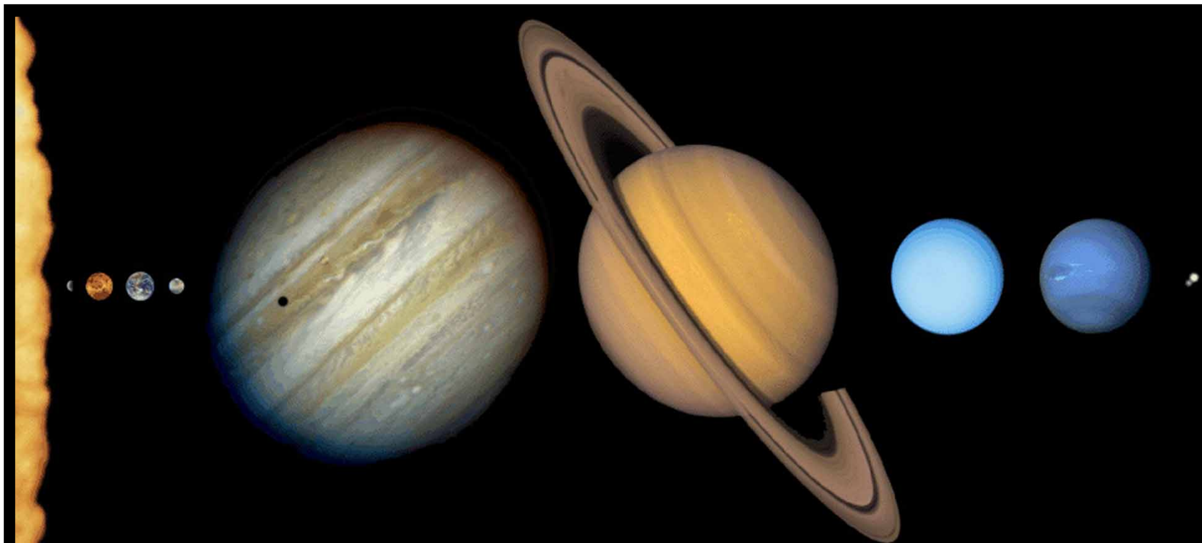
National Aeronautics and
Space Administration

Educational Product	
Teachers	Grades K–12

Solar System Lithograph Set
for Space Science



This set contains the following lithographs:

- Our Solar System
- Our Star— The Sun
- Mercury
- Venus
- Earth
- Moon
- Mars
- Asteroids: Mathilde, Gaspra, Ida
- Jupiter
- Moons of Jupiter
- Saturn
- Uranus
- Neptune
- Pluto and Charon
- Comets
- NASA Resources for Educators

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National Aeronautics and
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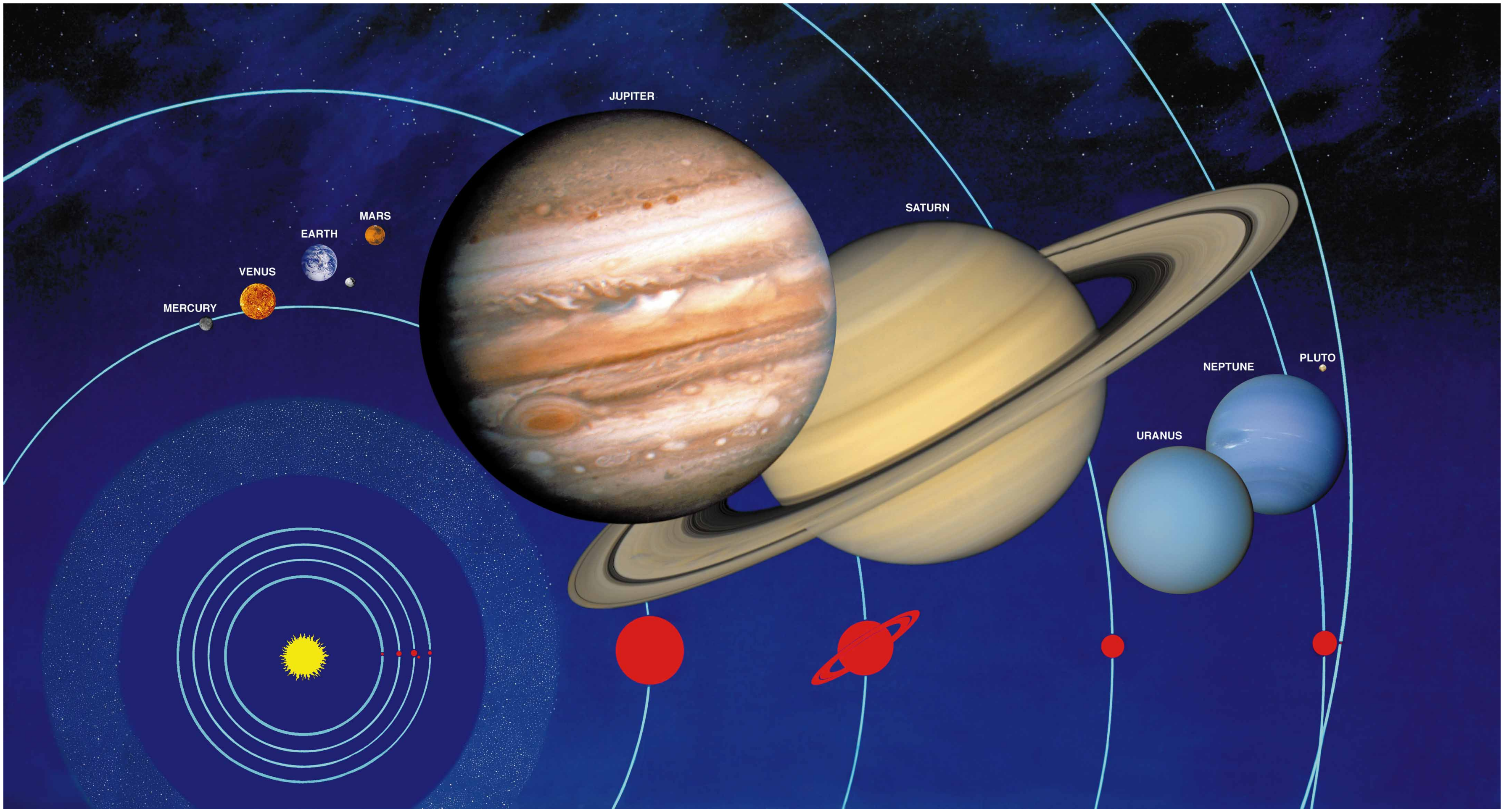
Our Solar System



