SOLAR SYSTEM

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Introduction

Today we are at a very privileged time in the exploration of our planetary system. The big space missions of the present and of the past have enabled us to start knowing the profile and the characteristics. So we can have a new image of this part of the universe, in which the Sun and the planets are not the only protagonists, and we find satellites, like the Moon, the asteroids, the comets, the dusts. And not only that, like a glue that does not allow the parts that are deep in space to disperse, there is the force of gravity and we make the effort to imagine a system of bodies of a different nature and size rotating around a medium sized star. We are now ready to start entering more deeply into this space.

Solar System knowledge

The Solar System is just like our back yard respect to the vast plains of the Universe. It is a system of bodies of different nature and size that orbit around a medium-sized star. The use of the word “system” indicates the dynamic nature of the structure; in fact, the components interact with and influence each other in complex ways.

Currently we are in a privileged moment in the exploration of our planetary system. The present and past space missions have allowed us to get to know its outline and characteristics. In fact, a new image of this part of the universe has emerged, in which the Sun and planets are not the only protagonists. The Solar System also includes satellites, like the Moon, that orbit around the planets, asteroids, rocky bodies of different sizes that are mainly found grouped in belts, in addition to comets, cosmic dust, the light coming from the Sun, and above all, the gravitational force which acts like a glue and prevents these various parts from dispersing into outer space.

The Birth of the Solar System

The origin of the Sun and of the Solar System is connected to the condensation of a primordial cloud of gas and dust as those often seen in our galaxy. It is probable that an external event triggered the collapse of the cloud since its parts were in equilibrium. Scientists have put forward the hypothesis that it could have been the explosion of a nearby supernova, i.e. a star with a great mass that has an explosive death expelling all its atmosphere into space. The silent shock wave must have given the cloud the initial push: so the death of a star can bring about the birth of another star.
Once the collapse has been triggered off it proceeds on its own: as the distance between the matter that composes the cloud diminishes, a stronger gravitational force is generated which tends to pull the mass together. The free-falling matter does not fall in a straight line towards the centre, but rotates around it in tighter and tighter spirals. Both the rotation of the Sun and the planets around their axis, and the revolution of the planets and other bodies around the Sun are a consequence of this initial vortex.

As the collapse proceeded, most of the cloud matter concentrated in the central regions reaching the density and temperature required to form a star, a body capable of producing and emitting energy on its own. On the edge of the cloud, instead, the remaining matter continued to rotate around the centre, thinned into the shape of a disc, and formed the planets from the dust grains present, through collisions and successive aggregations. Still today, the main bodies of the Solar System rotate around our star on the same plane, which is called the ecliptic. Scientists believe that the asteroids, frozen bodies and dust that are present in our planetary system represent the oldest residues of its formation; in other words, they are the result of primordial aggregations that were not able to evolve into planets. The fact that their orbits are more inclined respect to the ecliptic plane testifies that these bodies were excluded from the main formation mechanism that took place along the rotation disc.

Today the Sun has been burning for 5 billion years and will continue to do so for another 5 billion more. Once all the hydrogen, its main fuel, is consumed, it will expand into a red giant, engulfing the entire Solar System up to Mars' orbit (the Earth is included!). Subsequently, it will shed its outer layers in a gust of gas and it will enter the final phase of its life cycle changing into a white dwarf, a small dimly luminous star destined to get cold and to slowly die off.

Water in the Solar System

Water, an essential element for life as we know it, is much more widespread in the Solar system than we think. Water ice is a major constituent of the minor bodies at the extreme limits of our planetary system: comets, rings and the majority of the satellites of the giant planets. Water in its liquid state is another thing. Everyone's eyes are focused on our neighbour Mars for different reasons. On the one hand, man's desire for knowledge needs an answer to why the Red Planet has become so arid; in fact, it has been established that in the past the Martian climate was more humid than it is now. On the other, the main international space agencies are planning a landing on Mars in 2030; in this perspective, it is of extreme importance to know whether the future pioneers will have water supplies in situ or whether they will have to bring them from Earth, which would be very inconvenient not only from an economic point of view but also for the cumbersome weight. But Mars is not the only planet in the Solar System which could surprise us. Something new could be found on a small body that orbits around the giant Jupiter: we are referring to Europa, one of the four Galilean satellites. Slightly smaller than Earth's Moon, Europa's surface is completely covered with water ice. However, observations made by the Galileo probe support the hypothesis that under this layer of ice there could be an ocean of liquid water or of liquid water mixed with ice, up to 160 km deep. The tidal effects of Jupiter, in fact, probably produce an internal heating of the satellite sufficient to melt its water which does not disperse into space because of the external ice covering.

