



# OUR SOLAR SYSTEM

This set contains the following lithographs:

- Our Solar System
- Our Star – The Sun
- Mercury
- Venus
- Earth
- Earth's Moon
- Mars
- Asteroids
- Meteors and Meteorites
- Moons of the Solar System
- Jupiter
- Galilean Moons of Jupiter
- Saturn
- Moons of Saturn
- Uranus
- Neptune
- Pluto and Charon
- Comets
- Kuiper Belt and Oort Cloud



## NASA EDUCATIONAL RESOURCES

NASA's Central Operation of Resources for Educators (CORE) was established for the national and international distribution of NASA-produced educational materials in multimedia format. Educators can obtain a catalogue and an order form by one of the following methods:

### NASA CORE

Lorain County Joint Vocational School  
15181 Route 58 South  
Oberlin, OH 44074-9799  
Phone: (440) 775-1400  
FAX: (440) 775-1460  
E-mail: [nasaco@leeca.org](mailto:nasaco@leeca.org)  
Home Page: [www.nasa.gov/education/core](http://www.nasa.gov/education/core)

**Educator Resource Center Network (ERCN)** To make additional information available to the education community, NASA has created the NASA Educator Resource Center (ERC) network. Educators may preview, copy, or receive NASA materials at these sites. Phone calls are welcome if you are unable to visit the ERC that serves your geographic area. A list of the centers and the regions they serve includes:

**AK, Northern CA, HI, ID, MT, NV, OR, UT, WA, WY**  
NASA Educator Resource Center  
NASA Ames Research Center, Mail Stop 226-8  
Moffett Field, CA 94035-1000  
Phone: (650) 604-5544

**IL, IN, MI, MN, OH, WI**  
NASA Educator Resource Center  
NASA Glenn Research Center, Mail Stop 8-1  
21000 Brookpark Road  
Cleveland, OH 44135  
Phone: (216) 433-2017

**CT, DE, DC, ME, MD, MA, NH, NJ, NY, PA, RI, VT**  
NASA Educator Resource Center  
NASA Goddard Space Flight Center, Mail Code 130.3  
Greenbelt, MD 20771-0001  
Phone: (301) 286-8570

**CO, KS, NE, NM, ND, OK, SD, TX**  
NASA Educator Resource Center  
NASA Johnson Space Center  
Space Center Houston, 1601 NASA Road One  
Houston, TX 77058  
Phone: (281) 244-2129

**FL, GA, PR, VI**  
NASA Educator Resource Center  
NASA Kennedy Space Center, Mail Code ERC  
Kennedy Space Center, FL 32899  
Phone: (321) 867-4090

**KY, NC, SC, VA, WV**  
NASA Educator Resource Center  
NASA Langley Research Center  
Virginia Air and Space Center, 600 Settlers Landing Road  
Hampton, VA 23669-4033  
Phone: (757) 727-0900 ext. 757

**AL, AR, IA, LA, MO, TN**  
NASA Educator Resource Center  
NASA Marshall Space Flight Center  
U.S. Space and Rocket Center, One Tranquility Base  
Huntsville, AL 35807  
Phone: (256) 544-5812

**MS**  
NASA Educator Resource Center  
NASA Stennis Space Center, Building 1200  
Stennis Space Center, MS 39529-6000  
Phone: (228) 688-1974  
Toll Free: (800) 237-1821 Opt. #2

**CA**  
NASA Educator Resource Center  
NASA Jet Propulsion Laboratory  
Village at Indian Hill  
1460 East Holt Avenue, Suite 20  
Pomona, CA 91767  
Phone: (909) 397-4420

**AZ and Southern CA**  
NASA Educator Resource Center  
NASA Dryden Flight Research Center, Office of Academic Investments  
38256 Sierra Highway, Suite A  
Palmdale, CA 93550  
Phone: (661) 276-2445

**VA and MD's Eastern Shores**  
NASA Educator Resource Center  
GSFC/Wallops Flight Facility  
Visitor Center Building J-17  
Wallops Island, VA 23337  
Phone: (757) 824-2214

**Regional Educator Resource Centers** offer more educators access to NASA educational materials. NASA has formed partnerships with universities, museums, and other educational institutions to serve as regional ERCs in many states. A complete list of regional ERCs is available through CORE, or electronically via the NASA Portal at [education.nasa.gov/ercn](http://education.nasa.gov/ercn).

The **NASA Portal** serves as the gateway for information regarding content, programs, and services offered by NASA for the general public and, specifically, for the education community with the goals to inform,

involve, and inspire. NASA's goal is to improve interactions for students, educators, and families with NASA and its education resources. Visit the NASA Portal and begin a journey of personal discovery — [www.nasa.gov](http://www.nasa.gov).

**NASA's Education Home Page** serves as the education portal for information regarding educational programs and services offered by NASA for the American education community. This high-level directory of information provides specific details and points of contact for all of NASA's educational efforts, Field Center offices, and points of presence within each state. Visit this resource at [education.nasa.gov](http://education.nasa.gov).

NASA features electronic resources specifically developed for the educational community. To locate these resources, visit the NASA home page at [www.nasa.gov](http://www.nasa.gov); click on the "For Educators" bar, then click on the grade level in which you are interested.

**NASA Television (NTV)** features International Space Station (ISS) and Space Shuttle mission coverage, live special events, interactive educational live shows, electronic field trips, aviation and space news, and historical NASA footage. Programming includes the Video (News) File, NASA Gallery, and Education File, beginning at noon Eastern and repeated four more times throughout the day. Check the Internet for program listings at [www.nasa.gov/multimedia/nasatv/](http://www.nasa.gov/multimedia/nasatv/).

For more information on NTV, contact: NASA TV, NASA Headquarters, Washington, DC 20546-0001, phone: (202) 358-1308.

NTV Weekday Programming Schedules (Eastern Times):  
Video File — 6–7 a.m., 10–11 a.m., 12–1 p.m., 3–4 p.m., 6–7 p.m., 10–11 p.m., 12–1 a.m.  
NASA Gallery — 1–6 a.m., 1–3 p.m.  
Education File — 8–10 a.m., 4–6 p.m., 8–10 p.m.  
ISS Mission Coverage — 7–8 a.m., 11 a.m.–12 p.m., 7–8 p.m., 11 p.m.–12 a.m.

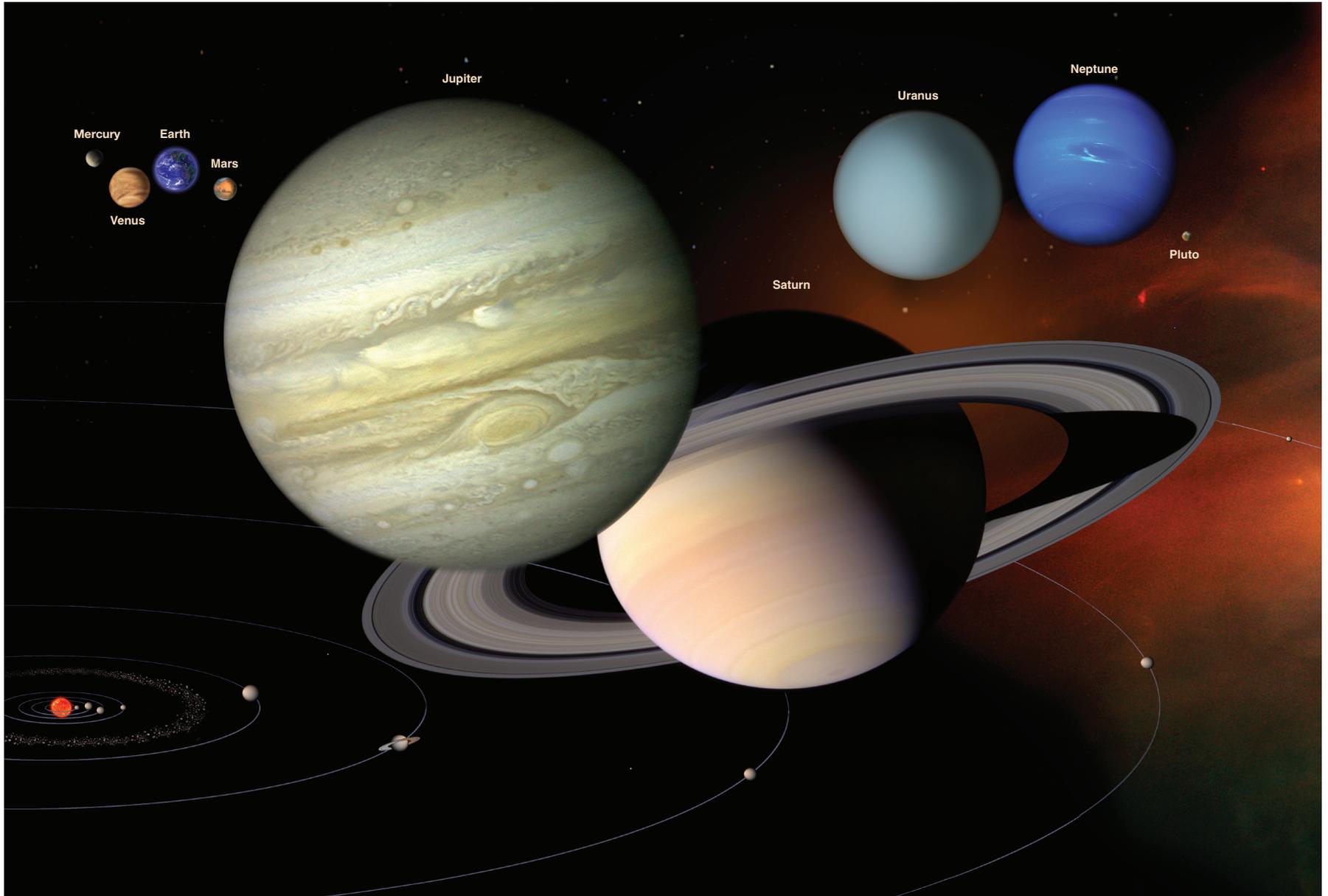
Saturday and Sunday: The weekday schedule repeats on Saturday and Sunday with one exception: the 8 a.m. Education File runs an additional two hours, until noon instead of 10 a.m. Live feeds preempt regularly scheduled programming.

**How to Access Information on NASA's Education Program, Materials, and Services** (EP-2002-07-345-HQ) — This brochure serves as a guide to accessing a variety of NASA materials and services for educators. Copies are available through the ERC network or through the NASA Education home page at [education.nasa.gov](http://education.nasa.gov).

### EDUCATORS

Please take a moment to evaluate this product at  
[ehb2.gsfc.nasa.gov/edcats/lithograph\\_set/](http://ehb2.gsfc.nasa.gov/edcats/lithograph_set/)  
Your evaluation and suggestions are vital to  
continually improving NASA educational materials. Thank you.

# Our Solar System





Humans have gazed upon and tried to understand the cosmos for thousands of years. Ancient civilizations placed great emphasis on careful astronomical observation, building impressive monuments that were used to observe the skies. Stories were created about the objects in the heavens and many different names were given to them. Ancient 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 move among the stars. The Greeks named the five points of light after their gods. The later Romans named the five bright objects after their own gods — 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 names, consult the Gazetteer of Planetary Nomenclature website at [planetarynames.wr.usgs.gov](http://planetarynames.wr.usgs.gov).

Ancient observers believed that the Sun and all the other stars revolved around Earth. Astronomers came to realize that this Earth-centered model did not account for the motions of the planets. With the development of a Sun-centered model, our understanding of the solar system and the universe deepened. In the early 17th century, Galileo Galilei's discoveries using the recently invented telescope strongly supported the Sun-centered model. With the telescope as a tool, planetary moons, the rings of Saturn, and three more planets were eventually discovered: Uranus (in 1781), Neptune (1846), and Pluto (1930). Telescopes also aided in the discovery of asteroids and the study of comets.

The four planets closest to the Sun — Mercury, Venus, Earth and Mars — are called the terrestrial planets because they have solid rocky surfaces. The four outer planets beyond the orbit of Mars — Jupiter, Saturn, Uranus, and Neptune — are called gas giants. Tiny, distant Pluto has a solid surface covered with ice.

Earth's atmosphere is primarily nitrogen and oxygen. Mercury has no atmosphere, while Venus has a thick atmosphere of mainly carbon dioxide. Mars' carbon dioxide atmosphere is extremely thin. The gas giants Jupiter, Saturn, Uranus, and Neptune are mostly composed of hydrogen and helium. When Pluto is near the Sun, it has a thin atmosphere, but when Pluto travels to the outer parts of its orbit, the atmosphere freezes.

Moons, rings, and magnetic fields characterize the planets. There are 153 known natural satellites (moons) orbiting the planets, and they are not all alike. One moon (Saturn's Titan) has a thick atmosphere; another has active volcanoes (Jupiter's Io). Rings are an intriguing planetary feature. From 1659 to 1977, 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 involved, 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. To envision the Sun in the Milky Way galaxy, think of a ship moving through the ocean. The area of the Sun's influence stretches 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 — like a ship in water — ahead of it in interstellar space as it crashes into the interstellar gases. The area where the solar wind is suddenly slowed by pressure from gas between the stars is called the termination shock.

A spacecraft that reached the termination shock would be able to measure the slowing effect, and that is exactly what happened when Voyager 1, traveling at a speed of 3.6 AU per year, began sending unusual data to Earth in November and December 2003. In May 2005, NASA confirmed that Voyager 1, 26 years after its launch, had entered the vast, turbulent expanse where the Sun's influence wanes — at about 94 AU, approximately 13 billion kilometers (8.7 billion miles) from the Sun. This is the solar system's final frontier. Voyager 1 is anticipated to have electrical power to continue to send data until at least 2020, when it may actually have traveled all the way through the last of the Sun's magnetic region and will enter an interstellar environment. It will be thousands of years before Voyager exits the region of the solar system's enormous Oort Cloud.

In 2004, President George W. Bush announced an exciting new Vision for Space Exploration that includes sustained robotic and human exploration of the solar system and beyond. It begins with robotic exploration of Earth's Moon with an orbiter and then a lander, with a human return to the Moon by 2018. The Moon would be a testbed for technologies to support human exploration of the Moon, Mars, and beyond.

As we explore the universe, we wonder: Are there other planets where life might exist? Are we alone? Only recently have astronomers had the tools to detect large planets around other stars in other solar systems using ground- and space-based telescopes.

## FAST FACTS

Body	Equatorial Radius		Mean Distance from the Sun		Moons*
	km	mi	km, millions	mi, millions	
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	1,737.4	1,079.6	**	**	—
Mars	3,397	2,111	227.94	141.63	2
Jupiter	71,492	44,423	778.41	483.68	62
Saturn	60,268	37,449	1,426.73	886.53	47
Uranus	25,559	15,882	2,870.97	1,783.94	27
Neptune	24,764	15,388	4,498.25	2,795.08	13
Pluto	1,180	733	5,906.38	3,670.05	1***

\*Known moons as of November 2005.

\*\*Mean Earth–Moon distance: 384,400 kilometers or 238,855 miles.

\*\*\*In October 2005, NASA announced that Hubble Space Telescope scientists had found two possible additional moons of Pluto.

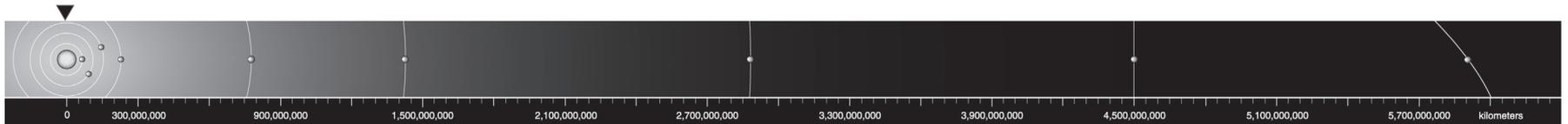
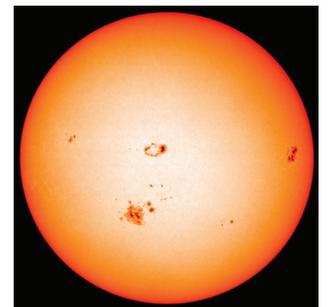
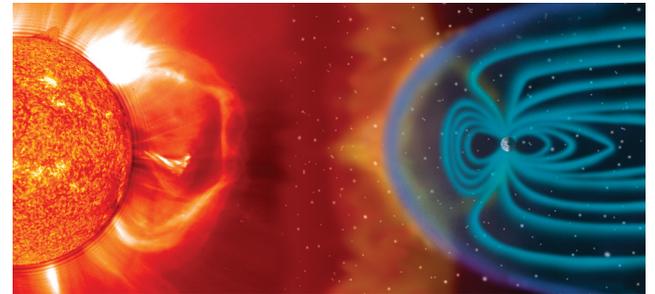
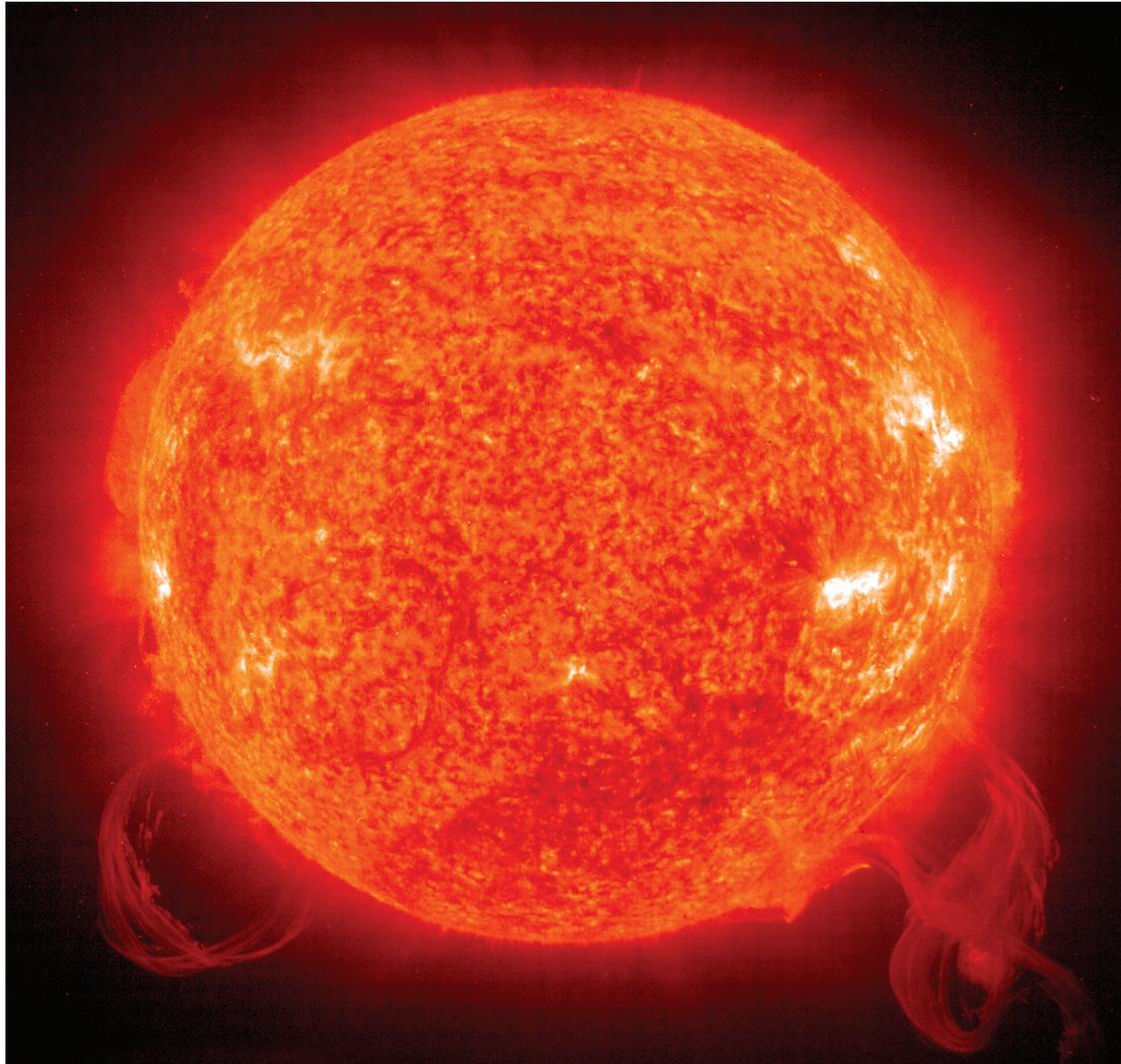
## ABOUT THE ILLUSTRATION

The planets are shown in the correct order of distance from the Sun, the correct relative sizes, and the correct relative orbital distances. The sizes of the bodies are greatly exaggerated relative to the orbital distances. The faint rings of Jupiter, Uranus, and Neptune are not shown.