Our Solar System

From our small world we have gazed upon the cosmic ocean for thousands of years. Ancient astronomers observed points of light that appeared to move among the stars. They called these objects planets, meaning wanderers, and named them after Roman deities — Jupiter, king of the gods; Mars, the god of war; Mercury, messenger of the gods; Venus, the god of love and beauty, and Saturn, father of Jupiter and god of agriculture. The stargazers also observed comets with sparkling tails, and meteors or shooting stars apparently falling from the sky.

Since the invention of the telescope, three more planets have been discovered in our solar system: Uranus (1781), Neptune (1846), and Pluto (1930). In addition, there are thousands of small bodies such as asteroids and comets. Most of the asteroids orbit in a region between the orbits of Earth and Mars, while the home of comets lies far beyond the orbit of Pluto, in the Oort Cloud.

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 large planets beyond the orbit of Mars—Jupiter, Saturn, Uranus, and Neptune—are called *gas giants*. Tiny, distant, Pluto has a solid but icier surface than the terrestrial planets.

Nearly every planet—and some of the moons—has an atmosphere. Earth's atmosphere is primarily nitrogen and oxygen. Venus has a thick atmosphere of carbon dioxide, with traces of poisonous gases such as sulfur dioxide. Mars' carbon dioxide atmosphere is extremely thin. Jupiter, Saturn, Uranus, and Neptune are primarily hydrogen and helium. When Pluto is near the Sun, it has a thin atmosphere, but when Pluto travels to the outer regions of its orbit, the atmosphere freezes and "collapses" to the planet's surface. In this regard, Pluto acts like a comet.

There are 61 natural satellites (also called moons) around the various planets in our solar system, ranging from bodies larger than our own Moon to small pieces of debris. Many of these were discovered by planetary spacecraft. Some of these have atmospheres (Saturn's Titan); some even have magnetic fields (Jupiter's Ganymede). Jupiter's moon Io is the most volcanically active body in the solar system. An ocean may lie beneath the frozen crust of Jupiter's moon Europa, while images of Jupiter's moon Ganymede show historical motion of icy crustal plates. Some planetary moons, such as Phoebe at Saturn may be asteroids that were captured by planet's gravity.

From 1610 to 1977, Saturn was thought to be the only planet with rings. We now know that Jupiter, Uranus, and Neptune also have ring systems, although Saturn's is by far the largest. Particles in these ring systems range in size from dust to boulders to house sized, and may be rocky and/or icy.

Most of the planets also have magnetic fields which extend into space and form a "magnetosphere" around each planet. These magnetospheres rotate with the planet, sweeping charged particles with them. The Sun has a magnetic field, the heliosphere, which envelops our entire solar system.

Ancient astronomers believed that the Earth was the center of the Universe, and that the Sun and all the other stars revolved around the Earth. Copernicus proved that Earth and the other planets in our solar system orbit our Sun. Little by little, we are charting the Universe, and an obvious question arises: are there other planets around other stars? Are there other planets where life might exist? Only recently have astronomers had the tools to indirectly detect large planets around other stars in nearby galaxies. Direct detection and characterization of such planets awaits development of yet more powerful observing tools and techniques.

