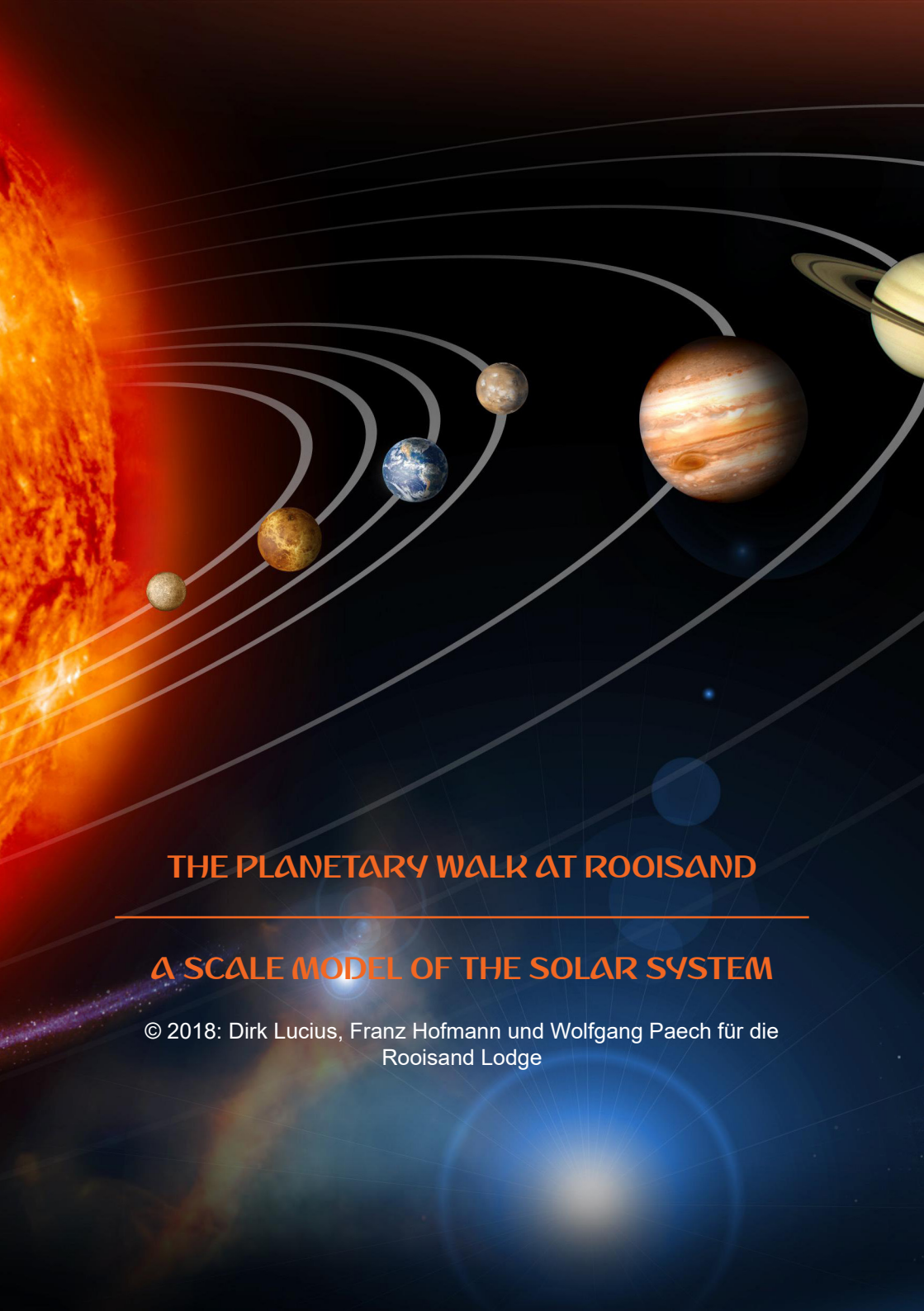
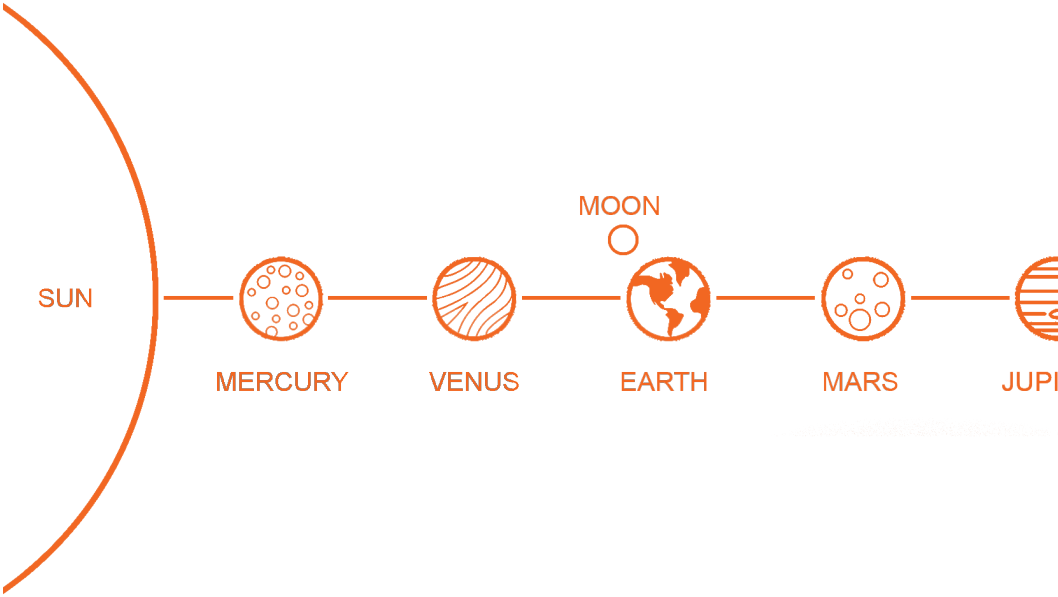


THE PLANETARY WALK AT ROOISAND

A SCALE MODEL OF THE SOLAR SYSTEM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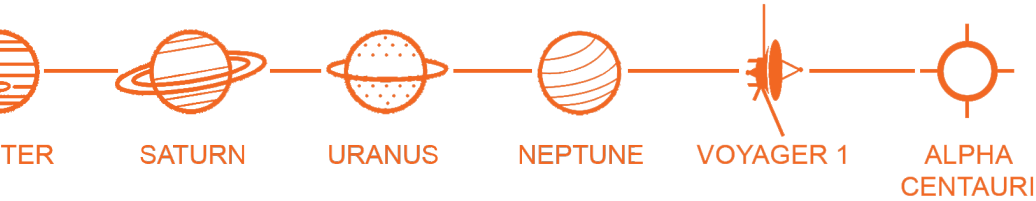
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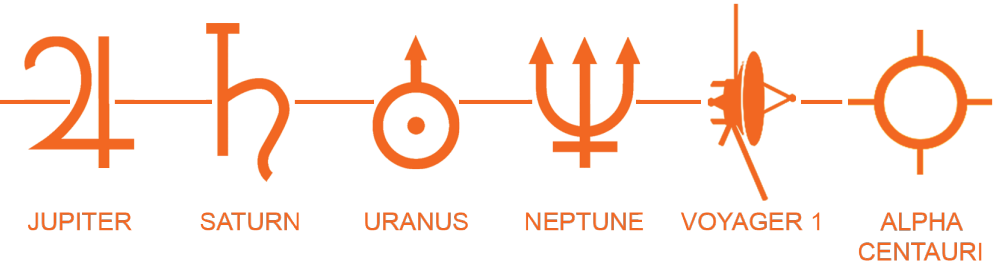
SUN MERCURY VENUS EARTH MOON MARS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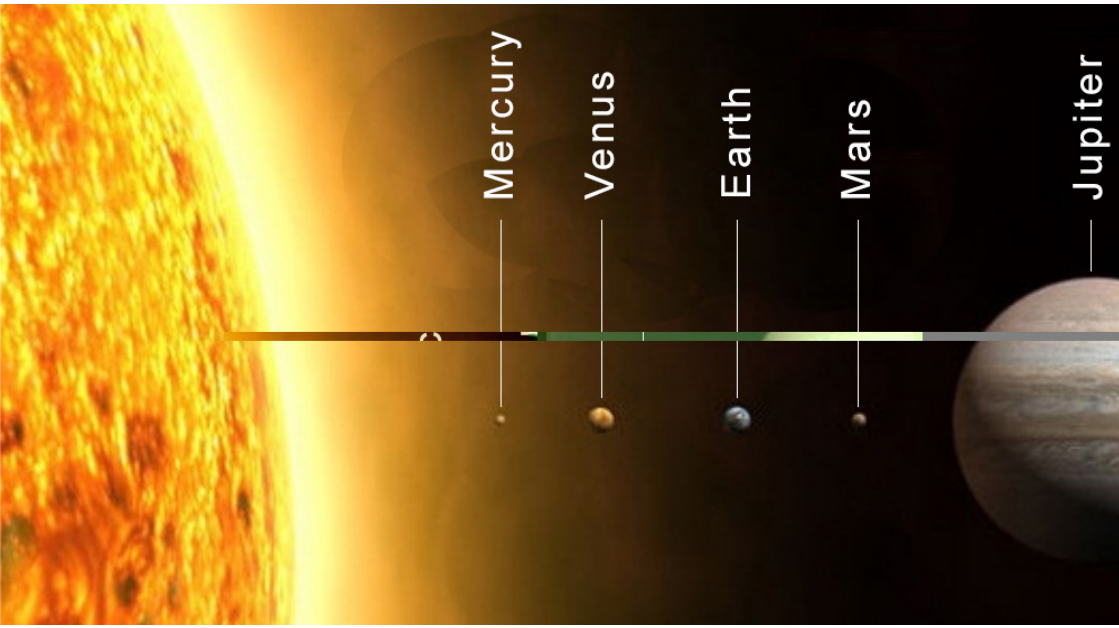


WHY A PLANETARY WALK AT ROOISAND?

Many of our guests take the opportunity to participate in astronomical observations with our telescope during their stay at the lodge. The crystal-clear night sky is inviting, and our telescope is one of the most modern and largest for public viewing in Namibia.

During our observation evenings, we also show the visible planets of the solar system and the Moon. Our guests often ask questions, such as “How far is the Earth away from the Sun?” or “How big is the Sun?”. Our solar system is extremely large and just giving some numbers is therefore not very meaningful.

If the distances in the solar system and the diameter of the planets are “shrunk”, you can “walk through” the solar system. The dimensions of our direct cosmic environment and the gigantic empty space between the planets can be experienced first-hand.

The Planetary Walk at Rooisand starts with the Sun at the lodge and planet Neptune at the observatory. The distance of 2340 meters corresponds to the distance between Sun and Neptune of 4.5 billion kilometers. Our scale factor is almost 1:2 billion. With each step of one meter in length, you cover a distance of 2 million kilometers in our solar system. This corresponds to a 50-fold circular trip around the Earth.

Tables with the most important data of the planets can be found at the corresponding distances to the “shrunk” Sun with a diameter of 0.72 meters (real diameter = 1.4 million kilometers).

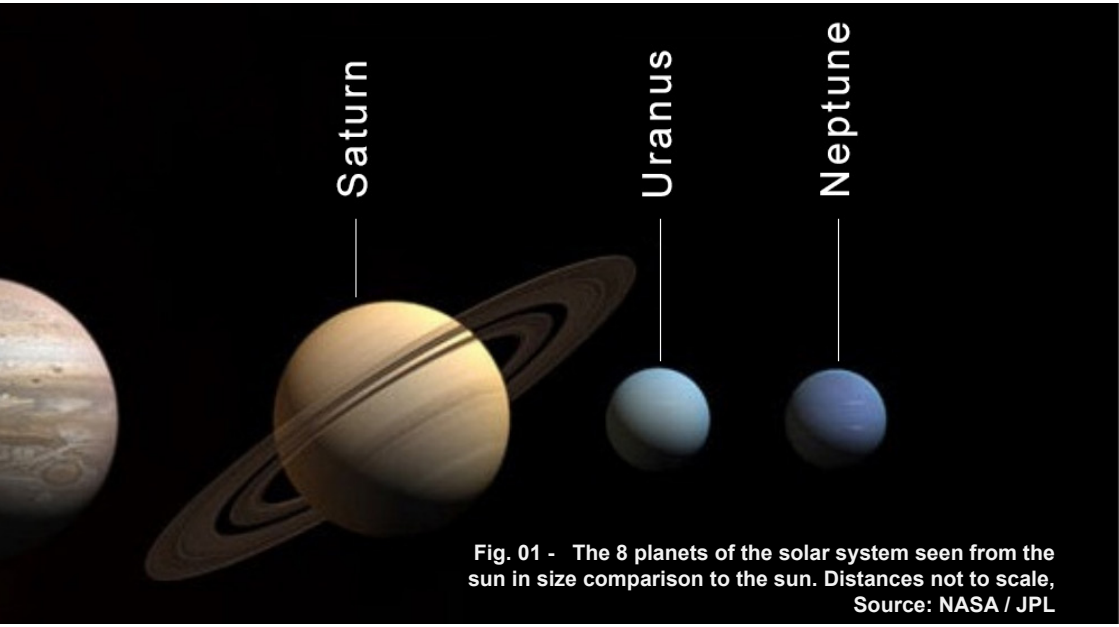


Fig. 01 - The 8 planets of the solar system seen from the sun in size comparison to the sun. Distances not to scale, Source: NASA / JPL

SOME REMARKS ON THE INFORMATION ON THE TABLES:

- The value of the “Length of day” refers to the average time between two Sunrises for an imaginary observer on the planet,
- The length of the year refers to a complete orbit of the planet around the Sun,
- The times refer to terrestrial hours, days and years,
- “Type” denotes the type of the planet. Earth-like denotes a planet with a solid, rocky surface. Gas planets do not have a rocky surface but consist for the most part of a gas mixture, which changes into a liquid or solid state in deeper layers. The chemical composition data refers to the external gas layers,
- All values are rounded.

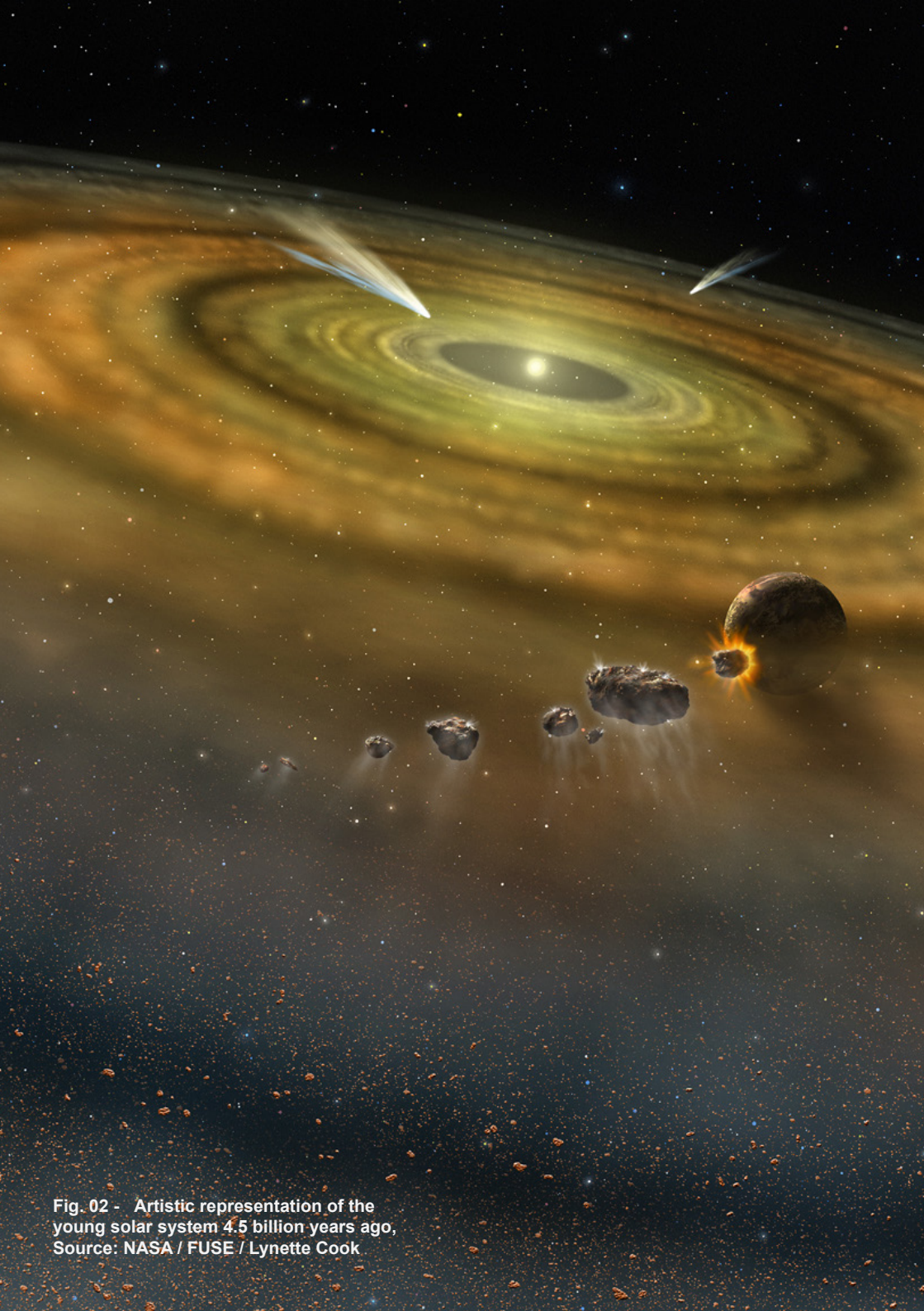


Fig. 02 - Artistic representation of the young solar system 4.5 billion years ago, Source: NASA / FUSE / Lynette Cook

SOME INFORMATION ABOUT THE SOLAR SYSTEM

The solar system is our cosmic home in the universe and consists of the Sun in the center and 8 planets with their moons, which orbit the Sun nearly in circles. There is also some matter in the form of so-called dwarf planets, asteroids, comets and cosmic dust. The distance to the next Sun (fixed star) is 4.3 light-years and between the solar system and the next star is ... nothing, empty space, vacuum and a few hydrogen atoms per m^3, nothing more.

The Sun and all planets formed almost 4.6 billion years ago as a result of a collapsing large cosmic gas and dust cloud. The solar system is located at the edge of the Milky Way (Galaxy), a gigantic system of about 200 billion stars (Sun) and huge clouds of gas, dust and molecules. The Milky Way has the shape of a flat disk with a central thickening and - like the solar system - is also a self-contained structure with a diameter of about 100,000 light years. The next galaxy to our Milky Way is the Andromeda Galaxy at a distance of about 2.5 million light-years. It is about twice the size of the Milky Way and in between there is ... right - nothing, empty space, vacuum, nothing more.

The planets in the solar system are generally distinguished into the so-called inner or Earth-like planets and into the outer or gas planets. The inner planets as seen from the Sun are: Mercury, Venus, Earth and Mars. They all have a solid, rocky surface. Mercury has no atmosphere, Venus a very dense and Mars a very thin atmosphere.

The outer planets are Jupiter, Saturn, Uranus and Neptune. They do not have solid rock surfaces, but mainly consist of a gas mixture whose pressure increases steadily into the direction of the planetary center. Whether these planets have a solid or rocky core is largely unknown. All 4 outer planets have a ring system.

Between the inner and outer planets there is a region called asteroid or planetoid belt. In this zone, rocks in sizes between 1000 kilometers and several meters orbit the Sun. Until the end of 2017, a number of 750,000 asteroids had been registered. The total mass of all asteroids is only about 0.006% of the Earth's mass.

All 8 planets and also the objects of the asteroid belt move approximately in a plane around the Sun, this plane is called ecliptic.

Important note: The only object in our solar system that emits energy in the form of light and heat is the Sun. All other objects of the solar system reflect only the light of the Sun. They do not produce their own light.

Fig. 03 - Sunset Mesosaurus Lodge,
Source: W. Paech

THE SUN

Our Sun is a normal star like millions of other stars in our Milky Way. From the rest of the material, as a by-product, planets and all other bodies of the solar system formed together with it.

The Sun has a diameter of 1.4 million kilometers. It is a gigantic sphere of gas and has no solid surface. The main components are 92.1% hydrogen (the basic substance of the universe) and 7.8% helium. The remaining 0.1% is made up of various elements such as carbon, oxygen, nitrogen, neon and others.

To reach the diameter of 1.4 million kilometers, 109 Earth spheres would have to be lined up and 330,000 Earth spheres would be needed to fill the Sun up. Our Earth, with the Moon in its orbit around the Earth, would easily find its place within the Sun. The mass of the Sun contains almost 99.8% of the total mass of the complete solar system.

The Sun is a so-called main sequence star of spectral class G2V with a color temperature of 5800 Kelvin. When viewed through a very strong neutral filter, it appears in yellowish color.

