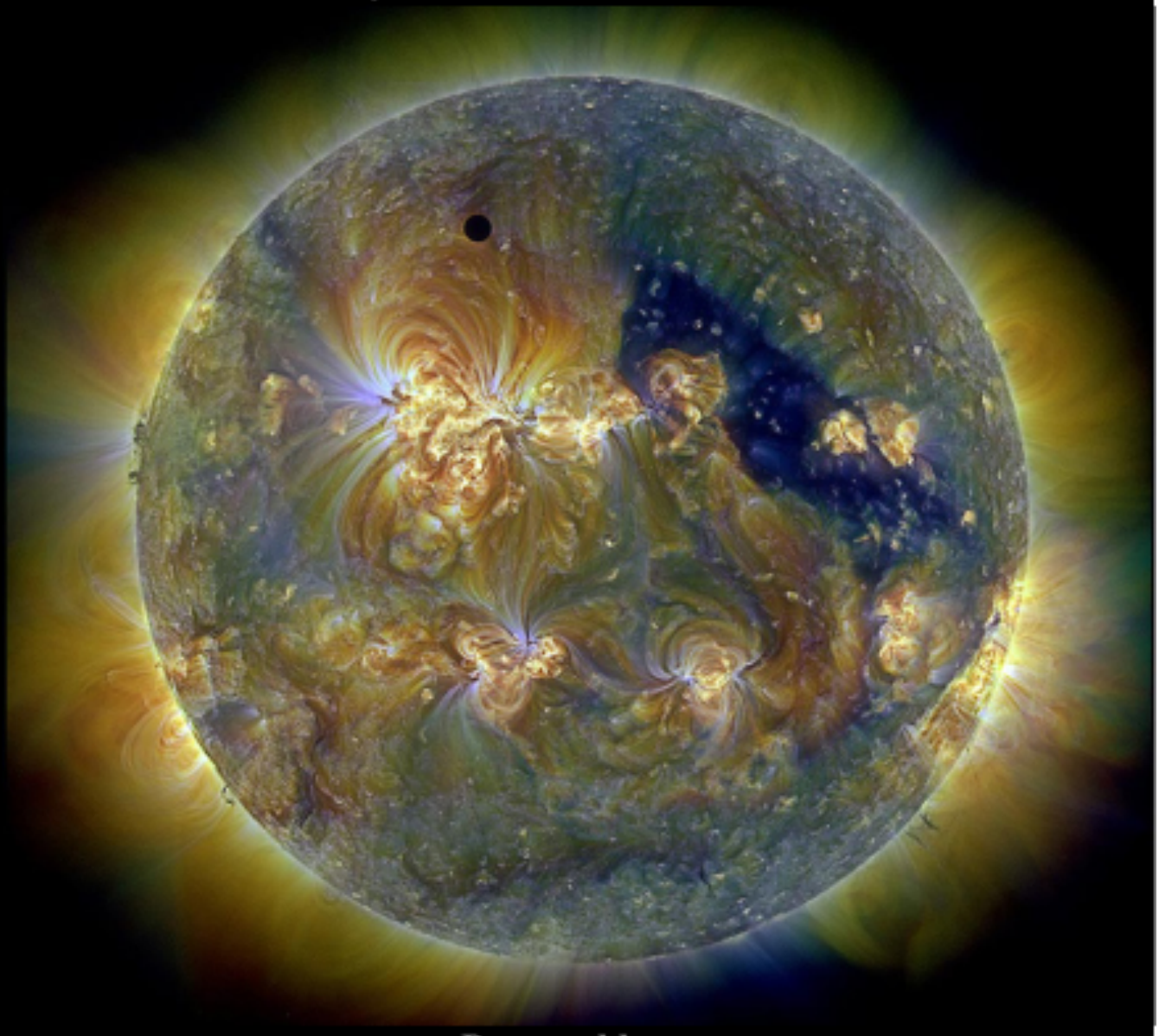
Year of the Solar System:
New Worlds
New Discoveries

# Our Solar System – Ancient Worlds, New Discoveries




Prepared by
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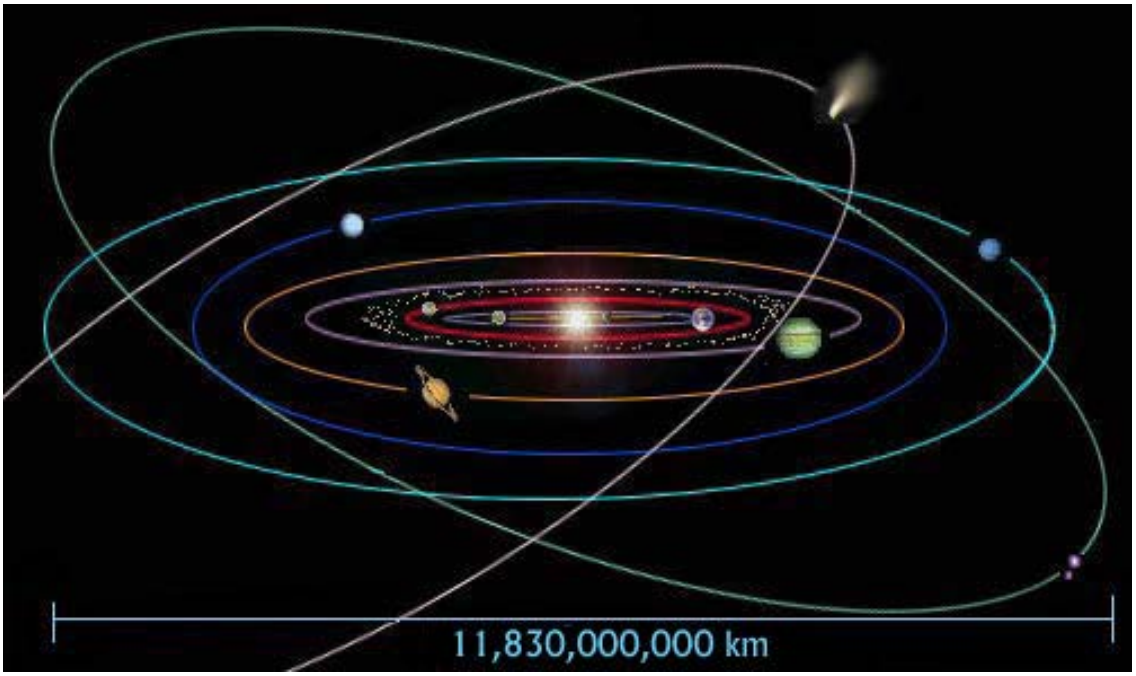



This graphic of the solar system was made using real images of the planets and comet Hale-Bopp. It is **not** to scale! To show a scale model of the solar system with the Sun being 1cm would require about 64 meters of paper! *Image credit: Maggie Mosetti, NASA*

This book was produced to commemorate the Year of the Solar System (2011-2013, a martian year), initiated by NASA. See http://solarsystem.nasa.gov/yss.

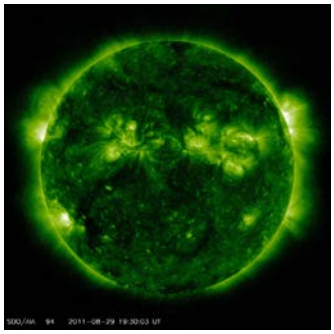
Many images and captions have been adapted from NASA's "From Earth to the Solar System" (FETTSS) image collection. See http://fettss.arc.nasa.gov/. Additional imagery and captions compiled by Deborah Scherrer, Stanford University, California, USA.

*Special thanks to the people of Suntrek (www.suntrek.org,) who helped with the final editing and allowed me to use Alphonse Sterling's awesome photograph of a solar eclipse!*

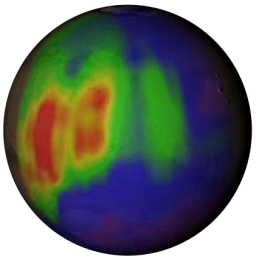

*Cover Images: Solar System: NASA/JPL; YSS logo: NASA; Sun: Venus Transit from NASA SDO/AIA*

# Table of Contents

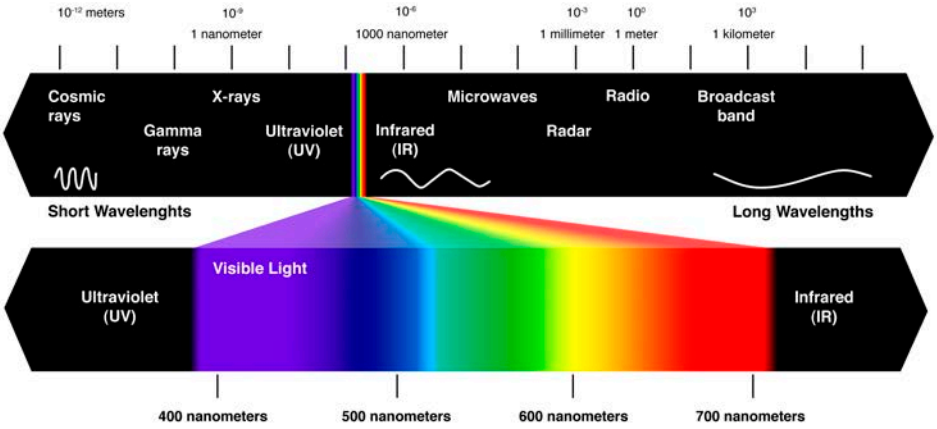
*Getting Started*



## Why Is the Sun Green and Mars Blue?



Human eyes see only visible light. Visible light is made up of all the colors of the rainbow (sometimes labeled red, orange, yellow, green, blue, violet) which, when combined, look white to our eyes. But there are many other, invisible forms of light, i.e. the electromagnetic spectrum – radio, microwaves, infrared, ultraviolet, X-rays, gamma rays. The various parts of the electromagnetic spectrum are differentiated by their wavelengths – radio wavelengths can be kilometers long and gamma ray wavelengths smaller than atoms.




Many scientific instruments are designed to detect infrared, ultraviolet, X-ray, or other wavelengths. These invisible forms of light have no colors associated with them. So scientists have their computers assign unusual colors (like neon orange) to their images, to allow them to observe details. The green Sun, above left, is a photo of the Sun taken in extreme ultraviolet light, which our eyes cannot see. The scientists have artificially colored the ultraviolet data green. We call that "false color".

Scientists also use false color to indicate additional information. The image of Mars, above right, shows the concentration of methane in Mars's atmosphere. Scientists have color-coded the highest concentrations of methane as red, the lowest in blue, to help us and them understand the data. Many of the images in this collection are likewise false colored. We have tried to highlight which images come from visible light and which represent false color or color-coded data.

*Image Credits: Green Sun NASA/SDO/AIA; Blue Mars – NASA/JPL*

# Our Sun – Source of Life

A total solar eclipse, as observed from Earth.
*Image Credit*: *Alphonse Sterling and the Suntrek website (*www.suntrek.org*)*
*Used with permission*

The Sun is our very own star, at the center of our solar system. The Sun is scientifically designated as a yellow dwarf (because of its place on the HR diagram[1]). However, our Sun is neither yellow nor a dwarf. The Sun appears white to the human eye -- it only looks yellow or orange when its rays are being scattered by Earth's atmosphere during sunrise and sunset. And it is now thought to be brighter and larger than about 85% of the stars in the Milky Way galaxy, most of which are red dwarfs (stars with low mass that shine in a relatively cool red).

The Sun consists of hot plasma (a state of matter where electrons have been stripped from their atoms) interwoven with magnetic fields. It has a diameter about 109 times that of of Earth, and a million Earths could fit inside it! Its mass accounts for about 99.86% of the total mass of the solar system. About three-quarters of the Sun consists of hydrogen; the rest is mostly helium. Less than 2% consists of heavier elements, including oxygen, carbon, gold, iron, and others. Many of these elements were originally forged in supernova explosions. So we, and everything in our solar system, are made of "star stuff"[2].

Every second, the Sun fuses 614 million metric tons of hydrogen into 609 metric tons of helium in its core. The difference is converted into gamma rays that eventually get

[1] The Hertzsprung-Russell diagram plots the temperature of stars against their luminosity/brightness. See https://astronomy.swin.edu.au/cosmos/H/Hertzsprung-Russell+Diagram
[2] Quote from Carl Sagan

radiated at the solar surface as lower-energy photons, primarily visible light. The Sun's hot atmosphere, called the corona, continuously expands in space creating the solar wind, a stream of charged particles that extends beyond the solar system. The bubble in the interstellar medium formed by the solar wind, called the heliosphere, is the largest continuous structure in the solar system.

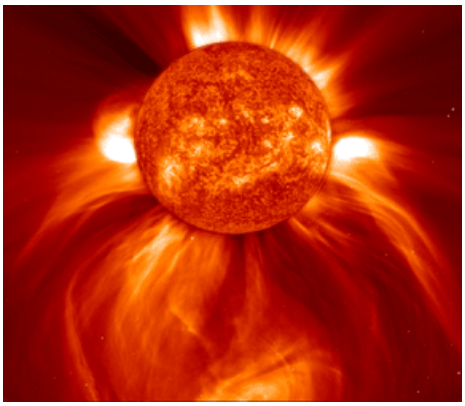
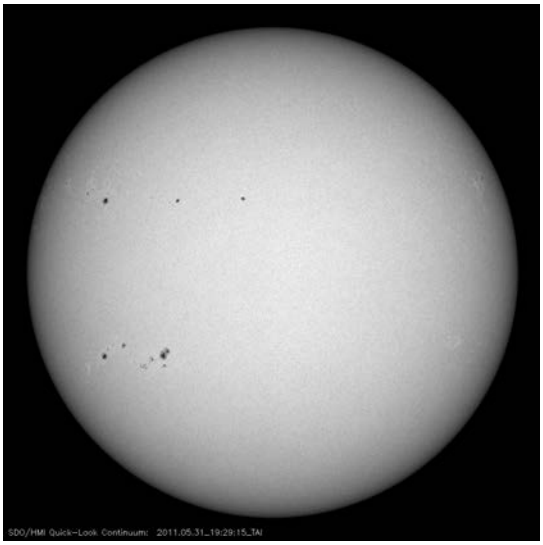


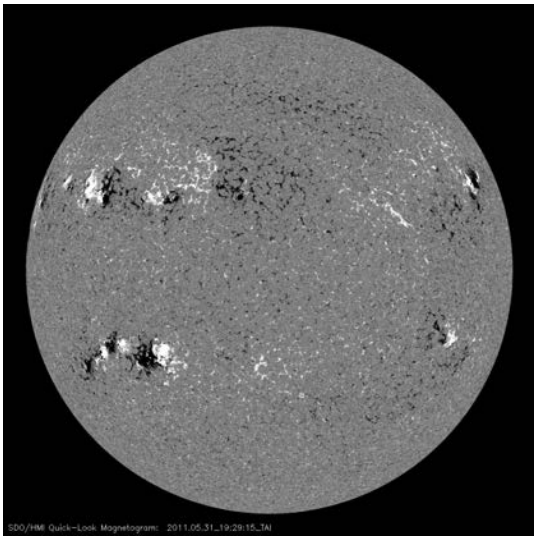
*Image Credit: ESA/ NASA's SOHO Mission (false color)*

## *Solar Activity*

Our Sun is a dynamic, active, and constantly changing star. Solar activity is driven by intense magnetic fields, generated deep within the solar interior then buoyantly rising up through its surface. Plasma caught in the magnetic field lines allows us to see these fields, as in the previous composite image.



Visible light image of the Sun
*Image credit: NASA SDO/HMI*



Solar magnetic fields
*Image Credit: NASA SDO/HMI*

On the left is a true color image of the Sun. The dark splotches are called sunspots. The image on the right, taken at the same time, is a map of the magnetic fields on the Sun. White indicates a positive field, and black a negative one (grey indicates little or no field). Note how the sunspots are associated with the magnetic fields – most activity on the Sun is a result of complex magnetic fields!

