Solar System

Magda Stavinschi
International Astronomical Union, Astronomical Institute of the Romanian Academy (Bucarest, Romania)

Summary

Undoubtedly, in a universe where we talk about stellar and solar systems, planets and exoplanets, the oldest and the best-known system is the solar one. Who does not know what the Sun is, what planets are, comets, asteroids? But is this really true? If we want to know about these types of objects from a scientific point of view, we have to know the rules that define this system.

Which bodies fall into these catagories (according to the resolution of the International Astronomical Union of 24 August 2006)?

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

By extension, any other star surrounded by bodies according to the same laws is called a stellar system.

What is the place of the Solar system in the universe? These are only some of the questions we will try to answer now.

Goals

- Determine the place of the Sun in the universe.
- Determine which objects form the solar system
- Find out details of the various bodies in the solar system, in particular of the most prominent among them

Solar System

What is a system? A system is, by definition, an ensemble of elements (principles, rules, forces, etc.), mutually interacting in keeping with a number of principles or rules.

What is a Solar System?To define it we shall indicate the elements of the ensemble: the Sun and all the bodies surrounding it and connected to it through the gravitational force.

What is the place of the Solar System in the universe? The Solar System is situated in one of the exterior arms of our Galaxy, also called the Milky Way. This arm is called the Orion Arm. It is located in a region of relatively small density.

The Sun, together with the entire Solar system, is orbiting around the center of our Galaxy, located at a distance of 25,000 – 28,000 light years (approximately half of the galaxy radius), with an orbital period of approximately 225-250 million years (the galactic year of the Solar system). The travel distance along this circular orbit is approximately 220 km/s, while the direction is oriented towards the present position of the star Vega.

Our Galaxy consists of approximately 200 billion stars, together with their planets, and over 1000 nebulae. The mass of the entire Milky Way is approx. 750-1000 billion times bigger than that of the Sun, and the diameter is approx. 100,000 light years.

Close to the Solar System is the system Alpha Centauri (the brightest star in the constellation Centaurus). This system is actually made up of three stars, two stars that are a binary system (Alpha Centauri A and B), that are similar to the Sun, and a third star, Alpha Centauri C, which is probably orbiting the other two stars. Alpha Centauri C is a red dwarf with a smaller luminosity than the sun, and at a distance of 0.2 light-years from the other two stars. Alpha Centauri C is the closest star to the Sun, at a distance of 4.24 light-years that is why it is also called "Proxima Centauri".

Our galaxy is part of a group of galaxies called the Local Group, made up of 3 large galaxies and at least 30 smaller ones.

Our Galaxy has the shape of a huge spiral. The arms of this spiral contain, among other things, interstellar matter, nebulae, and young clusters of stars, which are born out of this matter. The center of the galaxy is made up of older stars, which are often found in clusters that are spherical in shape, known as globular clusters. Our galaxy numbers approximately 200 such groups, from among which only 150 are well known. Our Solar system is situated 20 light years above the symmetry equatorial plane and 28,000 light years away from the galactic center.

The galaxy center is located in the direction of the Sagittarius Constellation, 25,000 – 28,000 light years away from the Sun.

Sun

The age of the Sun is approx. 4.6 billion years. At present the Sun has completed about half of its main evolutionary cycle. During the main stage of its evolution the Sun's hydrogen core turns into helium through nuclear fusion. Every second in the Sun's nucleus, over four million tons of matter are converted into energy, thus generating neutrinos and solar radiation.

The Sun's life cycle

In about 5 billion years the Sun will turn into a red giant, and then into a white dwarf, a period when it will give birth to a planetary nebula. Finally, it will exhaust its hydrogen, which will lead to radical changes, the total destruction of the Earth included. The solar activity, more specifically its magnetic activity, produces a number of phenomenon including solar spots on its surface, solar flares and solar wind variations, which carry matter into the entire Solar system and even beyond.

The Sun's composition is made up of mostly hydrogen and helium. Hydrogen accounts for approx. 74%, and helium accounts for approximately 25% of the Sun, while the rest is made up of heavier elements, such as oxygen, and carbon.

Fig. 1: The Sun

The formation and the evolution of the Solar System

The birth and the evolution of the solar system have generated many fanciful theories in the past. Even in the beginning of the scientific era, the source of the Sun’s energy and how the Solar System formed was still a mystery. However new advances in the space era, the discovery of other worlds similar to our Solar system, as well as advances in nuclear physics, have all helped us to better understand the fundamental processes that take place inside a star, and how stars form.

The modern accepted explanation for how the Sun and Solar System formed (as well as other stars) was first proposed back in 1755 by Emmanuel Kant and also separately by Pierre-Simon Laplace. According to this theory stars form in large dense clouds of molecular hydrogen gas. These clouds are gravitationally unstable and collapse into smaller denser clumps; in the case of the Sun this is called the “solar nebula”, these initial dense clumps then collapse even more to form stars and a disk of material around them that may eventually become planets. The solar nebula may have originally been the size of 100 AU and had a mass 2-3 times bigger than that of the Sun. Meanwhile as the nebula was collapsing more and more, the conservation of angular momentum made the nebula spin faster as it collapsed, and caused the center of the nebula to become increasingly warmer. This took place about 4.6 billion years ago. It is generally considered that the solar system looks entirely different today than it originally did when it was first forming.

But let’s take a better look at the Solar System, as it is today.

Planets

We shall use the definition given by the International Astronomical Union at its 26th General Meeting, which took place in Prague, in 2006.

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

1. is in orbit around the Sun,
2. has sufficient mass to assume hydrostatic equilibrium (a nearly round shape), and
3. has "cleared the neighborhood" around its orbit.

A non-satellite body fulfilling only the first two of these criteria is classified as a "dwarf planet". According to the IAU, "planets and dwarf planets are two distinct classes of objects". A non-satellite body fulfilling only the first criterion is termed a "small solar system body" (SSSB).

Initial drafts planned to include dwarf planets as a subcategory of planets, but because this could potentially have led to the addition of several dozens of planets into the Solar system, this draft was eventually dropped. In 2006, it would only have led to the addition of three (Ceres, Eris and Makemake) and the reclassification of one (Pluto). So, the Solar system has five dwarf planets: Ceres, Pluto, Makemake, Haumea and Eris.

According to the definition, there are currently eight planets and five dwarf planets known in the Solar system. The definition distinguishes planets from smaller bodies and is not useful outside the Solar system, where smaller bodies cannot be found yet. Extrasolar planets, or exoplanets, are covered separately under a complementary 2003 draft guideline for the definition of planets, which distinguishes them from dwarf stars, which are larger.

Let us present them one by one:

MERCURY

Mercury is the closest planet to the Sun and the smallest planet in the Solar system. It is a terrestrial[1] planet in the inner solar system. It gets its name from the Roman god Mercury.