The Sun generates energy (in the form of light and heat) in its core at an extremely high pressure and temperature by nuclear fusion. This can be roughly compared to the process that occurs when a hydrogen fusion bomb explodes. On Earth, researchers try to replicate the Sun in the form of nuclear fusion reactors. These power plants could revolutionize the energy production on Earth, because the needed “fuel” are the hydrogen isotopes deuterium and tritium, which are almost inexhaustible on Earth. Such reactors do not produce any emissions of greenhouse gases such as CO_2, but it is estimated that it will take another 50 years before fusion reactors will generate energy. The first concepts of these reactors date back to 1960.

The temperature in the inner core - where the energy is generated – is about 15 million degrees Celsius. The outer layers of gas (which we see visually as the Sun’s edge at sunset) still have a temperature of almost 6000 degrees Celsius.

On Earth - at a distance of 149.5 million kilometers - the energy of solar radiation is equivalent to 1.36 kW per m² (similar to a radiant heater). The Sun generates the same energy in a second as all nuclear power plants on Earth in 750,000 years.

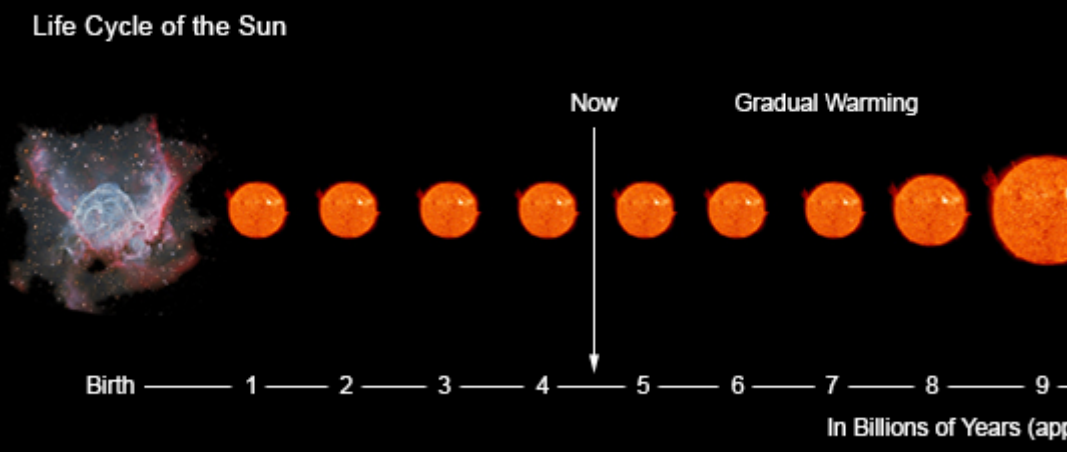
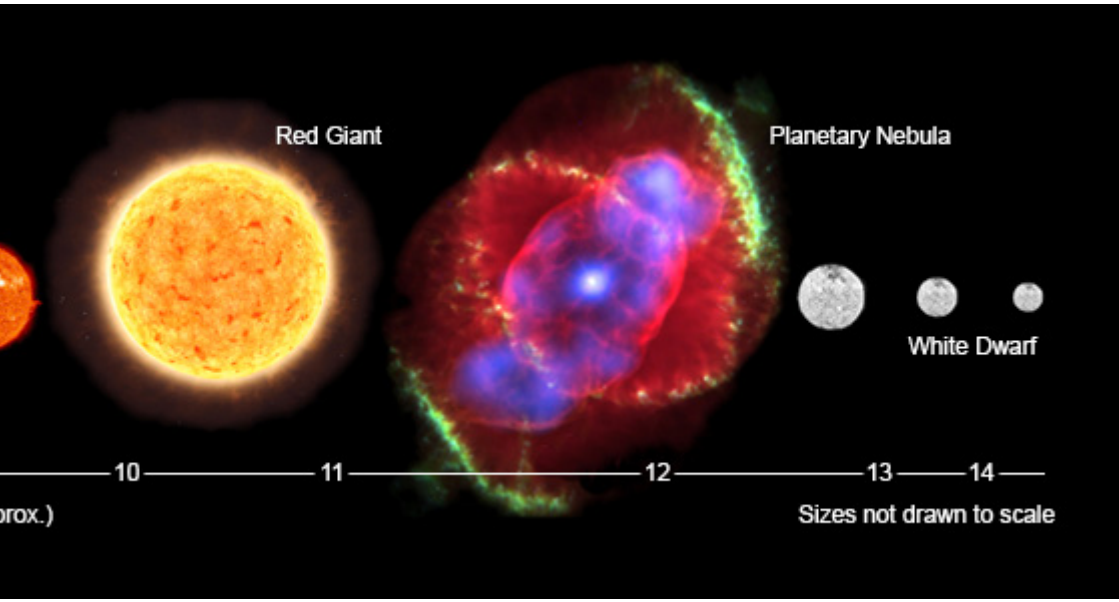


Fig. 04 - Journey of the Sun,
Source: NASA

Fig. 05 - Solar flare with scale earth,
Source: NASA



Another superlative number is the Sun's mass loss, which is caused by the conversion of hydrogen into helium. In each case 4 hydrogen nuclei are needed to produce a helium nucleus. However, the mass of the finished helium nucleus is smaller than the total mass of the four original hydrogen nuclei. The difference of the masses is converted into energy and radiated outwards. The mass loss amounts to almost unbelievable 4 million tons per second which, according to Einstein's famous formula $E= m \times c^2$, are converted directly into energy - and this for billions of years.

In addition to the light and heat a continuous stream of electrons and protons flows from the Sun into space. This particle flow is called solar wind. Furthermore, the Sun goes through an 11.3-year cycle of activity with sometimes violent radiation bursts. The interaction of the solar wind and radiation bursts with the Earth's magnetic field and the upper atmosphere produce the beautiful auroras which can be observed in the polar regions.

The Sun still has enough "fuel" to produce energy for the next 5 to 6 billion years. For this period of time, it retains its current size. Afterwards it will slowly inflate to a so-called red giant star. Its diameter will be so large that the Sun will reach the Earth's orbit. At the end, at the age of 13 billion years, the Sun becomes a white dwarf star of about half the size of the Earth.

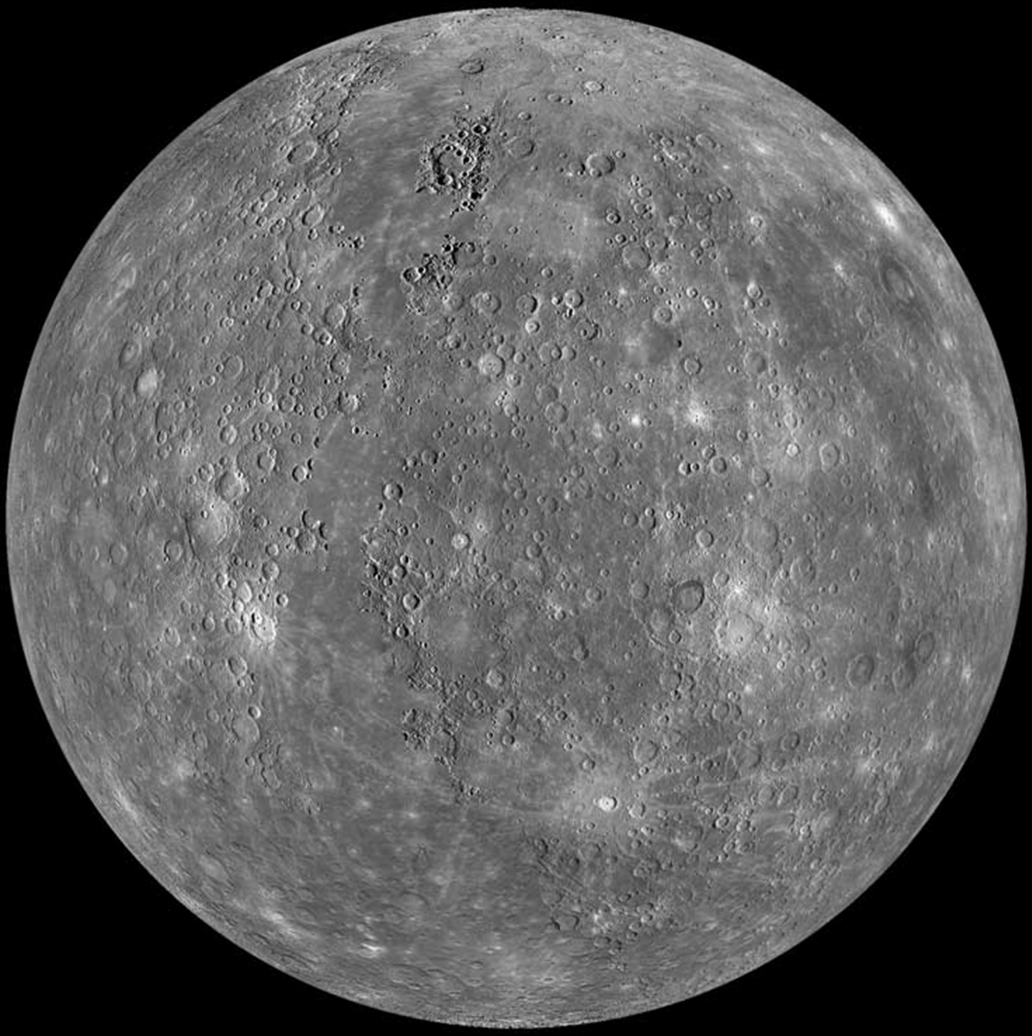


Fig. 06 - Mercury, recorded in 2012 by the NASA spacecraft Messenger, Source: NASA / JPL

MERCURY

Mercury is the innermost and smallest planet of our solar system. It orbits the Sun in a strongly elliptical orbit in about 88 days. The mean distance to the Sun is about 58 million kilometers. Mercury has a diameter of 4879 kilometers and is smaller as Jupiter's moon Ganymed or Saturn's moon Titan. The average density of 5.4 g/cm³ indicates that Mercury has a relatively large iron core. Mercury has a weak Earth-like magnetic field but no atmosphere.

Mercury is named after the messenger of the gods Mercurius, the Roman god of merchants and thieves.

In our scale model we find Mercury as a 3 millimeter small sphere at a distance of 30 meters from the Sun.

The rotation axis of the planet stands almost vertically on its orbit around the Sun. For this reason, and due to the absence of an atmosphere, no seasons such as those on Earth or on Mars occur on Mercury. However, the solar radiation varies considerably due to the orbital eccentricity: in the vicinity of the Sun (distance approx. 46 million kilometers) Mercury gets about 2.3 times more energy as in the part of the orbit which is far away from the Sun (approx. 70 million kilometers). Mercury rotates very slowly. Its length of day (time interval between two Sunrises) is with 176 days twice as long as the Mercury year with only 88 days.

Based on these facts, Mercury has the largest temperature differences of any planet in our solar system. The surface heats up to +430 degrees Celsius during the day of Mercury and drops to -170 degrees Celsius during the night.

For a long time, there was little known about the planet Mercury. Its distance to the Earth is so great that telescopic observations from the ground show almost no surface structures. Because of its close orbit around the Sun, it is difficult to observe it from Earth, because it is always located in a very small angular distance to the Sun. Visually with the naked eye, it can be only observed in twilight. A first Mercury map was published by Giovanni Schiaparelli in 1881, but it has little to do with the true surface structures.

The first facts and details were obtained by observations with space probes, e. g. NASA's Messenger probe, which orbited the planet for 4 years and carried out various measurements. The end of the mission was reached in 2015.

Fig. 07 - Size comparison between Earth and Mercury,
Source: NASA

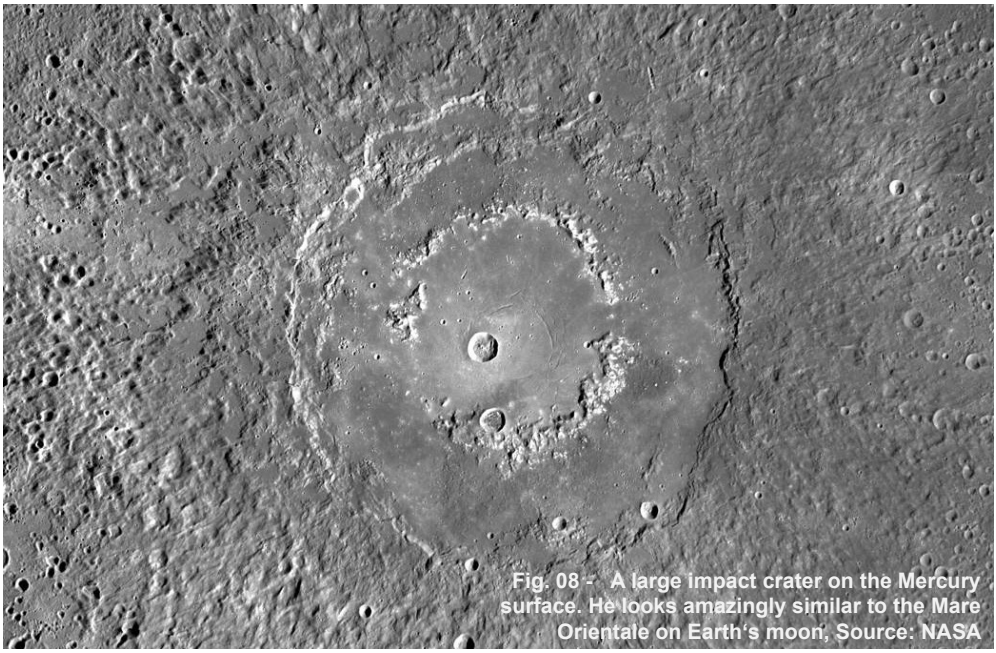


Fig. 08 - A large impact crater on the Mercury surface. He looks amazingly similar to the Mare Orientale on Earth's moon, Source: NASA

At first glance, Mercury seems rather uninteresting for an Earth-like planet, but its internal structure is rather contradictory: externally it resembles the geologically inactive Earth's Moon, but the interior corresponds much more to that of the geologically very dynamic Earth.

Its surface - similar to that of the Earth's Moon - is covered with craters. The similarity of both surfaces is so great that even experienced observers of the Moon cannot definitively say whether they had a crater landscape of the Moon or one of Mercury when they look on a small surface area.

Today, several hundred craters are named on Mercury. They are named after well-known visual artists, musicians and writers who have died at least 50 years ago.

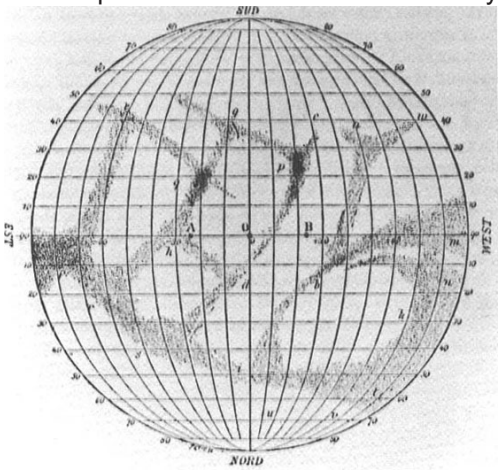


Fig. 09 - Historical Mercury map of Giovanni Schiaparelli, Source: NASA

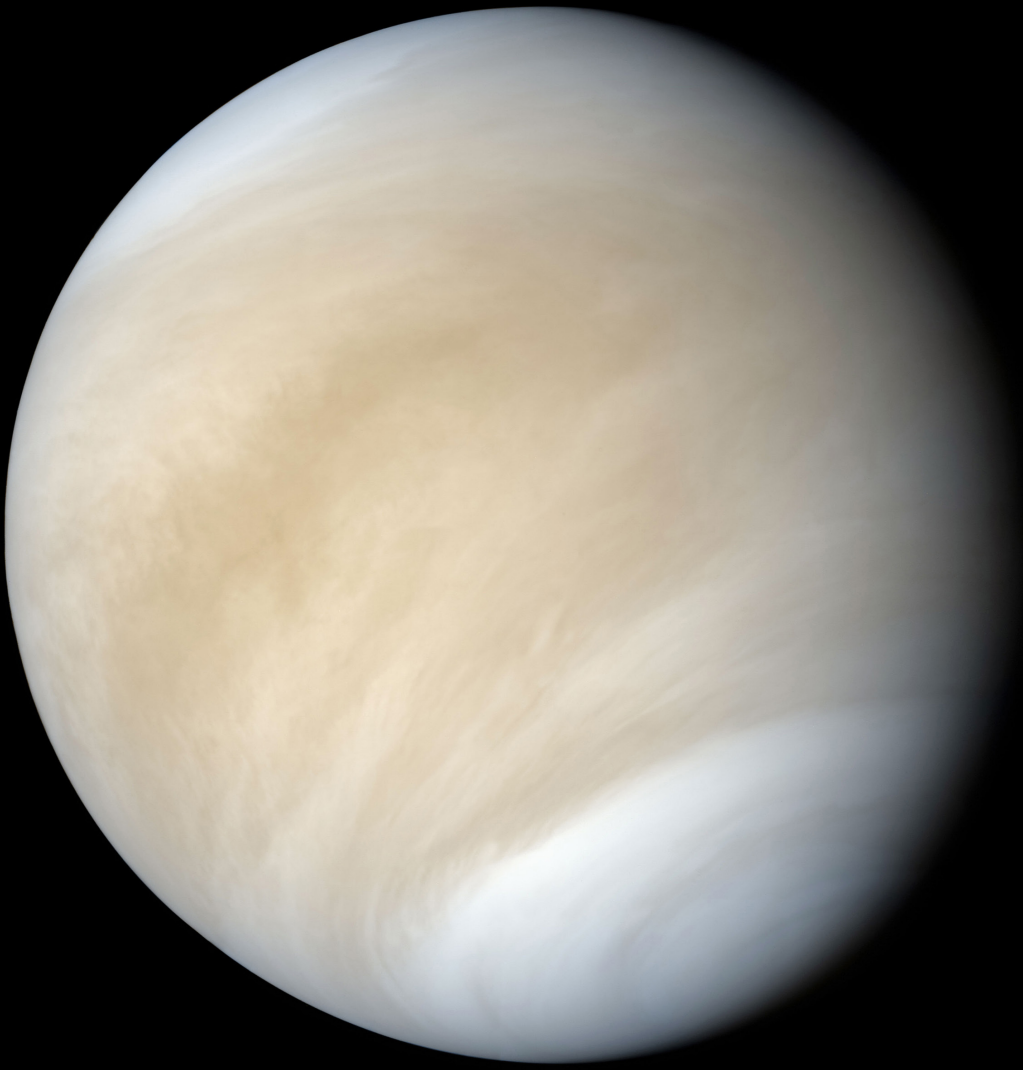


Fig. 10 - Venus in visible light, taken by the spacecraft Mariner 10, Source: NASA

VENUS

Venus is the second planet in our solar system after Mercury. Just like Mercury, it has no moon and with a diameter of 12 104 kilometers it is just a little bit smaller than the Earth. Also the mean density and gravity are almost identical with the corresponding values of the Earth. Venus is named after the Roman goddess of love.

Due to its Earth-like size, Venus was often perceived as a “sister planet” of the Earth. However, no matter how similar they are in mass and chemical composition, the surfaces and atmospheres of both planets differ enormously. Venus is the only rocky planet in the solar system with a permanently optical opaque atmosphere. Only Saturn’s moon Titan possesses such a dense atmosphere besides the planets.

The orbit of Venus has the smallest eccentricity among all planetary orbits, which means that the deviation of the planetary orbit from a circular orbit is very small. The average distance to the Sun is 108.2 million kilometers. Venus needs 225 days to orbit the Sun.

In our scale model we find Venus as a 6 mm sphere at a distance of 56.3 meters from the Sun.