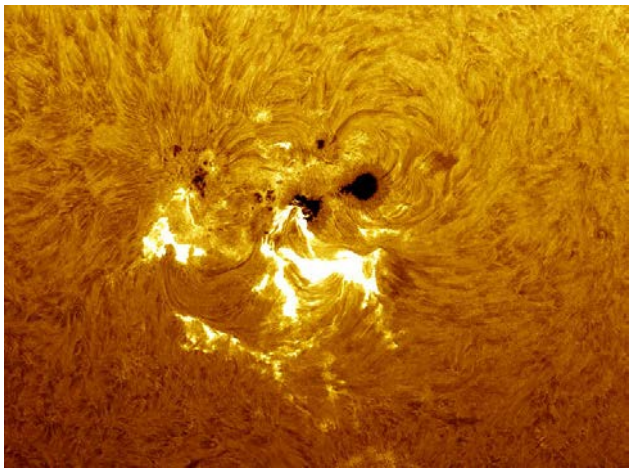


*Image credit: Jack Newton (false color)*

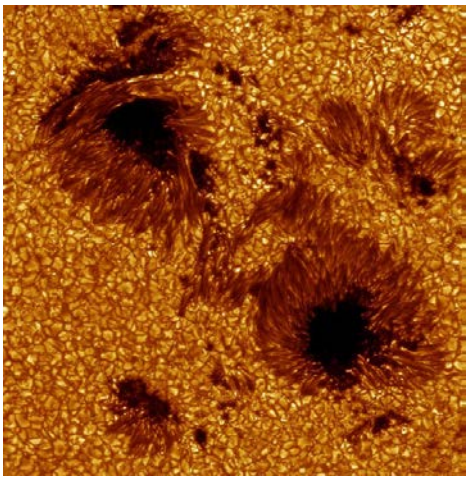


*Image Credit: Scharmer and K. Langhans, ISP Royal Swedish Academy of Sciences. (false color)*

Sunspots are temporary regions of reduced surface temperature caused by increased magnetic activity. The Sun goes through a cycle of about 11 years when it has a period of many sunspots (solar maximum), then few or no sunspots (solar minimum). Sunspots or similar magnetically active regions are the source of solar storms.

The Sun's magnetic fields are constantly in motion. When solar magnetic fields twist, break, and then reconnect, they can release a tremendous amount of energy. We see these as solar flares, like the white brightening near the center of the image on the right. Solar flares eject radiation and fast moving particles that can damage satellites, disrupt communications, and give high-flying planes and astronauts additional doses of radiation. Finding ways to protect astronauts from solar flares is one of the biggest challenges of going back to the Moon or to Mars.

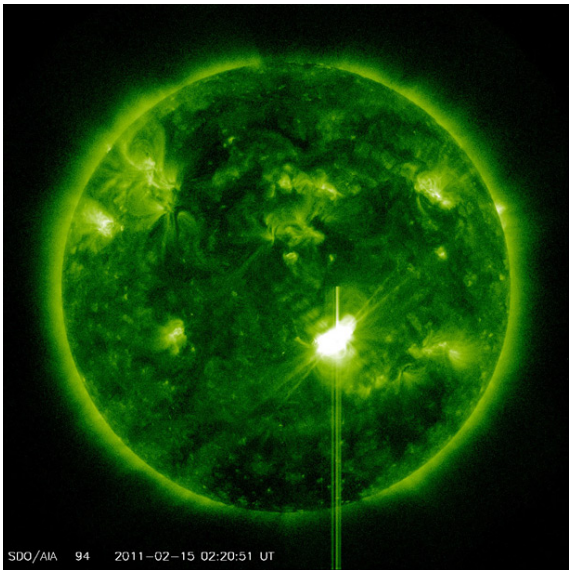
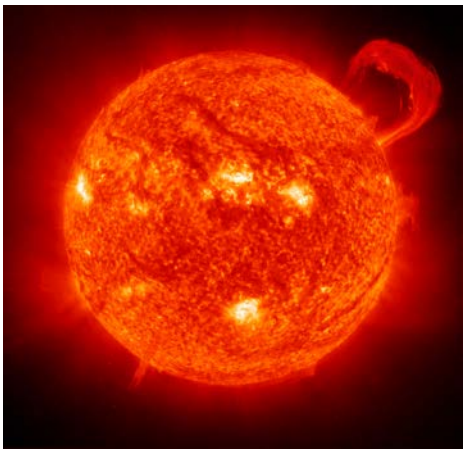



*Image Credit: NASA/SDO (false color)*



ESA[3]/NASA's Solar and Heliospheric Observatory (SOHO) produced the spectacular portrait (left) of our star. Featured is a huge, handle-shaped prominence—a cloud of relatively cooler plasma held aloft high in the corona (the Sun's atmosphere) by a large magnetic field that is rooted in the solar surface. A typical prominence extends over thousands of kilometers, and can last from minutes to months.

*Image Credit: ESA/NASA's SOHO spacecraft (false colors)*

Sometimes prominences erupt into coronal mass ejections (CMEs), as in the image on the right. These huge blasts of charged plasma, traveling at 1400 km/s, can impact objects of the solar system. Luckily, Earth's magnetic field acts as a shield, partially protecting us. But CME impacts on Earth may still generate effects such as aurora, satellite drag, power outages, communications disruptions, and GPS interference.

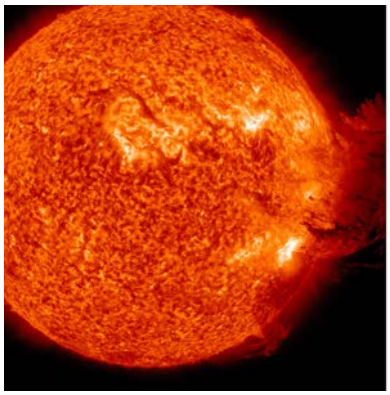


*Image Credit: NASA/SDO/AIA (false colors)*

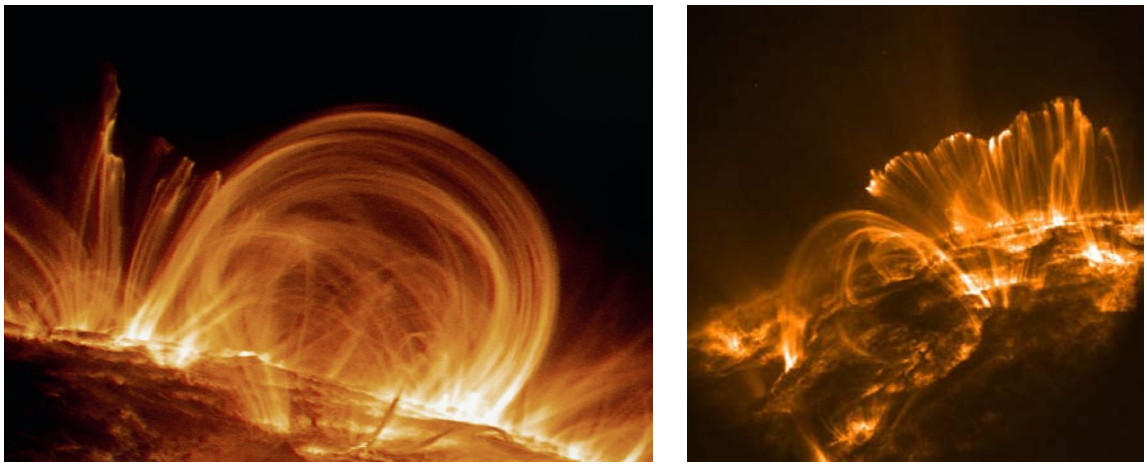


*Image Credits: NASA/Stanford-Lockheed Institute for Space Research's TRACE Team (false color)*

A close-up view of the Sun's surface, observed by NASA's Transition Region and Coronal Explorer (TRACE) mission, shows vast loop structures made of superheated plasma trapped in magnetic field lines. About 10 Earths could fit across any one of these loops! These areas of solar activity can contain multiple loops, often in "tunnel"

[3] The European Space Agency

formations, that can persist for weeks. The plasma reaches temperatures of more than 1,000,000 C° — whereas the Sun's surface temperature averages only about 5500 C°! Flares and CMEs usually erupt from active regions such as these.

## *Space Weather*

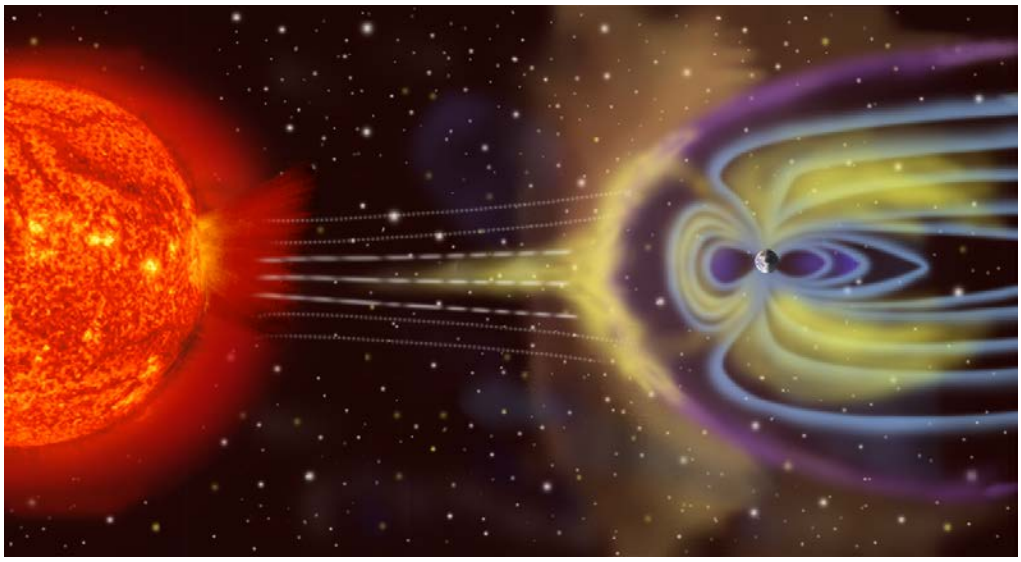


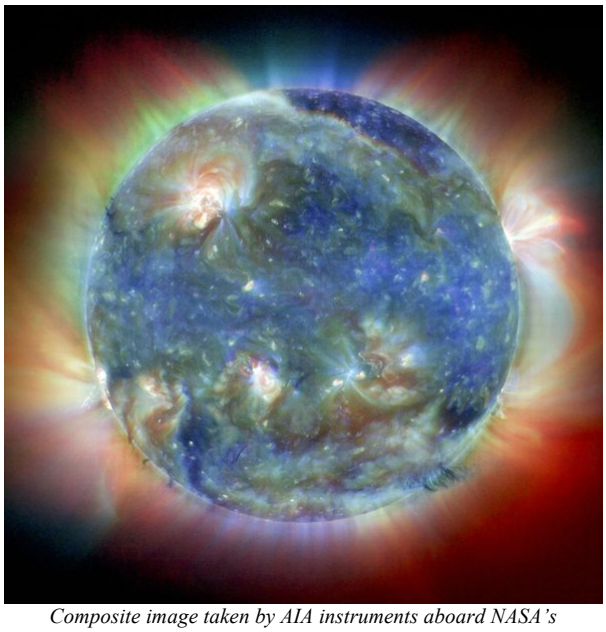
*Image Credits: NASA (Definitely not to scale!)*

Space weather refers to the affect the Sun has on the Earth and rest of the solar system. The solar wind is a fairly constant stream of charged particles, mostly high-energy electrons and protons, ejected from the upper atmosphere of the Sun. These particles can escape the Sun's gravity because of their high kinetic energy and the high temperature of the corona. As the solar wind buffets the Earth's magnetic field, it distorts it into a long oval, as shown in the (not-to-scale) image above.

Radiation storms and CMEs have the potential to seriously affect Earth and our modern technology. Besides triggering beautiful aurorae, these solar storms can damage satellites, disrupt power grids and electrical systems, interfere with cell phones and other communications, and disturb animal movements. They can even threaten astronauts and high-flying airplanes with their radiation! Space weather affects not only Earth but the other planets as well.

**Our Eye on the Sky –** Launched in February 2010, NASA's Solar Dynamics Observatory (SDO) mission is designed to study the Sun's variability and its effect on space weather, with the goal of eventually predicting dangerous solar activity.

*NASA's SDO spacecraft*



*Composite image taken by AIA instruments aboard NASA's SDO spacecraft (false colors)*

Our Sun was formed in a nebula of gas and dust about 4.5 billion years ago. It will shine for another 5 billion years before it expands into a red giant, eventually releasing what is left of its gas, and spending the last of its years as a dwindling white dwarf.

*Image credits: Red giant by B. Jacobs, from Wiki Commons; White dwarf - NASA*

| Sun Details | | | |
|---|---|---|---|
| Diameter | 1,391,000 km | Rotational Period | ~27 days at equator; more at poles |
| Temperature | Core: ~$1.5\times10^{7}$C°<br>Photosphere: 5,500C°<br>Corona: ~$5\times10^{6}$C° | Atmosphere | 85% Hydrogen<br>23% Helium<br>2% Others |
| Number of planets | 8 | Axial Tilt | 7.5 degrees |
| Mass | $2\times10^{30}$ kilograms | Magnetic Field | Dipole plus surface and subsurface fields |

# Mercury

## Land of Craters

*Image Credit: NASA*

Mercury is extreme. Of all the planets in our solar system, it is the smallest, it has the oldest surface, it is closest to the Sun, it has the largest daily variations in surface temperature, and, until recently it was the least explored. NASA's Mercury Surface, Space Environment, Geochemistry, and Ranging (MESSENGER) spacecraft, which inserted into Mercury orbit in March 2011 has changed all that! It has revealed rocky Mercury's geologic history, the nature of its weak magnetic field, the structure of its core, and the composition of its thin exosphere. MESSENGER has even found hints of water at Mercury's dark poles.

*Image Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington*

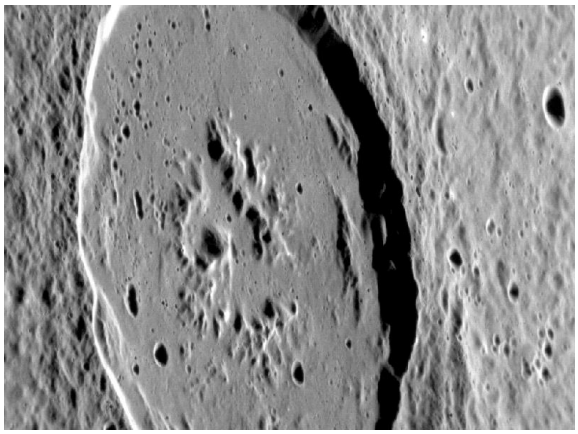


*Image Credit: NASA*

What is the source of the radiating streaks in the image on the left? It is the impact crater Hokusai, seen at the top of the frame, named for Japanese artist Katsushika Hokusai. Its impressive ray system extends for as far as 1000km. Such rays are formed when an impact excavates material from beneath the surface and explodes it outward from the crater. Rays such as these fade over time as they are exposed to the harsh space environment. Hence, craters with bright rays are thought to be relatively young.

Above right: At a diameter of 100km, the crater Atget is one of the largest craters within the Caloris Basin (see next image).

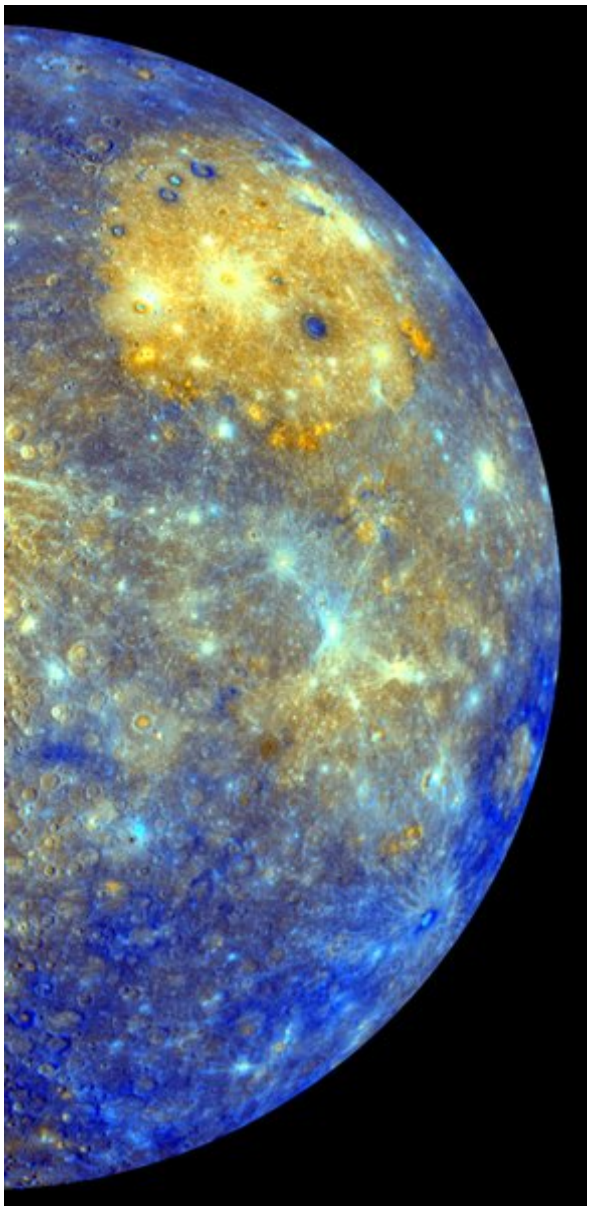
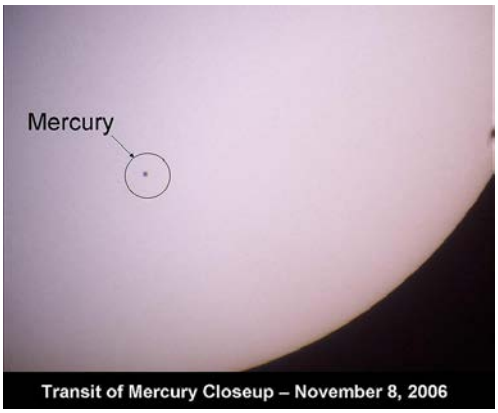


*Image Credit: NASA/Johns Hopkins University Applied Physics Laboratory/Arizona State University/Carnegie Institution of Washington*
*(false colors)*

The image on the left features the sprawling Caloris basin, one of the solar system's largest impact basins. Created during the early history of the solar system by the impact of a large asteroid-sized body, the basin spans about 1500 kilometers and is seen in yellowish hues in this enhanced color mosaic. The image data is from the January 14th flyby of the MESSENGER spacecraft. Orange splotches around the basin's perimeter are now thought to be volcanic vents, new evidence that Mercury's smooth plains are indeed lava flows.