## FOR MORE INFORMATION

[solarsystem.nasa.gov/planets/profile.cfm?Object=SolarSys](http://solarsystem.nasa.gov/planets/profile.cfm?Object=SolarSys)  
[solarsystem.nasa.gov/education/](http://solarsystem.nasa.gov/education/)

# Our Star — The Sun





Our solar system's 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 observe 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.

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. It powers photosynthesis in green plants, and is ultimately the source of all food and fossil fuel. The connection and interactions between the Sun and Earth drive the seasons, ocean currents, weather, and climate.

The Sun is 332,900 times more massive than Earth and contains 99.86 percent of the mass of the entire solar system. 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, known as the photosphere; the chromosphere; and the outermost region, the corona.

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 bounces around the radiative zone, taking about 170,000 years to get 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 radi-

ation 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.

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. 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 and the corona forms a beautiful white halo.

Above the photosphere, the temperature increases with altitude, reaching temperatures 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 have emerged from observations by the Solar and Heliospheric Observatory (SOHO) and the Transition Region and Coronal Explorer (TRACE) missions, which found patches of magnetic field covering the entire solar surface. Scientists now think that this magnetic "carpet" is probably a source of the corona's intense heat. The corona cools rapidly, losing heat as radiation and in the form of the solar wind — a stream of charged particles that flows to the edge of the solar system.

## 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	$1.989 \times 10^{30}$ kg
Density	1.409 g/cm <sup>3</sup>
Composition	92.1% hydrogen, 7.8% helium
Surface Temperature (Photosphere)	5,500 deg C (10,000 deg F)
Luminosity*	$3.83 \times 10^{33}$ ergs/sec

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

## SIGNIFICANT DATES

150 AD — Greek scholar Claudius Ptolemy launches a millennium of misconception when he writes that the Sun and planets revolve around Earth.

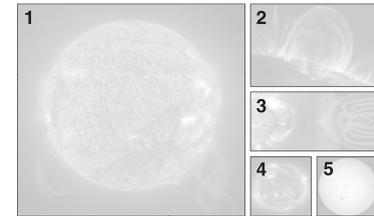
1543 — Nicolaus Copernicus publishes *On the Revolutions of the Celestial Spheres* describing his heliocentric (Sun-centered) model of the solar system, beginning a new age of astronomy.

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 history as it makes the first observations of the Sun's polar regions, which cannot be studied from Earth.

## ABOUT THE IMAGES



**1** Two huge clouds of plasma erupt from the chromosphere of the Sun (SOHO image).

**2** Magnetic fields are believed to cause huge, superhot coronal loops to tower above sunspots visible in the photosphere and chromosphere (TRACE image).

**3** This illustration shows a coronal mass ejection from the chromosphere and interaction with Earth's magnetic field (not to scale).

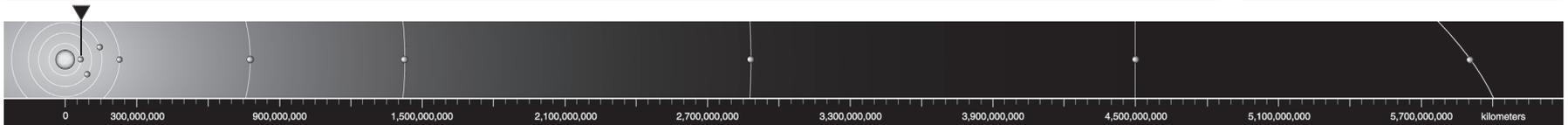
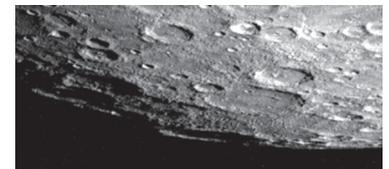
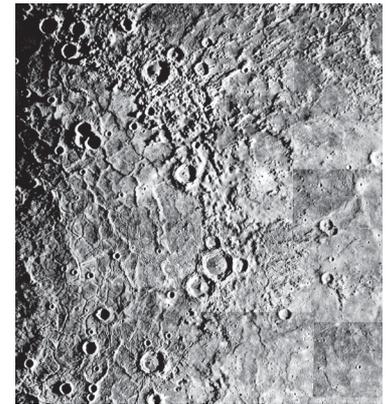
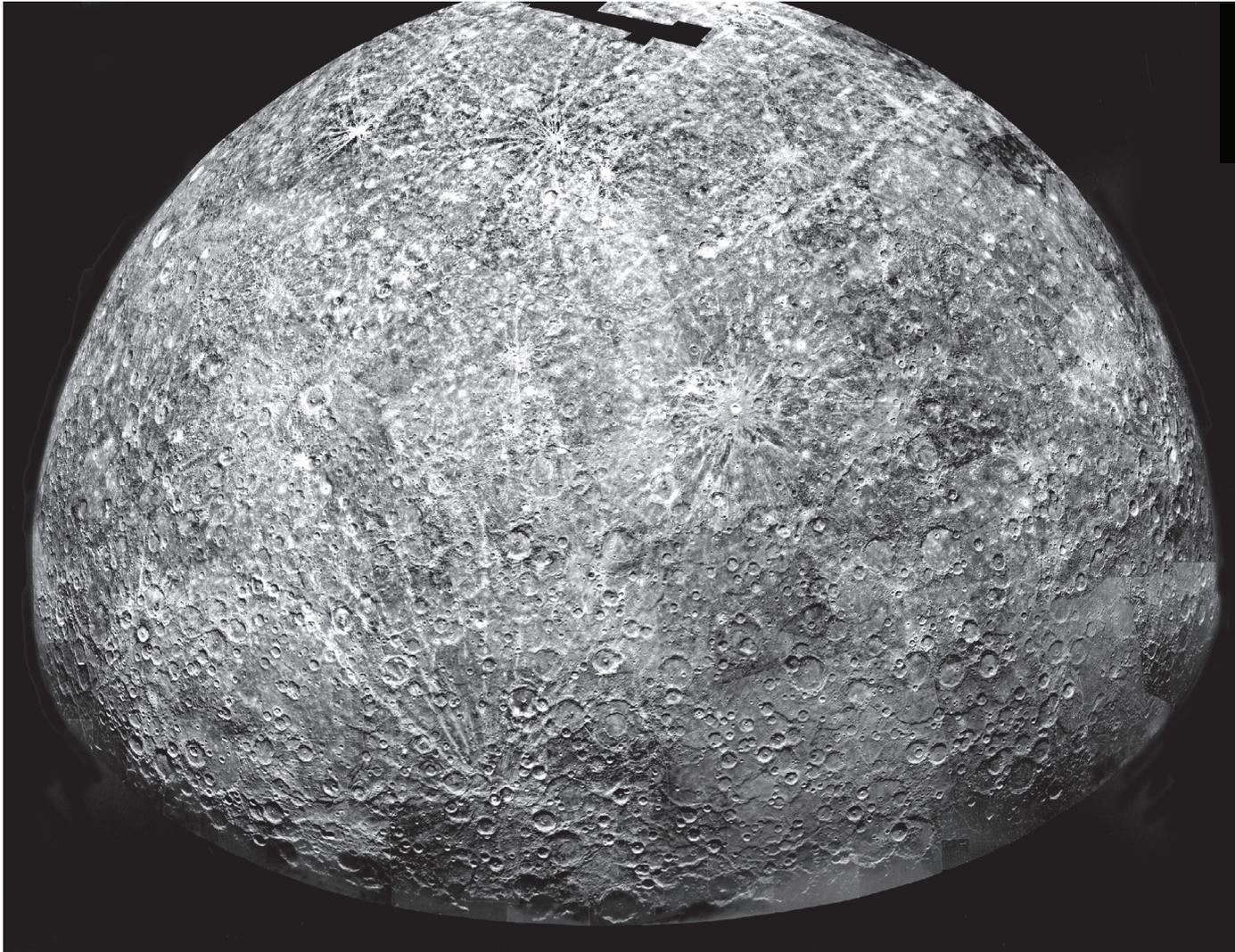
**4** A composite image of the Sun's corona taken in three wavelengths emitted at different temperatures shows a very active star (SOHO image).

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

## FOR MORE INFORMATION

[solarsystem.nasa.gov/planets/profile.cfm?Object=Sun](http://solarsystem.nasa.gov/planets/profile.cfm?Object=Sun)

# Mercury



# Mercury



Mercury's elliptical 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 almost 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 -170 degrees Celsius (-280 degrees Fahrenheit).

Because Mercury is so close to the Sun, it is hard to directly observe from Earth except during twilight. Mercury makes an appearance indirectly, however — 13 times each century, Earth observers 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 occur May 7, 2003, and November 8, 2006.

Scientists used to think that the same side of Mercury always faces the Sun, but in 1965 astronomers discovered that the planet rotates three times during every two orbits. 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 day equals 175.97 Earth days.

Rather than an atmosphere, Mercury possesses a thin "exosphere" made up of atoms blasted off its surface by the solar wind and striking micrometeoroids. Because of the planet's extreme surface temperature, the atoms quickly escape into space. With the thin exosphere, there has been no wind erosion of the surface and meteorites do not burn up due to friction as they do in other planetary atmospheres.

Mercury's surface resembles that of Earth's Moon, scarred by many impact craters resulting from collisions with meteoroids and comets. While there are 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 by early contraction of the crust. The Caloris Basin, one of the largest features on Mercury, is about 1,300 kilometers (800 miles) in diameter. It was the result of an asteroid impact on the planet's surface early in the solar

system's history. Over the next half-billion years, Mercury shrank in radius about 1 to 2 kilometers (0.6 to 1.2 miles) as the planet cooled after its formation. The outer crust contracted and grew strong enough to prevent magma from reaching the surface, ending the period of geologic activity.

Mercury is the second smallest planet in the solar system, larger only than Pluto. Mercury is the second densest planet after Earth, with a large iron core having a radius of 1,800 to 1,900 kilometers (1,100 to 1,200 miles), about 75 percent of the planet's radius. Mercury's outer shell, comparable to Earth's outer shell (called the mantle), is only 500 to 600 kilometers (300 to 400 miles) thick. Mercury's magnetic field is thought to be a miniature version of Earth's, but scientists are uncertain of the strength of the field.

Only one spacecraft has ever visited Mercury: Mariner 10, which imaged about 45 percent of the surface. In 1991, astronomers using radar observations showed that Mercury may have water ice at its north and south poles inside deep craters that are perpetually cold (below -212 degrees Celsius or -350 degrees Fahrenheit). Infalling comets or meteorites might have brought ice to these regions of Mercury, or water vapor might have outgassed from the interior and frozen out at the poles.

A new NASA mission to Mercury called MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) will begin orbiting Mercury in March 2011 to investigate key scientific areas such as the planet's composition, the structure of the core, the magnetic field, and the materials at the poles.

## FAST FACTS

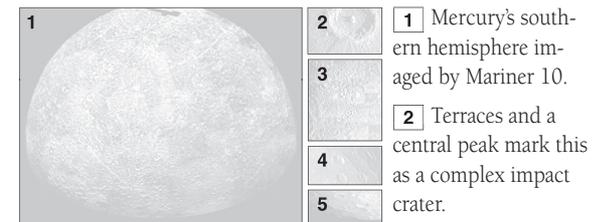
Namesake	Messenger of the Roman gods
Mean Distance from the Sun	57.91 million km (35.98 million mi)
Orbit Period	87.97 Earth days
Orbit Eccentricity (Circular Orbit = 0)	0.206
Orbit Inclination to Ecliptic	7 deg
Inclination of Equator to Orbit	0 deg
Rotation Period	58.65 Earth days
Successive Sunrises	175.97 days
Equatorial Radius	2,440 km (1,516 mi)

Mass	0.055 of Earth's
Density	5.43 g/cm <sup>3</sup> (0.98 of Earth's)
Gravity	0.38 of Earth's
Exosphere Components	hydrogen, helium, oxygen, sodium, potassium, calcium
Temperature Range	-170 to 430 deg C (-280 to 800 deg F)
Known Moons	0
Rings	0

## SIGNIFICANT DATES

- 1631 — Pierre Gassendi uses a telescope to watch from Earth as Mercury crosses the face of the Sun.
- 1965 — Though it was thought for centuries that the same side of Mercury always faced the Sun, astronomers find 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 tucked in permanently shadowed areas of craters in Mercury's polar regions.
- 2004 — MESSENGER launches on a mission to make the most comprehensive study yet of the innermost planet.

## ABOUT THE IMAGES

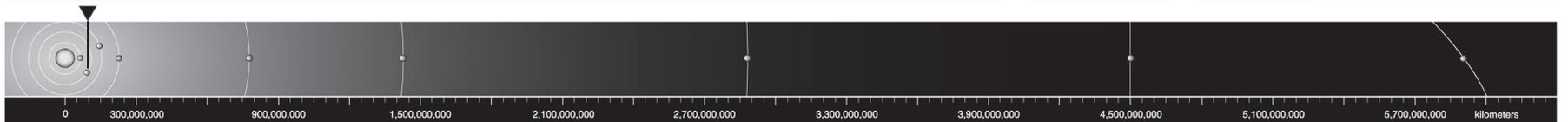
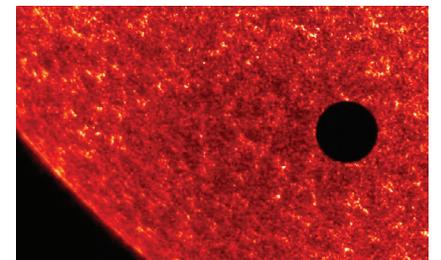
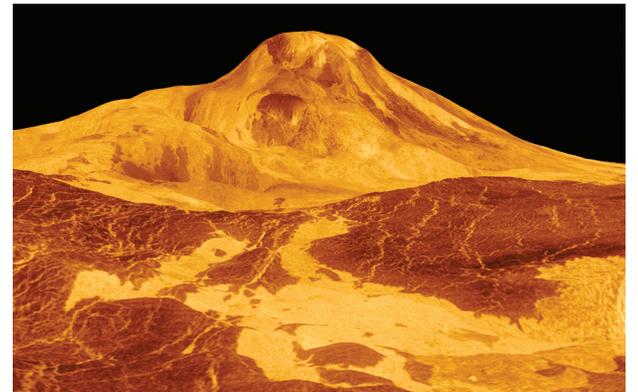
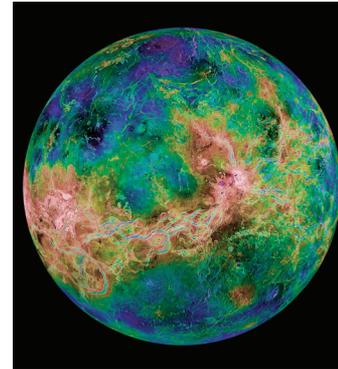
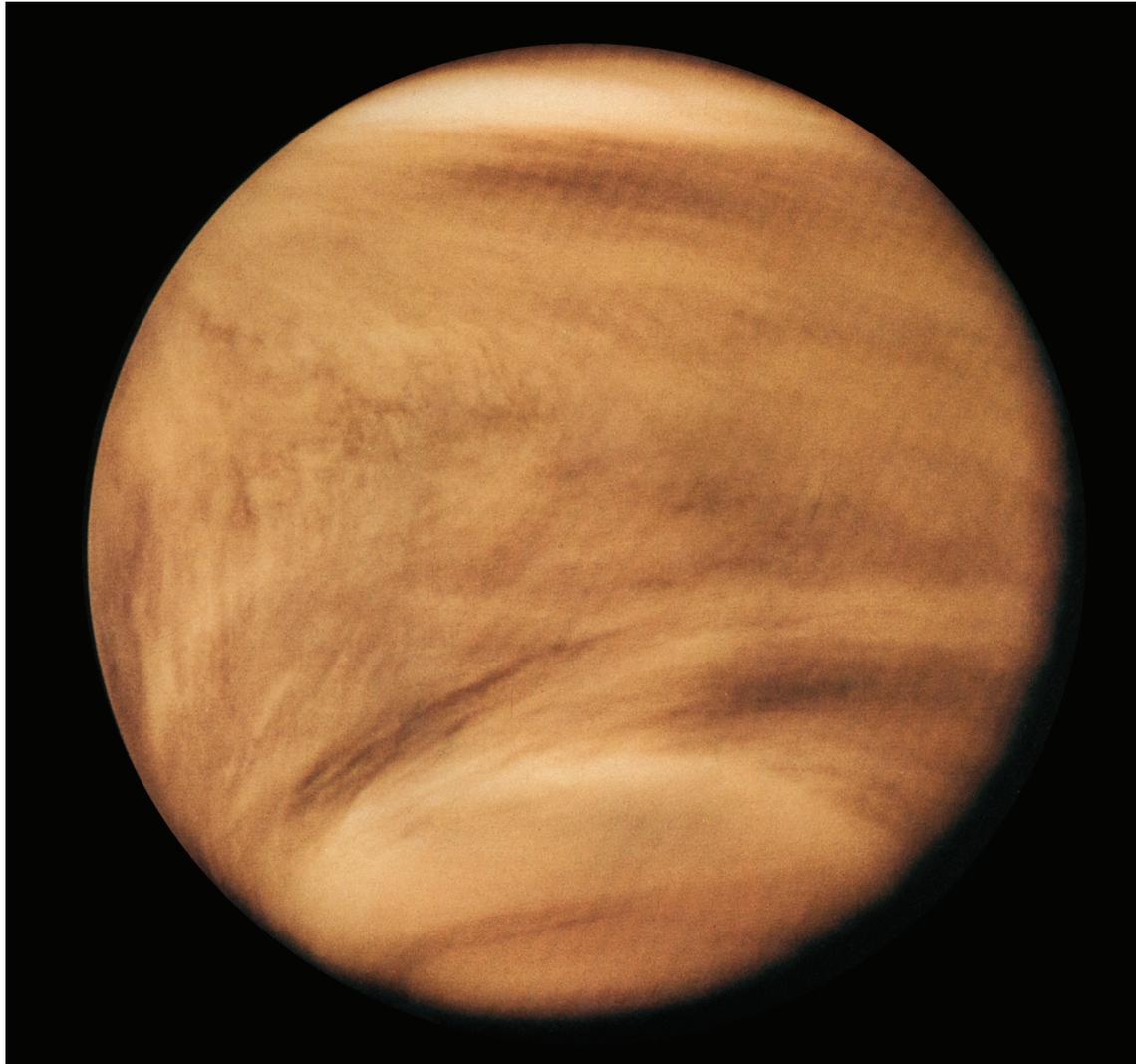


- 1** Mercury's southern hemisphere imaged by Mariner 10.
- 2** Terraces and a central peak mark this as a complex impact crater.
- 3** A Mariner 10 photomosaic of a portion of the Caloris Basin.
- 4** A scarp (cliff) more than 300 kilometers (185 miles) long extends from upper left to lower right in this image.
- 5** A close-up of Mercury's south pole taken by Mariner 10 in 1974.