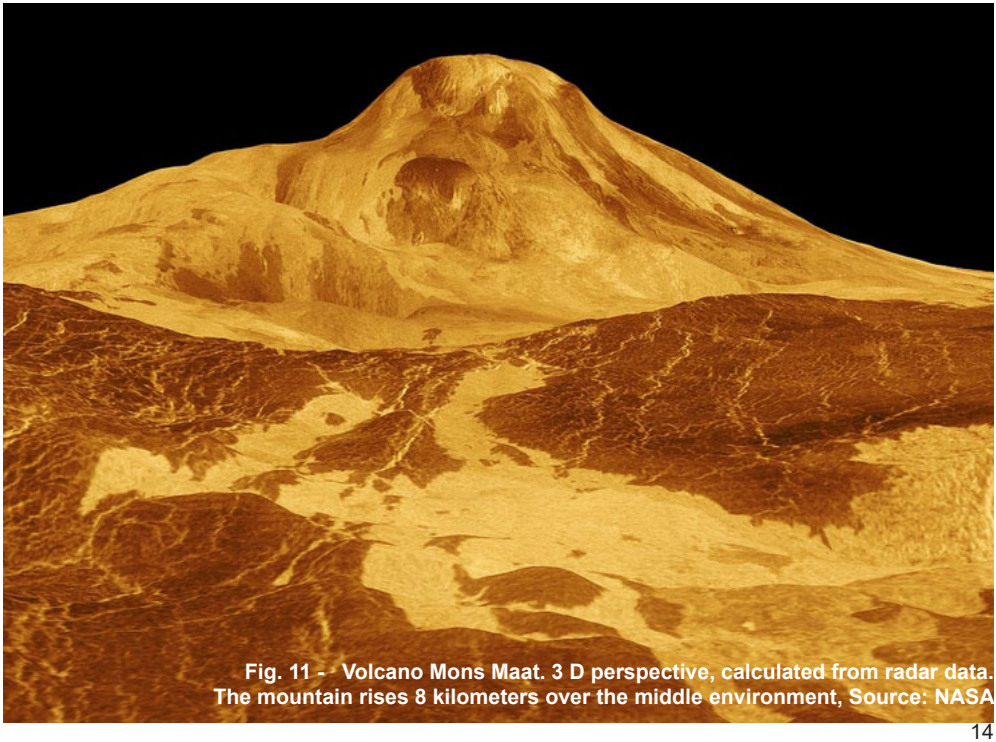
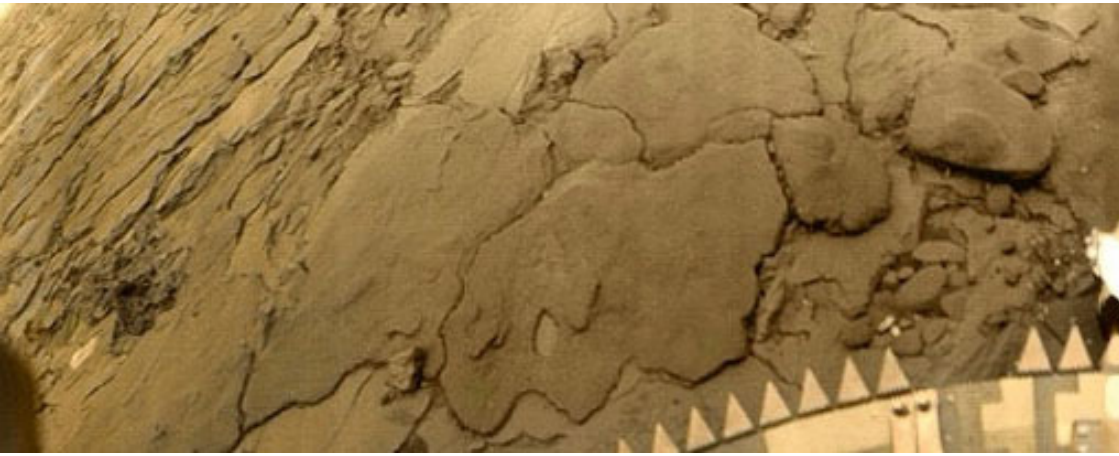


Fig. 11 - Volcano Mons Maat. 3 D perspective, calculated from radar data. The mountain rises 8 kilometers over the middle environment, Source: NASA



The planet Venus is unique in many aspects: while all planets rotate counterclockwise around their own axis as seen from the North Pole, Venus rotates exactly the other way around. This means that Venus Day begins with the sunrise in the west and ends with the sunset in the east, if one could see the Sun through the very dense cloud cover of Venus at all. And with 117 Earth-days an extremely long time passes between two sunrises on Venus. This is only surpassed by Mercury in the solar system. The rotation axis of the planet is almost perpendicular to the orbit plane, which means that there exists no seasons on Venus.

Since Venus orbits the Sun within the Earth's orbit, the planet shows phases in the telescope, similar to the phases of the Earth's Moon from new to full Venus.

Only few facts were known about Venus for a long time, because the permanently closed atmosphere prevented any telescopic observations of surface structures. Due to the smaller distance to the Sun resulting in a higher solar radiation, Venus was thought to be a kind of "primordial Earth", covered with humid, steaming jungle forests.

Since our exploration with space probes, we knew that Venus is a very hostile place to life. The pressure of the dense atmosphere reaches 90 bars on the ground - a value that corresponds to the pressure at a depth of 900 meters in the Earth's oceans. The temperatures on the ground are about +470 degrees Celsius. The high proportion of carbon dioxide as well as sulphuric acid vapor and Sulphur dioxide in the atmosphere cause a strong greenhouse effect, which is responsible for the high temperatures on Venus. Life - as we define it - is not possible there under these conditions.

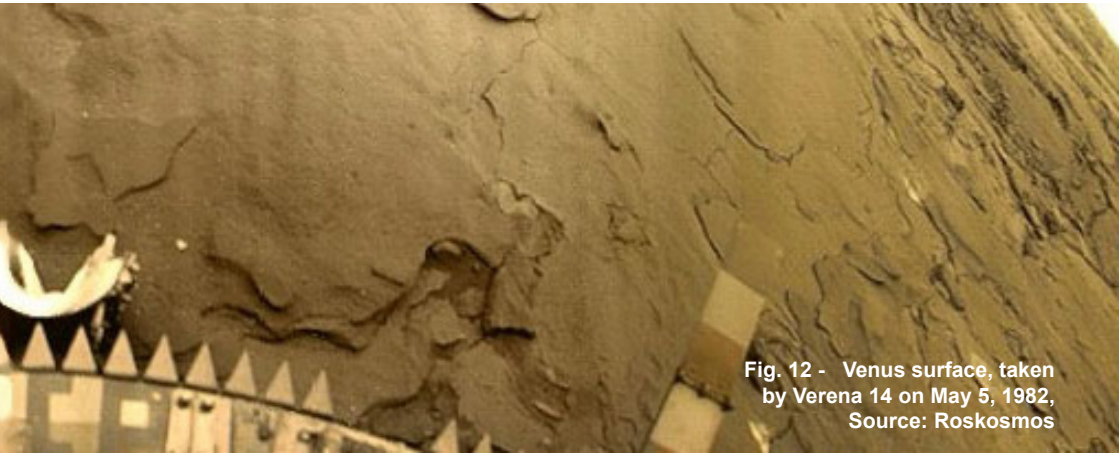


Fig. 12 - Venus surface, taken by Verena 14 on May 5, 1982, Source: Roskosmos

The radar observations of the US Magellan spacecraft allowed a precise planetary measurement of the Venus' surface. Since then it has been known that there are vast highlands on Venus, comparable to the continents on Earth. In addition, there are wide and deep basins, similar to the ocean basins on Earth. Extensive mountain ranges and fault lines are also visible as well as various structures of volcanic activity, e. g. large and long lava flows. If there are still active volcanoes on Venus today, they may be the after-effects of a once active Venus plate tectonics.

In the 1970s and 1980s, the former USSR succeeded in landing some spacecraft softly on the surface of Venus, but due to the high pressure and high temperatures, they only operated for a few minutes. We owe them the few photos of the landing sites on the surface in real colors. The picture was taken by Verena 14 on 05 May 1982 and shows a rocky, very flat surface.

Fig. 13 - Size comparison between earth and moon,
Source: NASA

EARTH AND MOON

The Earth is the third planet as seen from the Sun and orbits it at an average distance of 149.6 million kilometers (= 1 Astronomical Unit). The equatorial diameter is 12,756 kilometers. It was formed together with the Sun and the other planets about 4.6 billion years ago. Our home planet is currently the only place in the solar system where life exists. When seen from space the Earth appears predominantly blue due to the two-thirds of oceanic water at the surface. It is often referred to as a blue planet or metaphorically as “spaceship Earth”.

In our scale model, we find the Earth as a 7 millimeter sphere at a distance of just under 78 meters from the Sun.

According to its composition, the Earth defines the class of Earth-like planets. It is the largest of the four Earth-like planets in the solar system. Seismic measurements show that the Earth is mainly composed of three shells: the Earth’s core, the mantle and the crust above it.

The Earth’s core has a diameter of approx. 6000 km and consists for the most part of an approx. 6000°C hot metal melt made of iron and nickel. Due to the extremely high pressure in the core area, the molten metal is crystallized and liquid in the outer area. As a result of the Earth’s rotation, spiral currents are generated in the electrically conductive molten metal, which stimulate a dynamo effect that generates the Earth’s magnetic field. This large iron core is also responsible for the highest average density of all planets.

Above the Earth’s core lies the 3000 km thick mantle. Pressure and temperature increase with increasing depth. In the upper areas, the temperature is several hundred degrees Celsius, close to the core boundary about 3500 degrees Celsius. The chemical composition of the rock in the upper mantle differs from that of the rock in the lower mantle. The transition zone between the two mantle areas lies at a depth of approx. 1800 kilometers. The rocks of the Earth’s mantle mainly consist of minerals which are rich in magnesia and iron.

The Earth’s crust together with the uppermost part of the upper mantle forms the so-called lithosphere. It is between 50 and 100 kilometers thick and is divided into larger and smaller tectonic plates. The Earth is the only one of the Earth-like planets with proven active plate tectonics. It causes the continental plates to move slowly (continental drift) and thus the Earth’s surface is permanently renewed over very long periods of time. The processes and phenomena associated with plate tectonics include the formation of mountains due to the pressure of colliding continents as

Fig. 14 - Active volcanism due to plate tectonics in Iceland, Source: M. Rietze

well as the most common forms of volcanism and earthquakes. The continental plates move on the viscous rocks of the upper Earth's mantle, the 100 to 150 km thick asthenosphere. Some moons of the outer planets also show signs of a surface renewing in relatively short periods of time due to volcanism (e. g. the Jupiter moon Io).

The Earth's axis of rotation is inclined with an angle of 23.5 degrees to the vertical of the orbit around the Sun. This inclination of the rotation axis leads to distinct seasons on Earth, because the northern and southern hemispheres of the Earth are differently illuminated by the Sun at different points of their orbit.

In the mid latitudes there are four distinct seasons: spring, summer, autumn and winter. In the tropical areas, only two seasons alternate the rainy and dry season. The average temperature on Earth is +15 degrees Celsius, which varies with the latitude and altitude of the position on Earth.

About the naming:

In almost all languages of the world, the Earth has a female gender word. In all religions it plays an outstanding role as a whole. In many ethnic, ethnic and historical religions it is considered either as a diffuse deification of a “mother Earth” or as a personified Earth goddess.

Fig. 15 - Earthrise over the Moon‘s Horizon, taken by the Lunar Reconnaissance Orbiter, Source: NASA

MOON

The Moon (Latin Luna) is the only natural satellite of the Earth. Since the satellites of other planets of the solar system are often referred to as moons in the figurative sense, we sometimes speak of the Earth‘s Moon to avoid confusion. With a diameter of 3476 kilometers, it is the fifth largest moon in the solar system and has a density of 3.35 g/cm³ which corresponds approximately to the density of the Earth’s upper mantle. The ratio of lunar diameter to Earth diameter is 0.273. This is significantly larger than the ratio of the “moons” of the other planets. Due to this relatively small size difference between the two celestial bodies, the Earth and Moon are sometimes referred to as a double planet. Only the dwarf planet Pluto and its moon Charon have a similar size-ratio.

In our scale model we find the Moon as a 2 millimeter sphere at a distance of 20 centimeters from the Earth.

The Moon orbits the Earth in an average distance of 384,400 kilometers. Its minimum distance to Earth is 363,300 kilometers and its maximum distance is 405,500 kilometers.

It rotates around its own rotation axis in exactly the same time in which it orbits the Earth. This is called synchronous rotation and is the reason why we always see the same side of the Moon from Earth and never the “backside”.

The genesis of the Moon

The low average density, compared to the Earth, provided numerous theories on the origin of the Moon. Today’s most likely theory is that about 4.5 billion years ago, a celestial body of the size of Mars - called Theia - collided almost with the proto-Earth. A lot of matter, mainly from the Earth’s crust and the mantle of the hitting body, was thrown into an Earth orbit, compacted there and finally formed the Moon within a few years. The majority of the impactor merged with the proto-Earth to Earth. According to current simulations, the Moon formed at a distance of about three to five Earth radii, i.e. at a distance between 20,000 and 30,000 kilometers. Due to the collision and the energy released by it, the Moon was melted and completely covered by an ocean of magma. During the cooling process, a crust formed from the lighter minerals, which can still be found today in the “highlands” of the Moon (the bright areas on the Moon).

The name Theia comes from Greek mythology. The Moon goddess Selene was born according to this myth by the Titanium woman Theia.

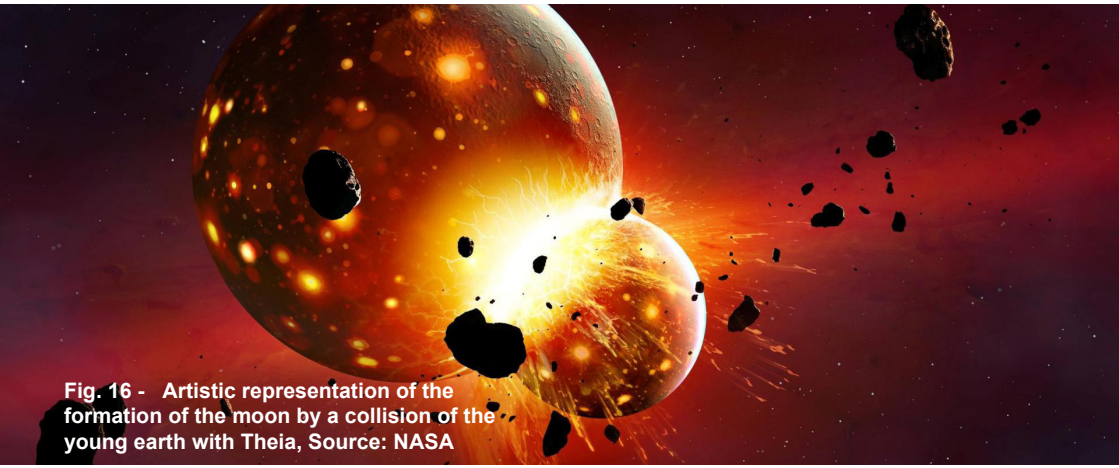


Fig. 16 - Artistic representation of the formation of the moon by a collision of the young earth with Theia, Source: NASA

In November 2005, an international research group was able to precisely date the origin of the Moon for the first time. They used analyses of the isotope tungsten 182 in the lunar rock and calculated the age of the Moon to 4.527 billion years (± 10 million years). Thus it was formed 30 to 50 million years after the formation of the solar system.

After the surface of the Moon had cooled down, several kilometer-large objects hit the Moon's surface. They perforated the Moon's crust so that new lava could flow from the Moon's mantle into the resulting craters. Maria, the "oceans" of the Moon, formed which completely cooled down a few hundred million years later. The so-called "Heavy Bombardment" describes the last epoch with violent impacts of great asteroids. It ended 3.8 to 3.2 million years ago.

Today, the Moon is a completely inactive celestial body with no evidence of active volcanism. The last major impacts probably occurred 100 million years ago (resulting in the Copernicus and Tycho craters). The reason why we can still observe the crater-covered lunar surface today as "fresh" as a few billion years ago is that the Moon shows neither plate tectonics nor a form of "weather" and thus there is no erosion.

Craters of the Heavy Bombardment are also found on the other Earth-like planets. Mercury and also Mars show many craters, also due to the (almost) missing atmosphere, which reduces such impacts. Due to the dense atmosphere Venus has considerably fewer large impact craters. Due to plate tectonics, the craters of the large impact craters are completely absent on our Earth, because the craters created at that time were dug up, so to speak.

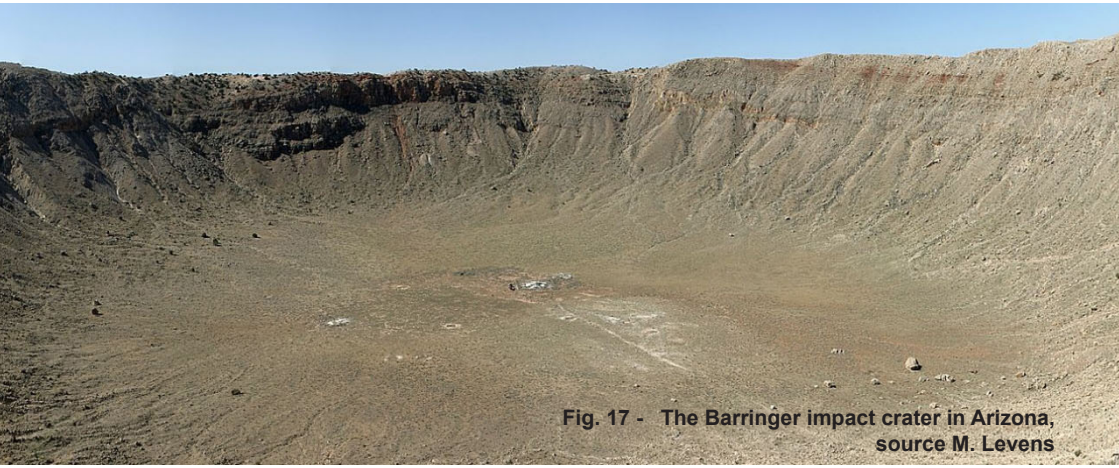


Fig. 17 - The Barringer impact crater in Arizona, source M. Levens

The Rote Kammkrater (a meteorite impact crater, “Red Ridge”) in Namibia, which is unfortunately not easily accessible due to its location in the diamond barrier area, shows that such impacts occurred even in much later geological periods of the Earth. In Windhoek’s pedestrian zone there is the meteorite fountain with the remainder of the Gibeon Impact and in the north of Namibia the Hoba meteorite can be found.

In Germany, the Steinheimer Becken and the Nördlinger Ries are impressive examples of impact craters. The Earth suffered the last catastrophic impact 65 million years ago, when a 15-kilometer-large boulder struck the Gulf of Mexico and hit a crater about 180 kilometers wide and 30 kilometers deep directly after the impact. Today, this impact is make responsible for the extinction of dinosaurs and many other life forms.

The youngest larger crater on Earth is the so-called Barringer Crater in Arizona/USA. It has a diameter of 1.2 kilometers and is 180 meters deep. The impacting meteorite had a diameter of 45 meters, weighed about 300,000 tons and consisted mainly of iron. The impact velocity was about 15-30 km/s (75 000 km/h). The age of the crater is 50,000 years.

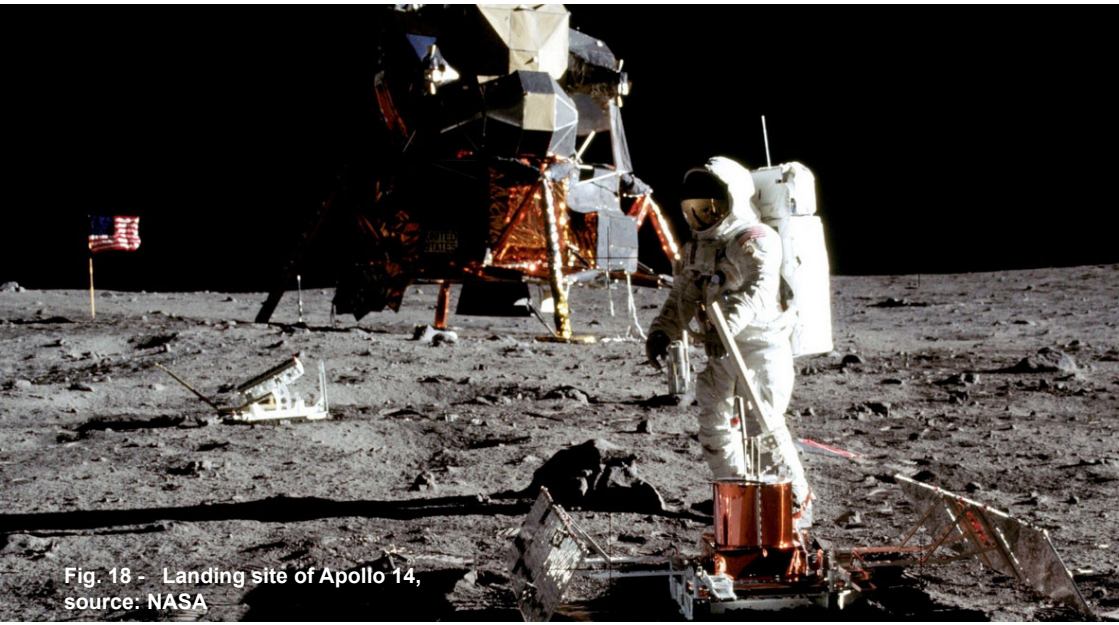


Fig. 18 - Landing site of Apollo 14, source: NASA

Moon landings

Because of its proximity to the Earth, the Moon is the only celestial body that has been entered by humans up to now. The Apollo Moon landing program of the US space agency NASA had less scientific reasons but mainly a political background. At the time of the Cold War in the 50s and 60s of the last century there was a so-called race into space between the former USSR and the USA. At that time, the Americans were technically far behind. The USSR launched the first satellite into orbit on 4 October 1957. Sputnik was a shock to the American government and the people. This was followed by the lunar probe Lunik 2, which was the first spacecraft to hit the Moon on September 13, 1959. On 3 February 1966, Luna 9 was the first missile to land softly on the Moon.