Scientists often add false color to images to help them see finer detail. Note how much easier it is to study this image rather than the ones on the previous page.

The image below shows the transit (crossing) of Mercury in front of the Sun's disk on 8 November 2006. (Mercury is about 57 million km away from the Sun.)




| Mercury Details | | | |
|---|---|---|---|
| Diameter | 4879 km | Rotational Period | 59 days |
| Distance from Sun | 57,910,000 km (.4 AU) | Orbital Period | 88 days |
| Number Moons | 0 | Atmosphere | tenuous |
| Temperature | -160C° to 430C° | Axial Tilt | .04 degrees |
| Mass | 3.30 x $10^{23}$kg<br>About 5% of Earth's | Magnetic Field | tiny |

# Venus

## Heaven or Hell?

*Image Credit: NASA (true color)*

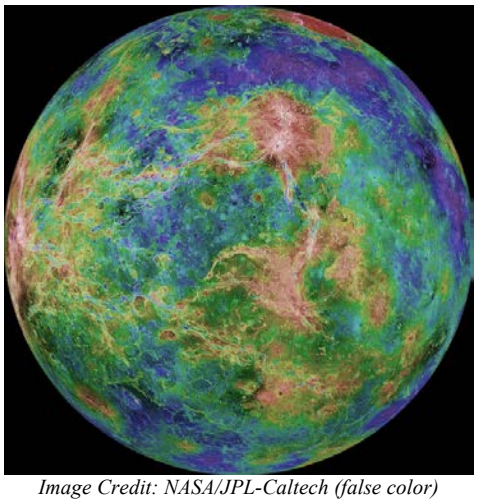


*Image Credit: NASA/JPL-Caltech (false color)*

Venus, second planet from the Sun, has roughly the same size, mass, density, and composition as Earth. Until the 1960s, scientists and science fiction writers speculated that Venus might be very Earth-like, and home to lush, tropical forests. That view changed when new observations confirmed a superheated surface with temperatures over 400C and atmospheric pressures nearly a hundred times that of Earth. But the biggest difference from Earth lies within Venus's atmosphere. The clouds on Venus, which hide its surface, are made not of water like they are on Earth, but rather of concentrated sulfuric acid—essentially battery acid. About 700 million years ago, just before life was diversifying on Earth, Venus experienced tremendous volcanic activity, flooding the surface with new lava and filling the atmosphere with greenhouse gases, causing a runaway greenhouse effect. Volcanoes continue to erupt on Venus.

Only radar can probe through the thick clouds in the Venusian atmosphere to make observations of the surface. Radar data collected over many years from multiple sources were used to create the beautiful, color-coded portrait of Venus's surface, above right.

This striking image, right, is a composite of the complete radar image collection of Venus's surface, obtained by NASA's Magellan mission. The image uses simulated colors based on actual color images recorded by the Soviet Venera 13 and 14 spacecraft.

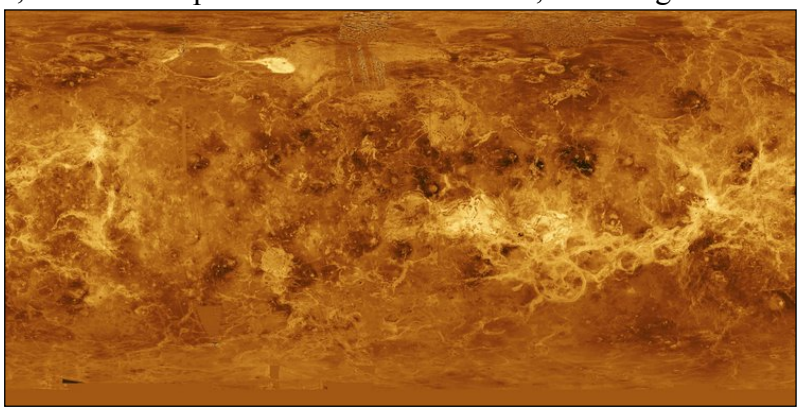
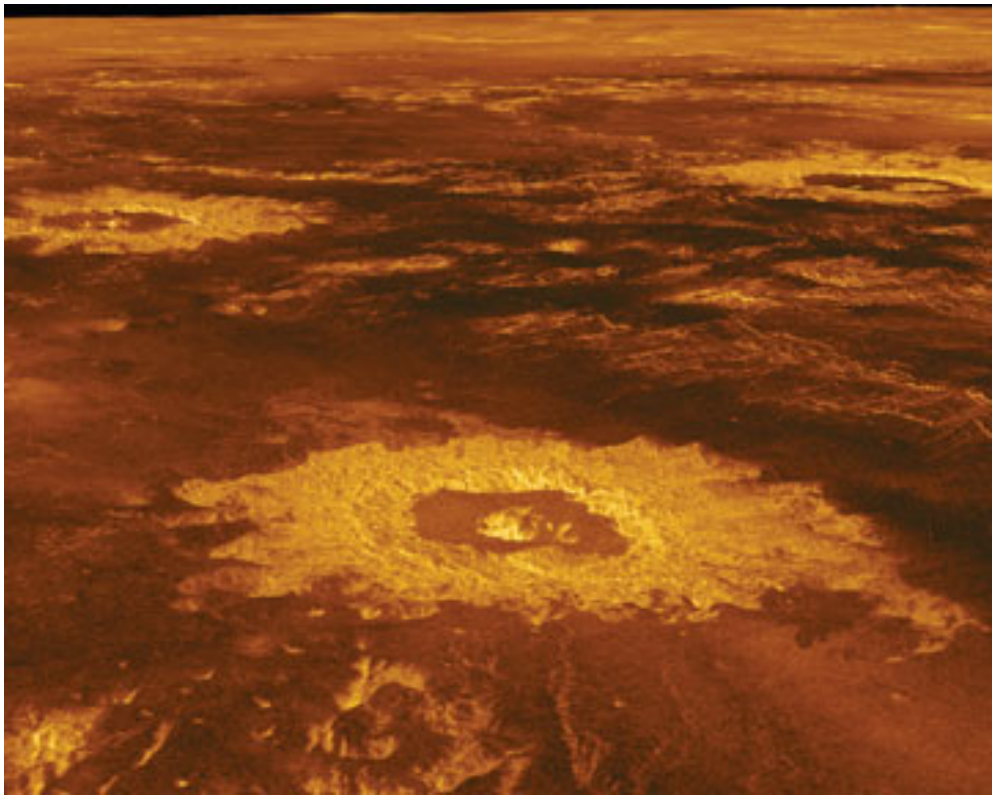


*Image Credit: NASA/JPL-Caltech*

The Magellan spacecraft was launched aboard Space Shuttle Atlantis in May 1989 and

began mapping the surface of Venus in September 1990. Magellan spacecraft operations ended on October 12, 1994, when radio contact was lost with the spacecraft during its controlled descent into the deeper portions of the Venusian atmosphere.



Impact craters on Venus - *Image credit: NASA/JPL*

**Was there life on Venus?** There is evidence that when it was young, Venus almost certainly had liquid water—an essential ingredient for life on Earth. Was Venus habitable in the past? Is it habitable now? Finding evidence of past life will be a big challenge, as massive volcanic activity caused a resurfacing of 80% of the planet within the last billion years. But if samples are someday returned from the ancient surface of Venus, they could be very revealing!

As for life on Venus now, some scientists speculate that single-celled organisms could actually survive within the harsh yet stable atmosphere, living off the sulfur chemistry there!

| **Venus Details** | | | |
|---|---|---|---|
| Diameter | 12,104 km | Rotational Period | 243 days (clockwise) |
| Distance from Sun | 108,200,000 km (.7 AU) | Orbital Period | 225 days |
| Number Moons | 0 | Atmosphere | Thick sulfuric clouds |
| Temperature | 480C° | Axial Tilt | 177 degrees (retrograde) |
| Mass | $4.868 \times 10^{24}$ kg<br>About 82% of Earth's | Magnetic Field | Nearly none |

# Earth

**You are here!**

*Image Credits: NASA/NOAA/GSFC/Suomi NPP/VIIRS/Norman Kuring*

Home. These beautiful images are each composites of six separate orbits taken on Jan. 23, 2012 by the Suomi National Polar-orbiting Partnership satellite. Compiled by NASA Goddard scientist Norman Kuring, the images have the perspective of a viewer looking down from 12,742km (7,918 miles) above the Earth's surface.

In December of 1968, the Apollo 8 crew flew from the Earth to the Moon and back again. Frank Borman, James Lovell, and William Anders were launched atop a Saturn V rocket, circled the Moon ten times in their command module, and returned to Earth on December 27. As the Apollo 8 command module rounded the farside of the Moon, the crew could look toward the lunar horizon and see the Earth appear to rise. The famous picture that resulted, below left, shows a distant blue Earth above the Moon's limb, and was a marvelous gift to the world.

*Image credits: NASA*

*Image Credit: Jeffrey R. Hapeman of Lac du Flambeau, Wis.*

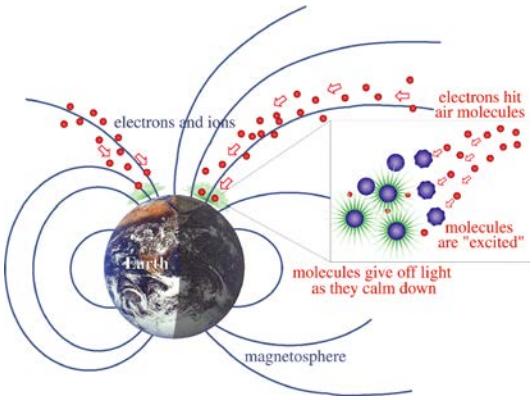



*Diagram courtesy of NASA*

For those who have seen them, the Aurora Borealis and Aurora Australis are spectacles to remember. Aurorae are caused by currents of energetic charged particles in Earth's magnetosphere flowing through the upper atmosphere. The interaction of the solar wind with Earth's magnetosphere drives these currents. The more active the Sun, especially during the peak of its 11-year solar cycle, the more charged particles flow to Earth's magnetic poles. These charged particles eventually collide with gas molecules in the upper atmosphere, causing them to ionize (lose electrons) and emit colored light.

Earth's thin atmosphere is all that stands between life on Earth and the cold, dark void of space. Our planet's atmosphere has no clearly defined upper boundary but gradually thins out into space. The layers of the atmosphere have different characteristics, such as protective ozone in the stratosphere and weather in the lowermost layer. The setting Sun seen through Earth's atmosphere is featured in this image, which was photographed by the crew of the International Space Station in 2008.

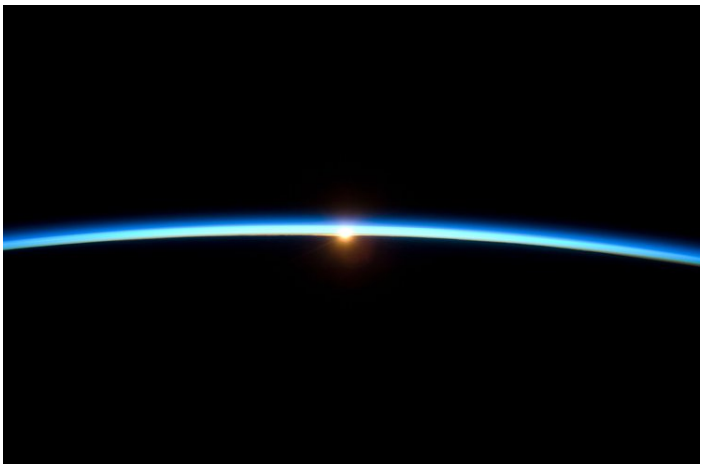


*Image credit: NASA*

| Earth Details | | | |
|---|---|---|---|
| Diameter | 12,742 km | Rotational Period | ~24 hours |
| Distance from Sun | 149,600,000 km (1.0 AU) | Orbital Period | ~365.25 days |
| Number Moons | 1 | Atmosphere | Nitrogen, oxygen |
| Temperature | -89C° to 70C° | Axial Tilt | 23.4 degrees |
| Mass | $6 \times 10^{24}$ kg | Magnetic Field | yes |

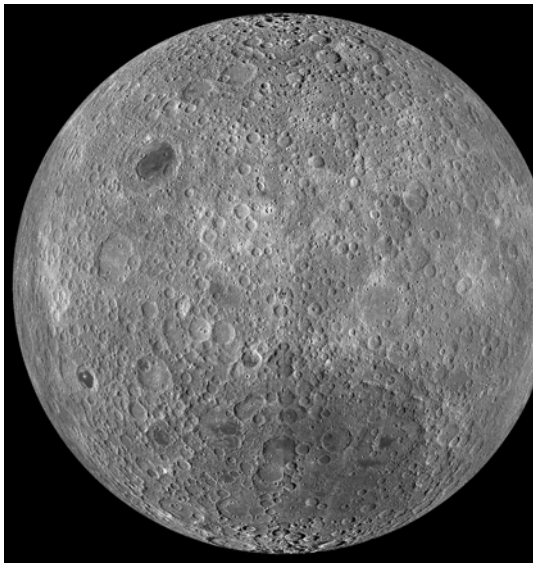
## *Earth's Moon*

*Image Credit: NASA*

ONE SMALL STEP FOR MAN…one giant leap for mankind! There is only one world in our solar system besides Earth on which humans have walked—the Moon. The image above was taken by astronauts on the Moon during the Apollo 17 mission in December 1972. Astronaut Harrison Schmitt is shown preparing to take a soil sample. The later Apollo missions, including 17, had a strong scientific focus. A few days after this image was taken, humanity left the Moon and has yet to return. Note the Sun in the upper left. It is daytime on the Moon, but with no air to scatter the light, the sky remains black.

Side of the Moon facing Earth

*Image Credit: NASA/JPL/Galileo Spacecraft*



Far Side of the Moon

*Image credit: NASA*

Virtually everyone can see the Moon, no matter where on Earth they are. Most people know that the Moon's gravitational pull on the Earth causes our ocean tides. But did you know that missions to the Moon have discovered the existence of Moonquakes, as well as water ice hidden in the permanently shadowed craters at the lunar poles?

The lunar samples brought back by Apollo astronauts have shed new light on how the Moon was formed—it is now thought that roughly 4.5 billion years ago, a rocky impactor about the size of Mars hit the young Earth. The debris scattered by that collision orbited the Earth briefly (only about a month!) before coalescing into the Moon. The Moon was further struck by a heavy bombardment of asteroids around 3.9 billion years ago, causing much of the cratering now seen. The dark blotches on the Earth-facing side of the Moon are lunar mare, essentially large, dark plains of basalt formed by volcanic eruptions.

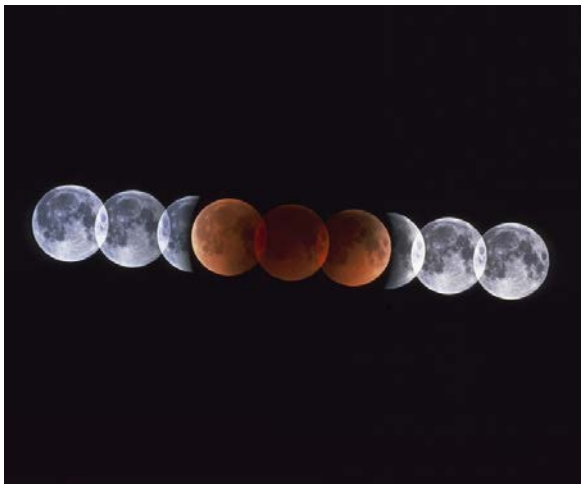


*Image Credit Akira Fujii/Ciel et Espace*

Why does the Moon have a reddish hue in these images of a lunar eclipse? It is the same reason that the Sun appears reddish during a sunset: scattered light. During a lunar eclipse, the Earth is situated directly between the Sun and the Moon. The only sunlight reaching the Moon travels through dense layers of Earth's atmosphere. Atmospheric particles preferentially scatter out shorter (bluer) wavelengths leaving only the longer (redder) wavelengths to refract (bend) through the atmosphere and illuminate the Moon.

