National Aeronautics and Space Administration

OUR SOLAR SYSTEM 2013

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Educational Product	
Educators	Grades K–12+

LS-2013-07-003-HQ
JPL 400-1489 07/13

NASA EDUCATIONAL RESOURCES

The NASA portal (*www.nasa.gov*) is the gateway for information about content, programs, and services offered for the general public and the education community. NASA's goal is to improve interactions for students, educators, and families with NASA and its education resources.

NASA's education home page (*www.nasa.gov*; click on "For Educators") serves as the portal for information about educational programs and services offered by NASA. A directory of information provides details and points of contact for all of NASA's educational efforts, NASA field center offices, and points of presence within each state.

A wide variety of NASA educational materials, video clips, and links to other NASA educational websites can be found using the NASA education materials finder at *www.nasa.gov/education/materials*.

Educator Resource Center Network (ERCN)
NASA's Educator Resource Center (ERC) network helps educators learn about NASA educational resources and provides NASA materials.

Regional Educator Resource Centers offer access to NASA educational materials for educators. NASA has formed partnerships with universities, museums, and other educational institutions to serve as Regional ERCs in many states.

Educators may wish to visit an individual NASA field center's ERC website for details on materials, resources, directions, hours of operation, and other information.

Go to *www.nasa.gov* and click on "For Educators" to locate the Regional ERCs.

NASA Wavelength (*www.nasawavelength.org*) is a digital collection of Earth and space science resources for educators of all levels, from elementary to college, to out-of-school programs. The resources were developed through funding from the NASA Science Mission Directorate and have been peer-reviewed by educators and scientists.

The EarthSpace portal (*www.lpi.usra.edu/earthspace*) is a national clearinghouse for higher information space and Earth sciences, with resources for undergraduate education in planetary science and solar and space physics.

NASA multimedia (*www.nasa.gov*) features International Space Station coverage, live special events, interactive educational live shows, electronic field trips, aviation and space news, and historical NASA footage. Links to a variety of NASA resources can be found here, such as the NASA image of the day, videos, audio and video podcasts, and interactive features.

NASA's Solar System Exploration website features formal and informal educational materials — visit *solarsystem.nasa.gov* and click on "Education."

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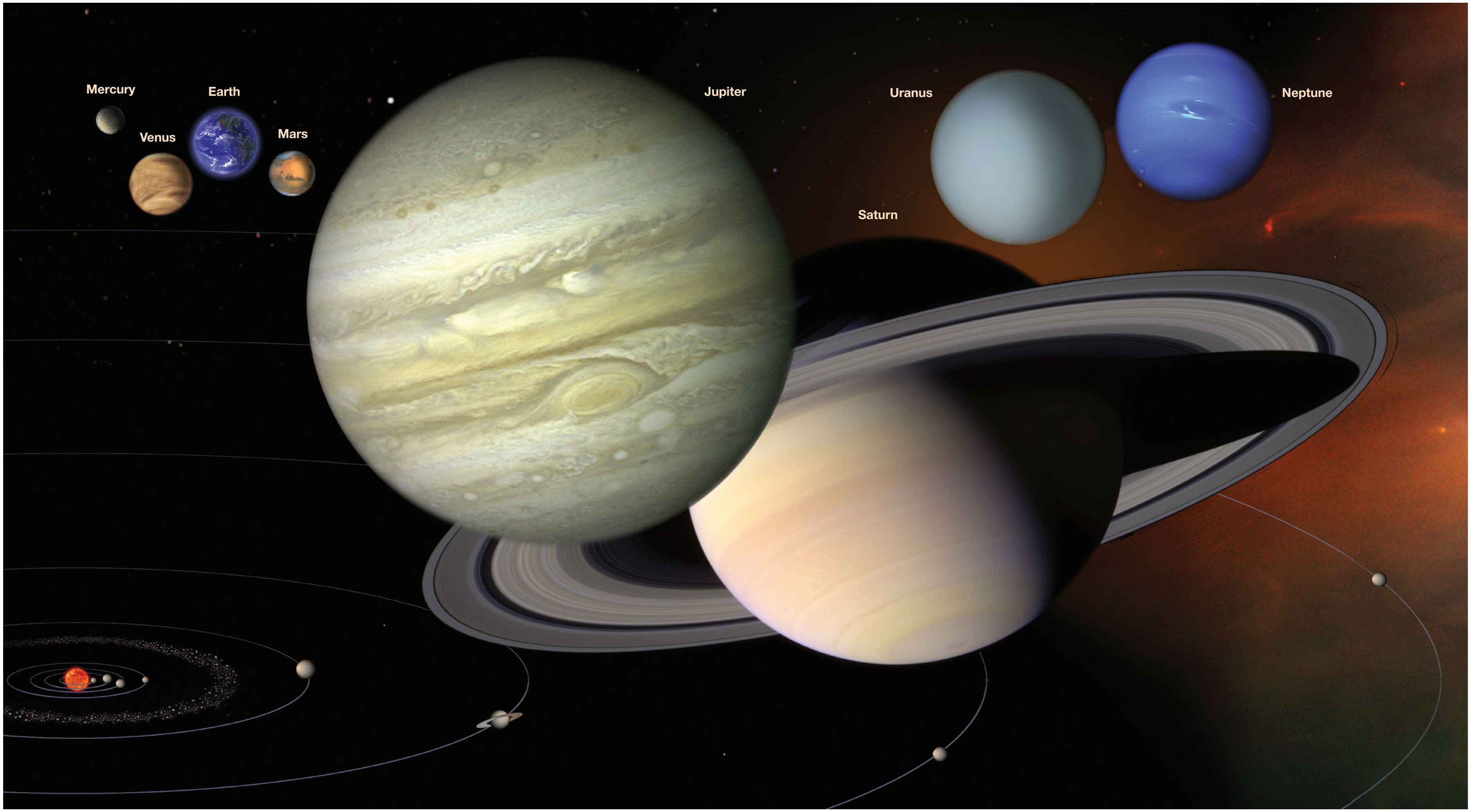

Our Solar System

Humans have gazed at the heavens and tried to understand the cosmos for thousands of years. Ancient civilizations placed great emphasis on careful astronomical observations. Early Greek astronomers were among the first to leave a written record of their attempts to explain the cosmos. For them, the universe was Earth, the Sun, the Moon, the stars, and five glowing points of light that moved among the stars. The Greeks named the five points of light — called *planetes*, or wanderers — after their gods. The Romans later translated the names into Latin — Mercury, Venus, Mars, Jupiter, and Saturn — and these are the names astronomers use today. Planetary features are named by the International Astronomical Union, founded in 1919. For more information about the names of planets, moons, and features, consult the Gazetteer of Planetary Nomenclature website at *planetarynames.wr.usgs.gov*.

Ancient observers believed that the Sun and all the other celestial bodies revolved around Earth. Astronomers gradually realized that the Earth-centered model did not account for the motions of the planets. In the early 17th century, Galileo Galilei's discoveries using the recently invented telescope strongly supported the concept of a "solar system" in which all the planets, including Earth, revolve around a central star — the Sun. Planetary moons, the rings of Saturn, and more planets were eventually discovered: Uranus (in 1781) and Neptune (1846). The largest known asteroid, Ceres, was discovered between Mars and Jupiter in 1801. Originally classified as a planet, Ceres is now designated a dwarf planet (but retains its asteroid label), along with Pluto, which was discovered in 1930; Eris, found in 2003; Haumea, found in 2004; and Makemake, found in 2005. There may be hundreds of dwarf planets in Pluto's realm.

Our solar system formed about 4.6 billion years ago. The four planets closest to the Sun — Mercury, Venus, Earth, and Mars — are called the terrestrial planets because they have solid, rocky surfaces. Two of the outer planets beyond the orbit of Mars — Jupiter and Saturn — are known as gas giants; the more distant Uranus and Neptune are called ice giants.

Earth's atmosphere is primarily nitrogen and oxygen. Mercury has a very tenuous atmosphere, while Venus has a thick atmosphere of mainly carbon dioxide. Mars' carbon dioxide atmosphere is extremely thin. Jupiter and Saturn are composed mostly of hydrogen and helium, while Uranus and Neptune are composed mostly of water, ammonia, and methane, with icy mantles around their cores. The Voyager 1 and 2 spacecraft visited the gas giants, and Voyager 2 flew by and imaged the ice giants. Ceres and the outer dwarf planets — Pluto, Eris, Haumea, and Makemake — have similar compositions and are solid with icy surfaces. NASA spacecraft are en route to two of the dwarf planets — the Dawn mission visits Ceres in 2015 and the New Horizons mission reaches Pluto in that same year. Neither Ceres nor Pluto has been previously visited by any spacecraft.

Moons, rings, and magnetic fields characterize the planets. There are 146 known planetary moons, with at least 27 moons awaiting official recognition. (Three of the dwarf planets have moons: Pluto has five, Eris has one, and Haumea has two.) The planetary moons are not all alike. One (Saturn's Titan) has a thick atmosphere; another has active volcanoes (Jupiter's Io). New moons are frequently discovered, so moon counts can change.

Rings are an intriguing planetary feature. From 1659 to 1979, Saturn was thought to be the only planet with rings. NASA's Voyager missions to the outer planets showed that Jupiter, Uranus, and Neptune also have ring systems.

Most of the planets have magnetic fields that extend into space and form a magnetosphere around each planet. These magnetospheres rotate with the planet, sweeping charged particles with them.

How big is our solar system? To think about the large distances, we use a cosmic ruler based on the astronomical unit (AU). One AU is the distance from Earth to the Sun, which is about 150 million kilometers or 93 million miles. Particles from the Sun can reach far beyond the planets, forming a giant bubble called the heliosphere. The enormous bubble of the heliosphere is created by the solar wind, a stream of charged gas blowing outward from the Sun. As the Sun orbits the center of the Milky Way, the bubble of the heliosphere moves also, creating a bow shock ahead of itself in interstellar space — like the bow of a ship in water — as it crashes into the interstellar gases. The region where the solar wind is abruptly slowed by pressure from gas between the stars is called the termination shock.

Two NASA spacecraft, launched in 1977, have crossed the termination shock — Voyager 1 in 2004 and Voyager 2 in 2007. In late 2011, Voyager 1 data showed that the spacecraft had entered the outermost region of the heliosphere. By 2013, Voyager 1 was about 18 billion kilometers (11 billion miles) from the Sun, and Voyager 2 was about 15 billion kilometers (9 billion miles) from the Sun. Scientists anticipate that Voyager 1 will cross into interstellar space, where gas and dust from other stars are found as well as the enormous Oort Cloud, within a few months to a few years. Both spacecraft should have enough electrical power to send data until at least 2020. It will be thousands of years before the two Voyagers exit the Oort Cloud, a vast spherical shell of icy bodies surrounding the solar system.

As we explore the universe, we wonder: Are there other planets where life might exist? Are we alone? These are the great questions that science is now probing. Only recently have astronomers had the tools — sensitive telescopes on Earth and in space — to detect planets orbiting stars in other solar systems.

FAST FACTS

Body	Equatorial Radius km	Equatorial Radius mi	Mean Distance from the Sun km, millions	Mean Distance from the Sun mi, millions	Moons*
Sun	695,500	432,200	—	—	—
Mercury	2,440	1,516	57.91	35.98	0
Venus	6,052	3,760	108.21	67.24	0
Earth	6,378	3,963	149.60	92.96	1
Moon	1,737	1,080	**	**	—
Mars	3,397	2,111	227.94	141.63	2
Jupiter	71,492	44,423	778.41	483.68	50†
Saturn	60,268	37,449	1,426.73	886.53	53‡
Uranus	25,559	15,882	2,870.97	1,783.94	27
Neptune	24,764	15,388	4,498.25	2,795.08	13$^{\Delta}$

*Known moons as of July 2013. The dwarf planet moons are not included in this list, nor are asteroid moons.
**Mean Earth–Moon distance: 384,400 kilometers or 238,855 miles.
†Jupiter has 17 moons awaiting official confirmation, bringing the total to 67.
‡Saturn has 9 moons awaiting official confirmation, bringing the total to 62.
$^{\Delta}$Neptune has 1 moon awaiting official confirmation, bringing the total to 14.

ABOUT THE ILLUSTRATION

The planets are shown in the upper part of the illustration in their correct order from the Sun and to the same relative size scale. If the distances between the planets were shown at the same scale, the illustration would be miles wide! The correct distance scale between planets is shown in the lower part of the illustration, but the sizes of the planets have been greatly exaggerated (even the Sun would be too small to see at the scale shown). The faint rings of Jupiter, Uranus, and Neptune are not shown. Dwarf planets Pluto, Eris, Haumea, and Makemake do not appear in the illustration. The dwarf planet Ceres is not shown separately; it resides in the asteroid belt between Mars and Jupiter.

FOR MORE INFORMATION

solarsystem.nasa.gov/planets/profile.cfm?Object=SolarSys

solarsystem.nasa.gov/education/

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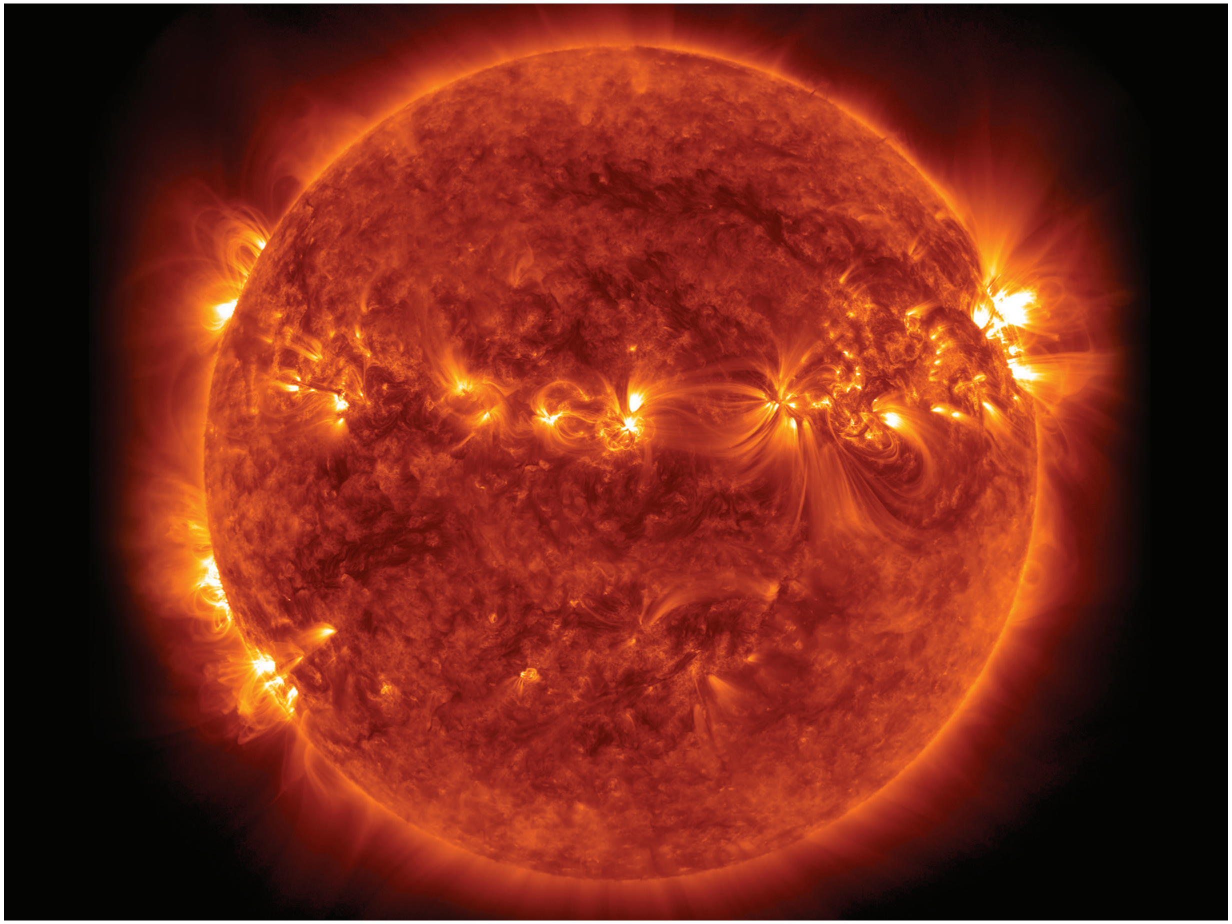
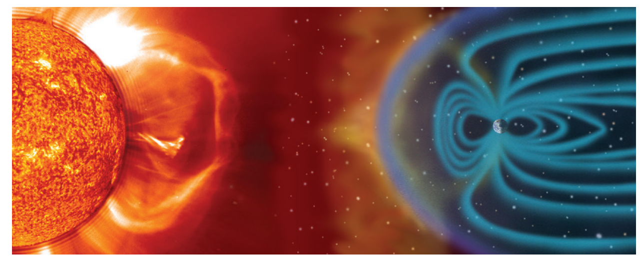
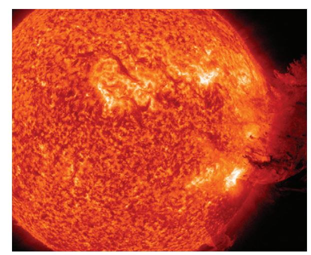
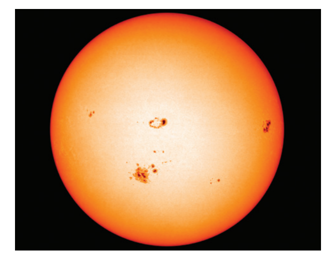
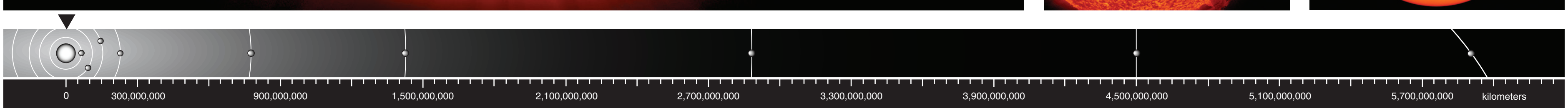










Our Star — The Sun

www.nasa.gov

Our solar system's central star, the Sun, has inspired mythological stories in cultures around the world, including those of the ancient Egyptians, the Aztecs of México, Native American tribes of North America and Canada, the Chinese, and many others. A number of ancient cultures built stone structures or modified natural rock formations to mark the motions of the Sun and Moon — they charted the seasons, created calendars, and monitored solar and lunar eclipses. These architectural sites show evidence of deliberate alignments to astronomical phenomena: sunrises, moonrises, moonsets, even stars or planets. Many cultures believed that the Earth was immovable and the Sun, other planets, and stars revolved about it. Ancient Greek astronomers and philosophers knew this "geocentric" concept from as early as the 6th century BCE. Now we know, of course, that all the planets orbit our lone star — the Sun.

The Sun is the closest star to Earth, at a mean distance from our planet of 149.60 million kilometers (92.96 million miles). This distance is known as an astronomical unit (abbreviated AU), and sets the scale for measuring distances all across the solar system. The Sun, a huge sphere of mostly ionized gas, supports life on Earth. The connection and interactions between the Sun and Earth drive the seasons, ocean currents, weather, and climate.

About one million Earths could fit inside the Sun. It is held together by gravitational attraction, producing immense pressure and temperature at its core. The Sun has six regions — the core, the radiative zone, and the convective zone in the interior; the visible surface (the photosphere); the chromosphere; and the outermost region, the corona. The Sun has no solid surface.

At the core, the temperature is about 15 million degrees Celsius (about 27 million degrees Fahrenheit), which is sufficient to sustain thermonuclear fusion. The energy produced in the core powers the Sun and produces essentially all the heat and light we receive on Earth. Energy from the core is carried outward by radiation, which bounces around the radiative zone, taking about 170,000 years to get from the core to the convective zone. The temperature drops below 2 million degrees Celsius (3.5 million degrees Fahrenheit) in the convective zone, where large bubbles of hot plasma (a soup of ionized atoms) move upwards.

The Sun's "surface" — the photosphere — is a 500-kilometer-thick (300-mile-thick) region, from which most of the Sun's radiation escapes outward and is detected as the sunlight we observe here on Earth about eight minutes after it leaves the Sun. Sunspots in the photosphere are areas with strong magnetic fields that are cooler, and thus darker, than the surrounding region. Sunspot numbers fluctuate every 11 years as part of the Sun's magnetic activity cycle. Also connected to this cycle are bright solar flares and huge coronal mass ejections that blast off of the Sun.

The temperature of the photosphere is about 5,500 degrees Celsius (10,000 degrees Fahrenheit). Above the photosphere lie the tenuous chromosphere and the corona ("crown"). Visible light from these top regions is usually too weak to be seen against the brighter photosphere, but during total solar eclipses, when the Moon covers the photosphere, the chromosphere can be seen as a red rim around the Sun while the corona forms a beautiful white crown with plasma streaming outward, forming the "points" of the crown.

Above the photosphere, temperature increases with altitude, reaching as high as 2 million degrees Celsius (3.5 million degrees Fahrenheit). The source of coronal heating has been a scientific mystery for more than 50 years. Likely solutions emerged from observations by the Solar and Heliospheric Observatory (SOHO) and the Transition Region and Coronal Explorer (TRACE) missions, but the complete answer still evades scientists. Recent missions — Hinode, Solar Terrestrial Relations Observatory (STEREO), and the Solar Dynamics Observatory (SDO) — greatly improved our knowledge of the corona, getting us still closer to the answer. They also give us an unprecedented understanding of the physics of space weather phenomena such as solar flares, coronal mass ejections, and solar energetic particles. Space weather can adversely affect our technology in space and on Earth; these missions help us to develop space weather reports.

FAST FACTS

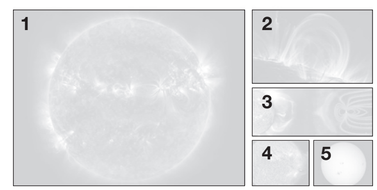
Spectral Type of Star	G2V
Age	4.6 billion years
Mean Distance to Earth	149.60 million km (92.96 million mi) (1 astronomical unit)
Rotation Period at Equator	26.8 days
Rotation Period at Poles	36 days
Equatorial Radius	695,500 km (432,200 mi)
Mass	1.989×10^{30} kg
Density	1.409 g/cm^3
Composition	92.1% hydrogen, 7.8% helium, 0.1% other elements
Surface Temperature (Photosphere)	5,500 deg C (10,000 deg F)
Luminosity*	3.83×10^{33} ergs/sec

*The total energy radiated by the Sun (or any star) per second at all wavelengths.

SIGNIFICANT DATES

150 CE — Greek scholar Claudius Ptolemy writes the *Almagest*, formalizing the Earth-centered model of the solar system. The model was accepted until the 16th century.
1543 — Nicolaus Copernicus publishes *On the Revolutions of the Celestial Spheres* describing his heliocentric (Sun-centered) model of the solar system.
1610 — First observations of sunspots through a telescope made independently by Galileo Galilei and Thomas Harriot.
1645–1715 — Sunspot activity declines to almost zero, possibly causing a "Little Ice Age" on Earth.
1860 — Eclipse observers see a massive burst of material from the Sun; it is the first recorded coronal mass ejection.
1994 — The Ulysses spacecraft makes the first observations of the Sun's polar regions.
2004 — NASA's Genesis spacecraft returns samples of the solar wind to Earth for study.
2007 — NASA's double-spacecraft STEREO mission returns the first three-dimensional images of the Sun.
2009 — After more than 18 years, the Ulysses mission ends.
2010 — SDO is launched and begins observing the Sun in super-high definition.
2011 — The STEREO spacecraft, from their dual perspective, see the entire Sun for the first time.

ABOUT THE IMAGES



1 Active regions spin out bright loops above the Sun that trace magnetic field lines (SDO image in extreme ultraviolet light).

2 Magnetic fields are believed to cause huge, super-hot coronal loops that tower above the Sun's surface (TRACE image).

3 An illustration of a coronal mass ejection and interaction with Earth's magnetic field (not to scale). The pressure from the Sun forces Earth's magnetic field into a windsock shape.

4 The Sun unleashed a solar flare with a spectacular coronal mass ejection on June 7, 2011 (SDO extreme ultraviolet image).

5 These large sunspots in the photosphere were associated with several powerful solar flares in 2003 (SOHO image).

FOR MORE INFORMATION

solarsystem.nasa.gov/sun

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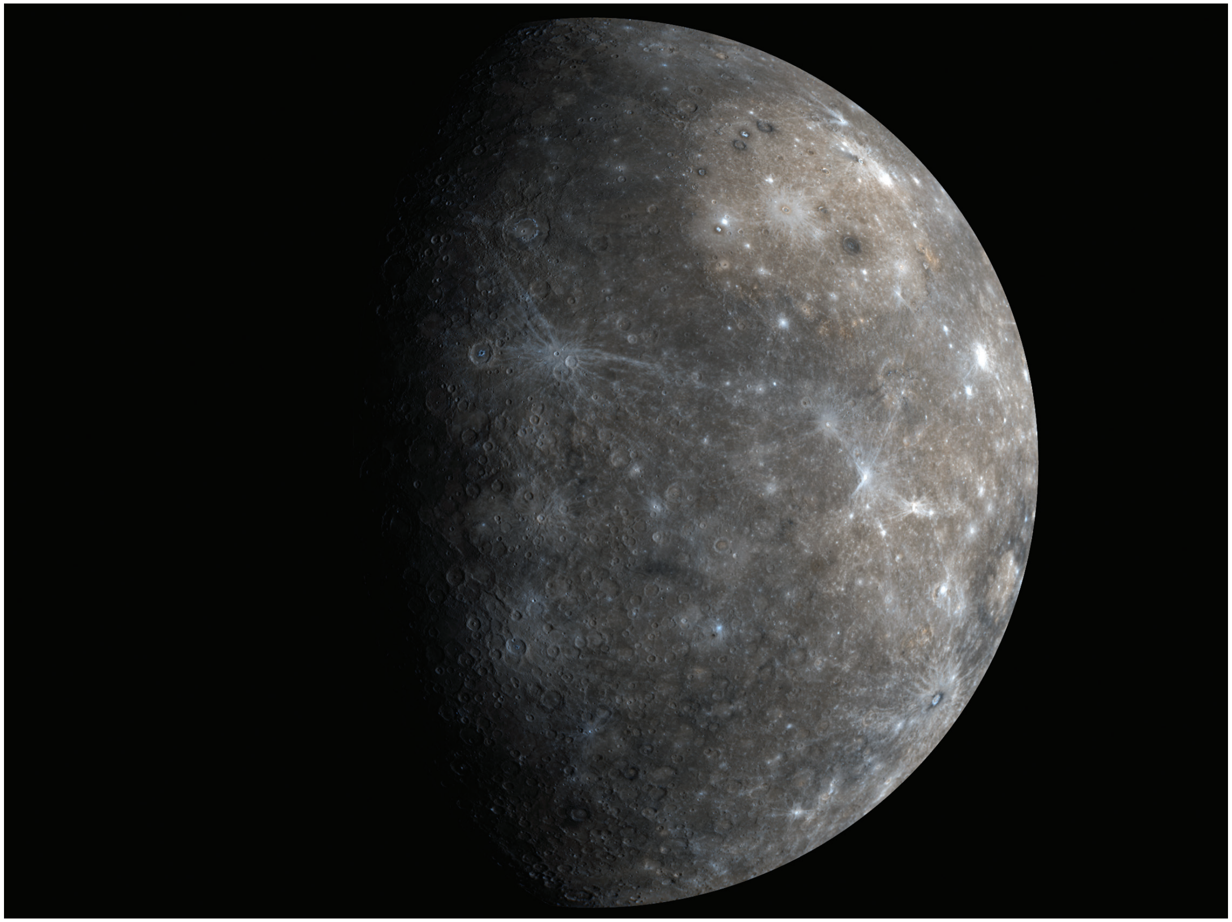

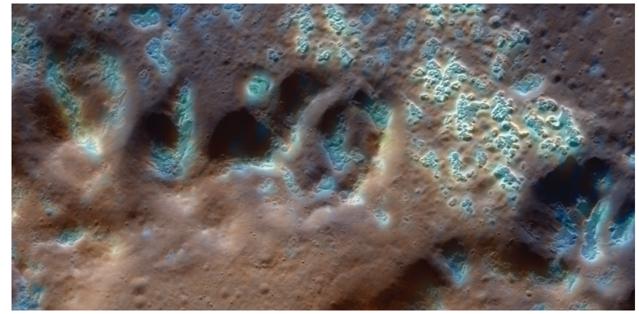

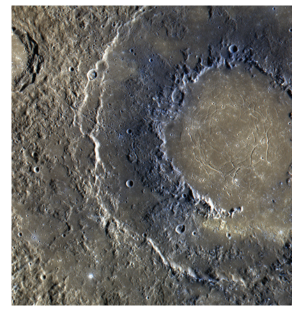

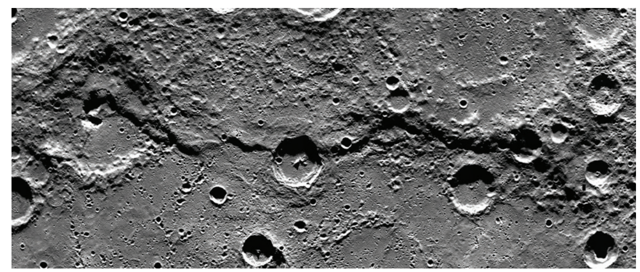

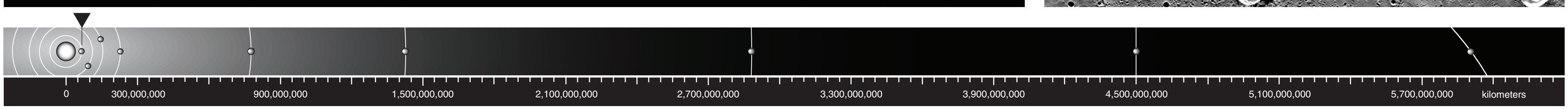
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Mercury

Mercury's eccentric orbit takes the small planet as close as 47 million kilometers (29 million miles) and as far as 70 million kilometers (43 million miles) from the Sun. If one could stand on the scorching surface of Mercury when it is at its closest point to the Sun, the Sun would appear more than three times as large as it does when viewed from Earth. Temperatures on Mercury's surface can reach 430 degrees Celsius (800 degrees Fahrenheit). Because the planet has no atmosphere to retain that heat, nighttime temperatures on the surface can drop to –180 degrees Celsius (–290 degrees Fahrenheit).

