

Solar System

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Summary

Undoubtedly, in a Universe in which we talk about stellar and solar systems, planets and exoplanets, the best known system is the Solar System. We could think that everyone knows what the Sun is, what are the planets, which are comets and asteroids. But is this really so? If we want to understand the Solar System from the scientific point of view, we have to know first the rules that define a system.

The bodies (in the Solar System, according to the resolution of the International Astronomical Union, of August 24, 2006) are:

- planets
- natural satellites of the planets
- dwarf planets
- other smaller bodies: asteroids, meteorites, comets, dust, objects of the Kuiper Belt, etc.

By extension, any other star surrounded by celestial bodies according to the same laws that govern our system, is called the exoplanetary system. One of the questions to answer on this topic is: What is the place of the Solar System in the Universe?, but it is not the only one. In this chapter, we will try to present the most important characteristics of our system and others.

Goals

- Know what place the Sun occupies in the Universe.
- Know what objects make up the Solar System.
- Know details of the different bodies of the Solar System, especially the most prominent ones.

Solar System

A system is, by definition, a set of elements (principles, laws, forces, etc.), which interact with each other according to a series of principles or rules.

To define the Solar System we will indicate, in principle, the elements of the set, which is

composed of a star, the Sun, and all the bodies that surround it and that are joined to it by the force of gravity.

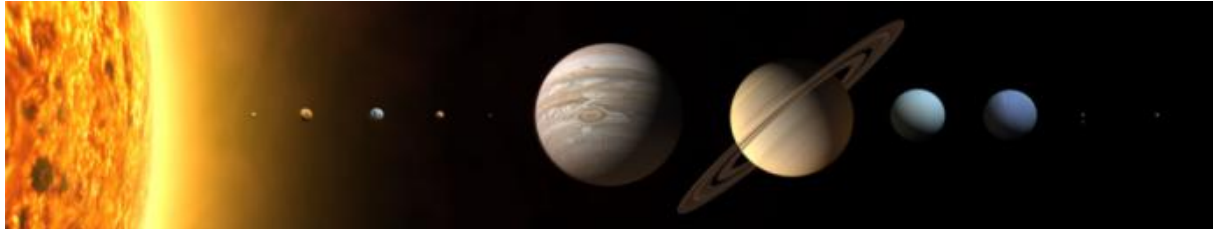


Fig. 1 Solar System is scale of size of the main bodies

The Solar System is located in one of the outer arms of our galaxy, also called the Milky Way. This arm is known as Orion's arm. It is located in a region of relatively small stellar density.

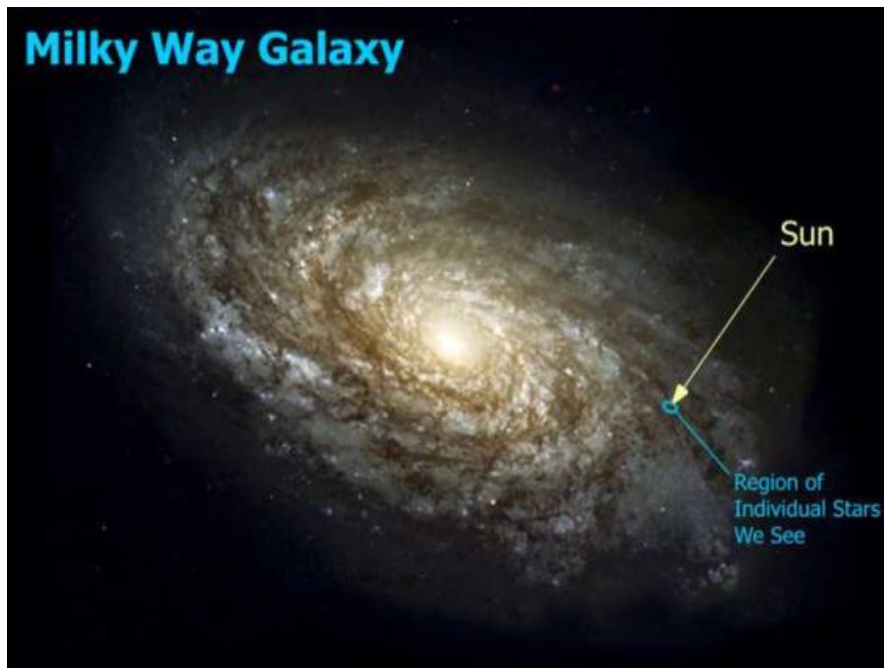


Fig. 2: Place of the Solar System in the Galaxy (simulation)

The Sun, together with the entire Solar System, is in a movement of revolution around the center of our galaxy, located at a distance of between 25,000 and 28,000 light years (approximately half the radius of the galaxy), with a period of revolution between 225 and 250 million years (the galactic year of the Solar System). The speed at which it moves in this almost circular orbit is about 220 km / s, while the direction of movement is towards the current position of the Vega star.

Our galaxy is composed of approximately 200 billion stars, together with their planets, and more than 1,000 nebulae. The mass of the whole set is approximately 1,000 billion times greater than that of the Sun and its diameter is about 100,000 light years.

Very close to the Solar System is the Alpha Centauri system (the brightest star of the Centaurus constellation), composed of three stars, that is, a pair of stars (Alpha Centauri A and B), similar to the Sun, that rotate to a distance of 0.2 light years around a red dwarf, called Alpha Centauri C, of a relatively small luminosity. The last one is the closest star to the Sun, it is at a distance of 4.24 light years; that's why it's also called "Proxima Centauri".

Our galaxy is part of a group of galaxies called the Local Group, composed of three large galaxies and a series of 30 smaller ones. Our galaxy has the shape of a spiral barred. The arms of this spiral that leave the ends of the bar formed by a particular distribution of stars, contain, between other objects, interstellar matter, nebulae and young stars that are born permanently from that matter. The center of the galaxy is composed of old stars concentrated in groups of spherical shape. Our galaxy has approximately 200 groups of these, of which only 150 are more known. These groups are concentrated mainly in the galactic center. The Solar System is located 20 light years above the plane of equatorial symmetry and 28,000 light years away from the galactic center. The center of the galaxy is in the direction of the constellation Sagittarius, between 25,000 and 28,000 light-years away from the Sun.

Solar System formation and evolution

According to the standard theory, about 4.6 billion years ago the solar system was formed from the gravitational contraction of an interstellar gas and dust cloud. The collapse of the cloud started from a strong perturbation (possibly a supernova event), which caused the gravitational force to overcome the pressure of the gases.

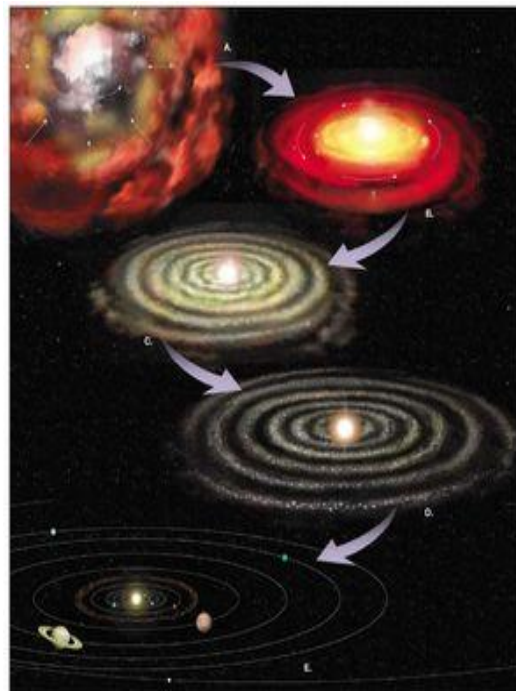


Fig. 3 Scheme of the Solar System formation process, according the Standar Theory, based onn the “nebuar hypotesis” first proposed by Kant and Laplace in the seventeen century

The conservation of the angular momentum caused the nebula to turn faster and faster, to flatten out, and to produce a protostar at its center, and a protoplanetary disk of gas and dust around it. In the protoplanetary disk were condensed small planetesimals (solid nuclei), which then were accumulated by an accretion process to form the planets.