## *Meteors and Impacts*

*Image Credit: Wally Pacholka/AstroPics.com*

The meteor fireball on the left, caused by a Geminid meteor, is one of the largest ever recorded. Most meteor showers result from debris that "boils" off a comet when it passes close to the Sun. When Earth passes through the debris, these specks may enter our atmosphere and we see a meteor shower!

Though most particles which cause our brilliant meteors are about the size of a grain of sand, the Geminids are different. Their source of meteors is not a comet, but a strange, rocky object thought to be either an asteroid or an extinct or dormant comet.

Meteors that are larger than a grain of sand (often chunks from asteroids) can sometimes reach the Earth's surface, as did the rock on the left image below. This one landed in the Sudan desert. Meteors that make it to the ground are called meteorites; large ones can leave impact craters (2 images below right).

*Image Credit: NASA/JPL*

# Mars

## The Red Planet

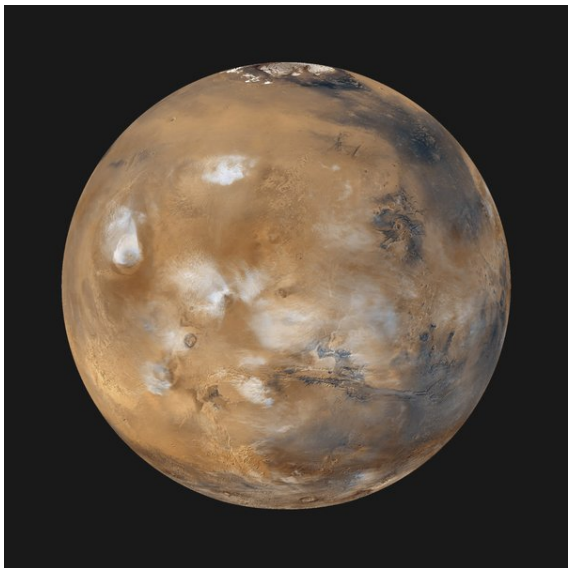


*Image Credit: NASA/Mars Global Surveyor*

Mars has been the subject of intense study for centuries. Its exploration has been wrought with success and failure, and has witnessed a dramatic evolution in knowledge. Speculations about the famous "irrigation canals" on Mars in the late 1800s were finally put to rest by images returned from NASA's Mariner 4 mission in 1965. Revealing icy deserts, impact craters and a barren landscape, they dispelled thoughts of thriving, agricultural civilizations. In the 1970s NASA's Viking mission carried out life-detection experiments on the surface. The results, suggesting a lifeless planet, raised more questions than answers.

The next two decades were met with struggle as several spacecraft from the US, Japan, Europe, and former USSR were lost. Success resurfaced in the late 1990s with the ESA orbiter Mars Express and NASA's Pathfinder rover, and Global Surveyor and Odyssey orbiters—heralding the mantra "Follow the Water." In 2004, NASA's twin rovers Spirit and Opportunity began work. NASA's Mars Reconnaissance Orbiter and Phoenix lander followed. As data from these robotic explorers piled up, so did evidence that Mars preserves a record of surface liquid water and possibly once-habitable environments. NASA's Mars Science Laboratory, which arrived in 2012, carried an unprecedented suite of instruments that can bring us one step closer to determining if life ever started on Mars. Its Curiosity rover is now offering a human-like perspective to martian landscapes.

ESA's Mars Express obtained this view of an unnamed impact crater located on Vastitas Borealis, a broad plain that covers much of Mars's far northern latitudes. The circular patch of bright material is residual water ice. The colors are very close to natural, but the vertical relief has been exaggerated three times. This patch of ice is present all year, remaining after frozen carbon dioxide overlaying it disappears during the martian summer.

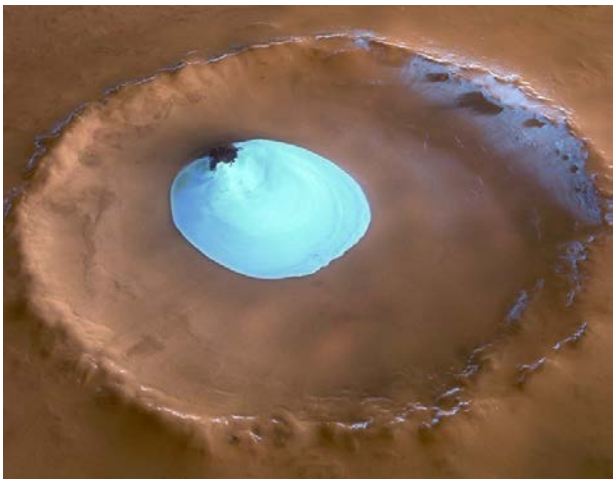


*Image Credit: ESA/DLR/FU Berlin (G. Neukum)*

*Image Credit: NASA/JPL/University of Arizona/Science Photo Library*

NASA's Mars Reconnaissance Orbiter spacecraft took this spectacular image of Victoria Crater, an impact crater near the equator of Mars where hematite mineral deposits suggest Mars had a wet past. Layered sedimentary rocks are exposed along the inner wall of the crater, and the floor of the crater is occupied by a striking field of sand dunes. NASA's twin Mars Exploration Rovers, Spirit and Opportunity, have been operating on the surface of Mars in search of answers about the history of water on the Red Planet since 2004 (unfortunately, Spirit was turned off). Five days before this image was taken in September 2006, the 'Opportunity' rover arrived at the rim of Victoria Crater, after a drive of more than 9km! It explored within the crater, staying at the site for about a year. The rover can actually be seen in this image as a small dot at the 'ten o'clock' position along the crater rim.

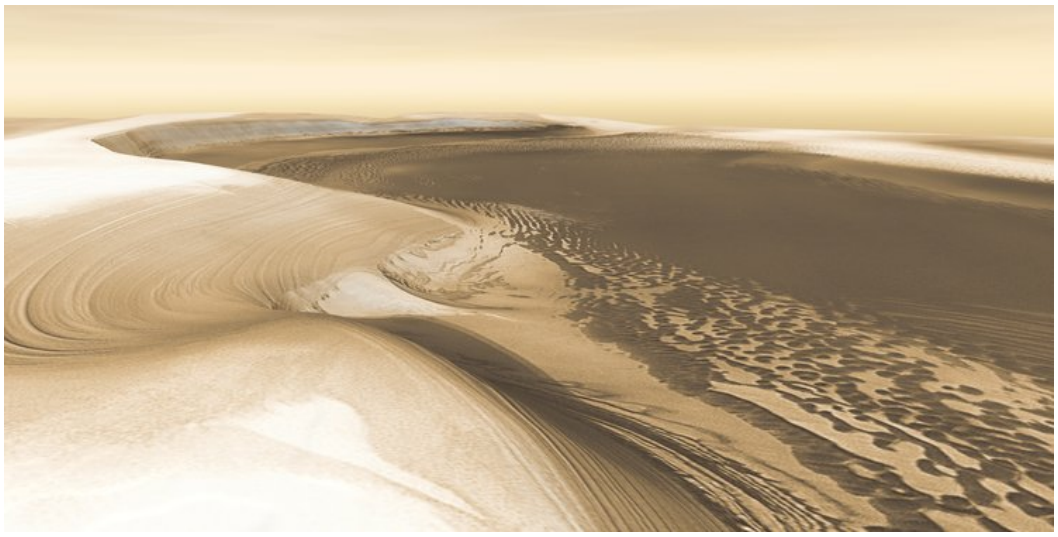


*Image Credit: NASA/JPL-Caltech/Arizona State University, Thermal Emission Imaging System (THEMIS)*

Chasma Boreale, pictured above, is a long valley that cuts deep into the north polar ice cap of Mars. Where the ice cap has retreated, sand from earlier, less icy climatic regimes is exposed. Winds have shaped them into dunes. In 2007, NASA's Phoenix mission landed in the northern arctic plains of Mars to study the history of water and potential habitability in the ice-rich soil. Phoenix verified the presence of water ice in the martian sub-surface, and found calcium carbonate, an indicator of a less acidic (more potentially habitable) planet in the past. Phoenix even observed snow falling from clouds in the martian atmosphere! This eerily Earth-like vista was made by combining data from NASA's Mars Odyssey and Global Surveyor orbiters.

*Image Credit: NASA/JPL-Caltech/University of Arizona*

*Image Credit: NASA*

The intriguing image on the left depicts the Nili Fossae region of Mars, which occupies an area between a large volcano and an ancient impact basin. It is home to a collection of curved troughs cutting about 500m into the crust. The European spacecraft Mars Express detected clay minerals there, good news for astrobiologists because the clays suggest the presence of water at some point in the past. Even better, the minerals also suggest that the water collected in pools on the surface, a possibly comfortable habitat for life.

Signs of water on Mars, above right, were discovered some time ago but scientists had no idea about much of the mineral composition of Mars. A recent discovery suggests that much of the planet was covered with water around 4 billion years ago.

Astrobiologists have also detected the presence of methane gas in the atmosphere of Mars, indicating that the planet is indeed "alive," either in a geologic or biologic sense. It is still unclear whether the methane was produced by purely geologic processes such as the oxidation of iron, or by microscopic organisms living in the martian sub-surface. Finding plumes of it that persist only during the martian spring and summer indicates that some ongoing, seasonal process is releasing the gas. Methane-producing microbes were one of the earliest forms of life on Earth, so if there is life on Mars today, it could be making the methane from carbon dioxide in the martian atmosphere.

It may look like a familiar sight, but this sunset is not from Earth. This lovely, otherworldly evening was captured by the rover Spirit in 2005 as it peered toward the western sky from its perch in Gusev Crater on Mars. Like no other spacecraft, the Mars Exploration Rovers have afforded us a perspective much like our own on another world, making Mars feel that much more like home.

*Image Credit: NASA/JPL/Texas A&M/Cornell (true color)*

| Mars Details | | | |
|---|---|---|---|
| Diameter | 6780 km | Rotational Period | 24.7 hrs |
| Distance from Sun | 227,900,000 km (1.5 AU) | Orbital Period | 687 days |
| Number Moons | 2 | Atmosphere | Thin carbon dioxide |
| Temperature | -143C° to 27C° | Axial Tilt | 25 degrees |
| Mass | 6.4 x $10^{23}$km (about 10% of Earth's) | Magnetic Field | Virtually none |

## *Mars's Moons – Phobos, Deimos*

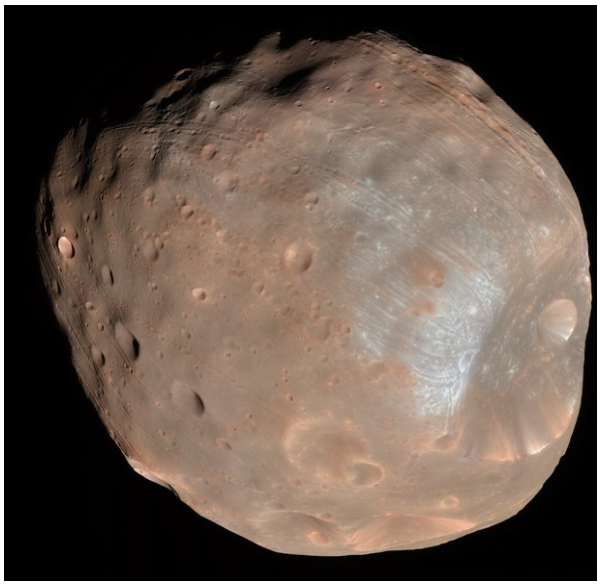


*Image Credit: NASA/JPL*

On the left is tiny (22.2 km) but fearsome Phobos, taking its name from the Greek word for fear. It is one of two moons of Mars -- and this moon is doomed! Phobos orbits very close to Mars, and the strong gravitational (i.e. tidal) forces are taking their toll. In about 100 million years, Phobos will likely be shattered by the stress of these relentless tidal forces. The debris may form a ring around Mars.

Deimos, named for the Greek word flight or panic and looking potato-like on the right, is the smaller (~12km) and outer moon of Mars. Both moons are likely captured asteroids originating in the main asteroid belt between Mars and Jupiter, or perhaps from even more distant reaches of the solar system.

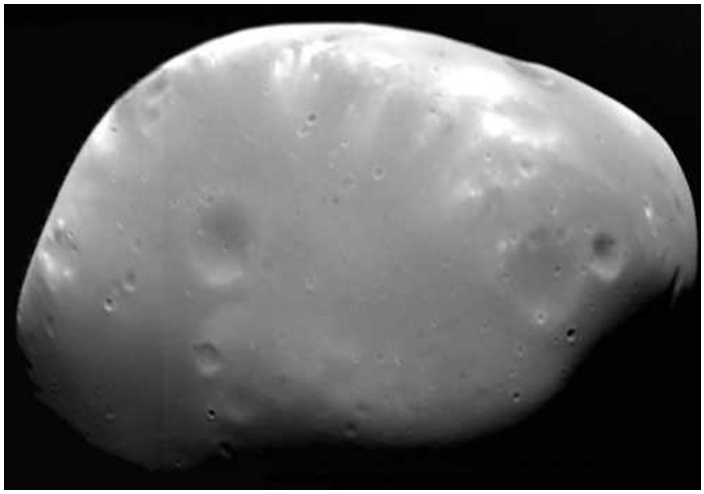


*Image Credit: NASA/JPL*

## *Asteroid Belt*

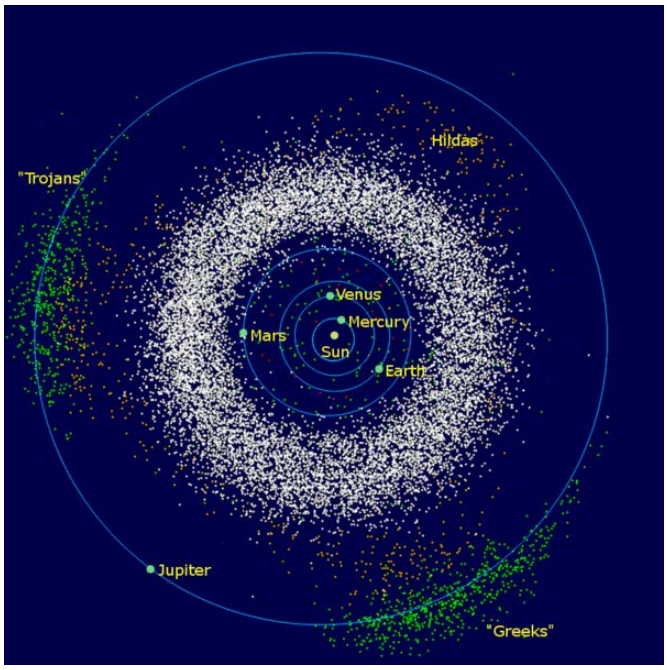



*Image credit: Wikipedia Commons*

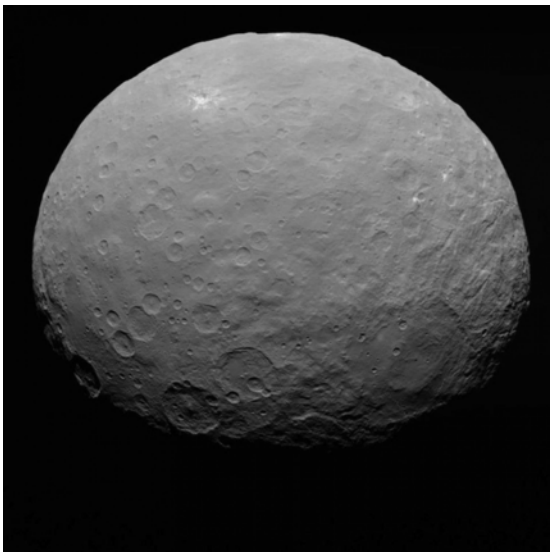
*Image Credit: NASA/JPL/USGS*

There are millions of asteroids, ranging in diameter from dust particles to 950km. Like most other small solar system bodies, asteroids are thought to be the shattered remnants of planetesimals, bodies within the young Sun's solar nebula that never grew large enough to become planets. Most known asteroids orbit in the main asteroid belt between the orbits of Mars and Jupiter or co-orbital with Jupiter. However, other orbital families exist with significant populations, including the near-Earth asteroids. In the image above right, Ida and Gaspra (superimposed with each other) are two such rocky, metallic objects. Shown here to the same scale, Ida is about 30km long, and Gaspra about 17km.

*Artistic impression courtesy NASA*

Asteroids have played a role in the evolution of life on Earth. Sometimes the orbits of asteroids bring them close to Earth and collisions ensue. There is strong evidence that the mass extinction that killed the dinosaurs 66 million years ago was caused by an asteroid at least 12km wide. If that had not happened, would humans be walking the Earth today?