The Sun and planets

On our stage, the role of main actor cannot but be conferred to the Sun, a star like many others in space, but very special for us because from the remains of its formation all the planets and the smaller bodies that rotate around it, and of which we are a part, have originated.
The Sun is so big that over 100 planets as big as Earth could be placed along its diameter. Its mass alone constitutes 99% of the total mass of the Solar System and it is capable of releasing, in the form of light and heat, an amount of energy equivalent to 1.000.000.000.000.000.000.000.000, 100 W light bulbs, or 10,000 billion atom bombs, per second. The main motor resides in the Sun's core where every second hundreds of millions of tonnes of hydrogen atoms, the most abundant chemical element in the universe, fuse together producing energy.
The Sun is a gigantic sphere of gas at a very high temperature and in perfect equilibrium that does not collapse on itself and does not get dispersed in space thanks to the state of balance between the gravitational and pressure forces which are of equal intensity but act in opposite directions.
Being made of gas, our star does not have a solid surface; we can think of the Sun as an enormous onion made of concentric layers of gas: what we see from Earth is the outline of the outer shell called the photosphere. The phenomena that take place in this region can be viewed even with small instruments as long as they have adequate filters: in fact, one must remember never to stare directly at the Sun because its light is so intense that it would cause permanent eye damage.

The Sun

On observing the photosphere, one notices that it is not compact, but made up of many small cells. This structure, called granulation, is caused by convective motion: columns of hot gas coming from the centre of the Sun reach the surface and then sink towards the interior. Also in the photosphere, groups of sunspots can be observed. These areas appear darker than the surrounding area because within them the gas is cooler than average. Even though they look small on the Sun's surface, these structures are so big that they could contain five planets the size of the Earth. In contrast, faculae are areas that appear brighter because they are warmer than the surrounding gas. Above the photosphere lies the stellar atmosphere made up of two distinct areas known as the chromosphere and the corona, in which the gas is more rarefied. Even in these regions some phenomena can be observed, such as protuberances, gigantic columns of gas that rise almost perpendicularly to the Sun's surface and which form beautiful arch-shaped structures. From the corona, the Sun extends into space releasing a stream of elementary particles called solar wind. Since the particles it is made up of, basically electrons and protons, are very energetic, the solar wind is harmful to all forms of life. Fortunately, the Earth has adequate defences: due to its magnetic field, that envelops the Earth like a protective shell, it is able to deviate these currents of particles, preventing them from reaching the surface. Some, however, manage to escape and to penetrate the upper parts of our atmosphere, colliding with the gas molecules and exciting them. The consequences of these interactions constitute one of the most beautiful natural phenomena: the spectacular polar auroras.

Moreover, it is the Sun that establishes the extreme boundaries of the Solar System, referred to as the heliopause. In fact, the solar wind creates a bubble in the interstellar medium, a very rarefied gas that pervades our galaxy. The interstellar medium is dotted by other bubbles similar to the Sun's, proof that there are other stars that belong to as many solar systems that could be similar or very different from ours, just like the daisies in a meadow.

The planets

Though the Sun is the main actor, the planets are also protagonists, but an important fact must be highlighted: since the mass of the Sun alone makes up 99% of the mass of the entire Solar System, the planets are like crumbs respect to our star. In addition to this, these particles orbit around the Sun at enormous distances respect to their own size. A proportion could be calculated between the size of the Sun and that of Jupiter, the biggest planet in the Solar System and the distances between them could be scaled down by the same factor. If the Sun were the size of a grapefruit, then Jupiter would be the size of a grape about 100 metres away, the length of a football pitch. There is a void space between them, with the exception of some other "grapes", and darkness, because out in space it is absolutely dark, if one is not looking directly at the Sun.

Since they are not stars, planets cannot produce their own light, but only reflect it. Some appear to be the brightest objects in the sky after the Moon and are visible even at dawn and dusk when the sky is not dark, the last to disappear when the Sun rises and the first to reappear when night falls.