## FOR MORE INFORMATION

[solarsystem.nasa.gov/planets/profile.cfm?Object=Mercury](http://solarsystem.nasa.gov/planets/profile.cfm?Object=Mercury)

# Venus





Venus and Earth are similar in size, mass, density, composition, and distance from the Sun. 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. Because of its proximity to Earth and the way its clouds reflect sunlight, Venus appears to be the brightest planet in the sky. Although we cannot normally see through Venus' thick atmosphere, NASA's Magellan mission to Venus used radar to image the surface, and Galileo used infrared mapping to view mid-level cloud structure.

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. Since the telescope was invented, transits were observed in 1631, 1639; 1761, 1769; and 1874, 1882. On June 8, 2004, astronomers worldwide saw the tiny dot of Venus crawl across the Sun; the second in this pair of early 21st-century transits occurs June 6, 2012.

The 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 over 470 degrees Celsius (880 degrees Fahrenheit). Probes that have landed on Venus have not survived more than a few hours before being destroyed by the incredible temperatures.

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 cloud-level atmosphere zips around the planet in the opposite direction from the rotation every four Earth days, driven by constant hurricane-force winds. How this atmospheric "superrotation" forms and is maintained continues to be a topic of scientific investigation.

About 90 percent of the surface of Venus appears to be recently solidified basalt lava; it is thought that the planet was completely resurfaced by volcanic activity 300 to 500 million years ago.

Sulfur compounds, possibly attributable to volcanic activity, are abundant in Venus' clouds. The corrosive chemistry and dense, moving atmosphere cause significant surface weathering and erosion. Radar images of the surface show wind streaks and sand dunes. 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.

More than 1,000 volcanoes or volcanic centers larger than 20 kilometers (12 miles) in diameter dot the surface of Venus. 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 about 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	5.204 g/cm <sup>3</sup> (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 AD — Mayan astronomers make detailed observations of Venus, leading to a highly accurate calendar.

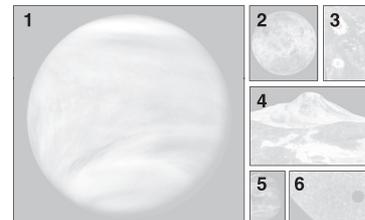
1761–1769 — Two European expeditions to watch Venus cross in front of the Sun lead to the first good estimate of the Sun's distance from Earth.

1962 — 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 — 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 — The Magellan spacecraft, in orbit around Venus, uses radar to map 98 percent of the planet's surface.

## ABOUT THE IMAGES



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

**2** This Magellan radar image is color-coded to represent varying elevations.

**3** Impact craters are revealed in this Magellan radar image.

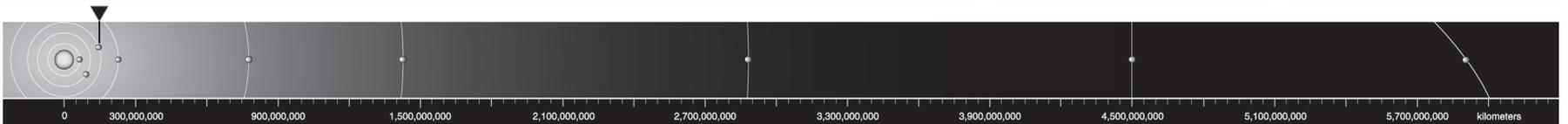
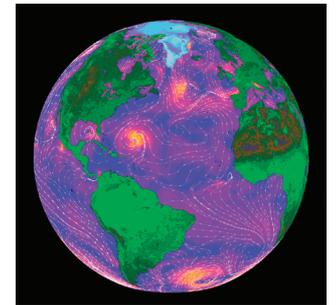
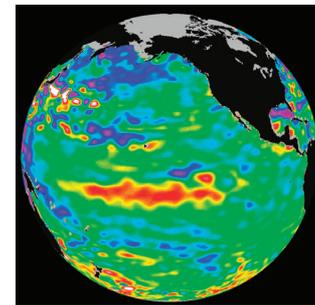
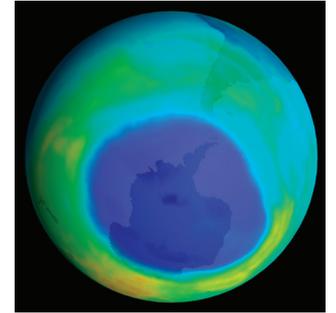
**4** Scientists used Magellan radar images to create this three-dimensional view of Venus' Maat Mons volcano.

**5** This false-color image taken by Galileo's infrared mapping instrument shows details of Venus' mid-level cloud structure.

**6** This view of the transit of Venus of 2004 was taken in ultraviolet light by NASA's Transition Region and Coronal Explorer spacecraft.

## FOR MORE INFORMATION

[solarsystem.nasa.gov/planets/profile.cfm?Object=Venus](http://solarsystem.nasa.gov/planets/profile.cfm?Object=Venus)





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 are often unpredictable. Air, water, land, and life — including humans — combine forces to 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, as we do other planets, using sensitive instruments to understand the delicate balance among its oceans, air, land, and life.

Some facts are well known. 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. During March and September, when spring and fall begin, both hemispheres receive roughly equal amounts of illumination from the Sun.

The ocean, which covers nearly 70 percent of Earth'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 temperature 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 ocean of air that consists of 78 percent nitrogen, 21 percent oxygen, and 1 percent other ingredients envelops us. This atmosphere affects Earth's long-term climate and short-term local weather, shields us from nearly all 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. Earth-orbiting satellites have revealed that the up-

per atmosphere actually swells by day and contracts by night due to solar heating during the day and cooling at night.

Our planet's rapid spin and molten nickel-iron core give rise to a magnetic field, which the solar wind distorts into a teardrop shape. (The solar wind is a stream of charged particles continuously ejected from the Sun.) Earth's magnetic field does not fade off into space, but has definite boundaries. 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, or the northern and southern lights.

Earth's lithosphere, which includes the crust (both continental and oceanic) and the uppermost, rigid 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. The theory of motion of the large plates of the lithosphere is known as plate tectonics. Developed within the last 40 years, this explanation has unified the results of centuries of study of our planet.

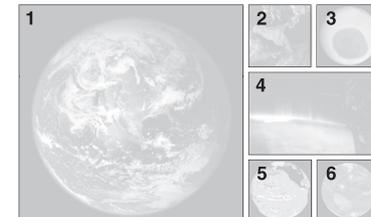
## FAST FACTS

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	$5.9737 \times 10^{24}$ kg
Density	5.515 g/cm <sup>3</sup>
Gravity (Global Average)	9.8 m/sec <sup>2</sup> (32.15 ft/sec <sup>2</sup> )
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 Tiros, the first weather satellite.
- 1972 — Landsat 1 is launched, the first in a series that continues today. The images are used in agriculture, geology, forestry, regional planning, mapping, and global change research.
- 1992 — Topex/Poseidon, a U.S.–France mission, begins measuring sea-surface height; the data revolutionize understanding of the ocean's role in weather and climate.
- 1997 — The U.S.–Japan Tropical Rainfall Measuring Mission is launched. It includes the first spaceborne instrument to provide three-dimensional maps of storm structure.
- 1999–2005 — A series of Earth-observing satellites is launched to provide complementary data sets on Earth's system: Terra (land, oceans, atmosphere), Aqua (water cycle), Aura (atmospheric chemistry), and Gravity Recovery and Climate Experiment (gravity fields). Planned are CloudSat (clouds) and the Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations mission (aerosols, clouds).

## ABOUT THE IMAGES



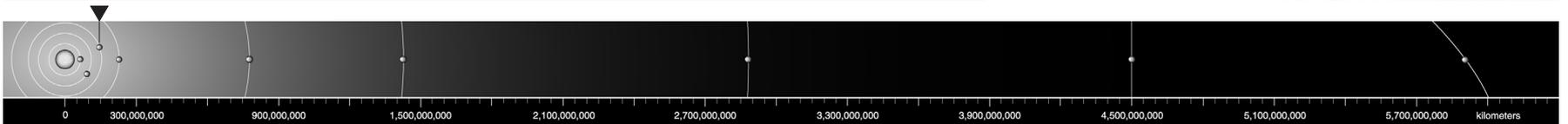
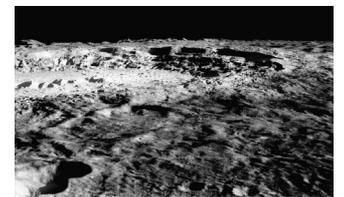
- 1** A true-color NASA satellite mosaic of Earth.
- 2** A view from orbit of the 2002 eruption of Mt. Etna, Sicily.

- 3** The 2003 Antarctic ozone hole was one of the largest ever recorded.
- 4** Astronauts aboard the space shuttle took this photograph of the Aurora Australis. Aurorae are caused when charged particles from the Sun interact with Earth's magnetic field.
- 5** Satellites track El Niño in the Pacific; red and yellow in this color-coded image indicate warmer ocean water.
- 6** A false-color image generated from radar data. Orange indicates fastest wind speed; arrows indicate wind direction.

## FOR MORE INFORMATION

[solarsystem.nasa.gov/planets/profile.cfm?Object=Earth](http://solarsystem.nasa.gov/planets/profile.cfm?Object=Earth)

# Earth's Moon





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 also been charted by many cultures in many ages. The presence of the Moon stabilizes Earth's wobble on its axis, leading to a stable climate over billions of years, which may have affected the course of the development and growth of life on Earth. From Earth, we see the same face of the Moon all the time because the Moon rotates just once on its own axis in very nearly the same time that it travels once around Earth (called synchronous rotation). Patterns of dark and light features on the near side have given rise to the fanciful "Man in the Moon" description. The light areas are lunar highlands. The dark features, called maria (Latin for seas), are impact basins that were filled with dark lava between 4 and 2.5 billion years ago.

How did the Moon come to be? The leading theory, based on research, is that a Mars-sized body collided with Earth and the resulting debris from both Earth and the impactor accumulated to form our natural satellite approximately 4.5 billion years ago (the age of the oldest collected lunar rocks). When the Moon formed, its outer layers melted under very high temperatures, forming the lunar crust, probably from a global "magma ocean" — a sea of molten rock. The lunar highlands contain the remnants of rocks that floated to the surface of the magma ocean.

After the ancient time of volcanism, the Moon cooled and has since been nearly unchanged, except for a steady rain of "hits" by meteorites and comets. Impacts over billions of years have ground up surface areas into powder. Because the Moon has essentially no atmosphere, even the tiniest meteorites strike the surface. The Moon's surface is charcoal gray and sandy, with much fine soil. This powdery blanket of lunar soil is called the lunar regolith. The regolith is thin, ranging from about 2 meters (7 feet) on the youngest maria to perhaps 20 meters (70 feet) on the oldest surfaces in the highlands.

Four impact craters are used to date objects on the Moon: Nectaris, Imbrium, Eratosthenes, and Copernicus. Lunar history is carved up into time segments associated with the date of each crater. A Copernican feature, for example, is associated with a

crater that is similar in age to the Copernicus impact crater, that is, 1 billion years old or less.

The Moon was first visited by the U.S.S.R. spacecraft Luna 2 in 1959, and a number of U.S. and U.S.S.R. robotic spacecraft followed. The U.S. first sent a series of Ranger spacecraft, designed to relay images and data and then crash-land onto the surface. This series was followed by the Surveyors, the first U.S. spacecraft to make lunar soft-landings. The first human landing on the Moon was on July 20, 1969. Twelve American astronauts walked upon its surface and brought back 382 kilograms (842 pounds) of lunar rock and soil to Earth during the Apollo lunar surface exploration missions of 1969 to 1972. The chief repository of the Apollo samples is NASA's Johnson Space Center in Houston.

Startling results from the Clementine and Lunar Prospector spacecraft indicate that there may be water ice on the Moon. Though a controlled crash of the Lunar Prospector in 1999 produced no observable signature of water, the issue of whether ancient cometary impacts delivered ice that is harbored in dark, cold areas of the Moon is still an open question.

In 2004, President George W. Bush announced a new Vision for Space Exploration that includes sustained robotic and human exploration of the solar system and beyond. It begins with robotic exploration of the Moon with an orbiter and then a lander, with a human return to the Moon by 2018. The Moon would be a test-bed for technologies to support human exploration of the Moon, Mars, and beyond.

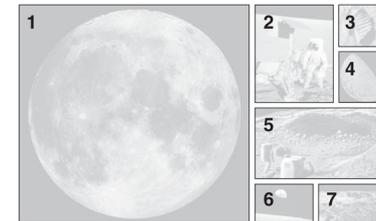
## FAST FACTS

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 <sup>3</sup> (0.61 of Earth's)
Gravity	0.166 of Earth's
Temperature Range	-233 to 123 deg C (-387 to 253 deg F)

## SIGNIFICANT DATES

- 1610 — Galileo Galilei is the first to use a telescope to make scientific observations of the Moon.
- 1959–1960 — Luna 1, 2, and 3 are the first to fly by, impact, and photograph the far side of the Moon.
- 1966 — Surveyor 1 makes the first soft landing on the Moon.
- 1969 — Astronaut Neil Armstrong is the first of 12 humans to walk on the lunar surface.
- 1996 — Clementine data indicate water ice at the south pole.
- 1998 — Lunar Prospector data indicate that ice exists at both lunar poles.

## ABOUT THE IMAGES



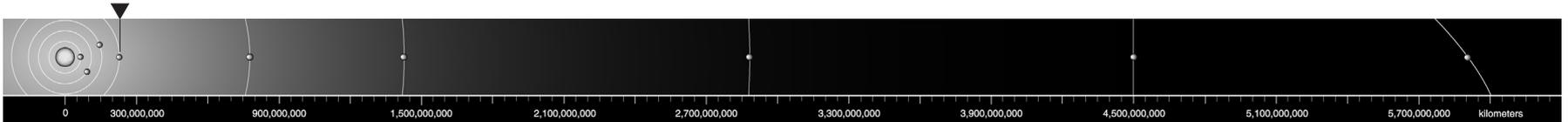
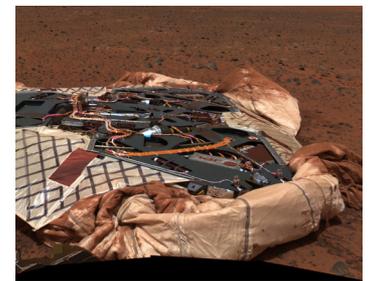
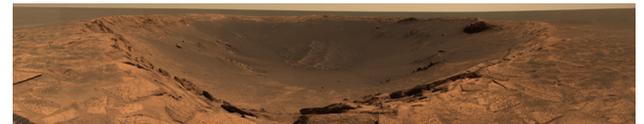
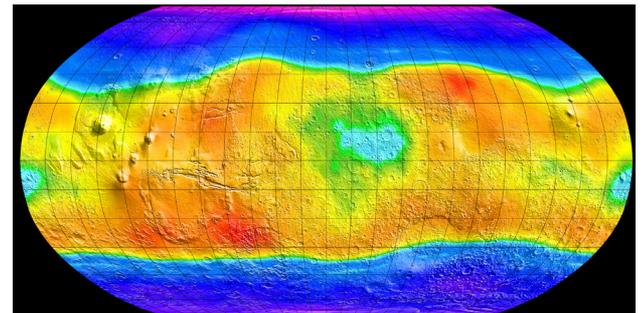
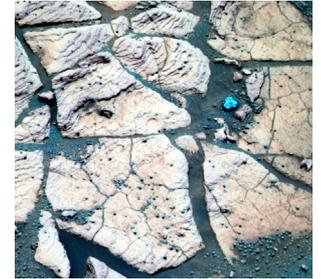
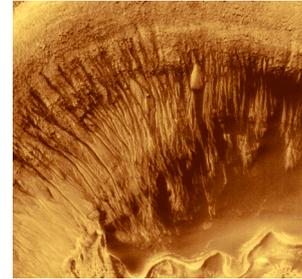
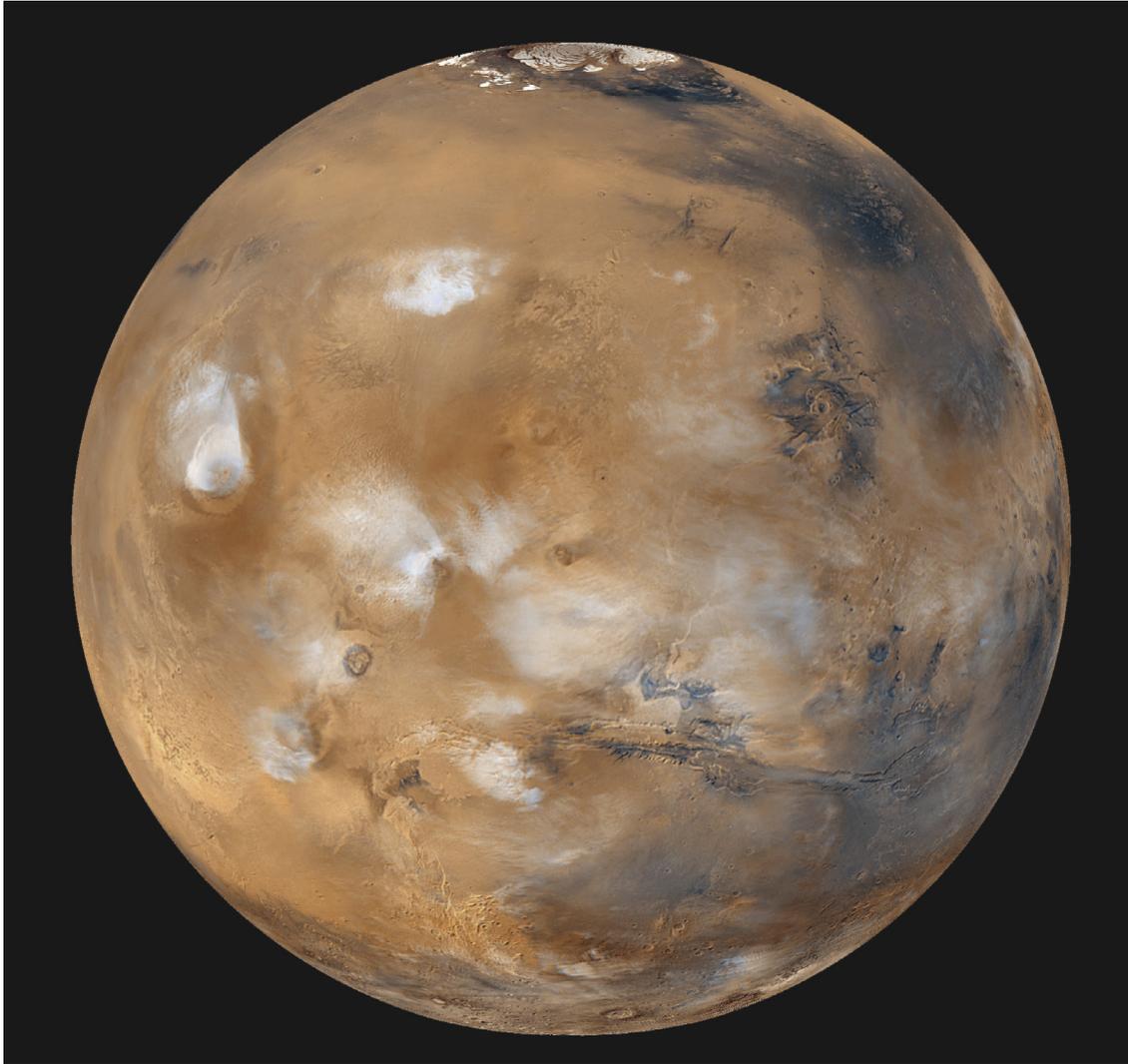
**1** The dark areas of this lunar image are lava-filled impact basins. The bright ray crater on the bottom is the Tycho impact basin.