Therefore, on 25 May 1961, the President of the United States gave a historic speech and said the decisive sentence: Before the end of the next ten years, an American should set foot on the Moon and return to Earth in good health. According to Kennedy, it is *“the time for this nation to take on a clear leadership role in space”*.

Kennedy’s dream came true in 1969 with the first Moon landing of the mission Apollo 11. Neil Armstrong and Edwin Aldrin were the first people to enter the Earth’s satellite. John F. Kennedy no longer experiences the triumph, he is murdered in Dallas, Texas, in 1963, two years after his keynote speech.

Fig. 19 - Buzz Aldrin's Footprint on the Moon, July 21, 1969, Source: NASA

The last lunar landing took place in December 1972. Afterwards the Apollo program was discontinued for cost reasons, although several landings were planned. On a total of six Apollo missions, two astronauts entered at each mission the Moon's surface.

In retrospect, the lunar landings were technically highly risky missions and it is actually a miracle that all astronauts returned to Earth. So the landing module of Apollo 11 - after Aldrin stopped the automatic landing and landed manually - had just 3 seconds of fuel left. At Apollo 13 an oxygen tank exploded and the crew could be safely brought back to Earth after a Moon orbit. In this respect, all manned lunar landings were highly critical situations.

It was not until the mid-1990s that the Moon was mapped extensively with unmanned probes from various nations and was remotely investigated from the orbit. Thus, it was also possible to photograph the landing sites of the Apollo missions from the orbit.

The return of humans to the Moon (and beyond) is regularly considered by the USA. As a new emerging space nation, China is planning a comprehensive Moon program for the period after 2020, which will explore the back of the moon and possibly culminate in a manned landing. Political willpower and financial resources will show what the future holds.

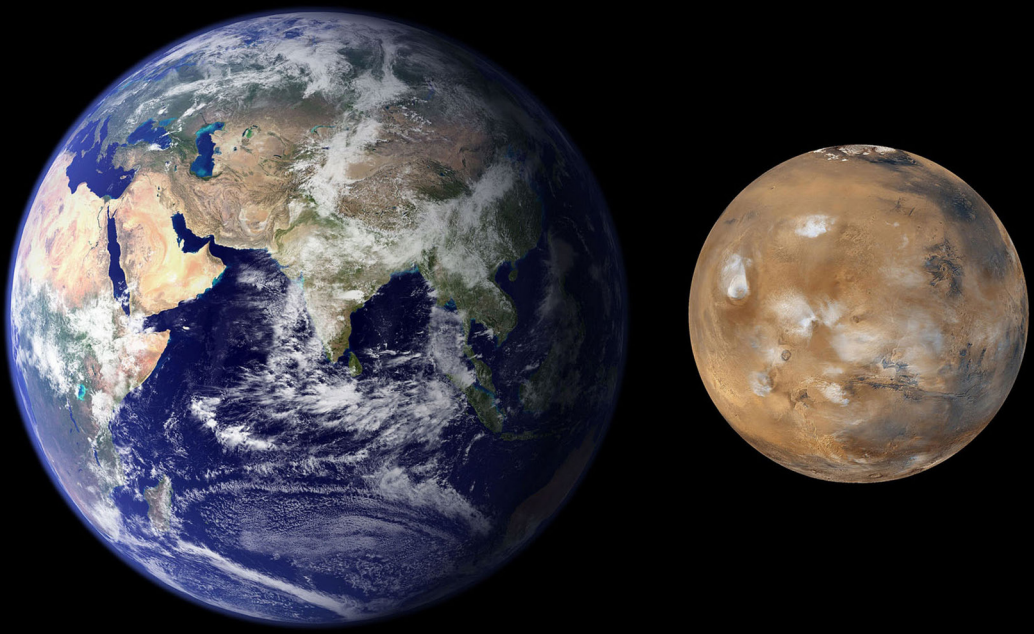


Fig. 20 - Scale comparison between Earth and Mars, Source: NASA

MARS

Mars is the fourth planet as seen from the Sun. Already looking at the night sky with the naked eye he shows a reddish glow, which earned him the name “Red Planet”. This color is due to iron oxide in the surface rocks and fine iron oxide dust in the atmosphere. Mars is considered to be the most Earth-like of all planets in the solar system. Mars is named after the Roman god of war.

With an equatorial diameter of nearly 6800 kilometers, it is about half the size of the Earth, with an average distance to the Sun of 228 million kilometers. The Mars year has a length of 687 days (1.9 years) and the length of day (time interval between two Sunrises) is - similar to that of Earth - 24 hours and 40 minutes. Mars’ axis of rotation is tilted by 25.2 degrees to the perpendicular of the orbit around the Sun. This causes distinct seasons on Mars - just like on Earth. The equatorial temperatures can rise to more than +20 degrees Celsius in the summer, whereas the winter temperatures at the poles are below -130 degrees Celsius. The average temperatures are about -55 degrees Celsius.

In our scale model we find Mars as a 4 millimeter large sphere at a distance of 118 meters from the Sun.

Mars owns two small, irregularly shaped moons called Phobos and Deimos (Greek for fear and terror), discovered in 1877 by the astronomer Asaph Hall. Interestingly enough, the existence of two small moons was fictitiously predicted by Jonathan Swift in the third part of Gulliver’s travels in 1727, long before their discovery. The book tells that the *“laputan”* astronomers would know “two smaller stars or satellites” orbiting Mars. This story was written in 1750 in Voltaire’s novel *“Micromégas”*, in which a giant from the star Sirius visits the solar system. In honor of these two writers, two of the craters on Deimos received their names.

Fig. 21 - The little Mars moon Deimos, Source: NASA

It is assumed that Phobos and Deimos did not formed together with Mars, but that they are objects from the asteroid belt, which eventually came too close to Mars and were forced into orbit by the gravitation of the planet.

Mars has a very thin atmosphere consisting of 96% carbon dioxide. The oxygen content is only 0.15%. The atmospheric pressure at the surface of Mars is only about 1/100th of the pressure of the Earth’s atmosphere at sea level. Future Mars-astronauts will have to be artificially ventilated similar

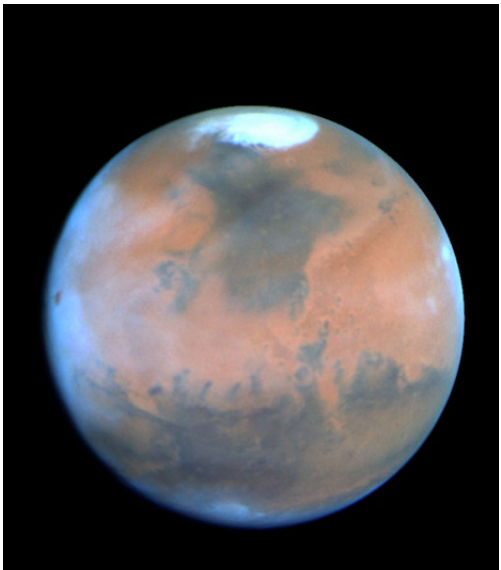


Fig. 22 - The polar caps of Mars, taken with the Hubble Space Telescope, Source: NASA

to the Moon astronauts, because carbon dioxide is deadly for the human organism.

Mars has two conspicuous polar caps, which are mainly composed of frozen carbon dioxide (dry ice) and a small portion of water ice. The northern polar cap has a diameter of about 1000 kilometers during the summer of Mars. Their thickness is estimated to be 5 kilometers. The southern polar cap is considerably smaller with a diameter of 350 kilometers and a thickness of 1.5 kilometers.

During the spring of Mars, violent dust storms can occur in the vast plains, sometimes covering the entire planet. The images of Mars probes also show

Fig. 23 - Mars surface inside the crater Gale, taken from the landing unit Curiosity, Source: NASA

tornadoes, which stretch across the Martian plains. Storms on Mars have less force than storms on Earth because of the very thin atmosphere. Even at high wind speeds, only small particles (dust) are blown up. However, dust on Mars remains in the atmosphere for much longer than on Earth because there is no precipitation to clean the air.
Mars appears today as a dry desert planet. However, the results of the Mars missions suggest that its atmosphere was significantly denser in the past (billions of years ago) and abundant liquid water was present on the surface of the planet. The space probes show multiple structures of large amounts of water that once flowed.

For centuries astronomers have been speculating about the possibility of life on Mars because of the closeness and similarity of the planet to Earth. The search for traces of life on Mars began in the 19th century. While the historical search was limited to phenomenological methods and speculations, modern science focuses on the search for water, chemical biomarkers in the soil and rocks, and gaseous biomarkers in the atmosphere. To date (2018) no life on Mars has been proven - but the search continues.

Fig. 24 - The great canyon Valles Marineris

Giovanni Schiaparelli triggered a boom in telescopic observation of Mars in 1877, after he believed that he recognized line structures on the surface of Mars, which he called “Canali” (Italian for “channels” or “ditches”) and entered into a detailed map. At first he did not give any information about the origins of the Canali (which he estimated to be more than 100 kilometers wide), but in the English media they were mistakenly translated as “channels” and soon interpreted as the work of intelligent Mars inhabitants. While some astronomers confirmed Schiaparelli’s’ observations, the existence of the Canali was questioned by others and described as the result of optical illusions.

Already in the early 20th century - with the increase of the efficiency of earthbound optical telescopes - it could be proven that Schiaparelli’s channels are based on optical illusions. The speculations were finally ended by the fly-bys of the American spacecraft at the beginning of the 1970s, which showed no canals, but to the astonishment of many astronomers quite a lot of craters.

The surface of Mars has two remarkable structures of the planets of the solar system:

Valles Marineris is the largest tectonic fracture zone of the solar system. It runs approximately parallel to the Martian equator and extends over a total length of 4000 kilometers, is up to 700 kilometers wide and up to 7 kilometers deep. In its western part it branches out into a chaotic maze of numerous gorges and valleys, which are up to 20 kilometers wide and up to 5 kilometers deep.

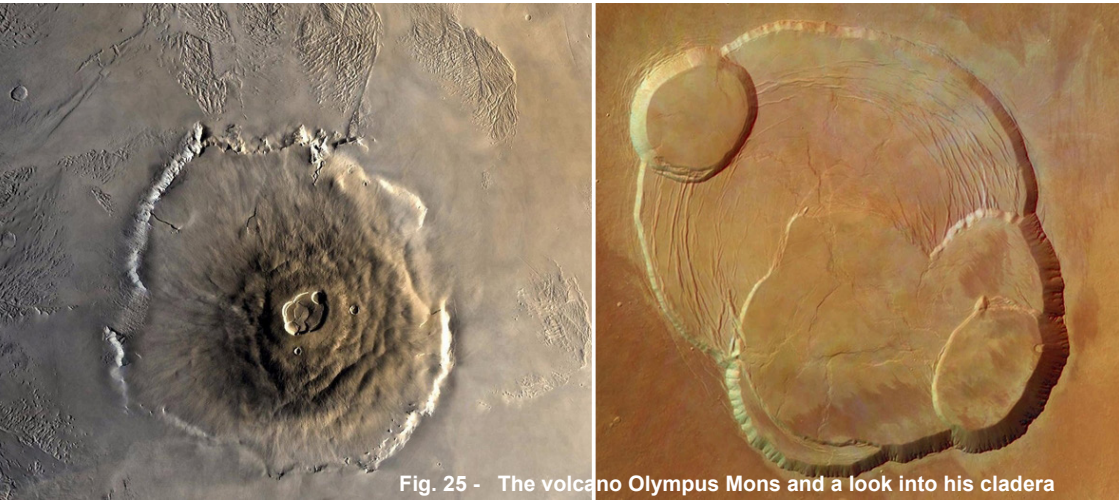


Fig. 25 - The volcano Olympus Mons and a look into his cladera

Olympus Mons is a shield volcano in the Tharsis region. With more than 22 kilometers above the average planetary level and 26 kilometers above the surrounding lowlands, it is the highest mountain in the solar system. This makes it three times higher than Mount Everest on Earth. It lies together with three other very large volcanoes near the Mars equator. Its base area has a diameter of about 600 kilometers. The caldera is 90 kilometers long and up to 3 kilometers deep.

It is not known whether Olympus Mons is extinguished or still active. Researchers however conclude from analyses of lava flows that the volcano was still active in the geologically “short” past. They date the lava flows to an age of about two million years.

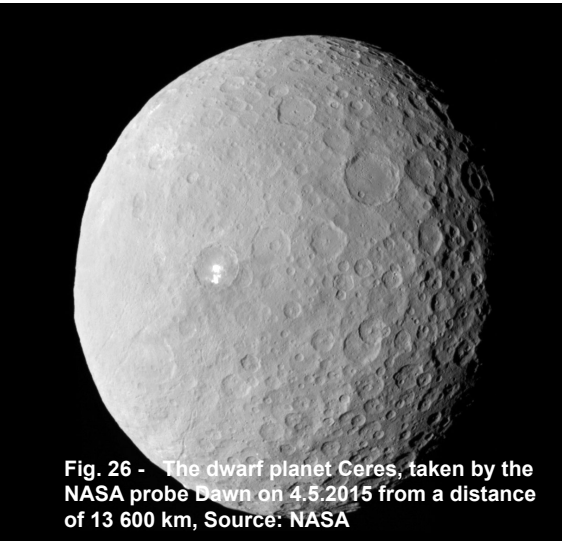


Fig. 26 - The dwarf planet Ceres, taken by the NASA probe Dawn on 4.5.2015 from a distance of 13 600 km, Source: NASA

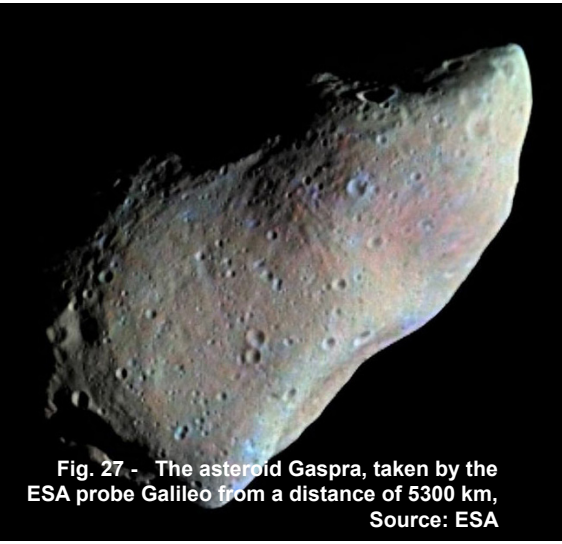


Fig. 27 - The asteroid Gaspra, taken by the ESA probe Galileo from a distance of 5300 km, Source: ESA

The Asteroid Belt

The asteroid belt, planetoid belt or main belt is the amount of objects in the solar system located between the orbits of Mars and Jupiter. The dwarf planet Ceres and most of the known asteroids of the solar system move in this range. By March 2017, more than 750,000 such objects had been identified.

Asteroids are objects ranging in size from small irregularly shaped chunks to the dwarf planet Ceres (diameter 963 kilometers) - the largest asteroid. Only the brightest asteroid, Vesta, is barely visible to the naked eye from Earth.

Note: The Asteroid Belt does not have a table on our planet walk. It would be 260 meters away from the Sun in our model. Ceres would appear with a diameter of less than 0.5 millimeters.

Asteroids consist of silicates and are partially mixed with metals such as iron or nickel. The total mass of all asteroids in the main belt is only about five percent of the mass of the Earth's Moon.

In the 18th century, an empirical formula called the Titius-Bode series described the order of the planets known to date. According to this formula, there must be another planet between Mars and Jupiter. Towards the end of the 18th century, a systematic search for the "missing" planet in this area began.

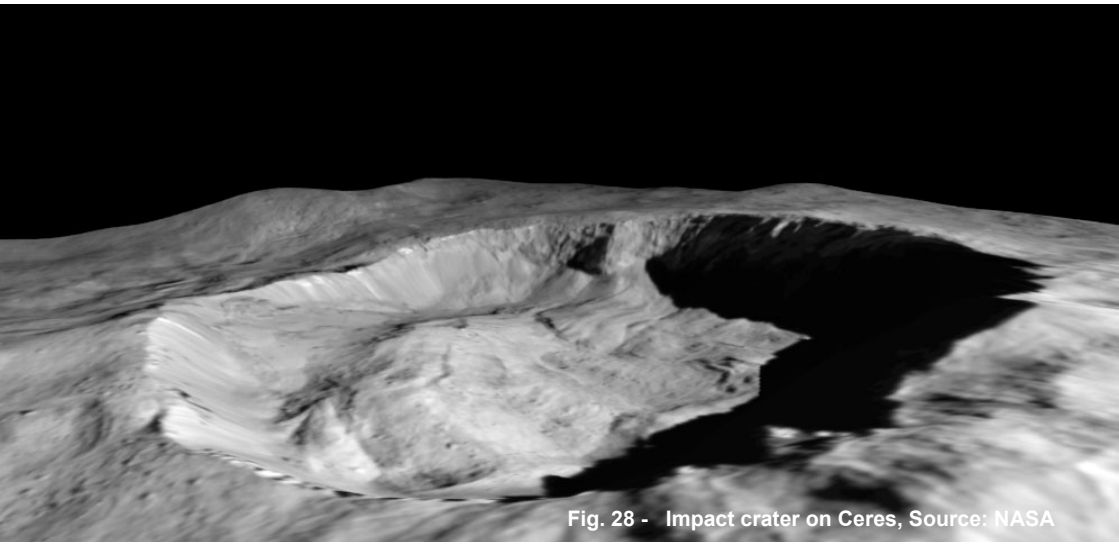


Fig. 28 - Impact crater on Ceres, Source: NASA

When Giuseppe Piazzi discovered the dwarf planet, which was later named Ceres, on 1 January in 1801, he believed that he had found the planet. But in the following years, however, further similar discoveries could gradually be added. Ceres has an equatorial diameter of nearly 1000 kilometers, a mean density of 2.2 g/cm3 and is by far the largest object in the asteroid belt.

As early as 1802, Heinrich Wilhelm Olbers discovered Pallas, a second object that orbits the Sun between Mars and Jupiter. This was followed by the discoveries of Juno (1804), Vesta (1807) and 38 years later the Astraea (1845). Although it was recognized that all objects between Mars and Jupiter were smaller by orders of magnitude than the classical planets, they were considered to be full-fledged planets. Thus it happened that the planet Neptune was counted as the thirteenth planet when it was discovered in 1846. By 1890, 300 asteroids were already known in this “planet gap”.

Today it is generally assumed that the objects of the asteroid belt formed simultaneously with the rest of the solar system from a large gas and dust cloud which could not grow together to a planet due to the gravitational influence of Jupiter. A theory that was popular in the past, according to which a small planet - called Phaeton - once existed at the corresponding place, which was torn to pieces by the collision with a larger asteroid, is hardly represented today.

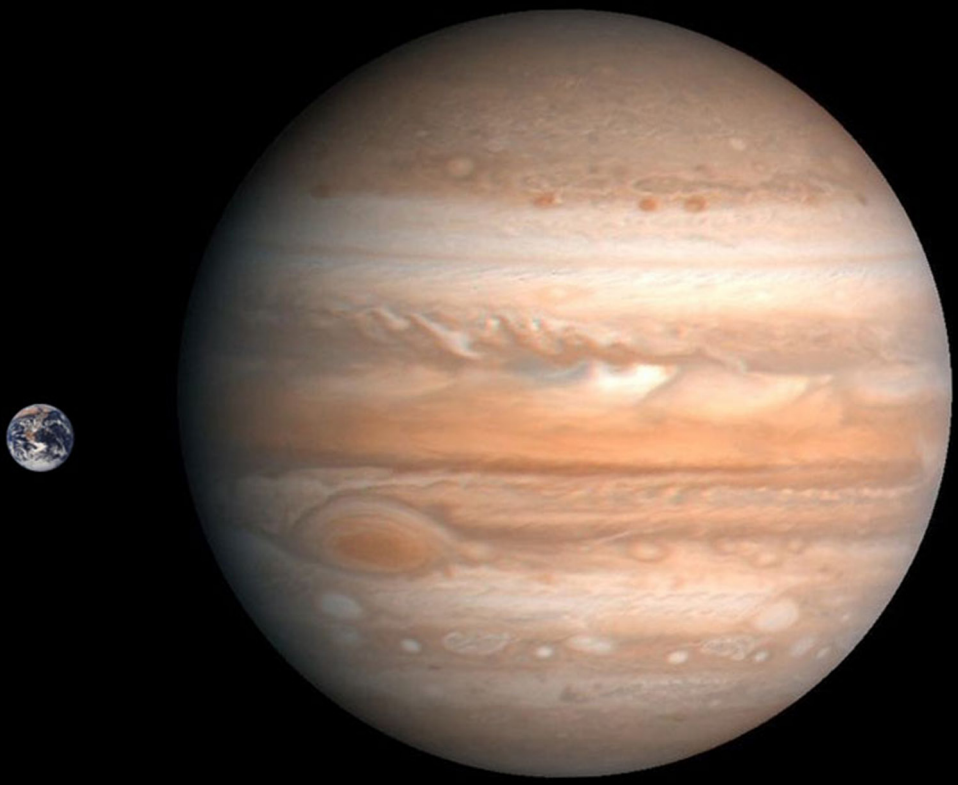


Fig. 29 - Comparison of sizes between Jupiter and Earth,
Source: NASA

JUPITER

Jupiter is the largest planet in the solar system with an equatorial diameter of about 143,000 kilometers. With an average distance of 778 million kilometers, it is the fifth planet as seen from the Sun. It runs around the Sun beyond the asteroid belt and has no visible solid surface. Due to its chemical composition it is - together with Saturn, Uranus and Neptune - one of the gas planets. These gas giants form the group of outer planets in the solar system and are also called Jupiter-like planets. In this group, Jupiter is the innermost planet and contains 2.5 times the mass of all other planets. Compared to the Earth, its mass is 320 times greater.

