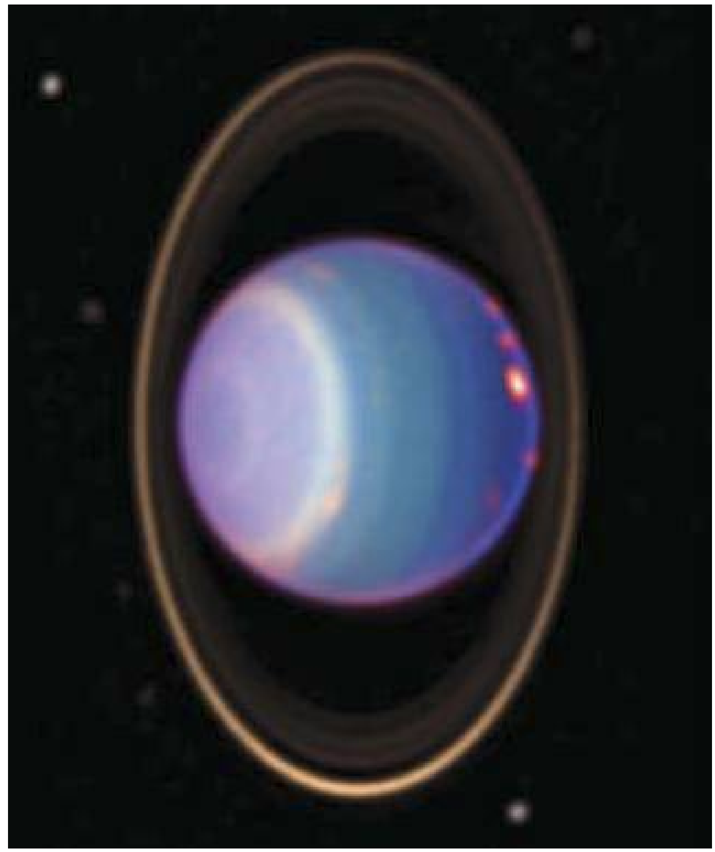

Figure 33: Uranus and its equatorial rings. The illuminated region is where it is exposed to the Sun.

Planet	Inclination	Day duration	Year duration
Earth	23º	24 h	1 year
Mars	24º	24h 39 m	1.88 years
Uranus	89º	17h 14 m	84 years

Modelling the seasons

The inclination of the rotation axis of the planets gives rise to seasons. Earth's equator forms a 23º angle with its translation plane, while Mars forms a 24º degree angle with its orbital plane. Therefore, Earth and Mars have very similar seasons. Uranus's equator forms an 89º (almost perpendicular) angle with its translation plane. The seasons (summer and winter) on Earth and Mars are very similar, but on Uranus they are much longer and instead of three months (six in Mars), they last for 21 years.

Let us build a model to analyse the seasons with four balls and a candle. The orbital plane can be the table on which we place a candle to represent the Sun. The rotation axis must be 67º (90º–23º) for the Earth, 66º (90º–24º) for Mars, and 1º (90º–89º) for Uranus. Place the four balls in the form of a cross, keeping in mind that the rotation axis of the 4 balls must be parallel. It is the height of the Sun over the horizon that determines the season: a hemisphere experiences summer when the Sun is higher (there are more sunshine hours and the rays fall vertically). But when the height of the Sun over the horizon is low, the hemisphere experiences winter (the Sun is in the sky for fewer hours than in summer)***.

Figure 34: Seasons on Earth.
Figure 35: Seasons on Uranus.

The inclination of the rotation axes of the other planets are more or less wide. Mercury has an inclination of 0º; therefore there are no seasons (nevertheless, its distance from the Sun varies so much that the effect is noticeable). On the other hand, Venus spins in the opposite direction to the other planets; this is possibly due to a great impact that caused a 180º turn in its axis.

*** For more details, look up the book 'Parallel Earth' from this same collection.

Neptune

Currently, Neptune is the last planet on the Solar System, ever since Pluto was downgraded to a 'dwarf planet'. It has a delicate blue colour because of the presence of methane, which absorbs red light and reflects a lot of blue light. Like Jupiter, Neptune has a huge spot in the shape of a dark oval, though it is not clear whether the planet has had this spot for long as the great red spot on Jupiter.

The wind on its cloudy layers is exceedingly violent, with velocities exceeding 2,000 km/h. It is not surprising that on a planet whose distance to the Sun is so great, the temperature in the observable region is very low.