- 2** Apollo 12 astronaut Charles Conrad visits Surveyor 3, a robotic spacecraft that landed on the Moon three years earlier.
- 3** This boot print marks one of the first steps human beings took on the Moon in July 1969.
- 4** False-color images help scientists identify different types of soil on the Moon's surface.
- 5** An illustration of future astronauts investigating a lava cave on the Moon.
- 6** The Apollo 8 crew took this picture of Earth rising over the surface of the Moon in 1968.
- 7** Copernicus Crater is part of the youngest assemblage of lunar rocks. The photo was taken by Lunar Orbiter 2 in 1966.

## FOR MORE INFORMATION

[solarsystem.nasa.gov/planets/profile.cfm?Object=Moon](http://solarsystem.nasa.gov/planets/profile.cfm?Object=Moon)

# Mars





Though details on 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, that Mars could be a likely place for life forms, and that water might exist in the polar caps. When the Mariner 4 spacecraft flew by Mars in 1965, many were shocked to see photographs of a bleak, cratered surface. Mars seemed to be a dead planet. Later missions, however, have shown that Mars is a complex member of the solar system and holds many mysteries yet to be solved.

Mars is a rocky body about half the size of Earth. Like the other terrestrial planets — Mercury, Venus, and Earth — its surface has been altered by volcanism, impacts, crustal movement, and atmospheric effects such as dust storms. Mars' polar ice caps grow and recede with the seasons; layered areas near the poles suggest that the planet's climate has changed more than once.

Mars has no global magnetic field as does Earth. However, NASA's Mars Global Surveyor orbiter found that areas of the martian crust in the southern hemisphere are highly magnetized — evidently traces of Mars' magnetic field remained in the planet's crust from about 4 billion years ago.

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, the Mars Exploration Rover named Opportunity found structures and minerals indicating that its landing site was once the shoreline of a salty martian sea. The rover's twin, Spirit, also found the signature of ancient water at its landing site halfway around Mars from Opportunity's location.

Many questions remain. The cold temperatures and thin atmosphere on Mars don't allow liquid water to exist at the surface

for long, and 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 also believed to be an essential ingredient for life; evidence of past or present water on Mars is expected to hold clues about whether Mars could ever have been a habitat for life.

Volcanism in the highlands and plains stopped 3 billion years ago, but some of the giant shield volcanoes are younger, forming between 1 and 2 billion years ago. Mars has the largest volcanic mountain in the solar system, Olympus Mons, as well as a spectacular equatorial canyon system, Valles Marineris. The length of Valles Marineris is equivalent to the distance from New York to Los Angeles.

Mars has two small moons, Phobos and Deimos. Although it is not known how they formed, they may be asteroids snared by Mars' gravity.

## 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 <sup>3</sup> (0.714 of Earth's)
Gravity	0.38 of Earth's
Atmosphere Primary Components	carbon dioxide, nitrogen, argon
Temperature Range	-143 to 17 deg C (-225 to 63 deg F)
Known Moons*	2
Rings	0

\*As of November 2005.

## SIGNIFICANT DATES

1877 — Asaph Hall discovers the two moons of Mars, Phobos and Deimos.

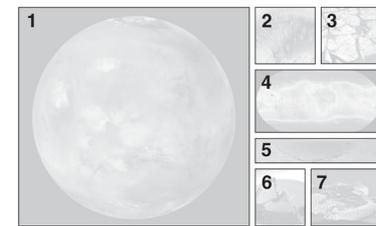
1965 — NASA's Mariner 4 sends back 22 photos of Mars, the world's first close-up photos of a planet beyond Earth.

1976 — Viking 1 and 2 make the first, and still one of the few, successful landings on the surface of Mars.

1997 — Mars Pathfinder lands and dispatches Sojourner, the first wheeled rover to explore the surface of another planet.

2004 — Twin Mars Exploration Rovers named Spirit and Opportunity land on Mars and find the strongest evidence yet obtained that the red planet once had long-standing bodies of water.

## ABOUT THE IMAGES



**1** A large water ice cloud hangs over Olympus Mons (upper left in the image).

**2** Gullies may be a sign that water has recently flowed on Mars.

**3** Sphere-like grains that once may have formed in water appear blue in this false-color image taken by Mars rover Opportunity near its landing site.

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

**5** A view of "Endurance Crater," near where Mars rover Opportunity landed in Meridiani Planum.

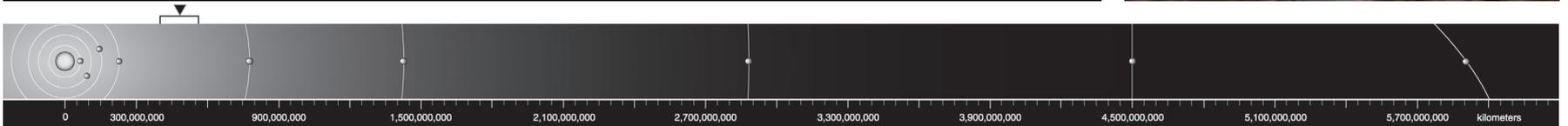
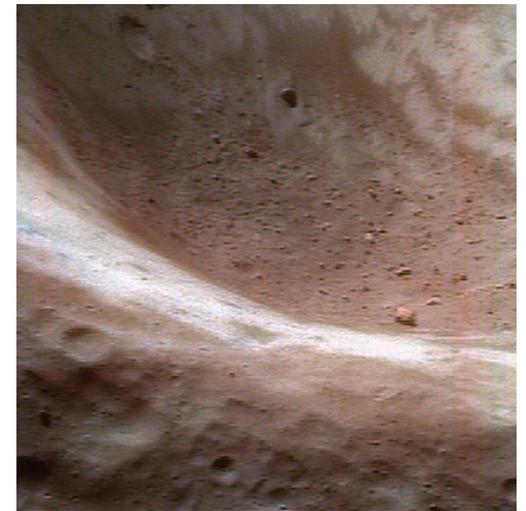
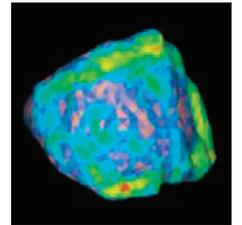
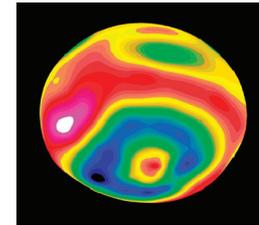
**6** Mars rover Spirit uses its robotic arm to examine a rock named "Adirondack."

**7** Mars rover Spirit photographed its empty landing platform after it rolled onto the surface of Mars at Gusev Crater.

## FOR MORE INFORMATION

[solarsystem.nasa.gov/planets/profile.cfm?Object=Mars](http://solarsystem.nasa.gov/planets/profile.cfm?Object=Mars)

# Asteroids



# Asteroids



Asteroids, sometimes called minor planets, are small, rocky fragments left over from the 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. Asteroids range in size from Ceres, about one-quarter the diameter of Earth's Moon, to bodies that are less than 1 kilometer (0.6 mile) across. The total mass of all the asteroids is less than that of the Moon.

Early in the history of the solar system, the formation of Jupiter brought an end to the formation of planetary bodies in the gap between Mars and Jupiter and caused the small bodies that occupied this region to collide with one another, fragmenting them into the asteroids we observe today. This region, called the asteroid belt or simply the main belt, may contain millions of asteroids. Because asteroids have remained mostly unchanged for billions of years, studies of them could tell us a great deal about the early solar system.

Most asteroids are irregularly shaped, though a few are nearly spherical, and 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. A few asteroids are known to have a small companion moon, and there are even some binary asteroids, in which two rocky bodies of roughly equal size orbit each other.

There are three broad composition classes of asteroids: C-, S-, and M-types. The C-type 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). Their compositional differences are related to how far from the Sun asteroids of different types formed. Some of the asteroids experienced high temperatures after they formed and partly melted, with iron sinking to the center and forcing basaltic (volcanic) lava to the surface. One such asteroid, Vesta, survives to this day.

Jupiter's gravity and occasional close encounters with Mars or with another asteroid change the asteroids' orbits, knocking them out of the main belt and hurling them into space in both directions across the orbits of the planets. Stray asteroids or as-

teroid 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 monitor asteroids whose paths intersect Earth's orbit, called Earth-crossing asteroids. Some of these come so close to Earth that they are further classified as near-Earth asteroids.

Radar observations that bounce signals off asteroids can tell scientists a great deal about an asteroid's size, shape, spin, and metal concentration. Radar is used to track asteroids that pass close to Earth; sometimes it detects small companion asteroids.

A few space missions have flown by and observed asteroids close up. 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 Deep Space 1 and Stardust have both had close encounters with asteroids. NASA's Dawn mission is planned to orbit asteroids Vesta and Ceres. Vesta and Ceres are considered "baby planets" — their growth was interrupted by the formation of Jupiter, and they followed different evolutionary paths. Scientists hope to characterize the conditions and processes of the solar system's earliest epoch by studying these two very different large asteroids.

## SIGNIFICANT DATES

- 1801 — Giuseppe Piazzi discovers the first asteroid, Ceres.
- 1898 — Gustav Witt discovers Eros, one of the largest near-Earth asteroids.

## FAST FACTS

	433 Eros	951 Gaspra	4 Vesta	1 Ceres	243 Ida
Mean Distance from the Sun (AU*)	1.46	2.21	2.36	2.77	2.86
Orbit Period (years)	1.76	3.29	3.63	4.60	4.84
Orbit Eccentricity (Circular = 0)	0.22	0.17	0.09	0.08	0.05
Orbit Inclination to Ecliptic (deg)	10.83	4.10	7.13	10.58	1.14
Rotation Period	5 hr, 16 min	7 hr, 2 min	5 hr, 20 min	9 hr, 4 min	4 hr, 38 min
Dimensions (km)	34 × 11 × 11	20 × 12 × 11	578 × 560 × 458	960 × 932	60 × 25 × 19
Dimensions (mi)	21 × 7 × 7	12 × 7 × 7	359 × 348 × 285	597 × 579	37 × 15 × 12

\*AU = astronomical unit, the mean distance from Earth to the Sun: 149.60 million km or 92.96 million mi.

1991–1994 — On its way to Jupiter, 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 — NEAR Shoemaker spacecraft flies by Mathilde and orbits and lands on Eros.

## ABOUT THE IMAGES

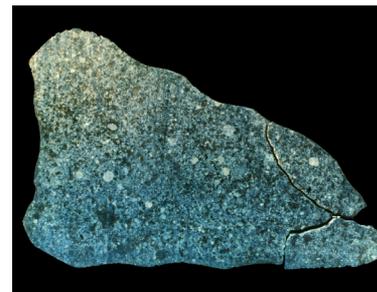
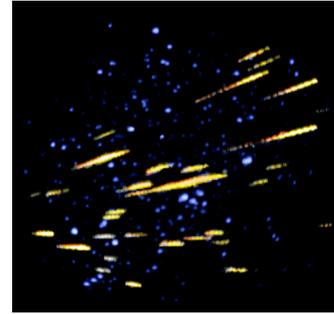


- 1** A four-image mosaic of asteroid Eros taken by the NEAR spacecraft.
- 2** A Galileo image of asteroid Ida and its moon Dactyl.
- 3** Elevation mapping using imagery from the Hubble Space Telescope reveals a giant crater (the blue ring) on asteroid Vesta.
- 4** This computer-generated model of asteroid Golevka was created from radar data. Tiny Golevka is just 0.5 kilometer (0.33 mile) across.
- 5** A false-color view of a large crater on Eros. Redder hues indicate rock and soil altered by exposure to the solar wind.

## FOR MORE INFORMATION

[solarsystem.nasa.gov/planets/profile.cfm?Object=Asteroids](http://solarsystem.nasa.gov/planets/profile.cfm?Object=Asteroids)

# Meteors and Meteorites



## Meteors and Meteorites



“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. Chunks of these extraterrestrial visitors that survive their journey through the atmosphere and fall to the ground are called meteorites.

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). Comet dust in meteor showers burns up in the atmosphere before reaching the ground.

Most meteorites are no bigger than an average Earth rock, but some have been quite large, especially in Earth’s early history. Large meteorites can cause extensive destruction when they strike. One of the most distinct impact craters is the Barringer Meteor Crater in Arizona, about 1,000 meters (3,300 feet) across. 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 160 impact craters have been identified on Earth. A very large asteroid impact 65 million years ago, which created the 300-kilometer (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, but in November 1954, Ann Hodges of Sylacauga, Alabama, was severely bruised by a 3.6-kilogram (8-pound) stony meteorite that crashed through her roof.

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 passed 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 planets. Imagine the excitement when Mars Exploration Rover Opportunity found an iron meteorite on Mars!

More than 30,000 meteorites have been found on Earth. Of these, 99.8 percent are thought to come from asteroids. Evidence for an asteroid origin includes: orbits calculated from photographic observations of meteorite falls project back to the asteroid belt; spectra of several classes of meteorites match those of some asteroid classes; and all but the rare lunar and martian meteorites 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 the original diverse materials from which the planets formed. The study of meteorites tells us much about the conditions and processes during the formation and earliest history of the solar system.

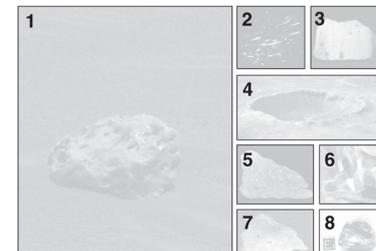
The remaining 0.2 percent of meteorites is split roughly equally between meteorites from the Moon and Mars. The current 35 known martian meteorites were blasted off Mars by meteoroid impacts. All are igneous rocks crystallized from magma, with distinctive composition indicating martian origin. Controversy continues about whether structures found in the meteorite known as ALH84001 might be evidence of fossil martian bacteria. The 36 lunar meteorites are similar in mineralogy and composition to Apollo 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 that leads to the death of dinosaurs and 75 percent of animals on Earth.  
50,000 years — Age of Barringer Meteor Crater in Arizona.  
1478 BC — First recorded observation of meteors.  
1794 AD — Ernst Friedrich Chladni publishes the first book on meteorites.  
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 ALH 84001 may contain evidence of microfossils from Mars.  
2005 — NASA’s Mars Exploration Rover Opportunity finds an iron meteorite on Mars.

### ABOUT THE IMAGES



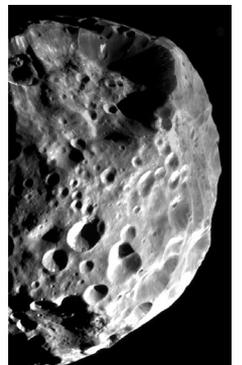
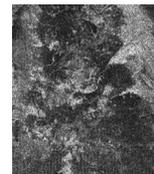
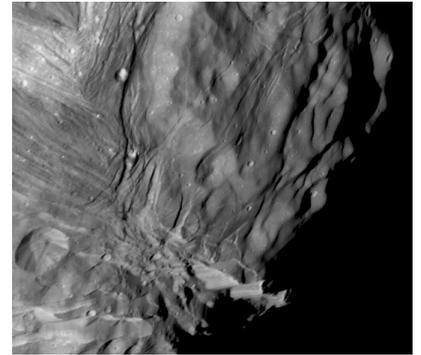
**1** A basketball-size iron meteorite found on Mars by Opportunity rover.  
**2** A burst of meteors photographed by NASA Ames Research Center scientists in 1995.

**3** The glassy black patches in this martian meteorite contain atmospheric gases.  
**4** Barringer Meteor Crater in Arizona.  
**5** A stony meteorite found in Antarctica.  
**6** A scientist working in the Meteorite Processing Lab at NASA Johnson Space Center.  
**7** An iron meteorite from Barringer Meteor Crater.  
**8** A lunar meteorite found in Antarctica similar in composition to lunar rocks brought back by Apollo astronauts.

### FOR MORE INFORMATION

[solarsystem.nasa.gov/planets/profilecm?Object=Meteoroids](http://solarsystem.nasa.gov/planets/profilecm?Object=Meteoroids)

# Moons of the Solar System





Moons come in many shapes, sizes, and types. They are generally solid bodies, and few have atmospheres. Most of the moons probably formed from the discs of gas and dust circulating around planets in the early solar system. As of November 2005, astronomers have found at least 153 moons orbiting planets in our solar system. The moon champion, Jupiter, has a total of 62 known moons, including the largest moon in the solar system, Ganymede. Many of Jupiter's smallest 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.

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. While both have nearly circular orbits and travel close to the plane of the planet's equator, 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.

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, Uranus, and Neptune) have many moons. As these planets grew in the early solar system, they were able to capture objects with their large gravitational fields.