The hypothesis of a primitive nebula was proposed in 1755 by Emmanuel Kant and also separately by Pierre-Simon Laplace.

The standard theory (based on the "Nebular Hypothesis" originally proposed by Kant and Laplace) explains the coplanarity and quasi-circularity of the orbits and has been confirmed by observations of several planetary systems around other stars.

The Sun

The Sun is a star of intermediate mass, Its age is approximately 4.6 billion years. At present, the Sun has completed nearly half of its evolution cycle, which is related to the transformation of hydrogen into helium in its nucleus, through the mechanism of nuclear fusion. Every second, in the core of the Sun, more than four million tons of matter become heavier matter and energy, generating not only helium, but also neutrinos and electromagnetic radiation.

Most of the Sun (74%) is Hydrogen, almost 25% is Helium, while the rest are heavy elements.



Fig. 4a: El Sthe Sun, infrared image

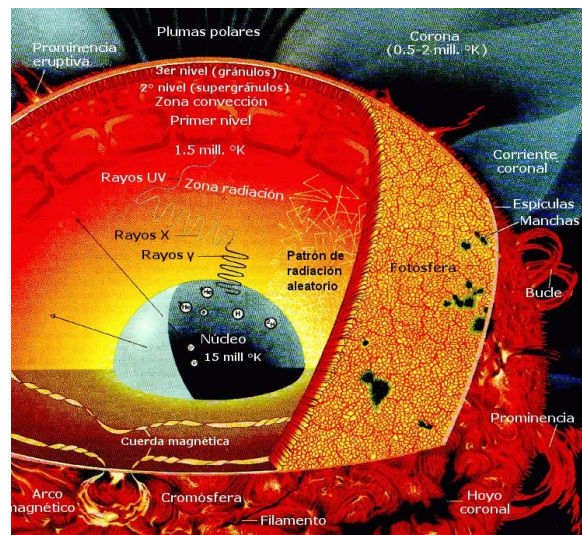


Fig 4b. Internat structure of the Sun

SUN LIFE CYCLE

In about 5 billion years, the Sun will become a giant and then a white dwarf, a period in which a planetary nebula will be born. Hydrogen will be depleted, and this will lead to radical changes, including the total destruction of Earth. Solar activity, more precisely its magnetic activity, is detected on sight by the number and size of the spots on its surface, as well as by

solar flares and variations of the solar wind, which dissipate the matter from the composition of the Sun in the Solar System and even beyond.

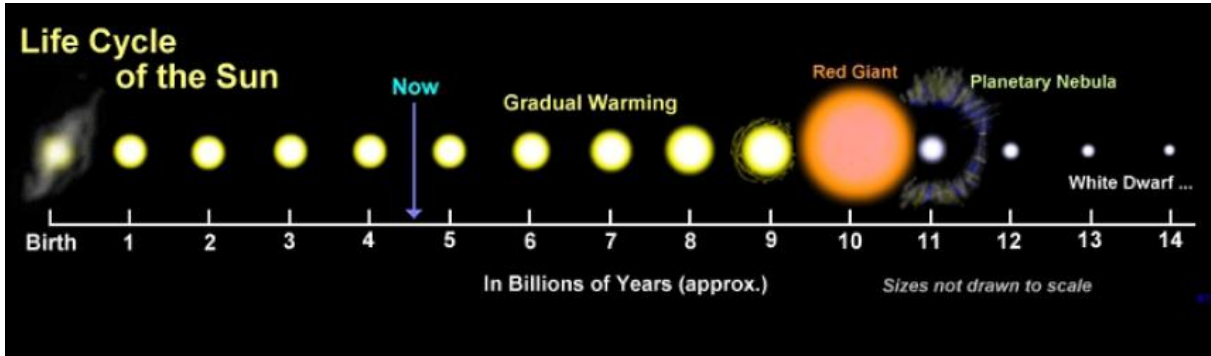


Fig. 5. Life cycle of the Sun, since proto star to white dwarf.

Planets

To classify the planets, we use the definition given by the International Astronomical Union (IAU), in its 26th General Assembly, which took place in Prague, in 2006.

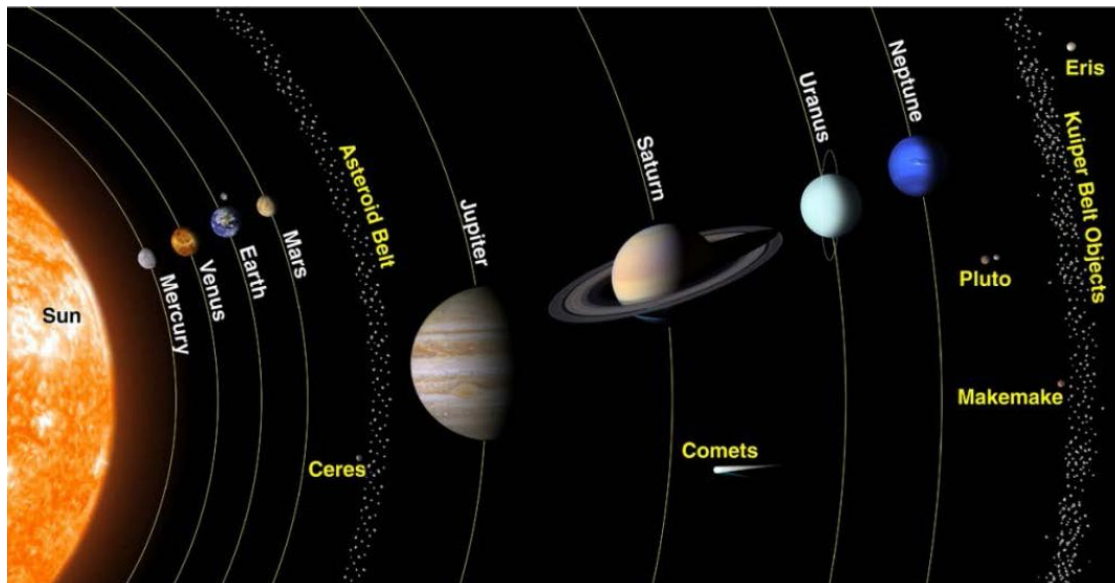


Fig 6. Solar System bodies. (image not in scale)

In the Solar System a planet is a celestial body that:

1. is in orbit around the Sun,
2. has sufficient mass to maintain hydrostatic balance (almost round shape), and
3. it has "cleaned the neighborhood" around its orbit.

A non-satellite body that meets only the first two of these criteria is classified as a "dwarf planet".

According to the IAU, the planets and the dwarf planets are two different kinds of objects. A non-satellite that meets only the first criteria, is called a "small body of the Solar System" (SSSB), such is the case of, for example, asteroids.

The initial projects of re-classification of bodies in the Solar System planned to include the dwarf planets as a sub-category of the planets, but as this could have led to the addition of several dozen new planets in the System, this project was abandoned. In 2006, three dwarf planets (Ceres, Eris and Makemake) and the re-classification of one (Pluto) were added. Thus, the 2006-Solar System had five dwarf planets: Ceres, Pluto, Makemake, Haumea and Eris. Over the years new bodies that were under study were added to the list of dwarf planets.

The definition distinguishes planets from smaller bodies and is not useful outside the Solar System, where smaller bodies can not be detected with current technology. Extrasolar planets, or exoplanets, are treated separately by virtue of a complementary 2003 project guideline for the definition of the planets, which distinguishes them from dwarf stars that are more massive and larger.

The 8 planets of the Solar System can be divided into:

- 4 Earth type planets, in the innermost region (Mercury, Venus, Earth and Mars).
 - Rocky, with approximate densities between 4 and 5 g / cm³.
- 4 Giant planets, in the outermost region, which in turn are divided into:
 - Gaseous Giants: Jupiter and Saturn. Richer in H and He, with a chemical composition similar to the solar one.
 - Ice Giants: Uranus and Neptune. The ice predominates with respect to the gases. Its chemical composition differs a lot from the solar.