Activities

How big is our solar system? To give you a rough idea, consider that it took the *Voyager 2* spacecraft, traveling in a sweeping arc at an average 65,000 kilometers (40,000 miles) per hour, 12 years to reach Neptune! How fast is that in meters per second? In feet per second? If you could travel that fast, how long would it take you to reach the next town? To get to the Moon?

Can you build a scale model of the solar system? If you use Earth's diameter as a unit of measure (Earth diameter = 1), figure out how big the other planets are compared to Earth. Hint: divide each planet's diameter by Earth's diameter. What objects might you use to depict the sizes of the Sun and planets? How far away would the planets be from each other? Map out a scale model of the solar system in your town.

	Actual Diameter (km)	Mean Distance from Sun (km)	No. of Moons
Sun	1,391,900	0	-
Mercury	4,878	57,910,000	0
Venus	12,104	108,200,000	0
Earth	12,756	149,600,000	1
Moon	3,476		-
Mars	6,794	227,940,000	2
Jupiter	142,984	778,330,000	16
Saturn	120,536	1,429,400,000	18
Uranus	51,118	2,870,990,000	15
Neptune	49,528	4,504,300,000	8
Pluto	2,300	5,913,520,000	1

References
1) Views of the Solar System—Solar System http://bang.lanl.gov/solarsys/
2) Planetary Photo Journal: http://photojournal.jpl.nasa.gov/
3) Stardate, The University of Texas of Austin, McDonald Observatory, 2609 University Ave., #3.118, Austin, TX 78712

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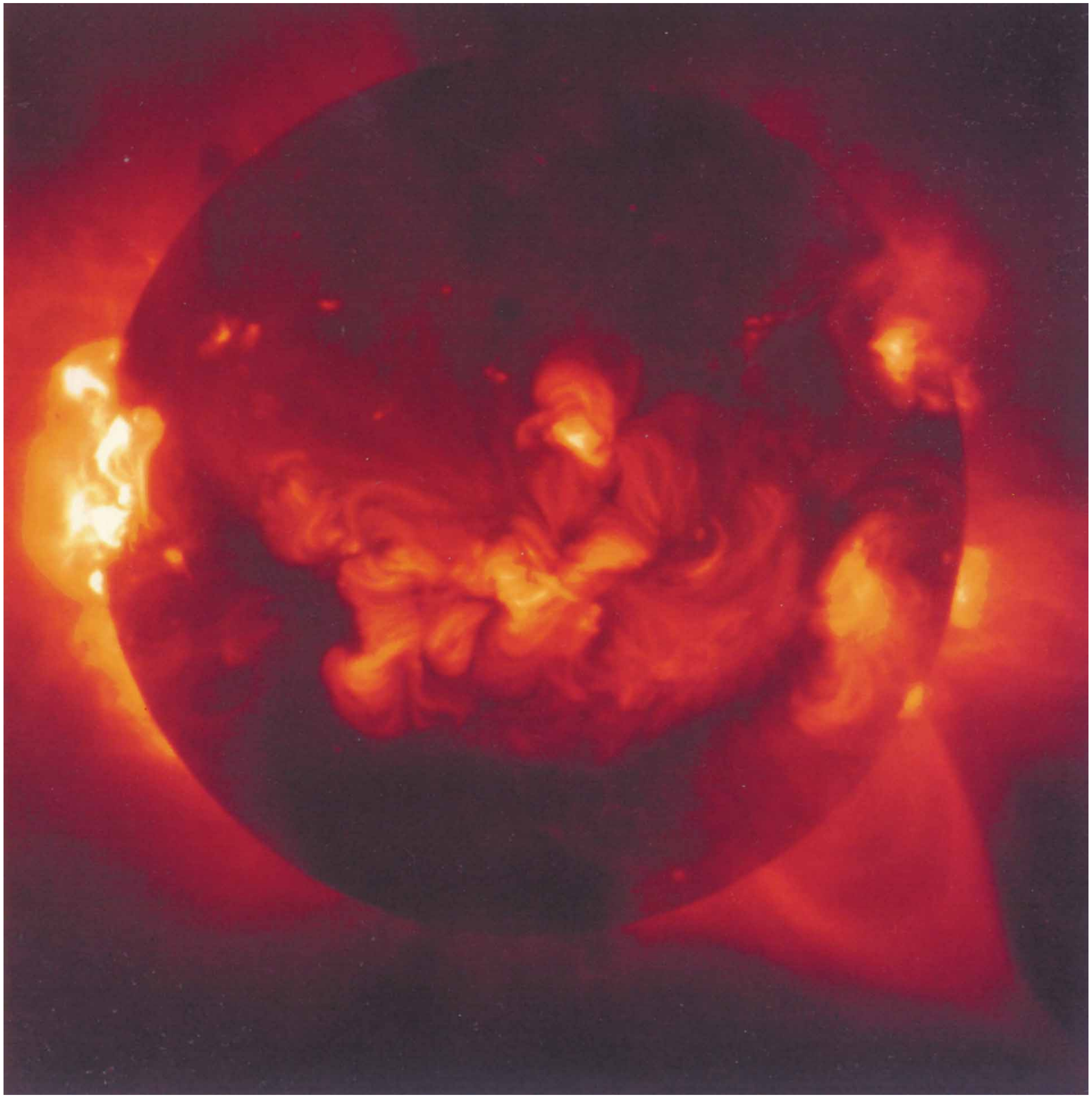