It has no natural satellite. It is one of the five planets that can be seen from the Earth with the naked eye. It was first observed with the telescope only in the 17th century. More recently it was surveyed by two space probes: Mariner 10 (three times in 1974-1975) and Messenger (two times in 2008).

Although it can be seen with the naked eye, it is not easily observable, precisely because it is the closest planet to the Sun. Its location on the sky is very close to the Sun and it can only be well observed around the elongations, a little before sunrise and a little after sunset. However, space missions have given us sufficient information, proving surprisingly that Mercury is very similar to the Moon.

It is worth mentioning several characteristics of the planet: it is the smallest one in the Solar system and the closest one to the Sun. It has the most eccentric orbit (e = 0.2056) and also the most inclined one against the ecliptic (i = 7°005). Its synodic period is of 115.88 days, which means that three times a year it is situated in a position of maximum elongation west of the Sun (it is also called " the morning star" and when it is three times in maximum elongation position east of the Sun it is called "the evening star". In either of these cases, the elongation does not exceed 28°.

It has a radius of 2440 km, making it the smallest planet of the Solar system, smaller even than two of Jupiter's Galilean satellites: Ganymede and Callisto. A density of 5.427 g/cm^3 makes it the densest planet after the Earth (5.5 g/ cm3). Iron might be the main heavy element (70% Iron and 30% rocky matter), which contributes to Mercury's extremely high density. It

[1] A **terrestrial planet** is a planet that is primarily composed of silicate rocks. Within the Solar system, the terrestrial (or telluric) planets are the inner planets closest to the Sun.

is generally asserted that Mercury has no atmosphere, which is not quite correct as its atmosphere is extremely rarified.

Mercury is the only planet (besides the Earth) with a significant magnetic field, which, although it is of the order of 1/100 of that of the terrestrial magnetic field, it is sufficient 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 the Earth: the magnetic field is created by a dynamo effect and the magnetic is also dipolar like Earth's, with a magnetic axis inclined at 11° to the rotation axis.

On Mercury the temperatures vary enormously. When the planet passes through the perihelion, the temperature can reach 427° C on the equator at noon, namely enough to bring about the fusion of a metal to zinc. However, immediately after night fall, the temperature can drop down to 183°C, which makes the diurnal variation rise to 610 C!. No other planet undergoes such a difference, which is due either to the intense solar radiation during the day, the absence of a dense atmosphere, and the duration of the Mercurian day (the interval between dawn and dusk is almost three terrestrial months), long enough time to stock heat (or, similarly, cold during an equally long night).

Orbital characteristics, Epoch J2000	
Aphelion	69,816,900 km, 0.466697 AU
Perihelion	46,001,200 km, 0.307499 AU
Semi-major axis	57,909,100 km, 0.387098 AU
Eccentricity	0.205630
Orbital period	87.969 days, (0.240 85 years), 0.5 Mercury solar day
Synodic Period	115.88 days
Average orbital speed	47.87 km/s
Mean anomaly	174.796°
Inclination	7.005° to Ecliptic
Longitude of ascending node	48.331°
Argument of perihelion	29.124°
Satellite	None

Physical Characteristics			
Mean radius	2,439.7 ± 1.0 km; 0.3829 Earths		
Flattening	0		
Surface area	7.48×10^7 km^2; 0.147 Earths		
Volume	6.083×10^{10} km^3; 0.056 Earths		
Mass	3.3022×10^{23} kg; 0.055 Earths		
Mean density	5.427 g/cm^3		
Equatorial surface gravity	3.7 m/s^2; 0.38 *g*		
Escape velocity	4.25 km/s		
Sidereal rotation period	58.646 day; 1407.5 h		
Albedo	0.119 (bond); 0.106 (geom.)		
Surface temperature	**Min**	**mean**	**max**
0°N, 0°W	100 K	340 K	700 K
85°N, 0°W	80 K	200 K	380 K
Apparent magnitude	−2.3 to 5.7		
Angular momentum	4.5" – 13"		

Atmosphere

Surface pressure trace

Composition: 42% Molecular oxygen, 29.0% sodium, 22.0% hydrogen, 6.0% helium, 0.5% potassium. Trace amounts of argon, nitrogen, carbon dioxide, water vapor, xenon, krypton, and neon.

We have to say a few things about the planetary surface.

Mercury's craters are very similar to the lunar ones in morphology, shape and structure. The most remarkable one is the Caloris basin, the impact that created this basin was so powerful that it also created lave eruptions and left a large concentric ring (over 2 km tall) surrounding the crater.

The impacts that generate basins are the most cataclysmic events that can affect the surface of a planet. They can cause the change of the entire planetary crust, and even internal disorders. This is what happened when the Caloris crater with a diameter of 1550 km was formed.

The advance of Mercury's perihelion

The advance of Mercury's perihelion has been confirmed. Like any other planet, Mercury's perihelion is not fixed but has a regular motion around the Sun. For a long time it was considered that this motion is 43 arcseconds per century, which is faster by comparison with the forecasts of classical "Newtonian" celestial mechanics. This advance of the perihelion was predicted by Einstein's general theory of relativity, the cause being the space curvature due to the solar mass. This agreement between the observed advance of the perihelion and the one predicted by the general relativity was the proof in favor of the latter hypothesis's validity.

VENUS

Venus is one of the eight planets of the Solar system and one of the four terrestrial planets in the inner system, the second distant from the Sun. It bears the name of the Roman goddess of love and beauty.

Its closeness to the Sun, structure and atmosphere density make Venus one of the warmest bodies in the solar system. It has a very weak magnetic field and no natural satellite. It is one of the only planets with a retrograde revolution motion and the only one with a rotation period greater than the revolution period.

It is the brightest body in the sky after the Sun and the Moon.

It is the second planet distant from the Sun (situated between Mercury and the Earth), at approximately 108.2 million km from the Sun. Venus' trajectory around the Sun is almost a circle: its orbit has an eccentricity of 0.0068, namely the smallest one in the Solar system.

A Venusian year is somewhat shorter than a Venusian sidereal day, in a ratio of 0.924.

Its dimension and geological structure are similar to those of the Earth. The atmosphere is extremely dense. The mixture of CO_2 and dense sulfur dioxide clouds create the strongest greenhouse effect in the Solar system, with temperatures of approx. 460°C. Venus' surface temperature is higher than Mercury's, although Venus is situated almost twice as far from the Sun than Mercury and receives only approx. 25% of solar radiance that Mercury does. The planet's surface has an almost uniform relief. Its magnetic field is very weak, but it drags a plasma tail 45 million km long, observed for the first time by SOHO in 1997.