It is named after the Roman main god Jupiter. In Babylon he was also considered to be a star of kings with its golden yellow light.

In our scale model, we find Jupiter as a 7.5 centimeter sphere at a distance of 405 meters from the Sun.

Jupiter's diameter is about 12 times larger than Earth's diameter. It moves on an almost circular orbit around the Sun in 11 years, 315 days and 8 hours. Its axis of rotation is tilted by about 3.1 degrees compared to the vertical of its orbit around the Sun. In the solar system, Jupiter is the planet that has the fastest rotation around its axis.

As a gas planet, Jupiter does not rotate like a rigid body. The upper gas layers are in a so-called differential rotation. On the equator, the rotation period is 9h 50min 30s while in the pole regions it is extended to 9h 55min 41s.

Due to the high rotational speed, especially in the equator region, a high centrifugal force acts on the planet. As a result, the planet is slightly "stretched" at the equator and shows a distinct flattening. The deviation from the spherical shape can easily be seen in our telescopes. In numbers, the diameter between the North and South Poles is about 9300 kilometers smaller than the equatorial diameter - this corresponds to a difference of 70% of the Earth's diameter!

The main components of the outer gas layers are hydrogen and helium as well as very small amounts of methane and ammonia. At greater depths, the hydrogen changed into a special electrically conductive phase at high pressure and is called "metallic hydrogen".

The interior of the planet consists of 87% hydrogen and 10% helium. The remaining 3% contain other compounds such as methane and ammonia. It is believed that Jupiter has a rock/ice core with up to 20 Earth masses with a maximum diameter of 20,000 kilometers. The core temperature is estimated to 36,000 degrees Celsius. Overall, Jupiter's composition resembles that of the gas disk from which formed the Sun about 4.6 billion years ago.

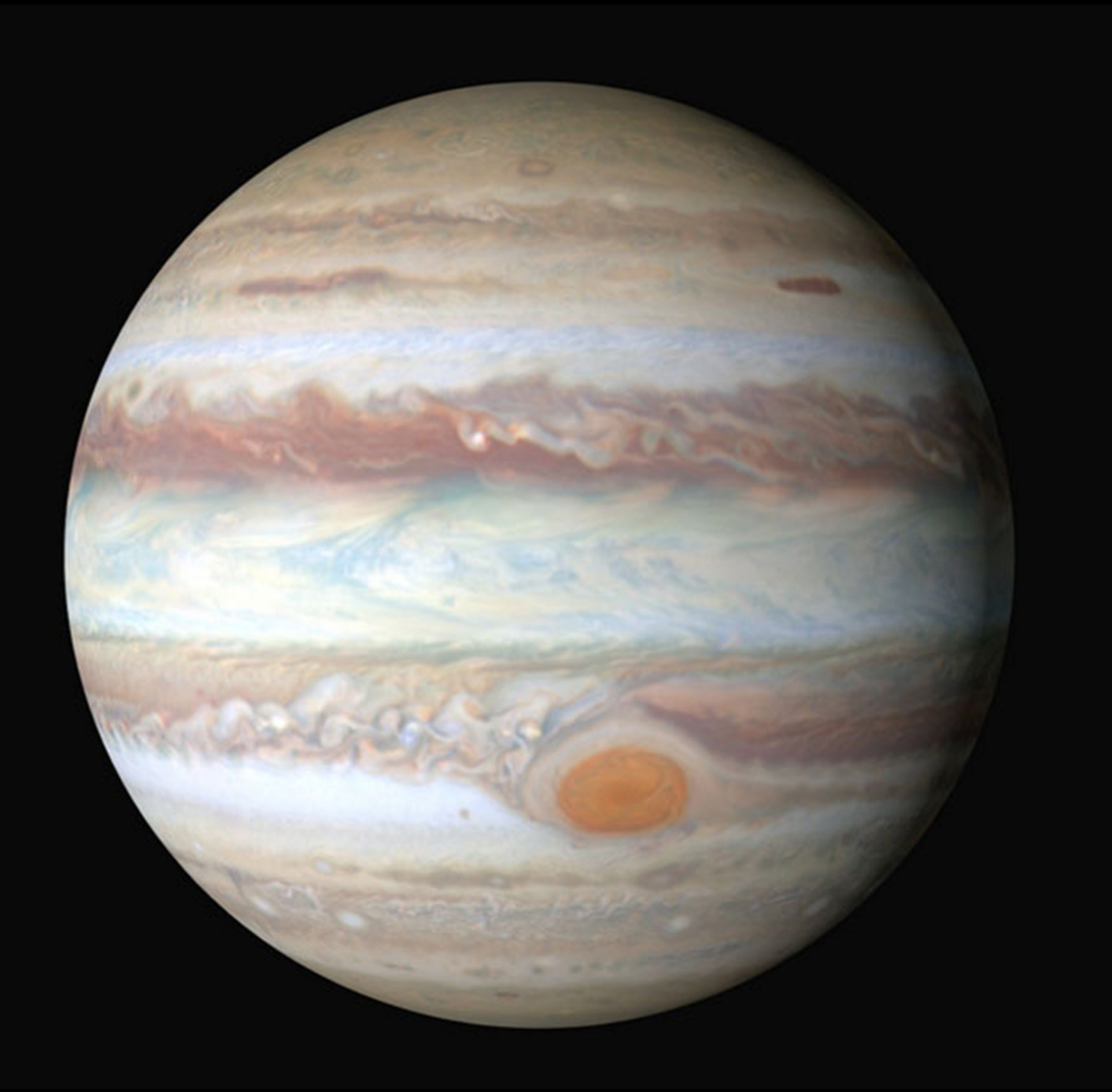


Fig. 30 - Bands and zones of the upper gas layers, Source: NASA

The outer gas layers are visible in the telescope in different colored bands and cloud swirls in white, red, orange, brown, yellow and partly also blue tones. The bands run around the planet at different latitudes in east-west direction. The lighter bands are called zones, the darker belts. The zones are cooler than the belts, denser, and contain ascending gases. It is assumed that its light color can be traced back to ammonia ice. The reason for the dark coloring of the belts is unsure so far, but they could contain phosphorus, sulphur and possibly carbon-hydrogens.

Apart from the light and dark cloud bands parallel to the equator, Jupiter's most striking feature is the so-called Great Red Spot (GRS). It is a unique structure in the solar system, a huge oval cyclone bigger than the Earth. It was first noticed in 1664 by the English natural scientist Robert Hooke. Since then it has undergone only slight changes, while on Earth such cloud vortices dissolve after a few weeks. Due to its size, the Great Red Spot is already clearly visible in amateur telescopes. Although its striking color is clearly redder than the surrounding area, it is not a deep, bright red, but fluctuates over the years around a brighter orange.

Jupiter has a very weakly pronounced ring system, which is not visible from the Earth. It was first photographed in 1979 by the space probe Voyager 1.

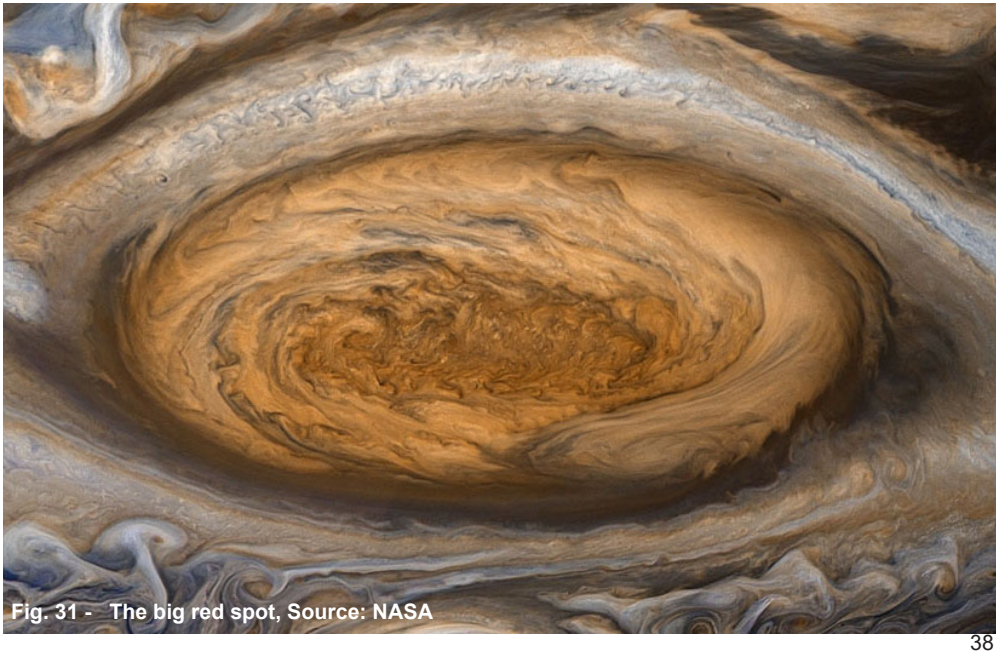


Fig. 31 - The big red spot, Source: NASA

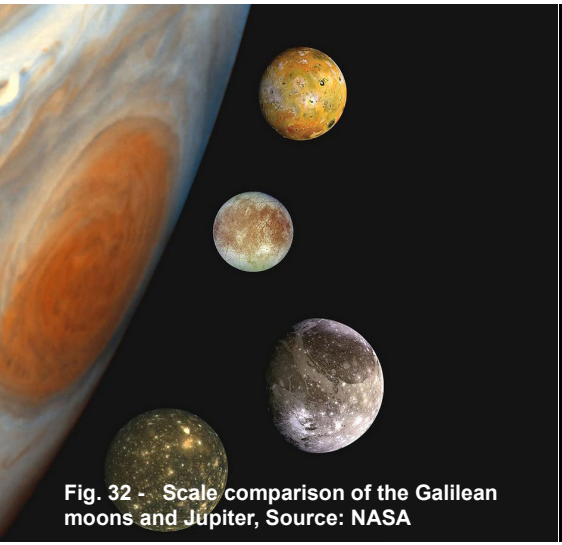


Fig. 32 - Scale comparison of the Galilean moons and Jupiter, Source: NASA

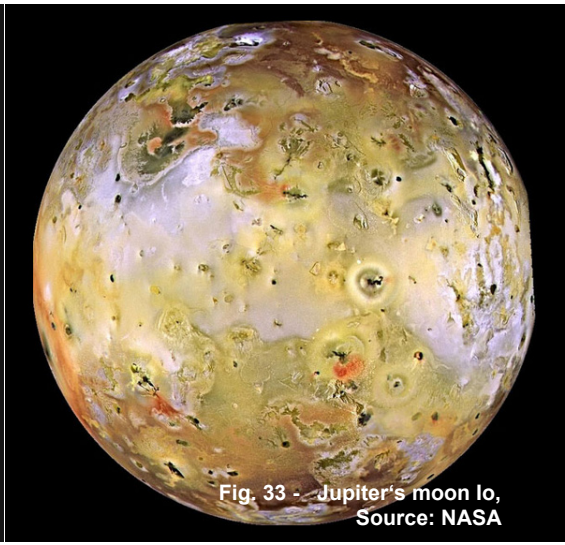


Fig. 33 - Jupiter's moon Io, Source: NASA

Jupiter and its moons

Jupiter owns 69 moons (status 2018). Most of them, however, are small rocks with a diameter of less than 10 kilometers and have only been discovered by space probes because they cannot be observed with earthbound telescopes.
The four so-called Galilean moons are the most important. They were discovered in 1610 by Galileo Galilei and underpinned the heliocentric view of the world of Copernicus. The names are Io, Europa, Ganymede and Callisto, the diameters are between 3122 and 5262 kilometers.

Io has a diameter of 3643 kilometers and orbits Jupiter at a distance of 421 600 kilometers. It consists of an iron core and an overlying shell. Tectonic processes cause the formation of mountains and valleys, while volcanoes constantly flood the surface with sulphur-containing lava. Io is the most geologically active body in the solar system. It is estimated that the complete surface will be completely restructured in a period of only 1000 years.

Europe has an iron core with a rocky mantle above. Over the mantle there is probably a 100 km deep ocean of water whose surface is frozen to a depth of 20 kilometers as ice crust. Europe's diameter is 3122 kilometers, orbiting Jupiter at a distance of 670,900 kilometers. The liquid ocean is - next to the planet Mars - a place where primitive life could exist.

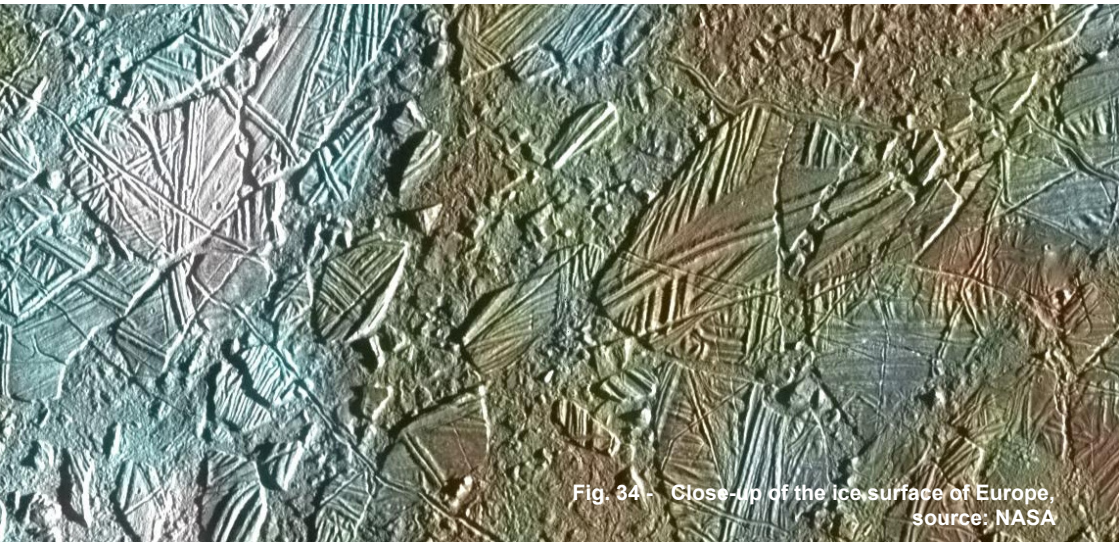


Fig. 34 - Close-up of the ice surface of Europe, source: NASA

Ganymede orbits Jupiter at a distance of almost 1.1 million kilometers. Its diameter is 5262 kilometers. This makes it the largest moon in the solar system. It consists of an iron core, a rocky mantle, an ice sheet and has a magnetic field.

Callisto has a diameter of 4821 kilometers and a distance of almost 1.9 million kilometers from Jupiter. It consists of a mixture of iron and stone and an ice crust. Also inside Callisto there are probably layers of liquid water. It is the darkest of the Galilean moons and its surface shows one of the highest crater densities in the solar system.

The four Galilean moons are already clearly visible in small amateur telescopes.

It is interesting from a historical point of view that the speed of light was determined for the first time by observations of the Jupiter moons. In 1676, Ole Rømer discovered that the observed orbit of the Jupiter moon Io shows a regular fluctuation depending on the distance of the Jupiter to Earth. From this he correctly concluded that light is spreading out at a finite speed. The value determined by him was already correct in the order of magnitude, but deviated by 30% from the actual value. The current value is exactly 299,792.458 kilometers per second. Up to Rømer's measurements, the propagation speed of light was regarded as infinitely fast.

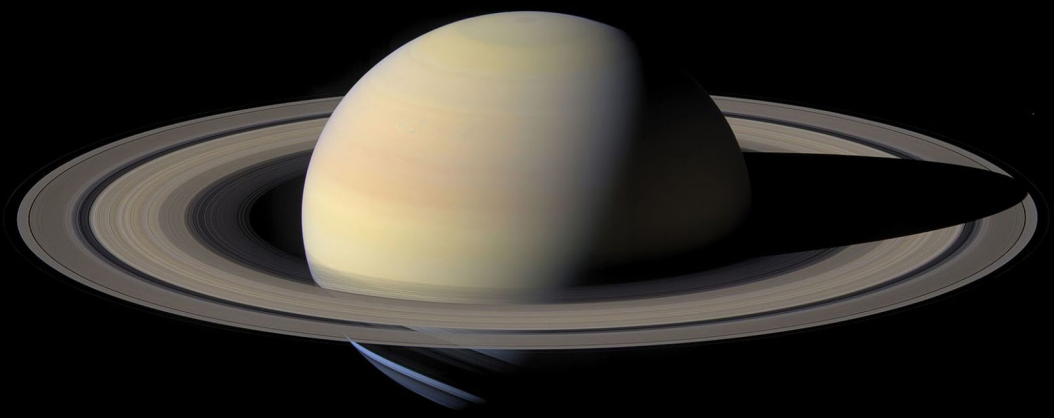


Fig. 35 - Saturn in natural colors, taken by the NASA spacecraft Cassini at a distance of 6.3 million kilometers, Source: NASA

SATURN

Saturn is certainly the most beautiful planet (except for our blue Earth, of course) in the solar system because of its large, visible ring system. It is the sixth planet of the solar system and with an equatorial diameter of about 120,500 kilometers (9.5 times the Earth's diameter) it is the second largest planet after Jupiter. With 95 Earth masses, however, it has only 30 % of the mass of Jupiter. The planet is named after the Roman god of wealth and harvest.

Saturn orbits the Sun at an average distance of 1.43 billion kilometers. It is the outermost planet that is easily visible to the naked eye and was therefore already known thousands of years before the invention of the telescope. This is where the solar system ended in ancient times. It is a gas planet like Jupiter, the uppermost layers contain about 93% hydrogen. Of all the planets in the solar system, Saturn has the lowest average density of only 0.69 g/cm³. Unlike all other bodies of the solar system, it would swim in water without sinking.

In our scaled model we find Saturn as a 6.4 centimeter sphere at a distance of 750 meters from the Sun.

Saturn needs about 29.5 years to circulate around the Sun, the length of the day is 10 hours and 14 minutes (sunrise to sunrise). Like Jupiter, it mainly consists of gas, the upper gas layers rotate differentially. The polar regions rotate about 25 minutes slower than equator regions.

The chemical composition - like that of Jupiter – mainly consists of hydrogen and helium, but in a different composition. The hydrogen content of about 93% of the mass is considerably higher; the helium content of under 7% is correspondingly lower than Jupiter's composition. There are also traces of methane, ammonia and other gases. While the atmosphere of Jupiter contains the elements hydrogen and helium in the same ratio as the Sun, the proportion of helium in Saturn is considerably lower. The rather detailed yellowish-brown upper gas layers contain mainly frozen ammonia crystals. Like Jupiter, Saturn also has a probably solid rock core inside with a mass of about 16 Earth masses at a temperature of about 11,700 degrees Celsius.