Ceres (image on right) is the largest asteroid and the only dwarf planet in the inner solar system. It is a rocky, icy body only about 950 km in diameter though it contains about one-third of the mass of the asteroid belt. Giuseppe Piazzi discovered Ceres in 1801. It was initially classified as a planet. As other objects were discovered in the area it was realized that Ceres represented the first of a class of many similar small bodies.



*Ceres as seen by the Dawn spacecraft. NASA*

NASA's unmanned *Dawn* spacecraft, launched on 27 September 2007, was tasked with the exploration and study of Vesta and Ceres, the two most massive objects of the asteroid belt. The probe entered orbit around Vesta on July 16, 2011 and left Vesta on September 5, 2012 on a course for Ceres, which is started orbiting in March 2015.

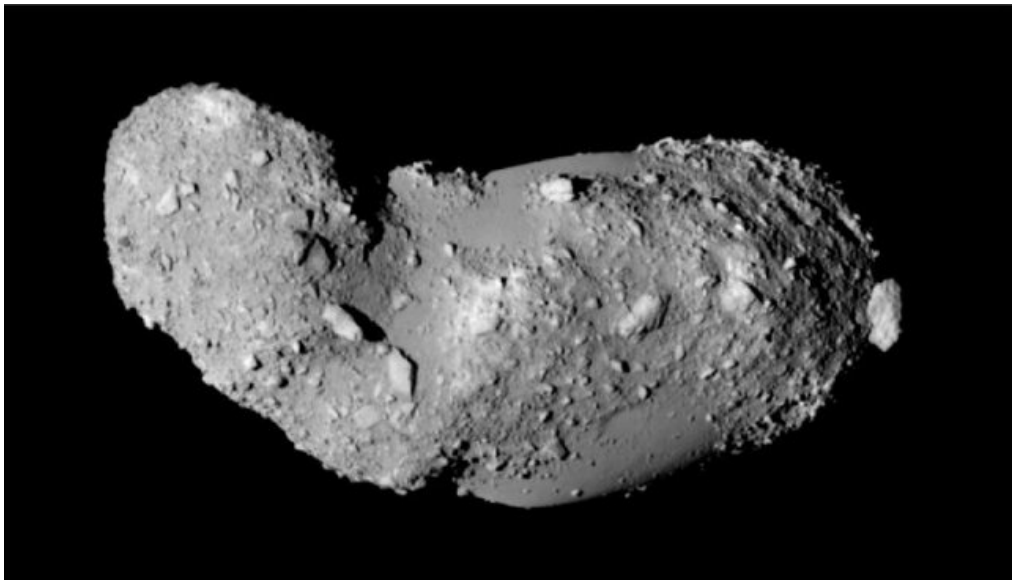


*Image Credit: JAXA (Japan Aerospace Exploration Agency)/ Hayabusa Mission*

Asteroid Itokawa, photo above, shows features common to many asteroids – indications of pieces from previous asteroid collisions that formed when gravity pulled the small bits together. Note the lack of impact craters and the rough surface studded with boulders.

# Jupiter

## King of the Planets

*Image Credit: NASA*

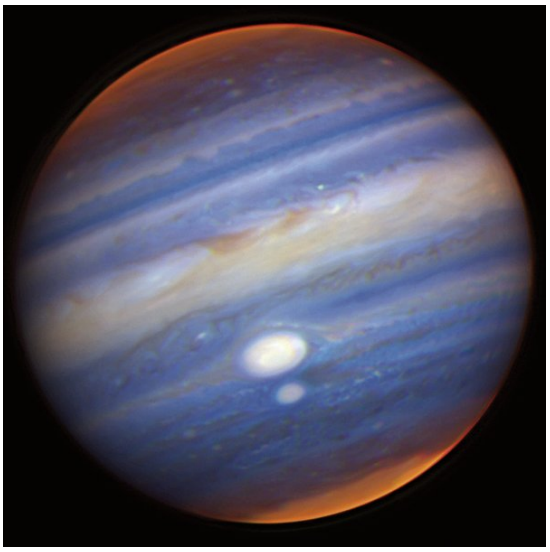


*Image Credit: Travis Rector (U. Alaska, Anchorage), Chad Trujillo and the Gemini Altair Team, NOAO/AURA/NSF (false color)*

Jupiter, the most massive planet in our solar system—with 79 known moons and an enormous magnetic field (magnetosphere) — forms a kind of miniature solar system. Gaseous Jupiter resembles a star in composition, but it never grew massive enough to start the fusion process. Several of its moons are of interest to astrobiologists searching for life elsewhere in the solar system.

The image above left shows Jupiter's true colors. The right image has been color-coded to show cloud height from high altitude (white) through mid-range (blue) to low altitude (red).

*Image Credit: JPL/NASA*

Jupiter's Great Red Spot, a vast cyclone located in Jupiter's southern hemisphere, is about three times the diameter of Earth and is visible even through small backyard telescopes. The colors change as different chemicals and gases are churned up from the bottom layers to the "surface" of the gaseous planet. The winds at the edge of the spot can reach up to 550km per hour. This long-lasting storm was probably first observed by astronomer Giovanni Cassini in the late 1600s. It was not seen up close until NASA's Pioneer 10 spacecraft made its flyby in 1974.

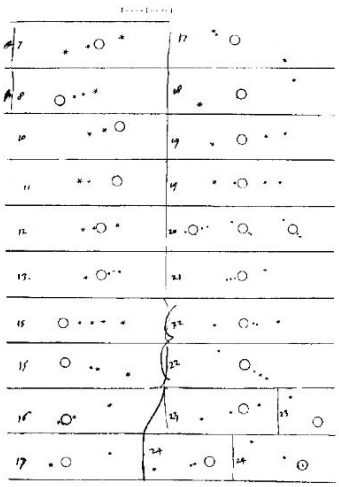
Everything visible in this image is a cloud. Unlike on Earth where only water condenses to form clouds, Jupiter's clouds are made of ammonia, hydrogen sulfide, and water. Jupiter's many jet streams shear clouds apart, forming characteristic streaks. The fastest jet stream winds blow eastward at 480km per hour. The most energetic features are the small, bright clouds to the left of the Great Red Spot—they grow and disappear over a few days and even generate lightning. The striking colors in this image of Jupiter, taken by NASA's Cassini spacecraft in 2000, are very close to the way the human eye would see them.

*Image Credit: NASA/JPL/Space Science Institute*

| Jupiter Details | | | |
|---|---|---|---|
| Diameter | 139,822 km | Rotational Period | 9.8 hrs |
| Distance from Sun | 778,500,000 km (5.2 AU) | Orbital Period | 11.9 yrs |
| Number Moons | 63 | Atmosphere | Hydrogen, helium |
| Temperature | -145C° | Axial Tilt | 3 degrees |
| Mass | 1.9 ×$10^{27}$ kg (about 318 Earths) | Magnetic Field | Strong & complex |

## *Jupiter's 79 Moons, including Io, Europa, Ganymede, Callisto*


Galileo discovered Jupiter's 4 largest moons in 1610, when he used the newly invented telescope to view our night sky. His sketches on the right show how the orbiting moons appeared on subsequent days.



## Io

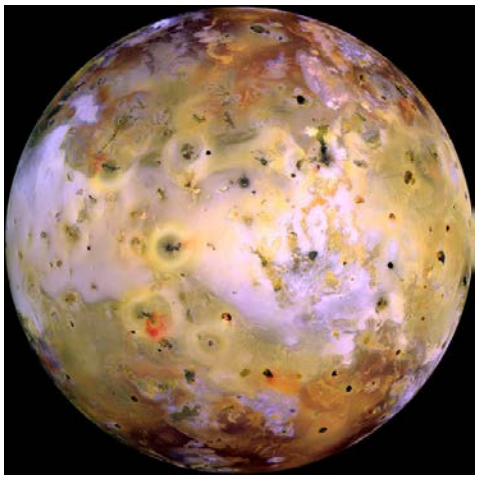


*Image Credit: NASA/JPL/University of Arizona*

This image shows Io, the closest to Jupiter of its moons and one of the most interesting. About the size of Earth's Moon, Io is the most volcanically active body in the solar system. Io's volcanoes erupt massive volumes of silicate lava, sulfur, and sulfur dioxide hundreds of kilometers above the surface, constantly changing Io's appearance. The irregular depressions on the surface, known as paterae, often correspond to active volcanic centers and have many straight edges and sharp angles, suggesting they are related to fractures in Io's crust. In many cases lava can be seen to erupt from them. Io's intense volcanism is a result of frictional heating of its interior due to bending and curving caused by the gravitational pull of Jupiter.

## Europa

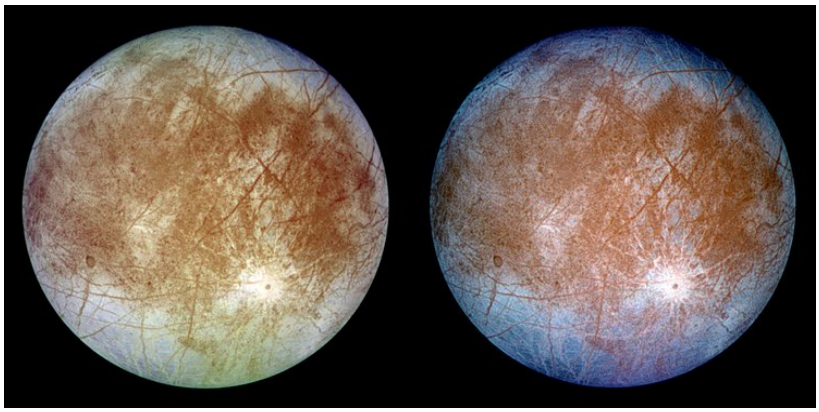


*Image Credit: NASA/JPL/DLR*

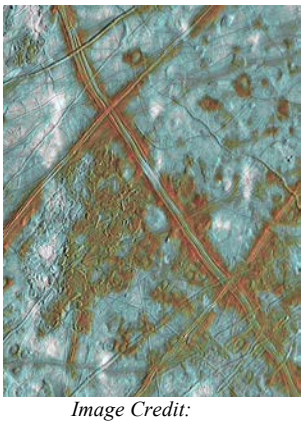


*Image Credit: NASA/JPL/University of Arizona*

Above are two views of Jupiter's icy moon Europa, about the size of Earth's Moon. The left side shows the approximate natural color appearance, while on the right is a false-color composite including infrared data. Dark brown areas represent salty material derived from the interior. Long, dark lines are fractures in the crust, some more than 3,000km long!

**Habitat for life?** Europa excites astrobiologists because of its potential to host life in the 100km thick liquid water ocean that scientists think exists beneath its icy exterior. Europa has many volcanoes, and entire ecosystems have been found thriving near volcanoes (hydrothermal vents) on Earth's seafloor, which serve as analogues to what may exist on Europa. Europa's ocean is covered with a shell of ice about 20km thick which forms the outer surface of the moon. Jupiter's gravitational pull raises and lowers the sea beneath the ice, causing extreme tides. These in turn keep Europa's icy surface in motion, and are probably the cause of the cracks and streaks. The same gravitational pull that affects the

ocean tides is also thought to heat Europa's core, keeping the water from freezing entirely, and driving geological activity. With both liquid water and a stable source of energy present, it is no wonder astrobiologists think Europa could be a habitat for extraterrestrial life!

## Ganymeade

*Image credit: NASA*

Ganymede is the largest moon in the solar system, 8% larger than the planet Mercury! Ganymede is composed of about equal amounts of silicate rock and water ice, with an iron-rich, liquid core. A saltwater ocean is believed to exist nearly 200km below Ganymede's surface, sandwiched between layers of ice. The satellite has a thin oxygen atmosphere that includes O, $O_2$ and possibly $O_3$ (ozone).

Ganymede's surface is composed of two main types of terrain. Dark regions, saturated with impact craters and dated to four billion years ago, cover about a third of the satellite. Lighter regions, crosscut by extensive grooves and ridges and only slightly less ancient, cover the remainder. The cause of the light terrain's disrupted geology is not fully known, but it was likely the result of tectonic activity brought about by the gravitation forces (i.e. tidal heating) by Jupiter.

Ganymede is the only satellite in the solar system known to possess a magnetosphere (protective magnetic shield), likely created through convection within the liquid iron core. The meager magnetosphere is buried within Jupiter's much larger magnetic field and connected to it through open field lines. Whether the satellite has an ionosphere associated with its atmosphere is unresolved.

## Callisto

*Image Credit: NASA*

Callisto, about the size of Mercury, has the most heavily cratered and oldest surface in the solar system. NASA's Galileo mission (1989-2003) observed Callisto, revealing evidence for a subsurface saltwater ocean—the same sort of evidence for the ocean scientists think exists on Europa. Can life emerge and thrive in such cold, lightless oceans? If there's life in one of these two oceans, it is more likely to be Europa's. The ocean there receives more heat because of Europa's stronger gravitational relationship with Jupiter. Callisto's ocean, if it exists, is so deep that dense, high-pressure phases of ice will form at the ocean bottom, possibly blocking liquid water and rock from interacting directly to create conditions for life.

# Saturn

## Ringworld

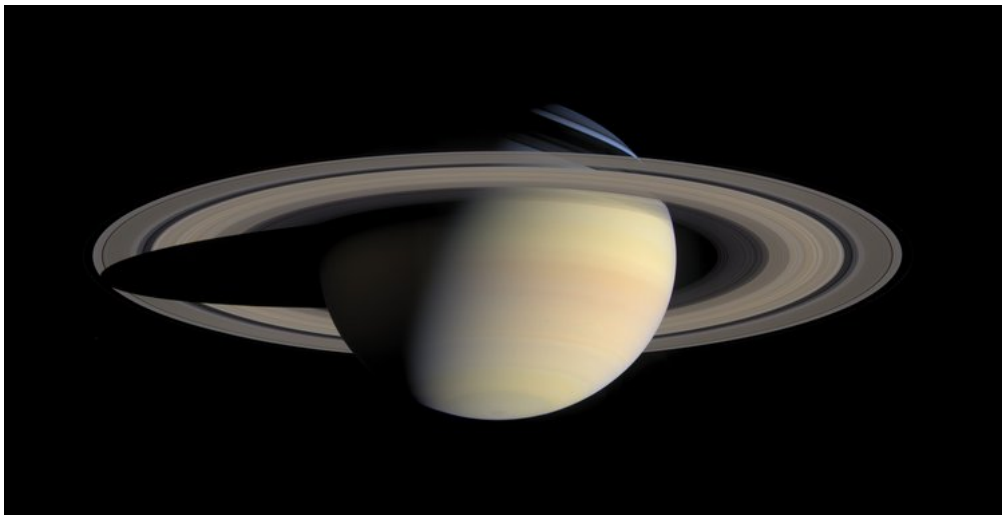
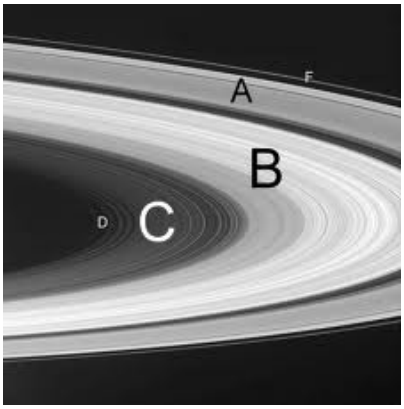


*Image Credit: NASA/JPL/Space Science Institute*

Gaseous Saturn is the second largest planet in the solar system, behind Jupiter. Despite their imposing appearance, the glorious rings around Saturn are only about 10m thick! The rings consist of billions of individual particles of mostly water ice. Interactions with the gravitational field of Saturn's moons create waves, wakes, and other structures. Tiny moons orbit within gaps in the rings, keeping the gaps open. Scientists still are not sure exactly how old the rings are nor how they were formed. But it is clear that the rings we observe today were not all created in the same way.




NASA's Cassini mission discovered that a great plume of icy material emanating from Saturn's moon Enceladus is a major source of material for the expansive E ring. Cassini has also discovered new ringlets, a moon that is stealing particles from the narrow F ring, and features within the rings shaped like straw and rope.

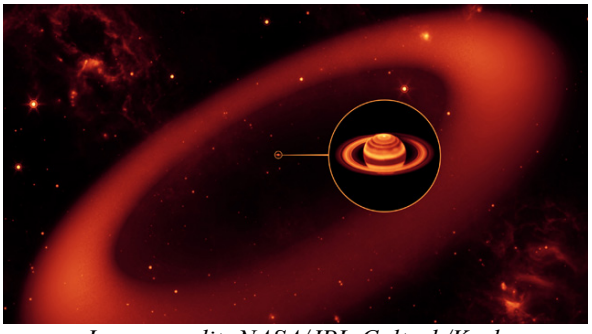


*Image credit: NASA/JPL-Caltech/Keck*

The artist's conception on the left shows a nearly invisible ring around Saturn - the largest of the giant planet's many rings. The new ring was discovered by NASA's Spitzer Space Telescope in 2009.