The giant planets are lighter than terrestrial ones, with densities between 0.7 g / cm³ (Saturn) and 2 g / cm³.

The giant planets had formed on time scales of the order of 10 million years (terrestrial planets did in about 100 million years). They were not formed "in situ", there was a migration caused by the exchange of angular momentum between the giant planets in formation and the planetesimals that were swept into other regions of the Solar System or ejected from the System.

Characterizing each planet implies determining its general properties, such as mass, radius, density, rotation period around its axis (the day), period of translation, around the Sun, (the year), chemical composition of its structure and its atmosphere, among other magnitudes. In this text, we will not present the data tables, since they are available on the Internet, in addition to traditional books. Here we will concentrate only on the description of the nature of each body, its origin, and those data of interest or color so that the teacher can work on the subject in the classroom. (For specific data of the planets and other bodies of the Solar System see information on the Internet).

MERCURY

Mercury is the closest planet to the Sun and the smallest planet in the Solar System. It is an Earth-type planet, in the inner Solar System. It receives its name from the Roman god of arts and commerce.

It does not have any natural satellite. It is one of the five planets that can be seen from Earth with the naked eye. It has been observed with the telescope only since the seventeenth century. Lately, it was studied by two space probes: Mariner 10 (three times in 1974-1975) and Messenger (twice in 2008).

Although it can be seen with the naked eye, it is not easily observable, precisely because it is the planet closest to the Sun. Its place in the celestial vault is very close to the Sun and can also be observed only around the elongations, a little before the dawn and a little after sunset. However, the space missions have given us enough information, which surprisingly shows that Mercury is very similar to the Moon.

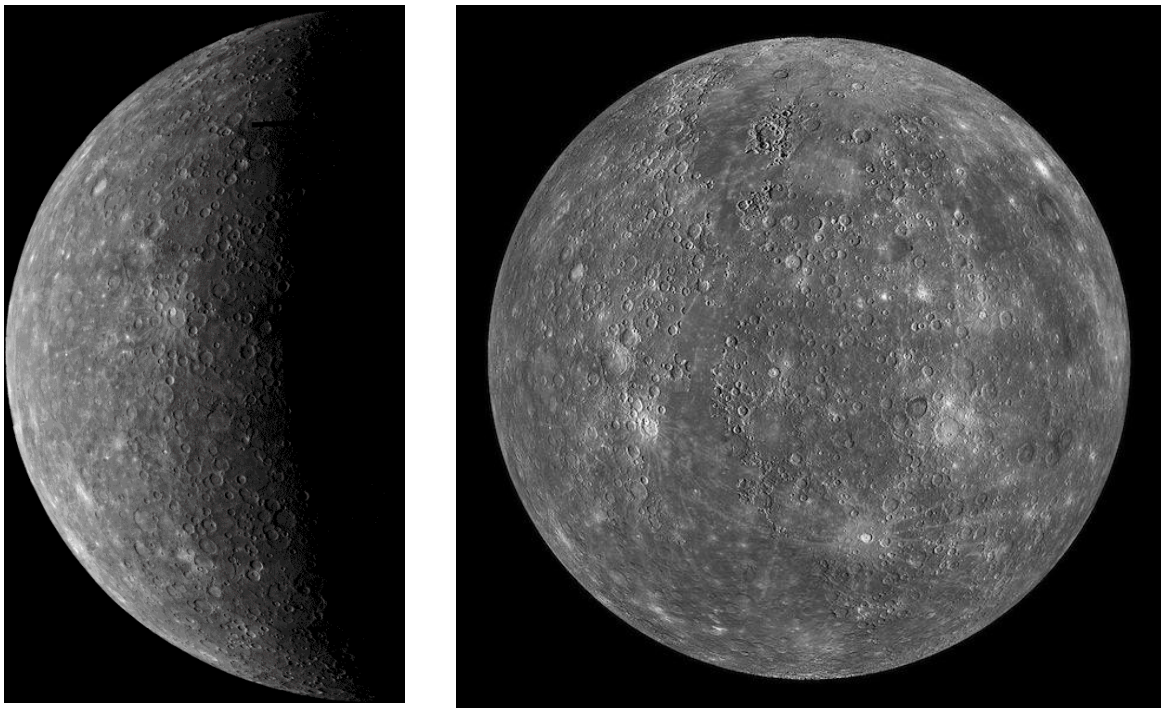


Fig. 7 : Mercury

It is worth mentioning some characteristics of the planet: it is the smallest of the Solar System and the closest to the Sun. It has the most eccentric orbit ($e = 0.2056$) and also the most inclined in the opposite direction to the ecliptic ($i = 7^\circ$). Its synodic period is 115.88 days, which means that three times a year it is placed in a position of maximum elongation west of the Sun (it is also called "the morning star", and in the three positions of maximum elongation east of the Sun is called "the evening star"). In any of these cases, the elongation does not exceed 28° .

Its radius of 2,440 kilometers makes it the smallest planet in the Solar System, smaller even than two of the Galilean satellites of Jupiter: Ganymede and Callisto.

The density of 5.427 g / cm³ makes it the densest planet after the Earth (5.5 g / cm³). Iron could be the main heavy element (70% against 30 and rocky matter), which contributes to the high density of Mercury. In general, it is assured that Mercury has no atmosphere, which is not correct, but its atmosphere is very uncommon: and very thin, formed by molecular Oxygen, 42%, Sodium, 29.0%, Hydrogen, 22.0%, Helium, 6.0 %, Potassium, 0.5% , and traces of Argon, Nitrogen, carbon dioxide, water vapor, Xenon, Crypton and Neon.

Mercury is the only planet (apart from Earth) with a significant magnetic field, which, although it is on the order of 1/100 that of the Earth's magnetic field, is enough to create a magnetosphere, which extends up to 1.5 planetary radii , compared to 11.5 radii in the case of the Earth. Finally, there is another analogy with Earth: the magnetic field is bipolar, with a magnetic axis tilted 11 °, opposite to the rotation axis.

In Mercury, temperatures vary enormously. When the planet passes through the perihelion, the temperature can reach 427 ° C at the equator, at midday, that is enough to cause the fusion of a metal such as zinc. However, immediately after nightfall, the temperature can drop to -183 ° C, which means that the increase in diurnal variation is 610 ° C! No other planet suffers such a large difference, which can be due to intense solar radiation during the day, the absence of a dense atmosphere and the duration of Mercury's day (the interval between sunrise and sunset is almost three Earth months). , that is, sufficient time to store heat or, analogously, cold during a night of equal length).

The craters of Mercury are very similar to those of the Moon in morphology, form and structure. The most notable is that of the Caloris basin, testimony to a great catastrophe.

The impacts that generate basins are the most catastrophic events that can affect the surface of a planet. They can cause the change of the planetary cortex, and even internal disorders. This is what happened when the Caloris crater with a diameter of 1,550 kilometers was formed.

Mercury perihelium precession

Like any other planet, the perihelion of Mercury is not fixed, but has a regular movement around the Sun. For a long time this movement was considered to be 43 seconds of arc per century faster compared to the predictions of celestial mechanics classic "Newtonian". This advance of perihelion was predicted by the general theory of Einstein's relativity, the cause being the curvature of space due to the solar mass. The coincidence between the observed advance of perihelion and that predicted by general relativity was the proof in favor of the validity of the hypothesis of the latter.



Fig. 8 Precetion movement of Mercury's perihelium

VENUS

One of the four planets of the system internal system, of constitution similar to that of the Earth and the second one in distance to the Sun. It is named after the Roman goddess of love and beauty.

ts closeness to the Sun and the structure and density of the Venus atmosphere make it one of the hottest bodies in the Solar System. It has a very weak magnetic field and has no natural satellites. It is one of the planets with a retrograde revolution movement and the only one with a period of rotation greater than the period of the revolution. It is the brightest body in the celestial vault after the Sun and the Moon.