Our Star—The Sun ⊙

The **SUN** has inspired mythology in many cultures including the Ancient Egyptians, the Aztecs, the Native Americans, and the Chinese. In these and other cultures, the Sun was seen as everything from a war god to a hummingbird. The Ancient Chinese believed there were actually ten suns. We now know that the Sun is a huge, bright sphere of mostly ionized gas about 5 billion years old and is the closest star to Earth at a distance of 145 million km (one Astronomical Unit). The next closest star is 300,000 times further away. There are probably millions of similar stars in the Milky Way galaxy (and even more galaxies in the Universe), but the Sun is the most important to us because it supports life on Earth. It powers photosynthesis in green plants and is ultimately the source of all food and fossil fuel. The Sun's power causes the seasons, the climate, the currents in the ocean, the circulation of the air, and the weather in the atmosphere.

The Sun is some 333,400 times more massive than Earth (mass=1.99 x 10^{30}kg), and contains 99.86% of the mass of the entire solar system. It is held together by gravitational attraction, producing immense pressure and temperature at its core (more than a billion times that of the atmosphere on Earth, and a density about 160 times that of water).

At the core the temperature is 16 million degrees Kelvin (K) which is sufficient to sustain thermonuclear fusion reactions. The released energy prevents the collapse of the Sun and keeps it in gaseous form. The total energy radiated is 383 billion trillion kilowatts/second, which is equivalent to that generated by 100 billion tons of TNT exploding each second.

In addition to the energy-producing solar core, the interior has two distinct regions: a radiative zone and a convective zone. From the dge of the core outward, first through the radiative zone and then through the convective zone, the temperature decreases from 8 million to 7,000°K, and density decreases from 20 gm/cm^3 to 4 X 10^{-7} gm/m^3. It takes about 10 million years for photons to escape from the dense core and reach the surface. Because the Sun is gaseous, it rotates faster at the equator (26.8 days) than at the poles (as long as 35 days).

The Sun's "surface," known as the photosphere, is just the visible 500 km thick layer from which most of the Sun's radiation and light finally escapes, and is the place where sunspots are found. Above the photosphere lies the chromosphere ("sphere of color") that may be seen briefly during total solar eclipses as a reddish rim, caused by hot hydrogen atoms, around the Sun. Temperature steadily increases with altitude up to 50,000°K, while density drops to 100,000 times less than in the photosphere. Above the chromosphere lies the corona ("crown"), extending outward from the Sun in the form of the "solar wind" to the edge of the solar system. The corona is extremely hot—millions of degrees Kelvin. The process that heats the corona is very mysterious and poorly understood, since the laws of thermodynamics state that heat energy flows from a hotter to a cooler place. Mysterious phenomena, such as this, are studied by researchers in NASA's Space Physics Division.

Significant Dates

585BC—	First solar eclipse successfully predicted.
1610—	Galileo observes sunspots with his telescope.
1650–1715—	Maunder Sunspot Minimum discovered.
1854—	First connection made between solar activity an geomagnetic activity.
1868—	Helium lines first observed in solar spectrum.
1908—	First measurement of sunspot magnetic fields taken.
1942—	First radio emission from Sun observed.
1946—	First observation of solar ultraviolet using a sounding rocket.
1946—	1,000,000˚ K temperature of corona discovered via coronal spectra lines.
1949—	First observation of solar x-rays using a sounding rocket.
1954—	Galactic cosmic rays found to change in intensity with the 11-year sunspot cycle.
1956—	Largest observed solar flare occurred.
1959—	First direct observations of solar wind made by Mariner 2.
1963—	First observations of solar gamma rays made by Orbiting Solar Observatory I (OSO1).
1967—	First measurement of solar neutrino flux taken.
1973-4—	Skylab observed Sun, discovered coronal holes.
1982—	First observations of neutrons from a solar flare by Solar Maximum Mission (SMM).
1994-5—	Ulysses flies over polar regions of Sun.