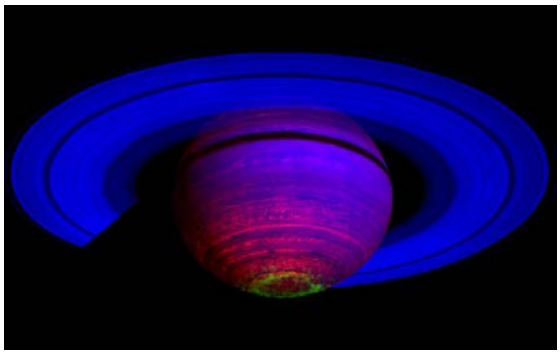


*Image Credit: NASA/JPL/ASI/University of Arizona/University of Leicester (false color)*

Saturn, though far from the Sun, is still subject to the Sun's storms. This false-color composite image, constructed from data obtained by NASA's Cassini spacecraft, shows the glow of aurorae streaking out about 1,000km from the cloud tops of Saturn's south polar region. Shown in green, the aurorae occur when energetic, charged particles from the Sun, carried by the solar wind, interact with Saturn's magnetic field. The dark spots and banded features are clouds and small storms that outline Saturn's deeper weather systems and circulation patterns.

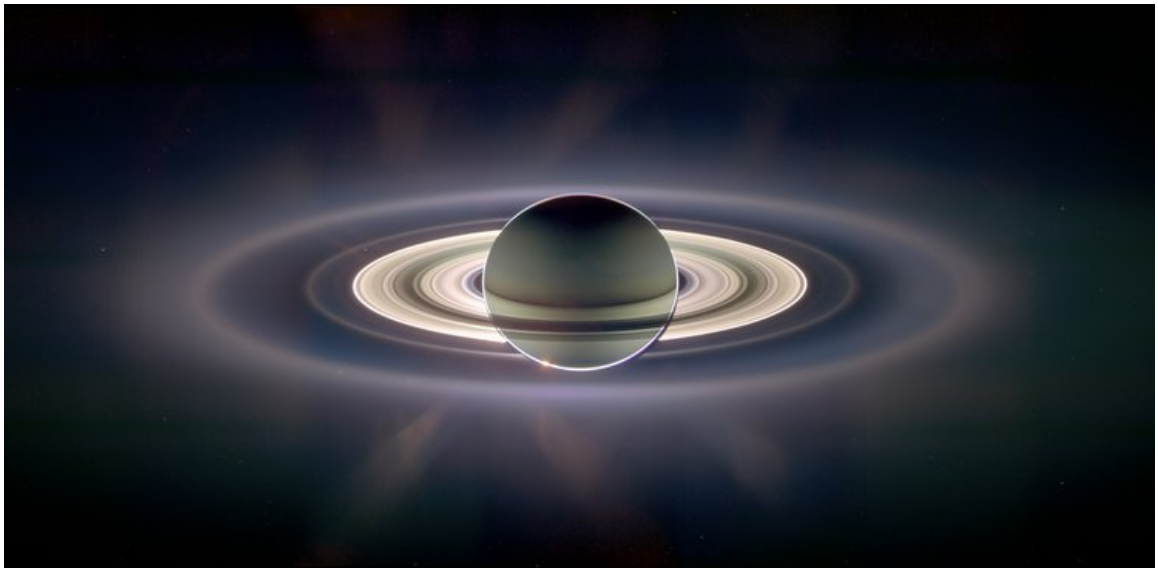


*Image Credit: NASA/JPL/Space Science Institute.*

Saturn's stunning ring system glows with scattered sunlight in this image captured by NASA's Cassini spacecraft as it passed behind the planet in 2006. This image also shows Earth—it is the just-barely-visible white dot at the ten o'clock position between the bright main rings and the thinner, light brown ring.

| Saturn Details | | | |
|---|---|---|---|
| Diameter | 116,464 km | Rotational Period | ~11 hrs |
| Distance from Sun | 1,433,000,000 km (9.5 AU) | Orbital Period | 29.5 yrs |
| Number Moons | 62+ | Atmosphere | Hydrogen, helium |
| Temperature | -178C° | Axial Tilt | 27 degrees |
| Mass | $5.7 \times 10^{26}$ kg (about the same as Earth) | Magnetic Field | Similar to Earth's |

## *Saturn's 82 Moons, including Titan, Enceladus, Iapetus, Hyperion, Phoebe*

Saturn has at least 62 moons, ranging in size from just under 3km to about 5000km. Two of the moons, Titan and Enceladus, are of great interest to astrobiologists: Titan provides an analogue to the chemistry of early Earth, and Enceladus's inner heat and jets of ice and water vapor could be a habitat for extraterrestrial life.

## Titan (and Tethys)

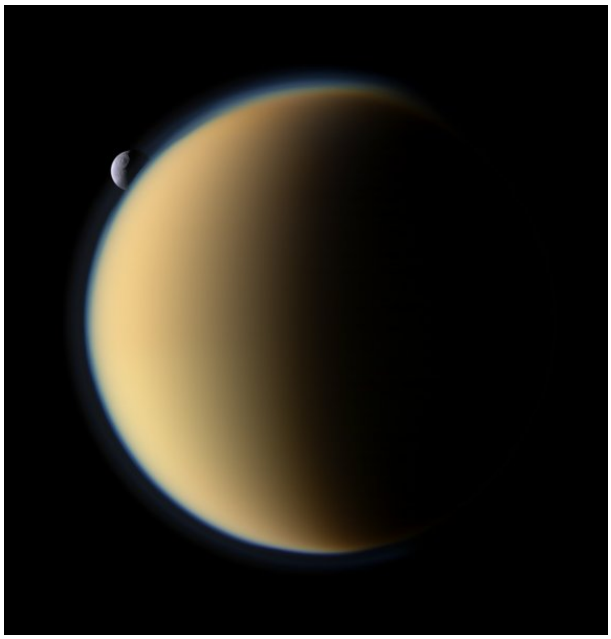


*Image Credit: NASA/JPL/Space Science Institute*

Titan is the largest of the moons orbiting Saturn. Until very recently, our view of Titan was much as it is depicted here: a hazy, orange sphere. NASA's Cassini mission changed all that. Cassini and the Huygens probe it launched into Titan's surface relayed data back to Earth about the atmosphere and weather it encountered. Revealed (see images below) was a world that looked a lot like home, with surface features like riverbeds, vast deserts covered in dunes, and even lakes filled not with water, but liquid hydrocarbons—much like the fuel we put into our cars! These lakes are the first open bodies of liquid found anywhere besides Earth.

Also in the above portrait is one of Saturn's smaller moons, Tethys. Tethys is thought to be made mostly of water ice. Its dominating surface feature is a giant impact crater called Odysseus Crater, which is two-fifths the diameter of Tethys itself.

*Image Credit: NASA/JPL/University of Arizona (false colors)*

NASA's Cassini spacecraft peered through Titan's atmosphere to obtain the false-color views (above) of its surface. Despite its distance from the Sun, Titan is arguably one of

the most Earth-like worlds we have found to date. With its thick atmosphere and complex, carbon-rich chemistry, Titan resembles a frozen version of Earth several billion years ago, before life began pumping oxygen into our atmosphere. Titan's surface is shaped by rivers and lakes of liquid ethane and methane, which form clouds and occasionally rain from the sky as water does on Earth. Winds sculpt vast regions of dark dunes that girdle the equator and low latitudes. Volcanism may occur as well, but with liquid water lava instead of molten rock lava like on Earth.

## Enceladus

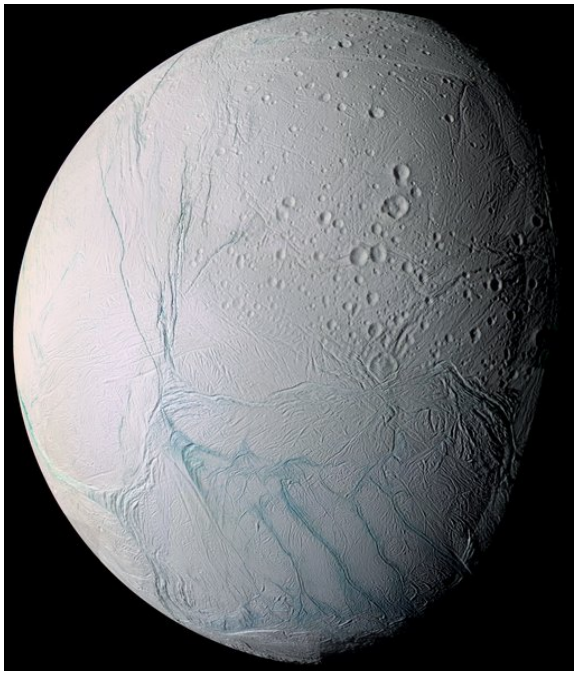


*Image Credit: NASA/JPL/Space Science Institute (false color)*

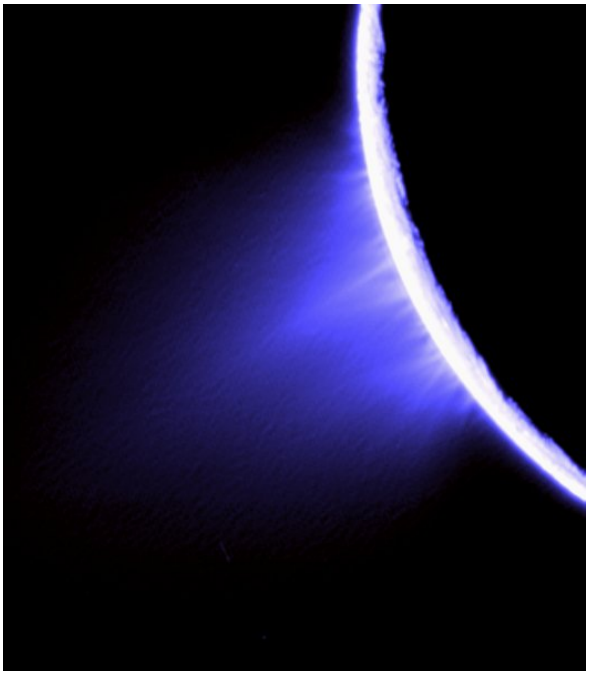


*Image Credit: NASA/JPL/Space Science Institute (false color)*

Close fly-bys of NASA's Cassini spacecraft revealed an array of narrow linear cracks straddling Enceladus's south pole, a region of relatively higher temperature. Visible in the false-color composite image on the left, they are called 'tiger stripes,' and are fissures in the surface where jets are spraying icy particles, water vapor, and organic compounds. Many jets erupt all along the tiger stripes, and the vigor of individual jets can vary with time. Some scientists think that the warmer the temperatures are at the surface, the greater the likelihood that jets are erupting from liquid. If true, could this liquid subsurface environment enriched with organic molecules be a possible habitat for extraterrestrial life? The image above right shows, in spectacular false-color, a view of jets on the surface of Enceladus spurting their ice particles, water vapor, and trace organic molecules into space!

## Iapetus

Iapetus has been called the 'yin and yang' of Saturn's moons because the surface of one of its hemispheres is dark, about as reflective as coal, while the other is much brighter. The original dark material is believed to have come from outside Iapetus, but now it

consists of lag from the sublimation of ice from the warmer areas of Iapetus's surface. It contains organic compounds similar to the substances found in primitive meteorites or on the surface of comets.

*Image Credit: NASA/JPL/Space Science Institute*

*Image credit: NASA/JPL/Cassini-Huygens Mission*

In the image above left, a huge impact crater can be seen in the south, spanning a tremendous 450 kilometers. It appears superposed on an older crater of similar size. The dark material mentioned previously is seen increasingly coating the easternmost part of Iapetus, darkening craters and highlands alike. Close inspection indicates that the dark coating typically faces the moon's equator and is less than a meter thick. A leading hypothesis is that the dark material is mostly dirt leftover when relatively warm but dirty ice sublimates. An initial coating of dark material may have been effectively painted on by the accretion of meteor-liberated debris from other moons.

The image above right shows a prominent feature of Iapetus -- an equatorial ridge that runs along the center of Cassini Regio. It was discovered when the Cassini spacecraft imaged Iapetus in 2004. Peaks in the ridge rise more than 20 km above the surrounding plains, making them some of the tallest mountains in the Solar System.

## Hyperion

Sponge or moon? This stunning image of Hyperion, following, has been enhanced to reveal crisp details across the strange, tumbling moon’s surface. Scientists think Hyperion's somewhat potato-shaped appearance can be attributed to its unusually low density for such a large object, giving it weak surface gravity and high porosity. Hyperion’s craters are particularly deep and there appear to have been landslides inside many of the larger ones. The result is a curious look, somewhat like the surface of a sponge or a wasp nest. Many of the crater walls on Hyperion are bright, suggesting an abundance of water ice.

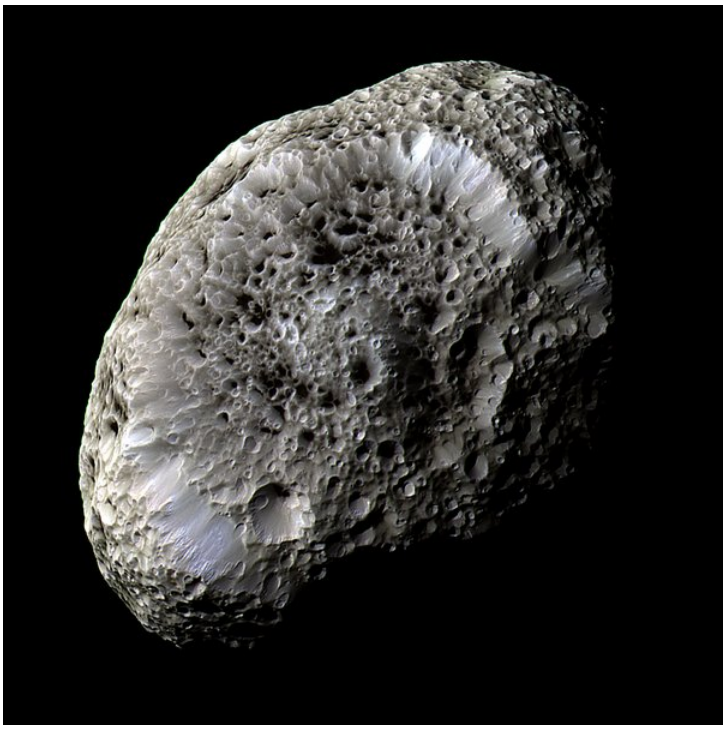


***Image Credit: NASA/JPL/Space Science Institute***

## Phoebe

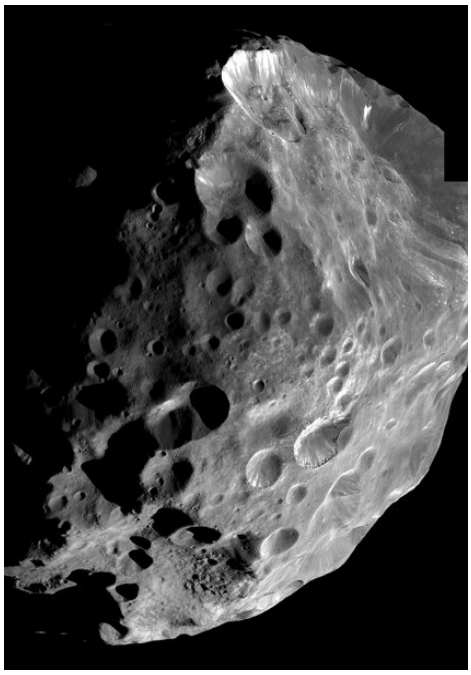


*Image Credit: NASA/JPL/Space Science Institute*

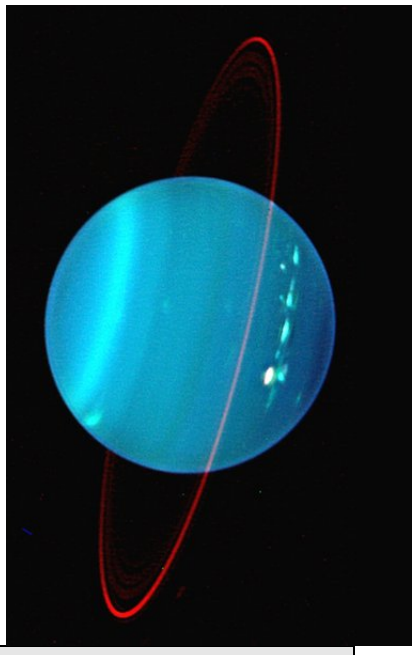
Phoebe's orbit around Saturn is in the opposite direction than the orbits of most objects in the solar system. This suggests Phoebe was a captured object, trapped by Saturn's gravitational pull and brought into orbit. Scientists think Phoebe might have been part of an ancestral population of small, icy bodies called Centaurs which originated in the outer solar system but migrated inward. Centaurs are of special interest to scientists because they are thought to be primordial objects—leftovers of solar system formation that never coalesced into a planet. If indeed it is a captured Centaur, then images and scientific data of Phoebe taken by NASA's Cassini spacecraft give scientists the first opportunity to study a Centaur.