The trajectory of Venus around the Sun is almost a circle: its orbit has an eccentricity of 0.0068, that is, the smallest of the Solar System. A year of Venus is somewhat shorter than a sidereal day of Venus, in a proportion of 0.924.

Its size and geological structure is similar to that of Earth. The atmosphere is very dense. The mixture of CO₂ and dense clouds of sulfur dioxide create the greatest greenhouse effect of the Solar System, with temperatures of about 460 ° C. Venus surface temperature is higher than that of Mercury, although Venus is almost twice as far away of the Sun that Mercury, and only receives approximately 25% of the solar radiation that Mercury. The surface of the planet has an almost uniform relief. Its magnetic field is very weak, but it drags a tail of plasma 45 million kilometers long, first observed by the Solar and Heliospheric Observatory SOHO in 1997.

A remarkable feature of Venus is its retrograde rotation (although Uranus also presents it): it rotates around its axis very slowly and counter-clockwise, while the planets of the Solar System do so in general clockwise. Its rotation period has been known only from 1962. This

rotation - slow and retrograde - produces solar days much shorter than the sidereal day, these days being longer than in the planets with clockwise rotation. Consequently, there are less than 2 full days in a solar year of Venus. The causes of the retrograde rotation of Venus have not yet been clarified. The most likely explanation would be a collision with another large body in the formation of the planets of the Solar System. It could also be that the atmosphere of Venus influenced the rotation of the planet due to its great density.

Venus presents a unique atmosphere.

With a surface pressure of 93 bar (9.3MPa) 90 times larger than that of the Earth and composed mainly of ~ 96.5% carbon dioxide, ~ 3.5% Nitrogen, 0.015% sulfur dioxide, 0.007% Argon , 0.002% water vapor, 0.001% 7% carbon monoxide, 0.0012% Helium, 0.0007% Neon.

Venus has been landed on in 1975 and 1982: the former Soviet Union's Venera missions managed to capture images of its rocky surface before being destroyed, less than two hours after landing, by the pressure and temperature on the planet's surface.

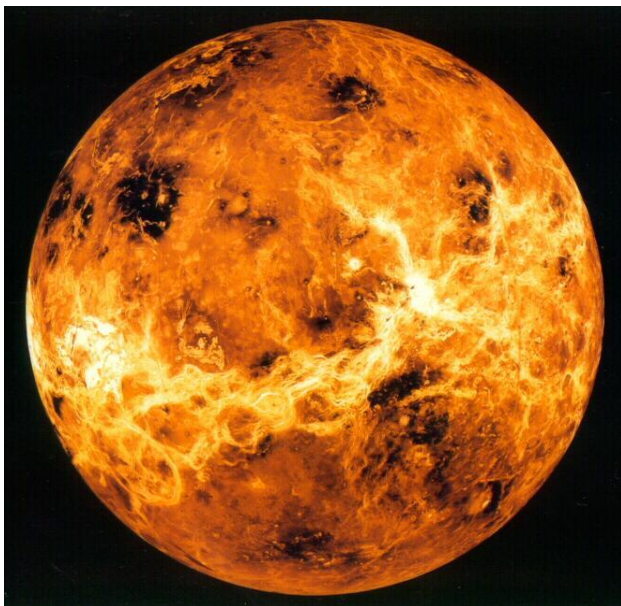


Fig. 9: Venus. Fotografía de su superficie (Misión Magallanes)

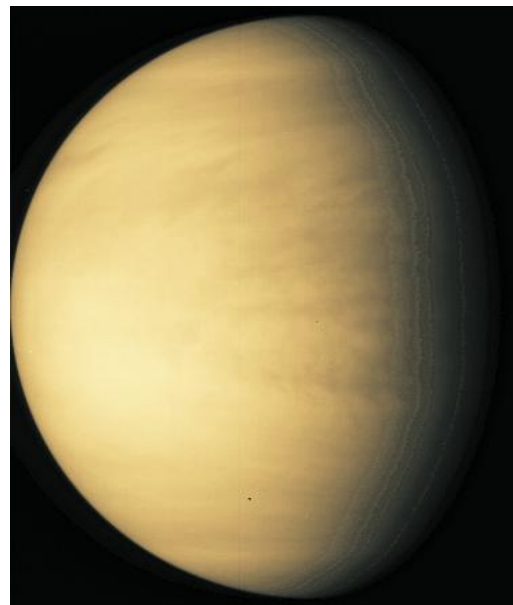


Fig. 10. Venus en luz Visible (Telescopio Hubble)

Venus the twin sister of Earth. Analogy.

- They were born at the same time, from the same gas and clouds of dust, 4.6 million ago of years.
- Both are planets of the internal Solar System
- Its surfaces have a varied terrain: mountains, fields, valleys, plateaus, volcanoes, impact craters, etc.
- Both have a relatively small number of craters, a sign of a relatively young surface and a dense atmosphere.

- They have similar chemical compositions.
- Volcanic activity has been discovered on Venus.

Transit of Venus

The transit of Venus occurs when the planet passes between the Earth and the Sun, and the shadow of Venus crosses the solar disk. Due to the inclination of the orbit of Venus, as opposed to terrestrial, this phenomenon is very rare in our time scale. It takes place twice a century, separated by 8 years, this double transit is separated from the next by more than a century. (105.5 and 121.5 years). The last transits took place on June 8, 2004 and June 6, 2012 and for the next it will have to wait until December 11, 2117.

EARTH

The Earth is the third most distant planet from the Sun in the Solar System, and it is the fifth in dimensions. It belongs to the inner planets. It is the largest rocky planet, and the only one in the known Universe where life was able to adapt. The Earth was formed about 4.57 billion ago. Its only natural satellite, the Moon, began its orbit soon after the Earth, about 4533 million years ago and there are several theories about its origin. 71% of the surface of the Earth is covered with water, the rest of 29% is solid and "dry", but water in total constitutes a tiny amount of matter compared to the general structure of the planet.



Fig. 11: Earth and Moon (Galileo Mission, 1998)

There is a permanent interaction between the Earth and the rest of the Universe. Thus, the Moon is the cause of the tides. In addition, it has continuously influenced the speed of the earth's rotation movement. All the bodies of the terrestrial globe, are attracted by the Earth, the force of attraction is called gravity and the acceleration with which these bodies fall in the gravitational field is called gravitational acceleration (denoted by a "g" = 9.81 m / s²). It is believed that the reason for the appearance of the oceans was a "shower" of comets in an early

period of the Earth. Later, the impacts of asteroids helped to modify the environment decisively. The changes in the orbit of the planet can be considered as responsible for the ice ages that took place in history, which covered the earth's surface with a layer of ice.

The pressure of its atmosphere on the surface is 101.3 kPa and is composed of 78% Nitrogen (N₂), 21% Oxygen (O₂), 0.93% Argon, 0.04% Carbon dioxide and 1% water vapor (varies with the weather).

The most widely accepted theory related to the existence of the Moon is that of an impact in ancient times on the planet Earth, when a body of enormous dimensions hit its surface and produced the so-called "drop effect." The Moon would be precisely the drop that breaks away from the surface of the Earth, but that constantly falls, remaining in orbit.

MARS

Mars is the fourth planet in distance to the Sun in the Solar System and the second in dimensions after Mercury. It belongs to the group of telluric planets. It is named after the Roman god of war, due to its reddish color. Several space missions have studied it since 1960 to find out as much as possible about its geography, climate, as well as other details and will continue to do so in search of water and, perhaps, signs of life, beneath its surface.

Mars can be observed with the naked eye. It is less bright than Venus and only rarely brighter than Jupiter. It surpasses the last one during its most favorable configurations (oppositions). Of all the bodies of the Solar System, the red planet is the one that has attracted most of the science fiction authors. The main reason for this are its famous channels, so called for the first time in 1858 by Giovanni Schiaparelli and considered by that author as the result of constructions, what we know today was completely wrong. The red color of Mars is due to the oxide of iron (also called hematite), which is found in minerals on its surface; Recent studies propose that the presence of ferrihydrite, a water-rich iron mineral, is the reason why Mars is red (Valantinas et al., 2025). Mars has a very steep relief, with the highest mountain in the Solar System (Mount Olympus volcano), with a height of about 25 km, or the largest known canyon on a planet (Valles Marineris), with an average depth of 6 km .