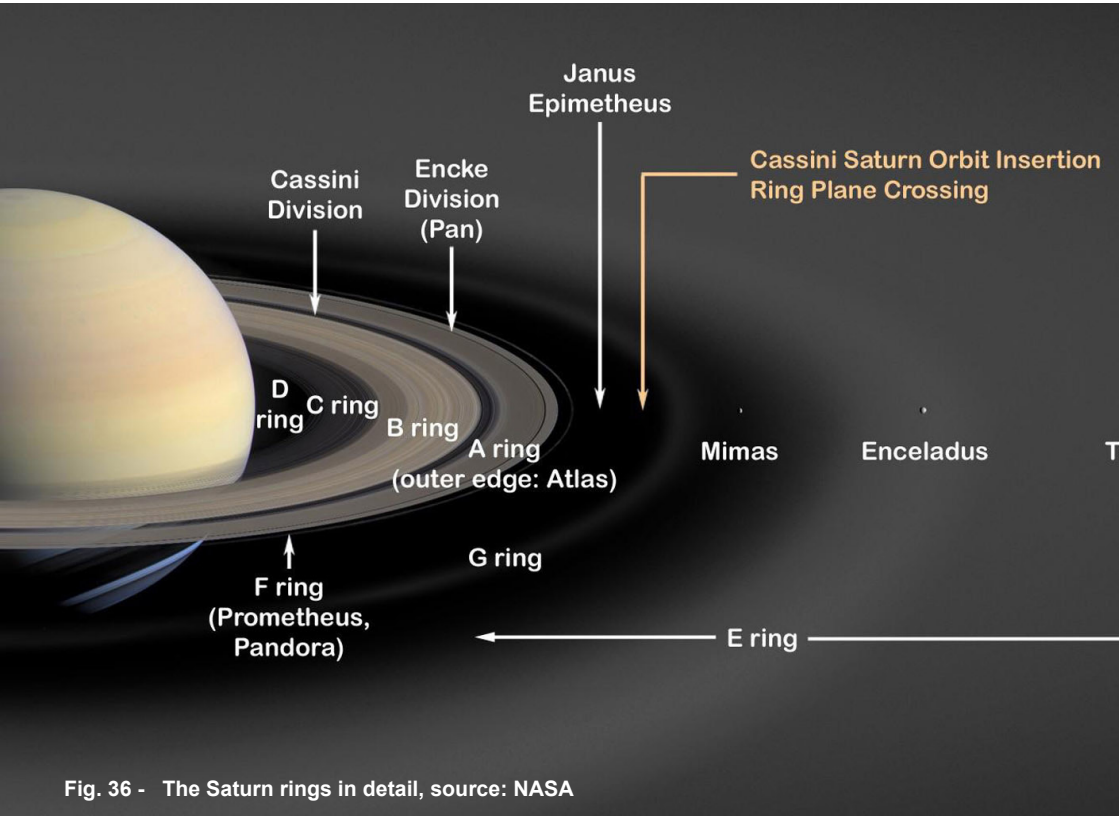


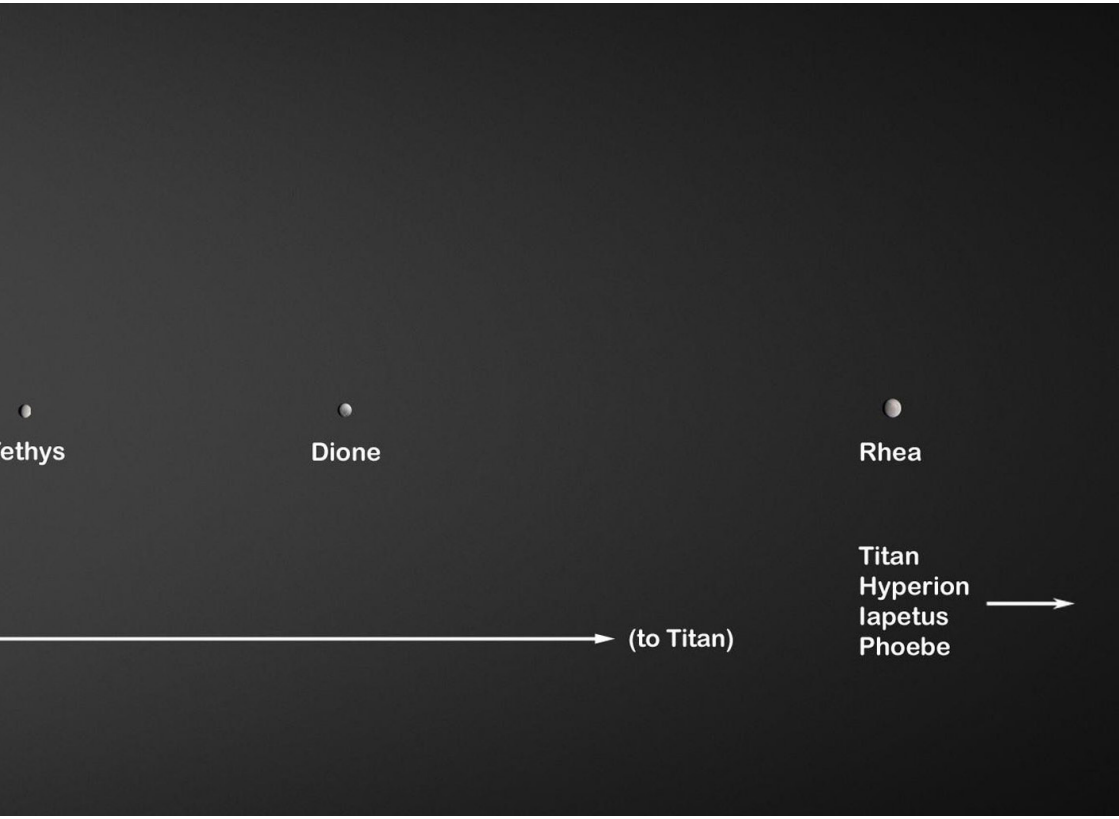
Fig. 36 - The Saturn rings in detail, source: NASA

The ring system of Saturn

Saturn surrounds an eye-catching ring system in its equatorial plane, which can be easily seen even in a small telescope. The ring system was discovered in 1610 by Galileo Galilei, who interpreted it as “handles”. Christiaan Huygens correctly described the rings 45 years later as a ring system. Giovanni Domenico Cassini was the first who supposed that the rings consist of small particles, and in 1675 he discovered the Cassini division which is named after him.

More than 100,000 individual rings with different compositions and color shades can be distinguished, which are clearly separated from each other by sharply defined gaps. The largest ring segments are called D-, C-, B-, A-, F-, G- and E-rings according to the order in which they are discovered.

The ring system has exceptional geometric dimensions. With a diameter of almost 1 million kilometers, it is only 100 meters thick on average. From the geometric dimensions, one can imagine Saturn rings as a single sheet of paper with the size of a football field - very large in diameter and extremely thin. The Saturn rings are not



a compact object, but consist of myriads of ice and rocks orbiting the Saturn. The particle size varies between the size of a pinhead and several meters.

There are various theories on the origin of Saturn rings. According to the theory proposed by Édouard Albert Roche back in the 19th century, the rings were created by a Saturn moon that had come so close to Saturn that it was torn apart by tidal forces. After a variation of this theory, the moon broke through a collision with a comet or another Saturn moon. The origin of Saturn rings has not been finally clarified up to now.

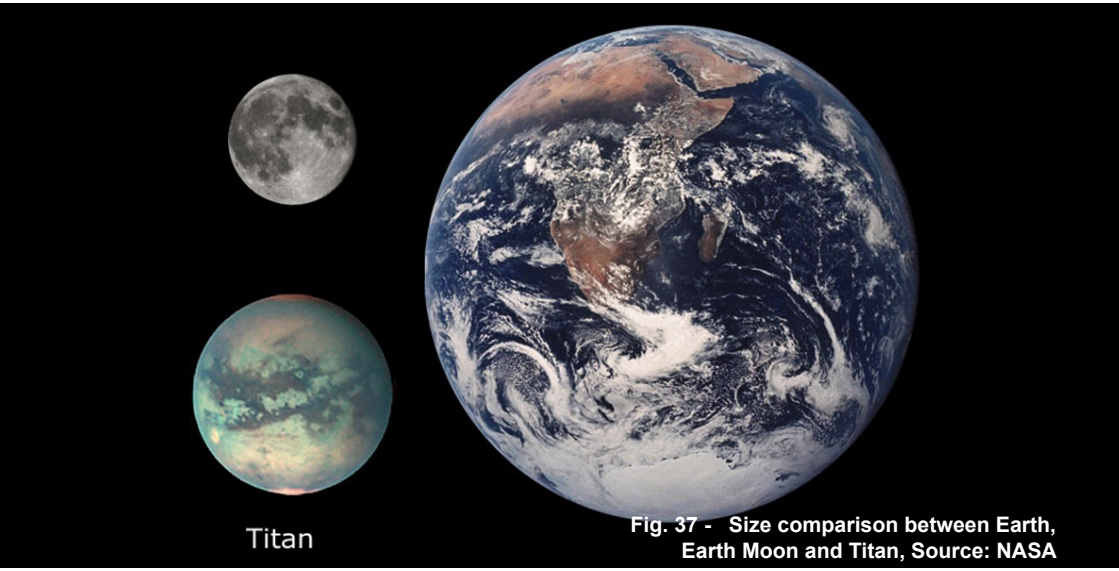


Fig. 37 - Size comparison between Earth, Earth Moon and Titan, Source: NASA

Saturn and its moons

Currently (as of 2018) Saturn has 62 moons, which are mostly irregular boulders of a few kilometers in diameter. The four larger moons Rhea, Dione, Tethys and Iapetus have diameters between 1050 km and 1530 km.

Very interesting are the small moons Janus and Epimetheus, which orbit the Saturn on two almost identical orbits. Every four years they come very close to each other and exchange their orbits around Saturn through their gravitational attraction. It is possible that there were similar moons a long time ago, which collided with each other and the Saturn rings emerged from the rubble.

The largest and most interesting Saturn moon is Titan. With a diameter of 5150 kilometers, it is the second largest moon in the solar system and the only one with its own dense atmosphere. It consists of nitrogen with a high methane content and generates a ground pressure of 1.5 bar (Earth = 1 bar). The atmosphere is opaque in visible light. Titan orbits Saturn at an average distance of 1.2 million kilometers and thus just outside Saturn's rings. It takes about 16 days for one orbit.

About half of the solid body of Titan consists of a shell of water ice and the other half of a core of silicate-like rocks. Thus, it must have a similar structure as the Jupiter moon Ganymede, Callisto and the Neptune moon Triton.

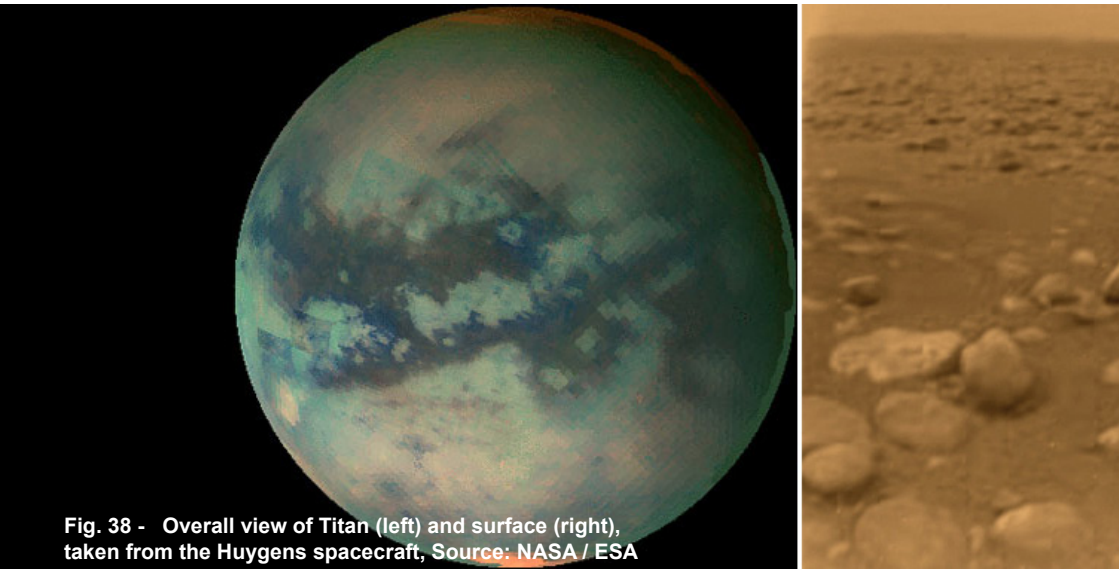


Fig. 38 - Overall view of Titan (left) and surface (right), taken from the Huygens spacecraft, Source: NASA / ESA

Titan's atmosphere deserves a special mention. It shows an intensive weather event with clouds of methane vapor and rain from methane droplets. Under the influence of the Sun's UV light, methane is transformed into complex organic molecules (no life), which turn the atmosphere into orange in visible light and make it hazy. The methane rain causes rivers on Titan's surface, which flow into huge lakes of liquid methane whose sizes vary with the seasons on Titan.

In January 2005 NASA succeeded in landing the Huygens space probe on the surface of Titan. Huygens was built by the European Space Agency (ESA). The probe was piggybacked to the NASA Saturn probe Cassini, which orbited Saturn for years. During the descent of Huygens through Titan's atmosphere and from its landing site, the probe sent data and images to Cassini for more than 3 hours, which then forwarded the data to Earth.

Titan could contain a key to understanding the origin of life on Earth. It is assumed that there was a similar atmosphere on the Earth and therefore similar conditions existed here. Since Saturn and its satellites are located far outside of the habitable zone, the emergence of life is unlikely, but precursors are not excluded. Further space missions to Titan are planned.

Fig. 39 - Size comparison between Uranus and Earth, Source: NASA

URANUS

Uranus is the seventh planet in the solar system as seen from the Sun. It orbits the Sun at an average distance of 2.9 billion kilometers and is classified as gas planet. Uranus requires 84 years for a complete orbit around the Sun and its mean length of day (Sunrise to Sunrise) is a little more than 17 hours. Uranus was discovered in 1781 by Friedrich Wilhelm Herschel, who was born in Hanover. The planet was unknown in ancient times. Its brightness is so low that it is barely visible to the naked eye.

Herschel was actually a military musician but also an autodidactic amateur astronomer and telescope designer. He became one of the most famous astronomers during his lifetime. Its home-made telescopes have been ordered worldwide. He discovered Uranus in his function as royal astronomer of the English royal family.

In Roman mythology, Uranus is the father of Saturn, who is Jupiter's father.

In our scale model, we find Uranus as a 2.7 centimeter sphere at a distance of just under 2 kilometers from the Sun.

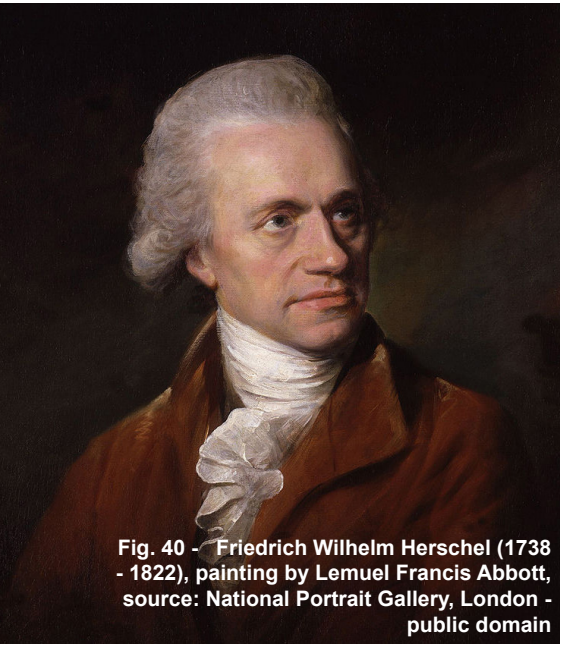


Fig. 40 - Friedrich Wilhelm Herschel (1738 - 1822), painting by Lemuel Francis Abbott, source: National Portrait Gallery, London - public domain

With a diameter of over 51,000 kilometers, Uranus is about four times as large as the Earth. Physically, Uranus is comparable to Neptune and, with about 14 Earth masses, it occupies fourth place in the mass ranking of plains in the solar system. In amateur telescopes, it appears almost point-shaped due to its great distance to Earth, but is noticeable due to its pale green/blueish color, which is due to about 3% methane in the upper gas layers. Besides methane, the upper gas layers mainly consist of hydrogen (approx. 82%) and helium (approx. 15%). Uranus presents itself as a very uniform planet without large storm systems and cloud bands like on Jupiter.

Under the dense, gaseous hydrogen-helium-methane shell, Uranus consists of partially liquefied gases, ice and possibly a small stone core, similar to Neptune. In contrast to the giant planets Jupiter and Saturn, Uranus and Neptune have a lower hydrogen and a higher helium content. Furthermore, the metallic hydrogen is missing in the atmosphere of Uranus and Neptune, because the mass of both planets is not sufficient to generate the necessary pressure inside.

In the core area, the temperature reaches 5000 degrees Celsius at a pressure of several million bar.

An absolute specialty in the solar system is the rotation axis of Uranus. In contrast to the other planets, the rotation axis is not nearly perpendicular to the orbital plane of the planet, but lies approximately in its orbital plane. While all planets - as an analogy - run around the Sun like children's spinning tops, Uranus rolls like a ball on its orbit.

During its orbit, the South Pole once points towards the Sun and a half orbit (42 years) later its North Pole. For observers on Uranus, it would be "day" without sunset for years on the Sun-facing hemisphere and "night" without sunrise for years on the Sun-averted hemisphere. A "normal" day/night cycle of 17 hours is only available at times when the equatorial plane points towards the Sun.

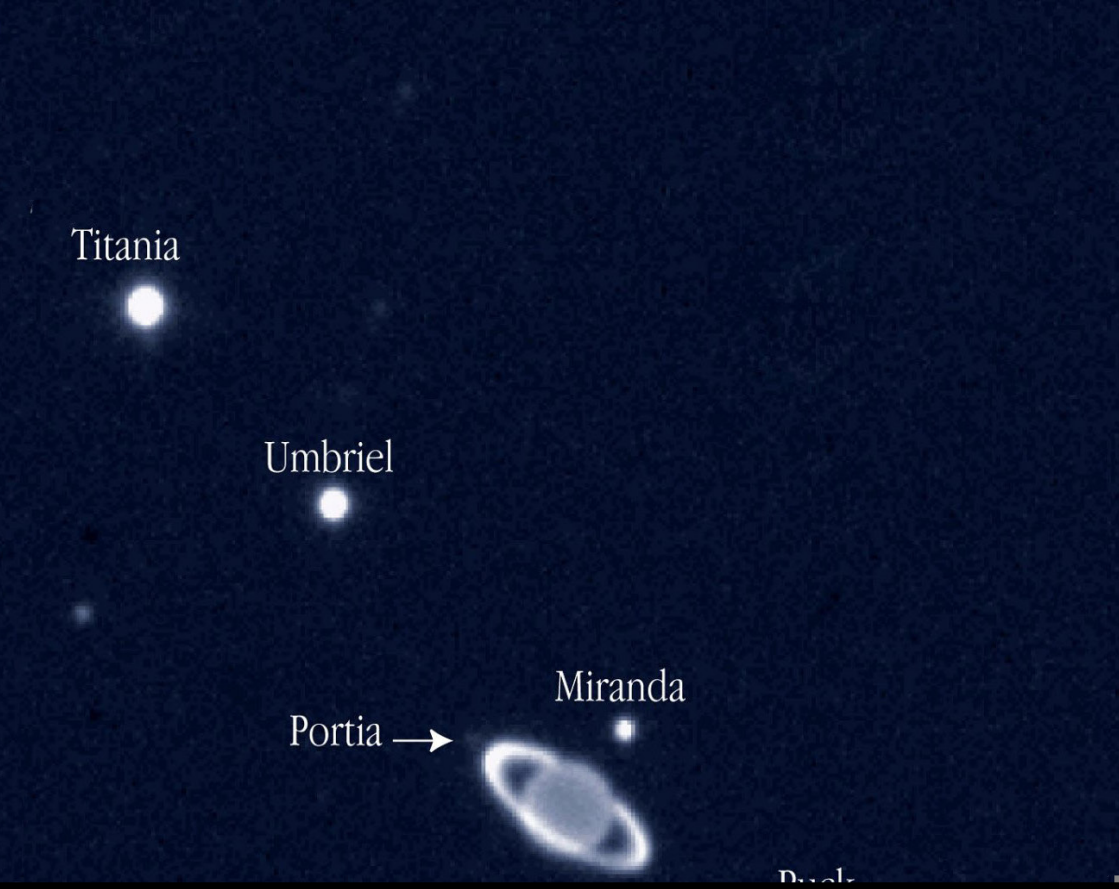


Fig. 41 - Uranus and some Uranus moons taken with a terrestrial telescope Source: ESO

The Ring System of Uranus

Uranus has a very fine but very dark system of several rings. It essentially consists of 13 thin individual rings with a width between 1 and 17,000 kilometers. The size and composition of the particles varies between pinhead sized dust and ice chunks up to 10 meters in diameter, much like the ring of Saturn. However, the total mass of the uranium rings is considerably less than that of the Saturn rings.

The ring system of Uranus was discovered on 10 March 1977 during the evaluation of measurement data from a Uranus observation. The first detailed photos were taken in 1986 by the spacecraft Voyager 2 and transmitted to Earth. Unlike in the past, they can nowadays be observed with Earthbound new large telescopes.

Uranus and its moons

As of 2018, 27 moons of Uranus are known. Their diameters range from 10 to 1600 kilometers. The five largest moons are Miranda, Ariel, Umbriel, Titania and Oberon. Its total mass amounts to only about 0.13% of the mass of the Earth's moon. The last two were discovered by Friedrich Wilhelm Herschel in 1787 and were named by his son, John Herschel, after characters from *Shakespeare's summer night's dream*.

Due to the low impact crater density, Ariel (diameter almost 1200 km) seems to have the youngest surface of the Uranus moons, while Umbriel (diameter also almost 1200 km) appears to be the one with the oldest surface. Miranda (diameter 480 kilometers) has canyons which are up to 20 kilometers deep with fault lines, terraced layers and a chaotic variation in age and characteristics of surfaces. According to a hypothesis, Miranda could have been completely destroyed by a massive impact a very long time ago and afterwards randomly reassembled.