Fast Facts

Spectral Type of Star	G2 V
Age	4.5 Billion Years
Mean Distance to Earth	150 Million Kilometers
Rotation Period (at equator)	26.8 days
Radius	695,000 Kilometers
Mass	1.99 x 103° Kilograms
Composition	Hydrogen 71%, Helium 26.5%, Other 2.5%
Effective Surface Temperature	5.770 K
Energy Output (Luminosity)	3.83 x 10~ ergs/sec
Solar Constant	0.1368 Watts/cm2
Inclination of Solar Equator to Ecliptic	7.25°

About the Image

This image of the Sun, taken January 24, 1992, is viewed from space at x-ray wavelengths. The image, as seen by the Soft X-ray Telescope on the Japan/US/UK Yohkoh Mission (orbiting solar observatory), reveals the hot, three-dimensional geometry of the corona across the full disk of the Sun. The large bright areas are regions where the Sun's magnetic field is so strong that it can trap hot gasses even though the temperature of the region is over 1 million degrees K. The dark areas are coronal holes, which are the origin of streams of particles, called the high speed solar wind, that flows past Earth and through the solar system at about 700 kilometers per second.

References

1) Views of the Solar System—Sun http://bang.lanl.gov/solarsys/sun.htm
2) Planetary Photo Journal: http://photojournal.jpl.nasa.gov/
3) Stardate, The University of Texas of Austin, McDonald Observatory, 2609 University Ave., #3.118, Austin, TX 78712

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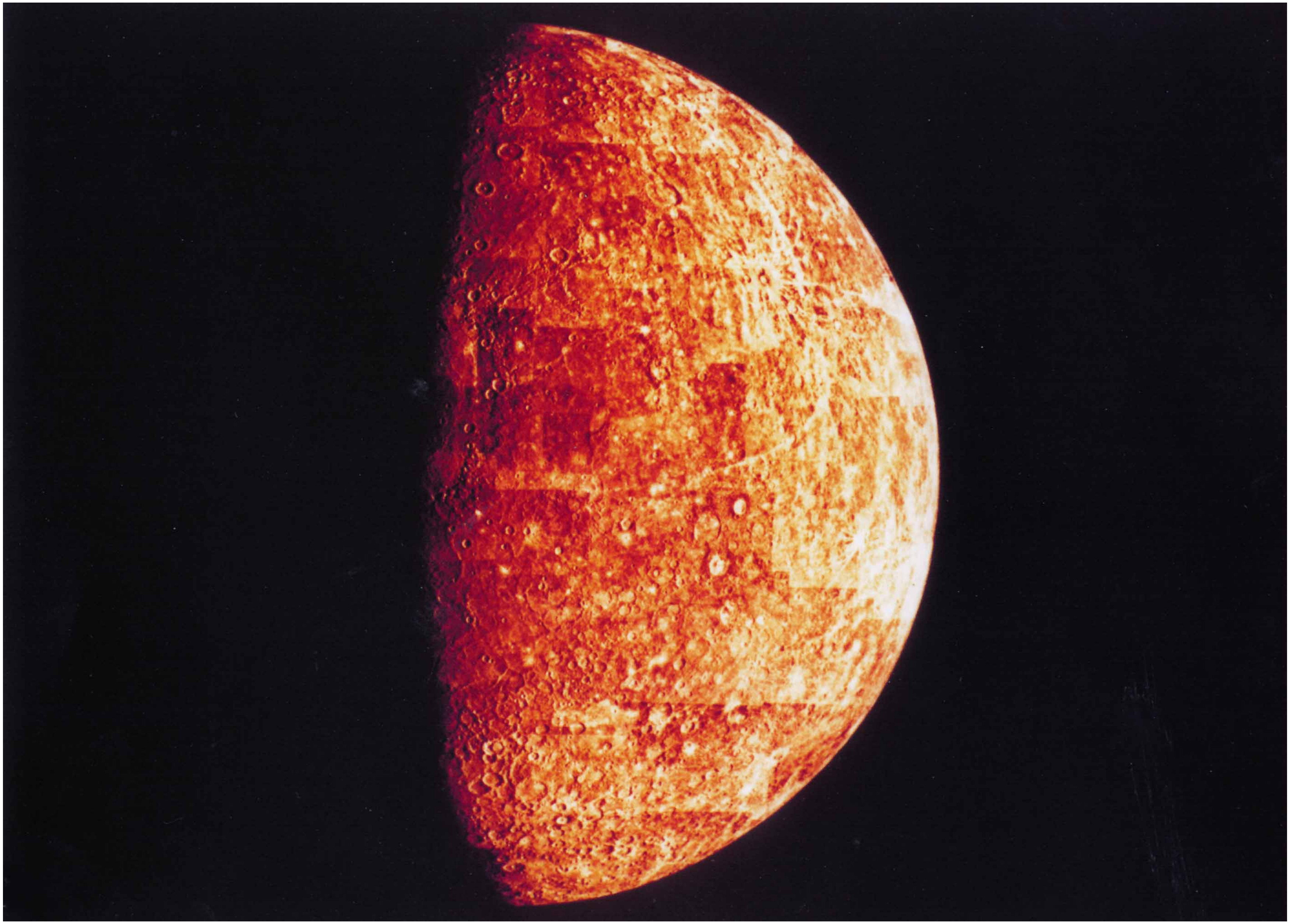