Remarkable among Venus' characteristics is its retrograde rotation; it rotates around its axis very slowly, counterclockwise, while the planets of the Solar system do this often clockwise (there is another exception: Uranus). Its rotation period has been known since 1962. This rotation – slow and retrograde – produces solar days that are much shorter than the sidereal day, sidereal days are longer on the planets with clockwise rotation[2]. Consequently, there are less than 2 complete solar days throughout a Venusian year.

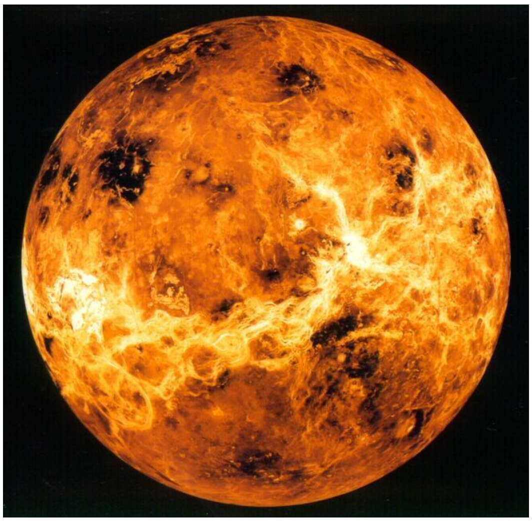

Fig. 3: Venus

The causes of Venus' retrograde rotation have not been determined yet. The most probable explanation would be a giant collision with another large body during the formation of the planets in the solar system. It might also be possible that the Venusian atmosphere influenced the planet's rotation due to its great density.

Venus – the Earth's twin sister. The analogy.

- They were born at the same time from the same gas and dust cloud, 4.6 billion years ago.
- both are planets in the inner solar system
- their surfaces have a varied ground: mountains, fields, valleys, high plateaus, volcanoes, impact craters, etc
- both have a relatively small number of craters, a sign of a relatively young surface and of a dense atmosphere
- they have close chemical compositions

Properties	Venus	Earth	Ratio Venus/Earth
Mass	4.8685×10^{24} kg	5.9736×10^{24} kg	0.815
Equatorial Radius	6,051 km	6,378 km	0.948
Mean density	5.204 g/cm^3	5.515 g/cm^3	0.952
Semi-major axis	108,208,930 km	149,597,887 km	0.723
Average orbital speed	35.02 km/s	29.783 km/s	1.175
Equatorial surface gravity	8.87 m/s^2	9,780327 m/s^2	0.906

Venus' transit

Venus' transit takes place when the planet passes between the Earth and the Sun, when Venus' shadow crosses the solar disk. Due to the inclination of Venus' orbit compared to the

[2] The solar day is the (average) interval between two suceeding passages of the Sun at the meridian. For instance, the Earth has a solar (average) day of 24 h and a sidereal day of 23 h 56 min 4,09 s. On Venus the solar day has 116.75 terrestrail days (116 days 18 hours), while the sidereal day has 243.018 terrestrial days.

Earth's, this phenomenon is very rare on human time scales. It takes place twice in 8 years, this double transit being separated from the following one by more than a century (105.5 or 121.5 years)
The last transit took place on 8 June 2004, the next one will be on 6 June 2012 and the following won't be until 11 December 2117.

Orbital characteristics, Epoch J2000	
Aphelion	108,942,109 km, 0.728231 AU
Perihelion	107,476,259 km, 0.718432 AU
Semi-major axis	108,208,930 km, 0.723332 AU
Eccentricity	0.0068
Orbital period	224.700 day, 0.615197 yr, 1.92 Venus solar day
Synodic Period	583.92 days
Average orbital speed	35.02 km/s
Inclination	3.394 71° to Ecliptic, 3.86° to Sun's equator
Longitude of ascending node	76.670 69°
Argument of perihelion	54.852 29°
Satellite	None

Physical characteristics	
Mean radius	6,051.8 ± 1.0 km, 0.949 9 Earths
Flattening	0
Surface area	4.60×10^8 km², 0.902 Earths
Volume	9.38×10^{11} km³, 0.857 Earths
Mass	4.8685 × 1024 kg, 0.815 Earths
Mean density	5.204 g/cm³
Equatorial surface gravity	8.87 m/s², 0.904 g
Escape velocity	10.46 km/s
Sidereal rotation period	-243.018 5 day
Albedo	0.65 (geometric) or 0.75 (bond)
Surface temperature (mean)	461.85 °C
Apparent magnitude	up to -4.6 (crescent), -3.8 (full)
Angular momentum	9.7" – 66.0"

Atmosphere
Surface pressure 93 bar (9.3 MPa)
Composition: ~96.5% Carbon dioxide, ~3.5% Nitrogen, 0.015% Sulfur dioxide, 0.007% Argon, 0.002% Water vapor, 0.001 7% Carbon monoxide, 0.001 2% Helium, 0.000 7% Neon.

EARTH

The Earth is the third planet from the Sun in the Solar system, and the fifth in size. It belongs to the inner planets of the solar system. It is the largest terrestrial planet in the Solar system, and the only one in the Universe known to accommodate life. The Earth formed approx. 4.57 billion years ago. Its only natural satellite, the Moon, began to orbit it shortly after that, 4.533 billion years ago. By comparison, the age of the Universe is approximately 13.7 billion years. 70.8 % of the Earth's surface is covered with water, the rest of 29.2% being solid and „dry". The zone covered with water is divided into oceans, and the land is subdivided into continents.

Fig. 4: Earth

Between the Earth and the rest of the Universe there is a permanent interaction. For example, the Moon is the cause of the tides on the Earth. The Moon also continuously influences the speed of Earth's rotational motion. All bodies that orbit around the Earth are attracted to the Earth; this attraction force is called gravity, and the acceleration with which these bodies fall into the gravitational field is called gravitational acceleration (noted with "g" = 9.81 m/s^2).

Orbital characteristics, Epoch J2000	
Aphelion	152,097,701 km; 1.0167103335 AU
Perihelion	147,098,074 km; 0.9832898912 AU
Semi-major axis	149,597,887.5 km; 1.0000001124 AU
Eccentricity	0.016710219
Orbital period	365.256366 days; 1.0000175 years
Average orbital speed	29.783 km/s; 107,218 km/h
Inclination	1.57869
Longitude of ascending node	348.73936°
Argument of perihelion	114.20783°
Satellite	1 (the Moon)

Physical characteristics	
Mean radius	6,371.0 km
Equatorial radius	6,378.1 km
Polar radius	6,356.8 k
Flattening	0.003352
Surface area	510,072,000 km²
Volume	1.0832073 × 1012 km^3
Mass	5.9736 × 10^{24} kg
Mean density	5.515 g/cm3
Equatorial surface gravity	9.780327 m/s²[9]; 0.99732 g
Escape velocity	11.186 km/s
Sidereal rotation period	0.99726968 d; 23h 56m 4.100s
Albedo	0.367
Surface temperature (mean)	min mean max −89 °C 14 °C 57.7 °C

It is believed that creation of the Earth's oceans was caused by a "shower" of comets in the Earth's early formation period. Later impacts with asteroids added to the modification of the environment decisively. Changes in Earth's orbit around the Sun may be one cause of ice ages on the Earth, which took place throughout history.