Because Mercury is so close to the Sun, it is hard to directly observe from Earth except during dawn or twilight. Mercury makes an appearance indirectly, however — 13 times each century, observers on Earth can watch Mercury pass across the face of the Sun, an event called a transit. These rare transits fall within several days of May 8 and November 10. The first two transits of Mercury in the 21st century occurred May 7, 2003, and November 8, 2006. The next are May 9, 2016, and November 11, 2019.

Mercury speeds around the Sun every 88 days, traveling through space at nearly 50 kilometers (31 miles) per second — faster than any other planet. One Mercury solar day equals 175.97 Earth days.

Instead of an atmosphere, Mercury possesses a thin "exosphere" made up of atoms blasted off the surface by the solar wind and striking micrometeoroids. Because of solar radiation pressure, the atoms quickly escape into space and form a "tail" of neutral particles. Though Mercury's magnetic field at the surface has just 1 percent the strength of Earth's, it interacts with the magnetic field of the solar wind to episodically create intense "magnetic tornadoes" that funnel the fast, hot solar wind plasma down to the surface. When the ions strike the surface, they knock off neutrally charged atoms and send them on a loop high into the sky.

Mercury's surface resembles that of Earth's Moon, scarred by many impact craters resulting from collisions with meteoroids and comets. Very large impact basins, including Caloris (1,550 kilometers, or 960 miles, in diameter) and Rachmaninoff (306 kilometers, or 190 miles), were created by asteroid impacts on the planet's surface early in the solar system's history. While there are large areas of smooth terrain, there are also lobe-shaped scarps or cliffs, some hundreds of miles long and soaring up to a mile high, formed as the planet's interior cooled and contracted over the billions of years since Mercury formed.

Mercury is the second densest planet after Earth, with a large metallic core having a radius of about 2,000 kilometers (1,240 miles), about 80 percent of the planet's radius. In 2007, researchers used ground-based radars to study the core, and found evidence that it is partly molten (liquid). Mercury's outer shell, comparable to Earth's outer shell (called the mantle and crust), is only about 400 kilometers (250 miles) thick.

The first spacecraft to visit Mercury was Mariner 10, which imaged about 45 percent of the surface. NASA's MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission flew by Mercury three times in 2008–2009 and has been in orbit around the planet since March 18, 2011. The entire planet has now been imaged, revealing a surface that has been shaped both by extensive volcanism and impacts.

Data from MESSENGER's scientific instruments have provided a trove of scientific discoveries. These include the identification of a new landform known as "hollows," measurements indicating that Mercury has a remarkably high abundance of the volatile elements sulfur and potassium, and the discoveries that Mercury's magnetic field is offset relative to the planet's equator and that the planet has a highly unusual internal structure. In 1991, astronomers on Earth using radar observations showed that Mercury may have water ice at its north and south poles inside deep craters. MESSENGER observations have shown that the materials identified by radar are present only in regions of permanent shadow, consistent with the idea that they are cold enough to preserve water ice, despite the extreme high temperatures experienced by sunlit parts of the planet.

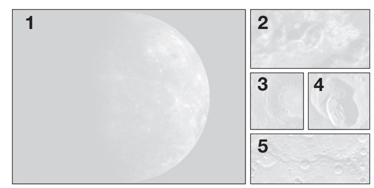
FAST FACTS

Namesake	Messenger of the Roman gods
Mean Distance from the Sun	57.91 million km (35.98 million mi)
Orbit Period	87.97 Earth days
Orbit Eccentricity (Circular Orbit = 0)	0.206
Orbit Inclination to Ecliptic	7 deg
Inclination of Equator to Orbit	0 deg
Rotation Period	58.65 Earth days
Successive Sunrises	175.97 days
Equatorial Radius	2,440 km (1,516 mi)
Mass	0.055 of Earth's
Density	5.43 g/cm^3 (0.98 of Earth's)
Gravity	0.38 of Earth's
Exosphere Components	hydrogen, helium, sodium, potassium, calcium, magnesium
Temperature Range	–180 to 430 deg C (–290 to 800 deg F)
Known Moons	0
Rings	0

SIGNIFICANT DATES

1609 — Thomas Harriott and Galileo Galilei observe Mercury with the newly invented telescope.
1631 — Pierre Gassendi uses a telescope to watch from Earth as Mercury crosses the face of the Sun.
1965 — Incorrectly believing for centuries that the same side of Mercury always faces the Sun, astronomers find that the planet rotates three times for every two orbits.
1974–1975 — Mariner 10 photographs roughly half of Mercury's surface in three flybys.
1991 — Scientists using Earth-based radar find signs of ice locked in permanently shadowed areas of craters in Mercury's polar regions.
2008–2009 — MESSENGER observes Mercury during three flybys.
2011 — MESSENGER begins its orbital mission of Mercury, yielding a treasure trove of images, compositional data, and scientific discoveries.

ABOUT THE IMAGES



1 A MESSENGER visible–infrared mosaic translated to colors the eye can see to accentuate subtle differences in color on the surface.

2 A close-up, enhanced color view of "hollows" located on the peak-ring of Raditladi basin. The image is 20 kilometers (12 miles) tall. A peak-ring basin has two rings; the outer ring is the rim of the basin.

3 A MESSENGER visible–infrared color image of the peak-ring basin Rachmaninoff.

4 The object that formed crater Ailey partially destroyed an older impact crater. Ailey, 21 kilometers (13 miles) in diameter, was imaged by MESSENGER and named in 2012.

5 A mosaic of Victoria Rupes, a scarp nearly 500 kilometers (310 miles) long, imaged by MESSENGER.

FOR MORE INFORMATION

solarsystem.nasa.gov/mercury

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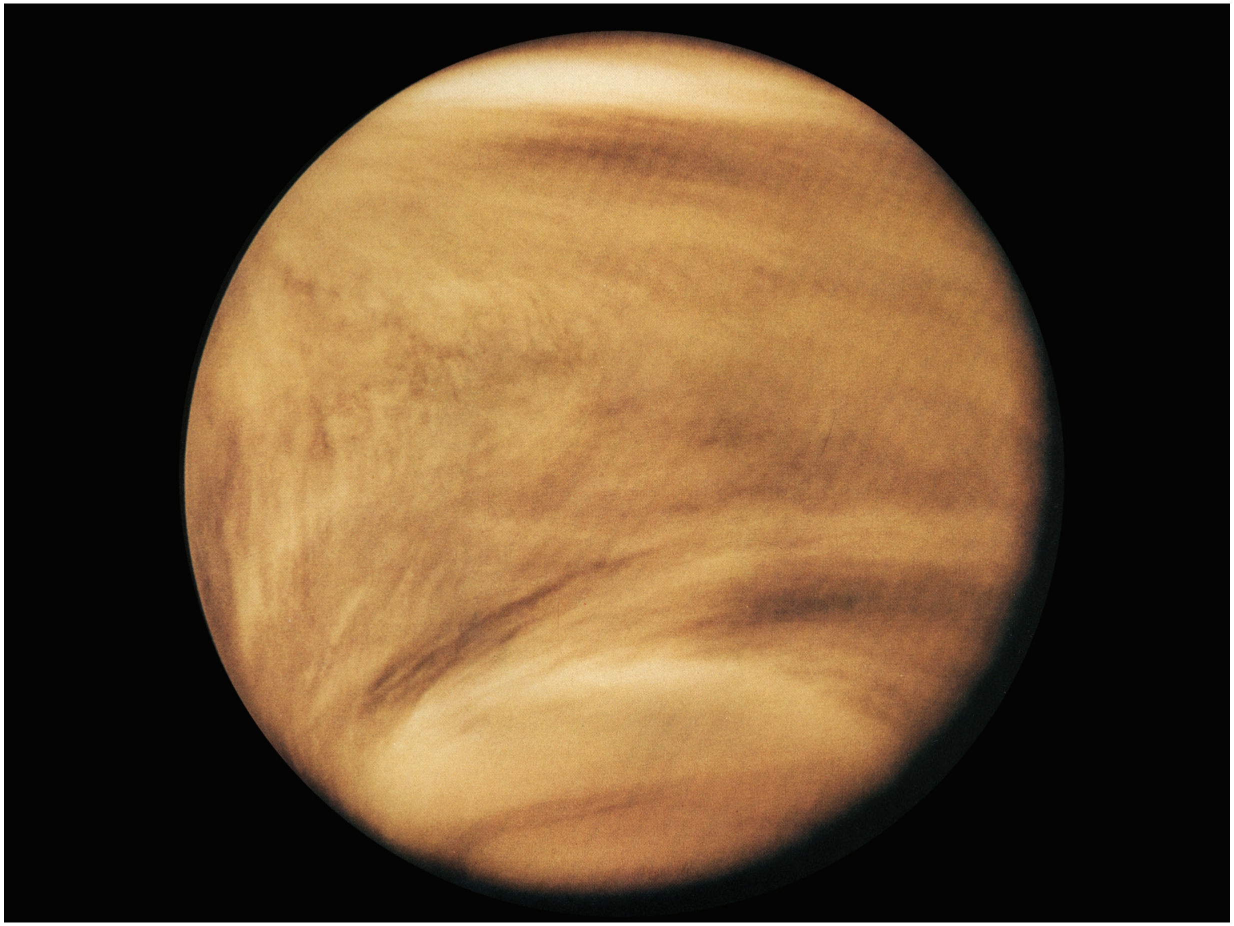

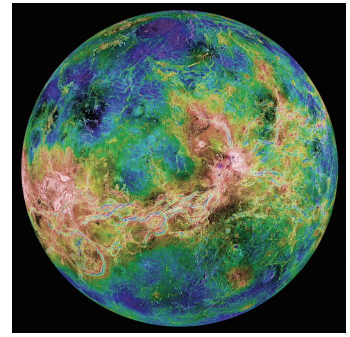

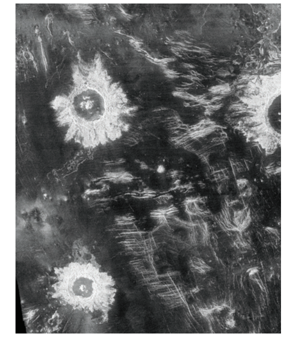

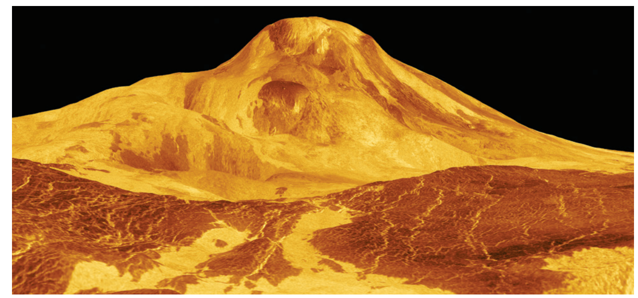

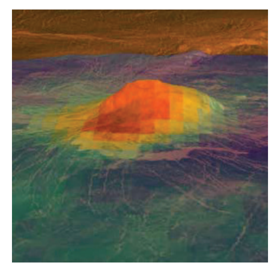

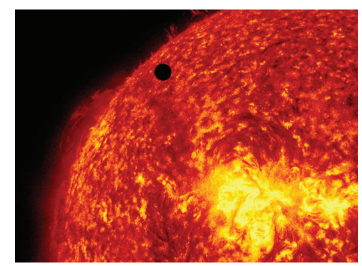

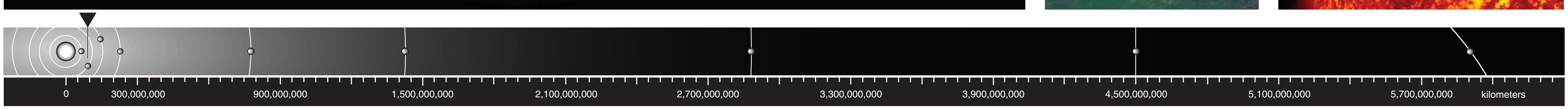
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Venus

Venus and Earth are similar in size, mass, density, composition, and gravity. There, however, the similarities end. Venus is covered by a thick, rapidly spinning atmosphere, creating a scorched world with temperatures hot enough to melt lead and surface pressure 90 times that of Earth (similar to the bottom of a swimming pool 1-1/2 miles deep). Because of its proximity to Earth and the way its clouds reflect sunlight, Venus appears to be the brightest planet in the sky. We cannot normally see through Venus' thick atmosphere, but NASA's Magellan mission during the early 1990s used radar to image 98 percent of the surface, and the Galileo spacecraft used infrared mapping to view both the surface and mid-level cloud structure as it passed by Venus on the way to Jupiter. In 2010, infrared surface images by the European Space Agency's Venus Express provided evidence for recent volcanism within the past several hundred thousand years. Indeed, Venus may be volcanically active today.

Like Mercury, Venus can be seen periodically passing across the face of the Sun. These "transits" of Venus occur in pairs with more than a century separating each pair. Transits occurred in 1631, 1639; 1761, 1769; and 1874, 1882. On June 8, 2004, astronomers worldwide watched the tiny dot of Venus crawl across the Sun; and on June 6, 2012, the second in this pair of transits occurred. The next transit is December 11, 2117. Observing these transits helps us understand the capabilities and limitations of techniques used to find and characterize planets around other stars.

Venus' atmosphere consists mainly of carbon dioxide, with clouds of sulfuric acid droplets. Only trace amounts of water have been detected in the atmosphere. The thick atmosphere traps the Sun's heat, resulting in surface temperatures higher than 470 degrees Celsius (880 degrees Fahrenheit). The few probes that have landed on Venus have not survived longer than 2 hours in the intense heat. Sulfur compounds are abundant in Venus' clouds; the corrosive chemistry and dense, moving atmosphere cause significant surface weathering and erosion.

The Venusian year (orbital period) is about 225 Earth days long, while the planet's rotation period is 243 Earth days, making a Venus day about 117 Earth days long. Venus rotates retrograde (east to west) compared with Earth's prograde (west to east) rotation. Seen from Venus, the Sun would rise in the west and set in the east. As Venus moves forward in its solar orbit while slowly rotating "backwards" on its axis, the top level of cloud layers zips around the planet every four Earth days, driven by hurricane-force winds traveling at about 360 kilometers (224 miles) per hour. Speeds within the clouds decrease with cloud height, and at the surface are estimated to be just a few kilometers per hour. How this atmospheric "super-rotation" forms and is maintained continues to be a topic of scientific investigation.

Atmospheric lightning bursts, long suspected by scientists, were confirmed in 2007 by the European Venus Express orbiter. On Earth, Jupiter, and Saturn, lightning is associated with water clouds, but on Venus, it is associated with sulfuric acid clouds.

Craters smaller than 1.5 to 2 kilometers (0.9 to 1.2 miles) across do not exist on Venus, because small meteors burn up in the dense atmosphere before they can reach the surface. It is thought that Venus was completely resurfaced by volcanic activity 300 to 500 million years ago. More than 1,000 volcanoes or volcanic centers larger than 20 kilometers (12 miles) in diameter dot the surface. Volcanic flows have produced long, sinuous channels extending for hundreds of kilometers. Venus has two large highland areas — Ishtar Terra, about the size of Australia, in the north polar region; and Aphrodite Terra, about the size of South America, straddling the equator and extending for almost 10,000 kilometers (6,000 miles). Maxwell Montes, the highest mountain on Venus and comparable to Mount Everest on Earth, is at the eastern edge of Ishtar Terra.

Venus has an iron core that is approximately 3,000 kilometers (1,200 miles) in radius. Venus has no global magnetic field — though its core iron content is similar to that of Earth, Venus rotates too slowly to generate the type of magnetic field that Earth has.

FAST FACTS

Namesake	Roman goddess of love and beauty
Mean Distance from the Sun	108.21 million km (67.24 million mi)
Orbit Period	224.70 Earth days
Orbit Eccentricity (Circular Orbit = 0)	0.0068
Orbit Inclination to Ecliptic	3.39 deg
Inclination of Equator to Orbit	177.3 deg
Rotation Period	243.02 Earth days (retrograde)
Successive Sunrises	116.75 days
Equatorial Radius	6,052 km (3,760 mi)
Mass	0.815 of Earth's
Density	5.24 g/cm^3 (0.95 of Earth's)
Gravity	0.91 of Earth's
Atmosphere Primary Component	carbon dioxide
Temperature at Surface	470 deg C (880 deg F)
Known Moons	0
Rings	0

SIGNIFICANT DATES

650 CE — Mayan astronomers make detailed observations of Venus, leading to a highly accurate calendar.

1761–1769 — Two European expeditions to watch Venus cross in front of the Sun lead to the first good estimate of the Sun's distance from Earth.

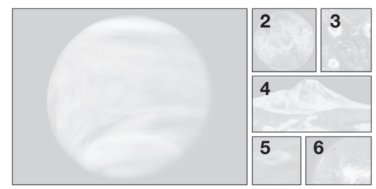
1962 — NASA's Mariner 2 reaches Venus and reveals the planet's extreme surface temperatures. It is the first spacecraft to send back information from another planet.

1970 — The Soviet Union's Venera 7 sends back 23 minutes of data from the surface of Venus. It is the first spacecraft to successfully land on another planet.

1990–1994 — NASA's Magellan spacecraft, in orbit around Venus, uses radar to map 98 percent of the planet's surface.

2005 — The European Space Agency launches Venus Express to study the atmosphere and surface. The orbiter reached Venus in April 2006, and will study the planet through at least December 31, 2014. Japan's Akatsuki ("Dawn") orbiter is en route to Venus, scheduled to arrive in 2015. Combining the Venus Express and Akatsuki datasets should greatly enhance our knowledge of the planet.

ABOUT THE IMAGES



1 A 1979 Pioneer Venus image of Venus' clouds seen in ultraviolet.

2 This composite global view created from Magellan radar images is color-coded to represent varying elevations.

3 This Magellan radar image reveals impact craters.

4 Magellan radar images were used to create this three-dimensional view of Venus' Maat Mons volcano (vertical scale is exaggerated 22.5 times).

5 This false-color composite image of Magellan radar and Venus Express infrared data show emissivity (orange) of the ground overlying a volcanic peak, characteristic of young, unweathered volcanic basalts less than a few hundred years old.

6 This view of Venus transiting the face of the Sun on June 6, 2012, was taken by NASA's Solar Dynamics Observatory.

FOR MORE INFORMATION

solarsystem.nasa.gov/venus

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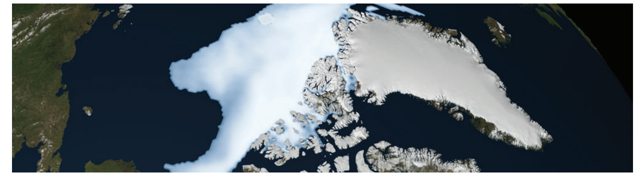

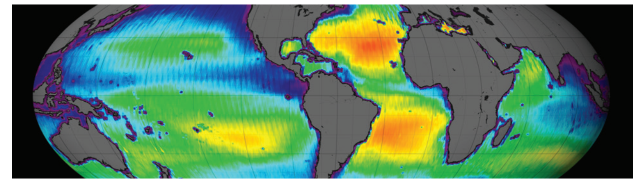

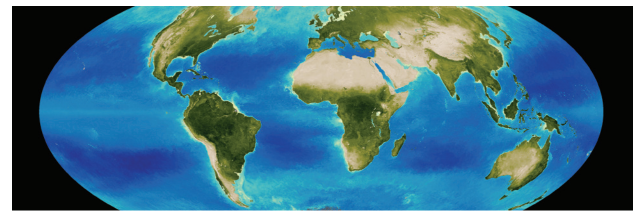

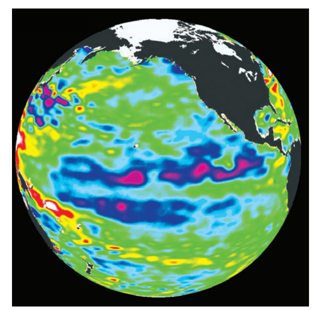

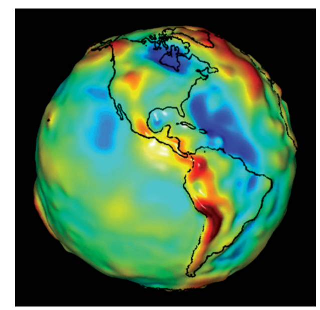

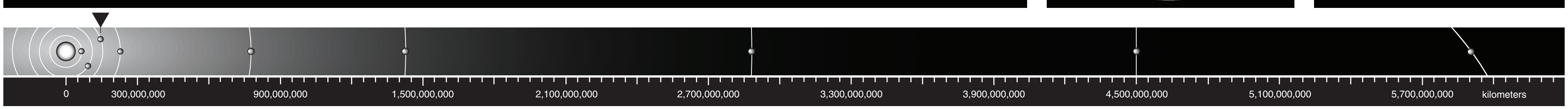
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Earth

Earth, our home planet, is the only planet in our solar system known to harbor life — life that is incredibly diverse. All the things we need to survive exist under a thin layer of atmosphere that separates us from the cold, airless void of space.

Earth is made up of complex, interactive systems that create a constantly changing world that we are striving to understand. From the vantage point of space, we are able to observe our planet globally, using sensitive instruments to understand the delicate balance among its oceans, air, land, and life. NASA satellite observations help study and predict weather, drought, pollution, climate change, and many other phenomena that affect the environment, economy, and society.

Earth is the third planet from the Sun and the fifth largest in the solar system. Earth's diameter is just a few hundred kilometers larger than that of Venus. The four seasons are a result of Earth's axis of rotation being tilted 23.45 degrees with respect to the plane of Earth's orbit around the Sun. During part of the year, the northern hemisphere is tilted toward the Sun and the southern hemisphere is tilted away, producing summer in the north and winter in the south. Six months later, the situation is reversed. When spring and fall begin, both hemispheres receive roughly equal amounts of solar illumination.

Earth's global ocean, which covers nearly 70 percent of the planet's surface, has an average depth of about 4 kilometers (2.5 miles). Fresh water exists in the liquid phase only within a narrow temperature span — 0 to 100 degrees Celsius (32 to 212 degrees Fahrenheit). This span is especially narrow when contrasted with the full range of temperatures found within the solar system. The presence and distribution of water vapor in the atmosphere is responsible for much of Earth's weather.

Near the surface, an atmosphere that consists of 78 percent nitrogen, 21 percent oxygen, and 1 percent other ingredients envelops us. The atmosphere affects Earth's long-term climate and short-term local weather, shields us from much of the harmful radiation coming from the Sun, and protects us from meteors as well — most of which burn up before they can strike the surface as meteorites. Our planet's rapid rotation and molten nickel–iron core give rise to a magnetic field, which the solar wind distorts into a teardrop shape in space. (The solar wind is a stream of charged particles continuously ejected from the Sun.) When charged particles from the solar wind become trapped in Earth's magnetic field, they collide with air molecules above our planet's magnetic poles. These air molecules then begin to glow, and are known as the aurorae — the northern and southern lights.

Earth's lithosphere, which includes the crust (both continental and oceanic) and the upper mantle, is divided into huge plates that are constantly moving. For example, the North American plate moves west over the Pacific Ocean basin, roughly at a rate equal to the growth of our fingernails. Earthquakes result when plates grind past one another, ride up over one another, collide to make mountains, or split and separate. Unifying centuries of Earth sciences studies, the theory of motion of lithospheric plates was developed within only the last 47 years.

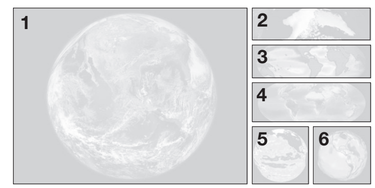
FAST FACTS

Mean Distance from the Sun	149.60 million km (92.96 million mi) (1 astronomical unit)
Orbit Period	365.26 days
Orbit Eccentricity (Circular Orbit = 0)	0.0167
Orbit Inclination to Ecliptic	0.00005 deg
Inclination of Equator to Orbit	23.45 deg
Rotation Period	23.93 hr
Successive Sunrises	24.00 hr
Equatorial Radius	6,378 km (3,963 mi)
Mass	5.9737×10^{24} kg
Density	5.515 g/cm^3
Gravity (Global Average)	9.8 m/sec^2 (32.15 ft/sec^2)
Atmosphere Primary Components	nitrogen, oxygen
Surface Temperature Range	–88 to 58 deg C (–126 to 136 deg F)
Known Moons	1
Rings	0

SIGNIFICANT DATES

1960 — NASA launches the Television Infrared Observation Satellite (TIROS), the first weather satellite.
1972 — The Earth Resources Technology Satellite 1 (renamed Landsat 1) is launched.
1987 — NASA's Airborne Antarctic Ozone Experiment helps determine the cause of the Antarctic ozone hole.
1992 — TOPEX/Poseidon, a U.S.–France mission, begins measuring sea-surface height. Jason 1 continues in 2001.
1997 — TOPEX/Poseidon captures the onset of one of the largest El Niño events of the 20th century.
1997 — The U.S.–Japan Tropical Rainfall Measuring Mission is launched to provide 3-D maps of storm structure.
1999 — Quick Scatterometer (QuikScat) launches in June to measure ocean surface wind velocity; in December the Active Cavity Irradiance Monitor Satellite launches to monitor the total amount of the Sun's energy reaching Earth.
1999–2006 — A series of satellites is launched to provide global observations of the Earth system: Terra (land, oceans, atmosphere), Aqua (water cycle), Aura (atmospheric chemistry) CloudSat (clouds), and the Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observation mission (aerosols, clouds).
2002 — The Gravity Recovery and Climate Experiment launches to monitor mass variations associated with land features and water movement.
2006 — The Antarctic ozone hole was the largest yet observed.
2007 — Arctic sea ice reaches the all-time minimum since satellite records began.
2008 — The third U.S.–France mission to measure sea-level height, Ocean Surface Topography Mission/Jason 2, is launched, doubling global data coverage.
2009 — NASA and Japan release the most accurate topographic map of Earth.
2011 — NASA launches Aquarius, its first instrument to measure the salinity of the global oceans.

ABOUT THE IMAGES



1 A "blue marble" composite image of Earth taken by NASA's Suomi National Polar-orbiting Partnership (NPP) satellite.

2 Studies show the oldest and thickest sea ice in the Arctic is disappearing even faster than younger and thinner ice at the fringe of the polar ice cap.

3 Color-coded data from Aquarius reveal the Atlantic Ocean's high salinity (orange), due in part to high evaporation, and the Pacific's low salinity (blue) along the tropical rain belt.

4 This map of the global biosphere shows plant growth (green) and phytoplankton (blue green).

5 Sea-level-measuring satellites track El Niño and La Niña in the Pacific; the blue area in this color-coded image shows La Niña (low sea level/cold water) in April 2008.

6 This visualization of a gravity model shows variations in Earth's gravity field across North and South America. Red indicates areas where gravity is stronger.