Planets are often accompanied by satellites, or moons, bodies that rotate around them and with which they form a single structure that revolves around the Sun. Moreover, the bigger planets have a ring system, probably the remains of satellites that in ancient times disintegrated and that the force of gravity has kept suspended around the planet.

In the Solar System, planets have been classified in two categories: rocky planets and gas planets. There are four rocky planets and they form the inner Solar System: in order of their distance from the Sun, they are Mercury, Venus, Earth and Mars. They are called rocky planets because their surface is made up mainly of solid material and they are surrounded by a thin atmosphere respect to the size of the planet itself. Moreover, they have moderate sizes and few or no satellites. The gas giants, instead, are part of the outer Solar System; they are Jupiter, Saturn, Uranus and Neptune. They are mainly made up of gas that becomes denser and denser as you move towards the centre. Some hypotheses claim that there is a very small solid nucleus at the centre. These planets have ring systems that can be more or less complex and bright and numerous small satellites that orbit around them.

Gravity and the planets' orbits

Most of the bodies of the Solar System revolve around the Sun in orbits that are not circular but elliptical and in which the Sun occupies one of the two foci (Kepler's First Law). In particular, planets move along orbits that are slightly eccentric, i.e. slightly squashed, and almost all on the same plane because of the mechanism with which they were created during the formation of our planetary

system. Dwarf planets and minor bodies on the contrary are characterised by more elongated and inclined orbits.
All bodies in the Solar System move at different speeds depending on their distance from the Sun; faster when they are closer to the star, and slower when they are further away (Kepler's Second Law). Moreover, as the distance increases so does the length of time taken to complete a revolution around the Sun (Kepler's Third Law); in fact, Mercury takes only 88 days while Neptune takes nearly 165 years.
The great force that keeps the Solar System together and prevents the single components from dispersing into space is gravity, a force generated by bodies simply because they have a mass. In fact, between any two bodies there exists a force of mutual attraction that is directly proportional to the product of their respective masses and inversely proportional to the square of the distance between them. Due to its mass, the Sun is the body that has the greatest gravitational influence on all the other components of the system that revolve around it; and following the same principle, satellites revolve around their parent planet. But planets influence each other too and influence the movement of minor bodies, even though this effect is greatly inferior to that of the Sun on each of them. For example, Neptune was discovered because Uranus's orbit was different from the predictions made on the basis of mathematical calculations; this difference was generated just by the gravitational pull of the outermost of the giant planets in the Solar System.
The orbits of the bodies in the Kuiper Belt are always disturbed by Neptune's gravitational force just as the asteroids within the main belt feel Jupiter's gravitational attraction. On Earth, the gravity of other bodies generates very different phenomena which are more or less well known to us; it is worth mentioning, for example, the ocean tides and the precession of the equinoxes, a long term variation of the inclination of the rotational axis.

The shape of things

A central force is a force whose direction depends only on the distance between the point of application and a fixed point, known as central point. Hence, in a central force field, the force vector in every point is parallel to half-lines extending in every direction from the origin. For this reason, a spherically symmetric field is originated.
Gravitational attraction is a central force. Its formula is as follows:

$$F=G(m1*m^2)/(r)^2$$

The only vector capable of giving a direction to the force is r, the distance between the masses taken into consideration. So, for example, in the absence of other factors, from the gravitational collapse of a cloud of gas and dust, spherical bodies are created, such as the stars and planets. Actually, we know that during the formation of a celestial body, the clouds of gas and dust rotate around their centre; as a consequence, the objects produced are not perfectly spherical, but slightly flattened at the poles as a result of the centrifugal force. The Earth, for example, is not perfectly spherical but is a rotating geoid: the radius at the Equator is about 20 km less than the radius at the Poles.