Atmosphere
Surface pressure 101.3 kPa (MSL)
Composition: 78.08% nitrogen (N_2), 20.95% oxygen (O_2), 0.93% argon, 0.038% carbon dioxide; about 1% water vapor (varies with climate).

MARS

Mars is the fourth distant planet from the Sun in the Solar system and the second smallest in size after Mercury. It belongs to the group of terrestrial planets. It bears the name of the Roman god of war, Mars, due to its reddish color.

Several space missions have been studying it starting from 1960 to find out as much as possible about its geography, atmosphere, as well as other details.Mars can be observed with the naked eye. It is not as bright as Venus and only seldom brighter than Jupiter. It overpasses the latter one during its most favorable configurations (oppositions).

Among all the bodies in the Solar system, the red planet has attracted the most science fiction stories. The main reason for this is often due to its famous channels, called this for the first time in 1858 by Giovanni Schiaparelli and considered to be the result of human constructions.

Mars' red color is due to iron oxide III (also called hematite), to be found in the minerals on its surface.Mars has a very strong relief; it has the highest mountain in the solar system (the volcano Olympus Mons), with a height of approx. 25 km, as well as the greatest canyon (Valles Marineris) with of an average depth of 6 km. The center of Mars is made up of an iron nucleus with a diameter of approx. 1700 km, covered with an olivine mantel and a basalt crust with an average width of 50 km.

Mars is surrounded by a thin atmosphere, consisting mainly of carbon dioxide. It used to have an active hydrosphere, and there was water on Mars once.It has two natural satellites, Phobos and Deimos, which are likely asteroids captured by the planet.

Mars' diameter is half the size of the Earth and its surface area is equal to that of the area of the continents on Earth. Mars has a mass that is about one-tenth that of Earth. Its density is the smallest among those of the terrestrial planets, which makes its gravity only somewhat smaller than of Mercury, although its mass is twice as large.

The inclination of Mars' axis is close to that of the Earth, which is why there are seasons on Mars just like on Earth. The dimensions of the polar caps vary greatly during the seasons through the exchange of carbon dioxide and water with the atmosphere.

Another common point, the Martian day is only 39 minutes longer than the terrestrial one. By contrast, due to its relative distance from the Sun, the Martian year is longer than an Earth year, more than 322 days longer than the terrestrial year.

Mars is the closest exterior planet to the Earth. This distance is smaller when Mars is in opposition, namely when it is situated opposite the Sun, as seen from the Earth. Depending on ellipticity and orbits inclination, the exact moment of closest approach to Earth may vary with a couple of days.

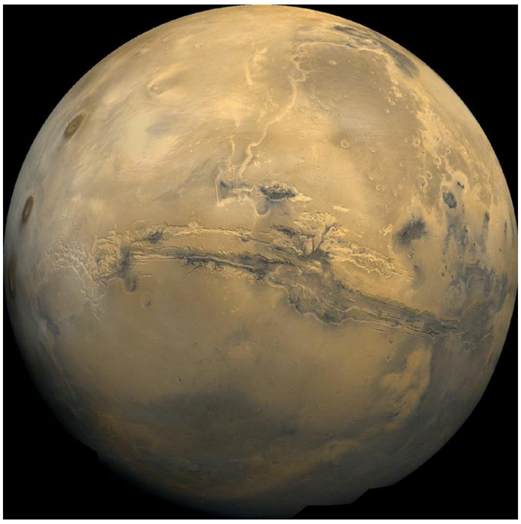

Fig. 5: Mars

On 27 August 2003 Mars was only 55,758 million km away from Earth, namely only 0.3727 AU away, the smallest distance registered in the past 59,618 years. An event such as this often results in all kinds of fantasies, for instance that Mars could be seen as big as the full Moon. However, with an apparent diameter of 25.13 arcseconds, Mars could only be seen with the naked eye as a dot, while the Moon extends over an apparent diameter of approx. 30 arcminutes. The following similar close distance between Mars and Earth will not happen again until 28 August 2287, when the distance between the two planets will be of 55,688 million km.

Orbital characterisitics, Epoch J2000	
Aphelion	249,209,300 km; 1.665861 AU
Perihelion	206,669,000 km; 1.381497 AU
Semi-major axis	227,939,100 km; 1.523679 AU
Eccentricity	0.093315
Orbital period	686.971 day; 1.8808 Julian years
Synodic period	779.96 day; 2.135 Julian years
Average orbital speed	24.077 km/s
Inclination	1.850° to ecliptic; 5.65° to Sun's equator
Longitude of ascending node	49.562°
Argument of perihelion	286.537°
Satellite	2

Physical characteristics	
Equatorial radius	3,396.2 ± 0.1 km; 0.533 Earths
Polar radius	3,376.2 ± 0.1 km; 0.531 Earths
Flattening	0.00589 ± 0.00015
Surface area	144,798,500 km²; 0.284 Earths
Volume	1.6318×10^{11} km³; 0.151 Earths
Mass	6.4185×10^{23} kg; 0.107 Earths
Mean density	3.934 g/cm³
Equatorial surface gravity	3.69 m/s²; 0.376 g
Escape velocity	5.027 km/s
Sidereal rotation period	1.025957 day
Albedo	0.15 (geometric) or 0.25 (bond)
Surface temperature	min mean max −87 °C −46 °C −5 °C
Apparent magnitude	+1.8 to −2.91
Angular diameter	3.5—25.1"

Atmosphere:
Surface pressure 0.6–1.0 kPa)
Composition 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; 2.5 ppm Neon; 300 ppb Krypton; 130 ppb Formaldehyde; 80 ppb Xenon; 30 ppb Ozone;10 ppb Methane.

JUPITER

Jupiter is the fifth distant planet from the Sun and the biggest of all the planets in our solar system. Its diameter is 11 times bigger than that of the Earth, its mass is 318 times greater than Earth, and its volume 1300 times larger than those of our planet.

- orbit: 778,547,200 km from the Sun
- diameter: 142,984 km (equatorial)
- mass: $1.8986 x 10^{27}$ kg

Jupiter is the fourth brightest object in the sky (after the Sun, Moon, Venus and sometimes Mars). It has been known from prehistoric times. The discovery of its four great satellites, Io, Europe, Ganymede and Callisto (known as Galilean satellites) by Galileo Galilei and Simon Marius in 1610 was the first discovery of an apparent motion center not centered on Earth. It was a major point in favor of the heliocentric theory of planetary motion of Nicolaus Copernicus. Galileo’s endorsement of the Copernican motion theory brought him trouble with the Inquisition. Before the Voyager missions, only 16 of its satellites were known, it is now known to have over 60 satellites.