FOR MORE INFORMATION

solarsystem.nasa.gov/earth

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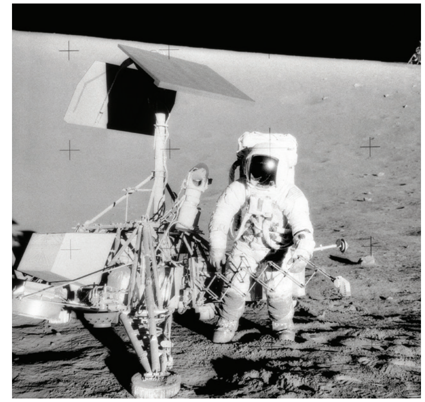
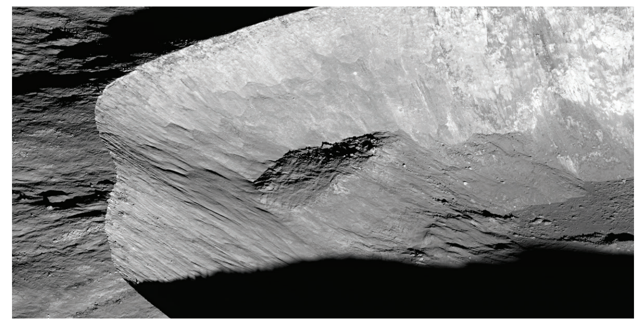
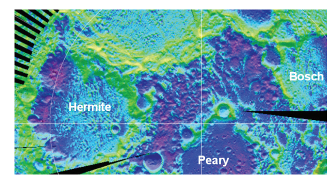
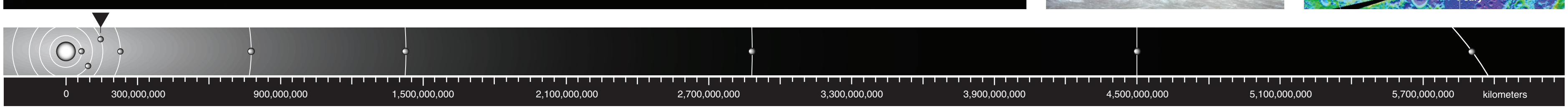
National Aeronautics and Space Administration









Earth's Moon

www.nasa.gov

The regular daily and monthly rhythms of Earth's only natural satellite, the Moon, have guided timekeepers for thousands of years. Its influence on Earth's cycles, notably tides, has been charted by many cultures in many ages. The Moon moderates Earth's wobble on its axis, leading to a relatively stable climate over billions of years. From Earth, we always see the same face of the Moon because the Moon is spinning on its axis at the same speed that it is going around Earth (that is, it is in synchronous rotation with Earth).

The light areas of the Moon are known as the highlands. The dark features, called maria (Latin for seas), are impact basins that were filled with lava between 4.2 and 1.2 billion years ago. These light and dark areas represent rocks of different composition and ages, which provide evidence for how the early crust may have crystallized from a lunar magma ocean. The craters themselves, which have been preserved for billions of years, provide an impact history for the Moon and other bodies in the inner solar system.

The leading theory of the Moon's origin is that a Mars-sized body collided with Earth approximately 4.5 billion years ago, and the resulting debris from both Earth and the impactor accumulated to form our natural satellite. The newly formed Moon was in a molten state. Within about 100 million years, most of the global "magma ocean" had crystallized, with less-dense rocks floating upward and eventually forming the lunar crust. The early Moon may have developed an internal dynamo, the mechanism for global magnetic fields for terrestrial planets.

Since the ancient time of volcanism, the arid, lifeless Moon has remained nearly unchanged. With too sparse an atmosphere to impede impacts, a steady rain of asteroids, meteoroids, and comets strikes the surface. Over billions of years, the surface has been ground up into fragments ranging from huge boulders to powder. Nearly the entire Moon is covered by a rubble pile of charcoal-gray, powdery dust and rocky debris called the lunar regolith. Beneath is a region of fractured bedrock referred to as the megaregolith.

The Moon was first visited by the U.S.S.R.'s Luna 1 and 2 in 1959, and a number of U.S. and U.S.S.R. robotic spacecraft followed. The U.S. sent three classes of robotic missions to prepare the way for human exploration: the Rangers (1961–1965) were impact probes, the Lunar Orbiters (1966–1967) mapped the surface to find landing sites, and the Surveyors (1966–1968) were soft landers. The first human landing on the Moon was on July 20, 1969. During the Apollo missions of 1969–1972, 12 American astronauts walked on the Moon and used a Lunar Roving Vehicle to travel on the surface and extend their studies of soil mechanics, meteoroids, lunar ranging, magnetic fields, and solar wind. The Apollo astronauts brought back 382 kilograms (842 pounds) of rock and soil to Earth for study.

After a long hiatus, lunar exploration resumed in the 1990s with the U.S. robotic missions Clementine and Lunar Prospector. Results from both missions suggested that water ice might be present at the lunar poles, but a controlled impact of the Prospector spacecraft produced no observable water.

The European Space Agency was first in the new millennium with SMART-1 in 2003, followed by Kaguya (Japan), Chang'e 1 (China), and Chandrayaan-1 (India) in 2007–2008. The U.S. began a new series of robotic lunar missions with the joint launch of the Lunar Reconnaissance Orbiter (LRO) and Lunar Crater Observation and Sensing Satellite (LCROSS) in 2009. In 2011, a pair of repurposed spacecraft began the ARTEMIS (Acceleration, Reconnection, Turbulence, and Electrodynamics of the Moon's Interaction with the Sun) mission. In 2012, the Gravity Recovery and Interior Laboratory (GRAIL) twin spacecraft studied the Moon's gravity field and produced the highest-resolution gravity field map of any celestial body. The Lunar Atmosphere and Dust Environment Explorer (LADEE) is scheduled to launch in 2013.

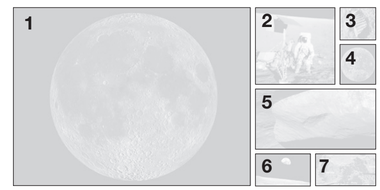
FAST FACTS

Mean Distance from Earth	384,400 km (238,855 mi)
Orbit Period	27.32 Earth days
Orbit Eccentricity (Circular Orbit = 0)	0.05490
Orbit Inclination to Ecliptic	5.145 deg
Inclination of Equator to Orbit	6.68 deg
Rotation Period	27.32 Earth days
Equatorial Radius	1,737.4 km (1,079.6 mi)
Mass	0.0123 of Earth's
Density	3.341 g/cm^3 (0.61 of Earth's)
Gravity	0.166 of Earth's
Temperature Range	–248 to 123 deg C (–414 to 253 deg F)

SIGNIFICANT DATES

1610 — Galileo Galilei is the first to use a telescope to make scientific observations of the Moon.
1959–1976 — The U.S.S.R.'s Luna program of 17 robotic missions achieves many "firsts" and three sample returns.
1961–1968 — The U.S. Ranger, Lunar Orbiter, and Surveyor robotic missions pave the way for Apollo human lunar landings.
1969 — Astronaut Neil Armstrong is the first human to walk on the Moon's surface.
1994–1999 — Clementine and Lunar Prospector data suggest that water ice may exist at the lunar poles.
2003 — The European Space Agency's SMART-1 lunar orbiter inventories key chemical elements.
2007–2008 — Japan's second lunar spacecraft, Kaguya, and China's first lunar spacecraft, Chang'e 1, both begin one-year missions orbiting the Moon; India's Chandrayaan-1 soon follows in lunar orbit.
2008 — The NASA Lunar Science Institute is formed to help lead NASA's research activities related to lunar exploration goals.
2009 — NASA's LRO and LCROSS launch together, beginning the U.S. return to lunar exploration. In October, LCROSS was directed to impact a permanently shadowed region near the lunar south pole, resulting in the discovery of water ice.
2011 — Twin GRAIL spacecraft launch to map the interior of the Moon from crust to core, and NASA begins the ARTEMIS mission to study the Moon's interior and surface composition.

ABOUT THE IMAGES



1 About 1,300 images from LRO's wide-angle camera were used to compose this spectacular view of the lunar nearside.

2 Apollo 12 astronaut Charles Conrad approaches Surveyor 3, a robotic spacecraft that soft-landed on the Moon in 1967.

3 This bootprint marks one of the first steps human beings took on the Moon in July 1969.

4 This LRO false-color image shows elevations on the farside of the Moon: highest elevations are in red and lowest in blue.

5 This LRO image reveals that one edge of Giordano Bruno crater has collapsed, creating a slump terrace.

6 The Apollo 8 crew took this picture of Earth rising over the surface of the Moon in 1968.

7 Diviner, LRO's temperature instrument, measured the floor of the permanently shaded crater Hermite and recorded the coldest temperature measured anywhere in the solar system (middle right, in purple): –240 deg C (33 kelvins or –400 deg F).

FOR MORE INFORMATION

solarsystem.nasa.gov/moon

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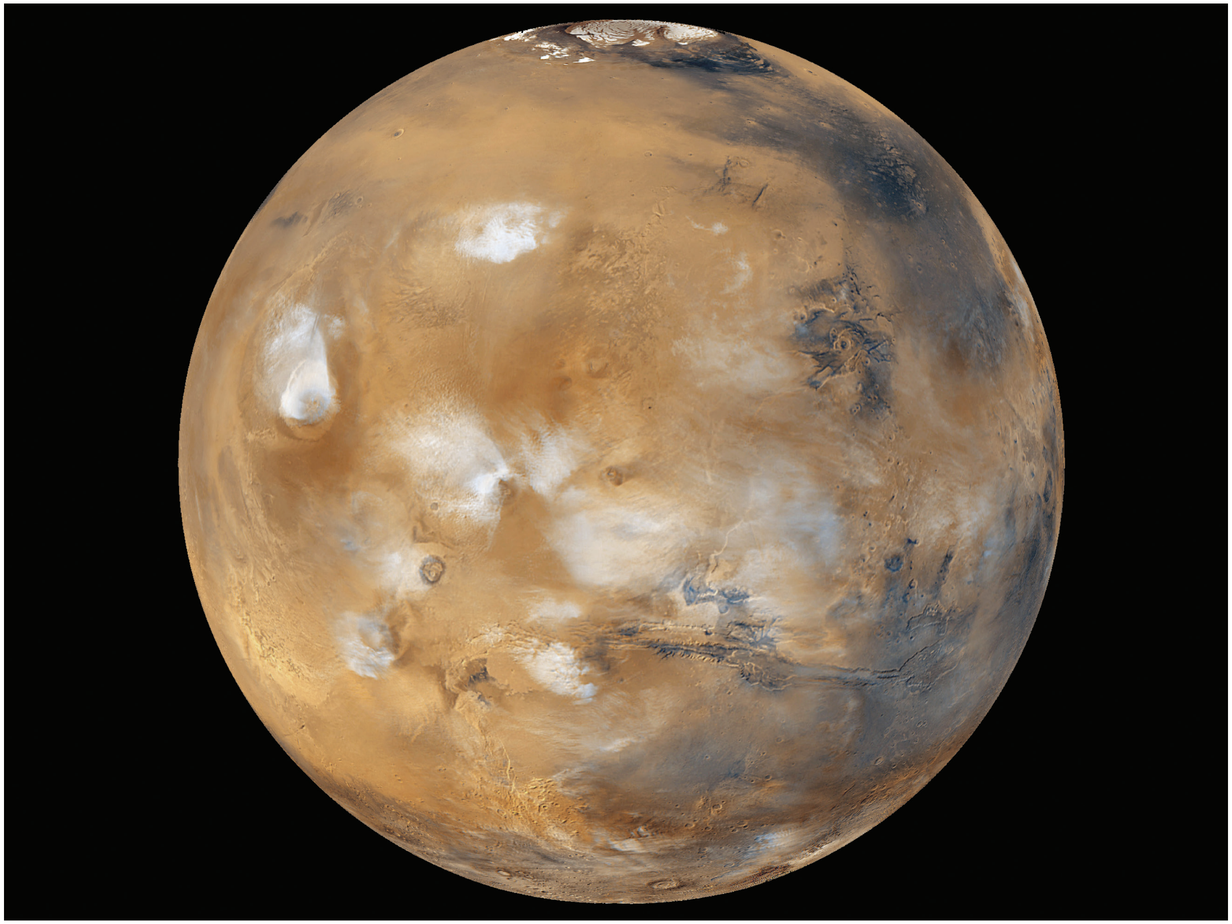
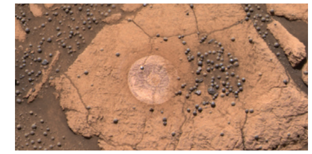
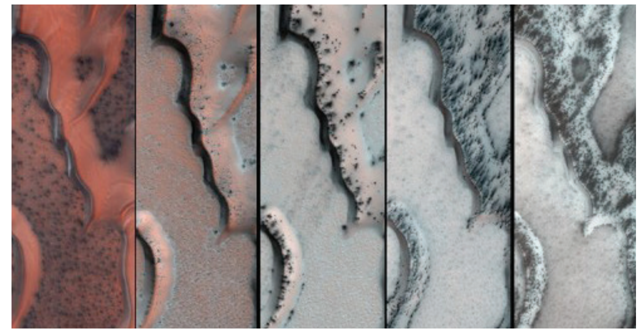
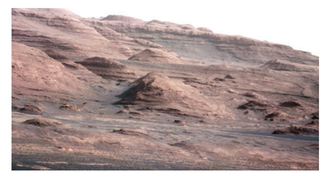
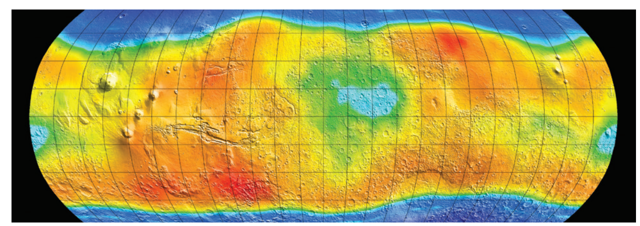
National Aeronautics and Space Administration

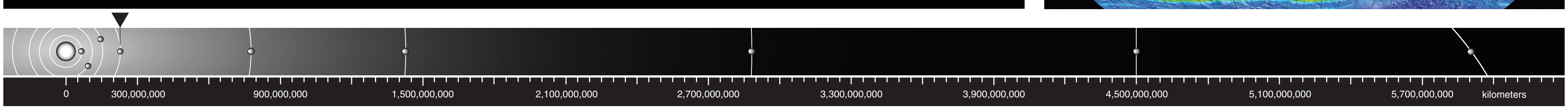












Mars

Though details of Mars' surface are difficult to see from Earth, telescope observations show seasonally changing features and white patches at the poles. For decades, people speculated that bright and dark areas on Mars were patches of vegetation, Mars was a likely place for advanced life forms, and water might exist in the polar caps. When the Mariner 4 spacecraft flew by Mars in 1965, photographs of a bleak, cratered surface shocked many — Mars seemed to be a dead planet. Later missions, however, showed that Mars is a complex planet and holds many mysteries yet to be solved. Chief among them is whether Mars ever had the right conditions to support small life forms called microbes.

Mars is a rocky body about half the size of Earth. As with the other terrestrial planets — Mercury, Venus, and Earth — volcanoes, impact craters, crustal movement, and atmospheric conditions such as dust storms have altered the surface of Mars.

Mars has two small moons, Phobos and Deimos, that may be captured asteroids. Potato-shaped, they have too little mass for gravity to make them spherical. Phobos, the innermost moon, is heavily cratered, with deep grooves on its surface.

Like Earth, Mars experiences seasons due to the tilt of its rotational axis. Mars' orbit is about 1.5 times farther from the Sun than Earth's and is slightly elliptical, so its distance from the Sun changes. That affects the length of martian seasons, which vary in length. The polar ice caps on Mars grow and recede with the seasons. Layered areas near the poles suggest that the planet's climate has changed more than once. Volcanism in the highlands and plains was active more than 3 billion years ago. Some of the giant shield volcanoes are younger, having formed between 1 and 2 billion years ago. Mars has the largest volcano in the solar system, Olympus Mons, as well as a spectacular equatorial canyon system, Valles Marineris.

Mars has no global magnetic field today. However, NASA's Mars Global Surveyor orbiter found that areas of the martian crust in the southern hemisphere are highly magnetized, indicating traces of a magnetic field from 4 billion years ago that remain.

Scientists believe that Mars experienced huge floods about 3.5 billion years ago. Though we do not know where the ancient flood water came from, how long it lasted, or where it went, recent missions to Mars have uncovered intriguing hints. In 2002, NASA's Mars Odyssey orbiter detected hydrogen-rich polar deposits, indicating large quantities of water ice close to the surface. Further observations found hydrogen in other areas as well. If water ice permeated the entire planet, Mars could have substantial subsurface layers of frozen water. In 2004, Mars Exploration Rover Opportunity found structures and minerals indicating that liquid water once existed at its landing site. The rover's twin, Spirit, also found the signature of ancient water near its landing site, halfway around Mars from Opportunity's location.

The cold temperatures and thin atmosphere on Mars do not allow liquid water to exist at the surface for long. The quantity of water required to carve Mars' great channels and flood plains is not evident today. Unraveling the story of water on Mars is important to unlocking its climate history, which will help us understand the evolution of all the planets. Water is an essential ingredient for life as we know it. Evidence of long-term past or present water on Mars holds clues about whether Mars could ever have been a habitat for life. In 2008, NASA's Phoenix Mars Lander was the first mission to "touch" water ice in the martian arctic. Phoenix also observed precipitation (snow falling from clouds), as confirmed by Mars Reconnaissance Orbiter. Soil chemistry experiments led scientists to believe that the Phoenix landing site had a wetter and warmer climate in the recent past (the last few million years). NASA's Mars Science Laboratory mission, with its large rover Curiosity, is examining martian rocks and soil at Gale Crater, looking for minerals that formed in water, signs of subsurface water, and carbon-based molecules called organics, the chemical building blocks of life. That information will reveal more about the present and past habitability of Mars, as well as whether humans could survive on Mars some day.

FAST FACTS

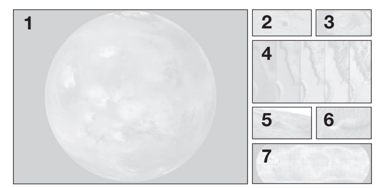
Namesake	Roman god of war
Mean Distance from the Sun	227.94 million km (141.63 million mi)
Orbit Period	1.8807 Earth years (686.98 Earth days)
Orbit Eccentricity (Circular Orbit = 0)	0.0934
Orbit Inclination to Ecliptic	1.8 deg
Inclination of Equator to Orbit	25.19 deg
Rotation Period	24.62 hr
Successive Sunrises	24.660 hr
Equatorial Radius	3,397 km (2,111 mi)
Mass	0.10744 of Earth's
Density	3.934 g/cm^3 (0.714 of Earth's)
Surface Gravity	0.38 of Earth's
Atmosphere Primary Components	carbon dioxide, nitrogen, argon
Temperature Range	–87 to –5 deg C (–125 to 23 deg F)
Known Moons*	2
Rings	0

*As of July 2013.

SIGNIFICANT DATES

1877 — Asaph Hall discovers the two moons of Mars.
1965 — NASA's Mariner 4 sends back 22 photos of Mars, the world's first close-up photos of a planet beyond Earth.
1976 — Viking 1 and 2 land on the surface of Mars.
1997 — Mars Pathfinder lands and dispatches Sojourner, the first wheeled rover to explore the surface of another planet.
2002 — Mars Odyssey begins its mission to make global observations and find buried water ice on Mars.
2004 — Twin Mars Exploration Rovers named Spirit and Opportunity find strong evidence that Mars once had long-term liquid water on the surface.
2006 — Mars Reconnaissance Orbiter begins returning high-resolution images as it studies the history of water on Mars and seasonal changes.
2008 — Phoenix finds signs of possible habitability, including the occasional presence of liquid water and potentially favorable soil chemistry.
2012 — NASA's Mars rover Curiosity lands in Gale Crater and finds conditions once suited for ancient microbial life on Mars.

ABOUT THE IMAGES



1 Water-ice clouds, polar ice, polar regions, and geological features can be seen in this full-disk image of Mars.

2 Mars rover Curiosity drilled this hole and fired its laser several times (creating small pits across the top of the hole) to learn more about the composition of the gray matter.

3 Mars rover Opportunity found sphere-like grains of hematite that likely formed in water.

4 Mars Reconnaissance Orbiter captured seasonal changes in this false-color image of sand dunes from the north polar region.

5 Curiosity will sample the layered rocks of Mount Sharp in Gale Crater to understand Mars as a possible place for life.

6 A dust devil towers about half a mile above the martian surface in this Mars Reconnaissance Orbiter image.

7 False color (blue) shows where water ice is buried beneath the martian surface in this Mars Odyssey orbiter image.

FOR MORE INFORMATION

solarsystem.nasa.gov/mars

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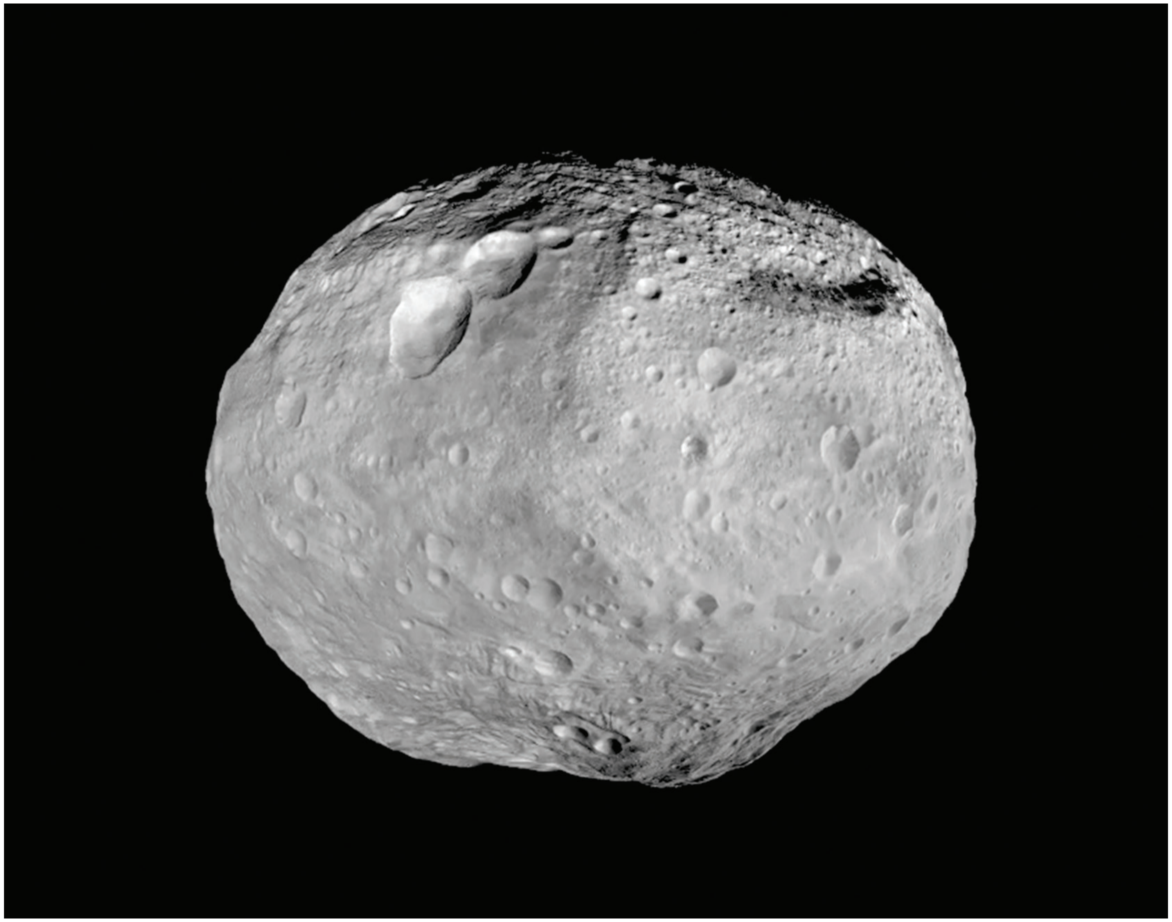
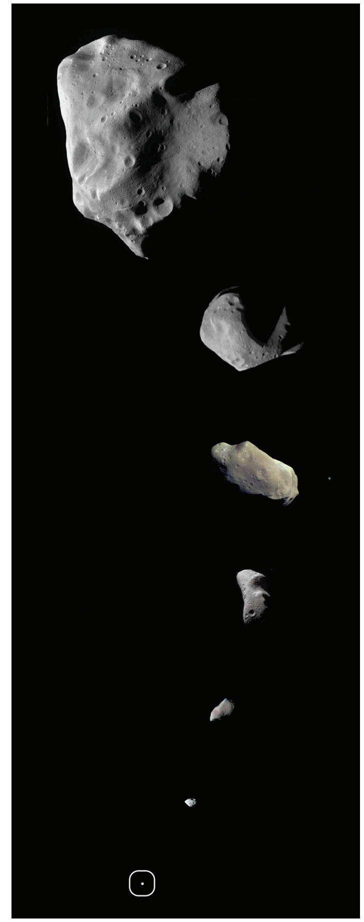
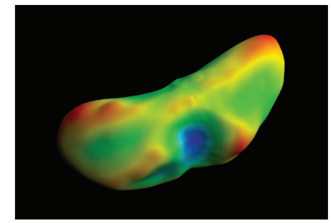
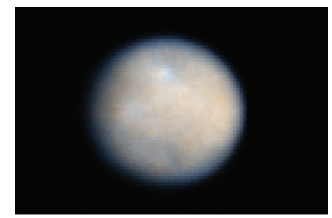
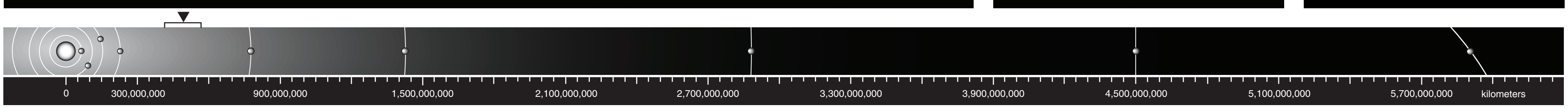
National Aeronautics and Space Administration











Asteroids

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Asteroids, sometimes called minor planets, are rocky remnants left over from the early formation of the solar system about 4.6 billion years ago. Most of this ancient space rubble can be found orbiting the Sun between Mars and Jupiter within the main asteroid belt. Asteroids range in size from Ceres — the largest at about 950 kilometers (590 miles) in diameter and also identified as a dwarf planet — to bodies that are less than 1 kilometer (0.6 mile) across. The total mass of all the asteroids combined is less than that of Earth's Moon.

Most asteroids are irregularly shaped, though a few are nearly spherical, and they are often pitted or cratered. As they revolve around the Sun in elliptical orbits, the asteroids also rotate, sometimes quite erratically, tumbling as they go. More than 150 asteroids are known to have a small companion moon (some have two moons). There are also binary (double) asteroids, in which two rocky bodies of roughly equal size orbit each other, as well as triple asteroid systems.

The three broad composition classes of asteroids are C-, S-, and M-types. The C-type (chondrite) asteroids are most common, probably consist of clay and silicate rocks, and are dark in appearance. They are among the most ancient objects in the solar system. The S-types ("stony") are made up of silicate materials and nickel–iron. The M-types are metallic (nickel–iron). The asteroids' compositional differences are related to how far from the Sun they formed. Some experienced high temperatures after they formed and partly melted, with iron sinking to the center and forcing basaltic (volcanic) lava to the surface. Only one such asteroid, Vesta, survives to this day.

Jupiter's massive gravity and occasional close encounters with Mars or another object change the asteroids' orbits, knocking them out of the main belt and hurling them into space in all directions across the orbits of the other planets. Stray asteroids and asteroid fragments slammed into Earth and the other planets in the past, playing a major role in altering the geological history of the planets and in the evolution of life on Earth.

Scientists continuously monitor Earth-crossing asteroids, whose paths intersect Earth's orbit, and near-Earth asteroids that approach Earth's orbital distance to within about 45 million kilometers (28 million miles) and may pose an impact danger. Radar is a valuable tool in detecting and monitoring potential impact hazards. By reflecting transmitted signals off objects, images and other information can be derived from the echoes. Scientists can learn a great deal about an asteroid's orbit, rotation, size, shape, and metal concentration.

Several missions have flown by and observed asteroids. The Galileo spacecraft flew by asteroids Gaspra in 1991 and Ida in 1993; the Near-Earth Asteroid Rendezvous (NEAR) mission studied asteroids Mathilde and Eros; and the Rosetta mission encountered Steins in 2008 and Lutetia in 2010.

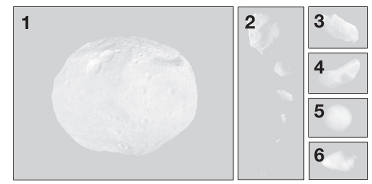
In 2005, the Japanese spacecraft Hayabusa landed on the near-Earth asteroid Itokawa and attempted to collect samples. On June 3, 2010, Hayabusa successfully returned to Earth a small amount of asteroid dust now being studied by scientists.

NASA's Dawn spacecraft, launched in 2007, orbited and explored asteroid Vesta for over a year. Once it left in September 2012, it headed towards dwarf planet Ceres, with a planned arrival of 2015. Vesta and Ceres are two of the largest surviving protoplanet bodies that almost became planets. By studying them with the same complement of instruments on board the same spacecraft, scientists will be able to compare and contrast the different evolutionary path each object took to help understand the early solar system overall.