This planet has in the center an iron core with a diameter of approx. 1,700 kilometers, covered with an olivine mantle and a basalt crust, with an average width of 50 km. It is surrounded by an atmosphere composed mainly of carbon dioxide. It used to have an active hydrosphere, that is, there was water on its surface sometime, but changes in atmospheric pressure conditions, probably due to the loss of its magnetic field, and its temperature, led to water evaporate at room temperature. At present, the Martian atmosphere is characterized by a pressure on the surface of 0.6-1.0 kPa and be composed of 95.72% Carbon dioxide; 2.7% Nitrogen; 1.6% Argon; 0.2% Oxygen; 0.07% Carbon monoxide, 0.03% water vapor; 0.01% nitric oxide; and traces of Neon, Crypton, Formaldehyde, Xenon, Ozone and Methane.

Mars has two natural satellites, Phobos and Deimos, probably asteroids captured by the planet. The diameter of Mars is twice less than that of the Earth and its surface is equal to that

of the continents. Its mass is one tenth of the terrestrial one. Its gravity is somewhat less than that of Mercury, although its mass is twice as large.

The plans of the Martian equator and its orbit around the Sun do not coincide. The tilt of the axis of Mars is similar to that of the Earth, that's why on Mars there are seasons like on Earth. The dimensions of the polar caps vary during the seasons through the exchange of carbon dioxide and water with the atmosphere. The Martian day is only 39 minutes longer than the Earth day. And due to its relative distance from the Sun, the year has a little more than 322 days than the Earth year.

Mars is the outer planet closest to Earth; this distance is smaller when it is in opposition, with the Earth between it and the Sun.

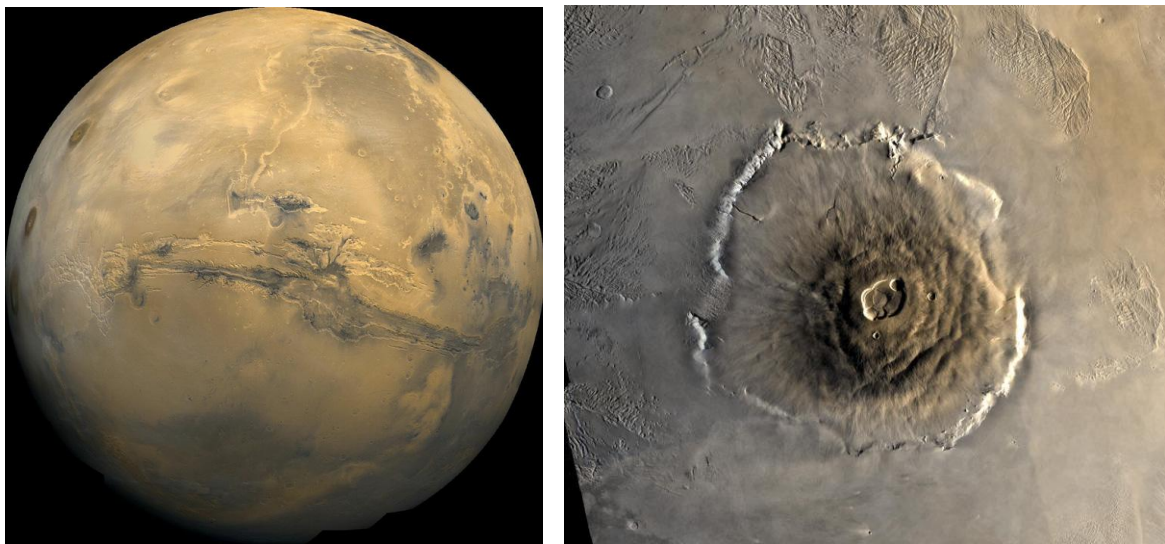


Fig. 12 Mars (left); Olympus Mons (right)

On August 27, 2003, Mars was only 55.76 million km away from Earth, that is, 0.3727 AU, the smallest distance recorded in 59,618 years. Such an event gave way to all kinds of fantasies, for example, that Mars could have been seen as big as the Moon. However, with an apparent diameter of 25.13 seconds of arc, Mars can be seen with the naked eye as a point, while the Moon extends over an apparent diameter of 30 arc minutes (1800 seconds of arc). A closeness similar to that of 2003 will take place on August 28, 2287, when the distance between the two planets is 55.69 million kilometers.

A mission from Earth landed on Mars for the first time in 1976, the Viking I. Since then, a significant number of satellites have orbited it and various probes have explored its surface. The most significant achievements in terms of discoveries and technology on Mars are the Curiosity rover (2012), the Perseverance rover (2021), and the small helicopter it carried, the Ingenuity rover (2021).

JUPITER

Jupiter is the fifth planet in distance from the Sun, with a diameter 11 times greater than that of Earth, it is the largest of all the planets in the Solar System. Regarding our planet, its mass is 318 times greater and its volume 1300 times greater. Orbit around the Sun at a distance of 778,547,200 kilometers. Jupiter is the fourth brightest object in the sky with the naked eye (after the Sun, the Moon, Venus and sometimes Mars). The discovery of its four great satellites: Io, Europa, Ganymedes and Callisto (known as the Galilean satellites) by Galileo Galilei and Simon Marius in 1610 was the first discovery of a center of apparent motion that was not found on Earth. It was an important point in favor of the heliocentric theory of the planetary movement of Nicolaus Copernicus. Galileo's verification of the Copernican theory brought him problems with the Inquisition. Before the Voyager missions (in the 1970s), only 16 of its satellites were known: today we know that they have more than 100 and surely some still remain to be discovered.

It is likely that the planet core is made of solid material, between 10 and 15 times the mass of the Earth. Above this core is the main part of the planet, composed of liquid metallic hydrogen: due to the temperature and pressure inside Jupiter, hydrogen is a liquid and not a gas. In this state, the material is an electrical conductor and the source of Jupiter's magnetic field. This layer contains some helium and some ice remains.

The most superficial layer of the planet is composed mainly of molecular hydrogen and helium, liquid in the inner part and gaseous in the outer part. The atmosphere we see is just the top of this deep layer. Water, carbon dioxide, methane, as well as other simple molecules are also present in small amounts.

The atmosphere of Jupiter is composed of approximately 86% of Hydrogen and 14% of Helium, with traces of methane, water, ammonia and other elements. It is believed that its composition is very similar to the original structure of the cloud from which the Solar System was formed (in that sense, Uranus and Neptune, which are also gaseous, have less hydrogen and helium).

A distinctive feature of Jupiter is its Great Red Spot that was observed for the first time thanks to ground-based telescopes, more than 300 years ago. It is an oval of approximately 12,000 by 25,000 kilometers, large enough to cover two Earth. It is a region of high pressure, whose upper clouds are much higher and cooler than the surrounding areas. Similar structures have been observed in Saturn and Neptune. It is not yet known why these types of structures resist so long.

On Jupiter and other gaseous planets, winds blow at great speed, in broad bands of latitude. The winds blow in opposite directions in two adjacent bands. The differences in temperature or chemical composition are responsible for the different coloration of the bands, an aspect that dominates the image of the planet. The atmosphere of Jupiter is very turbulent. The winds are driven, largely by the internal heat of the planet, not from the Sun, as it happens on Earth. The Jovian atmosphere has a surface pressure of 20-200 kPa (cloud layers) and its chemical composition is 90% hydrogen (H₂), 10% helium, ~ 0.3% methane, ~ 0.036% ammonia, ~

0.003% deuterium (HD), 0.0006% ethane, 0.0004% water. And also ice of: ammonia, water and ammonium hydrosulfide (NH₄SH) ..