Earth's Moon is another story. The Moon probably formed when a large body about the size of Mars collided with Earth, ejecting a lot of material from our planet into orbit. Debris from the early Earth and the impacting body accumulated to form the Moon approximately 4.5 billion years ago (the age of the oldest collected lunar rocks). Twelve American astronauts visited the Moon during the Apollo lunar landings in 1969 to 1972.

Saturn has more than 40 known moons. 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. 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.

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 Pluto, and orbits backwards compared with Neptune's direction of rotation. Neptune has 13 known moons.

Pluto's single moon, Charon, is about half the size of Pluto. Some astronomers think of them as forming a binary, or double, planet system. Like Earth's Moon, Charon may have formed from debris resulting from an early collision of an impactor with Pluto. In October 2005, scientists using the Hubble Space Telescope to study this distant planet announced that Pluto may have two additional moons. The candidate moons are about two to three times as far from Pluto as Charon and roughly 5,000 times fainter than Pluto.

## FAST FACTS

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
Pluto	Charon	600	373

## SIGNIFICANT DATES

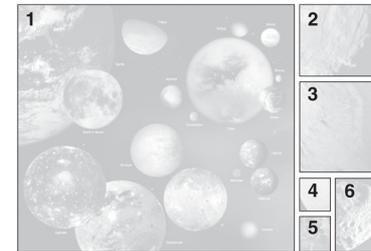
1610 — Galileo Galilei and Simon Marius independently discover four moons orbiting Jupiter. Galileo is credited and the moons are called "Galilean."

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 the Moon.

1980 — Voyager 1 instruments detect signs of surface features beneath the hazy atmosphere of Saturn's largest moon, Titan.

2000–2005 — Since the beginning of the year 2000, 84 of the 153 known moons of the solar system have been discovered. Jupiter's known moons have increased from 18 to 62. Saturn's known moons have jumped from 18 to 47. Uranus' moon count has gone from 21 to 27, and Neptune's known moons have increased in number from 8 to 13.

## 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 planet Earth.

**2** Miranda, a moon of Uranus, has many rugged features.

**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.

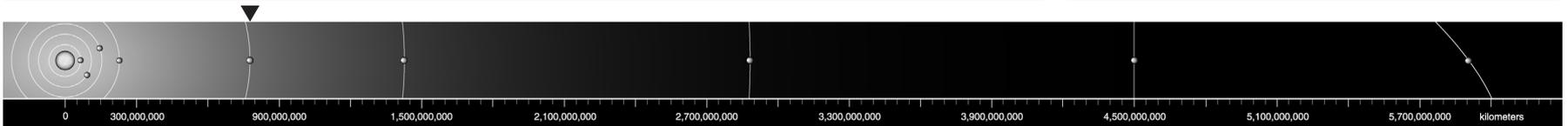
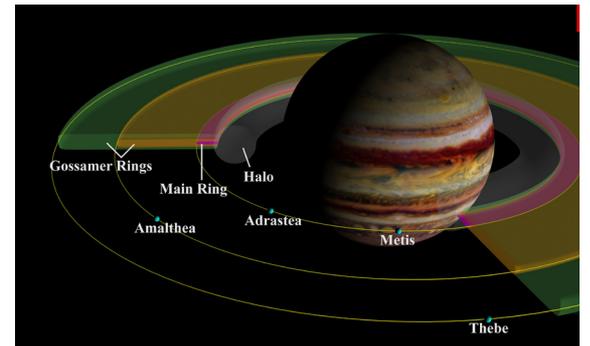
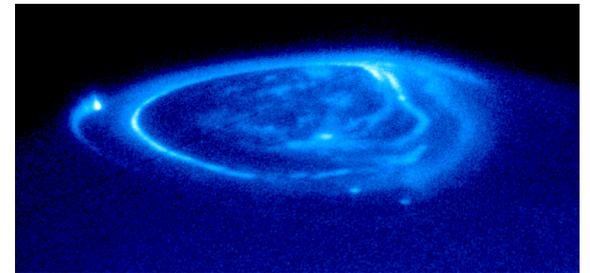
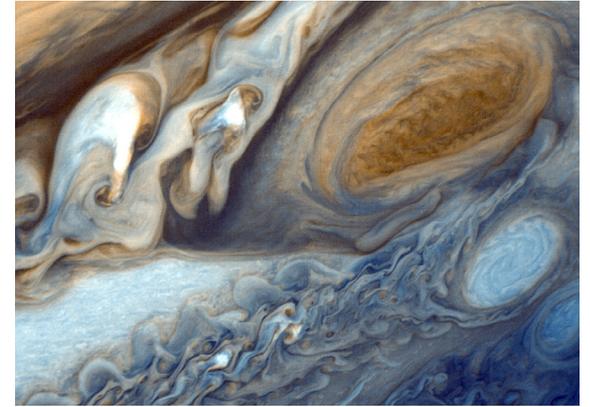
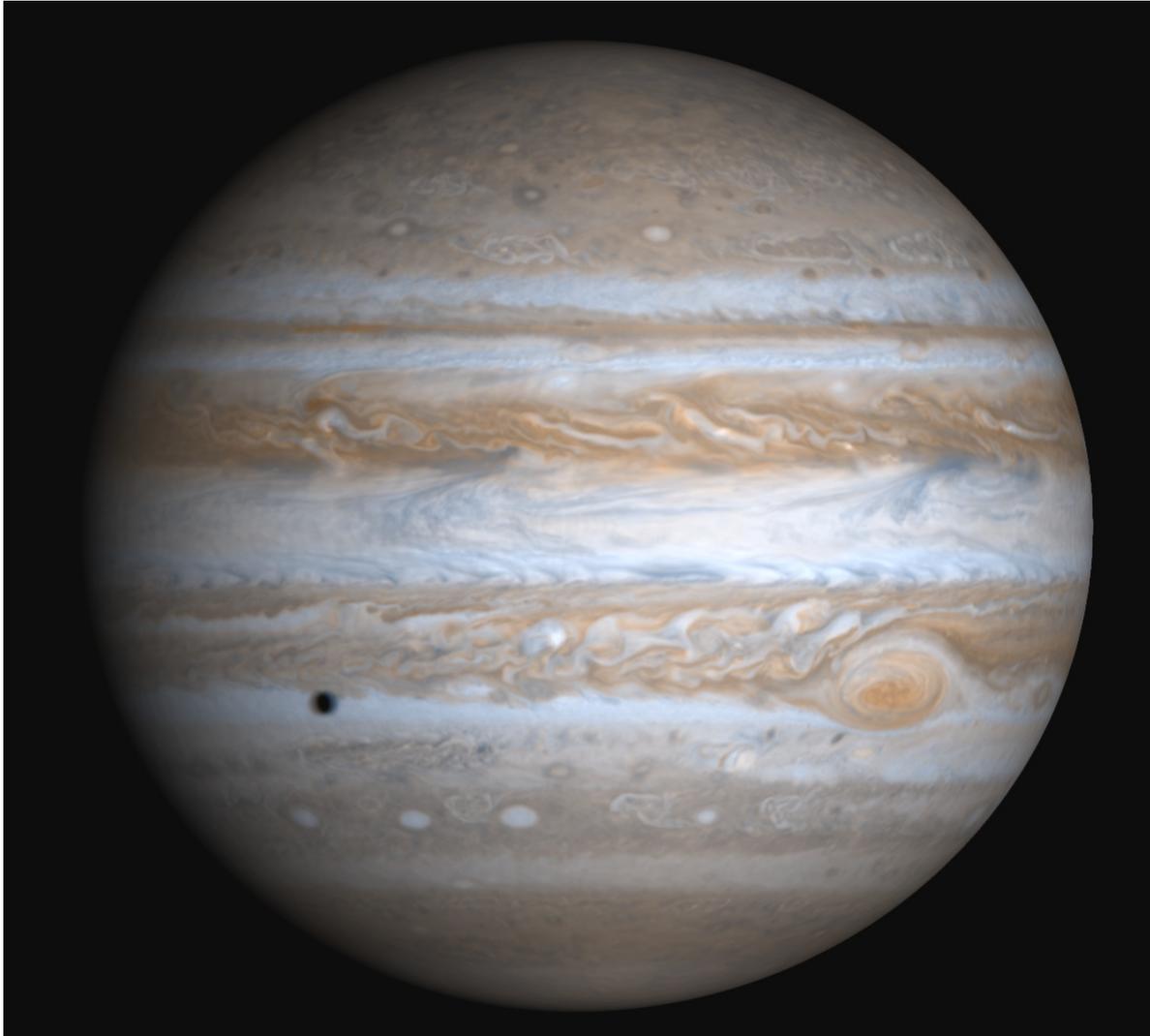
**5** A portion of a Cassini radar image of Saturn's largest moon, Titan, showing the complexity of the surface.

**6** Cassini imaged Saturn's outer moon Phoebe when the spacecraft was inbound for orbit insertion in June 2004.

## FOR MORE INFORMATION

[solarsystem.nasa.gov/index.cfm](http://solarsystem.nasa.gov/index.cfm)

# Jupiter



# Jupiter



The most massive planet in our solar system, with four planet-sized moons and many smaller moons, Jupiter forms a kind of miniature solar system. Jupiter resembles a star in composition. In fact, if it had been about eighty times more massive, it would have become a star rather than a planet.

On January 7, 1610, using his primitive telescope, astronomer Galileo Galilei saw four small “stars” near Jupiter. He had discovered Jupiter’s four largest moons, now called Io, Europa, Ganymede, and Callisto. Collectively, these four moons are known today as the Galilean satellites.

Galileo would be astonished at what we have learned about Jupiter and its moons in the past 30 years. Io is the most volcanically active body in our solar system. Ganymede is the largest planetary moon and is the only moon in the solar system known to have its own magnetic field. A liquid ocean may lie beneath the frozen crust of Europa. Icy oceans may also lie deep beneath the crusts of Callisto and Ganymede. In 2003 alone, astronomers discovered 23 new moons orbiting the giant planet, giving Jupiter a total moon count of 62 — the most in the solar system. The numerous small outer moons may be asteroids captured by the giant planet’s gravity.

Jupiter’s appearance is a tapestry of beautiful colors and atmospheric features. Most visible clouds are composed of ammonia. Water exists deep below and can sometimes be seen through clear spots in the clouds. The planet’s “stripes” are dark belts and light zones created by strong east–west winds in Jupiter’s upper atmosphere. Within these belts and zones are storm systems that have raged for years. The Great Red Spot, a giant spinning storm, has been observed for more than 300 years.

The composition of Jupiter’s atmosphere is similar to that of the Sun — mostly hydrogen and helium. Deep in the atmosphere, the pressure and temperature increase, compressing the hydrogen gas into a liquid. At depths about a third of the way down, the hydrogen becomes metallic and electrically conducting. In this metallic layer, Jupiter’s powerful magnetic field is generated by electrical currents driven by Jupiter’s fast rotation. At the center, the immense pressure may support a solid core of ice–rock about the size of Earth.

Jupiter’s enormous magnetic field is nearly 20,000 times as powerful as Earth’s. Trapped within Jupiter’s magnetosphere (the area in which magnetic field lines encircle the planet from pole to pole) are swarms of charged particles. Jupiter’s rings and moons are embedded in an intense radiation belt of electrons and ions trapped in the magnetic field. The jovian magnetosphere, comprising these particles and fields, 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.

Discovered in 1979 by NASA’s Voyager 1 spacecraft, Jupiter’s rings were a surprise: a flattened main ring and an inner cloud-like ring, called the halo, are both composed of small, dark particles. A third ring, known as the gossamer ring because of its transparency, is actually three rings of microscopic debris from three small moons: Amalthea, Thebe, and Adrastea. Jupiter’s ring system may be formed by dust kicked up as interplanetary meteoroids smash into the giant planet’s four small inner moons. The main ring probably comes from the moon Metis. Jupiter’s rings are only visible when backlit by the Sun.

In December 1995, NASA’s Galileo spacecraft dropped a probe into Jupiter’s atmosphere, which collected the first direct measurements of Jupiter’s atmosphere. Following the release of the probe, the Galileo spacecraft began a multiyear study of Jupiter and the largest moons. As Galileo began its 29th orbit, the Cassini–Huygens spacecraft was nearing Jupiter for a gravity-assist maneuver on the way to Saturn. The two spacecraft made simultaneous observations of the magnetosphere, solar wind, rings, and Jupiter’s auroras.

## 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 <sup>3</sup>
Gravity	20.87 m/sec <sup>2</sup> (68.48 ft/sec <sup>2</sup> )
Atmosphere Primary Components	hydrogen, helium
Effective Temperature	–148 deg C (–234 deg F)
Known Moons*	62
Rings	1 (three major components)

\*As of November 2005.

## SIGNIFICANT DATES

- 1610 — Galileo Galilei makes the first detailed observations of Jupiter using a telescope.
- 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 watch pieces of comet Shoemaker–Levy 9 collide with Jupiter.
- 1995–2003 — The Galileo spacecraft conducts extended observations of Jupiter and its moons and rings.

## ABOUT THE IMAGES

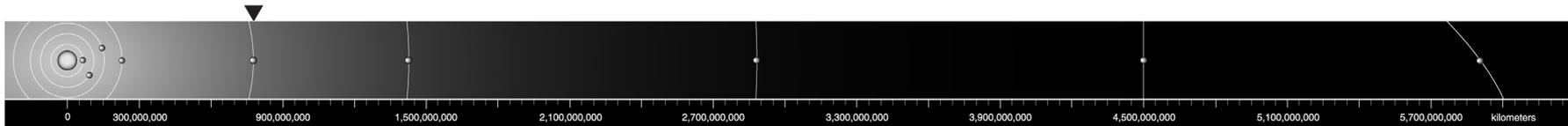
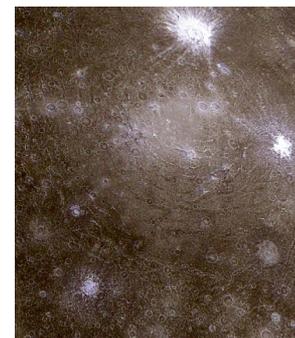
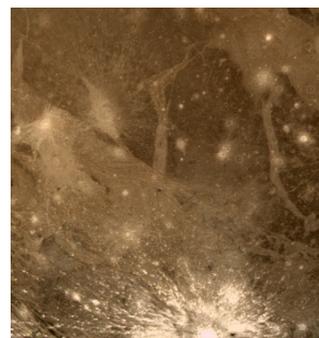
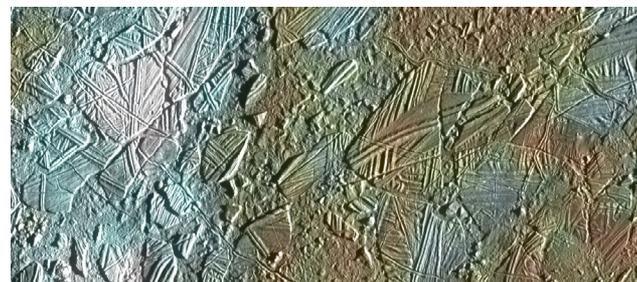
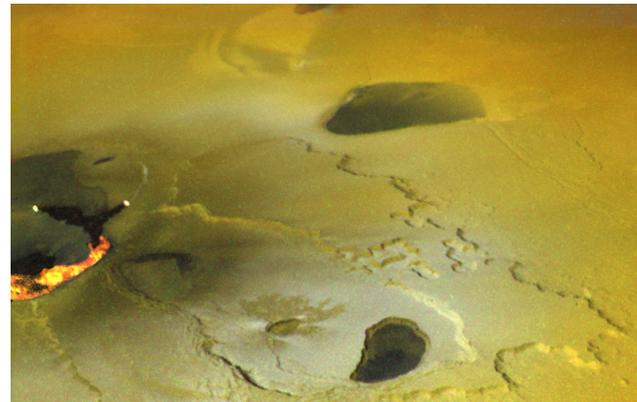


- 1** A detailed, true-color image of Jupiter taken by the Cassini spacecraft. The Galilean moon Europa casts a shadow on the planet.
- 2** A Voyager 1 image of Jupiter’s Great Red Spot.
- 3** An image of Jupiter’s aurora, a sign of the interaction between Jupiter’s magnetic field and energy from the Sun.
- 4** A schematic of the components of Jupiter’s ring system.

## FOR MORE INFORMATION

[solarsystem.nasa.gov/planets/profile.cfm?Object=Jupiter](http://solarsystem.nasa.gov/planets/profile.cfm?Object=Jupiter)

# Galilean Moons of Jupiter



## Galilean Moons of Jupiter



The planet Jupiter's four largest moons are called the Galilean satellites, after Italian astronomer Galileo Galilei, who observed them in 1610. The German astronomer Simon Marius claimed to have seen the moons around the same time, but he did not publish his observations and so Galileo is given the credit for their discovery. These large moons, named Io, Europa, Ganymede, and Callisto, are each distinctive worlds.

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

Europa's surface is mostly water ice, and there is evidence that it may be covering an ocean of water or slushy ice. Europa is thought to have twice as much water as does Earth. This moon intrigues astrobiologists because of its potential for having a "habitable zone." Life forms have been found thriving near subterranean volcanoes on Earth and in other extreme locations that may be analogues to what may exist on 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, the very few small craters on Callisto indicate a small degree of current surface activity.

The interiors of Io, Europa, and Ganymede have a layered structure (as does Earth). Io has a core, and a mantle of at least partially molten rock, topped by a crust of solid rock coated with sulfur compounds. Europa and Ganymede both have a core; a rock envelope around the core; a thick, soft ice layer; and a thin crust of impure water ice. In the case of Europa, a global subsurface water layer probably lies just below the icy crust. Layering at Callisto is less well defined and appears to be mainly a mixture of ice and rock.

Three of the moons influence each other in an interesting way. Io is in a tug-of-war with Ganymede and Europa, and Europa's orbital period (time to go around Jupiter once) is twice Io's period,

and Ganymede's period is twice that of Europa. In other words, every time Ganymede goes around Jupiter once, 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.

Pioneers 10 and 11 (1973 to 1974) and Voyagers 1 and 2 (1979) offered striking color views and global perspectives from their flybys of the Jupiter system. From 1995 to 2003, the Galileo spacecraft made observations from repeated elliptical orbits around Jupiter, passing as low as 261 kilometers (162 miles) over the surfaces of the Galilean moons. These close approaches resulted in 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 smoothly 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 type of tidal forces that drive Io's volcanoes.

### FAST FACTS

Moon	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)

Moon	Mean Radius
Io	1,821.6 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)

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

Moon	Density (g/cm <sup>3</sup> )
Io	3.528
Europa	3.013
Ganymede	1.942
Callisto	1.834

### SIGNIFICANT DATES

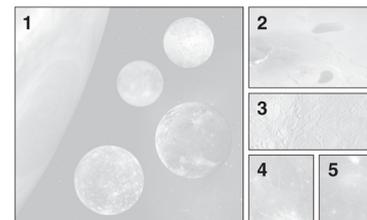
1610 — Galileo Galilei and Simon Marius independently discover four moons orbiting Jupiter.