SIGNIFICANT DATES

1801 — Giuseppe Piazzi discovers the first and largest asteroid, Ceres, orbiting between Mars and Jupiter.
1898 — Gustav Witt discovers Eros, one of the largest near-Earth asteroids.
1991–1994 — The Galileo spacecraft takes the first close-up images of an asteroid (Gaspra) and discovers the first moon (later named Dactyl) orbiting an asteroid (Ida).
1997–2000 — The NEAR spacecraft flies by Mathilde and orbits and lands on Eros.
1998 — NASA establishes the Near-Earth Object Program Office to detect, track, and characterize potentially hazardous asteroids and comets that could approach Earth.
2006 — Ceres attains a new classification, "dwarf planet," but retains its distinction as the largest known asteroid.
2008 — The European spacecraft Rosetta, on its way to study a comet in 2014, flies by and photographs asteroid Steins, a rare type of asteroid composed of silicates and basalts.
2010 – Rosetta flies by asteroid Lutetia, revealing a primitive survivor from the violent birth of our solar system.
2011–2012 — Dawn studies Vesta. Dawn is the first spacecraft to orbit a main-belt asteroid and continues on to dwarf planet Ceres in 2015.

ABOUT THE IMAGES



1 Dawn view of Vesta images showing a towering mountain at the south pole (more than twice as high as Mount Everest).

2 Asteroids compared to Vesta. From the top: Lutetia, Mathilde, Ida and moon Dactyl, Eros, Gaspra, Steins, and Itokawa (circled).

3 A Galileo image of asteroid Ida and its moon Dactyl.

4 NEAR gravity map of near-Earth asteroid Eros used to determine its shape and density.

5 The Hubble Space Telescope provides our best view of dwarf planet Ceres until Dawn arrives there in 2015.

6 Asteroid Annefrank was seen as an irregularly shaped, cratered body by NASA's Stardust spacecraft in 2002.

FOR MORE INFORMATION

solarsystem.nasa.gov/asteroids

ASTEROID CLASSIFICATIONS

Main asteroid belt — The majority of known asteroids orbit within the asteroid belt between Mars and Jupiter, generally with not very elongated orbits. The belt is estimated to contain between 1.1 and 1.9 million asteroids larger than 1 kilometer (0.6 mile) in diameter, and millions of smaller ones. Early in the history of the solar system, the gravity of newly formed Jupiter brought an end to the formation of planetary bodies in this region and caused the small bodies to collide with one another, fragmenting them into the asteroids we observe today.

Trojans — These asteroids share an orbit with a larger planet, but do not collide with it because they gather around two special places in the orbit (called the L4 and L5 Lagrangian points). There, the gravitational pull from the Sun and the planet are balanced by a trojan's tendency to otherwise fly out of the orbit. The Jupiter trojans form the most significant population of trojan asteroids. It is thought that they are as numerous as the asteroids in the asteroid belt. There are Mars and Neptune trojans, and NASA announced the discovery of an Earth trojan in 2011.

Near-Earth asteroids — These objects have orbits that pass close by that of Earth. Asteroids that actually cross Earth's orbital path are known as Earth-crossers. As of June 19, 2013, 10,003 near-Earth asteroids are known and the number over 1 kilometer in diameter is thought to be 861, with 1,409 classified as potentially hazardous asteroids — those that could pose a threat to Earth.

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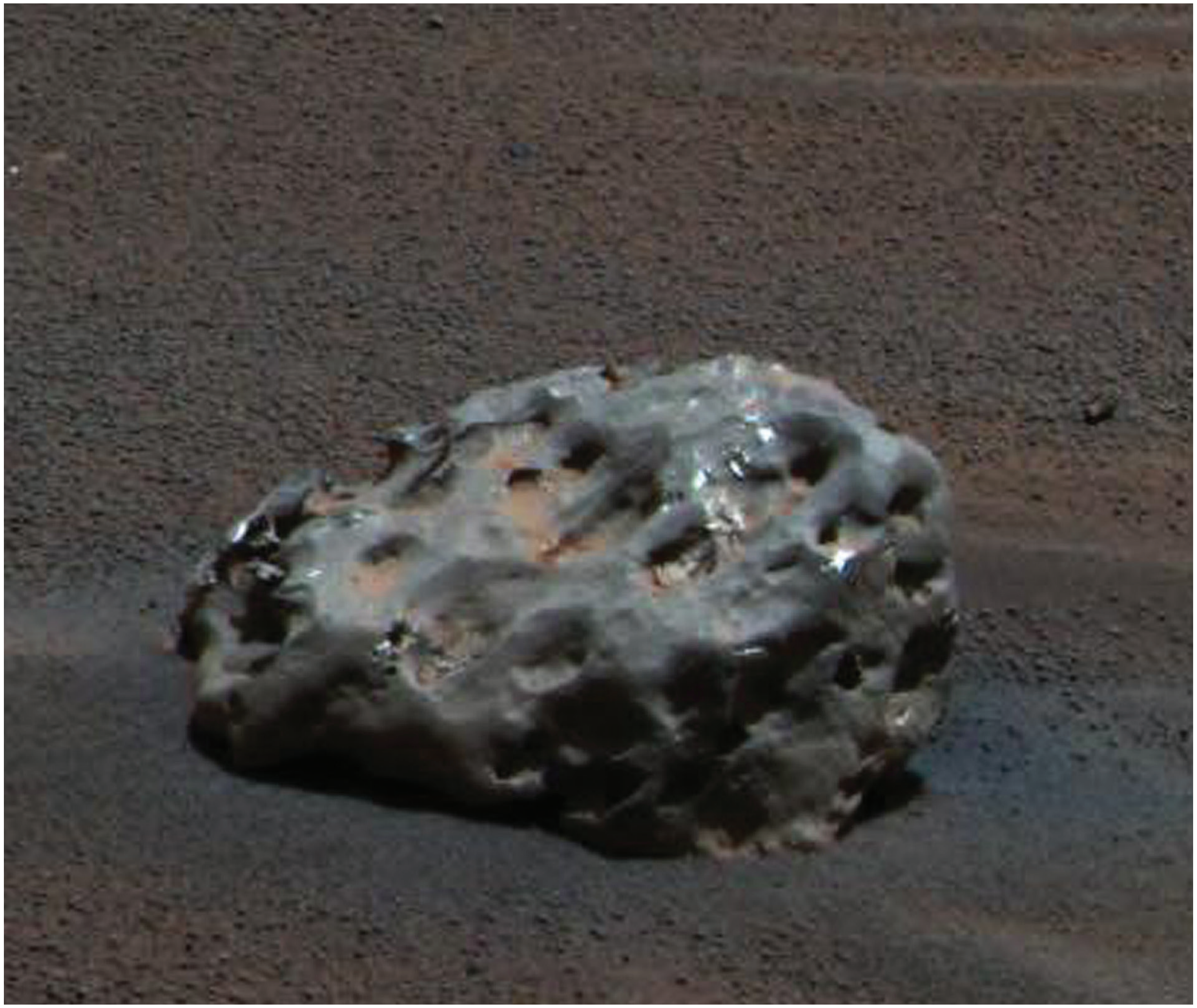
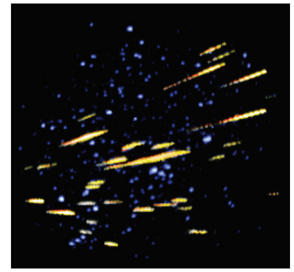
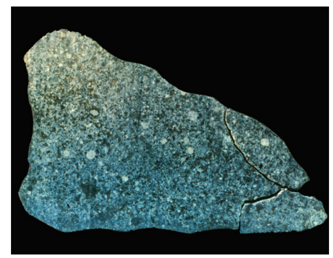
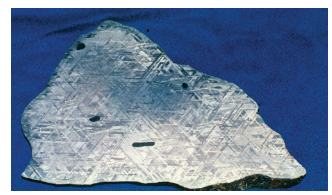
National Aeronautics and Space Administration




Meteors and Meteorites

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"Shooting stars," or meteors, are bits of interplanetary material falling through Earth's atmosphere and heated to incandescence by friction. These objects are called meteoroids as they are hurtling through space, becoming meteors for the few seconds they streak across the sky and create glowing trails.

Several meteors per hour can usually be seen on any given night. Sometimes the number increases dramatically — these events are termed meteor showers. Some occur annually or at regular intervals as the Earth passes through the trail of dusty debris left by a comet. Meteor showers are usually named after a star or constellation that is close to where the meteors appear in the sky. Perhaps the most famous are the Perseids, which peak around August 12 every year. Every Perseid meteor is a tiny piece of the comet Swift–Tuttle, which swings by the Sun every 135 years. Other meteor showers and their associated comets are the Leonids (Tempel–Tuttle), the Aquarids and Orionids (Halley), and the Taurids (Encke). Most comet dust in meteor showers burns up in the atmosphere before reaching the ground; some dust is captured by high-altitude aircraft and analyzed in NASA laboratories.

Chunks of rock and metal from asteroids and other planetary bodies that survive their journey through the atmosphere and fall to the ground are called meteorites. Most meteorites found on Earth are pebble to fist size, but some are larger than a building. Early Earth experienced many large meteorite impacts that caused extensive destruction.

One of the most intact impact craters is the Barringer Meteorite Crater in Arizona, about 1 kilometer (0.6 mile) across, formed by the impact of a piece of iron–nickel metal approximately 50 meters (164 feet) in diameter. It is only 50,000 years old and so well preserved that it has been used to study impact processes. Since this feature was recognized as an impact crater in the 1920s, about 170 impact craters have been identified on Earth.

A very large asteroid impact 65 million years ago, which created the 300-kilometer-wide (180-mile-wide) Chicxulub crater on the Yucatán Peninsula, is thought to have contributed to the extinction of about 75 percent of marine and land animals on Earth at the time, including the dinosaurs.

Well-documented stories of meteorite-caused injury or death are rare. In the first known case of an extraterrestrial object to have injured a human being in the U.S., Ann Hodges of Sylacauga, Alabama, was severely bruised by a 3.6-kilogram (8-pound) stony meteorite that crashed through her roof in November 1954.

Meteorites may resemble Earth rocks, but they usually have a "burned" exterior. This fusion crust is formed as the meteorite is melted by friction as it passes through the atmosphere. There are three major types of meteorites: the "irons," the "stones," and the "stony-irons." Although the majority of meteorites that fall to Earth are stony, more of the meteorites that are discovered long after they fall are "irons" — these heavy objects are easier to distinguish from Earth rocks than stony meteorites. Meteorites also fall on other solar system bodies. Mars Exploration Rover Opportunity found the first meteorite of any type on another planet when it discovered an iron–nickel meteorite about the size of a basketball on Mars in 2005, and then found a much larger and heavier iron–nickel meteorite in 2009 in the same region. In all, Opportunity has discovered six meteorites during its travels on Mars.

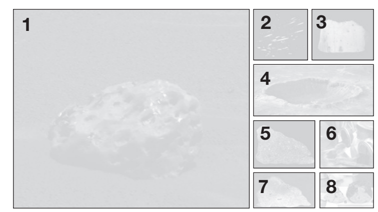
More than 50,000 meteorites have been found on Earth. Of these, 99.8 percent come from asteroids. Evidence for an asteroid origin includes orbits calculated from photographic observations of meteorite falls projected back to the asteroid belt; spectra of several classes of meteorites match those of some asteroid classes; and they are very old, 4.5 to 4.6 billion years. However, we can only match one group of meteorites to a specific asteroid — the eucrite, diogenite, and howardite igneous meteorites come from the third-largest asteroid, Vesta. Asteroids and the meteorites that fall to Earth are not pieces of a planet that broke apart, but instead are the original diverse materials from which the planets formed. The study of meteorites tells us much about the earliest conditions and processes during the formation and earliest history of the solar system, such as the age and composition of solids, the nature of the organic matter, the temperatures achieved at the surface and interiors of asteroids, and the degree to which materials were shocked by impacts.

The remaining 0.2 percent of meteorites is split roughly equally between meteorites from Mars and the Moon. The over 60 known martian meteorites were blasted off Mars by meteoroid impacts. All are igneous rocks crystallized from magma. The rocks are very much like Earth rocks with some distinctive compositions that indicate martian origin. The nearly 80 lunar meteorites are similar in mineralogy and composition to Apollo mission Moon rocks, but distinct enough to show that they have come from other parts of the Moon. Studies of lunar and martian meteorites complement studies of Apollo Moon rocks and the robotic exploration of Mars.

SIGNIFICANT DATES

4.55 billion years ago — Formation age of most meteorites, taken to be the age of the solar system.
65 million years ago — Chicxulub impact leads to the death of 75 percent of the animals on Earth, including the dinosaurs.
50,000 years — Age of Barringer Meteorite Crater in Arizona.
1478 BCE — First recorded observation of meteors.
1794 — Ernst Friedrich Chladni publishes the first book on meteorites, in which he proposes that they have an extraterrestrial origin.
1908 (Tunguska), 1947 (Sikote Alin), 1969 (Allende and Murchison), 1976 (Jilin) — Important 20th-century meteorite falls.
1969 — Discovery of meteorites in a small area of Antarctica leads to annual expeditions by U.S. and Japanese teams.
1982–1983 — Meteorites from the Moon and Mars are identified in Antarctic collections.
1996 — A team of NASA scientists suggests that martian meteorite ALH84001 may contain evidence of microfossils from Mars, a still-controversial claim.
2005 — NASA's Mars Exploration Rover Opportunity finds a basketball-size iron–nickel meteorite on Mars.
2009 — Opportunity finds another iron–nickel meteorite on Mars.

ABOUT THE IMAGES



1 The iron–nickel meteorite found on Mars by Opportunity rover in 2005.

2 A meteor swarm photographed in November 1995.

3 The glassy black patches in this martian meteorite contain atmospheric gases that point to a Mars origin.

4 The Barringer Meteorite Crater in Arizona.

5 A stony meteorite found in Antarctica.

6 A scientist working in the Meteorite Processing Laboratory at NASA's Johnson Space Center.

7 An iron meteorite from the Barringer Meteorite Crater.

8 A meteorite found in Antarctica of the type considered to originate from asteroid Vesta, supported by data from the Dawn spacecraft. The scale cubes indicate size and orientation.

FOR MORE INFORMATION

solarsystem.nasa.gov/meteors

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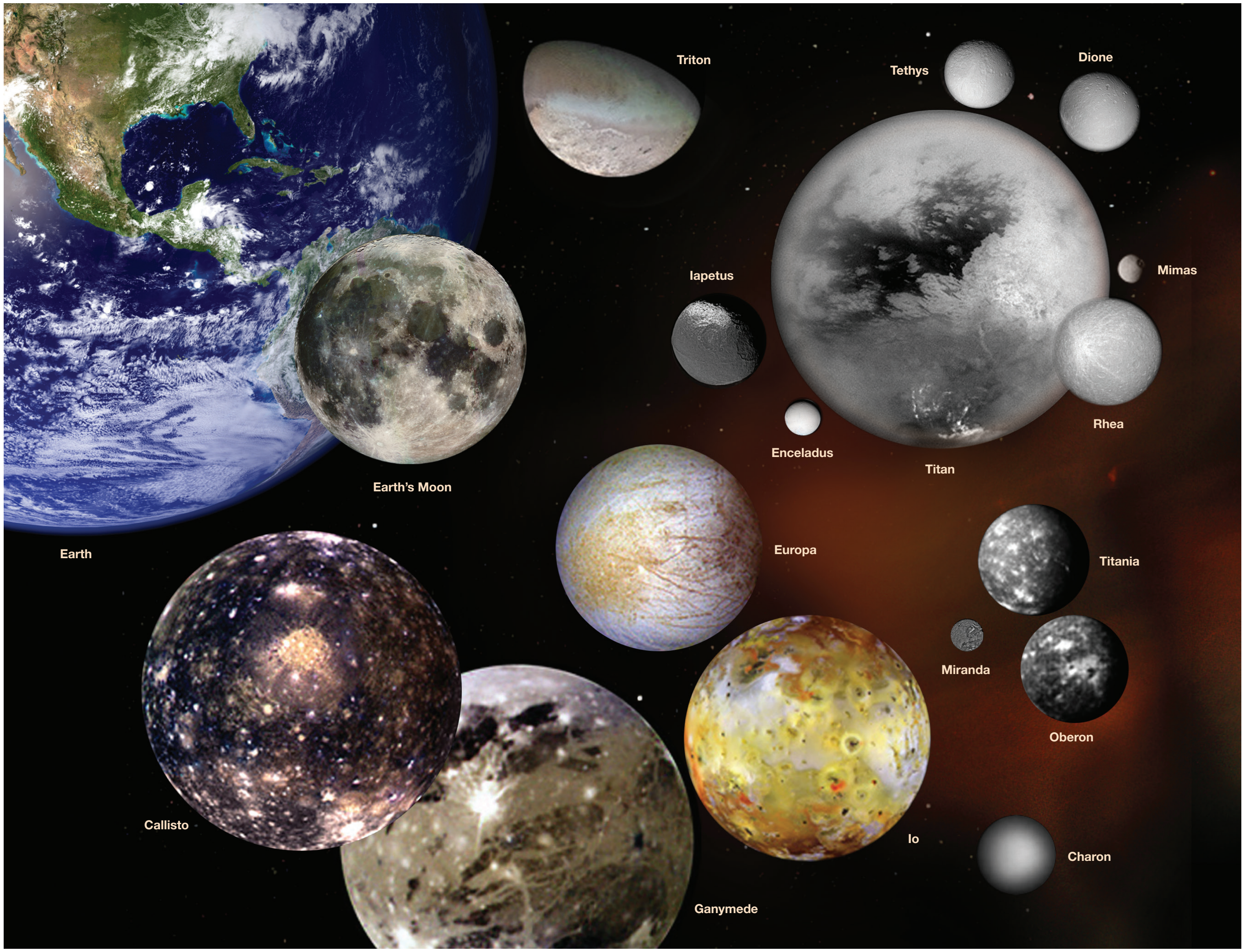
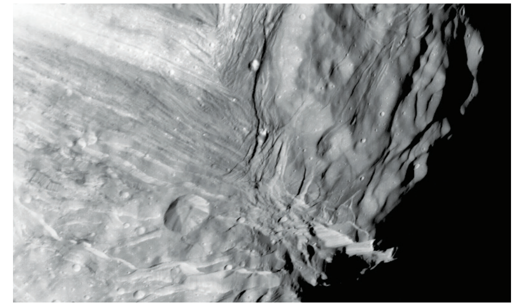
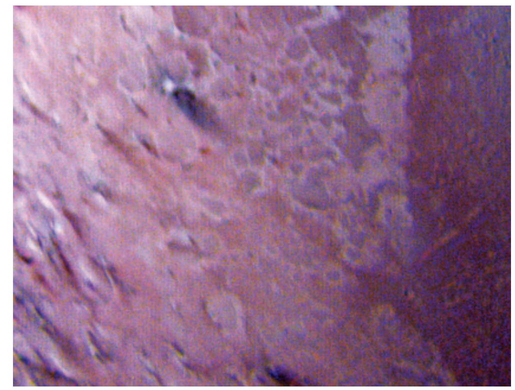
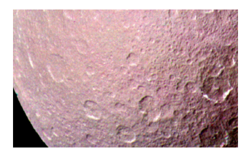
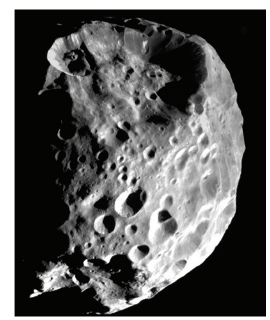
National Aeronautics and Space Administration

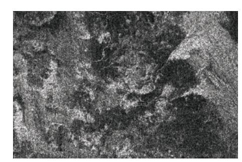












Moons of the Solar System

Moons — also called satellites — come in many shapes, sizes, and types. They are generally solid bodies, and few have atmospheres. Most of the planetary moons probably formed from the discs of gas and dust circulating around planets in the early solar system. Some moons are large enough for their gravity to cause them to be spherical, while smaller moons appear to be captured asteroids, not related to the formation and evolution of the body they orbit. The International Astronomical Union lists 146 moons orbiting planets in our solar system — this number does not include the moons awaiting official recognition and naming, the eight moons of the dwarf planets, nor the tiny satellites that orbit some asteroids and other celestial objects.

Of the terrestrial (rocky) planets of the inner solar system, neither Mercury nor Venus has any moons at all, Earth has one, and Mars has its two small moons. In the outer solar system, the gas giants (Jupiter, Saturn) and the ice giants (Uranus and Neptune) have numerous moons. As these huge planets grew in the early solar system, they were able to capture objects with their large gravitational fields.

Earth's Moon probably formed when a large body about the size of Mars collided with Earth, ejecting material from our planet into orbit. This material accumulated to form the Moon approximately 4.5 billion years ago (the age of the oldest collected lunar rocks). Twelve American astronauts landed on the Moon during NASA's Apollo program in 1969 to 1972, studying the Moon and bringing back rock samples.

Usually the term "moon" brings to mind a spherical object, like Earth's Moon. The two moons of Mars, Phobos and Deimos, are somewhat different. Both have nearly circular orbits and travel close to the plane of the planet's equator, and they are lumpy and dark. Phobos is slowly drawing closer to Mars, and could crash into Mars in 40 or 50 million years, or the planet's gravity might break Phobos apart, creating a thin ring around Mars.

Jupiter has 50 known moons (plus 17 awaiting official confirmation), including the largest moon in the solar system, Ganymede. Many of Jupiter's outer moons have highly elliptical orbits and orbit "backwards" (opposite to the spin of the planet). Saturn, Uranus, and Neptune also have some "irregular" moons, which orbit far from their respective planets.

Saturn has 53 known moons (plus 9 awaiting official confirmation). The chunks of ice and rock in Saturn's rings (and the particles in the rings of the other outer planets) are not considered moons, yet embedded in Saturn's rings are distinct moons or "moonlets." Small "shepherd" moons help keep the rings in line. Saturn's moon Titan, the second largest in the solar system, is the only moon with a thick atmosphere.

Beyond Saturn, Uranus has 27 known moons. The inner moons appear to be about half water ice and half rock. Miranda is the most unusual; its chopped-up appearance shows the scars of impacts of large rocky bodies. Neptune's moon Triton is as big as the dwarf planet Pluto, and orbits backwards compared with Neptune's direction of rotation. Neptune has 13 known moons plus a 14th awaiting official confirmation.

Pluto's large moon, Charon, is about half the size of Pluto, and some scientists consider Pluto/Charon to be a double system. Like Earth's Moon, Charon may have formed from debris from an early collision of an impactor with Pluto. Scientists using the Hubble Space Telescope to study Pluto have found five additional smaller moons. Eris, a dwarf planet even more distant than Pluto, has a small moon of its own, named Dysnomia. Haumea, another dwarf planet, has two satellites, Hi'iaka and Namaka.

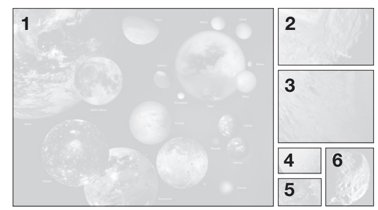
FAST FACTS — PLANETS AND SELECTED MOONS

Planet	Moon	Mean Radius (km)	Mean Radius (mi)
Earth	Moon	1,737.4	1,079.6
Mars	Phobos	11.1	6.9
Mars	Deimos	6.2	3.9
Jupiter	Io	1,821.6	1,131.9
Jupiter	Europa	1,560.8	969.8
Jupiter	Callisto	2,410	1,498
Jupiter	Ganymede	2,631	1,635
Saturn	Mimas	198.6	123.4
Saturn	Enceladus	249.4	154.9
Saturn	Tethys	529.9	329.3
Saturn	Dione	560	348
Saturn	Rhea	764	475
Saturn	Titan	2,575	1,600
Saturn	Iapetus	718	446
Uranus	Miranda	235.8	146.5
Uranus	Ariel	578.9	359.7
Uranus	Umbriel	584.7	363.3
Uranus	Titania	788.9	490.2
Uranus	Oberon	761.4	473.1
Neptune	Triton	1,353.4	841
Neptune	Nereid	170	106

SIGNIFICANT DATES

1610 — Galileo Galilei and Simon Marius independently discover four moons orbiting Jupiter. Galileo is credited and the moons are called "Galilean." This discovery changed the way the solar system was perceived.
1877 — Asaph Hall discovers Mars' moons Phobos and Deimos.
1969 — Astronaut Neil Armstrong is the first of 12 humans to walk on the surface of Earth's Moon.
1979 — Voyager 1 photographs an erupting volcano on Jupiter's moon Io; the first ever seen anywhere other than Earth.
1980 — Voyager 1 instruments detect signs of surface features beneath the hazy atmosphere of Saturn's largest moon, Titan.
2005 — The Cassini spacecraft discovers jets or geysers of water ice particles venting from Saturn's moon Enceladus.
2000–present — Using improved ground-based telescopes, the Hubble Space Telescope, and spacecraft observations, scientists have found dozens of new moons in our solar system. Newly discovered moons (as well as other solar system objects) are given temporary designations until they are confirmed by subsequent observations and receive permanent names from the International Astronomical Union.

ABOUT THE IMAGES



1 Selected solar system moons, displaying a variety of surface features, are shown at correct relative sizes to each other and to Earth.

2 Miranda, a moon of Uranus, has many rugged features: canyons, grooved structures, ridges, and broken terrain. The large cliff in this image is a 12-mile-high vertical drop.

3 This false-color image of Neptune's moon Triton shows what appear to be volcanic deposits.

4 This Voyager 1 close-up of Saturn's moon Rhea shows the moon's ancient, cratered surface.

5 A portion of a Cassini radar image of Saturn's largest moon, Titan, showing the complexity of the surface.

6 Cassini imaged the small irregular moon Phoebe when the spacecraft was inbound for Saturn orbit insertion in June 2004.

FOR MORE INFORMATION

solarsystem.nasa.gov/planets/profile.cfm?Object=SolarSys&Display=Sats

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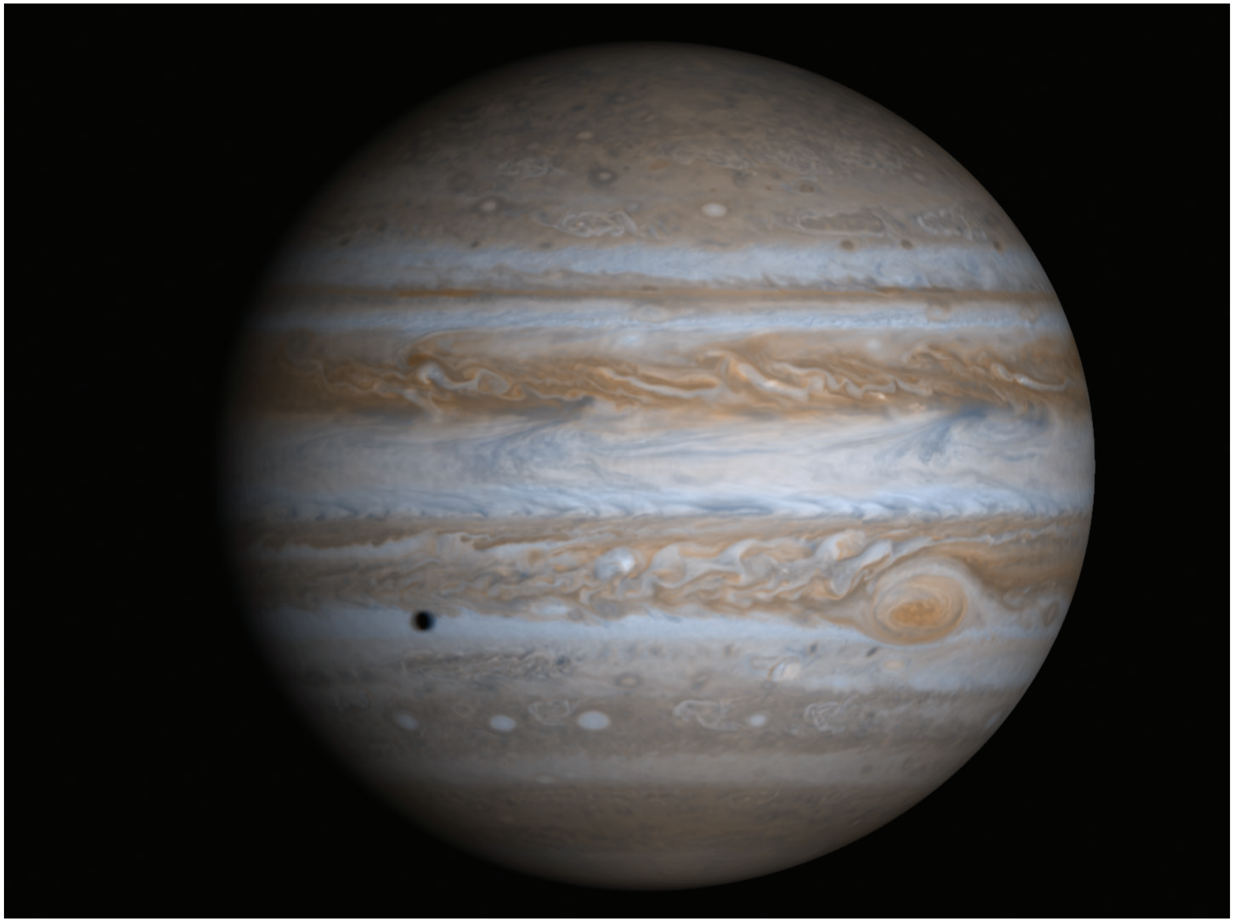

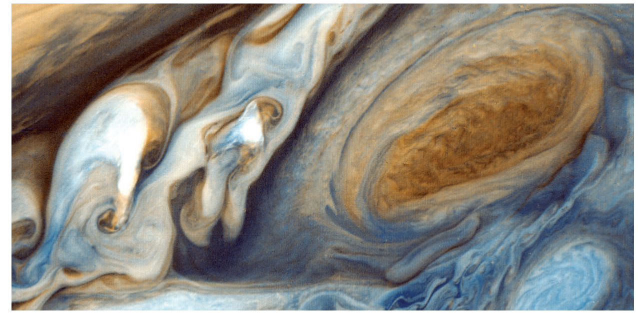

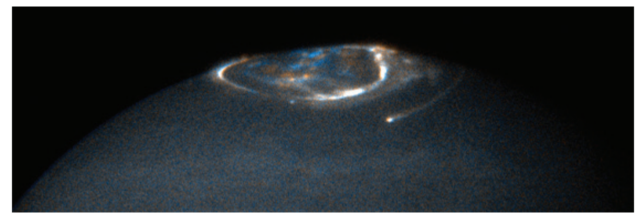

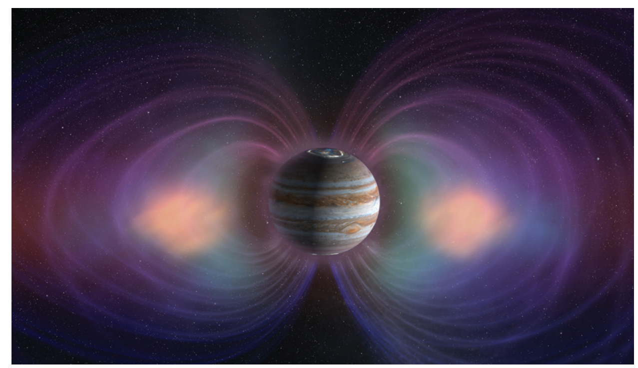

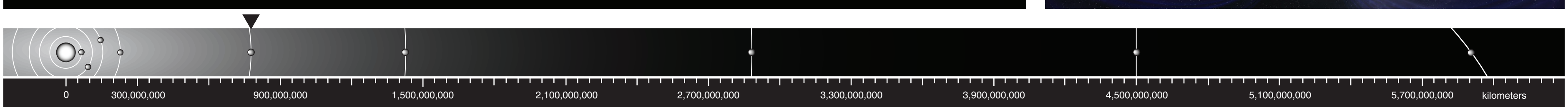
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kilometers

Jupiter

Jupiter is the largest and most massive planet in our solar system, containing more than twice the amount of material of the other bodies orbiting our Sun combined. Most of the material left over after the formation of the Sun went to Jupiter, forming a type of planet called a gas giant.