As all big planets, Neptune has a number of satellites, the biggest of which is Triton, with a diameter of 2,700 km. As before mentioned, it is surrounded by some small and dark rings in the shape of an arc (they do not go around the planet).

Figure 36: Neptune (Source: NASA)

Neptune was not discovered, it was calculated.

It is said that Johann Gottfried Galle discovered Neptune in 1847, but this statement requires further clarification.

Actually, the existence of Neptune was deduced with the help of some mathematical calculations. Astronomy is a science and therefore it predicts phenomena. For instance, mathematical calculations are used to predict eclipses that will be visible from any part of Earth.

As it happens John Couch Adams, at that time a student with Cambridge University, predicted the existence of Neptune. To explain the anomalies in the orbit of Uranus, he argued that some body had to be disturbing its movements. Thus, Adams could calculate the celestial position where the new planet was expected to be. He asked the director of the Cambridge observatory, James Challis, to focus his telescopes on the spot, to verify the existence of the new planet, but Challis ignored him.

Almost at the same time, Urbain Leverrier, professional astronomer, made the same calculations as Adams and sent them to Galle, the director of Berlin's observatory. Galle immediately confirmed the existence of the planet, close to the predicted position.

Thus, Leverrier came to the same conclusion as Adams, without knowing anything about the latter's calculations. However, because Adams was a young student, for many years, his work was not acknowledged by the international community.

Figure 37: John Couch Adams
Figure 38: Urbain Leverrier

The Kuiper belt and the Oort cloud

The Kuiper belt consists of objects that orbit the Sun further away from Neptune's orbit. Hence, they are also known as 'transneptunian objects'. They are mainly made up of dirty ice, that is, ice with rocks and dust (Figure 39).

The most well-known object in the region is Pluto, which was discovered in 1930 and considered a planet for many years. In 2006 it was classified as a dwarf planet since its characteristics were clearly different from those of the other planets. For instance, its orbit is much more extended than that of the planets, it is almost circular, and it gets to be closer to the Sun than Neptune. Moreover, its orbit is at an incline of 17º from the orbits of all the other planets (Figure 39) that are essentially on a single plane (with the exception of Mercury, whose orbit is 7º inclined). Because treating Pluto as a planet would qualify many other objects to be planets, a new concept called a 'the dwarf planet' was defined. A dwarf planet is a spherical object that has not freed its orbit from other objects.

Beyond the Kuiper belt, almost half the distance to the closest star, we find the Oort cloud, formed by thousands of millions of comets. Unlike the Kuiper belt, which is shaped like a ring, the Oort cloud is a sphere. Its existence is yet to be confirmed, since the vast majority of the objects that make it up are very far and too small to be seen with our instruments. However, its existence has been deduced from the observation of comets.

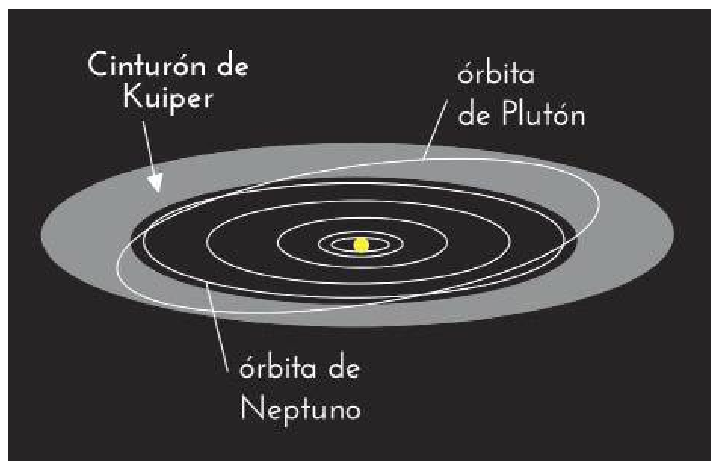

Figure 39: Objects that spin around the Sun beyond Neptune's orbit form the Kuiper belt.

Pluto detection method

In 1930, when studying the images taken from the Lowel Observatory in Arizona, Clyde Tombaugh found an object that seemed to have moved from one frame to the next. To reproduce this experience, place images 41 and 42 one over the other and move your eyes over them quickly. It gives the impression that a white point (Pluto) seems to jump from one position to another (Figure 43).