Mercury ☿

The planet **MERCURY** is the closest to the Sun, orbiting within 46 million km to the Sun at its closest point. Because it rotates on its axis once every 58.9 days and circles the Sun once every 87.9 days, Mercury rotates exactly three times around its axis for every two orbits around the Sun. If you wanted to stay up for one solar day on Mercury (sunrise to sunrise), you would be awake for two Mercurian years (176 Earth days). The surface temperature has the greatest temperature range of any planet or satellite in our system, reaching 427° C on the day side and -183° C on the night side. Mercury's atmosphere is composed of sodium and potassium, which is probably derived from the surface. While Mercury does have an atmosphere, it does not have satellites.

Smaller than all the other planets, except for Pluto, Mercury is about one-third the size of Earth. This planet has a magnetic field, although Earth's magnetic field is considerably stronger. However, the planet's density (5.4 g/cm^3) is about the same as Earth's. Scientists think the density indicates an enormous iron core composing some 75 percent of Mercury's diameter. A rocky mantle and crust only about 600 km thick surround the core. When the core and mantle cooled, the radius of the planet reduced by 2 to 4 km. The probable result of the planet's crust shrinking is Mercury's unique system of compressive fractures.

Mercury has experienced a unique geological history which has resulted in a global system of fractures caused by shrinkage of the planet. Soon after the planet formed it nearly melted from decay of radioactive elements and the inward migration of iron that formed its enormous core. This led to the expansion of the planet and extensive fracturing of the surface which provided an exit for lava to reach the surface and form the smooth plains within and between the craters. At about the same time and like the other planets, Mercury was subjected to heavy bombardment by asteroidal and cometary debris left over from accretion of the solar system. During this early period of heavy bombardment, the 1300 km diameter Caloris basin was formed by the collision of a gigantic asteroid with Mercury. The strong shock wave produced by the impact traveled through the planet to instantaneously form the hilly, lineated terrain on the opposite side. Over the next half-billion years, the core and mantle began to cool. Mercury's radius decreased by about 2 to 4 km, and the crust was subjected to compressive stresses that resulted in the lithosphere becoming strong enough to close off magma sources. Prior to the magma sources being closed off, eruptions of lava within and surrounding the large basins, such as Caloris, formed the smooth plains. Since that time, only occasional impacts of comets and asteroids have occurred on Mercury.

To date the only spacecraft to explore Mercury was *Mariner* 10 in 1974–75. It imaged about half of the planet on its three encounters, so half of the planet is still unexplored. Although the surface of Mercury resembles the Moon, there are significant geological differences. Like the Moon, it has heavily cratered upland regions and large areas of smooth plains that surround and fill impact basins. It also has a surface covering of porous, fine-grained soil like the lunar surface. Unlike the Moon, Mercury's heavily cratered uplands contain large regions of gently rolling, smooth plains—the major type of terrain on the planet.

Fast Facts

Namesake	Messenger of the Roman Gods
Diameter	4,878 Kilometers
Mean Distance from Sun	57.8 million Kilometers
Mass	6/100 the Mass of the Earth
Density	5.44 g/cc
Surface Temperature	
Maximum Day Side	740˚ Kelvin (467˚C)
Maximum Night Side	90˚ Kelvin (-183˚C)
Rotational Period	58.6 days
Ecentricity of Orbit	0.206
Rotational Period (1 Mercury Day)	58.6 Earth days

Significant Dates

1610— Italian astronomer Galileo Galilei made first telescopic observation of Mercury.

1631— French astronomer Pierre Gassendi made first telescopic observations of the transit of Mercury across the face of the Sun.

1639— Italian astronomer Giovanni Zupus discovered Mercury has phases, which is evidence that the planet circles the Sun.

1641— German astronomer Johann Franz Encke made the first mass determination using the gravity effect on the comet Encke.

1889— Italian astronomer Giovanni Schiaparelli produced the first map of Mercury's surface features.

1965— American radio astronomers Gordon Pettengill and Rolf Dyce measured Mercury's rotation period to be about 59 days.

1968— Surveyor 7 took the first spacecraft picture of Mercury from the lunar surface.

1974— Mariner 10 made the first fly-by within 900 km of Mercury.

1975— Mariner 10 made the third and final fly-by of Mercury.