Jupiter's appearance is a tapestry of colorful cloud bands and spots. Most visible clouds are composed of ammonia and ammonia compounds, with unknown chemicals providing color. Jupiter's fast rotation — spinning once every 10 hours — creates strong jet streams, smearing its clouds into bands across the planet.

With no solid surface to slow them down, Jupiter's spots can persist for many years. The Great Red Spot, a swirling oval of clouds twice as wide as Earth, has been observed on the giant planet for more than 300 years. More recently, three smaller ovals merged to form the Little Red Spot, about half the size of its larger cousin. Scientists do not yet know if these ovals and planet-circling bands are shallow or deeply rooted to the interior.

The composition of Jupiter's atmosphere is similar to that of the Sun — mostly hydrogen and helium. Deep in the atmosphere, pressure and temperature increase, compressing the hydrogen gas into a liquid. This gives Jupiter the largest ocean in the solar system — an ocean made of hydrogen instead of water. Scientists think that, at depths perhaps halfway to the planet's center, the pressure becomes so great that electrons are squeezed off the hydrogen atoms, making the liquid electrically conducting. Jupiter's fast rotation is thought to drive electrical currents in this region, generating the planet's powerful magnetic field. It is still unclear if, deeper down, Jupiter has a central core of solid material.

The Jovian magnetosphere is the region of space influenced by Jupiter's powerful magnetic field. It balloons 1 to 3 million kilometers (600,000 to 2 million miles) toward the Sun and tapers into a windsock-shaped tail extending more than 1 billion kilometers (600 million miles) behind Jupiter, as far as Saturn's orbit. The magnetic field rotates with the planet and sweeps up particles that have an electric charge. Near the planet, the magnetic field traps a swarm of charged particles and accelerates them to very high energies, creating intense radiation that bombards the innermost moons and can damage spacecraft.

With four large moons and many smaller moons, Jupiter forms a kind of miniature solar system. In total, the planet has more than 60 moons, including several that were discovered in just the past few years.

Jupiter's four largest moons — Io, Europa, Ganymede, and Callisto — were first observed by the astronomer Galileo Galilei in 1610 using an early version of the telescope. These four moons are known today as the Galilean satellites. Galileo would be astonished at what we have learned about these moons, largely from the NASA mission named for him: Io is the most volcanically active body in the solar system; Ganymede is the largest moon in the solar system and the only moon known to have its own magnetic field; and a liquid-water ocean with the ingredients for life may lie beneath the frozen crust of Europa, making it a tempting place to explore.

Discovered in 1979 by NASA's Voyager 1 spacecraft, Jupiter's rings were a surprise, as they are composed of small, dark particles and are difficult (but not impossible) to see except when backlit by the Sun. Data from the Galileo spacecraft indicate that Jupiter's ring system may be formed by dust kicked up as interplanetary meteoroids smash into the giant planet's small innermost moons.

In December 1995, NASA's Galileo spacecraft dropped a probe into one of the dry, hot spots of Jupiter's atmosphere. The probe made the first direct measurements of the planet's composition and winds. Galileo studied Jupiter and its largest moons until 2003. Beginning in 2016, NASA's Juno spacecraft will conduct an in-depth investigation of the planet's atmosphere, deep structure, and magnetosphere for clues to its origin and evolution.

FAST FACTS

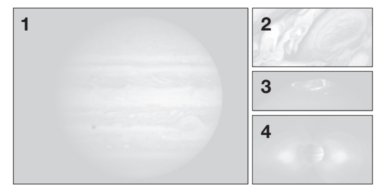
Namesake	King of the Roman gods
Mean Distance from the Sun	778.41 million km (483.68 million mi)
Orbit Period	11.8565 Earth years (4,330.6 Earth days)
Orbit Eccentricity (Circular Orbit = 0)	0.04839
Orbit Inclination to Ecliptic	1.305 deg
Inclination of Equator to Orbit	3.12 deg
Rotation Period	9.92 hr
Equatorial Radius	71,492 km (44,423 mi)
Mass	317.82 of Earth's
Density	1.33 g/cm^3
Gravity	20.87 m/sec^2 (68.48 ft/sec^2)
Atmosphere Primary Components	hydrogen, helium
Effective Temperature at 1 bar	–108 deg C (–163 deg F)
Known Moons*	50
Rings	1 (three major components)

*Plus 17 awaiting official confirmation, total 67, as of July 2013.

SIGNIFICANT DATES

1610 — Galileo Galilei makes the first detailed observations of Jupiter.
1973 — Pioneer 10 becomes the first spacecraft to cross the asteroid belt and fly past Jupiter.
1979 — Voyager 1 and 2 discover Jupiter's faint rings, several new moons, and volcanic activity on Io's surface.
1994 — Astronomers observe as pieces of comet Shoemaker–Levy 9 collide with Jupiter's southern hemisphere.
1995–2003 — The Galileo spacecraft drops a probe into Jupiter's atmosphere and conducts extended observations of Jupiter and its moons and rings.
2007 — Images taken by NASA's New Horizons spacecraft, on the way to Pluto, show new perspectives on Jupiter's atmospheric storms, the rings, volcanic Io, and icy Europa.
2009 — On July 20, almost exactly 15 years after fragments of comet Shoemaker–Levy slammed into Jupiter, a comet or asteroid crashes into the giant planet's southern hemisphere, creating a dark scar.

ABOUT THE IMAGES



1 A natural-color image taken by the Cassini spacecraft as it flew by on its way to Saturn. Europa's shadow can be seen against the planet's cloud tops.

2 A Voyager 1 image of Jupiter's Great Red Spot.

3 A Hubble Space Telescope ultraviolet image of Jupiter's complex, glowing aurora. The bright spot with a curving tail at the right is the auroral footprint of the moon Io.

4 An artist's rendering of Jupiter's inner magnetosphere, showing magnetic field lines (connecting the north and south poles) and auroras, along with a region of intense radiation around the planet's middle.

FOR MORE INFORMATION

solarsystem.nasa.gov/jupiter

solarsystem.nasa.gov/planets/profile.cfm?Object=Jupiter&Display=Moons

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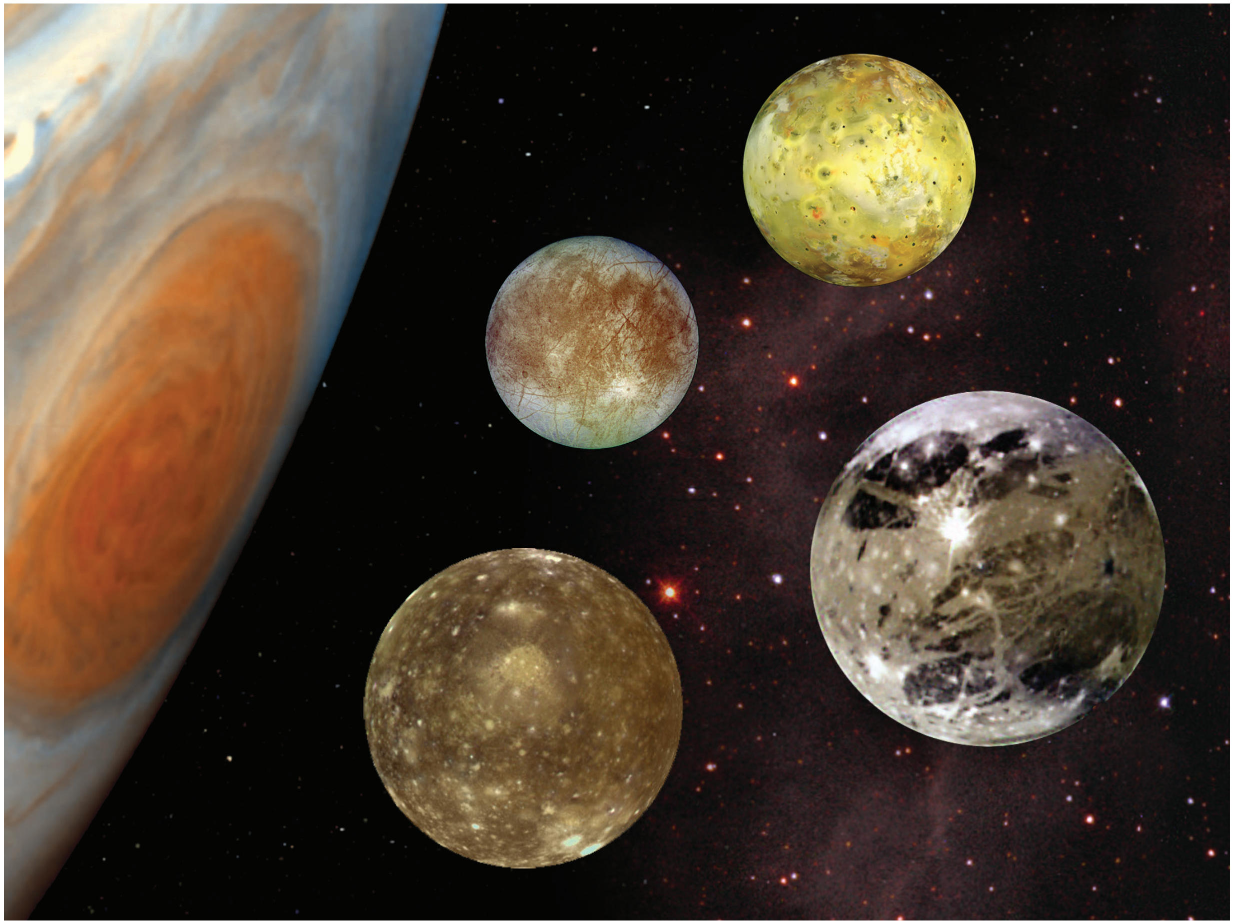
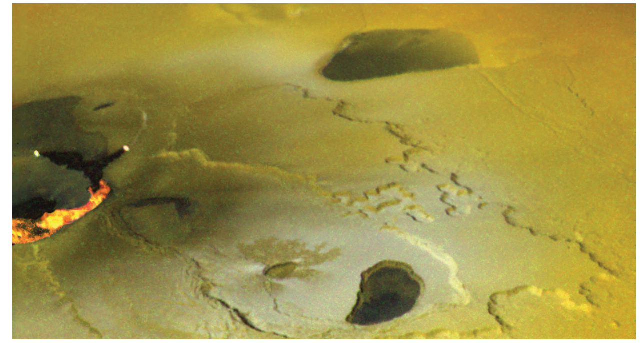
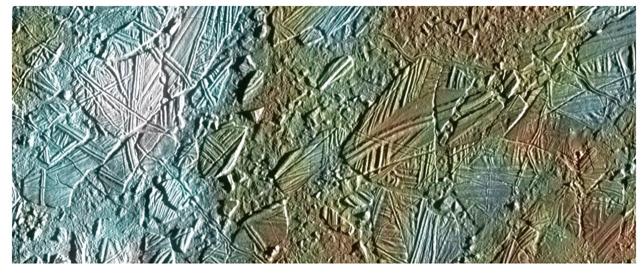
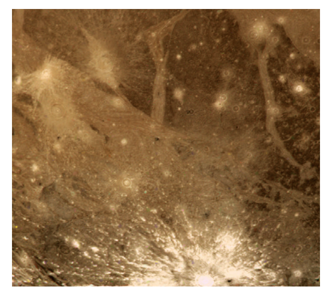
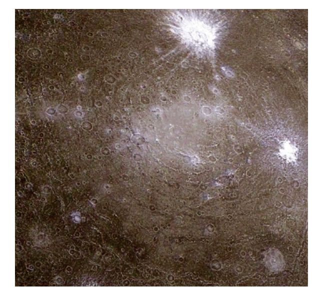
National Aeronautics and Space Administration

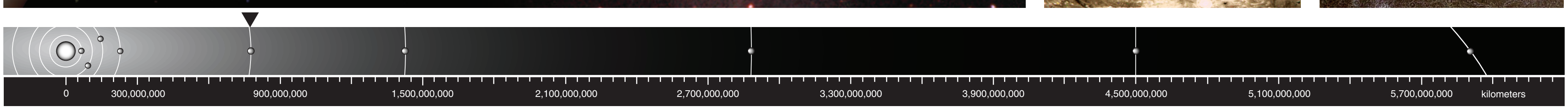












Galilean Moons of Jupiter

The planet Jupiter's four largest moons, or satellites, are called the Galilean moons, after Italian astronomer Galileo Galilei, who observed them in 1610. The German astronomer Simon Marius apparently discovered them around the same time. The names Marius proposed for the moons in 1614 (suggested to him by a fellow astronomer, Johannes Kepler) are the ones we use today — Io, Europa, Ganymede, and Callisto.

Io is the most volcanically active body in the solar system. Its surface is covered by sulfur and lava in many colorful forms. As Io travels in its slightly elliptical orbit, Jupiter's immense gravity causes tides in Io's solid surface 100 meters (300 feet) high, generating enough heat to give rise to the volcanic activity and drive off most water. Io's volcanoes are driven by hot silicate magma.

Europa's surface is mostly water ice, and the icy crust is believed to cover a global water ocean. Europa is thought to have twice as much liquid water as Earth. This moon intrigues astrobiologists because of its potential for having a habitable ocean very much like Earth's. Life forms have been found thriving near underwater volcanoes and in other extreme locations on Earth that are possible analogs to what may exist at Europa.

Ganymede is the largest moon in the solar system (larger than the planet Mercury), and is the only moon known to have its own internally generated magnetic field. Callisto's surface is extremely heavily cratered and ancient — a record of events from the early history of the solar system. However, at a small scale, Callisto shows very few craters, suggesting that landslides have happened throughout its history, and probably occur even today.

The interiors of Io, Europa, and Ganymede have a layered structure (as does Earth). Io has a core, and a mantle of partially molten rock, topped by a crust of solid rock coated with sulfur compounds. Both Europa and Ganymede have an iron-rich core, a rock envelope around the core, and an upper layer of water in ice and liquid forms. Like Europa, Ganymede and Callisto have oceans, but they are deeper and less accessible than Europa's. Their seafloors are covered with thick layers of ice — if formed under more pressure, water ice can become denser than ice typically found on Earth, and sink rather than float.

Three of the moons influence each other in an interesting way. Io is in a gravitational tug-of-war with Ganymede and Europa that drives the tides that make these moons so geologically active. Europa's orbital period (time to go around Jupiter once) is twice Io's, and Ganymede's period is twice that of Europa. For every time Ganymede goes around Jupiter, Europa makes two orbits and Io makes four orbits. The moons all keep the same face towards Jupiter as they orbit, meaning that each moon turns once on its axis for every orbit around Jupiter.

Voyagers 1 and 2 offered striking color views and global perspectives from their flybys of the Jupiter system in 1979. From 1995 to 2003, the Galileo spacecraft made observations from repeated elliptical orbits around Jupiter, making numerous close approaches over the surfaces of the Galilean moons and producing images with unprecedented detail of selected portions of the surfaces.

Close-up images taken by the Galileo spacecraft of portions of Europa's surface show places where ice has broken up and moved apart, and where liquid may have come from below and frozen on the surface. The low number of craters on Europa leads scientists to believe that a subsurface ocean has been present in recent geologic history and may still exist today. The heat needed to melt the ice in a place so far from the Sun is thought to come from inside Europa, resulting primarily from the same tidal tug-of-war that drives Io's volcanoes. The possibility of life existing on Europa in a subsurface ocean is so compelling that planetary scientists set among their highest priorities plans to send another spacecraft to study this intriguing moon.

FAST FACTS

Satellite	Mean Distance from Jupiter
Io	422,000 km (262,200 mi)
Europa	671,000 km (417,000 mi)
Ganymede	1,070,000 km (665,000 mi)
Callisto	1,883,000 km (1,170,000 mi)

Satellite	Mean Radius
Io	1821.6 km (1,131.9 mi)
Europa	1,560.8 km (969.8 mi)
Ganymede	2,631 km (1,635 mi)
Callisto	2,410 km (1,498 mi)

Satellite	Orbital Period (Earth Days)
Io	1.769
Europa	3.551
Ganymede	7.155
Callisto	16.689

Satellite	Density (g/cm^3)
Io	3.528
Europa	3.013
Ganymede	1.942
Callisto	1.834

SIGNIFICANT DATES

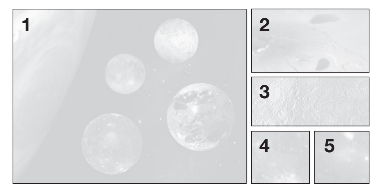
1610 — Galileo Galilei and Simon Marius independently discover four moons orbiting Jupiter. This discovery, among others by Galileo, helped change the way people thought about the heavens. The prevailing idea of the time was that all heavenly bodies orbit Earth: a planet with its own small orbiting bodies did not conform to this geocentric model.

1979 — Voyager 1 photographs an erupting volcano on Io: the first ever seen anywhere other than Earth.

1979–2000 — Using data from the Voyager and Galileo spacecraft, scientists gather strong evidence of an ocean beneath the icy crust of Europa; Galileo data indicate oceans within Ganymede and Callisto as well.

2003 — The Galileo mission ends with the spacecraft deliberately descending into Jupiter's atmosphere and being vaporized. Mission controllers purposely put Galileo on a collision course with Jupiter to eliminate any chance that the spacecraft would crash into Europa and contaminate that moon with terrestrial microbes.

ABOUT THE IMAGES



1 A comparison "portrait" of Jupiter's four Galilean moons Io, Europa, Ganymede, and Callisto, each with different characteristics. (In this image composite, Jupiter is not at the same scale as the satellites.)

2 During one flyby of Io in 2000, the Galileo spacecraft photographed Tvashtar Catena, a chain of giant erupting volcanoes. White and orange at the left of the image show newly erupted hot lava, seen in the false-color image because of infrared emission.

3 This false-color image of Europa shows the icy crust broken up into blocks that appear to have "rafted" into new positions.

4 Fresh, bright material was thrown out of an impact crater on Ganymede.

5 Ice on Callisto excavated by younger impact craters contrasts with darker, redder coatings on older surfaces.

FOR MORE INFORMATION

solarsystem.nasa.gov/jupiter

solarsystem.nasa.gov/planets/profile.cfm?Object=Jupiter&Display=Moons

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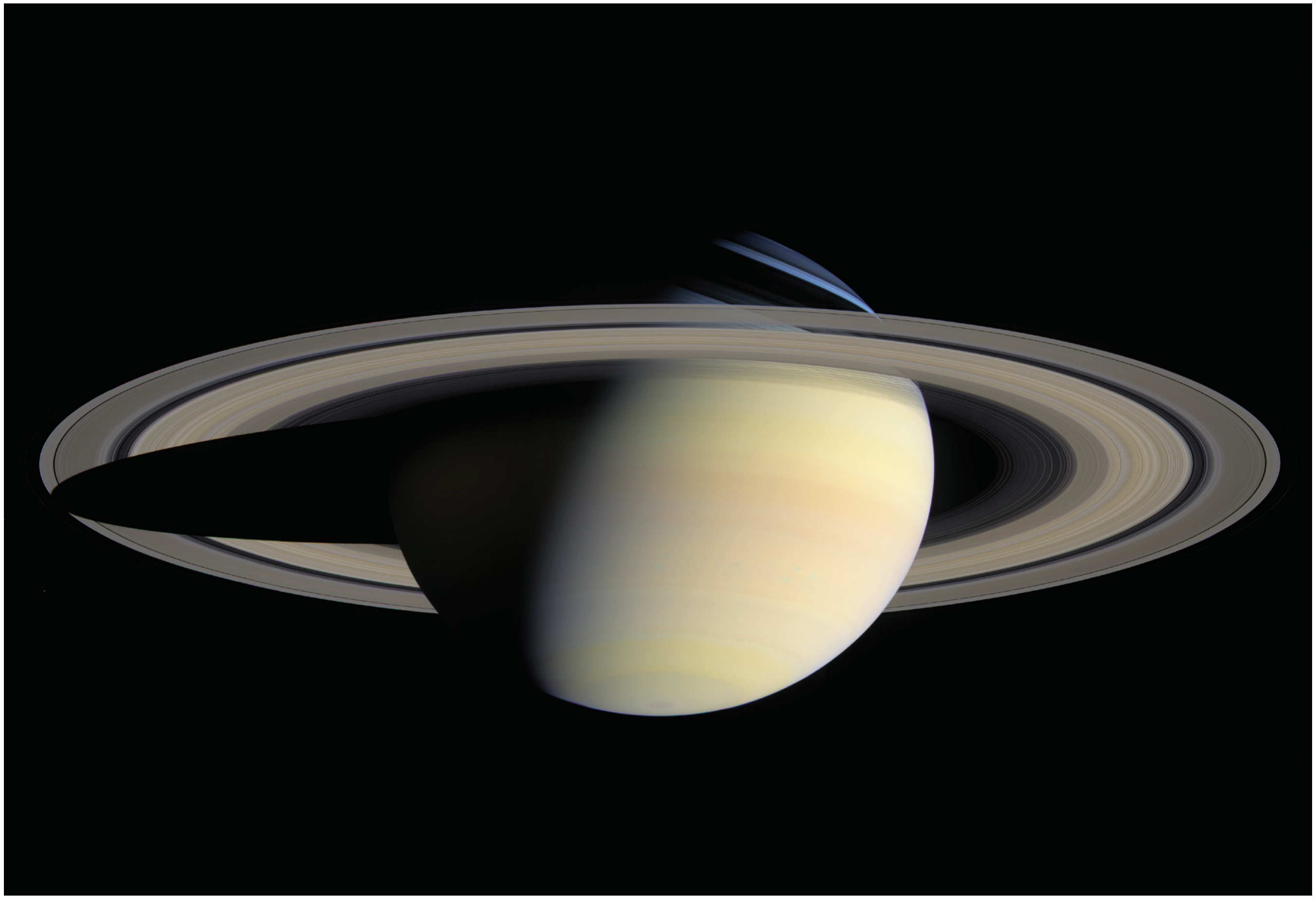
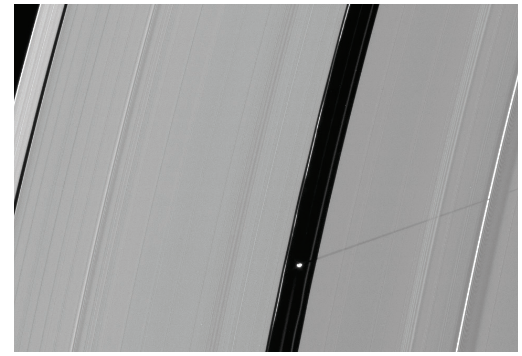
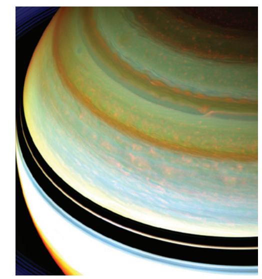
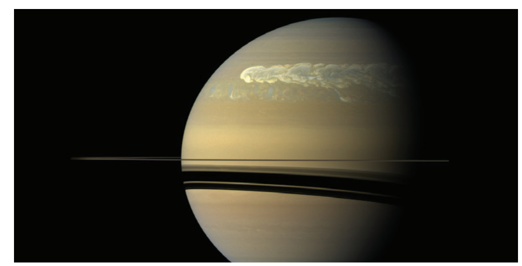
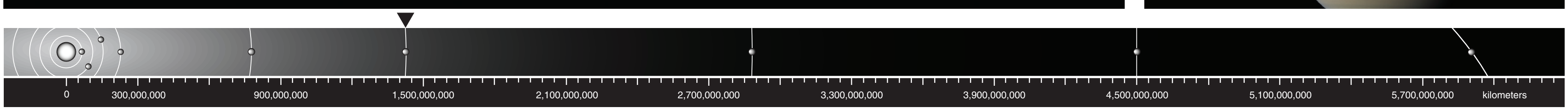
National Aeronautics and Space Administration











Saturn

Saturn was the most distant of the five planets known to the ancients. In 1610, Italian astronomer Galileo Galilei was the first to gaze at Saturn through a telescope. To his surprise, he saw a pair of objects attached to the planet. He sketched them as separate spheres, thinking that Saturn was triple-bodied. Continuing his observations over the next few years, Galileo drew the lateral bodies as arms or handles attached to Saturn. In 1659, Dutch astronomer Christiaan Huygens, using a more powerful telescope than Galileo's, proposed that Saturn was surrounded by a thin, flat ring. In 1675, Italian-born astronomer Jean-Dominique Cassini discovered a "division" between what are now called the A and B rings. It is now known that the gravitational influence of Saturn's moon Mimas is responsible for the Cassini Division, which is 4,800 kilometers (3,000 miles) wide.

Like Jupiter, Saturn is made mostly of hydrogen and helium. Its volume is 755 times greater than that of Earth. Winds in the upper atmosphere reach 500 meters (1,600 feet) per second in the equatorial region. In contrast, the strongest hurricane-force winds on Earth top out at about 110 meters (360 feet) per second. These super-fast winds, combined with heat rising from within the planet's interior, cause the yellow and gold bands visible in the atmosphere.

In the early 1980s, NASA's two Voyager spacecraft revealed that Saturn's rings are made mostly of water ice, and they imaged "braided" rings, ringlets, and "spokes" — dark features in the rings that form and initially circle the planet at different rates from that of the surrounding ring material. Saturn's ring system extends hundreds of thousands of kilometers from the planet, yet the vertical height is typically about 10 meters (30 feet) in the main rings. During Saturn's equinox in autumn 2009, when sunlight illuminated the rings edge-on, Cassini spacecraft images showed tall vertical formations in some of the rings; the particles seem to pile up in bumps or ridges more than 3 kilometers (2 miles) high.

Saturn's largest satellite, Titan, is a bit bigger than the planet Mercury. (Titan is the second-largest moon in the solar system; only Jupiter's moon Ganymede is bigger.) Titan is shrouded in a thick, nitrogen-rich atmosphere that might be similar to what Earth's was like long ago. Further study of this moon promises to reveal much about planetary formation and, perhaps, about the early days of Earth. Saturn also has many smaller icy satellites. From Enceladus, which shows evidence of recent (and ongoing) surface changes, to Iapetus, with one hemisphere darker than asphalt and the other as bright as snow, each of Saturn's satellites is unique.