Fig. 6: Jupiter

Composition: Jupiter probably has a core of solid material that amounts up to 10 - 15 Earth masses. Above this core, is a deep layer of liquid metallic hydrogen. Due to the temperature and pressure inside Jupiter, its hydrogen is a liquid and not a gas. It is an electric conductor and the source of Jupiter’s magnetic field. This layer probably contains some helium and some traces of “drifts of ice”. The surface layer is mainly made up of molecular hydrogen and helium, liquid inside and gaseous outside. The atmosphere we see is only the superior part of this deep stratum. Water, carbon dioxide, methane, as well as other simple molecules are also present in small quantities.

Atmosphere: Jupiter consists of approx. 86% hydrogen and 14% helium (according to the number of atoms, approx. 75/25% by mass) with traces of methane, water, ammonia and “stone”. This is very close to the original composition of the Solar Nebula, from which the entire solar system formed. Saturn has a similar composition, while Uranus and Neptune have less hydrogen and helium.

The Great Red Spot (GRS) was observed for the first time by the telescopes on Earth, more than 300 years ago. It is an oval of approximately 12000 by 25000 km, large enough to encompass two or three Earths. It is a region of high pressure, whose superior clouds are much higher and colder than the surrounding zones. Similar structures have been observed on Saturn and Neptune. The way in which such structures exist for such a long time has not been fully understood yet.

Jupiter and the other gaseous planets have winds of great speed in large bands at different latitudes. The winds blow in opposite directions in two adjoining bands. The small temperature or chemical composition differences are responsible for the different coloring of the bands, an aspect that dominates the image of the planet. Jupiter’s atmosphere is very turbulent. This proves that the winds are driven, to a great extent, by the internal heat of the planet and not by coming from the Sun, as is the case with the Earth.

The Magnetosphere Jupiter has a huge magnetic field, 14 times stronger than that of Earth’s magnetic field. Its magnetosphere extends over 650 million km (beyond Saturn’s orbit). Jupiter’s satellites are included in its magnetosphere, which partially explains the activity on Io. A possible problem for future space voyages, as well as a great problem for the designers of the probes Voyager and Galileo, is that the medium in the neighborhood of Jupiter has large quantities of particles caught by Jupiter’s magnetic field. This “radiation” is similar, but much more intense than that observed in the Van Allen belts of the Earth. It would be lethal for any unprotected human being.

The Galileo probe discovered a new intense radiation between Jupiter’s rings and the upper layer of the atmosphere. This new radiation belt has an intensity approx. 10 times higher than that of the Van Allen belts on Earth. Surprisingly, this new belt contains helium ions of high energy, of unknown origins.

The planet’s rings Jupiter has rings just like Saturn, but much paler and smaller. Unlike those of Saturn, Jupiter’s rings are dark. They are likely made up of small grains of rocky material. Unlike Saturn’s rings, Jupiter’s ring seem unlikely to contain ice. The particles from Jupiter’s rings likely do not remain there for long (because of the atmospheric and magnetic attraction). The Galileo probe found clear evidence that indicates that the rings are continuously supplied by the dust formed by the impacts of micrometeorites with the inner four moons.

Orbital characteristics, Epoch J2000	
Aphelion	816,520,800 km (5.458104 AU)
Perihelion	740,573,600 km (4.950429 AU)
Semi-major axis	778,547,200 km (5.204267 AU)
Eccentricity	0.048775
Orbital period	4,331.572 days; 11.85920 years; 10,475.8 Jupiter solar days
Synodic period	398.88 days
Average orbital speed	13.07 km/s
Mean anomaly	18.818°
Inclination	1.305° to ecliptic; 6.09° to Sun's equator
Longitude of ascending node	100.492°
Argument of perihelion	275.066°
Satellite	67

Physical characteristics	
Equatorial radius	71,492 ± 4 km; 11.209 Earths
Polar radius	66,854 ± 10 km; 10.517 Earths
Flattening	0.06487 ± 0.00015
Surface area	6.21796×10^{10} km²; 121.9 Earths
Volume	1.43128×10^{15} km³; 1321.3 Earths
Mass	1.8986×10^{27} kg; 317.8 Earths; 1/1047 Sun
Mean density	1.326 g/cm³
Equatorial surface gravity	24.79 m/s²; 2.528 g
Escape velocity	59.5 km/s
Sidereal rotation period	9.925 h
Albedo	0.343 (bond); 0.52 (geom.)
Apparent magnitude	-1.6 to -2.94
Angular diameter	29.8" — 50.1"

Atmphofere
Surface pressure 20–200 kPa[12] (cloud layer)
Scale height 27 km
Composition: 89.8±2.0% Hydrogen (H2), 10.2±2.0% Helium, ~0.3% Methane, ~0.026% Ammonia, ~0.003% Hydrogen deuteride (HD), 0.0006% Ethane, 0.0004% water. Ices: Ammonia, water, ammonium hydrosulfide(NH_4SH).

SATURN

Saturn is the sixth distant planet from the Sun in the Solar system. It is a gas giant planet, the second in mass and volume after Jupiter. It has a diameter approx. nine times greater than that of the Earth and is made up of mostly hydrogen. It bears the name of the Roman god Saturn

Mass and dimensions Saturn has the form of a flattened spheroid: it is flattened at the poles and swollen at the equator. Its equatorial and polar diameters differ approx. by 10%, as a result of its rapid rotation around its axis and of an extremely fluid internal composition. The other gas giant planets in the solar system (Jupiter, Uranus, Neptune) are also flattened, but less so.

Saturn is the second most massive planet in the Solar system, 3.3 times smaller than Jupiter, but 5.5 times bigger than Neptune and 6.5 times bigger than Uranus. It is 95 times more massive than the Earth. Its diameter is almost 9 times larger than the Earth's. Saturn is the only planet in the Solar system whose average density is smaller than that of water: 0.69

g/cm^3. Although Saturn's core is denser than water, its average density is smaller than that of water because of its large hydrogen gaseous atmosphere.