# Uranus

**God of the Sky**

Uranus, third largest planet in our solar system, was discovered by astronomer William Herschel in 1781, and shares its name with the Greek god of the sky. Most of what we know about Uranus came from the NASA Voyager 2 spacecraft's flyby of the planet in 1986. Uranus has nine major, though extremely faint, rings and 27 known moons.

*Image Credit: NASA/JPL (left)*



This image of the gas giant, right, taken in infrared light, reveals cloud structures not normally visible to human eyes. Methane gas in the upper atmosphere absorbs red light, giving the planet its blue-green color. Uranus is spinning on its side, probably because of a collision with a large object early in the solar system's history.

*Image Credit: California Association For Research In Astronomy/Science Photo Library (false color)*

| Uranus Details | | | |
|---|---|---|---|
| Diameter | 50,724 km | Rotational Period | ~17 hrs (on its side) |
| Distance from Sun | 2,877,000,000 km (19 AU) | Orbital Period | 84 yrs |
| Number Moons | 27 | Atmosphere | Hydrogen, helium, methane |
| Temperature | -224C° | Axial Tilt | 98 degrees |
| Mass | 8.68 x $10^{25}$ kg (14 times Earth) | Magnetic Field | Strong dipole but offset |

## *Uranus's 27 Moons*

Taking its first peek at Uranus, NASA Hubble Space Telescope's Near Infrared Camera and Multi-Object Spectrometer (NICMOS) took the images below 90 minutes apart. Because the human eye cannot detect infrared light, false colors were assigned to the images.

The rings of Uranus are extremely faint in visible light, but quite prominent in the near infrared. The brightest ring, the epsilon ring, has a variable width around its circumference. Its widest and thus brightest part is at the top in this image. Two fainter, inner rings are visible next to the epsilon ring.

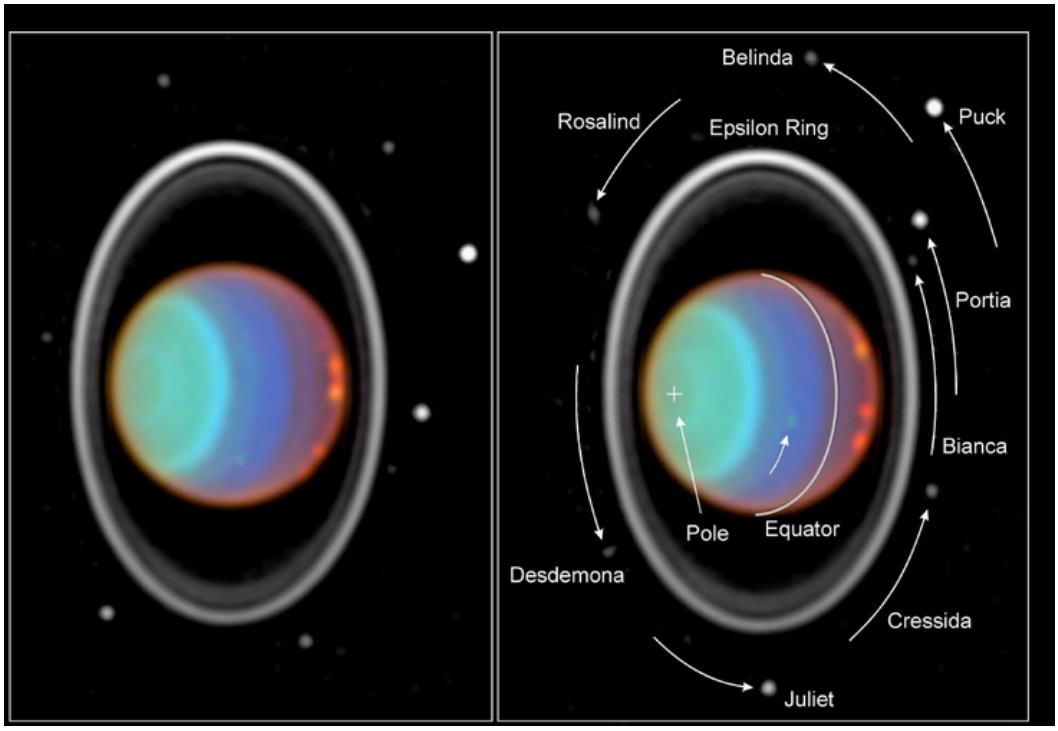


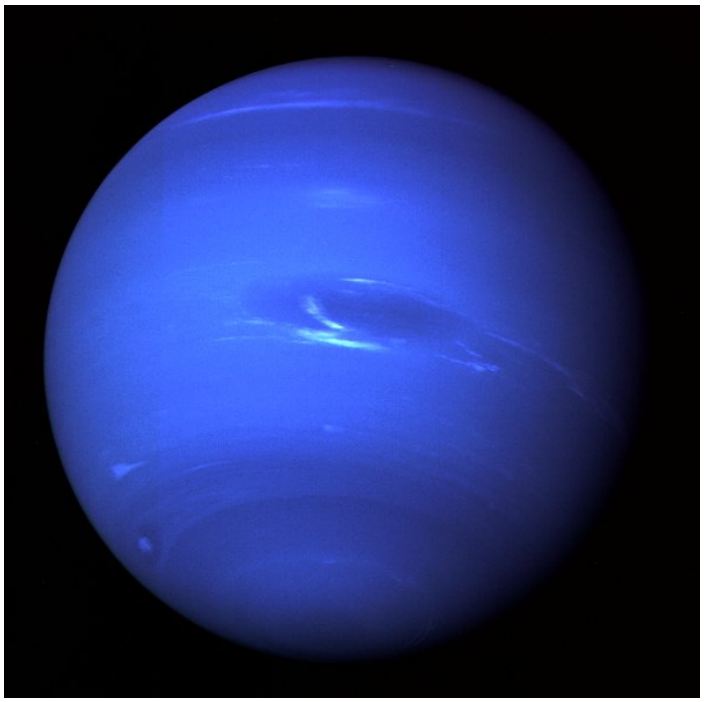

*Image Credit: NASA/Hubble Space Telescope (false color)*

Eight of the 10 small Uranian satellites discovered by Voyager 2 can be seen in the images above. Their sizes range from about 40km for Bianca to 150km for Puck. These eight satellites revolve around Uranus in less than a day, the inner ones faster than the outer. Their motion in the 90 minutes between both images is marked in the right panel. The area outside the rings was slightly enhanced in brightness to improve the visibility of these faint satellites.


*Image credit: NASA*

# Neptune

## Mysterious Cold World



Dark, frigid, and whipped by supersonic winds, Neptune is the furthest away from the Sun of the hydrogen and helium gas giants in our solar system. Its thick atmosphere acts as a dark veil to the surface below. We do know that it has at least 14 moons and a faint ring system, and takes almost 165 Earth years to orbit the Sun. Neptune's atmosphere extends to great depths, gradually merging into water and other melted ices over a heavier, approximately Earth-sized, solid core. In 1989, NASA's Voyager 2 spacecraft tracked a large, oval-shaped storm called the 'Great Dark Spot' (similar to the Great Red Spot on Jupiter). In 1994 when NASA's Hubble Space Telescope imaged the planet, no sign of the Great Dark Spot could be seen.

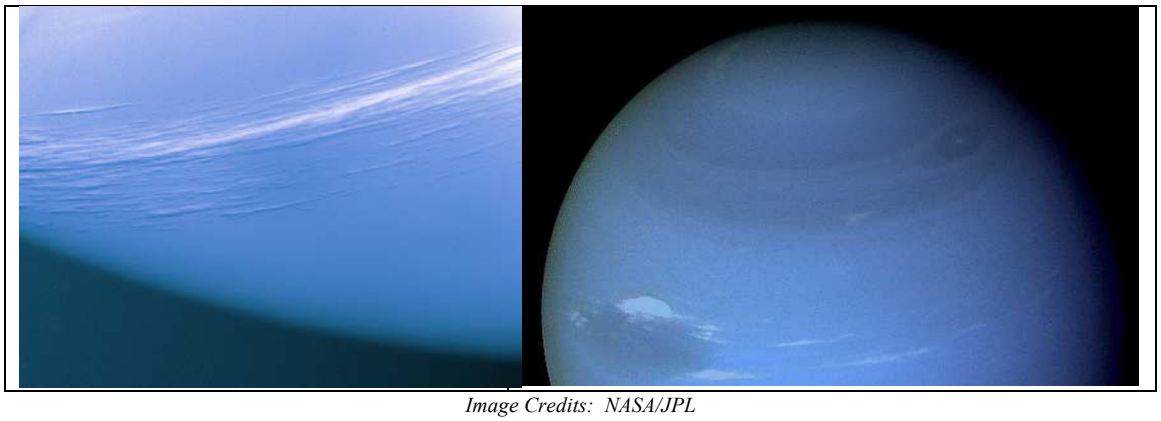


*Image Credits: NASA/JPL*

| Details | | | |
|---|---|---|---|
| Diameter | 49,244 km | Rotational Period | ~16 hrs |
| Distance from Sun | 4,503,000,000 km (30 AU) | Orbital Period | 165 yrs |
| Number Moons | 13 | Atmosphere | Hydrogen, helium, methane |
| Temperature | -210C° | Axial Tilt | 28 degrees |
| Mass | $1.02 \times 10^{26}$kg (about 17 times Earth) | Magnetic Field | Dipole field but at right angles to rotation axis |

## *Neptune's 14 Moons, including Triton*

### Triton

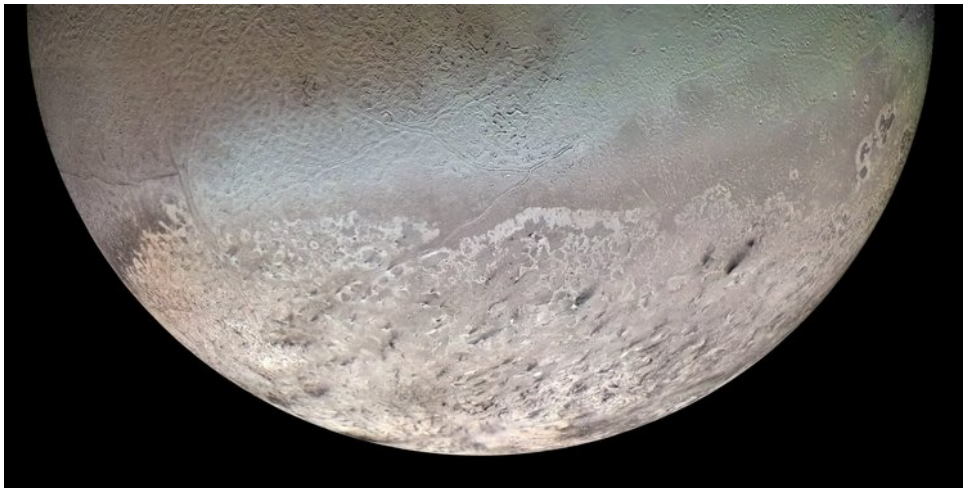


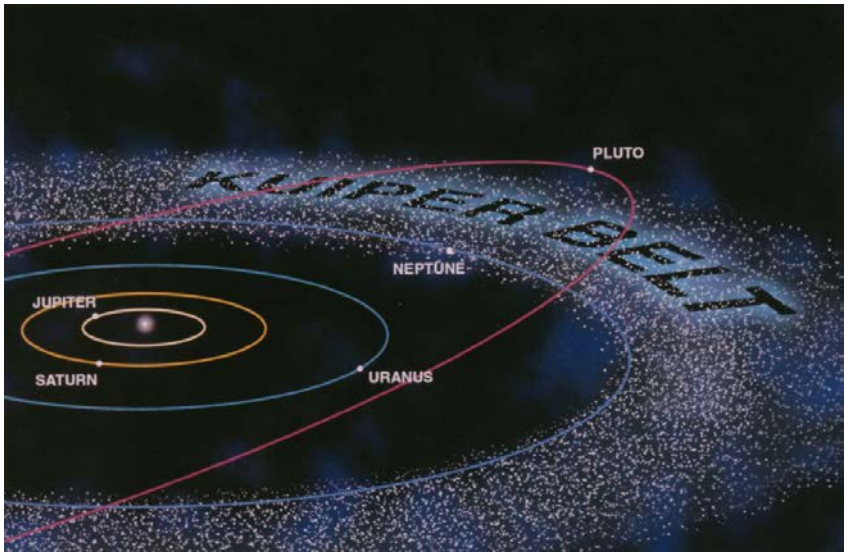
*Image Credit: NASA/JPL/USGS (false color)*

Triton is the largest by far of Neptune's 14 known moons. This beautiful portrait is a false-color mosaic taken in 1989 by NASA's Voyager 2 spacecraft. Triton is one of only a few objects in the solar system known to have a nitrogen-dominated atmosphere (the others are Earth, Saturn's moon Titan, and Pluto). Its frozen surface is made primarily of nitrogen ice, with some methane ice at the south pole. Voyager 2 observed active geyser-like plumes erupting from the surface, perhaps like those active now on Saturn's moon Enceladus. Like Phoebe's orbit around Saturn, Triton orbits Neptune in the opposite direction than the orbits of most objects in the solar system.

The image at left shows Neptune (top) and Triton (background) 3 days after the flyby of Voyager 2.

*Image Credit: NASA*

# The Kuiper Belt, Dwarf Planets, Trans-Neptunian Objects, and Comets

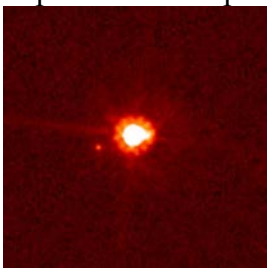



*Artist conception from NASA*

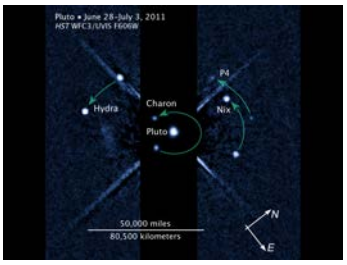
The Kuiper belt is a region of the outer solar system, extending from the orbit of Neptune (at 30 AU[4]) to approximately 50 AU from the Sun. It is similar to the asteroid belt, though far larger — 20 times as wide. Like the asteroid belt, it consists mainly of small bodies, remnants from the solar system's formation. But while the asteroid belt is composed primarily of rock and metals, Kuiper belt objects are made of rocks and frozen ices such as methane, ammonia and water. The Kuiper belt is home to Pluto, Eris, and other dwarf planets and is a source of comets

## *Dwarf Planets*

The International Astronomical Union defines a dwarf planet as a celestial body in direct orbit of the Sun that is massive enough for its shape to be controlled by gravitation (i.e. is round), but that unlike a planet has not cleared its orbital region of other objects. There may be hundreds to thousands of dwarf planets in the solar system. We currently have named five: Ceres, Pluto, Haumea, Makemake, and Eris. Ceres resides in the asteroid belt. The other 4 are part of the Kuiper belt or are trans-Neptunian objects.