About the Image

This false color photomosaic of Mercury is composed of images taken by the Mariner 10 as it flew by the planet after the first encounter in March 1974. The image shows the Caloris basin at the left of the terminator surrounded and filled by younger smooth plains deposits. This 1,300 km diameter impact basin formed about 4 billion years ago when a large asteroid or comet struck Mercury. The smooth plains resemble the lunar maria, the smooth, dark lava plains that are concentrated on the Moon's nearside. However, the Mercurian plains display less contrast in reflectivity with heavily crater terrain shown on the right, top and bottom than is seen between the lunar maria (dark) and the lunar highland (light).

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1) Views of the Solar System—Mercury http://bang.lanl.gov/solarsys/mercury.htm
2) Planetary Photo Journal: http://photojournal.jpl.nasa.gov/
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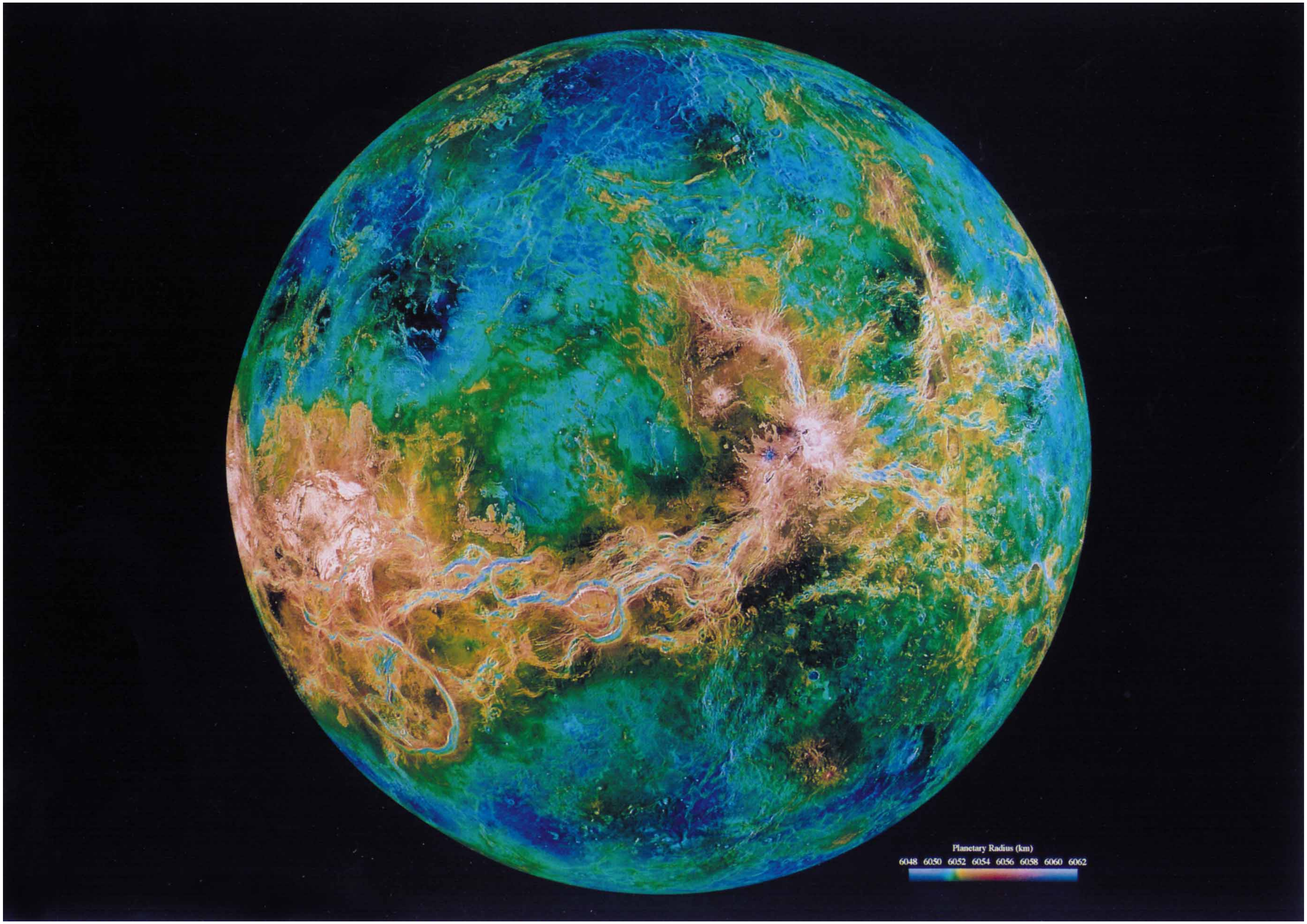
Venus ♀



Venus ♀

At first glance, if Earth had a twin, it would be **VENUS**. The two planets are similar in size, mass, composition, and distance from the Sun. But the similarities end there. Venus has no oceans, and its scorching surface temperatures of about 484°C (900°F) could melt lead. Venus hides behind a persistent global shroud of sulfuric acid clouds in an atmosphere composed mostly of carbon dioxide. The atmosphere is so dense that it crushes down on the planet's surface with a pressure equal to that found at 3,000-foot depths in Earth's oceans. Oddly, Venus rotates in a direction opposite that of Earth, which means that if you were standing on Venus, you would see the Sun rising in the west and setting in the east. Its sluggish rotation makes one Venus "day" last as long as 243 Earth days.