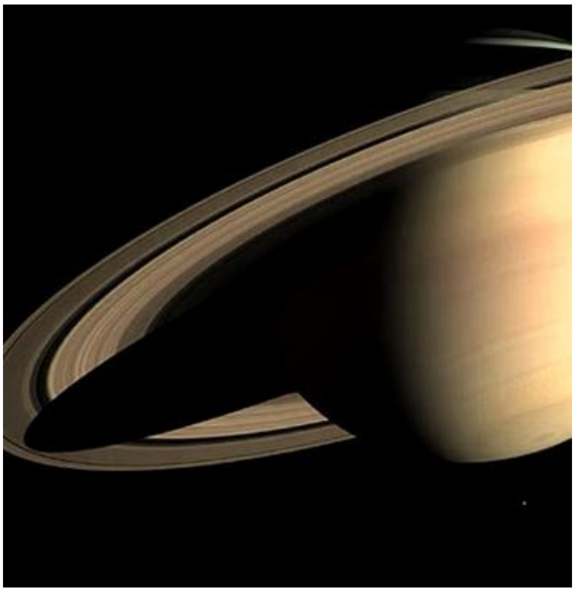

Fig. 7: Saturn

Atmosphere: Just like Jupiter, Saturn's atmosphere is organized in parallel bands, however these are less visible than Jupiter's and are wider near the equator. Saturn's cloud systems (as well as the long lasting storms) were first observed by the Voyager missions. The cloud observed in 1990 is an example of a great white spot, an ephemeral Saturnian phenomenon that takes place every 30 years. If periodicity remains the same, the next storm will probably take place in 2020. In 2006 NASA observed a storm of hurricane dimensions, stationed at the Southern pole of Saturn that had a well defined eye. It is the only eye observed on another planet other than Earth.Saturn's atmosphere undergoes a differential rotation.

Saturn's rings are one of the most beautiful phenomena in the solar system, making up its defining characteristic. Unlike the other gas giant planets with rings, they are extremely bright (albedo between 0.2 and 0.6) and can also be seen with a pair of binoculars. They are dominated by permanent activity: collisions, matter accumulations, etc.

Saturn has a great number of satellites. It is difficult to say how many there are, as any piece of ice in the rings can be considered a satellite. In 2009 62 satellites were identified. 53 were confirmed and were given names. Most of them are small: 31 have diameters fewer than 10 km, while 13 are smaller than 50 km. Only seven are big enough to take on a spheroidal shape under the influence of their own gravity. Titan is the largest one, bigger than Mercury and Pluto, and the only satellite in the solar system with a dense atmosphere.

Atmosphere:
Scale height: 59.5 km
Composition: ~96% Hydrogen (H_2), ~3% Helium, ~0.4% Methane, ~0.01% Ammonia, ~0.01% Hydrogen deuteride (HD), 0.000 7% Ethane, Ices: Ammonia, water, ammonium hydrosulfide ((NH_4SH)

Orbital characteristics, Epoch J2000	
Aphelion	1,513,325,783 km; 10.115958 AU
Perihelion	1,353,572,956 km; 9.048076 AU
Semi-major axis	1,433,449,370 km; 9.582017 AU
Eccentricity	0.055723
Orbital period	10,759.22 days; 29.4571 years
Synodic period	378.09 days
Average orbital speed	9.69 km/s
Mean anomaly	320.346 750°
Inclination	2.485 240° to ecliptic; 5.51° to Sun's equator
Longitude of ascending node	113.642 811°
Argument of perihelion	336.013 862°
Satellite	~ 200 observed (61 with secure orbits)

Physical characteristics	
Equatorial radius	60,268 ± 4 km; 9.4492 Earths
Polar radius	54,364 ± 10 km; 8.5521 Earths
Flattening	0.09796 ± 0.000 18
Surface area	4.27×10^{10} km²; 83.703 Earths
Volume	8.2713×10^{14} km³; 763.59 Earths
Mass	5.6846×10^{26} kg; 95.152 Earths
Mean density	0.687 g/cm³; (less than water)
Equatorial surface gravity	10.44 m/s²; 1.065 g
Escape velocity	35.5 km/s
Sidereal rotation period	10.57 hours; (10 hr 34 min)
Equatorial rotation velocity	9.87 km/s; 35 500 km/h
Axial tilt	26.73°
Albedo	0.342 (bond); 0.47 (geom.)
Apparent magnitude	+1.2 to -0.24
Angular diameter	14.5" — 20.1" (excludes rings)

URANUS

Uranus is a gas giant planet. It is the seventh distant planet from the Sun in the solar system, the third in size and the fourth in mass. It bears the name of Chronos' father (Saturn) and of Zeus' grandfather (Jupiter). It is the first planet discovered in the modern epoch. Although it can be seen with the naked eye like the other 5 classical planets, because of its low luminosity it was not easily identified as being a planet. William Herschel announced its discovery on 13 March 1781, thus enlarging the frontiers of the Solar system for the first time in the modern epoch. Uranus is the first planet discovered by means of the telescope.

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

Uranus' atmosphere, although made up mainly of hydrogen and helium, also contains large quantities of water ice, ammonia and methane, as well as the usual traces of hydrocarbons. Uranus has the coldest atmosphere in the solar system, which reaches a minimum of – 224 ºC. It has a complex structure of clouds: the clouds in the lower layers might be made up of water, those in the upper layers of methane.

Like the other gas giant planets, Uranus has a system of rings, a magnetosphere and numerous natural satellites. The Uranian system is unique in the Solar system because its rotation axis is tilted sideways and is almost into the plane of its revolution about the Sun. Its northern and southern poles therefore lie where the other planets have their equator. In 1986, Voyager 2 took images of Uranus that show a planet almost featureless in visible light, without cloud bands or storms as on the other gaseous planets. However, recent observations have shown signs of seasonal change and an increase of the meteorological activity, in a period when Uranus approached its equinox of December 2007. The wind on Uranus can attain speeds of 250 m/s on its surface.

Orbit and rotation Uranus' revolution period around the Sun is 84 terrestrial years. Its average distance from the Sun is of approx. 3 billion km. The solar flux intensity on Uranus is of approx. 1/400 of that received on Earth.

The rotation period of Uranus' interior is 17 hours and 14 minutes. In the upper atmosphere violent winds take place in the rotation direction, as is the case with all the giant gaseous planets. Consequently, around 60 latitude , visible parts of the atmosphere travel faster and make a complete rotation in less than 14 hours.