The Earth is a spinning top

The Earth is not motionless in space but is subjected to different movements. The most well-known are the rotational movement around its own axis, which determines the alternation of day and night and the apparent movement of the sky above our heads, and the revolution around the Sun in a slightly elliptical orbit. The two main units of time, days and years, derive respectively from the rotation and revolution movements. The length of a day can be measured as the time interval between two consecutive transits of the Sun or of a given star on the same meridian. The former is called solar day and lasts 24 hours; the latter is known as sidereal day and lasts about 4 minutes less. The difference between the two periods derives from the fact that the Earth rotates around its own axis as it is moving along its orbit. In doing so, it varies the alignment with the Sun and this entails an additional time to reach the same Earth-Sun orientation once again; this does not occur for the other stars that are so distant that they can be considered fixed. When measuring a year, things get more complicated. In fact, the sidereal year measures the time interval between two successive alignments of a given star with the Earth, and it corresponds to a complete revolution of our planet around the Sun respect to the “fixed” stars. There is also the solar year which represents the time interval between two successive passages of the Sun through the vernal equinox. The latter is one of the two points of interception of the ecliptic and the celestial equator, an extension of the plane of the terrestrial equator into space. If the Earth’s orbit were immovable in space, these two definitions would coincide. However, in actual fact, bodies have a reciprocal influence on each other within the Solar System; hence, the gravitational attraction of the Sun and the planets modifies the terrestrial movements in relation to their mass and the distance away from the Earth. As a consequence, the Earth’s rotational axis describes a slow movement in the opposite sense respect to the orbital one, tracing a cone-shape in the lapse of time of 26,000 years. This cone-shape is also influenced by nutation, an oscillation with a period of 18 years generated by the Moon’s gravity. The sum of movements causes the slow migration of the North Celestial Pole, currently pointing at the Pole Star in the Little Bear constellation, towards different stars; in 15,000 years, for example, the Vega Star in the Lyre constellation will indicate the North. As the axis wobbles, so does the equatorial plane that is perpendicular to it, modifying some of its orbital parameters; as a result, every year the Earth reaches the equinoxes, i.e. the intersections of the equatorial and ecliptic planes, earlier. Hence the solar year differs from the sidereal year by about 6 hours and for this reason it has been necessary to introduce one day every four years to make up for the difference. This explains leap years and February 29. Time can also be measured in months, which are tied to the cycle of phases of our satellite. In fact, the Moon’s orbit around the Earth is inclined by 5° respect to the plane of the ecliptic. This implies that we can observe the different phases in which our satellite is illuminated by the Sun’s rays; as it changes from new moon to full moon, the lunar phase cycle takes a lunar month (28 days). In the points in which the lunar orbit intersects the Earth’s, the Sun, Earth and Moon are aligned and eclipses occur. There is a solar eclipse when the Moon passes between the Sun and the Earth: it is a coincidence that the small lunar disc is at the right distance in perspective to cover the gigantic Sun. If the Earth is in between the other two bodies instead, a lunar eclipse occurs.

The seasons. The alternation of the seasons is caused by the inclination of the Earth's axis and by the revolution of our planet around the Sun. The Earth follows a slightly elliptical trajectory with respect to its orbital plane. During its revolution, the Earth's axis of rotation maintains a constant inclination respect to the ecliptic and the Earth's two hemispheres do not receive the same amount of radiation, which is dependent on the position of the planet respect to the Sun. The variation of the angle of incidence of the Sun's rays on the Earth's surface results in a consequent difference in the amount of heat received. Hence, seasonal variations in temperature are not due to a greater or shorter distance from our star: in fact, the Earth's orbit is closest to the Sun during the winter solstice and furthest from it during the summer solstice. The inclination of the Earth's axis respect to the orbital plane also explains the change in the length of day and night during the year.
It must be mentioned that the Moon has had an important role in stabilising the Earth's rotation axis and therefore favouring the development of life. The more inclined the rotation axis is on the ecliptic plane, the more marked are the differences between the seasons. Had there been no Moon, the gravitational attraction of the Sun and the other planets could have made the tilt of the Earth vary in the course of time. In this case, temperatures would have been more extreme, making the evolution of life on Earth more difficult.

The origin of the Moon

All the satellites of the Solar System are small: from 25 to thousands of times smaller than their relative planets. The only exceptions are the Earth-Moon and the Pluto-Charon systems; our Moon has a diameter that is only 1/3 the Earth's diameter. This implies that maybe the processes that brought to the formation of the Moon were different from those of the other satellites. To date, four hypotheses have been advanced regarding the origin of the Moon:

1. The Moon might be a fragment that separated from the Earth shortly after its formation (fission hypothesis);
2. After having being formed in some part of the Solar System, the Moon might have been captured by Earth's gravity (capture hypothesis).
3. The Moon might have formed from dust and debris orbiting around Earth (accretion hypothesis).
4. The Moon might be the result of the aggregation of many planetesimals orbiting around our planet, resulting from the collision of the Earth with a planetary body the size of Mars (collision hypothesis).