This is how Pluto was detected, using the images reproduced in Figures 41 and 42. This procedure is still used to discover objects on the Solar System, as photographs can show displacement against a starry background.

Figures 41 and 42: Starry background with Pluto in two different positions.

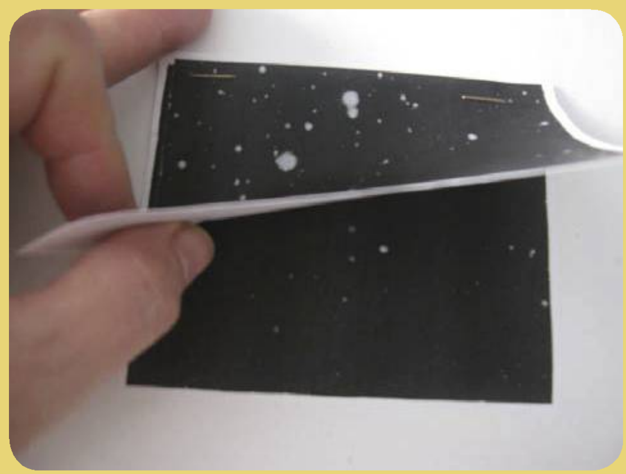

Figure 43: The steps of the experiment.

Figure 40: Pluto and its moon Charon form a system that spins around the gravitational centre of the system. (Source: NASA).

Comets

Comets are small bodies of a few kilometres in diameter, made of dirty ice (ice mixed with rocks and dust), that vapourize when they approach the Sun (i.e., they go directly from solid to gas). Comets move in elliptic orbits (very outstretched) that keep them at a great distance from the Sun, where they almost cannot be observed. During their period of maximum brightness, comets are identified by the presence of a tail of gas and a tail of dust.

A comet can crash with a planet and result in a catastrophe. While it is a very rare phenomenon, it seems the ancient civilizations were not wrong in considering them a bad sign. In 1994, we saw how the Shoemaker-Levy 9 crashed against Jupiter, and in 2013 an object of about 30 metres in diameter (possibly a piece of a comet) disintegrated over the north of Russia.

All the comets we know belong to the Solar System, and they are classified into short-period comets (seen before 200 years, such as Halley's Comet, which is seen every 76 years) and long-period comets (seen in a frequency of thousands of years or more). It seems that some short-period comets come from the Kuiper belt, while others with a longer period may come directly from the Oort cloud. In any case, the interactions with planets often change their orbits.

Figure 44: The comet Shoemaker-Levy 9 disintegrated because of the intense gravitational field of Jupiter and eventually crashed on its surface (Source: NASA).

Comet model

We can make a simple model to simulate the tail of a comet. Take a ball and using some sticking tape (about 1 cm wide or a bit less), attach two thin strips of fabric: nylon and satin (it is better if they are of different colours).

With a hair dryer, we can simulate the effect of the magnetic field that acts on the comet's tails. Hold the ball such that the side with the strips is away from direction of the air. This how a comet travelling in the direction of the Sun will look.

Figure 45: Hale Bopp comet with the double tail: the ionic tail in the opposite direction of the Sun and the dust tail slightly curved (Source: Observatoire de Haute, Provence, France).

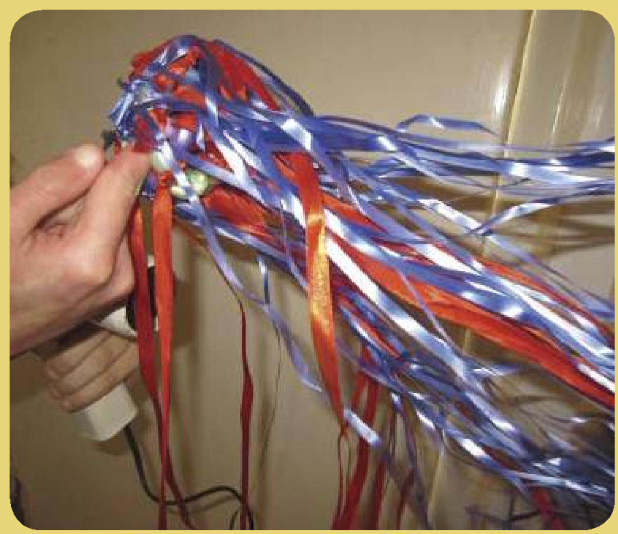

Figure 46: Comet model with the hair dryer.

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