1979 — Voyager 1 photographs an erupting volcano on Io: the first ever seen anywhere but on 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 possible oceans on Ganymede and Callisto.

2003 — The Galileo mission ends with the spacecraft deliberately descending into Jupiter's atmosphere. In the same year, scientists discover 23 new moons of Jupiter.

### ABOUT THE IMAGES



**1** A composite "portrait" of Jupiter's four Galilean moons Io, Europa, Ganymede, and Callisto (Jupiter is not at the same scale as the satellites).

**2** During one flyby of Io, the Galileo spacecraft photographed Tvashtar Catena, an area of giant erupting volcanoes.

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

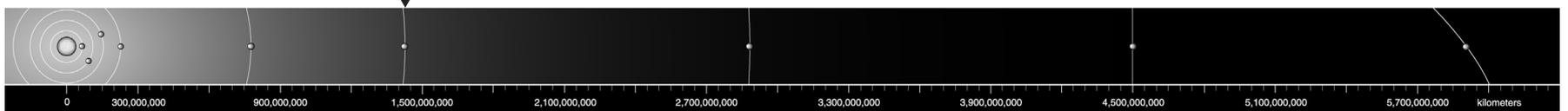
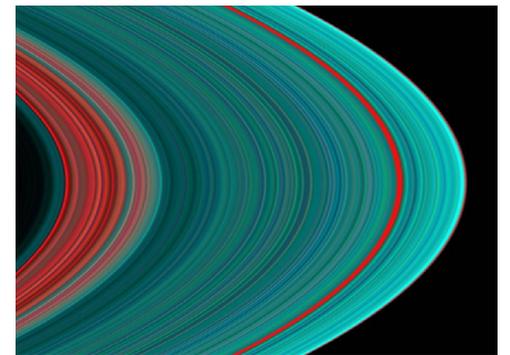
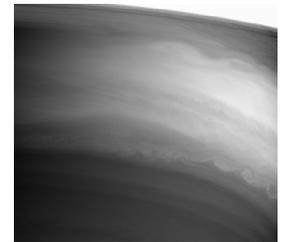
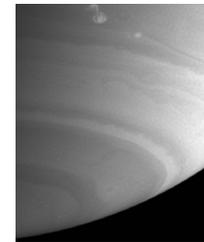
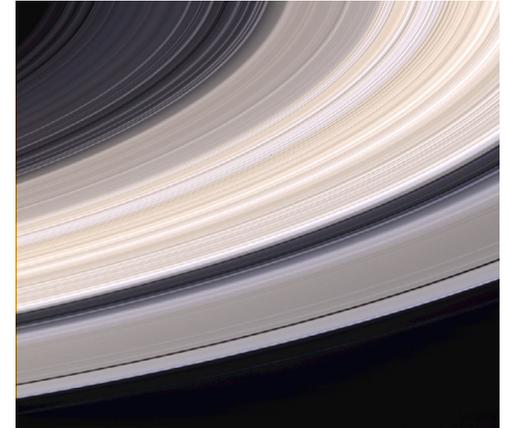
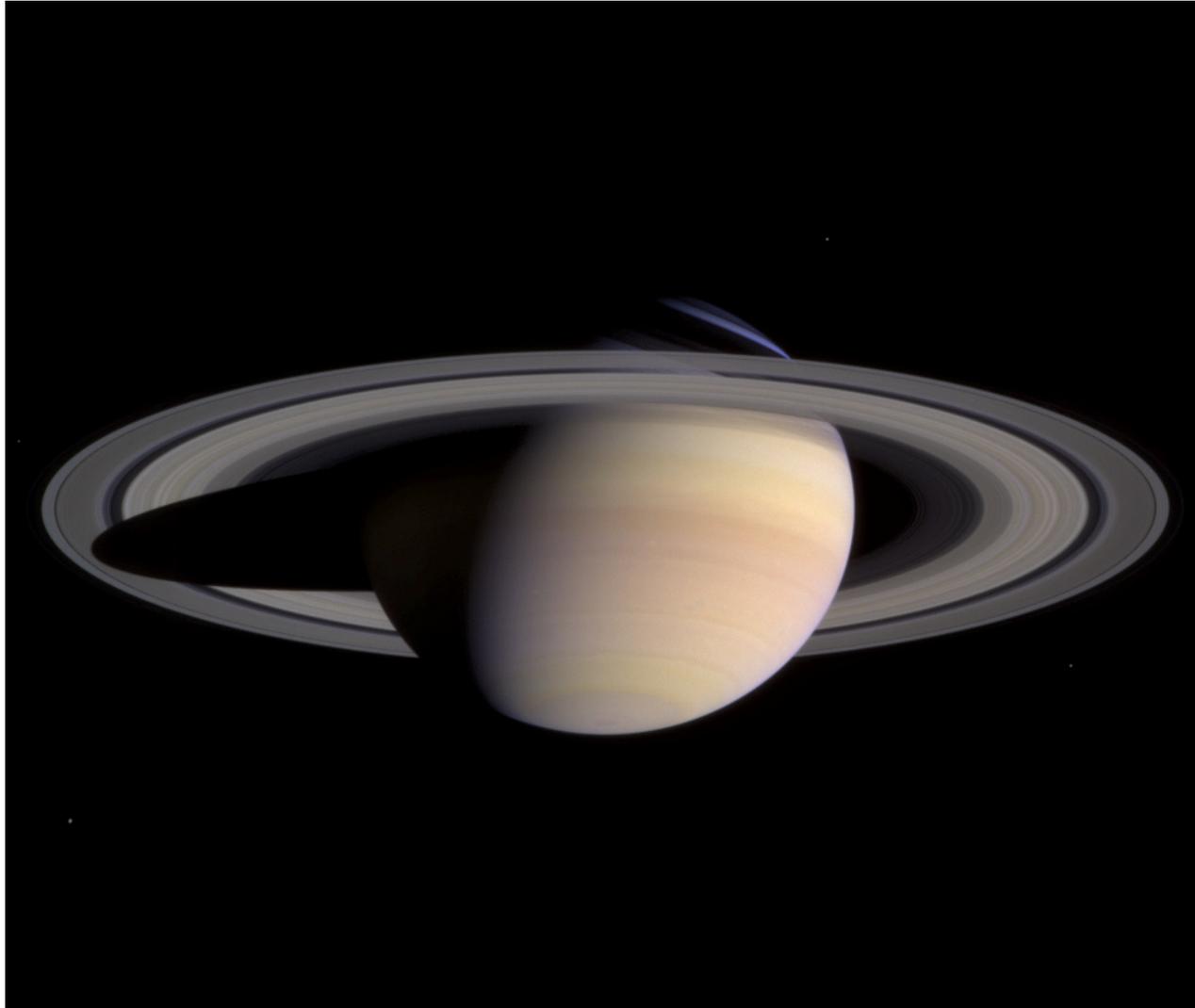
**4** Fresh, bright material was thrown out of an impact crater on Ganymede.

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

### FOR MORE INFORMATION

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

# Saturn



0 300,000,000

900,000,000

1,500,000,000

2,100,000,000

2,700,000,000

3,300,000,000

3,900,000,000

4,500,000,000

5,100,000,000

5,700,000,000

kilometers



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 on either side of the planet. He sketched them as separate spheres and wrote that Saturn appeared to be 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, or 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.

Saturn's ring system is the most extensive and complex in the solar system, extending hundreds of thousands of kilometers from the planet. In the early 1980s, NASA's two Voyager spacecraft revealed that Saturn's rings are made mostly of water ice, and they found "braided" rings, ringlets, and "spokes" — dark features in the rings that circle the planet at different rates from that of the surrounding ring material. Material in the rings ranges in size from a few micrometers to several tens of meters. Two of Saturn's small moons orbit within gaps in the main rings.

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.

Though Saturn's magnetic field is not as huge as Jupiter's, it is 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. Hubble Space Telescope images show that Saturn's polar regions have aurorae similar to Earth's. Aurorae occur when charged particles spiral into a planet's atmosphere along magnetic field lines.

Voyagers 1 and 2 flew by and photographed Saturn in 1981. The next chapter in our knowledge of Saturn is underway, as the Cassini-Huygens spacecraft continues its exploration of the Saturn system. The Huygens probe descended through Titan's atmosphere in January 2005, collecting data on the atmosphere and surface. Cassini will orbit Saturn more than 70 times during a four-year study of the planet and its moons, rings, and magnetosphere. Cassini-Huygens is sponsored by NASA, the European Space Agency, and the Italian Space Agency.

## FAST FACTS

Namesake	Roman god of agriculture
Mean Distance from the Sun	1,426.73 million km (886.53 million mi)
Orbit Period	29.4 Earth years (10,755.7 Earth days)
Orbit Eccentricity (Circular Orbit = 0)	0.0541506
Orbit Inclination to Ecliptic	2.484 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 <sup>3</sup>
Gravity	7.207 m/sec <sup>2</sup> (23.64 ft/sec <sup>2</sup> )
Atmosphere Primary Components	hydrogen, helium
Effective Temperature	-178 deg C (-288 deg F)
Known Moons*	47

Rings 7 main rings (C, B, A, D, F, G, E)

\*As of November 2005.

## SIGNIFICANT DATES

1610 — Galileo Galilei reports seeing odd appendages on either side of Saturn.

1979 — Pioneer 11 is the first spacecraft to reach Saturn, flying within 22,000 kilometers (13,700 miles) of the ringed planet's cloud tops.

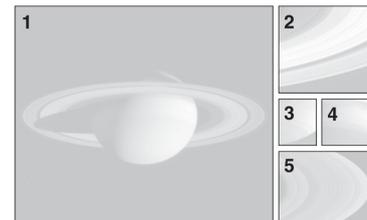
1981 — Using Saturn's powerful gravity as an interplanetary "slingshot," Voyager 2 is placed on a path toward Uranus, then Neptune, then out of the solar system.

1994 — The Hubble Space Telescope finds evidence of surface features beneath the hazy atmosphere of Saturn's largest moon, Titan.

2004 — After a seven-year journey, the Cassini-Huygens spacecraft becomes the first spacecraft to orbit Saturn; 76 orbits of Saturn and 45 Titan flybys are planned for the four-year mission.

2005 — The Huygens probe successfully lands on Titan, returning images of the complex surface.

## ABOUT THE IMAGES



**1** Cassini captured this true-color image of Saturn and its magnificent rings.

**2** A natural-color close-up view of Saturn's rings.

**3** This Cassini image shows a bright storm in a region of high atmospheric activity.

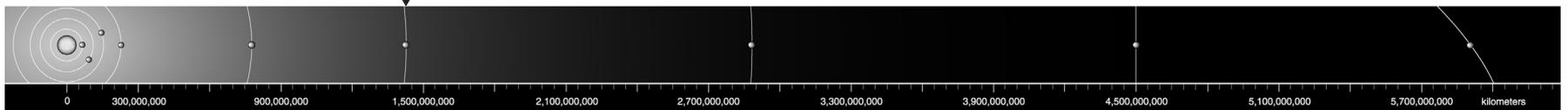
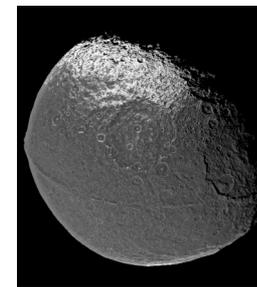
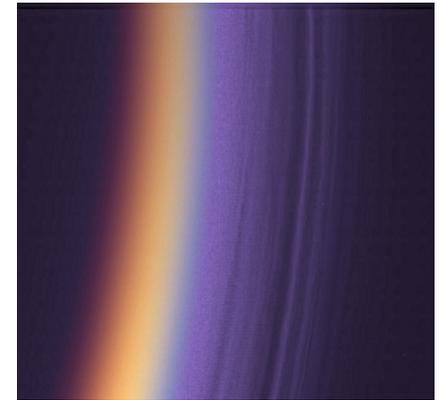
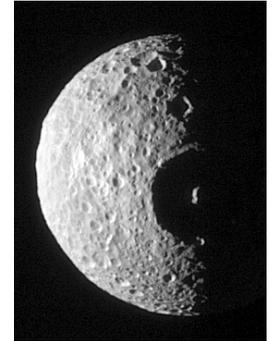
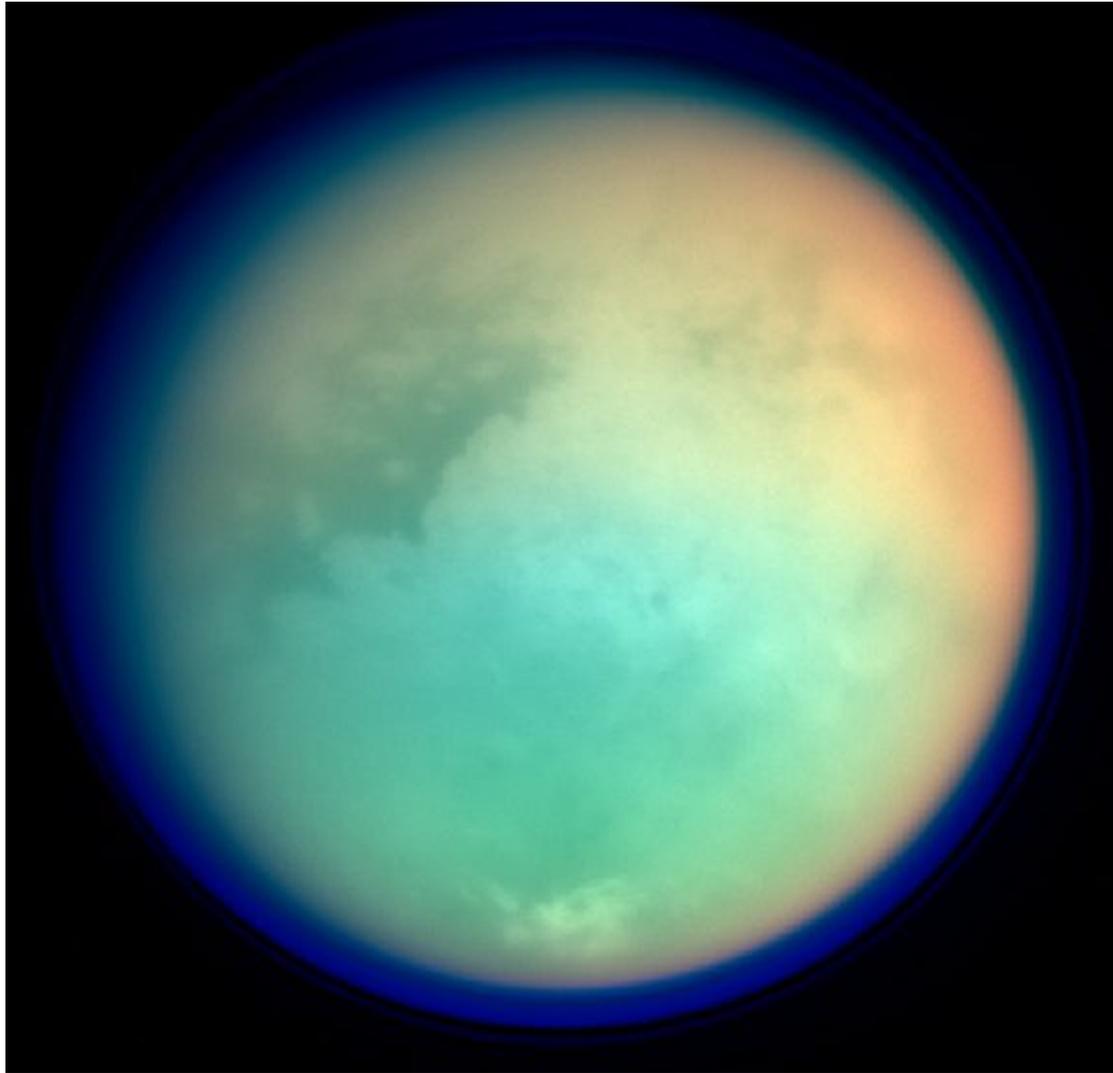
**4** Saturn's bright equatorial region displays swirls and eddies in this Cassini image.

**5** An ultraviolet image of Saturn's rings shows more ice (turquoise colors) near the outer edge of the rings.

## FOR MORE INFORMATION

[solarsystem.nasa.gov/planets/profile.cfm?Object=Saturn](http://solarsystem.nasa.gov/planets/profile.cfm?Object=Saturn)

# Moons of Saturn



# Moons of Saturn



Saturn, the sixth planet from the Sun, is home to a vast array of intriguing and unique worlds. From the cloud-shrouded surface of Titan to crater-riddled Phoebe, each of Saturn's moons tells another piece of the story surrounding the Saturn system.

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 increased through the 19th century, Saturn's family of known moons grew. In 1966 Epimetheus and Janus were discovered. By the time Cassini-Huygens was launched in 1997, Saturn's moon count had reached 18. The number of known moons soon increased with high-resolution imaging techniques used on ground-based telescopes. Cassini discovered four more moons after its arrival at Saturn and may find even more during its mission.

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

- **Titan** — Titan is so large that it affects the orbits of other nearby moons. At 5,150 kilometers (3,200 miles) across, it is the second-largest moon in the solar system. Titan hides its surface with a thick nitrogen-rich atmosphere. Titan's atmosphere is similar to Earth's atmosphere of long ago, before biology took hold on our home planet. Titan's atmosphere is approximately 95% nitrogen with traces of methane. While Earth's atmosphere extends about 60 kilometers (37 miles) into space, Titan's extends nearly 600 kilometers (ten 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.

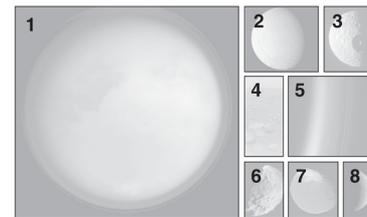
The Cassini spacecraft will fly past Titan 45 times during its four-year primary mission. In addition, Cassini will gather data about many of the other satellites in an effort to fully understand the nature, formation, and dynamics of Saturn's moons.

## FAST FACTS

- Largest Moon of Saturn Titan  
Titan's Diameter 5,150 km (3,200 mi)
- Farthest Moon from Saturn Ymir  
Ymir's Distance from Saturn 23,096,000 km (14,354,164 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 3  
(Atlas, Prometheus, and Pandora)
- Number of Moons Discovered by Cassini (So Far) 4  
(Methone, Pallene, Polydeuces, and the moonlet 2005S1)

## ABOUT THE IMAGES

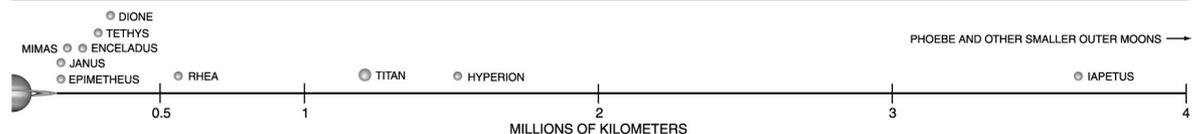


- 1** An ultraviolet (blue) and infrared (red and green) image of Titan.
- 2** False color (blue) emphasizes icy walls of fractures on Enceladus.