Currently, the most favoured hypothesis seems the last one. After the gigantic "slap", the Moon must have formed as a result of the mutual gravitational attraction of the remains of the collision, bringing about further re-fusion and differentiation of the layers and matter and a consequent cooling. During this process, the surface must have been subjected to an intense meteorite bombardment that transformed the rocks on the surface into a layer of dust and debris. Subsequently, the internal heating must have caused the eruption of matter, creating the basalt lava flows called maria, and the other characteristic tectonic and volcanic activities that are present on the surface. This sequence of events would explain why the Moon is very similar to the Earth as far as some characteristics are concerned, but not respect to others that it might have "inherited" from the body that collided with our planet.

Other tenants

We have already mentioned that the planets with their satellites and rings are not the only bodies that occupy the Solar System. To start with, between the orbits of Mars and Jupiter, there is the Main Asteroid Belt that is not just a flat disc with rocks of different sizes and shapes as we usually imagine it. Scientists have known for some years that it is actually a three-dimensional doughnut-shaped ring curved around our star. The vertical size of this tube is equal to the distance between the Earth and the Sun, about the length of the penalty area of a football pitch (according to the scale mentioned in the preceding paragraph). Within the belt, the asteroids are not distributed uniformly, but form ringed structures interrupted by some gaps, empty zones that Jupiter has "cleaned out" expelling the bodies that were present. The orbit of the Trojans, two groups of asteroids coming from the Main Belt, is influenced by Jupiter; in fact, they revolve around the Sun, one preceding and one following the giant planet.

Far from the heat of our star, at the border of the Solar System, the Kuiper Belt and the Oort Cloud can be found, real reservoirs of asteroids and comets. The former, older but less famous than the Main Belt, begins right after Neptune's orbit and extends up to 100 times the distance between the Earth and the Sun, i.e. the length of 20 football pitches. Today we are aware of about 40 bodies belonging to this belt with sizes greater than 100 km, but scientists estimate many more, about 50,000, not counting those with smaller sizes. Since August 2006, to classify the new bodies discovered beyond Pluto's orbit, scientists have created a new category: the dwarf planets. Currently, there are three: Pluto, the progenitor, Xena or Eris, bigger and further than Pluto itself, and Ceres, the biggest asteroid of the Main Belt. Some comets too can originate in the Kuiper Belt. These bodies are subject to the gravitational pull of the giant planets and their trajectories can undergo modifications; this is the case of the family of Centaurs, bodies of different sizes that orbit between Jupiter and Neptune.

The Oort Cloud lies even further from the Sun, a vast reservoir of comet nuclei that envelops us completely; it is an enormous shell with a diameter 1,500 times that of the Solar System it contains. The comet nuclei are smaller respect to the bodies of the Kuiper Belt and are made up of blocks of ice mixed with rock, with diameters ranging from 1 to 10 km. If they are subjected to the gravitational attraction of the giant planets for having passed close to them, these solid, opaque objects are removed from their secluded orbits in the dark recesses of the Solar System and become one of the most luminous and fascinating objects of the sky: comets. They plunge into the Solar System like bullets and as they approach the Sun, the water their nuclei are composed of starts to sublimate (i.e. it passes from the solid to the gaseous state) and creates the characteristic tail. Comets get more and more consumed with each successive passage near to our star, until they totally disintegrate, leaving a trail of rocky debris. This phenomenon is at the basis of shooting stars: when the Earth, as it revolves around the Sun, passes through the orbit of a comet, its debris comes into contact with the Earth's atmosphere and air friction causes it to burn forming the trail of light we all know.

The asteroid population

Asteroids, also known as minor planets, are rocky fragments ranging widely in size, which originated during the formation of our Solar System about 4.6 billion years ago. The first asteroid was discovered in 1801 by Father Giuseppe Piazzi at the Palermo Observatory. It was named Ceres and was considered the eighth planet for half a century. However, from 2006 it has been classified as a dwarf planet like Pluto, Eris, Makemake and Haumea. From that distant 1801, over 300,000 asteroids have been identified and catalogued and probably other hundreds of thousands, maybe a million, are still to be discovered.