At Saturn's center is a dense core of rock, ice, water, and other compounds made solid by the intense pressure and heat. It is enveloped by liquid metallic hydrogen, inside a layer of liquid hydrogen — similar to Jupiter but considerably smaller. Saturn's magnetic field is smaller than Jupiter's but still 578 times as powerful as Earth's. Saturn, the rings, and many of the satellites lie totally within Saturn's enormous magnetosphere, the region of space in which the behavior of electrically charged particles is influenced more by Saturn's magnetic field than by the solar wind. Aurorae occur when charged particles spiral into a planet's atmosphere along magnetic field lines. On Earth, these charged particles come from the solar wind. Cassini showed that at least some of Saturn's aurorae are like Jupiter's and are largely unaffected by the solar wind.

The next chapter in our knowledge of Saturn is being written right now by the Cassini–Huygens mission. The Huygens probe descended through Titan's atmosphere in January 2005, collecting data on the atmosphere and surface. The Cassini spacecraft, orbiting Saturn since 2004, continues to explore the planet and its moons, rings, and magnetosphere. The Cassini Equinox Mission studied the rings during Saturn's autumnal equinox, when the Sun was shining directly on the equator, through 2010. Now the spacecraft is seeking to make exciting new discoveries in a second extended mission called the Cassini Solstice Mission, which continues until September 2017.

FAST FACTS

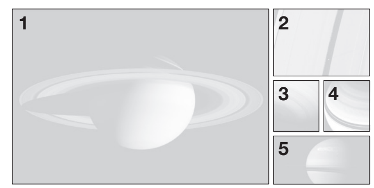
Namesake	Roman god of agriculture
Mean Distance from the Sun	1,426.666 million km (886,489 million mi)
Orbit Period	29.4 Earth years (10,755.7 Earth days)
Orbit Eccentricity (Circular Orbit = 0)	0.05386179
Orbit Inclination to Ecliptic	2.486 deg
Inclination of Equator to Orbit	26.73 deg
Rotation Period	10.656 hours
Equatorial Radius	60,268 km (37,449 mi)
Mass	95.16 of Earth's
Density	0.70 g/cm^3
Gravity	7.207 m/sec^2 (23.64 ft/sec^2)
Atmosphere Primary Components	hydrogen, helium
Effective Temperature	–178 deg C (–288 deg F)
Known Moons*	53
Rings	7 main rings (C, B, A, D, F, G, E)

*Plus 9 awaiting official confirmation, total 62, as of July 2013.

SIGNIFICANT DATES

1610 — Galileo Galilei reports seeing odd appendages on either side of Saturn; he did not realize he was viewing Saturn's rings.
1979 — Pioneer 11 is the first spacecraft to reach Saturn, flying within 22,000 kilometers (13,700 miles) of the cloud tops.
1981 — Using Saturn's powerful gravity as an interplanetary "slingshot," Voyager 2 is placed on a path toward Uranus, then Neptune, then out of the solar system.
1994 — The Hubble Space Telescope finds evidence of surface features beneath the hazy atmosphere of Titan.
2004 — After a seven-year journey, Cassini–Huygens becomes the first spacecraft to orbit Saturn.
2005 — The Huygens probe successfully lands on Titan, returning images of the complex surface.
2005–2008 — The Cassini spacecraft continues to return high-resolution images of the Saturn system. Mission discoveries include evidence for liquid hydrocarbon lakes of methane and ethane on Titan, a new radiation belt around Saturn, new rings and moons, and icy jets and geysers at the south polar region of the moon Enceladus.
2008–2010 — Cassini's mission is extended for two years and designated the Cassini Equinox Mission.
2010–2017 — Cassini's mission is extended for seven years and designated the Cassini Solstice Mission.

ABOUT THE IMAGES



1 A true-color image by Cassini of Saturn.

2 The moon Pan casts a long shadow across the A ring as equinox approaches.

3 This false-color enhanced Cassini image of the southern hemisphere brings out the subtle details in Saturn's clouds.

4 A strong jetstream churns through Saturn's northern hemisphere in this false-color view from Cassini. The dark band is the unilluminated rings.

5 Cassini captured dramatic views of a huge storm churning through Saturn's atmosphere in 2011.

FOR MORE INFORMATION

solarsystem.nasa.gov/saturn

solarsystem.nasa.gov/planets/profile.cfm?Object=Saturn&Display=Moons

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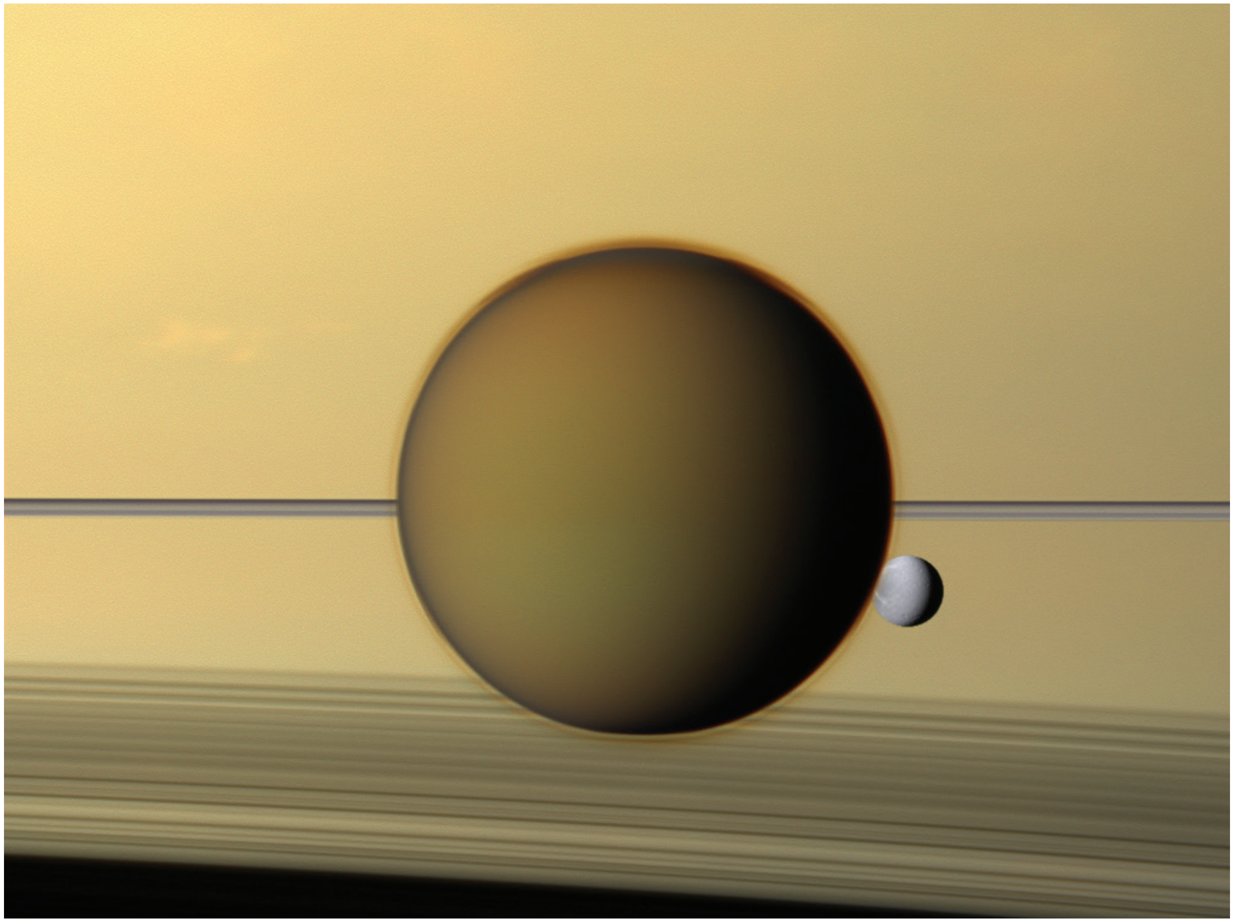
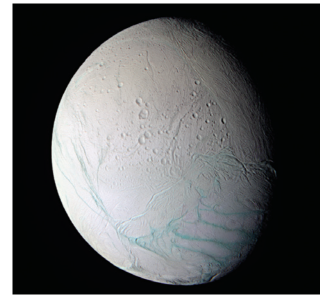
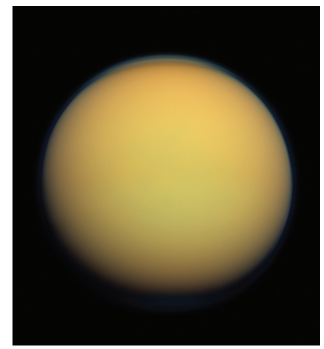
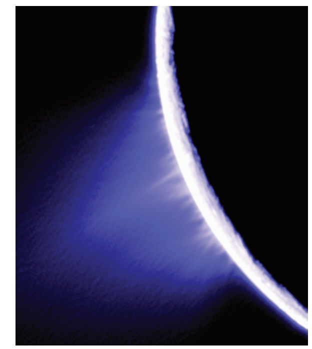
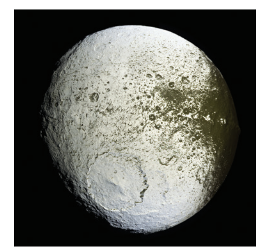
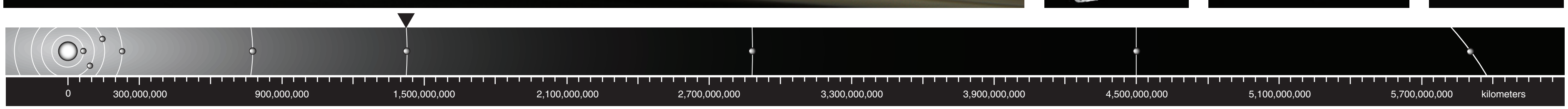












Moons of Saturn

Saturn, the sixth planet from the Sun, is home to a vast array of intriguing and unique satellites — 53 plus 9 awaiting official confirmation. Christiaan Huygens discovered the first known moon of Saturn. The year was 1655 and the moon is Titan. Jean-Dominique Cassini made the next four discoveries: Iapetus (1671), Rhea (1672), Dione (1684), and Tethys (1684). Mimas and Enceladus were both discovered by William Herschel in 1789. The next two discoveries came at intervals of 50 or more years — Hyperion (1848) and Phoebe (1898).

As telescopic resolving power improved, Saturn's family of known moons grew. Epimetheus and Janus were discovered in 1966. By the time Cassini–Huygens was launched in 1997, high-resolution imaging techniques used on Earth-based telescopes had added to the moon count. Cassini has discovered six moons and may find more during its mission. Cassini focuses its cameras mainly on objects relatively close to Saturn; the bright rings complicate moon-hunting efforts. Earth-based telescopes focus on the outer part of the Saturn system, and have found a number of moons in the outer regions.

Each of Saturn's moons bears a unique story. Two of the moons orbit within gaps in the main rings. Some, such as Prometheus and Pandora, interact with ring material, shepherding the ring in its orbit. Some small moons are trapped in the same orbits as Tethys or Dione. Janus and Epimetheus occasionally pass close to each other, causing them to periodically exchange orbits. In 2006, Cassini found evidence for a new class of "moonlets" residing within Saturn's rings, sweeping out small gaps in the ring particles. There may be as many as 10 million moonlets within just one of the rings.

Here's a sampling of some of the unique aspects of the moons:

• Titan — At 5,150 kilometers (3,200 miles) across, Titan is the solar system's second-largest moon. Titan hides its surface beneath a thick, nitrogen-rich atmosphere, but Cassini's instruments have revealed that Titan possesses many parallels to Earth — clouds, dunes, mountains, lakes, and rivers. Titan's atmosphere is approximately 95 percent nitrogen with traces of methane. While Earth's atmosphere extends about 60 kilometers (37 miles) into space, Titan's extends nearly 600 kilometers (10 times that of Earth's atmosphere) into space.

• Iapetus has one side as bright as snow and one side as dark as black velvet, with a huge ridge running around most of its dark-side equator.

• Phoebe orbits the planet in a direction opposite that of Saturn's larger moons, as do several of the recently discovered moons.

• Mimas has an enormous crater on one side, the result of an impact that nearly split the moon apart.

• Enceladus displays evidence of active ice volcanism: Cassini observed warm fractures where evaporating ice evidently escapes and forms a huge cloud of water vapor over the south pole.

• Hyperion has an odd flattened shape and rotates chaotically, probably due to a recent collision.

• Pan orbits within the main rings and helps sweep materials out of a narrow space known as the Encke Gap.

• Tethys has a huge rift zone called Ithaca Chasma that runs nearly three-quarters of the way around the moon.

• Four moons orbit in stable places around Saturn called Lagrangian points. These places lie 60 degrees ahead of or behind a larger moon and in the same orbit. Telesto and Calypso occupy the two Lagrangian points of Tethys in its orbit; Helene and Polydeuces occupy the corresponding Lagrangian points of Dione.

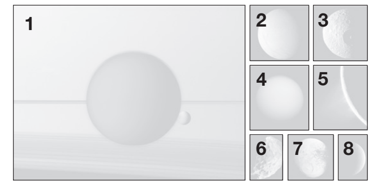
• Sixteen of Saturn's moons keep the same face toward the planet as they orbit. Called "tidal locking," this is the same phenomenon that keeps our Moon always facing toward Earth.

In addition to studies of Titan, Cassini continues to gather data about many of the other satellites in an effort to fully understand the nature, formation, and dynamics of Saturn's many intriguing moons.

FAST FACTS

• Largest Moon of Saturn	Titan
Titan's Diameter	5,150 km (3,200 mi)
• Closest Moon to Saturn	Pan
Pan's Distance from Saturn	133,583 km (83,022 mi)
• Fastest Orbit	Pan
Pan's Orbit Around Saturn	13.8 hours
• Number of Moons Discovered by Voyager (Atlas, Prometheus, Pandora, and Pan)	4
• Number of Moons Discovered by Cassini (Methone, Pallene, Polydeuces, Daphnis, Anthe, and Aegaeon)	6

ABOUT THE IMAGES



1 Saturn's fourth-largest moon, Dione, is seen through the haze of the planet's largest moon, Titan, against Saturn and its rings.

2 False color (blue) emphasizes icy walls of fractures on Enceladus.

3 The Herschel crater on Mimas is a relic of a large impact that nearly destroyed this moon.

4 Titan's atmosphere makes Saturn's largest moon look like a fuzzy orange ball in this natural-color view.

5 A false-color view processed to enhance the individual jets spurting ice particles on Enceladus.

6 This image is a mosaic of images of Phoebe taken by Cassini during its historic close encounter in June 2004.

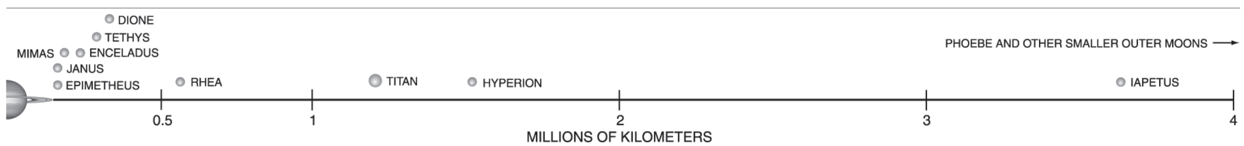
7 This image of Iapetus, the two-toned moon, shows the bright trailing hemisphere.

8 Cassini's false-color image of Rhea enhances the slight differences in natural color across the moon's face.

FOR MORE INFORMATION

solarsystem.nasa.gov/saturn

For the most recent Saturn moon count, visit:
solarsystem.nasa.gov/planets/profile.cfm?Object=Saturn&Display=Moons



Some of Saturn's moons are shown at relative distances to the planet.

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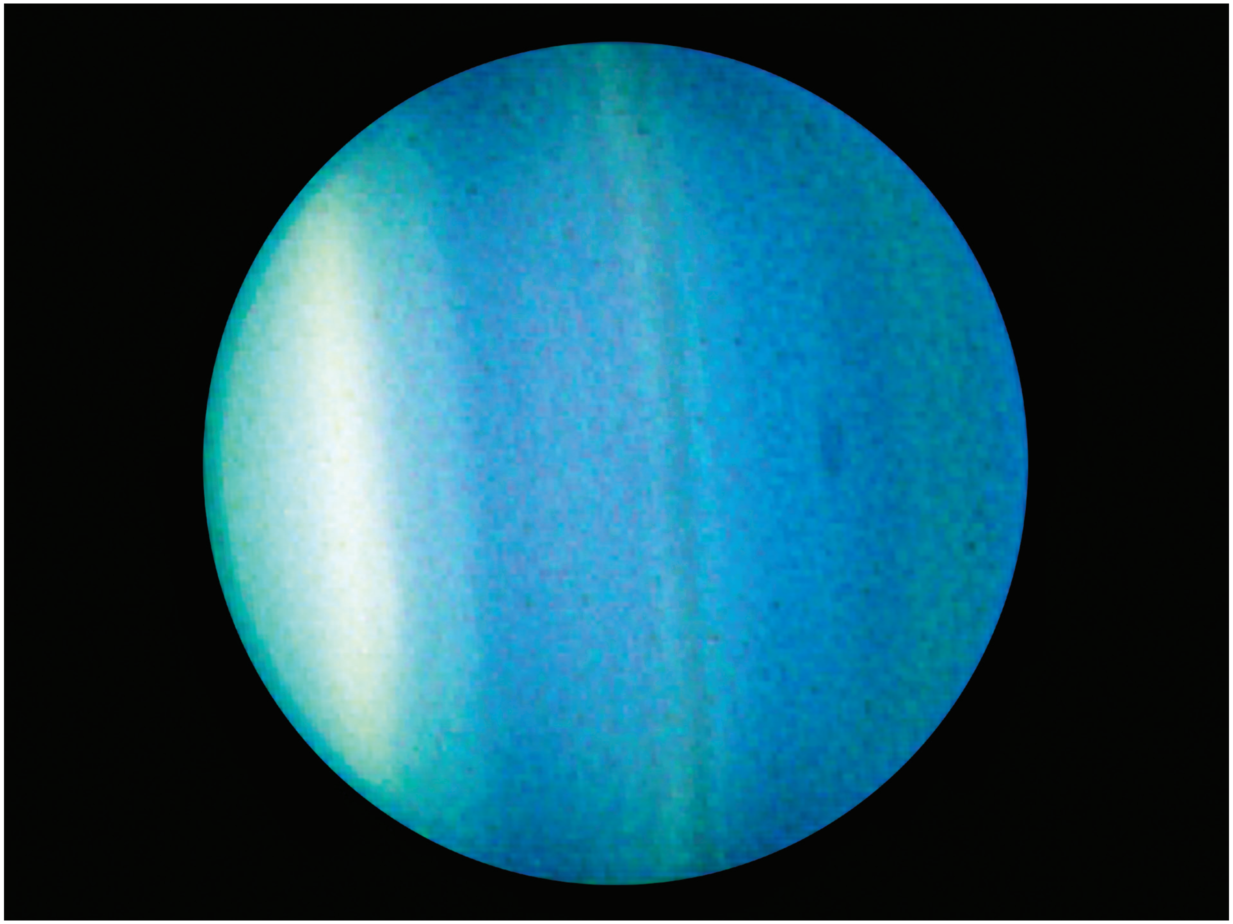
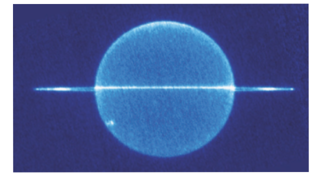
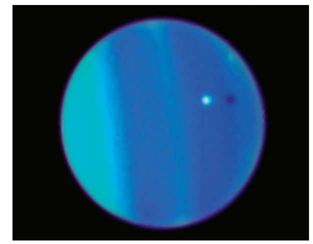
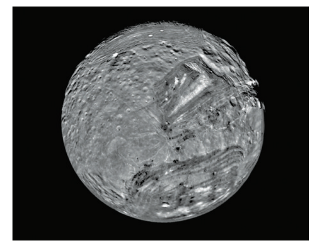
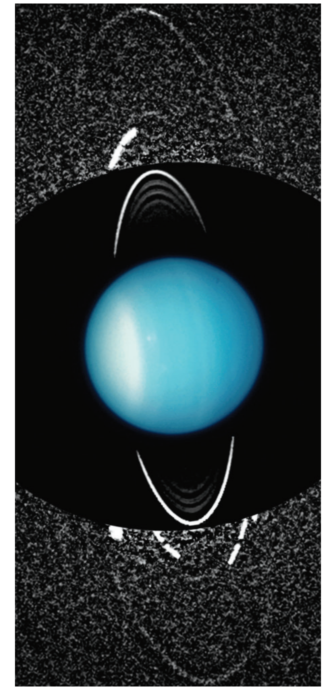
National Aeronautics and Space Administration

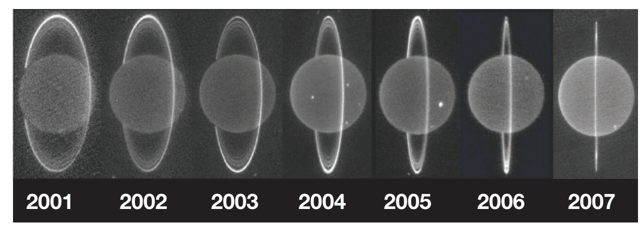


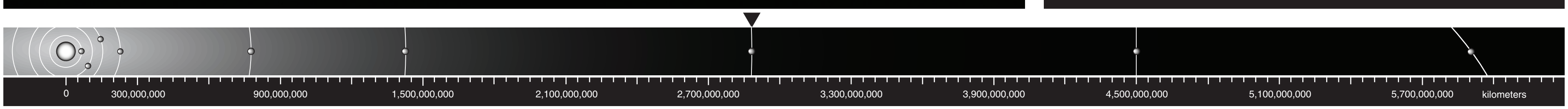












Uranus

The first planet found with the aid of a telescope, Uranus discovered in 1781 by astronomer William Herschel, alth originally thought it was a comet or star. The seventh pla the Sun is so distant that it takes 84 years to complete o

Like Venus, Uranus rotates east to west. Uranus' rotatior tilted almost parallel to its orbital plane, so Uranus appea rotating on its side. This situation may be the result of a c with a planet-sized body early in the planet's history, whi parently radically changed Uranus' rotation. Because of unusual orientation, the planet experiences extreme variations in sunlight during each 20-year-long season.

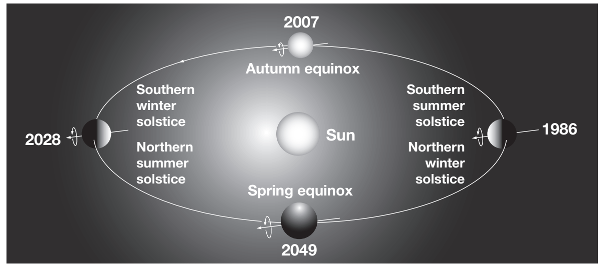
Voyager 2, the only spacecraft to visit Uranus, imaged a bland-looking sphere in 1986. When Voyager flew by, the south pole of Uranus pointed almost directly at the Sun because Uranus was near its southern summer solstice, with the southern hemisphere bathed in continuous sunlight and the northern hemisphere radiating heat into the blackness of space.

Uranus reached equinox in December 2007, when it was fully illuminated as the Sun passed over the planet's equator. By 2028, the north pole will point directly at the Sun, a reversal of the situation when Voyager flew by. Equinox also brings ring-plane crossing, when Uranus' rings appear to move more and more edge-on as seen from Earth.

The Hubble Space Telescope and the Keck Observatory in Hawaii captured detailed images of Uranus as the planet approached equinox. While Voyager 2 saw only a few discrete clouds, more recent observations reveal that Uranus exhibits dynamic clouds as it approaches equinox, including rapidly evolving bright features and a new Great Dark Spot like those seen on Neptune.

Uranus is one of the two ice giants of the outer solar system (the other is Neptune). The atmosphere is mostly hydrogen and helium, with a small amount of methane and traces of water and ammonia. Uranus gets its blue-green color from methane gas in the atmosphere. Sunlight passes through the atmosphere and is reflected back out by Uranus' cloud tops. Methane gas absorbs the red portion of the light, resulting in a blue-green color. The bulk (80 percent or more) of the mass of Uranus is contained in an extended liquid core consisting mostly of icy materials (water, methane, and ammonia).

For nearly a quarter of the Uranian year (equal to 84 Earth years), the Sun shines directly over each pole, plunging the other half of the planet into a long, dark winter.



The varying positions of Uranus over its 20-year seasons.

While magnetic fields are typically in alignment with a planet's rotation, Uranus' magnetic field is tipped over: the magnetic axis is tilted nearly 60 degrees from the planet's axis of rotation, and is also offset from the center of the planet by one-third of the planet's radius. The magnetic fields of both Uranus and Neptune are very irregular.

Uranus has two sets of rings. The inner system of nine rings, discovered in 1977, consists mostly of narrow, dark rings. Voyager 2 found two additional inner rings. An outer system of two more-distant rings was discovered in Hubble Space Telescope images in 2003. In 2006, Hubble and Keck observations showed that the outer rings are brightly colored. Uranus has 27 known moons, named for characters from the works of William Shakespeare or Alexander Pope. Miranda is the strangest-looking Uranian moon: its complex surface may indicate partial melting of the interior, with icy material drifting to the surface.

FAST FACTS

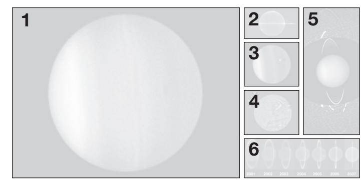
Namesake	Greek god of the heavens ("Ouranos")
Mean Distance from the Sun	2,870.97 million km (1,783.94 million mi)
Orbit Period	84.02 Earth years (30,687.2 Earth days)
Orbit Eccentricity (Circular Orbit = 0)	0.047168
Orbit Inclination to Ecliptic	0.770 deg
Inclination of Equator to Orbit	97.86 deg
Rotation Period	17.24 hours (retrograde)
Equatorial Radius	25,559 km (15,882 mi)
Mass	14.371 of Earth's
Density	1.32 g/cm^3
Gravity	8.43 m/sec^2 (27.7 ft/sec^2)
Atmosphere Primary Components	hydrogen, helium
Effective Temperature	–216 deg C (–357 deg F)
Known Moons*	27
Known Rings	13 (Zeta, Six, Five, Four, Alpha, Beta, Eta, Gamma, Delta, Lambda, Epsilon, Nu, Mu)

*As of July 2013.

SIGNIFICANT DATES

1781 — Astronomer William Herschel discovers Uranus.
1787–1851 — Four Uranian moons are discovered and named Titania, Oberon, Ariel, and Umbriel.
1948 — Another moon, Miranda, is discovered.
1977 — Scientists discover nine faint rings of Uranus while observing a distant star pass behind the planet.
1986 — Voyager 2 discovers 10 moons and two additional rings during its historic flyby.
1997–2005 — Astronomers discover more tiny moons.
2003–2005 — The Hubble Space Telescope images two delicate rings far from the planet, and two new moons.
2007 — Uranus reaches equinox.

ABOUT THE IMAGES



1 This 2006 image taken by the Hubble Space Telescope shows bands and a new "dark spot" in Uranus' atmosphere.

2 This infrared image of the dark side of the rings was taken by the Keck Observatory in 2007. The rings are visible because the widely separated ring particles scatter sunlight from the sunlit side of the planet to the dark side. The image is rotated 90 degrees.

3 Uranus' moon Ariel (white dot) and its shadow (black dot) were caught crossing the face of Uranus in this Hubble Space Telescope image.

4 Uranus' moon Miranda as seen by Voyager 2.

5 This Hubble composite image shows two very faint outer rings revealed in 2003. The very bright streaks in the outer ring system are moons, their images smeared out by the long exposure.

6 Keck Observatory infrared images show how Uranus and its rings changed, as viewed from Earth, from 2001–2007. The south pole is at the left in the images.