- 3** The Herschel crater on Mimas is a relic of a large impact that nearly destroyed this moon.
- 4** One of the first images from the surface of Titan taken by the Huygens probe.
- 5** Titan's layers of haze are revealed in this ultraviolet image.
- 6** A mosaic of high-resolution 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 equatorial ridge as well as the icy-bright and dark regions.
- 8** Cassini's false-color image of Rhea enhances the slight differences in natural color across the moon's face.

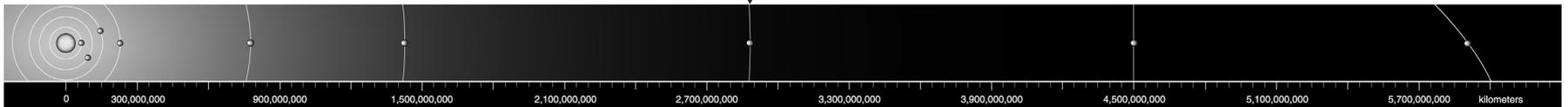
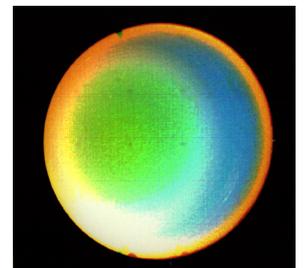
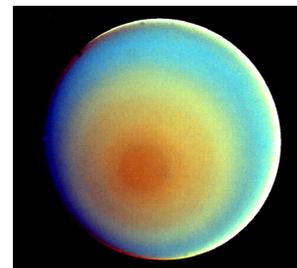
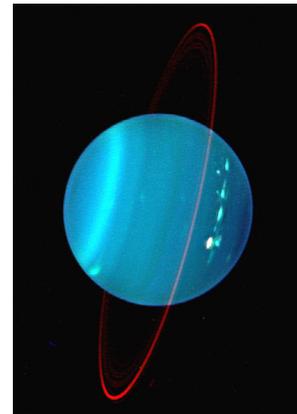
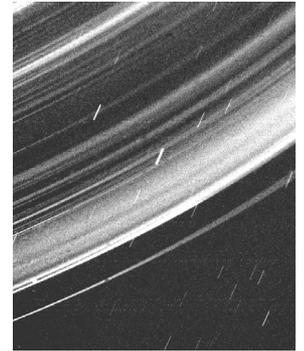
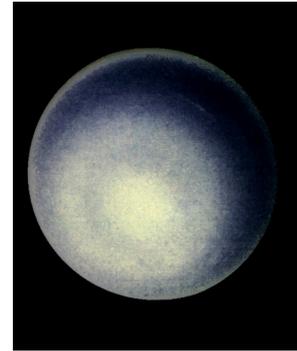
## FOR MORE INFORMATION

[solarsystem.nasa.gov/planets/profile.cfm?Object=Saturn](http://solarsystem.nasa.gov/planets/profile.cfm?Object=Saturn)



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

# Uranus





Once considered one of the blander-looking planets, Uranus (pronounced YOOR un nus) has been revealed as a dynamic world with some of the brightest clouds in the outer solar system and 11 rings. The first planet found with the aid of a telescope, Uranus was discovered in 1781 by astronomer William Herschel. The seventh planet from the Sun is so distant that it takes 84 years to complete one orbit. Uranus, with no solid surface, is one of the gas giant planets (the others are Jupiter, Saturn, and Neptune).

The atmosphere of Uranus is composed primarily of hydrogen and helium, with a small amount of methane and traces of water and ammonia. Uranus gets its blue-green color from methane gas. Sunlight is reflected from Uranus' cloud tops, which lie beneath a layer of methane gas. As the reflected sunlight passes back through this layer, the methane gas absorbs the red portion of the light, allowing the blue portion to pass through — resulting in the blue-green color that we see. The planet's atmospheric details are very difficult to see in visible light. The bulk (80 percent or more) of the mass of Uranus is contained in an extended liquid core consisting primarily of “icy” materials (water, methane, and ammonia), with higher-density material at depth.

In 1986, Voyager 2 observed faint cloud markings in the southern latitudes blowing westward between 100 and 600 kilometers (60 and 400 miles) per hour. In 2004, the Keck Observatory in Hawaii used advanced optics to capture highly detailed images of Uranus as the planet approached its southern autumnal equinox, when the equator will be vertically illuminated by the Sun.

Uranus' rotation axis is nearly horizontal with respect to the ecliptic plane — the imaginary plane containing Earth's orbit, as well as the orbits of most of the planets — as though Uranus had been knocked on its side. This unusual orientation may be the result of a collision with a planet-sized body early in the planet's history, which apparently radically changed Uranus' rotation. Additionally, while magnetic fields are typically in alignment with a planet's rotation, Uranus' magnetic field is tipped over: instead of aligning along the rotational axis, 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. Unlike the magnetic fields of Earth, Jupiter, and Saturn, which

can be thought of as acting like dipole bar magnets, the fields of Uranus (and Neptune also) are very irregular. Uranus' magnetic field is about 48 times more powerful than Earth's.

Even though Uranus is tipped on its side and experiences seasons that last over 20 years, the temperature differences on the summer and winter sides do not differ greatly because the planet is so far from the Sun. Near the cloud tops, the temperature of Uranus is  $-216$  degrees Celsius ( $-357$  degrees Fahrenheit).

Because of the planet's unusual orientation, Uranus' rings are perpendicular to its orbital path about the Sun. The 10 outer rings are dark, thin, and narrow, while the 11th ring is inside the others and is broad and diffuse.

Uranus has 27 known moons, named mostly for characters from the works of William Shakespeare and Alexander Pope. Miranda is the strangest-looking Uranian moon, appearing as though it were made of spare parts. The high cliffs and winding valleys of the moon may indicate partial melting of the interior, with icy material occasionally drifting to the surface.

## FAST FACTS

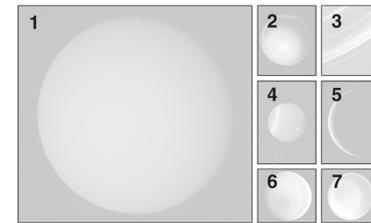
Namesake	Greek supreme sky god
Mean Distance from the Sun	2,870.97 million km (1,783.94 million mi)
Orbit Period	84.02 Earth years (30,687.2 Earth days)
Orbit Eccentricity (Circular Orbit = 0)	0.047168
Orbit Inclination to Ecliptic	0.770 deg
Inclination of Equator to Orbit	97.86 deg
Rotation Period	17.24 hours (retrograde)
Equatorial Radius	25,559 km (15,882 mi)
Mass	14.371 of Earth's
Density	1.32 g/cm <sup>3</sup>
Gravity	8.43 m/sec <sup>2</sup> (27.7 ft/sec <sup>2</sup> )
Atmosphere Primary Components	hydrogen, helium, methane
Effective Temperature	$-216$ deg C ( $-357$ deg F)
Known Moons*	27
Rings	11 (1986U2R, 6, 5, 4, Alpha, Beta, Eta, Gamma, Delta, Lambda, Epsilon)

\*As of November 2005.

## SIGNIFICANT DATES

- 1781 — Astronomer William Herschel discovers Uranus, increasing the number of known planets to seven.
- 1787–1851 — Four Uranian moons are discovered and named Titania, Oberon, Ariel, and Umbriel.
- 1948 — A new moon, Miranda, is discovered.
- 1977 — Scientists discover Uranus' faint ring system while watching a distant star pass behind the planet.
- 1986 — Voyager 2 becomes the first, and still the only, spacecraft to visit Uranus, discovering 10 moons and several additional rings during its flyby.
- 1997–1999 — Astronomers discover more tiny moons orbiting Uranus.

## ABOUT THE IMAGES



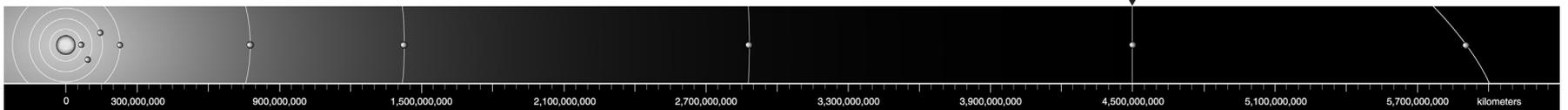
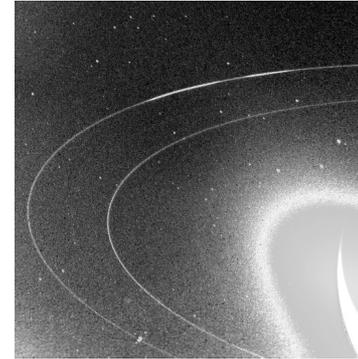
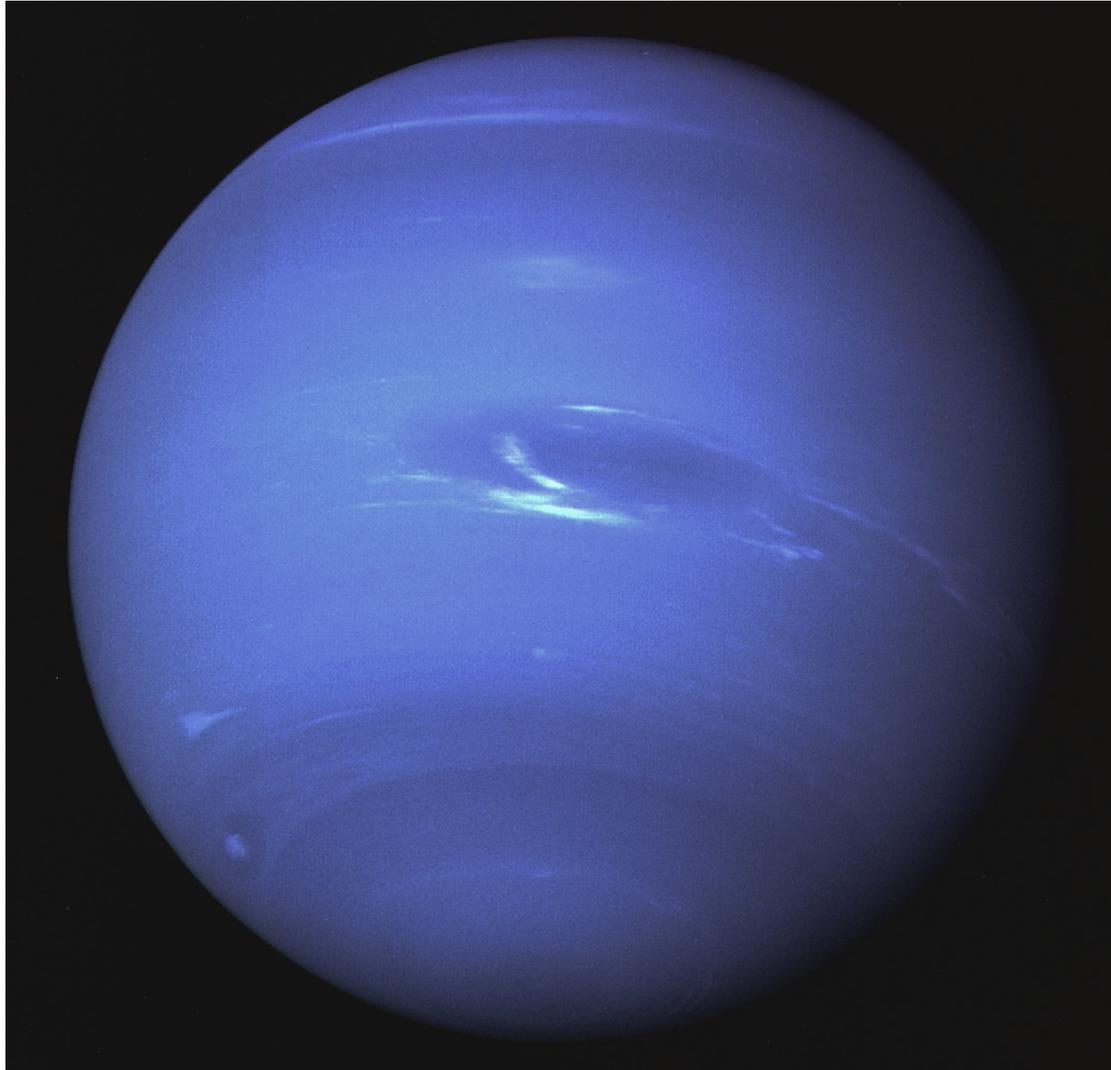
- 1** A true-color composite image by Voyager 2.
- 2** A Voyager 2 computer-enhanced image emphasizing high-level haze in the atmosphere.

- 3** Voyager 2 imaged “lanes” of fine dust particles in the rings.
- 4** An infrared composite image taken by the Keck Observatory in November 2004 shows atmospheric details and turns the rings a reddish color.
- 5** As it departed Uranus for Neptune, Voyager 2 looked back and captured this crescent view of the planet.
- 6** Slight contrasts are exaggerated in this false-color image, showing Uranus' dark “polar hood” — a veil of ice and dust.
- 7** Exaggerated contrast and false color reveal some details of Uranus' clouds.

## FOR MORE INFORMATION

[solarsystem.nasa.gov/planets/profile.cfm?Object=Uranus](http://solarsystem.nasa.gov/planets/profile.cfm?Object=Uranus)

# Neptune



# Neptune



The eighth planet from the Sun, 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, due to Pluto's unusual elliptical orbit, Neptune is actually the farthest planet from the Sun for a 20-year period out of every 248 Earth years.

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-sized 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 that we see. The cause of Neptune's bluish tinge remains a mystery.

Despite its great distance from the Sun and lower energy input, Neptune's winds are three times stronger than Jupiter's and nine times stronger than Earth's. In 1989, Voyager 2 tracked a large oval dark storm in Neptune's southern hemisphere. This hurricane-like "Great Dark Spot" was observed to be large enough

to contain the entire Earth, spun counterclockwise, and moved westward at almost 1,200 kilometers (750 miles) per hour. (Subsequent images from the Hubble Space Telescope showed no sign of the Great Dark Spot photographed by Voyager. A comparable spot appeared in 1994 in Neptune's northern hemisphere but had disappeared by 1997.) Voyager 2 also photographed clouds casting shadows on a lower cloud deck, enabling scientists to visually measure the altitude differences between the upper and lower cloud decks.

The planet has six rings of varying thicknesses, confirmed by Voyager 2's observations in 1989. Neptune's rings are believed to be relatively young and relatively short-lived.

Neptune has 13 known moons, six of which were discovered by Voyager 2. The largest, Triton, orbits Neptune in a direction opposite to the direction of the planet's rotation. Triton is the coldest body yet visited in our solar system — 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 seen 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 <sup>3</sup>
Gravity	10.71 m/sec <sup>2</sup> (35.14 ft/sec <sup>2</sup> )
Atmosphere Primary Components	hydrogen, helium, methane
Effective Temperature	-214 deg C (-353 deg F)

Known Moons\*

Rings

13  
6 (Galle, Arago, Lassell, Le Verrier,  
the ring coorbital with the moon Galatea, Adams)

\*As of November 2005.

## 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.

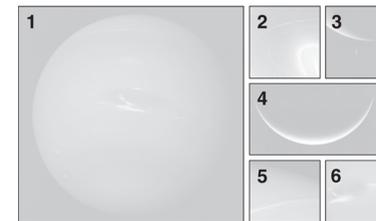
1984 — Astronomers find evidence for the existence of a ring system, but the rings are clearly not uniform in density.

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.

2003 — Using improved observing techniques, astronomers discover five new moons orbiting Neptune.

2001 — Neptune completes its first 165-year orbit of the Sun since its discovery in 1846.

## ABOUT THE IMAGES



**1** Voyager 2 captured this image of Neptune in 1980.

**2** A detailed look at Neptune's thin rings.

**3** The crescents of Neptune and Triton

were imaged by Voyager 2 shortly after the spacecraft's closest approach to the planet.

**4** Voyager 2's view of Neptune's south pole as the spacecraft sped away from its encounter.

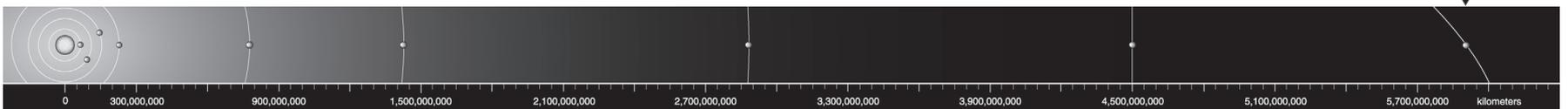
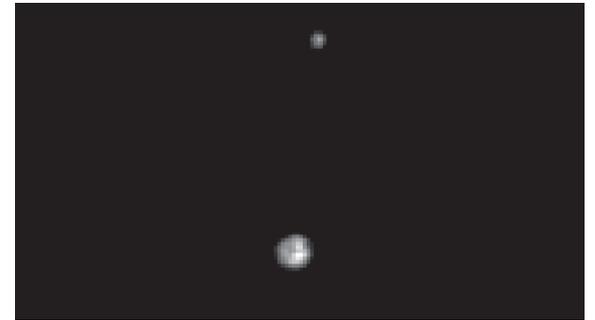
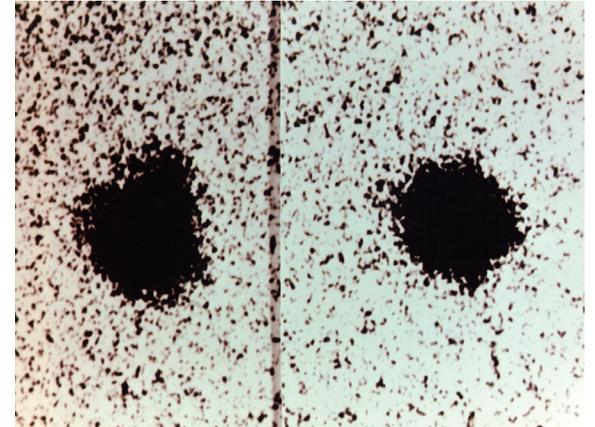
**5** The clouds in this image are estimated to be about 50 kilometers (31 miles) tall.

**6** Voyager 2's closest image of Neptune's mysterious Great Dark Spot.

## FOR MORE INFORMATION

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

# Pluto and Charon



# Pluto and Charon



The smallest, coldest, and most distant planet from the Sun, Pluto has a dual identity — it 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. Pluto and its companion moon, Charon, orbit the Sun in this region. This distant realm is populated with thousands of miniature icy worlds, which formed early in the history of the solar system. While Pluto retains its position as the only recognized planet beyond Neptune, recent discoveries of a number of icy objects orbiting the Sun in Pluto's realm — at least one of which may be as large or larger than Pluto — have prompted a re-examination of how a planet should be defined.