There are just 26 asteroids with diameters over 200 km; among these is Ceres whose diameter is 900-1000 km, followed by Pallas and Vesta both with diameters of about 500 km. The rest of the asteroids has smaller dimensions, with diameters ranging from below 200 km to just a few metres.

The vast majority of asteroids orbit the Sun in a region between the orbits of Mars and Jupiter, called the Main Belt, more precisely between 2 and 3.3 A.U. (1 A.U. = 150,000,000 km, the average distance between Earth and Sun). Well separated from the Main Belt, within the orbit of Jupiter, are asteroids such as Hilda and Thule. Besides the latter, there are two large groups of objects that share Jupiter's orbit, in two equilibrium points (called Lagrangian equilibrium points). These groups are called Trojans and are several hundreds of thousands, one group is behind and one in front of Jupiter's orbit. Lastly, there is another sub-population of asteroids generally divided into three groups named Aten, Apollo and Amor.

Their orbits extend to the innermost region of the Solar System. In particular, Aten asteroids have a semi-major axis of less than 1 A.U, but their aphelion distances (maximum distance from the Sun) are greater than Earth's perihelion distance (minimum distance between Earth and Sun, 0.983 A.U.). Hence Aten asteroids lie primarily inside the orbit of the Earth, but at their aphelion they might lie outside Earth's orbit.

Apollo asteroids instead have a semi-major axis that is larger than Earth's and a perihelion distance less than Earth's aphelion distance (1.017 A.U.). Consequently, these asteroids spend most of their time outside Earth's orbit but are briefly within it. Lastly, the Amor asteroids have perihelion distances between 1.017 and 1.3 A.U. hence between the orbits of Earth and Mars.

In short, asteroids are generally defined as minor bodies of the Solar System with sizes of at least a few tens of metres across and whose orbits never go beyond that of Jupiter. Trojans are included in this category.

The shape and composition of an asteroid

Nearly all asteroids are irregular in shape, although some are almost spherical, and they often have a cratered surface. As they revolve around the Sun in elliptical orbits, asteroids also rotate,

sometimes quite erratically. To date over 150 asteroids have been discovered with a small companion moon. There are also binary and triple systems made up of two or three asteroids.
Asteroids are subdivided according to their chemical composition into three major types: C, S and M. The different composition of asteroids depends on their distance from the Sun at the moment of formation. C-type asteroids are the most common variety and are rich in carbon. They are very dark and are concentrated in the outer part of the main belt.
S-type asteroids are made up of silicates, nickel and iron; they are mainly found among Apollo and Amor asteroids. M-type asteroids are completely metallic in composition, made up of nickel-iron.

NEOs (Near-Earth Objects)

The acronym NEO refers to all objects whose orbit brings them near to terrestrial planets. Asteroids can be found in different areas of the Solar System and besides revolving around the Sun, their orbits are also affected by forces that are difficult to predict. One of these is a collision with other asteroids that could result in the break up of the objects involved. The fragments produced can reassemble to form a new object or move along independent trajectories thus creating new asteroids. The collisions do not hurl the asteroid far from the impact zone, to make it become a NEO, for example. For the trajectory to be modified substantially, some dynamic processes must also take place, which change the orbital parameters significantly.
Gravitational perturbations caused by a giant planet can change orbital parameters such as eccentricity and orbital inclination in a relatively short time, reducing the perihelion distances of these objects. Hence, an asteroid captured by a perturbation might cross the orbits of the planets Mars, Earth, Venus and Mercury and come into the inner Solar System. Frequently the perihelion of these asteroids moves closer to the Sun and they end up colliding against it. This process eliminates the problem of that asteroid. As their eccentricity increases, not only does the perihelion increase but the aphelion moves further away; hence the objects of the main belt that are affected by gravitational perturbations can reach the orbit of Jupiter and be subsequently ejected from the Solar System. Both these phenomena are in our favour.
Hence some asteroids hit the Sun and others are hurled into the outer Solar System and yet others can be affected by the inner planets. Although the mass of these planets is greatly inferior to that of Jupiter, they can have a perturbing effect on asteroids, and bring them into contact with their orbits. Naturally, the greater the mass, the stronger the ejection mechanism will be. Earth and Venus are among the most probable candidates, having a greater mass than Mars and Mercury.
When these conditions occur, the asteroid that changes its orbit becomes an object that might collide with Earth and is called NEA (Near Earth Asteroid). In this phase, the asteroid's orbit is chaotic because it is influenced by continuous close encounters with the inner planets and hence a prevision of its long-term trajectory is very difficult. Therefore, one of these asteroids could potentially hit an inner planet, especially Earth and Venus. NEAs have been further subdivided, and the subset of PHAs (Potentially Hazardous Asteroids) has been introduced. PHAs are NEAs which have a higher probability of colliding with Earth; in fact their minimum orbit distance with respect to Earth is less than 0.05 A.U. and they are larger than 150 metres in diameter. To date at least a thousand of these