FOR MORE INFORMATION

solarsystem.nasa.gov/uranus

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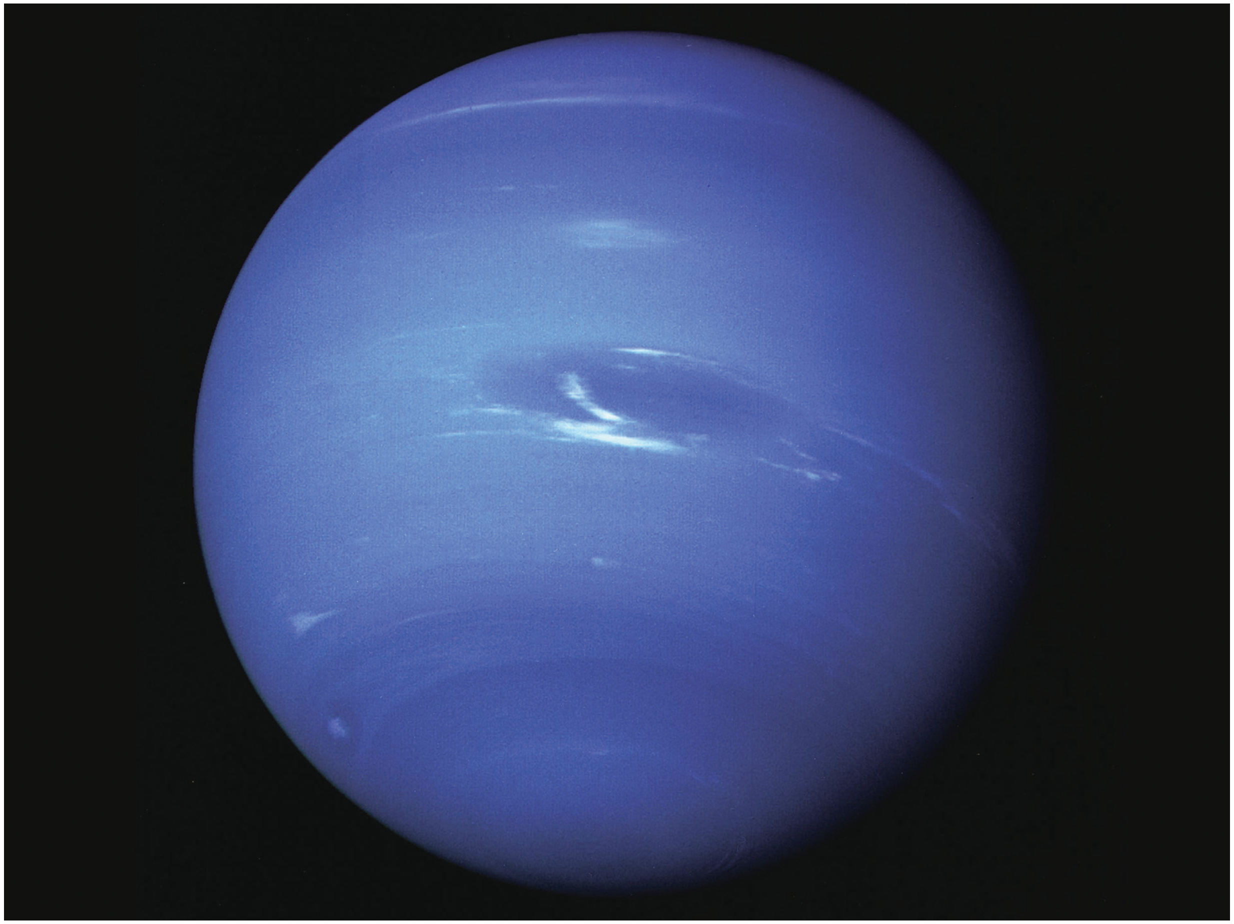
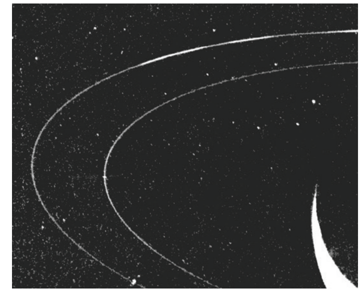
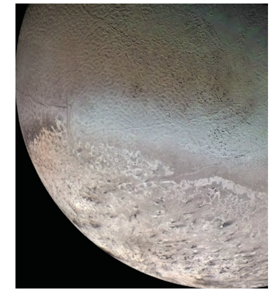
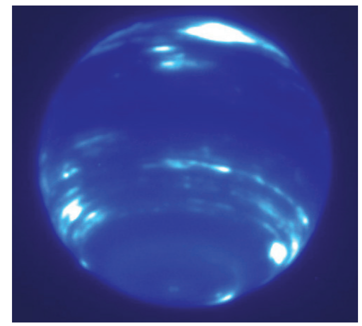
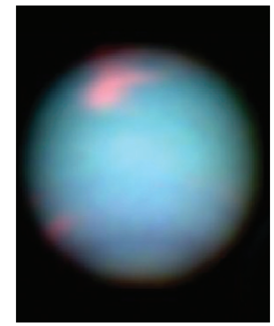
National Aeronautics and Space Administration

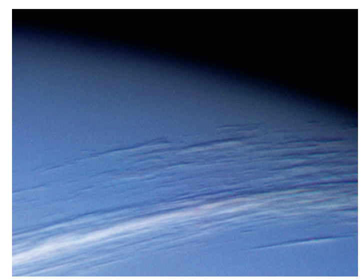


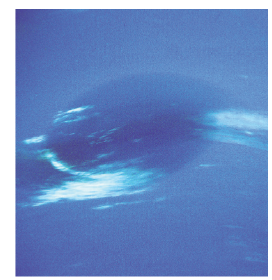


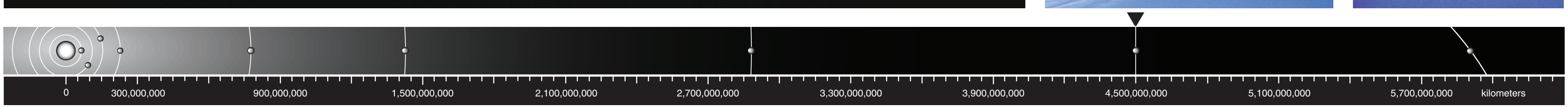












Neptune

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The ice giant Neptune was the first planet located through mathematical predictions rather than through regular observations of the sky. (Galileo had recorded it as a fixed star during observations with his small telescope in 1612 and 1613.) When Uranus didn't travel exactly as astronomers expected it to, a French mathematician, Urbain Joseph Le Verrier, proposed the position and mass of another as yet unknown planet that could cause the observed changes to Uranus' orbit. After being ignored by French astronomers, Le Verrier sent his predictions to Johann Gottfried Galle at the Berlin Observatory, who found Neptune on his first night of searching in 1846. Seventeen days later, its largest moon, Triton, was also discovered.

Nearly 4.5 billion kilometers (2.8 billion miles) from the Sun, Neptune orbits the Sun once every 165 years. It is invisible to the naked eye because of its extreme distance from Earth. Interestingly, the highly eccentric orbit of the dwarf planet Pluto brings Pluto inside Neptune's orbit for a 20-year period out of every 248 Earth years. Pluto can never crash into Neptune, though, because for every three laps Neptune takes around the Sun, Pluto makes two. This repeating pattern prevents close approaches of the two bodies.

The main axis of Neptune's magnetic field is tipped over by about 47 degrees compared with the planet's rotation axis. Like Uranus, whose magnetic axis is tilted about 60 degrees from the axis of rotation, Neptune's magnetosphere undergoes wild variations during each rotation because of this misalignment. The magnetic field of Neptune is about 27 times more powerful than that of Earth.

Neptune's atmosphere extends to great depths, gradually merging into water and other melted ices over a heavier, approximately Earth-size solid core. Neptune's blue color is the result of methane in the atmosphere. Uranus' blue-green color is also the result of atmospheric methane, but Neptune is a more vivid, brighter blue, so there must be an unknown component that causes the more intense color.

Despite its great distance and low energy input from the Sun, Neptune's winds can be three times stronger than Jupiter's and nine times stronger than Earth's. In 1989, Voyager 2 tracked a large, oval-shaped, dark storm in Neptune's southern hemisphere. This "Great Dark Spot" was large enough to contain the entire Earth, spun counterclockwise, and moved westward at almost 1,200 kilometers (750 miles) per hour. Subsequent images taken by the Hubble Space Telescope showed no sign of this Great Dark Spot, but did reveal the appearance and then fading of two other Great Dark Spots over the last decade. Voyager 2 also imaged clouds casting shadows on a lower cloud deck, enabling scientists to visually measure the altitude differences between the upper and lower cloud decks.

Neptune has six known rings. Voyager 2's observations confirmed that these unusual rings are not uniform but have four thick regions (clumps of dust) called arcs. The rings are thought to be relatively young and short-lived.

Neptune has 13 known moons, six of which were discovered by Voyager 2. A 14th tiny, very dim, moon was discovered in 2013 and awaits official recognition. Triton, Neptune's largest moon, orbits the planet in the opposite direction compared with the rest of the moons, suggesting that it may have been captured by Neptune in the distant past. Triton is extremely cold — temperatures on its surface are about –235 degrees Celsius (–391 degrees Fahrenheit). Despite this deep freeze at Triton, Voyager 2 discovered geysers spewing icy material upward more than 8 kilometers (5 miles). Triton's thin atmosphere, also discovered by Voyager, has been detected from Earth several times since, and is growing warmer — although scientists do not yet know why.

FAST FACTS

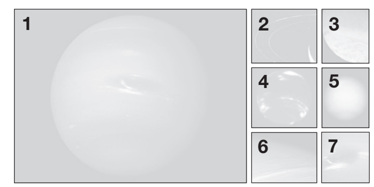
Namesake	Roman god of the sea
Mean Distance from the Sun	4,498.25 million km (2,795.08 million mi)
Orbit Period	164.79 Earth years (60,190 Earth days)
Orbit Eccentricity (Circular Orbit = 0)	0.00859
Orbit Inclination to Ecliptic	1.769 deg
Inclination of Equator to Orbit	29.58 deg
Rotation Period	16.11 hours
Equatorial Radius	24,764 km (15,388 mi)
Mass	17.147 of Earth's
Density	1.64 g/cm^3
Gravity	10.71 m/sec^2 (35.14 ft/sec^2)
Atmosphere Primary Components	hydrogen, helium
Effective Temperature	–214 deg C (–353 deg F)
Known Moons*	13
Known Rings	6 (Galle, Arago, Lassell, Le Verrier, unnamed ring co-orbital with the moon Galatea, Adams)

*Plus 1 awaiting official confirmation, total 14, as of July 2013.

SIGNIFICANT DATES

1846 — Using mathematical calculations, astronomers discover Neptune, increasing the number of known planets to eight. Neptune's largest moon, Triton, is found the same year.
1984 — Astronomers find evidence for the existence of a ring system around Neptune.
1989 — Voyager 2 becomes the first and only spacecraft to visit Neptune, passing about 4,800 kilometers (2,983 miles) above the planet's north pole.
1998 — Scientists using telescopes on Earth and in space image Neptune's rings and ring arcs for the first time.
2001 — Neptune completes its first 165-year orbit of the Sun since its discovery in 1846.
2003 — Using improved observing techniques, astronomers discover five new moons orbiting Neptune.
2005 — Scientists using the Keck Observatory image the outer rings and find that some of the ring arcs have deteriorated.
2013 — A scientist studying Neptune's ring arcs in archival Hubble Space Telescope images finds a previously unknown 14th moon of Neptune, provisionally designated S/2004 N 1.

ABOUT THE IMAGES



1 Voyager 2 captured this image of Neptune in 1989.

2 This Voyager 2 image shows the arcs in the outer rings.

3 The moon Triton's complex surface is shown in this Voyager 2 image. The surface is covered in nitrogen ice.

4 The Keck Observatory in Hawaii took this infrared image of Neptune using adaptive optics that compensate for the blurring effect of Earth's atmosphere.

5 This Hubble Space Telescope image of Neptune shows bright, high-altitude clouds of methane ice crystals.

6 The clouds in this Voyager 2 image are estimated to be about 50 kilometers (31 miles) tall.

7 Voyager 2 took this close-up image of Neptune's mysterious Great Dark Spot.

FOR MORE INFORMATION

solarsystem.nasa.gov/neptune

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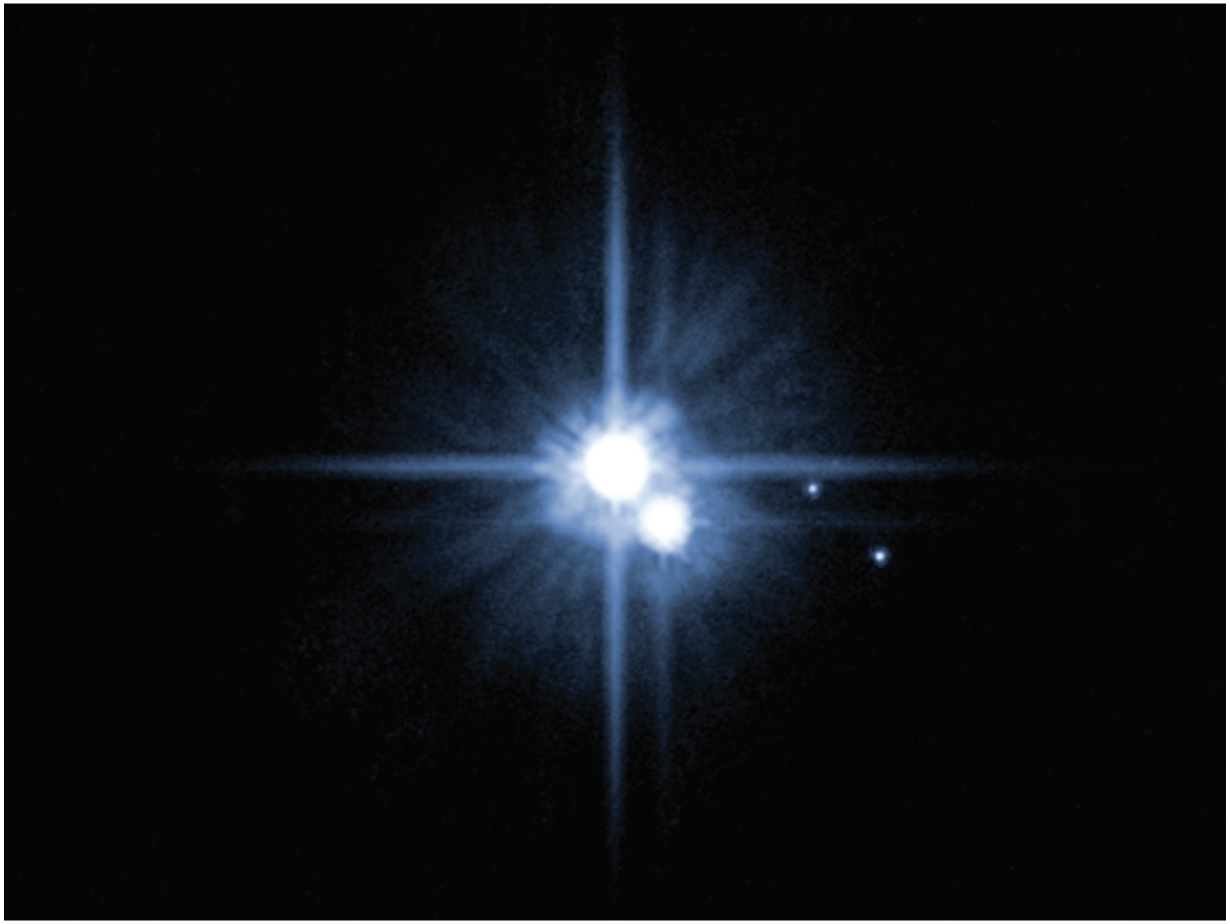
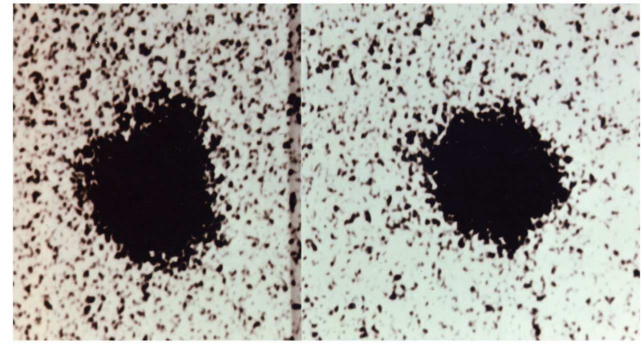
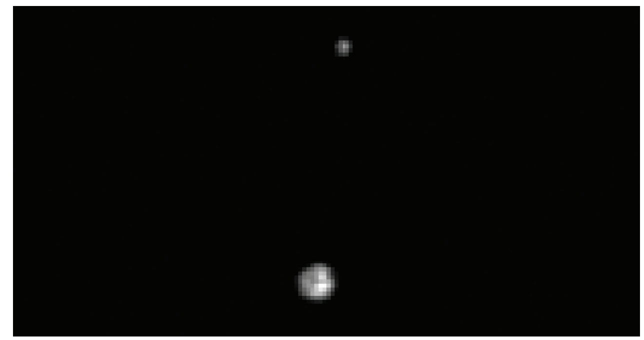
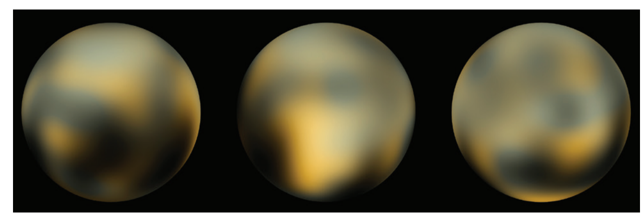
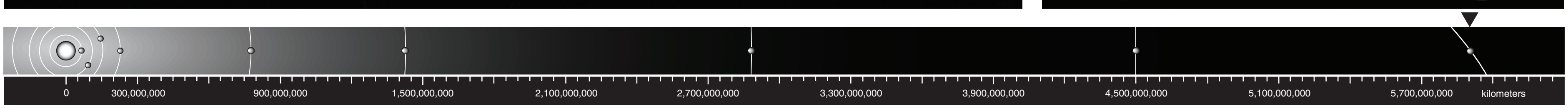
National Aeronautics and Space Administration











Pluto and Charon

www.nasa.gov

Pluto's discovery in 1930 resulted from an attempt to find a planet beyond Neptune that was theorized to be disturbing the orbits of Uranus and Neptune. Astronomers initially calculated Pluto's mass based on its presumed effect on the two giant outer planets. With the 1978 discovery of Pluto's large moon, Charon, astronomers could compute Pluto's mass for the first time, and it proved to be far too small to account for discrepancies in the orbits of Uranus or Neptune.

Pluto is classified as a dwarf planet and is also a member of a group of objects that orbit in a disc-like zone beyond the orbit of Neptune called the Kuiper Belt. This distant realm is populated with thousands of miniature icy worlds, which formed early in the history of the solar system. These icy, rocky bodies are called Kuiper Belt objects or transneptunian objects.

Pluto's 248-year-long elliptical orbit can take it as far as 49.3 astronomical units (AU) from the Sun. (One AU is the mean distance between Earth and the Sun: about 150 million kilometers or 93 million miles.) From 1979 to 1999, Pluto was actually closer to the Sun than Neptune, and in 1989, Pluto came to within 29.7 AU of the Sun, providing rare opportunities to study this small, cold, distant world. Pluto's orbit occasionally brings it closer to the Sun than the Kuiper Belt.

Pluto is about two-thirds the diameter of Earth's Moon. Exotic ices like methane and nitrogen frost coat its surface. Owing to its size and lower density, Pluto's mass is about one-sixth that of Earth's Moon. Its density indicates that it is partially composed of ices, not rocky materials. Pluto is more massive than Ceres — the dwarf planet that resides in the asteroid belt between Mars and Jupiter — by a factor of 20.

When Pluto is close to the Sun, its surface ices thaw, rise, and temporarily form a thin atmosphere. Pluto's low gravity (about 6 percent of Earth's) causes the atmosphere to be much more extended in altitude than our planet's atmosphere. Pluto becomes much colder during the part of each orbit when it is traveling far away from the Sun, and it is thought that the bulk of the planet's atmosphere freezes during this time.

Pluto's very large moon, Charon, is almost half the size of Pluto. Charon is so big that the two are sometimes referred to as a double dwarf planet system. The distance between them is 19,640 kilometers (12,200 miles). The Hubble Space Telescope photographed Pluto and Charon in 1994 when Pluto was about 30 AU from Earth. These photos showed that Charon is grayer than Pluto (which is red), indicating that they have different surface compositions and structure.

In 2005, scientists photographing Pluto with the Hubble Space Telescope in preparation for the New Horizons mission found two tiny moons orbiting in the same plane as Charon, but two to three times farther away from Pluto than Charon. Named Nix and Hydra, the two moons are thought to be perhaps 50 to 100 kilometers (31 to 62 miles) in diameter. In 2011, Hubble observers found an even smaller moon (later named Kerberos), and in 2012, yet another tiny moon was discovered (later named Styx). The space telescope is being used to scour the Pluto system to uncover potential orbital debris hazards to the New Horizons spacecraft, which will be traveling at about 48,280 kilometers per hour (30,000 miles per hour). The New Horizons team may be able to plan observations of these newly discovered moons. By July 2013, the spacecraft was halfway to Pluto — beyond the orbit of Uranus and heading for its Pluto rendezvous in 2015.

Charon's orbit around Pluto takes 6.4 Earth days, and one Pluto rotation (a Pluto day) takes 6.4 Earth days. Charon neither rises nor sets but "hovers" over the same spot on Pluto's surface, and the same side of Charon always faces Pluto — this is called tidal locking. Compared with most of the planets and moons, the Pluto–Charon system is tipped on its side, like Uranus. Pluto's rotation is retrograde: it rotates "backwards," from east to west (Uranus and Venus also have retrograde rotation). It isn't known whether Pluto has a magnetic field, but its small size and slow rotation suggest little or no magnetic field.

Because Pluto and its family of moons are so small and far away, they are extremely difficult to observe from Earth. Careful analyses of images taken by the Hubble Space Telescope have allowed astronomers to make rudimentary maps showing areas of relative brightness and darkness.

FAST FACTS

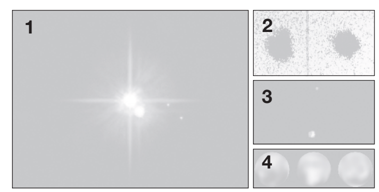
Namesake	Roman god of the underworld
Mean Distance from the Sun	5,906.38 million km (3,670.05 million mi)
Orbit Period	247.92 Earth years (90,553 Earth days)
Orbit Eccentricity (Circular Orbit = 0)	0.2488
Orbit Inclination to Ecliptic	17.14 deg
Inclination of Equator to Orbit	119.61 deg
Rotation Period	6.387 Earth days (retrograde)
Equatorial Radius (Pluto)	1,180 km (733 mi)
Equatorial Radius (Charon)	600 km (373 mi)
Mass	0.0022 of Earth's
Density (Pluto)	2.03 g/cm^3
Gravity	0.65 m/sec^2 (2.1 ft/sec^2)
Atmosphere Primary Components	nitrogen, carbon monoxide, methane
Surface Temperature	–233 to –223 deg C (–387 to –369 deg F)
Known Moons*	5
Rings	None known

*As of July 2013.

SIGNIFICANT DATES

1930 — Clyde Tombaugh discovers Pluto.
1977–1999 — Pluto's lopsided orbit brings it slightly closer to the Sun than Neptune. It will be at least 230 years before Pluto moves inward of Neptune's orbit for 20 years.
1978 — American astronomers James Christy and Robert Harrington discover Pluto's unusually large moon, Charon.
1988 — Astronomers discover that Pluto has an atmosphere.
2005 — Scientists using the Hubble Space Telescope announce the discovery of two additional moons of Pluto.
2006 — NASA's New Horizons mission launches to explore Pluto and the Kuiper Belt region.
2011–2012 — Three more small moons are found, bringing the total of known moons to five.

ABOUT THE IMAGES



1 Pluto, Charon (just below and to the right of Pluto), and the tiny moons Nix and Hydra were imaged by the Hubble Space Telescope.

2 Astronomers investigating a changing bulge in Pluto images eventually determined that Pluto had a companion — Charon, a large moon nearly half Pluto's size.

3 The Hubble Space Telescope resolved Pluto and Charon as separate discs in the 1990s, enabling better measurements of both bodies.

4 Surface maps of Pluto created from Hubble Space Telescope images reveal a complex-looking world with white, dark-orange, and charcoal-black terrain.

FOR MORE INFORMATION

solarsystem.nasa.gov/pluto

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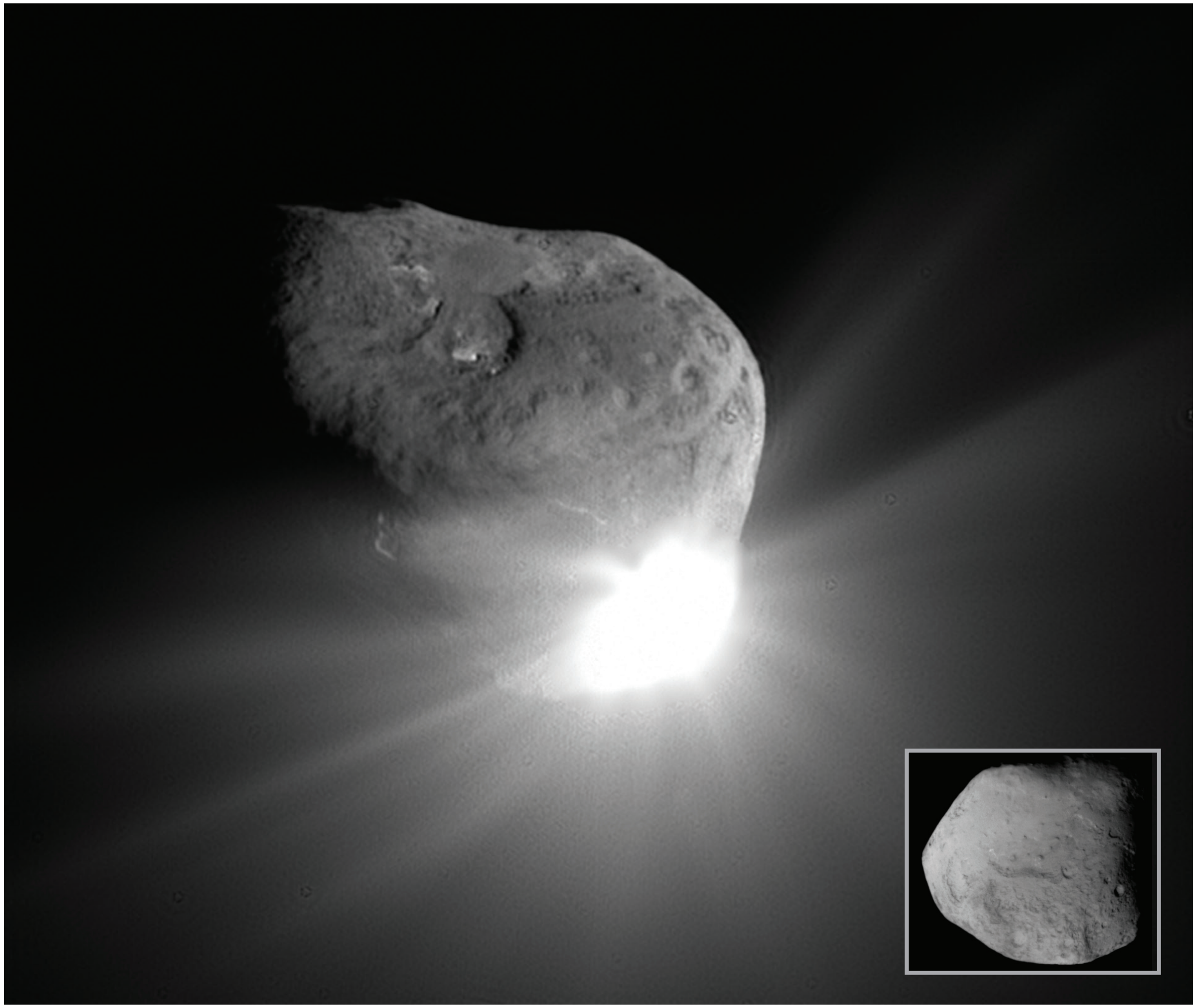
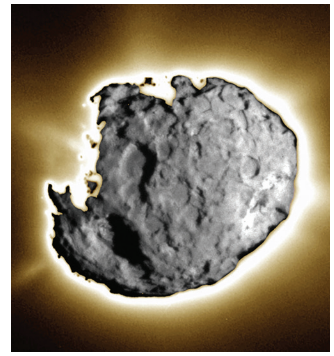
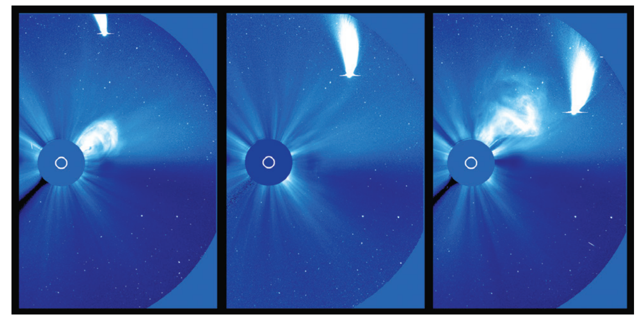
National Aeronautics and Space Administration







Comets

In the distant past, people were both awed and alarmed by comets, perceiving them as “long-haired” stars that appeared in the sky unannounced and unpredictably. Chinese astronomers kept extensive records for centuries, including illustrations of characteristic types of comet tails, times of cometary appearances and disappearances, and celestial positions. These historic comet annals have proven to be a valuable resource for later astronomers.

We now know that comets are leftovers from the dawn of the solar system around 4.6 billion years ago, and consist mostly of ice coated with dark organic material. They have been referred to as “dirty snowballs.” They may yield important clues about the formation of our solar system. Comets may have brought water and organic compounds, the building blocks of life, to the early Earth and other parts of the solar system.

As theorized by astronomer Gerard Kuiper in 1951, a disc-like belt of icy bodies exists beyond Neptune, where a population of dark comets orbits the Sun in Pluto’s realm. These icy objects, occasionally pushed by gravity into orbits bringing them closer to the Sun, become the so-called short-period comets. Taking less than 200 years to orbit the Sun, in many cases their appearance is predictable because they have passed by before. Less predictable are long-period comets, many of which arrive from a region called the Oort Cloud about 100,000 astronomical units (that is, 100,000 times the distance between Earth and the Sun) from the Sun. These Oort Cloud comets can take as long as 30 million years to complete one trip around the Sun.