Discovered by American astronomer Clyde Tombaugh in 1930, Pluto takes 248 years to orbit the Sun in a highly elliptical orbit. Pluto's closest approach to the Sun was in 1989, when its path carried it inward from its usual distance of about 39 astronomical units (AU) to within 29.7 AU of the Sun. (One AU is the mean distance between Earth and the Sun: about 150 million kilometers or 93 million miles.) Between 1979 and 1999, Pluto's orbit brought it closer to the Sun than Neptune (Neptune's mean distance is about 30 AU), providing rare opportunities to study this small, cold, distant world and its moon.

Pluto is about two-thirds the diameter of Earth's Moon and probably has a rocky core surrounded by a mantle of water ice. More exotic ices like methane and nitrogen frost coat its surface. Owing to its lower density, Pluto's mass is about one-sixth that of the Moon. While it is close to the Sun, these 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. Because Pluto's orbit is so elliptical, Pluto becomes much colder during the part of each orbit when it is traveling away from the Sun. During this time, the bulk of the planet's atmosphere may freeze.

In 1978, astronomers discovered that Pluto has a large moon, which was named Charon. Charon is almost half the size of Pluto and shares the same orbit; thus, Pluto and Charon are essentially a double planet system. The distance between the two 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 bluer than Pluto, indicating that they have different surface compositions and structure. Charon is known to have water ice on its surface.

Charon's orbit around Pluto takes about 6-1/2 Earth days. One Pluto rotation (a Pluto day) takes 6-1/2 Earth days, so 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. Pluto's axis of rotation is highly tilted the planet's rotation is retrograde (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 Charon are so small and far away, they are extremely difficult to observe from Earth. In the late 1980s, Pluto and Charon passed in front of each other repeatedly for several years. Observations of these rare events allowed astronomers to make rudimentary maps of each body showing areas of relative brightness and darkness.

No spacecraft has ever visited Pluto, but NASA is preparing a mission called New Horizons that would explore both Pluto and the Kuiper Belt region. Expected to launch in 2006, the spacecraft would reach Pluto about 2015.

## 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
Equatorial Radius (Pluto)	1,180 km (733 mi)
Equatorial Radius (Charon)	600 km (373 mi)
Mass	0.0022 of Earth's
Density	2.03 g/cm <sup>3</sup>
Gravity	0.65 m/sec <sup>2</sup> (2.1 ft/sec <sup>2</sup> )

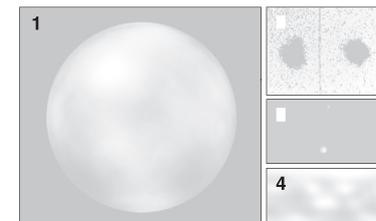
Atmosphere Primary Components	nitrogen, carbon monoxide, methane
Surface Temperature	–233 to –223 deg C (–387 to –369 deg F)
Known Moons*	1
Rings	None known

\*As of November 2005. In late October 2005, NASA announced that scientists using the Hubble Space Telescope had discovered that Pluto may have two additional moons. If the finding is confirmed, Pluto will be the only object beyond Neptune known to have more than one moon.

## 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 again gets another 20-year stint as the eighth planet.
- 1978 — American astronomers James Christy and Robert Harrington discover Pluto's only moon, Charon.
- 1988 — Astronomers discover that Pluto has an atmosphere.
- 2010–2025 — Pluto's atmosphere may freeze and collapse as the planet moves farther from the Sun.

## ABOUT THE IMAGES



- 1 Pluto is mostly brown and is probably covered with methane frost.
- 2 Astronomers investigating the sometimes-elongated shape of Pluto in

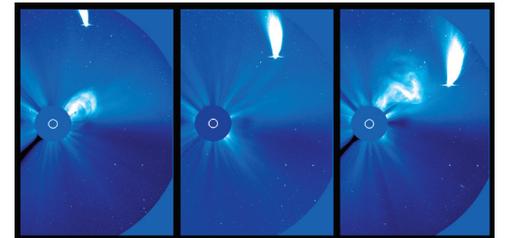
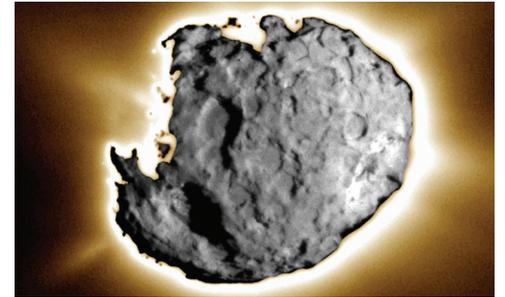
some images eventually determined that Pluto had a companion — a large moon nearly half Pluto's size.

- 3 The Hubble Space Telescope resolved Pluto and Charon as separate disks, enabling better measurements of both bodies.
- 4 A surface map of Pluto created from four Hubble Space Telescope images, showing distinct areas of brightness.

## FOR MORE INFORMATION

[solarsystem.nasa.gov/planets/profile.cfm?Object=Pluto](http://solarsystem.nasa.gov/planets/profile.cfm?Object=Pluto)

# Comets





Throughout history, people have been both awed and alarmed by comets, perceiving them as “long-haired” stars that appeared in the sky unannounced and unpredictably. To many ancient observers, an elongated comet looked like a fiery sword or some other symbol of death and destruction blazing across the night sky. Chinese astronomers kept extensive records for centuries, including illustrations of characteristic types of tails. As well as noting associated disasters, they recorded the times of cometary appearances and disappearances in addition to celestial positions. These comet annals have proven to be a valuable resource for later astronomers.

We now know that comets are “dirty-ice” leftovers from the dawn of the solar system around 4.6 billion years ago. They are among the least-changed objects and, as such, 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 just beyond Neptune, where a population of dark comets orbits the Sun in the realm of Pluto. These icy objects occasionally fall towards the Sun and become the so-called short-period comets. Short-period comets take less than 200 years to orbit the Sun, and 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 only a tiny solid part, called a nucleus, often no bigger than a few kilometers across. The nucleus contains icy chunks and frozen gases with bits of embedded rock and dust. At its center, the nucleus may have a small rocky core.

Traveling in a highly elliptical orbit, a comet warms up as it nears the Sun and develops an atmosphere, or coma. The Sun’s heat causes ices on the comet’s surface to change to gases so that its

coma gets larger. This coma may be hundreds of thousands of kilometers in diameter. The pressure of sunlight and high-speed solar particles blow the coma materials away from the Sun, forming the comet’s long, and sometimes bright, tails. These tails point away from the Sun’s direction.

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 sun-grazers, 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. Another NASA mission, called Stardust, was designed to approach a comet, photograph the nucleus, then capture dust samples from the coma and return them to Earth for analysis. Stardust successfully flew within 236 kilometers (147 miles) of the nucleus of Comet Wild 2 (pronounced “Vilt 2”) in January 2004, collecting cometary particles as well as interstellar dust particles for a later sample return to Earth.

Another NASA mission, called Deep Impact, consisted of a flyby spacecraft and a small “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. A camera on the impactor and two cameras and a spectrometer on the flyby spacecraft showed dramatic brightening that revealed the interior composition and structure of the nucleus.

## SIGNIFICANT DATES

1070–1080 — The comet later designated Halley’s Comet is pictured in the Bayeux Tapestry, which chronicles 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 determines that the comets of 1531, 1607, and 1682 are the same comet 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 snaps photos and collects dust samples from comet Wild 2 during the closest-ever flyby of a comet nucleus. The photographs show jets of dust and a rugged, textured surface.

2005 — The Deep Impact impactor collides with comet Tempel 1 to reveal the interior of the nucleus.

## ABOUT THE IMAGES



**1** The hyperspeed collision of the Deep Impact impactor with comet Tempel 1 generated a huge cloud of dust that reflected sunlight.

**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 for analysis.

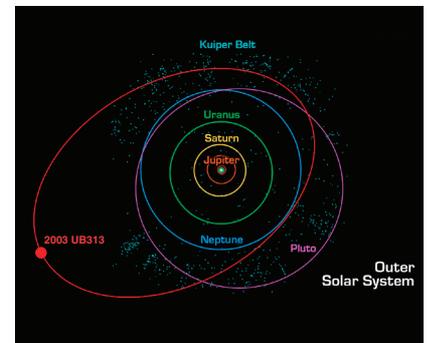
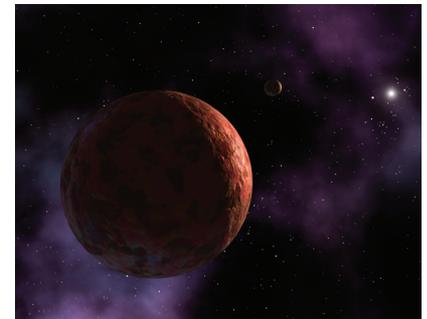
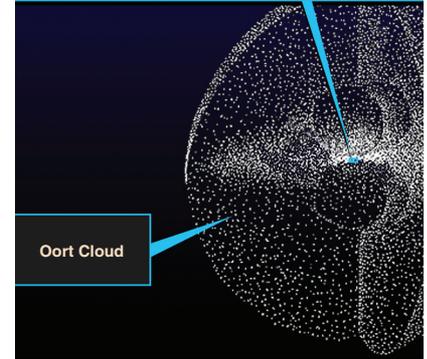
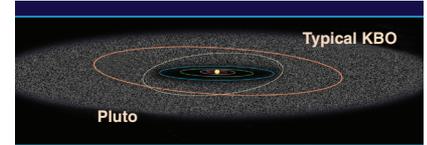
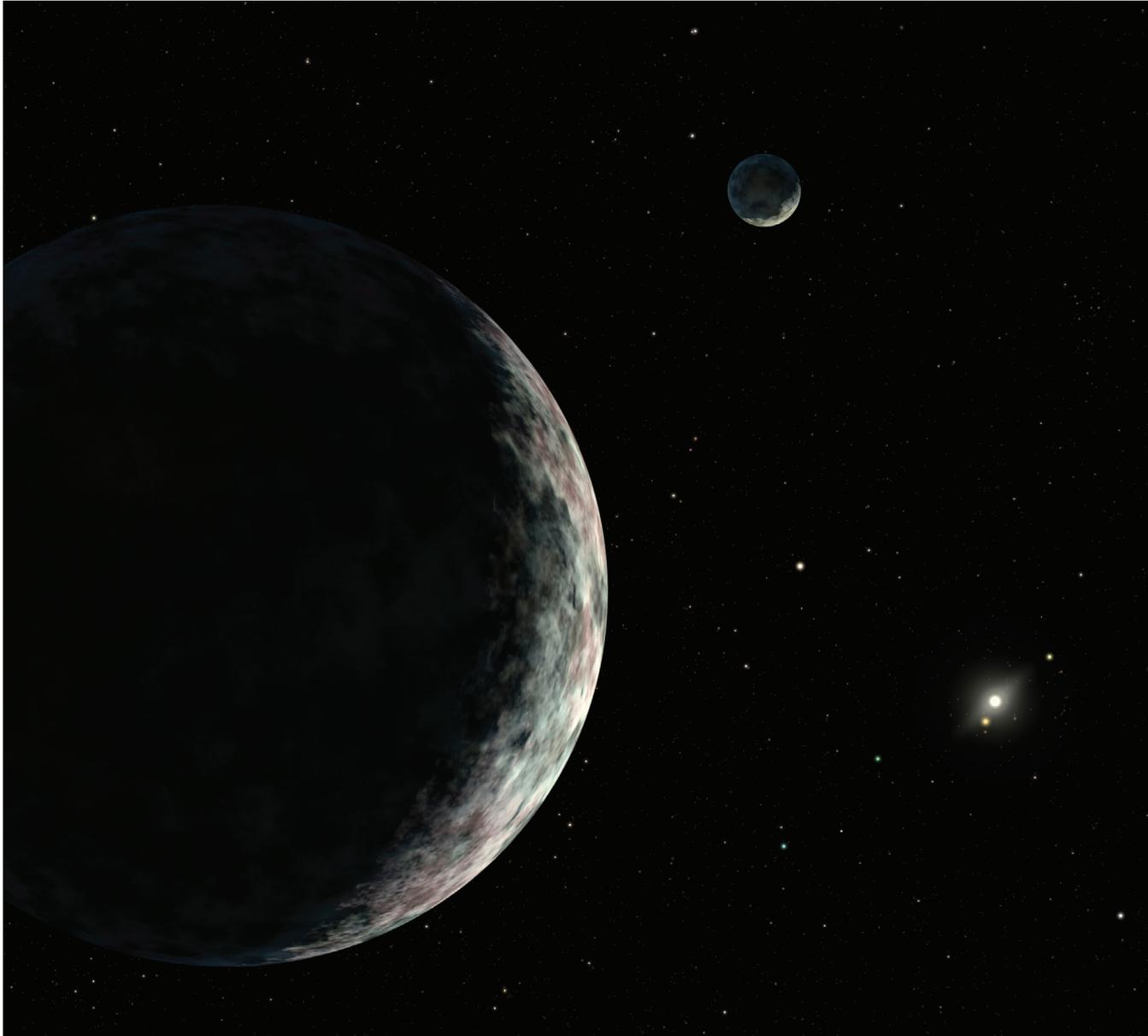
**3** The tail of comet C/2001 Q4 (NEAT) expands as it brushes close to a coronal mass ejection from the Sun in 2003.

**4** A beautiful cloud of dust and gas surround comet NEAT as it passes through the inner solar system in 2004.

## FOR MORE INFORMATION

[solarsystem.nasa.gov/planets/profile.cfm?Object=Comets](http://solarsystem.nasa.gov/planets/profile.cfm?Object=Comets)

# Kuiper Belt and Oort Cloud



## Kuiper Belt and Oort Cloud



In 1950, Dutch astronomer Jan Oort proposed that certain comets came from a vast spherical shell of icy bodies near the edge of the solar system. This giant swarm of objects is now named the Oort Cloud, occupying space at a distance between 5,000 and 100,000 astronomical units. (One astronomical unit, or AU, is the mean distance of Earth from the Sun: about 150 million kilometers or 93 million miles.)

The Oort Cloud contains billions of icy bodies in solar orbit. Occasionally, passing stars disturb the orbit of one of these bodies, causing it to come streaking into the inner solar system as a long-period comet. These comets have very large 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 come from a region beyond Neptune called the Kuiper Belt, named for astronomer Gerard Kuiper, who proposed its existence in 1951. The Kuiper Belt, extending out to about 50 AU around the Sun, is populated with thousands of small icy bodies.

In 1992, astronomers detected a reddish speck about 42 AU from the Sun — the first time a Kuiper Belt object (or KBO for short) had been sighted. More than 1,000 KBOs have been identified since 1992. (They are sometimes called Edgeworth–Kuiper Belt objects, acknowledging another astronomer who also is credited with the idea, or they are simply called transneptunian objects — TNOs.)

One of the largest KBOs is Quaoar (2002 LM60), named by its discoverers after the mythical creation-force figure of the Tongva tribe of the Los Angeles basin. Quaoar orbits the Sun every 288 years about a billion miles beyond the orbit of Pluto (somewhere around 42 AU). Quaoar was photographed in 1980, but was not recognized as a KBO until 2002. An even larger KBO (2004 DW, now officially named Orcus) was found at a distance of about 45 AU from the Sun. It is considered a “plutino” or “little Pluto” because of its similar orbit with the planet.

In March 2004, a team of astronomers announced the discovery of a planet-like object, or planetoid, orbiting the Sun at an extreme distance, in the coldest known region of our solar system. The planetoid (2003 VB12), 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. Sedna is about one-quarter to three-eighths the size of the planet Pluto. At the farthest point in its long, elliptical orbit, Sedna is 130 billion kilometers (84 billion miles) from the Sun — that’s about 86 AU, compared with the mean distances of Neptune (about 30 AU) and Pluto (about 39 AU).

The discoverers of Sedna describe it as an inner Oort Cloud object, because it never enters the Kuiper Belt — Sedna never comes closer to the Sun than 76 AU. Sedna is quite an oddity: nobody expected to find an object like it in the largely empty space between the Kuiper Belt and the Oort Cloud. Possibly the Oort Cloud extends much farther in towards the Sun than previously thought, or perhaps Sedna is yet another type of object from the very early solar system, trapped between the Kuiper Belt and the Oort Cloud.

Because KBOs are so distant, their sizes are difficult to measure. The given diameter of a KBO depends on assumptions about how its brightness relates to its size. To estimate size based on brightness, one assumes what percentage of sunlight the object’s surface reflects; this percentage is known as the albedo. Thinking that the albedo of an average KBO is similar to that of comets, astronomers calculated the sizes of KBOs based on the reflectivity of comets, which is about 4 percent. An efficient way to calculate an object’s albedo is to measure the heat it radiates in the infrared. In 2004, astronomers using the Spitzer Space Telescope did a survey of KBOs at infrared wavelengths and found that they averaged about 12 percent; thus, KBOs might be smaller objects than astronomers originally thought. However, new discoveries may alter this perception.

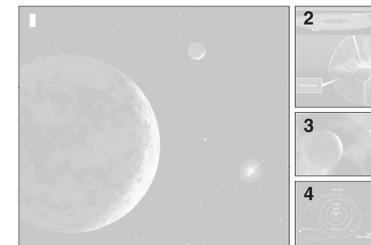
Until recently, all the KBOs found were judged to be significantly smaller than Pluto. In July 2005, a team of scientists announced the discovery of a body that appears to be as large as, or possibly even larger, than Pluto. The object, provisionally designated 2003 UB313, orbits the Sun about every 560 years, its distance varying from about 38 to 98 AU. Initial analysis indicates that the surface is covered with methane ice, similar to Pluto. In September 2005, the team found that 2003 UB313 even has a small moon, thought to be made of water ice.

The discovery of large objects in this frozen outer realm may eventually affect the planetary status of Pluto. This is the nature of planetary astronomy, to reconsider past conclusions in the light of new discoveries and change our theories or definitions to respond to those discoveries. No spacecraft has ever traveled to the Kuiper Belt, but NASA’s New Horizons mission, planned to arrive at Pluto in 2015, might be able to penetrate farther into the Kuiper Belt to study one of these mysterious objects.

### SIGNIFICANT DATES

- 1943 — Astronomer Kenneth Edgeworth suggests that a reservoir of comets exists beyond the planets.
- 1950 — Astronomer Jan Oort theorizes that a vast population of comets may exist on the distant edges of our solar system.
- 1951 — Astronomer Gerald 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 Kuiper Belt object, 1992 QB1.
- 2002 — Scientists using the 48-inch Oschin telescope at Palomar Observatory find Quaoar.
- 2004 — Astronomers using the Palomar 48-inch Oschin telescope announce the discovery of Sedna (2003 VB12).
- 2005 — Astronomers announce the discovery of 2003 UB313, a distant icy solar system body that has a small moon.

### ABOUT THE IMAGES



- 1 Artist’s concept of 2003 UB313 and its moon. The Sun appears in the distance at right.
- 2 An illustration of the Kuiper Belt and the Oort Cloud.

- 3 Artist’s concept of Sedna and a hypothetical moon.
- 4 A diagram showing the highly tilted orbit of 2003 UB313.

### FOR MORE INFORMATION

[solarsystem.nasa.gov/planets/profile.cfm?Object=KBOs](http://solarsystem.nasa.gov/planets/profile.cfm?Object=KBOs)