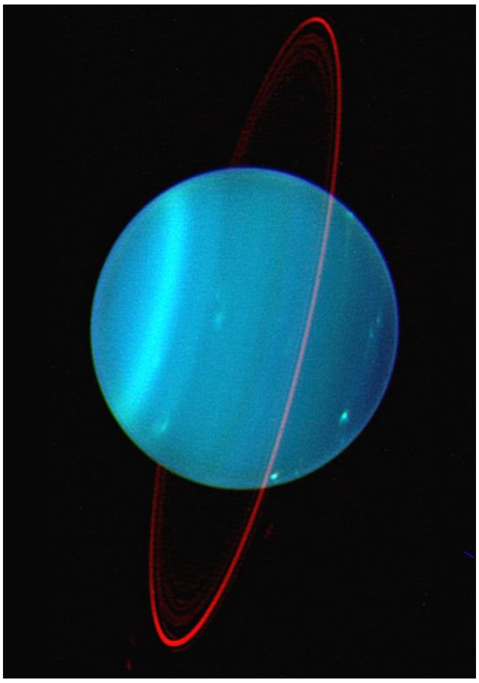

Fig. 8 Uranus

Uranus is a giant planet, like Jupiter, Saturn and Neptune. Even if we know very few things about its internal composition, we do know that it is certainly different from that of Jupiter or Saturn. Models of the internal structure of Uranus show that it should have a solid nucleus of iron silicates, with a diameter of approx. 7500 km, surrounded by a mantle made up of water ice mixed with helium, methane and ammonia that is 10,000 km wide, followed by a superficial atmosphere of hydrogen and liquid helium, of approx. 7600 km. Unlike Jupiter and Saturn, Uranus is not massive enough to preserve hydrogen in a metallic state around its nucleus.

The bluish-green color is due to the presence of methane in the atmosphere, which absorbs especially in the red and the infrared.

Uranus has at least 13 main rings.
Unlike any other planet in the solar system, Uranus is very inclined against its axis, as the latter one is almost parallel to its orbital plane. We might say that it rolls on its orbit and exposes to the Sun its north pole and its southern pole successively.

One consequence of this orientation is that the polar regions receive more energy from the Sun than the equatorial ones. Nevertheless, Uranus remains warmer at the equator than at the poles, a mechanism still unexplained. Any theory for the formation of Uranus that also accounts for its inclination, usually incorporates the idea of a cataclysmic collision with another body before its present formation.
Uranus has at least 27 natural satellites. The first two were discovered by William Herschel on 13 March 1787 and were called Titania and Oberon.

Orbital characteristics, Epoch J2000	
Aphelion	3,004,419,704 km, 20.083305 AU
Perihelion	2,748,938,461 km, 18.375518 AU
Semi-major axis	2,876,679,082 km, 19.229411 AU
Eccentricity	0.044405
Orbital period	30,799.095 days, 84.3233 years
Synodic period	369.66 day
Average orbital speed	6.81 km/s
Mean anomaly	142.955 717°
Inclination	0.772 556° to ecliptic, 6.48° to Sun's equator
Longitude of ascending node	73.989 821°
Argument of perihelion	96.541 318°
Satellite	27

Physical characteristics	
Equatorial radius	25,559 ± 4 km, 4.007 Earths
Polar radius	24,973 ± 20 km, 3.929 Earths
Flattening	0.0229 ± 0.0008
Surface area	8.1156×10^9 km², 15.91 Earths
Volume	6.833×10^{13} km³, 63.086 Earths
Mass	$(8.6810 \pm 0.0013) \times 10^{25}$ kg, 14.536 Earths
Mean density	1.27 g/cm³
Equatorial surface gravity	8.69 m/s², 0.886 g
Escape velocity	21.3 km/s
Sidereal rotation period	−0.718 33 day, 7 h 14 min 24
Equatorial rotation velocity	2.59 km/s, 9,320 km/h
Axial tilt	97.77°
Albedo	0.300 (bond), 0.51 (geom.)
Apparent magnitude	5.9 to 5.32
Angular diameter	3.3"–4.1"

Atmosphere
Composition *(below 1.3 bar)*: 83 ± 3% Hydrogen (H_2), 15 ± 3% Helium, 2.3% Methane, 0.009% (0.007–0.015%) Hydrogen deuteride (HD). Ices: Ammonia, water, ammonium hydrosulfide (NH_4SH), methane (CH_4).

NEPTUNE
Neptune is the eighth and the farthest planet from the Sun in the Solar system. It is also the last gaseous giant planet. It was discovered by the German astronomer Johann Gottfried Galle on 23 September 1847, following the predictions of Urban Le Verrier who, like the English

astronomer John Couch Adams, had found through matematical calculations the region in the sky where it could likely be found.

It bears the name of the Roman god of the seas, Neptune. Neptune is not visible with the naked eye and does not appear as a bluish-green disk through the telescope. It was visited only once by a space probe, Voyager 2, who passed by it on 25 August 1989. Its largest satellite is Triton.

Its internal composition is similar to that of Uranus. It is believed that it has a solid nucleus made of silicates and iron, almost as big as the mass of the Earth. Its nucleus, just like Uranus', is supposedly covered with a rather uniform composition (rocks in fusion, ice, 15% hydrogen and a few helium); it does not have any structure in "layers" like Jupiter and Saturn.

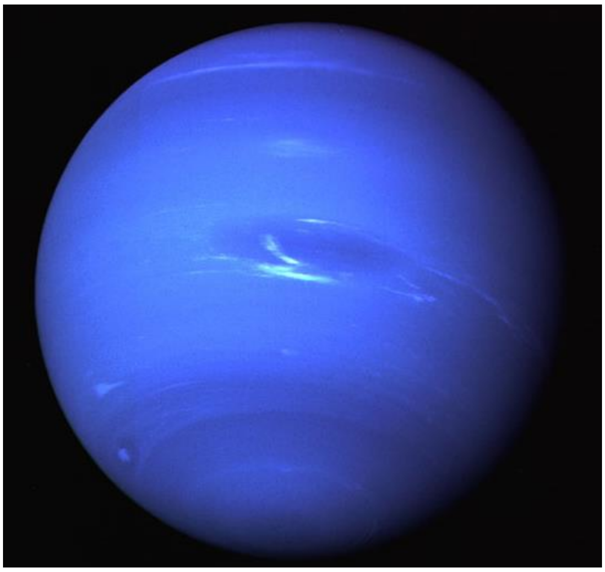

Fig. 10: Neptune

Its bluish color comes mainly from methane, which absorbs light in the wavelengths of red. It seems that another composition give Neptune its bluish color, but that has not been defined yet.

Like the other giant gaseous planets, it has an aeolian system made up of very rapid winds in bands parallel to the equator, of immense storms and vortexes. The fastest winds on Neptune blew at speeds over 2,000 km/h. During the survey of Voyager 2, the most interesting formation discovered was the "Dark Great Spot", which was about the size of the "Red Great Spot" on Jupiter. This spot was not observed about 5 years later when the Hubble Space Telescope took observations of Uranus. The winds on Uranus might have speeds as high as 300 m/s (1080 km/h) or even up to 2500 km/h. This spot might be a dark giant hurricane that supposedly travels at 1000 km/h.

Neptune has fewer visible planetary rings. They are dark and their origin is yet unknown.
Neptune has at least 14 natural satellites, among them the largest is Triton, discovered by William Lassell only 17 days after the discovery of Neptune.