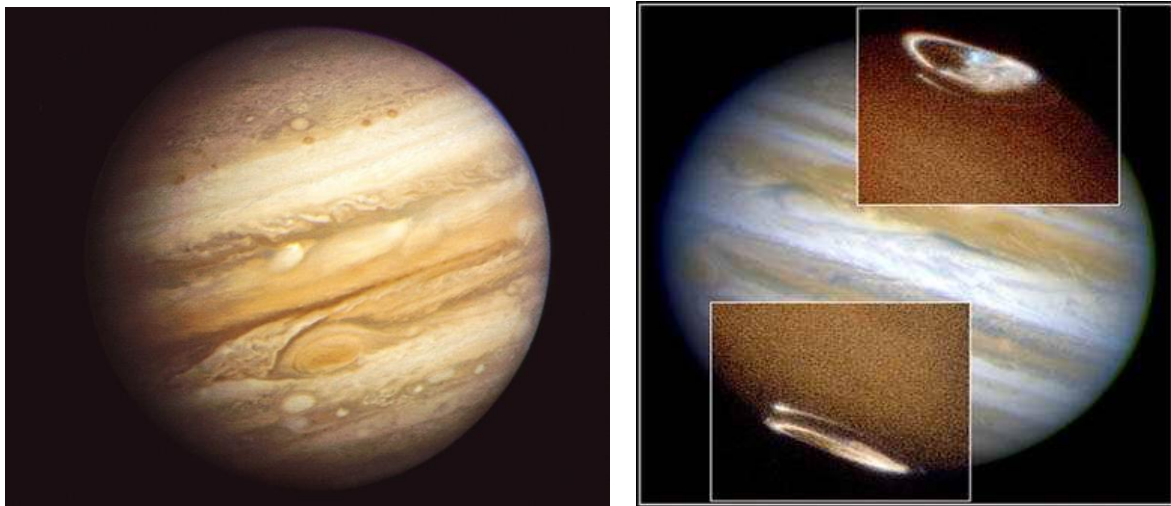


Fig. 13: Jupiter (left); Aurora on Jupiter (right, Hubble Space Telescope image)

Jupiter's Magnetosphere is very intense, 14 times stronger than Earth's, and extends some 650 million km (beyond Saturn's orbit). The satellites of Jupiter are included in its atmosphere, which partially explains the activity in Io. A major drawback to the space travel of the future, as well as a problem for the designers of the Voyager and Galileo probes, is that in the surrounding environment of Jupiter there are large amounts of particles captured by the magnetic field of Jupiter. This "radiation" is similar, but much more intense, than that observed in the Van Allen belts of the Earth, it would be lethal to any unprotected human being. The Galileo probe discovered a new and intense radiation between Jupiter's rings and the upper strata of the atmosphere. This new radiation belt has an intensity 10 times greater than that of the Van Allen belts on Earth. Surprisingly, this new belt contains high-energy Helium ions of unknown origin.

Jupiter has rings like Saturn, but much thinner and opaque: unlike those of Saturn, Jupiter's rings are dark. They are probably composed of small grains of rocky material and do not seem to contain ice. Probably, the particles of Jupiter's rings do not remain there for a long time (because of the atmosphere and the magnetic field). The Galileo probe found clear evidence that the rings are continuously fed by the dust formed by the impacts of the micro meteorites with the interior, which are very energetic, due to Jupiter's gravitational field.

SATURN

The sixth most distant planet from the Sun in the Solar System, Saturn is a giant gas planet, second in mass and volume after Jupiter. (3.3 times smaller than Jupiter, but 5.5 times larger than Neptune and 6.5 times larger than Uranus) It is 95 times more massive than Earth, its diameter is almost 9 times greater than that of Earth. Saturn is the only planet in the Solar

System, whose average mass-volume is less than that of water: 0.69 g / cm^3 . This means that its atmosphere, composed mostly of Hydrogen, is less dense than water, but its core is much denser. It has an approximate diameter nine times that of Earth and is composed mostly of Hydrogen.

This planet has the shape of a flattened spheroid, is flattened at the poles and bulging at the equator. Its equatorial and polar diameter differ approximately by 10%, as a consequence of its rapid rotation around its axis and of a very fluid internal composition. The other giant gaseous planets of the Solar System (Jupiter, Uranus, Neptune) are also flattened, but to a lesser degree.

Like Jupiter, Saturn's atmosphere is organized in parallel bands, although these are less visible and larger at the equator. Saturn's cloud systems (as well as long-duration storms) were first observed by Voyager missions. The cloud observed in 1990 is an example of a large white spot, an ephemeral phenomenon of Saturn that occurs every 30 years. If the periodicity remains the same, the next storm will probably take place in 2020. In 2006 NASA observed a storm the size of a hurricane, stationed at the South Pole, which had a well-defined eye. It is the only eye observed on another planet except on Earth.

The rings of Saturn are part of one of the most beautiful spectacles of the Solar System and constitute its main characteristic. Unlike the other two giant gas planets, which are very bright (albedo between 0.2 and 0.6) and prevent detecting rings that are dark, Saturn's rings can be seen through a pair of binoculars. They have a permanent activity: collisions, accumulations of matter, etc.

Saturn has a large number of satellites. It is difficult to say how many there are, any piece of ice from the rings can be considered a satellite. In 2009, 62 satellites were identified. but there are currently about 100. Most of them are small: 31 have a diameter of less than 10 km, while 13 are less than 50 km. Only seven are large enough to assume a spherical shape under the influence of their own gravity. Titan is the largest of them, larger than Mercury and Pluto and the only satellite in the Solar System with a dense atmosphere on whose surface the Cassini mission deposited a probe, the Huygens, in 2004. The mission studied this world where it produces a cycle similar to that of water on Earth, but of methane, an element found in the three states on the surface of the satellite.

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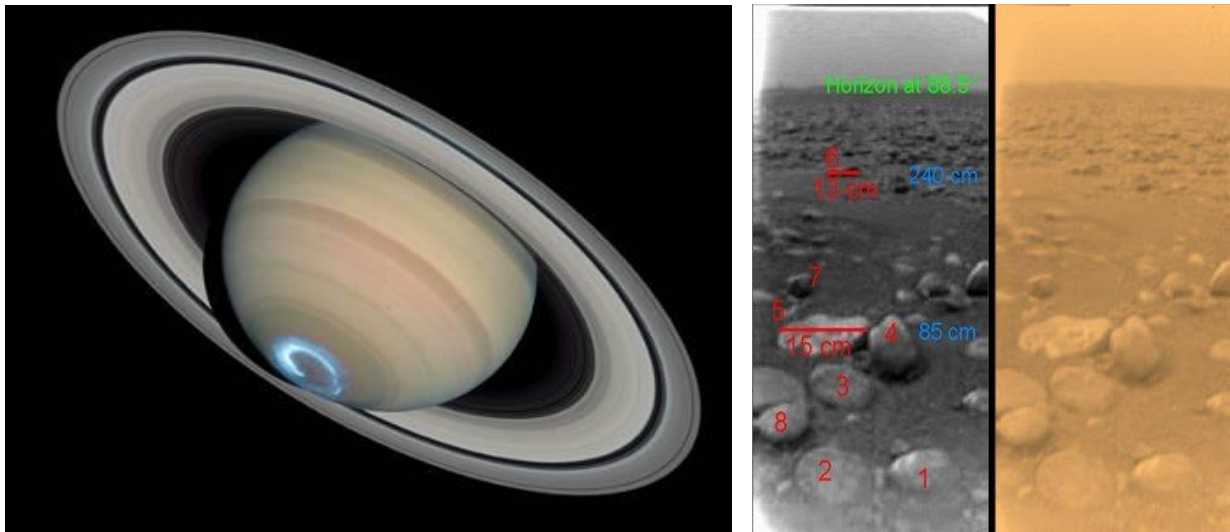


Fig. 14 Saturno's aurora photographed by the Hubble Space Telescope (left); Last photo on Titan, Cassini-Huygens Mission (right.)