Naming:

Uranus was unknown in antiquity and therefore nameless. His discoverer Herschel named it in honor of the English king George III Georgium Sidus - George's star. However, this name did not prevail and the planet was named Uranus after a proposal of the astronomer Bode 1850. In Roman mythology, Uranus is the father of Saturn, who is again the father of Jupiter.

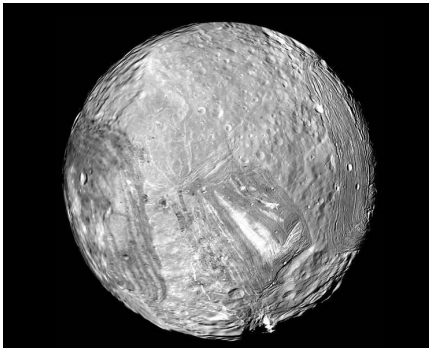


Fig. 42 - The Chaotic Uranus Moon Miranda, Source: NASA

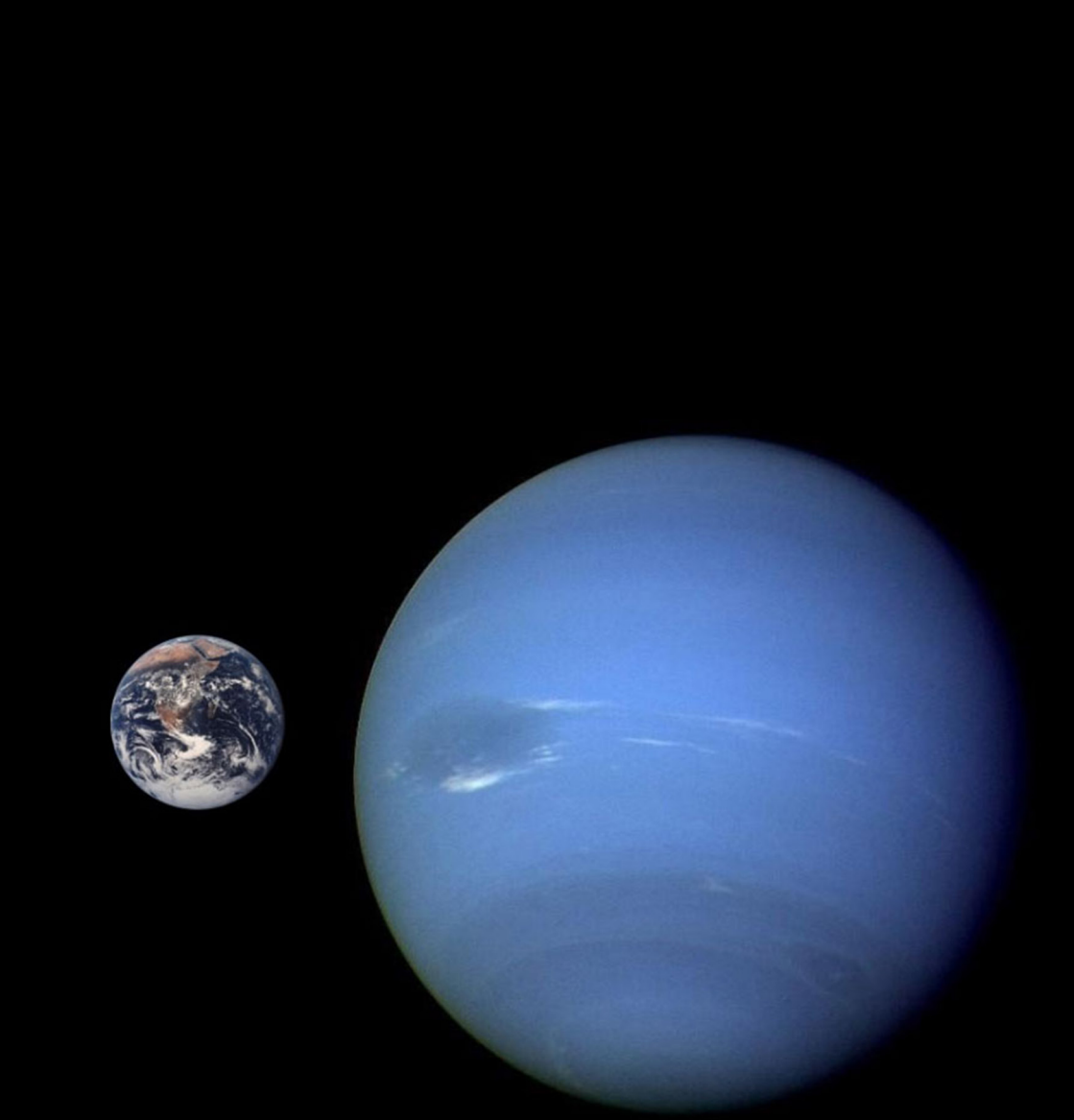


Fig. 43 - Size comparison between Neptune and Earth,
Source: NASA

NEPTUNE

With a diameter of 49,528 kilometers, Neptune is only marginally smaller than Uranus. Its orbit around the Sun is almost circular, with an average distance to the Sun of barely 4.5 billion kilometers. It takes nearly 165 years for the planet to surround the Sun once. Like all gas planets Neptune rotates very fast for its size, the length of day (sunrise to sunrise) is only 16 hours. Here – far away from the Sun - the temperature in the outer gas layers is only -200 degrees Celsius. Neptune is named after the Roman god of the sea and rivers.

In our scale model we find Neptune as a 2.6 centimeter sphere at a distance of 2.34 kilometers from the Sun.

In the outer part of the solar system, Neptune influences the orbits of many smaller bodies due to its relatively large mass. These bodies are called trans-Neptunian objects, which also include the dwarf planet Pluto since 2006.

With a diameter of just under 50,000 kilometers, Neptune belongs to the large gas planets. The upper gas layers mainly consist of water (80%) and helium (19%) with small amounts of methane. In amateur telescopes, the planet appears almost point-shaped like a fixed star and shows a distinctly bluish color, which is caused by methane, as by Uranus.

Like Uranus, Neptune probably has a rocky solid core with a total mass of about 1 to 1.5 times the Earth's mass. The temperature in its centre is about 7000 degrees Celsius and the pressure is several million bar (atmospheric pressure on Earth at sea level = 1 bar).

A difference between Neptune and Uranus is the extent of meteorological activity. When the Voyager 1 spacecraft passed Uranus in 1986, the upper gas layers were virtually unstructured, while Neptune showed remarkable weather phenomena during the approach of Voyager 2 in 1989. Long bright clouds resembling the cirrus clouds of the Earth and storm systems could be observed.

Neptune's Ring System

Neptune has a very fine ring system consisting of several rings. Like the rings of Uranus and Jupiter, they are unusually dark and contain a high proportion of microscopic dust, which could be caused by the impact of tiny meteorites on Neptune's moons. The various rings were named after astronomers who made significant contributions to Neptune's research.

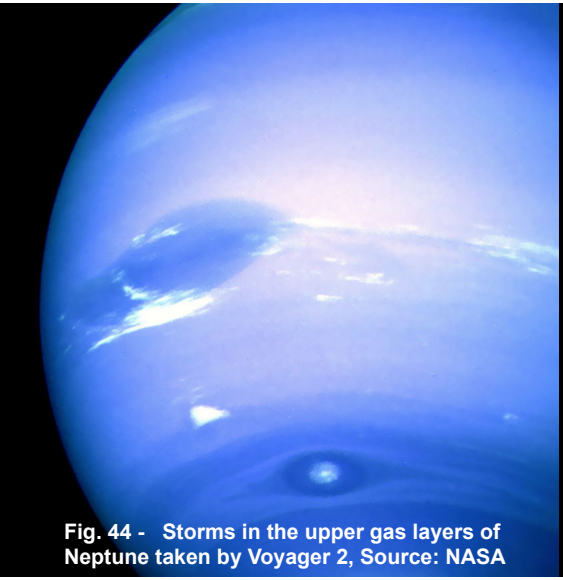


Fig. 44 - Storms in the upper gas layers of Neptune taken by Voyager 2, Source: NASA

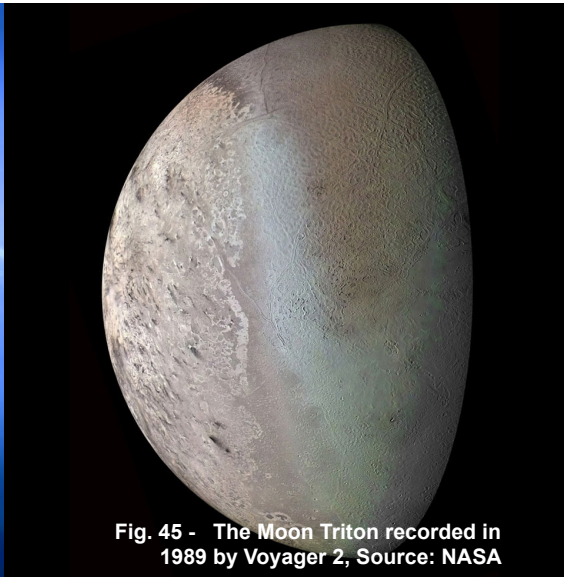


Fig. 45 - The Moon Triton recorded in 1989 by Voyager 2, Source: NASA

Neptune's Moons

Up to the year 2018, 14 Neptune moons are known. By far the largest of them is Triton with a diameter of 2701 kilometers.

Triton was discovered by William Lassell, a beer brewer and amateur astronomer, only 17 days after the discovery of Neptune on 10 October 1846. Because of its great closeness to Neptune, it rotates synchronous like the Moon of the Earth. Triton thus always shows with the same side to Neptune during his orbit. With -235 degrees Celsius, the moon has the coldest temperature ever measured in the solar system. Triton was named after a sea god from Greek mythology, who is also called the son of Poseidon.

Triton orbits Neptune on an almost perfectly circular orbit with a mean distance of 355,000 kilometers in just under 5.5 days. Contrary to most of the moons of the solar system, it runs around the planet retrograde (reverse), i.e. against its direction of rotation. This is extremely unusual and unique in the solar system for a moon of this size and with a relatively small distance to the planet. Triton has a high albedo of 0.76, which means that 76% of the Sunlight is reflected. This is due to the fact that a large part of its surface is covered with ice.

When NASA's Voyager 2 probe passed Neptune and its moons on August 25, 1989, it sent fascinating images of Triton's surface to Earth. They show a network of distortions where the ice crust has been deformed and broken, with only a few visible impact craters. This suggests that the moon is geologically very active, whereas the

traces of old impact craters have been “erased” by geological and/or atmospheric processes. Very surprising was the evidence of a type of volcanism, also known as cryovolcanism (cold or ice volcanism). Active geysers have been observed which emit a mixture of liquid nitrogen and entrained rock dust up to an altitude of 8 kilometers.

Discovering Neptune

Neptune was discovered on 23 September 1846 by the Berlin astronomer Johann Gottfried Galle. It was the first body of the solar system which was planned searched for and the discovery developed into a scientific detective novel.

Long-term observations of the orbit of Uranus showed disturbances, which could not be completely explained by the attraction of the Sun and the other planets (Mercury to Saturn). From these discrepancies, the astronomers concluded that there was a further large planet orbiting outside Uranus.

In addition, it is important to know that the planets like Uranus nearly appeared as points like stars in the telescopes of that time. One could only identify such a planet by determining the extremely slow movement of a star-like object in its orbit against the background of the farther away stars.

The telescopes at that time showed tens of millions of stars, so where in the sky should one look? In 1846, the French mathematician Urbain Le Verrier calculated a hypothetical position on which the unknown planet should be located. And indeed, Galle found the unknown planet Neptune only about 1 degree (corresponding to 2 full moon diameters) next to the position calculated by Le Verrier. That was an incredible computing effort without the support of calculators or computers, just with pencil on paper.

Pluto, which is currently no longer defined as a planet but as a dwarf planet, was also searched for due to further apparent deviations of the Uranus and Neptune orbits and then discovered in 1930. However, the flyby of Voyager 2 at Neptune showed that the Neptune mass was overestimated by 0.5% and there were no unobserved discrepancies in the orbit of Uranus and Neptune. The discovery of Pluto was therefore purely coincidental. After the discovery of other bodies beyond the Neptune orbit (so-called trans-Neptunian objects), their orbits could provide an indication of another planet far beyond the Neptune orbit.

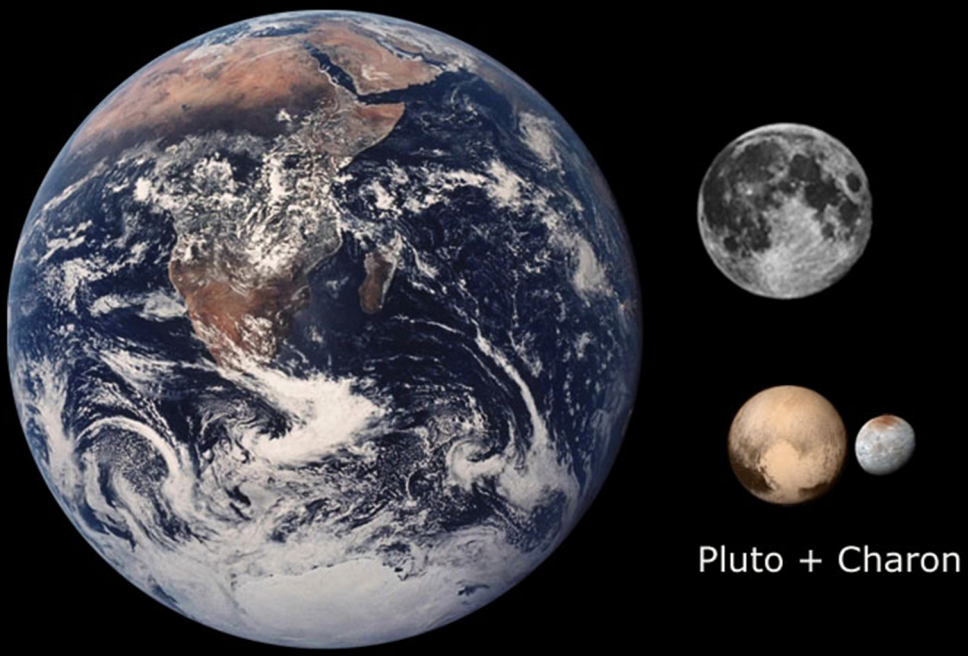


Fig. 46 - Size comparison between Earth, Earth Moon, Pluto and Charon, Source: NASA

THE DWARF PLANET PLUTO

Pluto no longer belongs to the Rooisand's model of the solar system. Since 2006 it is officially no longer classified as a planet, but assigned to a new class of objects in the solar system, the dwarf planets. Nevertheless, he should find a brief mention in this accompanying text.

Pluto is named after the Roman god of the underworld, Charon the ferryman who, in Greek mythology, takes the deceased across the river into the realm of the dead god Pluto.

The decision to create a new class of objects was made by the International Astronomical Union (IAU). The IAU - a non-governmental organization founded in Paris in 1919 - is made up of professional astronomers from 86 countries around the world. Among other things, it is also responsible for the official naming of objects of the solar system as well as craters, mountains and other surface structures on the planets and their moons.

The decision to "downgrade" Pluto to a dwarf planet has been long discussed controversially. The discussion about whether Pluto even deserves the name "Planet" began earlier, when, in addition to its highly elliptical and inclined orbit, its small size of 2374 kilometers in diameter was discovered. Pluto's orbit around the Sun is so eccentric that it sometimes comes closer to the Sun than the planet Neptune.

In addition, since 1998 astronomers have discovered many other objects outside the Neptunian orbit, some of them are even larger than Pluto. They are called trans-Neptunian objects, abbreviated TNOs. Some of these objects have extremely elliptical orbits around the Sun, which are also strongly inclined towards the orbit plane of the other planetary orbits. This region in the solar system is known as the Kuiper Belt and it is believed that about 70,000 objects with a diameter of more than 100 kilometers and many smaller objects can be found out there. In principle, it could be a second asteroid belt lying outside the Neptune orbit.

In our scale model, Pluto would be found as a 1 mm sphere at a distance of 3,000 meters from the Sun.

Pluto has a solid surface of frozen gases and ice. Therefore, with a diameter of only 2374 kilometers, it has a mean density of only 1.9 g/cm³. The length of day is 6.4 days. Pluto's average distance from the Sun is 5.9 billion kilometers. Pluto therefore needs almost 248 years for a complete surrounding of the Sun. The mean surface temperature is -230 degrees Celsius.

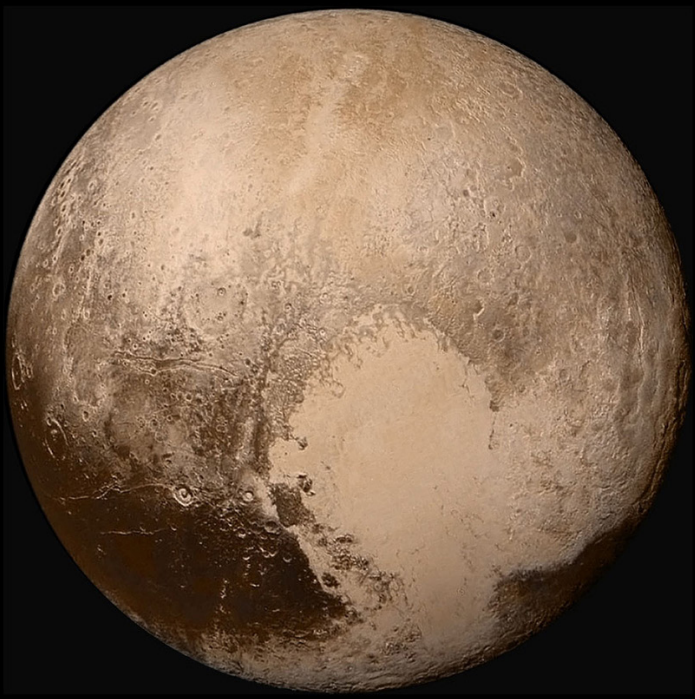


Fig. 47 - View of the northern polar area of Pluto taken by the NASA New Horizons spacecraft on July 14, 2015 from a distance of approximately 450,000 km, source: NASA

Fig. 48 - Pluto‘s Great Moon Charon, Source: NASA

Fig. 49 - IAU conference on the status of Pluto in 2006

Pluto has five known moons whose orbits are approximately circular. Charon, with a diameter of 1210 kilometers, is a relatively large moon - compared to Pluto - so it is sometimes referred to as the “double system Pluto-Charon”. Charon is the innermost moon and orbits Pluto at an average distance of only 20,000 kilometers. While the Earth’s Moon is in a synchronous rotation around the Earth (i.e. it always points with the same side to the Earth), the Pluto-Charon system is in a double synchronous rotation. The rotation of both bodies was slowed down by tidal forces, so that Pluto and Charon always look at each other with the same side. An observer on Pluto only sees one side of Charon and vice versa. The other four smaller moons have sizes below 100 kilometers and are of irregular shape.

In 2006, just as Pluto was being deprived of its planet status, NASA launched the New Horizon space probe to explore the planet. The voyage time was nearly 9.5 years and New Horizons flew through the Pluto-Charon system on July 14, 2015 at a distance of only 12,500 kilometers from the surface of Pluto. The spacecraft transmitted a large number of photos and measurements of many physical data, which enormously expanded the knowledge, because from earthbound observations only little was known about Pluto and Charon due to the great distance to Earth.

Fig. 50 - The great comet Donati in 1858 about Venice, public domain

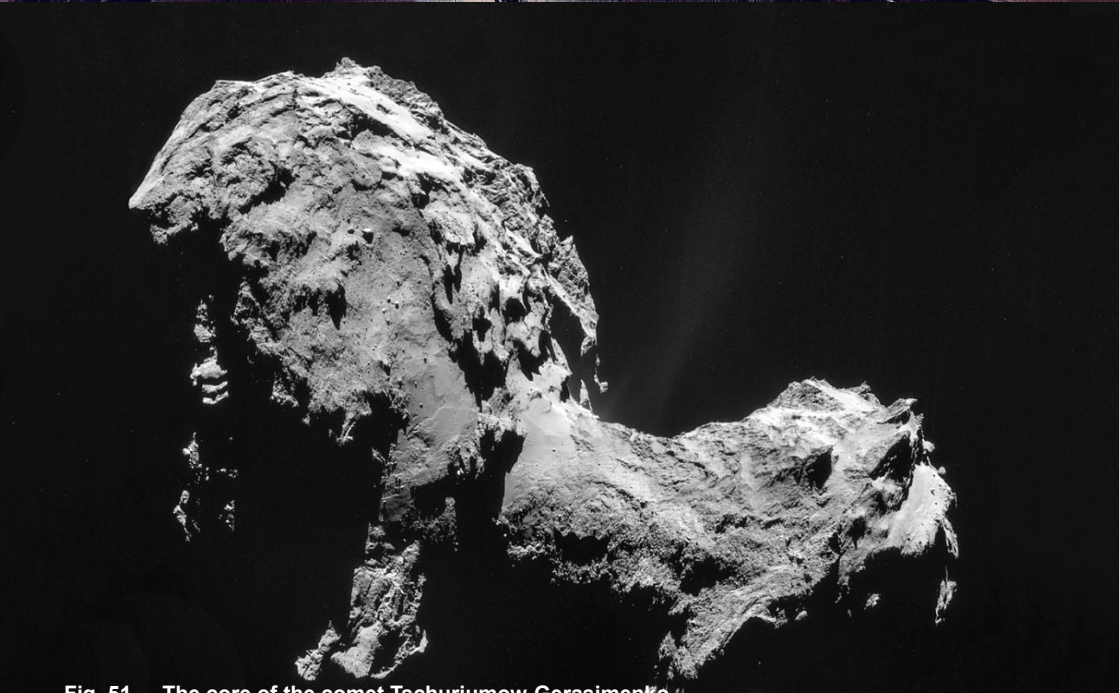


Fig. 51 - The core of the comet Tschurjumow-Gerasimenko, taken from the spacecraft Rosetta, Source: ESA

COMETS AND THE OORT CLOUD

Comets are generally referred to as tail stars, because the translation derived from ancient Greek means “hair star”.