Each comet has a tiny frozen part, called a nucleus, often no larger than a few kilometers across. The nucleus contains icy chunks — frozen gases with bits of embedded dust. A comet warms up as it nears the Sun and develops an atmosphere, or coma. The Sun’s heat causes the comet’s ices to change to gases so the coma gets larger. The coma may extend hundreds of thousands of kilometers. The pressure of sunlight and high-speed solar particles (solar wind) can blow the coma dust and gas away from the Sun, sometimes forming a long, bright tail. Comets actually have two tails — a dust tail and an ion (gas) tail.

Most comets travel a safe distance from the Sun — comet Halley comes no closer than 89 million kilometers (55 million miles). However, some comets, called sungrazers, crash straight into the Sun or get so close that they break up and evaporate.

Scientists have long wanted to study comets in some detail, tantalized by the few 1986 images of comet Halley’s nucleus. NASA’s Deep Space 1 spacecraft flew by comet Borrelly in 2001 and photographed its nucleus, which is about 8 kilometers (5 miles) long.

NASA’s Stardust mission successfully flew within 236 kilometers (147 miles) of the nucleus of comet Wild 2 in January 2004, collecting cometary particles and interstellar dust for a sample return to Earth in 2006. The photographs taken during this close flyby of a comet nucleus show jets of dust and a rugged, textured surface. Analysis of the Stardust samples suggests that comets may be more complex than originally thought. Minerals formed near the Sun or other stars were found in the samples, suggesting that materials from the inner regions of the solar system traveled to the outer regions where comets formed.

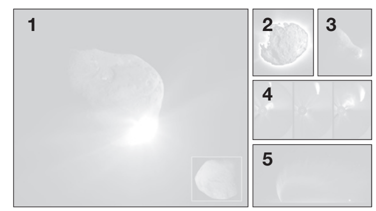
Another NASA mission, Deep Impact, consisted of a flyby spacecraft and an impactor. In July 2005, the impactor was released into the path of the nucleus of comet Tempel 1 in a planned collision, which vaporized the impactor and ejected massive amounts of fine, powdery material from beneath the comet’s surface. En route to impact, the impactor camera imaged the comet in increasing detail. Two cameras and a spectrometer on the flyby spacecraft recorded the dramatic excavation that helped determine the interior composition and structure of the nucleus.

After their successful primary missions, the Deep Impact spacecraft and the Stardust spacecraft were still healthy and were retargeted for additional cometary flybys. Deep Impact’s mission, EPOXI (Extrasolar Planet Observation and Deep Impact Extended Investigation), comprised two projects: the Deep Impact Extended Investigation (DIXI), which encountered comet Hartley 2 in November 2010, and the Extrasolar Planet Observation and Characterization (EPOCh) investigation, which searched for Earth-size planets around other stars on route to Hartley 2. NASA returned to comet Tempel 1 in 2011, when the Stardust New Exploration of Tempel 1 (NExT) mission observed changes in the nucleus since Deep Impact’s 2005 encounter.

SIGNIFICANT DATES

1070–1080 — The comet later designated Halley’s Comet is pictured in the Bayeux Tapestry, a chronicle of the Battle of Hastings of 1066.
1449–1450 — Astronomers make one of the first known efforts to record the paths of comets across the night sky.
1705 — Edmond Halley publishes that the comets of 1531, 1607, and 1682 are the same object and predicts its return in 1758. The comet arrives on schedule and is later named Halley’s Comet.
1986 — An international fleet of five spacecraft converges on comet Halley as it makes its regular (about every 76 years) pass through the inner solar system.
1994 — In the first observed planetary impact by a comet, awed scientists watch as fragments of comet Shoemaker–Levy 9 smash into Jupiter’s atmosphere.
2001 — Deep Space 1 flies by and photographs comet Borrelly.
2004 — NASA’s Stardust spacecraft collects dust samples from comet Wild 2 and images the nucleus.
2005 — The Deep Impact impactor collides with comet Tempel 1 to enable scientists to study the interior of the nucleus.
2006 — The Stardust sample return capsule lands in Utah carrying cometary particles and interstellar dust.
2009 — Scientists announce that the amino acid glycine, a building block of life, was collected by the Stardust spacecraft from comet Wild 2.
2010 — The Deep Impact spacecraft studies its second cometary target, Hartley 2, a small, “hyperactive” comet.
2011 — The Stardust spacecraft encounters Tempel 1 and captures views of the Deep Impact impact site, the opposite side of the nucleus, and signs of evolution on the comet’s surface.

ABOUT THE IMAGES



1 The collision of the Deep Impact impactor with comet Tempel 1 generated a cloud of dust. Stardust imaged the back side of the nucleus (inset).

2 Stardust revealed the nucleus of comet Wild 2 during a 2004 flyby. Tiny cometary and interstellar dust particles were captured for return to Earth.

3 Hartley 2 was very active at the time of the Deep Impact flyby, with ice jets propelled by carbon dioxide clearly seen emanating from the nucleus.

4 The tail of comet C/2002 V1 is disrupted as it comes closer to the Sun in 2003. The image is from the Solar and Heliospheric Observatory, with the Sun’s bright disc covered.

5 This image of comet McNaught was captured by the European Southern Observatory in Chile in January 2007 as both the comet and the Sun were setting over the Pacific Ocean.

FOR MORE INFORMATION

solarsystem.nasa.gov/comets

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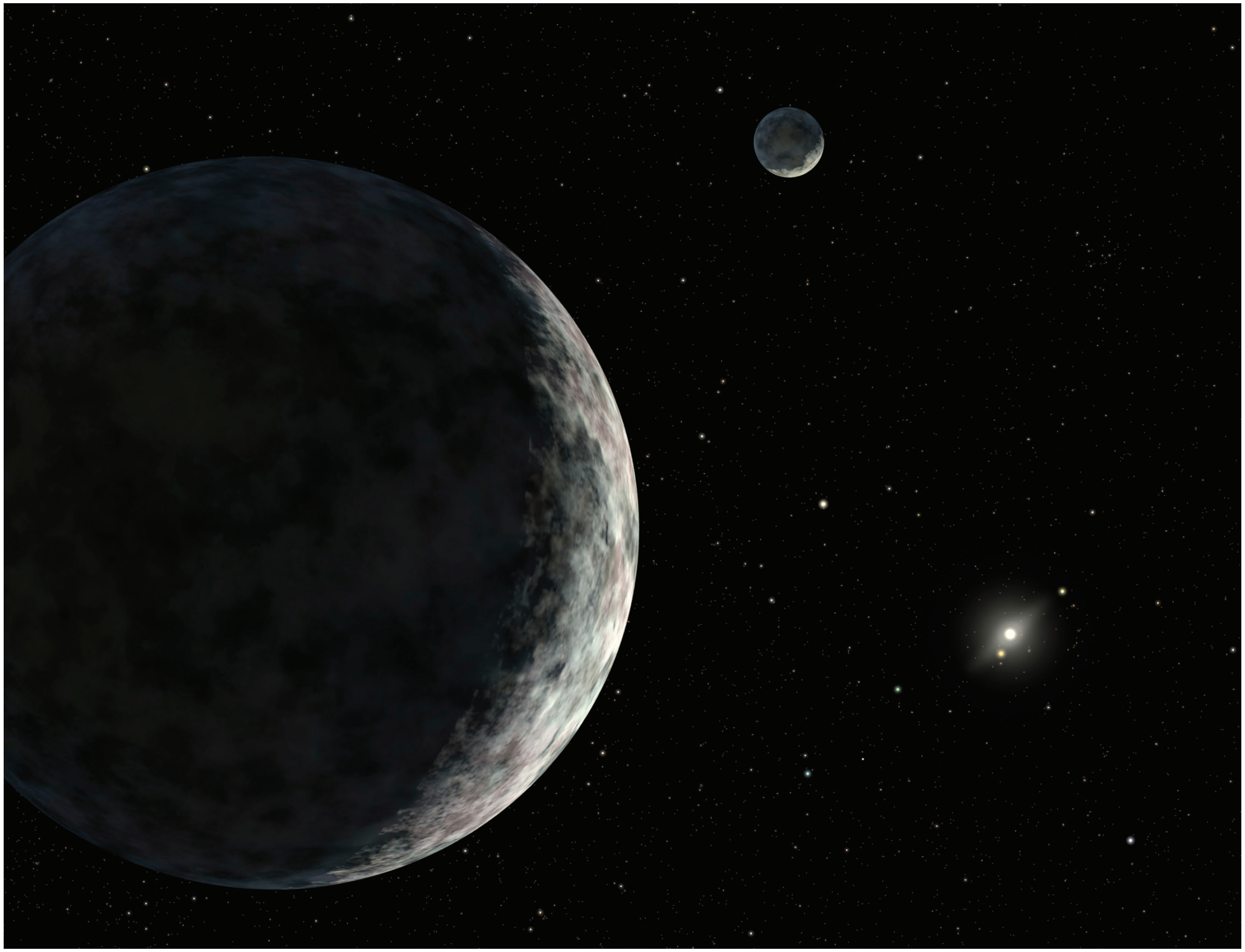
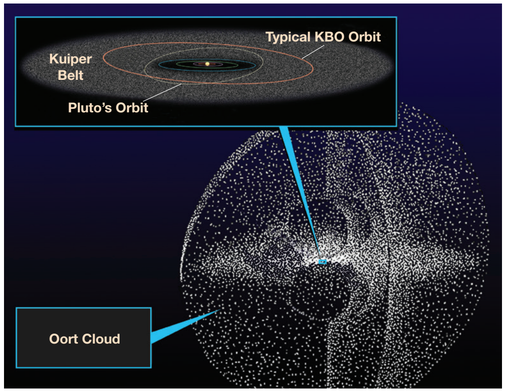
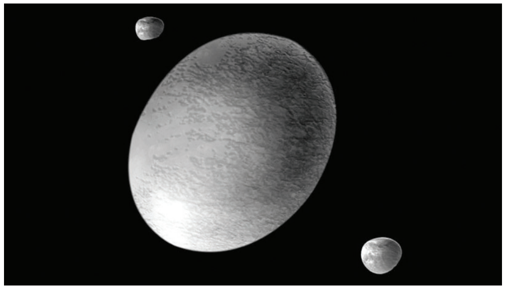
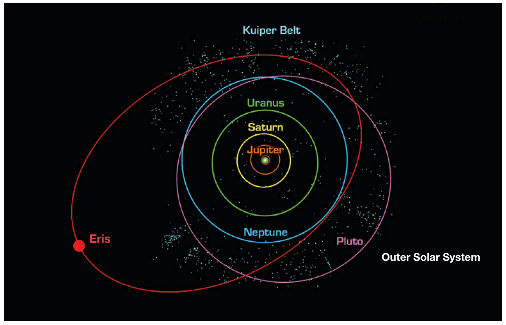








Kuiper Belt and Oort Cloud

In 1930, soon after the discovery of Pluto, astronomer Frederick C. Leonard suggested that Pluto was but one of many "ultra-Neptunian" or "trans-Neptunian" small bodies. In 1943, astronomer Kenneth Edgeworth hypothesized that many small, icy bodies exist in a disc in the region beyond Neptune, having condensed from widely spaced ancient material, and that from time to time one of them visits the inner solar system. Eight years later, Gerard Kuiper proposed the existence of such a disc, which formed early in the solar system's evolution. In 1992, astronomers detected a faint speck of light from an object about 42 AU from the Sun — the first time a Kuiper Belt object (or KBO for short) had been sighted. (One astronomical unit, or AU, is the mean distance of Earth from the Sun: about 150 million kilometers or 93 million miles.) More than 1,300 KBOs have been identified since 1992. They are sometimes called Edgeworth–Kuiper Belt objects or transneptunian objects — TNOs for short.

The Kuiper Belt should not be confused with the Oort Cloud, which is a thousand times more distant. In 1950, astronomer Jan Oort proposed that certain comets come from a vast, extremely distant spherical shell of icy bodies surrounding the solar system. This giant swarm of objects, now named the Oort Cloud, occupies space at a distance between 5,000 and 100,000 astronomical units. No objects residing within the Oort Cloud have ever been directly observed. The outer extent of the Oort Cloud is where the Sun's gravitational influence can be overpowered by that of other stars.

The Oort Cloud probably contains 0.1 to 2 trillion icy bodies in solar orbit. Occasionally, giant molecular clouds, stars passing nearby, or tidal interactions with the Milky Way's disc disturb the orbit of one of these bodies in the outer region of the Oort Cloud, causing the object to streak into the inner solar system as a so-called long-period comet. These comets have very large, eccentric orbits and are observed in the inner solar system only once. In contrast, short-period comets take less than 200 years to orbit the Sun and they travel along the plane in which most of the planets orbit. They are thought to come from the Kuiper Belt or from the so-called scattered disc, a dynamic zone created by the outward motion of Neptune that contains many icy objects with eccentric orbits. The objects in the Oort Cloud and in the Kuiper Belt are presumed to be remnants from the formation of the solar system about 4.6 billion years ago.

The Kuiper Belt extends from about 30 to 55 AU and is probably populated with hundreds of thousands of icy bodies larger than 100 kilometers (62 miles) across and an estimated trillion or more comets. Because KBOs are so distant, their sizes are difficult to measure. The calculated diameter of a KBO depends on assumptions about how brightness relates to size. With infrared observations by the Spitzer Space Telescope, most of the largest KBOs have known sizes.

One of the most unusual KBOs is Haumea, part of a collisional family orbiting the Sun, the first found in the Kuiper Belt. The parent body, Haumea, apparently collided with another object that was roughly half its size. The impact blasted large icy chunks away and sent Haumea reeling, causing it to spin end-over-end every four hours. It spins so fast that it has pulled itself into the shape of a squashed American football. Haumea and two small moons — Hi'iaka and Namaka — make up the family.

In March 2004, a team of astronomers announced the discovery of a planet-like transneptunian object orbiting the Sun at an extreme distance, in one of the coldest known regions of our solar system. The object (2003VB12), since named Sedna for an Inuit goddess who lives at the bottom of the frigid Arctic ocean, approaches the Sun only briefly during its 10,500-year solar orbit. It never enters the Kuiper Belt, whose outer boundary region lies at about 55 AU — instead, Sedna travels in a long, elliptical orbit between 76 and nearly 1,000 AU from the Sun. Since Sedna's orbit takes it to such an extreme distance, its discoverers have suggested that it is the first observed body belonging to the inner Oort Cloud.

In July 2005, a team of scientists announced the discovery of a KBO that appeared to be slightly larger than Pluto. The object, temporarily designated 2003UB313 and later named Eris, orbits the Sun about every 560 years, its distance varying from about 38 to 98 AU. (For comparison, Pluto travels from 29 to 49 AU in its solar orbit.) Eris's size is difficult to measure, owing to its extreme distance, but a 2011 estimate from a ground-based telescope suggested that Eris is about 27 percent more massive than Pluto. Eris has a small moon named Dysnomia.

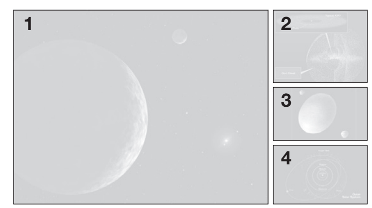
The discovery of Eris — orbiting the Sun and larger than Pluto (which was then designated the ninth planet) — forced astronomers to consider whether Eris should be classified as the tenth planet. Instead, in 2006, the International Astronomical Union created a new class of objects called *dwarf planet*, and placed Pluto, Eris, and the asteroid Ceres in this category. Subsequent discoveries added Haumea and Makemake to the dwarf planet family. Pluto, Eris, Haumea, and Makemake retain their classification as KBOs (or TNOs).

While no spacecraft has yet traveled to the Kuiper Belt, NASA's New Horizons spacecraft, which is scheduled to arrive at Pluto in 2015, plans to study other KBOs after the Pluto mission is complete.

SIGNIFICANT DATES

1943 — Astronomer Kenneth Edgeworth suggests that a reservoir of comets and larger bodies resides beyond the planets.
1950 — Astronomer Jan Oort theorizes that a vast population of comets may exist in a huge cloud surrounding our solar system.
1951 — Astronomer Gerard Kuiper predicts the existence of a belt of icy objects just beyond the orbit of Neptune.
1992 — After five years of searching, astronomers David Jewitt and Jane Luu discover the first KBO, 1992QB1.
2002 — Scientists using the 48-inch Oschin telescope at Palomar Observatory find Quaoar, the first large KBO hundreds of kilometers in diameter. This object was photographed in 1980 but was not noticed in those images.
2004 — Astronomers using the 48-inch Oschin telescope announce the discovery of Sedna.
2005 — Astronomers announce the discovery of 2003UB313. This object, later named Eris, is slightly larger than Pluto.
2008 — The Kuiper Belt object provisionally known as 2005FY9 was recognized in July as a dwarf planet and named Makemake (pronounced MAHkeh-MAHkeh) after the Polynesian (Rapa Nui) creation god. In September, 2003EL61 was designated a dwarf planet and given the name Haumea after the Hawaiian goddess of fertility and childbirth.

ABOUT THE IMAGES



1 Artist's concept of Eris and its moon. The Sun is in the distance.

2 An illustration of the Kuiper Belt and Oort Cloud in relation to the solar system.

3 Artist's concept of Haumea and its two small moons.

4 A diagram showing solar system orbits. The highly tilted orbit of Eris is in red.

FOR MORE INFORMATION

solarsystem.nasa.gov/kuiper

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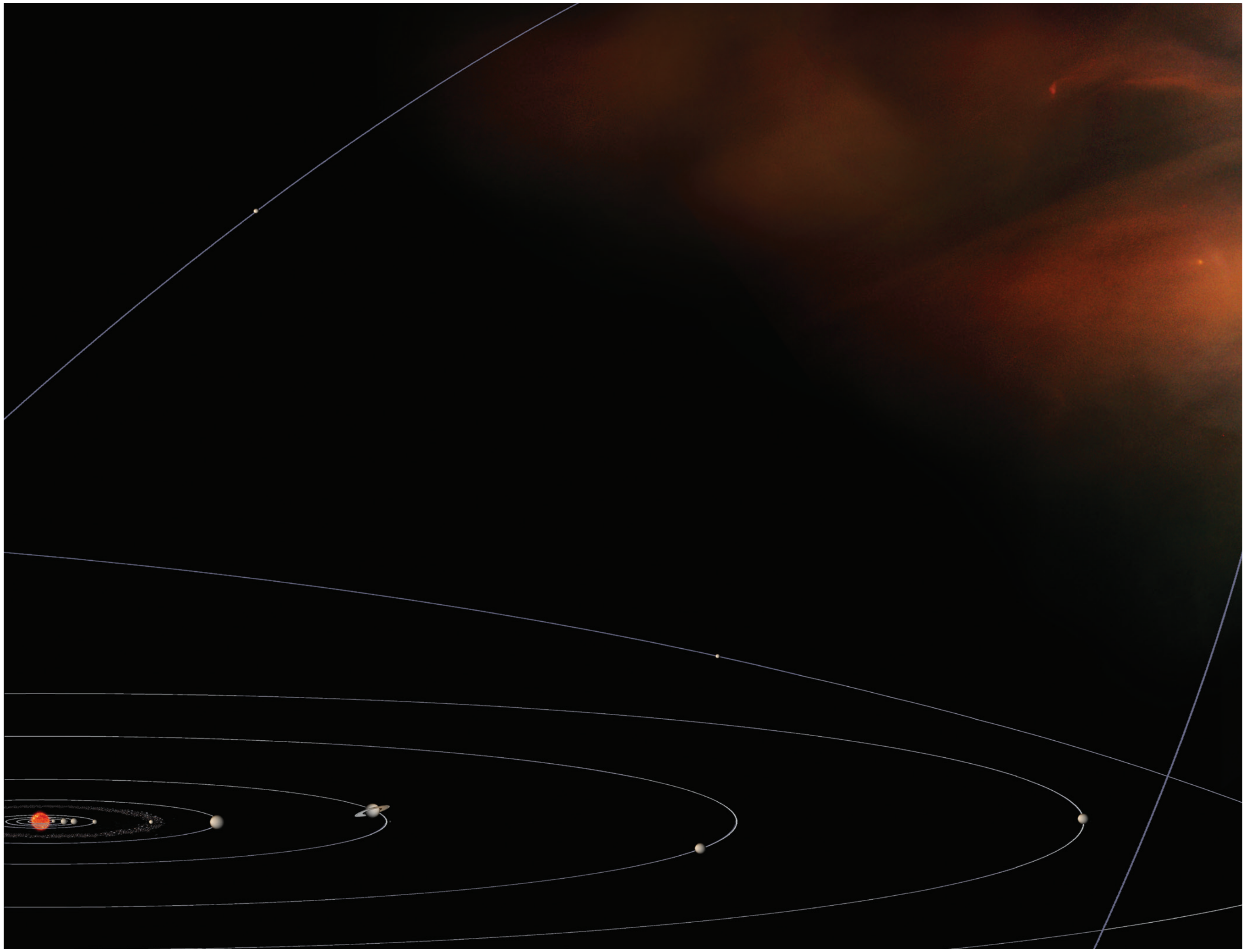
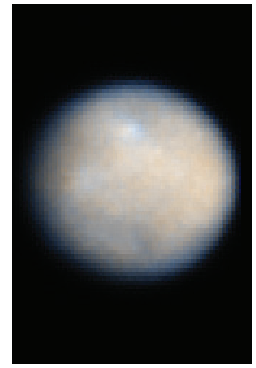
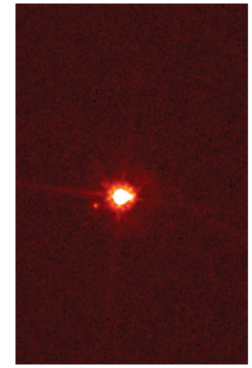
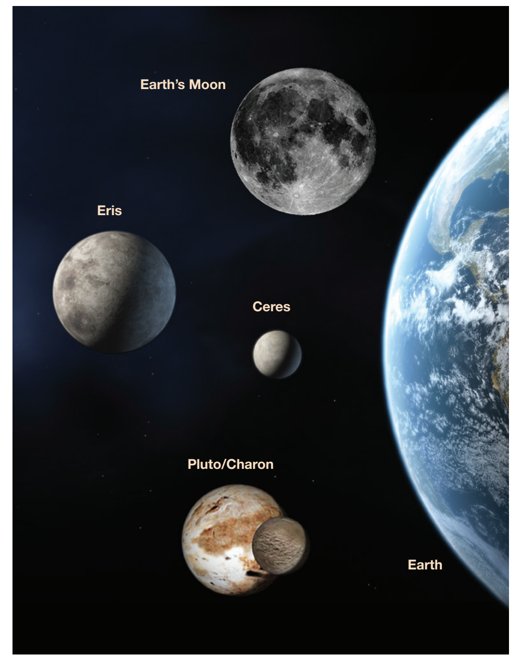








What Is a Planet?

Science is a dynamic process of questioning, hypothesizing, discovering, and changing previous ideas based on what is learned. Scientific ideas are developed through reasoning and tested against observations. Scientists assess and question each other's work in a critical process called peer review.

Our understanding about the universe and our place in it has changed over time. New information can cause us to rethink what we know and reevaluate how we classify objects in order to better understand them. New ideas and perspectives can come from questioning a theory or seeing where a classification breaks down.

Defining the term *planet* is important, because such definitions reflect our understanding of the origins, architecture, and evolution of our solar system. Over historical time, objects categorized as planets have changed. The ancient Greeks counted the Moon and Sun as planets along with Mercury, Venus, Mars, Jupiter, and Saturn. Earth was not considered a planet, but rather was thought to be the central object around which all the other celestial objects orbited. The first known model that placed the Sun at the center of the known universe with the Earth revolving around it was presented by Aristarchus of Samos in the third century BCE, but it was not generally accepted. It wasn't until the 16th century that the idea was revived by Nicolaus Copernicus. By the 17th century, astronomers (aided by the invention of the telescope) realized that the Sun was the celestial object around which all the planets — including Earth — orbit, and that the Moon is not a planet, but a satellite (moon) of Earth. Uranus was added as a planet in 1781 and Neptune was discovered in 1846.

Ceres was discovered between Mars and Jupiter in 1801 and originally classified as a planet. But as many more objects were subsequently found in the same region, it was realized that Ceres was the first of a class of similar objects that were eventually termed asteroids ("star-like") or minor planets.

Pluto, discovered in 1930, was identified as the ninth planet. But Pluto is much smaller than Mercury and is even smaller than some of the planetary moons. It is unlike the terrestrial planets (Mercury, Venus, Earth, Mars), or the gas giants (Jupiter, Saturn), or the ice giants (Uranus, Neptune). Charon, its huge satellite, is nearly half the size of Pluto and shares Pluto's orbit. Though Pluto kept its planetary status through the 1980s, things began to change in the 1990s with some new discoveries.

Technical advances in telescopes led to better observations and improved detection of very small, very distant objects. In the early 1990s, astronomers began finding numerous icy worlds orbiting the Sun in a doughnut-shaped region called the Kuiper Belt beyond the orbit of Neptune — out in Pluto's realm. With the discovery of the Kuiper Belt and its thousands of icy bodies (known as Kuiper Belt objects, or KBOs; also called transneptunians), it was proposed that it is more useful to think of Pluto as the biggest KBO instead of a planet. Then, in 2005, a team of astronomers announced that they had found a "tenth planet" — it was a KBO even larger than Pluto. People began to wonder what planethood really means. Just what *is* a planet, anyway? Suddenly the answer to that question didn't seem so self-evident, and, as it turns out, there are plenty of disagreements about it.

The International Astronomical Union (IAU), a worldwide organization of astronomers, took on the challenge of classifying the newly found KBO (later named Eris). In 2006, the IAU passed a resolution that defined *planet* and established a new category, *dwarf planet*. Eris, Ceres, Pluto, and two more recently discovered KBOs named Haumea and Makemake, are the dwarf planets recognized by the IAU (as of July 2013). Pluto, Eris, Haumea, and Makemake are also classified as KBOs, and Ceres retains its asteroid label. There may be another 100 dwarf planets in the solar system and hundreds more in and just outside the Kuiper Belt.

Astronomers and planetary scientists did not unanimously agree with these definitions. To some it appeared that the classification scheme was designed to limit the number of planets; to others it was incomplete and the terms unclear. Some astronomers argued that location (context) is important, especially in understanding the formation and evolution of the solar system.

One idea is to simply define a planet as a "natural object in space that is massive enough for gravity to make it approximately spherical." But some scientists objected that this simple definition does not take into account what degree of measurable roundness is needed for an object to be considered round. In fact, it is often difficult to accurately determine the shapes of some distant objects. Others argue that where an object is located or what it is made of do matter and there should not be a concern with dynamics; that is, whether or not an object sweeps up or scatters away its immediate neighbors, or holds them in stable orbits. The lively planethood debate continues.

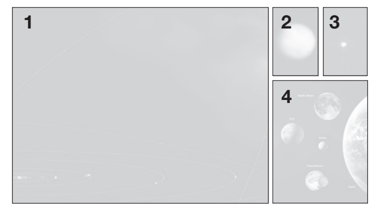
As our knowledge deepens and expands, the more complex and intriguing the universe appears. Researchers have found hundreds of extrasolar planets, or exoplanets, that reside outside our solar system; there may be billions of exoplanets in the Milky Way Galaxy alone, and some may be habitable (have conditions favorable to life). Whether our definitions of "planet" can be applied to these newly found objects remains to be seen.

PLANET CHARACTERISTICS

What makes a planet, according to the definitions adopted by the International Astronomical Union —

	PLANET	DWARF PLANET
Is in orbit around the Sun	✓	✓
Has sufficient mass to assume a nearly round shape	✓	✓
Is not a satellite	✓	✓
Has cleared the neighborhood around its orbit	✓	
Has *not* cleared the neighborhood around its orbit		✓

ABOUT THE IMAGES



1 This illustration* of our solar system shows Eris in its highly tilted orbit beyond Pluto.

2 A Hubble Space Telescope image of Ceres. NASA's Dawn mission will visit Ceres in 2015 for a much closer look.

3 The Hubble Space Telescope took this image of Eris and its small moon, Dysnomia. Astronomers combined images from Hubble and the Keck Telescope to calculate Eris's mass and Dysnomia's orbit.

4 A size comparison of dwarf planets Eris, Pluto, and Ceres (artist's concepts); Pluto's moon Charon (artist's concept); Earth's Moon; and Earth.

FOR MORE INFORMATION

solarsystem.nasa.gov/dwarf

*In the illustration, the orbit of dwarf planet Eris, out beyond Pluto, is not to scale. Eris's mean distance from the Sun is 67.6 astronomical units (AU), compared to Pluto's mean distance of 39 AU. (One AU is the mean distance from Earth to the Sun.)

ACTIVITY: WHAT IS A PLANET?

In this activity, students (grades 9–12) compare the characteristics of planets, comets, asteroids, and transneptunian objects. Download the activity from this website — *pluto.jhuapl.edu/education/educators_eduGuide.php*

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