URANUS

Uranus is also an icy gaseous giant planet and as such has rings: at least 13 main. It is the seventh farthest from the Sun in the Solar System, the third in dimensions and the fourth in mass. It is the first planet discovered in the telescopic era. Although it can be seen with the naked eye like the other 5 classic planets, due to its weak luminosity it was not easily identifiable as a planet. William Herschel announced his discovery on March 13, 1781, thus expanding the boundaries of the Solar System for the first time in modern times. Uranus is the first planet discovered through the telescope.

Uranus and Neptune have different internal and atmospheric compositions from that of the other great gas planets, Jupiter and Saturn. That is why astronomers sometimes place them in a different category, that of the frozen giants or subgiants.

The atmosphere of Uranus, although composed mainly of hydrogen and helium, also contain large amounts of water ice, ammonia and methane, as well as hydrocarbon traces. Uranus presents the coldest atmosphere of the Solar System, which reaches a minimum of -224°C . It has a complex structure of clouds, those of the lower strata could be formed of water and in the upper strata of methane. Like the other gaseous giant planets, Uranus has a ring system, a magnetosphere and numerous natural satellites. The Uranus system is unique in the Solar System, because its axis of rotation is practically in the orbit of its plane of revolution around the Sun. Its north and south poles are where the other planets have their equator. In 1986, Voyager 2 acquired images of Uranus, which show a planet with no special characteristics in visible light, no cloud layers or cloud systems as in the other gaseous planets. However, recent observations have shown signs of changing seasons and an increase in meteorological activity, when Uranus approached its equinox of December 2007. The wind can reach the speed of 250 m/s on its surface.

Unlike any other planet in the Solar System, Uranus has a very steep axis of rotation, almost parallel to its orbital plane. We could say that it rolls in its orbit and exposes the Sun to its North pole and its South pole successively. One consequence of this orientation is that the polar regions receive more energy from the Sun than the equatorial ones. However, Uranus remains warmer at the equator than at the poles, a mechanism not yet explained. No theory about its inclination can overlook the idea of a catastrophic collision with another body before its current formation.

The period of Uranus's revolution around the Sun is 84 terrestrial years. Its average distance to the Sun is about 3 billion kilometers. The intensity of the solar flux in Uranus is approx. 1/400 of which receives the Earth.

The rotation period of the inner layers of Uranus is 17 hours and 14 minutes. However, in the upper atmosphere violent winds in the direction of rotation occur, as occurs with all giant gas planets. Consequently, around 60° of latitude, the visible parts of the atmosphere travel faster and make a complete rotation in less than 14 hours. The atmospheric pressure is less than 1.3 bar) and its chemical composition is 83% Hydrogen (H₂), 15% Helium, 2.3% Methane, 0.009%, traces of Deuterium and ice of: ammonia, water, ammonium hydrosulfide (NH₄SH) and methane (CH₄).

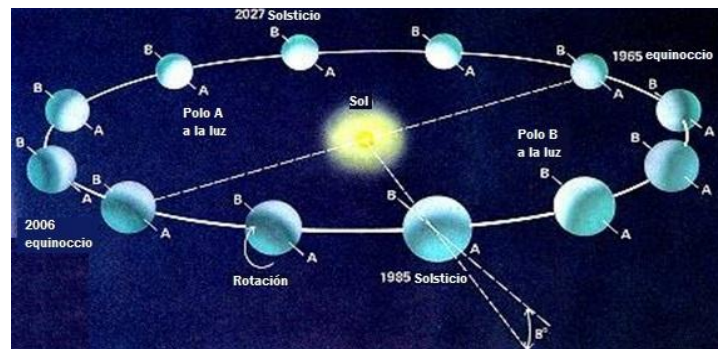
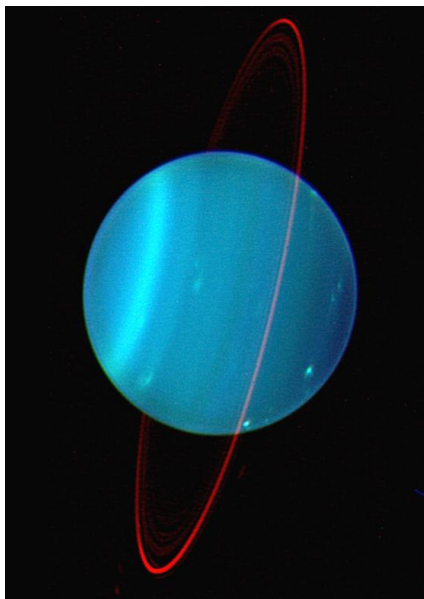


Fig. 15a: Uranus (left) Fig. 15b: Orbit of Uranus (right) .

Although we know very little about its internal composition, we know with certainty that it is different from that of Jupiter or Saturn. In theory, it should have a solid core of iron silicates, with a diameter of about 7,500 km, surrounded by a shield consisting of ice water mixed with helium, methane and ammonia, 10,000 km wide, followed by a surface layer of hydrogen and liquid helium, of approx. 7,600 kilometers, which slowly melts in the atmosphere. Unlike Jupiter and Saturn, Uranus is not so massive as to keep hydrogen in a metallic state around its nucleus. The blue-green color is due to the presence of methane in the atmosphere, which

absorbs red and infrared sunlight.

Uranus has at least 27 natural satellites. The first two were discovered by William Herschel on March 13, 1787 and were called Titania and Oberon.

NEPTUNE

Neptune is the eighth and the farthest planet from the Sun in the Solar System. It is also the last gas giant planet. It was discovered by the German astronomer Johann Gottfried Galle, on September 23, 1847, following the indications of Urbano Le Verrier, who, like the English astronomer John Couch Adams, had foreseen through calculation, that in that region of the sky, he could to be found.

Neptune is not visible to the naked eye and appears as a blue-green disc through the telescope. It has only been visited once by the space probe Voyager 2, which passed close to it on August 25, 1989. Its largest satellite is Triton. Its internal composition is similar to that of Uranus. It is believed to have a solid core formed of silicates and iron, almost as large as Earth's mass. Its nucleus, like Uranus, is supposedly covered with a fairly uniform composition (melting rocks, ice, 15% Hydrogen and some Helium), it does not have any structure in "layers" like Jupiter and Saturn.

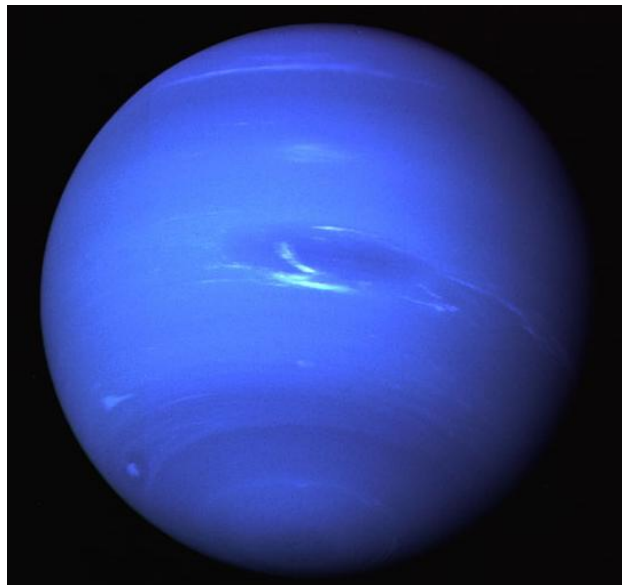


Fig. 16: Neptune

Its bluish color comes mainly from methane, which absorbs light at the wavelengths of red. Its atmosphere is composed of 80% Hydrogen (H₂), 19% Helium, 1.5% Methane, ~ 0.019% deuterium, ~ 0.00015 Ethane and ice of: ammonia, water, ammonium hydrosulfide and methane.

Like the other gaseous giant planets, it has a wind system formed by very fast winds in bands

parallel to the equator, of strong storms and vortices. The fastest winds in Neptune blow at more than 2,000 km / h. During the visit of Voyager 2, the most interesting formation observed was the "Great Dark Spot", which could be the size of the "Great Red Spot" of Jupiter. . This spot could be a giant dark hurricane that supposedly travels at about 1,000 km / h. The planetary rings of Neptune are little visible, dark, and of origin is still unknown. Neptune has at least 14 natural satellites, among which the most important is Triton, discovered by William Lassell only 17 days after the discovery of Neptune.