In the Middle Ages, comets were regarded as bad luck messengers for coming bad nourishments, outbreak of wars, epidemics of disease and other adversity, because comets became visible in the sky without warning and disappeared just as quickly after a short time without a trace. The picture on the top left shows the big comet Donati in 1858 over Venice

Today we know that a large number of comets belong to our solar system. The fact that they appear so suddenly in the sky is due to their extremely elliptical orbits around the Sun and most of the time they are very far away from Sun and Earth on their orbit. There, far out in the solar system, they are so weak that they cannot be observed with telescopes.

Compared to the planets they are very, very small celestial bodies of mostly only a few kilometers diameter, as well as of very irregular shape and dark surface.

The picture on the bottom left shows the core of the comet Churyumov-Gerasimenko, photographed by the space probe Rosetta (ESA)

Like asteroids, comets are remnants from the time the Sun was formed and consist of ice, dust and loose rocks. They were formed in the outer, cold areas of the solar system (mostly far beyond the Neptune orbit), where the abundant hydrogen and carbon compounds condensed to ice. In the middle of the last century, the American astronomer Fred Whipple described them as “big dirty snowballs”.

If comets come into the vicinity of the Sun, the ice is melted due to the increased heat radiation and the comet core is surrounded by a diffuse, foggy shell called coma. Melting the ice releases large amounts of dust, chemical molecules and compounds. The diameter of the coma can easily reach several million kilometers. The most conspicuous characteristic, however, is the tail of the comet. It develops only in the shortest distance of the comet to the Sun, but can reach a length up to several hundred million kilometers depending of the activity and distance to the Sun.

The tail arises when the components of the coma are practically “blown away” by radiation pressure and the so-called solar wind (a permanent particle flow of the Sun from electrons and protons, see also the section on the Sun). More precisely, however, two tails are formed.

The Type 1 tail is a narrow, elongated tail consisting essentially of chemical molecules and is also called plasma tail. It is often of a clear blue-green color.

The Type 2 tail is a diffuse, slightly curved tail whose main constituents are the smallest dust particles. It is yellowish in color because of the reflected sunlight and is also called dust tail.
The figure above shows the two tail types of the comet Hale Bopp in 1995 (NASA)
The orbits of comets around the Sun vary greatly between a few years (short-period comets) and many millennia (long-period comets).

The most famous is certainly Halley’s comet. It is named after the mathematician and astronomer Edmond Halley (1656-1742). While the appearance of comets was considered unpredictable until this time, Halley assumed in 1705 that the comet observed by Saxon farmer and astronomer Christoph Arnold in 1682 must have been identical to earlier comet sightings in 1531 and 1607. From the earlier observations he calculated a solar orbit with an average period of 76 years and predicted the comet’s return for 1758, which actually happened. The comet was not named after its first discoverer, but the astronomer who was the first to calculate a comet’s orbit.

Fig. 52 - The two types of potholes of comet Hale Bopp in 1995, Source: NASA

Most recently, Halley was near the Earth in 1986, when he was also the target of five space probes of the ESA, Japan and the Soviet Union in partial international coordination. With his orbit period of 76 years, it will not be visible again from Earth until 2061.

With every rotation, comets in the vicinity of the Sun lose mass, i.e. they slowly dissolve in long periods of time. For the Halley comet, the estimated mass loss is 50 tons per second near the Sun. These dust particles are distributed along the comet's path around the Sun. If the Earth crosses the comet's path on orbit around the Sun, we can observe more and more shooting stars in the night sky.

It's the dust particles that burn up in the Earth's atmosphere. Residual material from Halley's comet is responsible for two meteor streams called Orionids and Eta aquariids. The better known meteor current of the Perseids is due to the short period comet Swift-Tuttle. It has an orbital period of 133 years, its minimum distance to the Sun is about 150 million kilometers, the most remote point of its elliptical orbit lies at a distance of almost 7.5 billion kilometers, far outside the Neptune orbit.

Fig. 53 - The nucleus of the comet Halley, taken from the ESA spacecraft Giotto, Source: ESA

Fig. 54 - Artistic representation of the Oort cloud, Source: NASA

THE OORT CLOUD

Where do the comets come from? In the middle of the last century, the Dutch astronomer J. H. Oort put forward the theory that there had to be a hypothetical collection of protocomets that encircle the solar system in a spherical form. Oort based his hypothesis on the investigation of very long-periodic comet trajectories and on the consideration that these comets cannot come from the known regions of the solar system. Moreover, in the long period of time that has elapsed since the formation of the solar system, all comets should have dissolved. So there must be a reservoir of “fresh” comets.

According to today’s common understanding, the Oort Cloud consists of millions of rock, dust and ice bodies of different sizes, which were left over from the formation of the solar system and did not form into large planets. They are called planetesimals. To this day, however, the Oort cloud could not be detected by observations because of its very large distance to the Sun.

However, the direct investigation of comet material is of great importance for the understanding of the origin of our solar system. Comets consist of almost unadulterated primordial matter from the time of the origin of the Sun system. For example, there have been and still are planned some space missions to explore comets.

The first photos of an outgassing comet showed the core of the comet Halley and were taken in 1986 by the ESA’s space probe Giotto (left picture, ESA).

From 2014 to 2016, ESA’s Rosetta probe orbited the comet Churjumow-Gerasimenko and in 2016 even placed a small landing unit softly on top of the comet core, which was only able to transmit data for a short time due to energy problems.

Nevertheless, Rosetta was a great success because this was the first landing and investigation of one of these ancient bodies consisting of ice, dust and organic compounds.

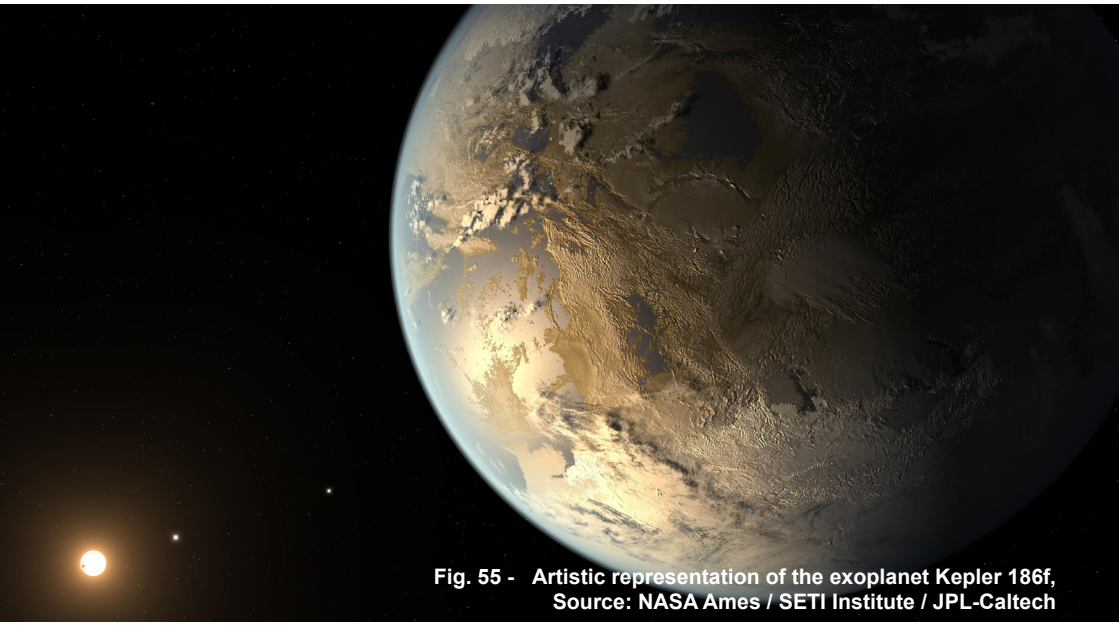


Fig. 55 - Artistic representation of the exoplanet Kepler 186f, Source: NASA Ames / SETI Institute / JPL-Caltech

EXOPLANETS

Exoplanets or extrasolar planets are large planetary-like objects that are on orbits around other stars. Extrasolar planets therefore do not belong to the solar system, but to another planetary system.

Until 1995, astronomers did not know whether there were planetary systems around other stars in our galaxy or whether our solar system might be unique, which astronomers did not expect. However, no exoplanets had been detected until 1995. This was due to the fact that these objects, in contrast to the star they orbit around, are very weak are overshadowed by the light of the central star. In addition, the angular resolution of earthbound telescopes was not sufficient to separate two objects so close together with such a large difference in brightness as a planet and its star.

The first definitive discovery of an exoplanet in orbit around a star similar to the Sun was made in 1995 by Swiss astronomers using the so-called radial velocity method. The planet 51 Pegasi b orbits in only 4.2 days around the fixed star 51 Pegasi, which is 40 light years away from Earth and has a mass of almost 0.5 Jupiter.

Today there are mainly three different methods for the discovery of exoplanets, but they are not discussed here.

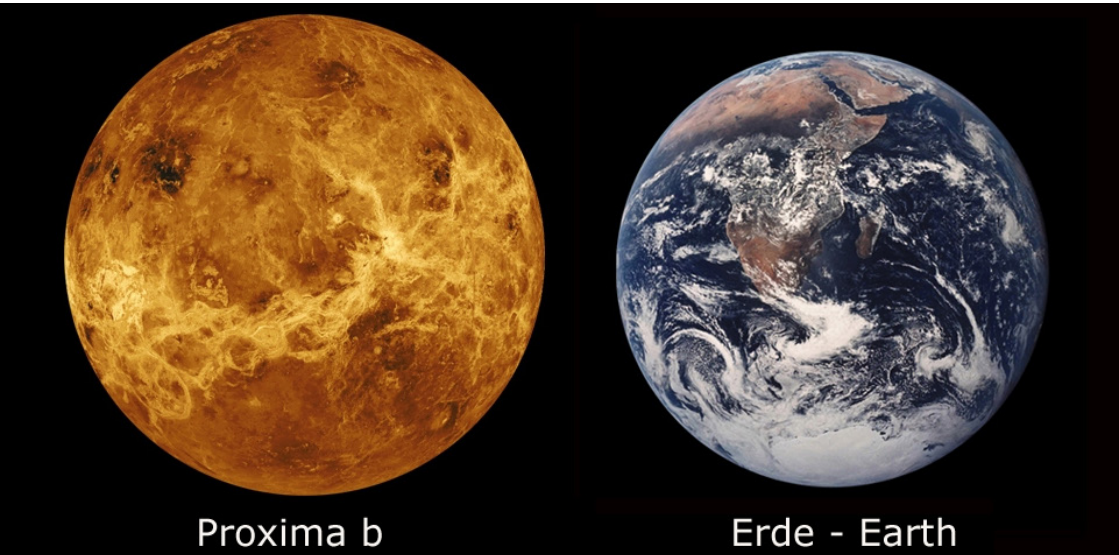


Fig. 56 - Scale comparison between Proxima b and Earth, Source: NASA / W. Paech

As of March 2018, 3743 exoplanets are known, which can be assigned to 2794 fixed stars. 625 multiplanetary systems have two to seven verified planets. Many of these exoplanets are very large (several Jupiter masses) others have very narrow orbits around the central star, so that their surfaces are molten. However, there are also Earth-like rocky planets that orbit their central stars in a so-called habitable zone. This habitable zone is a distance range in which a planet must be located from its central star, so that water can be permanently in liquid form as a prerequisite for Earth-like life on the surface.

A big surprise in 2016 was the discovery of an exoplanet orbiting the star Proxima Centauri in a habitable zone. Proxima Centauri is the closest fixed star to our solar system. It is a so-called red dwarf star, with significantly less mass (12% of the Sun) and less luminosity than our Sun.

Proxima is a member of a triple star system, consisting of two main stars which are very similar to our Sun in size, colour and temperature. The exoplanet, called Proxima b, orbits the red dwarf star at a mean distance of 7 million kilometres in only 11.2 days. Its mass is estimated to 1.3 Earth masses. The discovery is important because of the relative proximity of the exoplanet, as further earthbound investigations are facilitated.

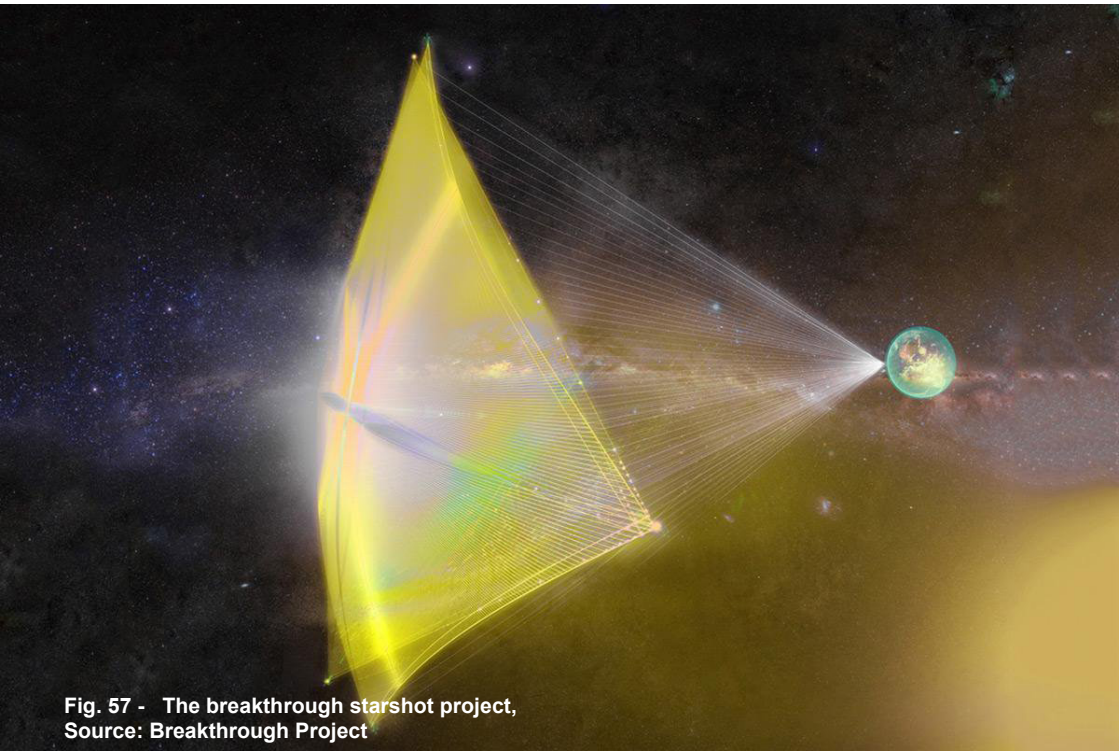


Fig. 57 - The breakthrough starshot project, Source: Breakthrough Project

The Breakthrough Starshot Project

The aim of the project is to develop a miniature space probe with the size of an electronic microchip and to send it on its way to Proxima b. The chip should not be larger than a stamp and weigh only a few grams. It should contain a computer, energy source, camera, receiver and a transmitter and be coupled to a solar panel several square meters in size. This solar panel is to be “bombarded” with extremely powerful laser beams from Earth, which will serve as propulsion and accelerate the probe to 20% of the speed of light in a short time.
The initiators of starshot estimate the development time to be20 years and the travel time also to about 20 years plus the necessary running time of the radio signals back to Earth. The project was founded in April 2016 by financier Yuri Milner (a Russian-born American multi-billionaire) and the British astrophysicist Stephen Hawking, who died in 2018. Also in the executive management is Facebook founder Marc Zuckerberg. The project will initially be financed with a sum of 100 million dollars, which will come from Yuri Milner.

What sounds like science fiction at first is technically “conceivable” today. In order to really implement the project, however, major breakthroughs are required in many

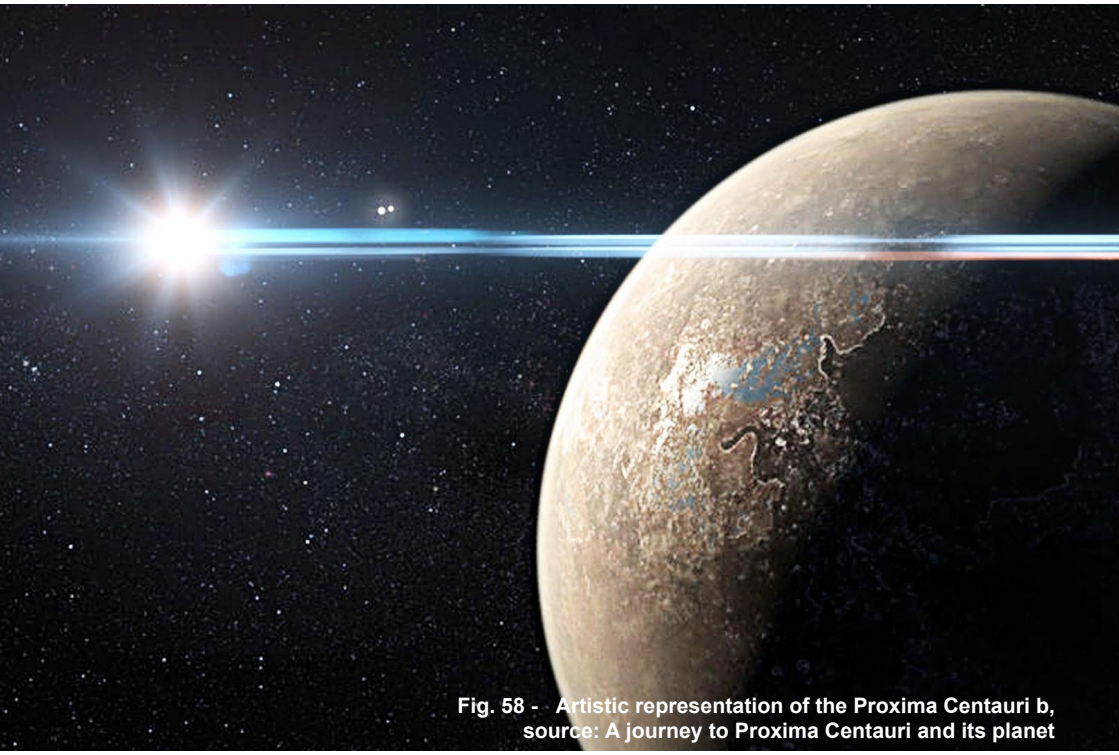


Fig. 58 - Artistic representation of the Proxima Centauri b, source: A journey to Proxima Centauri and its planet

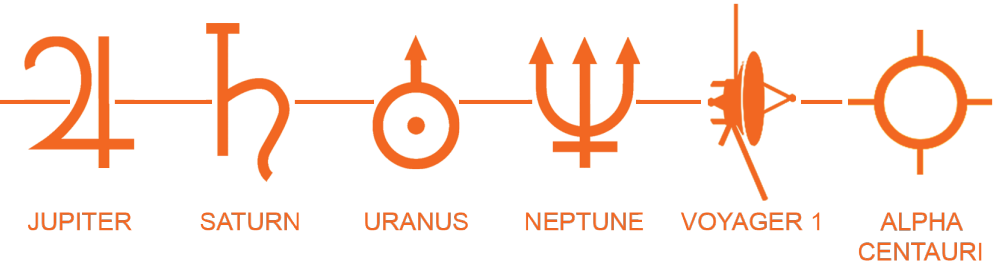
technical areas and also in materials development, since the necessary techniques and materials are not yet available today. And the initial capital of $100 million will certainly not be enough to make the project a reality.

The current observation technique has not yet been developed to such an extent that observations of such Earth-like exoplanets allow us to say something about the possible presence of atmospheres or their chemical composition.

However, great hopes are being pinned on new and larger space telescopes and the new large earthbound telescope, the Extremely Large Telescope (ELT) with a mirror diameter of just under 40 meters, the construction began in Chile in 2017.

A second blue Earth with large water areas has not yet been found (status 2018).

SUN MERCURY VENUS EARTH MOON MARS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