Orbital characteristics, Epoch J2000	
Aphelion	4,553,946,490 km, 30.44125206 AU
Perihelion	4,452,940,833 km, 29.76607095 AU
Semi-major axis	4,503,443,661 km, 30.10366151 AU
Eccentricity	0.011214269
Orbital period	60,190 days, 164.79 years
Synodic period	367.49 day
Average orbital speed	5.43 km/
Mean anomaly	267.767281°
Inclination	1.767975° to ecliptic, 6.43° to Sun's equator
Longitude of ascending node	131.794310°
Argument of perihelion	265.646853°
Satellite	14

Physical characteristics	
Equatorial radius	24,764 ± 15 km, 3.883 Earths
Polar radius	24,341 ± 30 km, 3.829 Earths
Flattening	0.0171 ± 0.0013
Surface area	7.6408×10^9 km², 14.98 Earths
Volume	6.254 × 1013 km³, 57.74 Earths
Mass	1.0243×10^{26} kg, 17.147 Earths
Mean density	1.638 g/cm³
Equatorial surface gravity	11.15 m/s², 1.14 g
Escape velocity	23.5 km/s
Sidereal rotation period	0.6713 day, 16 h 6 min 36 s
Equatorial rotation velocity	2.68 km/s, 9,660 km/h
Axial tilt	28.32°
Albedo	0.290 (bond), 0.41 (geom.)[7]
Apparent magnitude	8.0 to 7.78
Angular diameter	2.2″–2.4

Atmosphere:
Composition: 80±3.2% Hydrogen (H2), 19±3.2% Helium, 1.5±0.5% Methane, ~0.019% Hydrogen deuteride (HD), ~0.00015 Ethane. Ices: Ammonia, water, (NH_4SH), Methane

Other Bodies in the Solar System

The interplanetary environment

Besides light, the Sun radiates a continuous flux of charged particles (plasma) called solar wind. This flux dissipates at a speed of 1.5 millions km/h, thus creating the heliosphere, a thin atmosphere which surrounds the Solar system out to a distance of approx. 100 AU (marking the heliopause). The matter which makes up the heliosphere is called interplanetary medium. The solar cycle of 11 years, as well as the frequent solar flares and coronal mass ejections, disturb the heliosphere and create a space climate. The rotation of the solar magnetic field acts upon the interplanetary medium, creating the stratum of heliospheric current, which is the greatest structure of the Solar system.

The terrestrial magnetic field protects the atmosphere from the solar wind. The interaction between the solar wind and the terrestrial magnetic field brings about the polar aurora.

The heliosphere ensures a partial protection of the Solar system from cosmic rays, that is higher on the planets with a magnetic field.

The interplanetary medium accommodates at least two regions of cosmic dust under the form of a disk. The first one, the cloud of zodiacal dust, is in the internal Solar system and produces the zodiacal light. It probably formed through a collision inside the asteroid belt caused by the interactions with the planets. The second one extends between 10 and 40 AU and was probably created during similar collisions in the Kuiper belt.

THE BELT OF ASTEROIDS

Asteroids are mainly small bodies in the solar system made up of rocks and non-volatile metallic minerals. The asteroid belt occupies an orbit located between Mars and Jupiter, at a distance of 2.3 up to 3.3 AU from the Sun. The asteroid belt formed from the primordial solar nebula as a group of planetesimals, the smaller precursors of planets. These planetesimals were too strongly perturbed by Jupiter's gravity to form a planet.

Asteroids range between several hundred kilometers down to microscopic dust. All, except the greatest one, Ceres, are considered small bodies. A few of the other large asteroids such as Vesta and Hygeia are also still considered small bodies, they could be classified as dwarf planets at some point, if in the future it can be determined that they have reached hydrostatic equilibrium.

The asteroid belt contains thousands, even millions of bodies with a diameter of over one kilometer. Nevertheless, the total mass of the belt is only 4% of the Moon's mass.
Ceres (2.77 AU) is the largest body in the asteroid belt and the only dwarf planet (classified thus in 2006). With a diameter of almost 1000 km, and enough mass that it is in hydrostatic equilibrium and has a spherical shape.

COMETS

Comets are small bodies in the Solar system, with diameters on the order of kilometers, comets are generally made up of volatile ices. They have very eccentric orbits, with the perihelion sometimes situated in the inner Solar system, while the aphelion is beyond Pluto. When a comet enters the inner Solar system, its close approach to the Sun leads to the sublimation and ionization of its surface, creating a tail: a long trail made up of gas and dust.

Fig. 11: Comet

Short period comets (e.g. Halley Comet) complete their orbits in less than 200 years and seem to originate in the Kuiper belt. Long period comets (e.g. Hale-Bopp comet) have a periodicity of several thousands years and seem to originate in Oort's cloud. Finally, there are some comets that have a hyperbolic trajectory, suggesting they may eventually escape the Solar system. Old comets have lost the greatest part of their volatile components and today are often considered asteroids.t

Centauri, situated between 9 and 30 AU, are icy bodies analogous to the comets, that orbit between Jupiter and Neptune. The greatest centaur known, Chariklo, has a diameter ranging between 200 and 250 km. The first centaur discovered, Chiron, was considered in the beginning to be a comet because it developed a cometary tail. Some astronomers classify centaurs as bodies of Kuiper belt.

The **Kuiper belt** is a great ring made up of debris belonging to a large debris ring, similar to the asteroid belt, but made up mainly of ice. The first part of the Kuiper belt extends between 30 and 50 AU from the Sun and stops at "Kuiper's cliff ", from there begins the second part of the belt out to 100 AU. This region is believed to be the source of short period comets.
It is mainly made up of small bodies, as well as of some rather big ones, like Quaoar, Varuna or Orcus, which might be classified as dwarf planets.
The Kuiper belt can be divided largely into "classical" objects and objects in resonance with Neptune. An example to this effect would be the plutinos that complete two orbits for every three that Neptune has completed.

PLUTO and CHARON

Pluto (39 AU on average), a dwarf planet, is the largest known body of the Kuiper belt. Discovered in 1930, it was considered a planet and re-classified in August 2006. Pluto has an eccentric orbit inclined by 17º to its ecliptic plane. Pluto's orbital distance extends up to 29.7 AU at the perihelion and 49.5 AU at the aphelion.

Pluto's largest satellite, Charon, is massive enough so that the two orbit around each other, around a common center of mass that is situated above the surface of each of the bodies. Two other small satellites, Nix and Hydra, orbit the Pluto-Charon system. Pluto is in an orbital resonance of 3:2 with Neptune (the planet orbits the Sun twice, for every three times Neptune orbits the Sun). The other bodies of the Kuiper belt that participate in this resonance with Neptune are called plutinos (namely small Plutos).

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