DWARF PLANETS

PLUTO, CARONTE AND ERIS

Although there are a dozen confirmed dwarf planets, Pluto (39 AU of average distance), its satellite Charon and Eris, enan planet of greater dimension than Pluto and that defined the reclassification of these objects in the Solar System, are particularly interesting.

Pluto was discovered in 1930 by Clive Thombaugh, considered a planet and re-classified in August 2006, as a dwarf planet. It has an eccentric orbit, inclined 17° against its ecliptic plane. Its perihelion extends to 29.7 AU and aphelion to 49.5 AU. Pluto's largest satellite, Charon, is large enough for the whole to gravitate around a center of gravity located above the surface of each of the bodies. Four other small satellites, Nix, Hydra, Cerberus, Styx, orbit around the couple Pluto-Charon. Pluto is in orbital resonance of 3: 2 with Neptune (the planet orbits the Sun twice, while Neptune does it three times).

Eris was discovered in January 2005 by a team from the Palomar Observatory chaired by Michael E. Brown. Of slightly larger dimensions than Pluto, it was considered the tenth planet until the re-classification of the UAI in 2006. It has a small moon baptized with the name of Disnomia. Like Pluto, it is part of the Kuiper belt or transneptunian objects. In this "second asteroid belt" of the Solar System, there are more bodies classified as dwarf planets, such as Haumea, Makemake, Quoar and Sedna.

OTHER BODIES OF THE SOLAR SYSTEM

The Interstellar medium

In addition to light, the Sun radiates a continuous flow of charged particles (plasma) called solar wind. This flow dissipates at a speed of 1.5 million km / h, thus creating the heliosphere, a fine atmosphere that bathes the Solar System to approx. 100 AU (marked the heliopause). The matter that constitutes the heliosphere is called interplanetary medium. The 11-year solar cycle, as well as frequent solar flares and coronal mass ejections, disturb the heliosphere and create a spatial climate. The rotation of the solar magnetic field acts on the interplanetary medium, creating the current heliospheric layer, which is the largest structure of the Solar System.

The earth's magnetic field protects the atmosphere from the solar wind. The interaction

between the solar wind and the earth's magnetic field causes the auroras borealis. The heliosphere ensures a partial protection of the Solar System from cosmic rays, which is greater in planets with a magnetic field.

The interplanetary medium has at least two regions of cosmic dust in the form of a disk. The first, the cloud of zodiacal dust, is in the inner Solar System and produces the zodiacal light. It was probably formed through a collision inside the asteroid belt caused by interactions with the planets. The second runs between 10 and 40 AU and was probably formed during similar collisions in the Kuiper Belt. They are the remnants of the planetary accretion. They comprise diverse populations of asteroids, comets and transneptunian objects.

COMETS

Comets are small bodies of the Solar System, with diameters of the order of kilometers, usually composed of volatile ice. They have very eccentric orbits, with perihelion sometimes in the inner Solar System, while aphelion is beyond Pluto. When a comet enters the inner Solar System, its proximity to the Sun leads to the sublimation and ionization of its surface, creating a tail: a long tail formed of gas and dust.

Short-period comets (eg, Halley's comet) complete their orbit in less than 200 years and appear to originate in the Kuiper Belt. Long-period comets (for example, the Hale-Bopp comet) have a periodicity of several thousand years and appear to originate in the Oort cloud. Finally, there are some comets that have a hyperbolic trajectory and seem to come from outside the Solar System. Old comets that have lost most of their volatile components are now considered asteroids.

The Centaurs, located between 9 and 30 AU, are bodies of ice similar to comets, which orbit between Jupiter and Neptune. The largest known centaur, Chariklo, has a diameter of between 200 and 250 km. The first discovered centaur, Chiron, was initially considered a comet, since it developed a tail like these. Some astronomers classify the centaurs as bodies of the Kuiper belt.

THE RESERVOIRS OF MINOR BODIES IN THE SOLAR SYSTEM

Reservoirs are relatively stable regions of the Solar System, where objects can remain for times comparable to the age of the System, until some perturbative force changes its orbit.

There are three large reservoirs in the SS:

1. The Main Asteroid Belt. Other populations would come from this region, such as the asteroids that approach Earth (known as NEAS by its acronym in English). The asteroids are mainly small bodies of the Solar System formed by rocks and non-volatile metallic minerals. The asteroid belt occupies an orbit between Mars and Jupiter, at a distance of 2.3 and up to 3.3 AU from the Sun. They could be remnants of the Solar System in formation, which have not been able to make a greater celestial body, due to the gravitational interference of Jupiter.

The size of the asteroids varies from several hundred kilometers to microscopic specks of dust. All, except the largest, Ceres, are considered small bodies, although some of them like Vesta and Hygeia could be classified as dwarf planets, if they are shown to reach hydrostatic equilibrium. The asteroid belt contains thousands, even millions of bodies with a diameter of more than a kilometer. However, the total mass of the belt is not greater than one thousandth of that of the Earth.

Ceres (2.77 AU) is the largest body in the asteroid belt and the only dwarf planet (classified as such in 2006). With a diameter of almost 1,000 km, it is sufficient for its gravity to give it its spherical shape.

2. The Transneptunian Belt. It is the region where short-period comets come from. The Kuiper belt is a large ring formed by the debris coming from the debris of a large ring, similar to that of the asteroid belt, but mainly composed of ice. The first part of the Kuiper belt extends between 30 and 50 AU from the Sun and stops at "the Kuiper cliff", where its second part starts at 100 AU. This region is believed to be the source of short period comets. They consist mainly of small bodies, as well as some larger ones, such as Quaoar, Varuna or Orcus, which can be classified as dwarf planets. The Kuiper belt could be divided mostly into "classical" objects and objects in resonance with Neptune. An example in this effect would be the plutinis that complete two orbits while Neptune has completed three.

3. The Oort Cloud. It has a spherical distribution and is formed by the frozen planetesimals swept out by giant planets during the formation of the SS. Thanks to perturbations due to the close passage of stars or giant molecular clouds, or to galactic tides, the orbits of some of these objects can change, drifting into the Solar System, transforming into long-period comets.

EXO WORLDS

In 1995 Swiss astronomers Michael Mayor and Didier Queloz announced the detection of an exoplanet orbiting 51 Pegasi. This star and its planet were baptized as Helvetios and Dimidio in 2015, after a public vote, promoted by the IAU. Mayor and Qeloz were awarded the Nobel Prize in Physics in 2019 for the discovery of 51 Pegasi b.

On May 10, 2016, the collaboration of scientists working on the project that orbited the Kepler telescope, intended for the detection of terrestrial exoplanets, announced the largest exoplanet collection of any news. Of a total of Some 5,000 candidates, more than 3,200 have been verified, and 2,325 of these were discovered by the Kepler telescope.

The NASA satellite "Transiting Exoplanet Survey", placed in orbit in 2018, uses the same method as the Kepler telescope to monitor 200,000 nearby bright stars and search for planets, especially the size of Earth or larger (the super Earths).

By 2025, nearly 6,000 exoplanets have been confirmed, and several of them have detected atmospheres where photochemical processes produce complex molecules. Some of these molecules are linked to what are called biosignatures, such as K2-18 b, a super-Earth exoplanet orbiting an M-type star. It has a mass of 8.92 Earths, takes 32.9 days to complete an orbit around its star, and is located 0.1429 AU from it. Its discovery was announced in 2015, and in 2023, dimethyl sulfide was detected in infrared observations by the James Webb Space Telescope (Madhusudhan, 2023), a molecule that on Earth is produced by phytoplankton.

How many stars have planets? How many of these exoplanetary systems have planets in the zone of habitability, where the water can be in a liquid state, and of those planets located at a suitable distance from its star, in how many life developed? Are question for which modern astronomers have no answer for the moment.

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