objects have been identified, among which the famous Apophis. The latter came close to Earth in January this year and will pass by again in 2029, when the asteroid will brush past Earth at a distance of 30,000 kilometres, about one-tenth of the distance Earth-Moon, keeping at a safe distance, however. We can stay calm, Earth is not in danger.

Predicting asteroid impacts

Predicting the trajectory of an object forced to move under the influence of different planets is practically impossible. This is generally defined as the N-body problem, which does not have a simple solution as in the case of Kepler's laws, which apply only when there are two bodies. So let's discard the analytical interpretation of the phenomenon. There are numerical integration methods which consist in simulating the orbit of an asteroid and reconstructing, at short time intervals, the positions of all the objects involved. Simulation precision increases with the decrease in the time interval taken into consideration. However, it must be underlined that it is impossible to predict asteroid collisions for time intervals beyond 100 years. A curiosity: in order to determine the impact hazard of each NEO in an objective way, a scale has been adopted, similar to the Mercalli intensity scale for earthquakes, known as the Torino Scale, because it was proposed during a conference held in Torino (Turin) in 1999.

Asteroids: a future source of energy

Although NEAs are dangerous, they undoubtedly possess some characteristics which make them particularly interesting. First of all, since they vary widely in composition and origin, they are objects that can be used to obtain a more accurate understanding of the mechanism that led to the formation of the Solar System. Secondly, they can be easily reached when they pass into the inner Solar System, since it is cheaper to send up probes and make spacecraft land on their surface, due to their low mass.

The enormous interest they have aroused is due largely to their composition: NEAs, in fact, are attractive sources of raw materials such as iron, nickel, cobalt and platinum.

Currently it is not worthwhile to extract these minerals to bring them back to Earth. The transportation costs are too high. However, these raw materials could be used to develop space structures and to generate fuel for future missions to explore and colonise our Solar System. There is an unresolved doubt: when raw materials are extracted from asteroids, who will they belong to? Currently, outer space remains an area without private property rights or speculation. The worry is that in the future the situation could change rapidly.

Emergency measures

We now know that the Earth has been hit at regular intervals by space objects. Evidence of the collisions are the craters found on the surface of our planet; these craters range in diameter from a few metres up to 300 km. Since there is an impact risk, nowadays NEOs are monitored and studied through a network of American astronomical observatories.

At the same time the best techniques to adopt in case of a potential Earth impact event are being evaluated. There are two basic strategies regarding this last point: diverting the object from its collision path or trying to destroy it. These strategies can be carried out with both nuclear and non-nuclear techniques. In fact, both to deflect and to disrupt an asteroid, nuclear explosives can be detonated. The choice of whether to pulverise or deflect an NEO depends on its mass and also on the warning time before impact. The problem with using nuclear devices is that there is always the possibility that the asteroid might break up into fragments that are able to continue on their course towards Earth, thus amplifying the problem.

Currently even non-nuclear strategies are being examined to deflect Earth-threatening asteroids or comets. Among the most interesting is the “space tugboat”; as the name suggests, this strategy involves the use of a space device which is capable of activating an ion-propelled engine once the asteroid has been captured, and which employs a low-thrust tug for a prolonged period of time. In this way the asteroid orbital period is shifted enough to prevent it from impacting Earth.

The functionality of the ion propulsion engine has already been tested on the Deep Space probe, launched in 1988. Another method envisages the use of solar sails that use solar radiation pressure to produce a small but constant thrust on the asteroid in order to deviate it sufficiently.

The problem with these methods consists in the fact that neither of them have been adequately tested and are certainly more difficult to implement with respect to nuclear strategies.

Text updated to August 2022