*Eris with its moon*



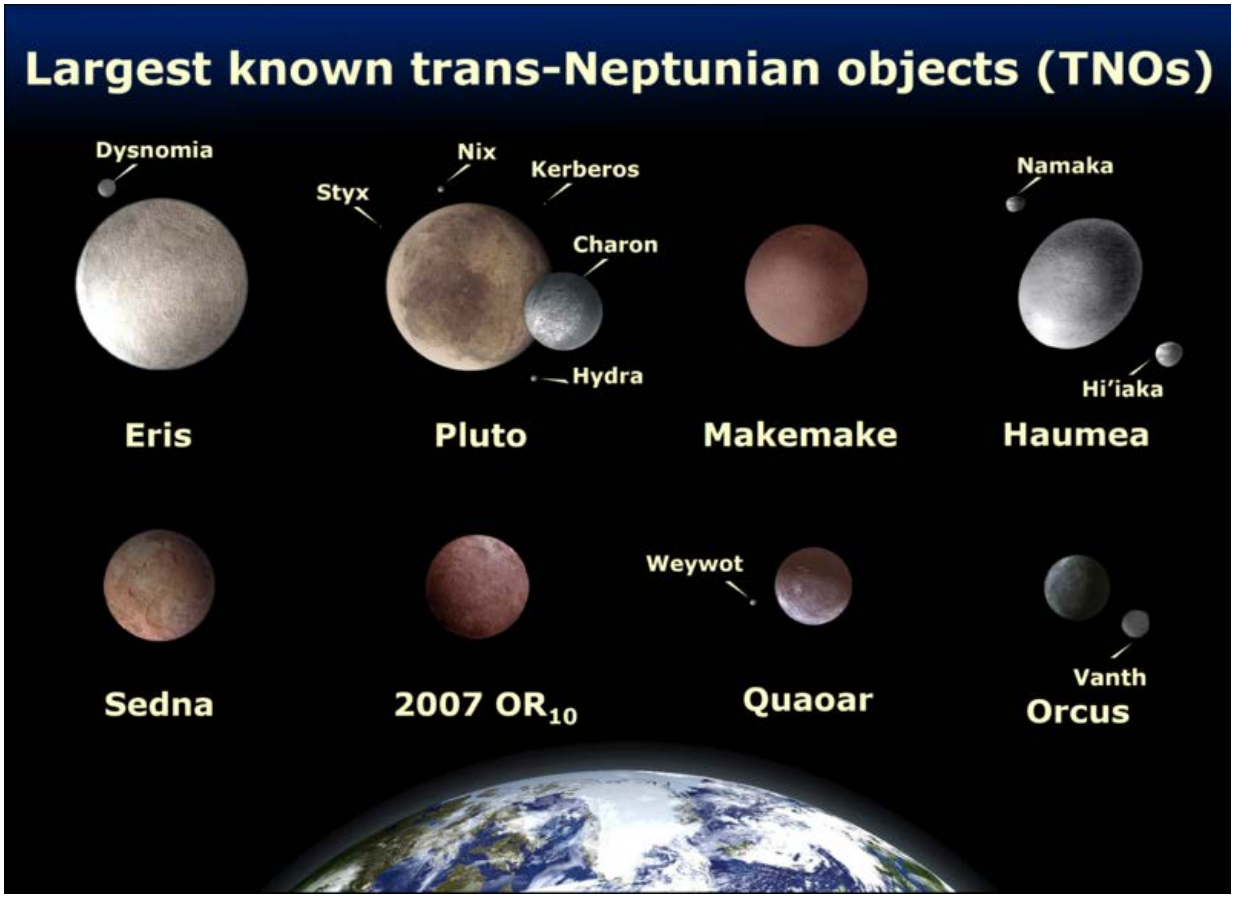

*Pluto and 4 of its 5 moons. (NASA)*

[4] An AU is the mean distance from the Earth to the Sun, about 150,000,000km.

## *Trans-Neptunian Objects*

A trans-Neptunian object (TNO**)** is any object in the solar system that orbits the Sun at a greater average distance than Neptune, hence including objects in the Oort Cloud (more later) as well as the Kuiper belt.

Sedna is a large trans-Neptunian object, which in 2012 was about three times as far from the Sun as Neptune. Like other TNOs its surface is largely a mixture of water, methane and nitrogen ices, though it is also one of the reddest in the solar system. It is probably a dwarf planet. Sedna's exceptionally long and elongated orbit, taking approximately 11,400 years to complete, and distant point of closest approach to the Sun, at 76 AU, have led some astronomers to conclude that it is the first known member of the inner Oort cloud.




*Earth shown to scale* *Credit: NASA/JPL*

# *Comets*

*Image credit: Dan Schechter*


*Image credit: Takacs – Kiss (Uni. Sydney) – Szabo (Uni. Szeged)*

Most comets originate from the Kuiper belt, having been nudged out of their orbits by collisions or the gravity of a passing star. Would there be life on Earth without comets? There is increasing evidence that water and organic molecules, both needed for life to form, were partially delivered to the early Earth by comets. Comets are enriched with water ice. Studies of comet Halley in 1986 revealed it to be some of the most organic-rich material ever measured in the solar system, NASA's 2004 Stardust Mission to Comet Wild 2 found a range of complex hydrocarbon molecules, and NASA's 2005 Deep Impact mission to Comet Tempel 1 discovered a mixture of organic and clay particles. Scientists think comet impacts and deliveries were a common occurrence in the early solar system, but still question if Earth's water was incorporated as it formed or was a result of cometary impacts after formation was complete.

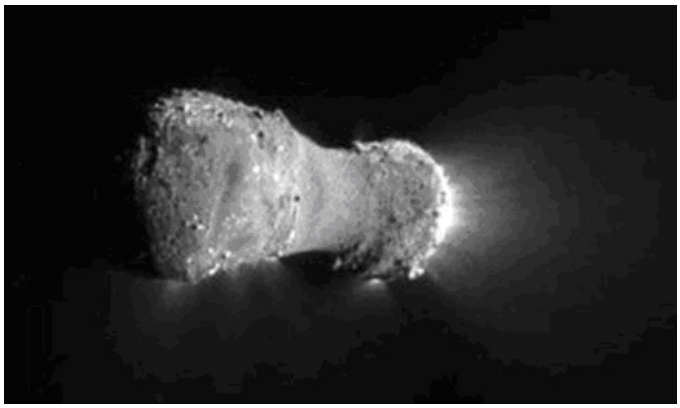


*Image Credit: NASA/JPL-Caltech/UMD*

To the left is a close up of comet Hartley 2. After its encounter with comet Tempel 1 in 2005, NASA recycled its Deep Impact spacecraft and deployed it on a new mission, EPOXI, to investigate comet Hartley 2, hoping to understand how comets form and evolve by comparing EPOXI observations with prior observations of other comets!

The spacecraft made its closest approach with Hartley 2 on November 4, 2010. Preliminary observations show a very active comet! The main region of jet activity originates from the rough lobe on the Sun-facing side of the nucleus. It is powered by the release of subsurface carbon dioxide, propelling water ice and dust into the coma (the comet's extremely tenuous atmosphere). As scientists continue to study the data, they are able to track the jets to individual topographic features on the comet's nucleus. Yet as more observations arise, so do more questions.

## *Interplanetary Dust Particles*

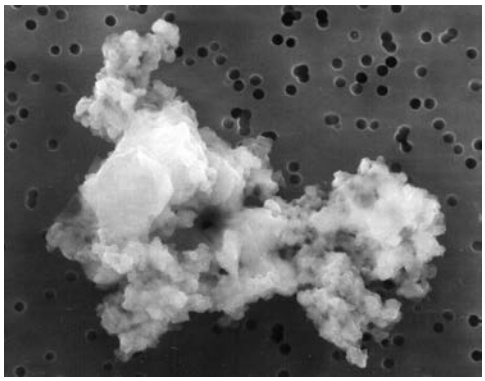


*Image Credit: NASA*

*Image Credit: Pierre Martin of Arnprior, Ontario, Canada.*

Space is not empty. Certainly the smallest "bodies" in the solar system, interplanetary dust particles, or IDPs, are microscopic. This one (above left) is about a tenth the width of a human hair, and is composed of glass, carbon, and a conglomeration of silicate mineral grains (akin to beach sand). IDPs are bits of material from the early days of our solar system. They can be captured then later ejected by a passing comet. This IDP was collected by an aircraft flying high in Earth's atmosphere. In 2004, NASA's STARDUST mission passed through the tail of comet Wild 2, collecting cometary particles and returning them to Earth for study. Primitive material like this offers scientists a glimpse into the conditions of the early solar system.

When large versions of these dust particles chance to enter Earth's atmosphere, they may appear as bright meteors (above right)!

# The Sun's Heliosphere

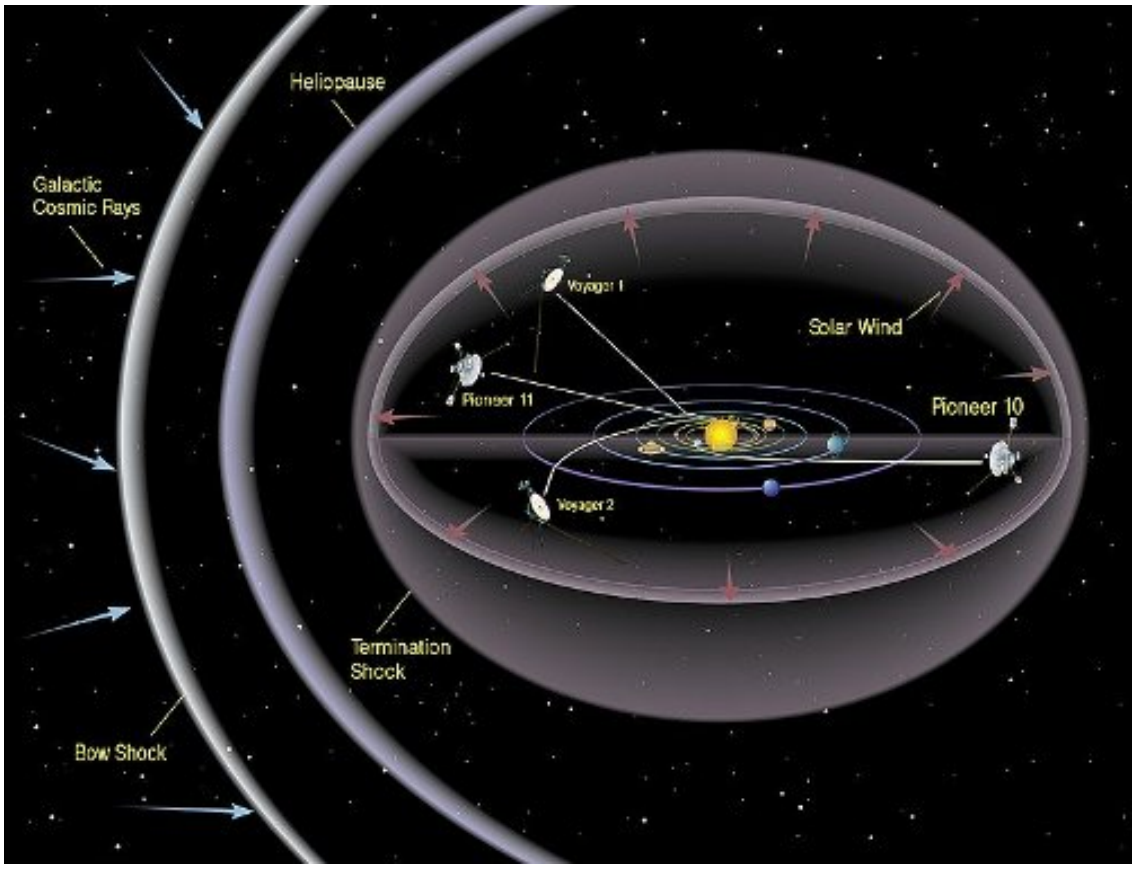


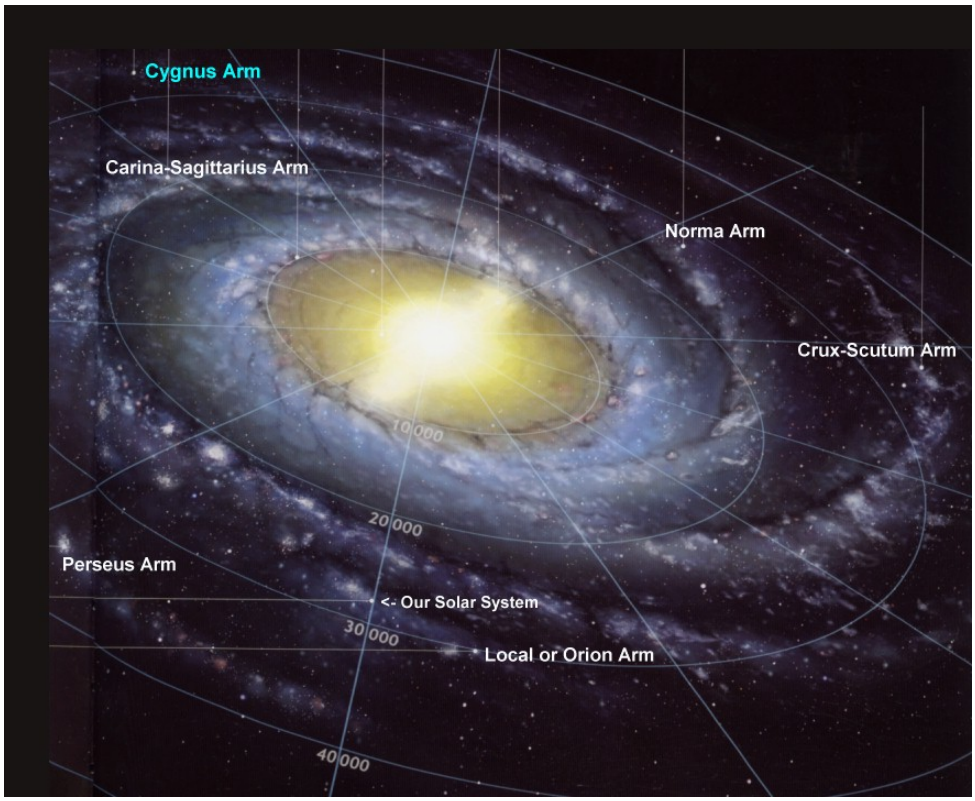

*Image credit: NASA*

The heliosphere is an immense magnetic bubble, originating from the Sun, surrounding and enveloping our solar system and blocking out many of the dangerous cosmic rays coming from our galaxy. It is depicted here as a bubble in space "blown" into the interstellar medium (the hydrogen and helium gas that permeates the galaxy) by the solar wind. Although electrically neutral atoms from the interstellar medium can penetrate this bubble, virtually all of the material in the heliosphere emanates from the Sun itself.

For the first ten billion kilometers of its radius, the solar wind travels at over a million kilometers per hour. As it begins to drop out with the interstellar medium, it slows down before finally ceasing altogether. The point where the solar wind slows down is the Termination Shock. After the Termination Shock is the heliosheath area. Then comes the point where the interstellar medium and solar wind pressures balance – the heliopause. The point where the interstellar medium, traveling in the opposite direction, slows down as it collides with the heliosphere is the bow shock.

It was thought for decades that the heliosphere extends in a long comet-like heliotail, but in 2009 data from Cassini and IBEX show a different shape. The heliosheath area is not smooth but filled with magnetic bubbles pushed out by the solar wind.

# Where Are We?

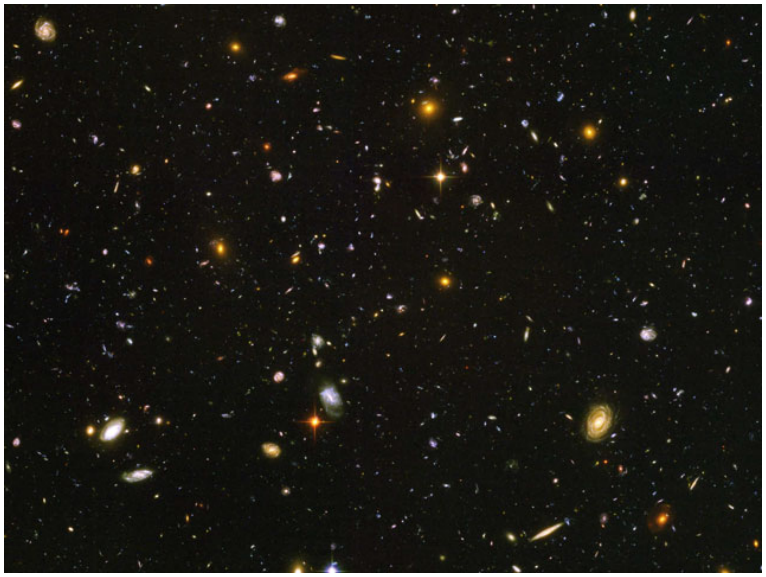



Our galaxy, the Milky Way, is home to our solar system, Earth, a black hole at its center, plus 200-400 billion stars. Our solar system is located about two-thirds of the way out from the center of the galaxy, on the inner edge of the Orion Arm. The Sun orbits the center of the galaxy in a galactic year—once every 225-250 million Earth years. Besides stars, the Milky Way is estimated to have at least 50 billion planets, 500 million of which could be located in the habitable zone of their parent star. New data suggest there may be up to twice as many free-floating planets (planets no longer attached to their stars) in the Milky Way as there are stars. Our Milky Way is one of around 200 billion galaxies in the observable universe.

*Image credits: NASA*

# Our Immense Universe

The Hubble Ultra-Deep Field image below is of a tiny region of space in the constellation Fornax, composited from Hubble Space Telescope data accumulated over a period from September 24, 2003 through January 16, 2004. It is the deepest image of the universe ever taken, looking back approximately 13 billion years (to between 400 and 800 million years after the Big Bang). This image was taken in an "empty" section of the sky with a low density of bright stars in the near-field, allowing much better viewing of dimmer, more distant objects. The image contains an estimated 10,000 galaxies.



Hubble Ultra Deep Field image *courtesy of NASA*

Our Sun is only one of billions of stars in the Milky Way galaxy. And the Milky Way is only one of billions of galaxies in the universe. Do you think we are alone?


*The band of light around the Earth is scattered light in the camera.*
*Image Credit: NASA/Voyager 1*

In 1990, upon request by Carl Sagan, NASA commanded the Voyager 1 spacecraft, having completed its primary mission and now leaving the solar system, to turn its camera around to take a final photograph of Earth across a great expanse of space. The **Pale Blue Dot** is this photograph of planet Earth from over 6 billion kilometers away, showing it against the vastness of space.