Because of its convenient orbit and scientific interest, Venus has been visited by more spacecraft, both U.S. and Russian, than any other planet, with flyby missions, orbiters, surface landers, and even atmosphere-floating balloons. In 1962, the U.S. launched Mariner 2, the first successful probe to flyby another planet. Mariner 2's flyby verified Venus' high temperatures. Since then, there has been a series of successful space-flight missions to Venus (see "Significant Dates"), revealing more and more about the cloud-veiled planet.

Despite the wealth of valuable data given to us by these missions, we still had only a rough sketch of the face of Venus. The Pioneer Venus and Venera spacecraft were able to image the surface with radar, thus answering many of our questions about large-scale surface features, but many more questions remained unanswered about the extent to which the surface has been shaped by volcanoes, plate tectonics, impact craters, and water and wind erosion. To address these questions, NASA, in 1989, launched a new radar imaging spacecraft named Magellan, named after the early Portugese explorer Ferdinand Magellan, whose fleet was the first to circumnavigate Earth.

Magellan arrived at Venus on August 10, 1990. During its mission, Magellan used synthetic aperture radar to penetrate the thick atmosphere of Venus and return the highest resolution images ever taken of 98% of the planet's surface. Magellan revealed that at least 85% of Venus is covered by volcanic rock—mostly lava flows that form vast plains. Much of the remaining surface is mountainous terrain deformed repeatedly by geologic activity. In addition, more than 900 impact craters are randomly scattered over the Venusian surface. Because no rainfall, oceans, or strong winds exist on Venus, little erosion occurs.
After two years of radar mapping, Magellan began acquiring global gravity data in September 1992. In the summer of 1993, the spacecraft's orbit was changed to bring it closer to the planet for additional observations of the atmosphere and gravity. The mission ended in October 1994.

From data returned by Magellan, scientists will create and study maps of Venus for years to come. With Venus' face unveiled, we now have a better understanding of Earth's fraternal twin, and a store of information that will help us understand the evolution of our own planet.

Fast Facts

Namesake	Roman Goddess of Love and Beauty
Distance from Sun	108.2 Million Kilometers
Period of Revolution (One Venusian Year)	0.62 Earth Years
Equatorial Diameter	12,100 Kilometers
Atmosphere (Main Component)	Carbon Dioxide
Inclination of Orbit to Ecliptic	3.4°
Eccentricity of Orbit	.007
Rotation Period (One Venusian Day)	243 earth Days (Retrograde)
Inclination of Axis	177.2°

Significant Dates

1962 — Mariner 2 (U.S.) flew by Venus (12/14/62); verified high temperatures.
1970 — Venera 7 (U.S.S.R.) soft landed on Venus (12/15/70).
1972 — Venera 8 (U.S.S.R.) landed on Venus (7/22/72); transmitted nearly an hour of data.
1974 — Mariner 10 (U.S.) bound for Mercury, flew by Venus (2/5/74); tracked global atmospheric circulation with visible and violet imagery.
1975 — Venera 9 (U.S.S.R.) sent the first surface pictures of Venus via its orbiter (10/22/75).
1978 — Pioneer Venus Orbiter (U.S.) radar mapped Venus (12/78); Pioneer Venus Multiprobe (U.S.) dropped four probes through Venusian clouds.
1983 — Veneras 15 and 16 (U.S.S.R.) provided high-resolution mapping radar and atmospheric analyses.
1984 — Vegas 1 and 2 (U.S.S.R.) dropped off landers and balloon probes at Venus while en route to Halley's comet.
1989 — Magellan (U.S.) was launched toward Venus (5/4/89).
1990 — Magellan arrived at Venus and mapped 98% of the planet. Mission ended in 1994.

About the Image

This mosaic of Venus was composed from Magellan images taken during radar investigations from 1990–1994, centered at 180° east longitude. Magellan spacecraft imaged more than 98% of venus' surface at a resolution of about 100 meters. This image has an effective resolution of about 3 kilometers. Gaps in the Magellan coverage were filled with images from Earth-based Arecibo radar in a region roughly centered at 0° latitude and longitude and near the south pole. This mosaic was color-coded to represent elevation. Missing elevation data from the Magellan radar altimeter were filled with altimetry from the Venera spacecraft and the U.S. Pioneer Venus missions. Brown areas denote rough terrain; the dark blue areas are smooth surfaces or possibly areas covered with dust.

References

1) Views of the Solar System—Venus http://bang.lanl.gov/solarsys/venus.htm
2) Planetary Photo Journal: http://photojournal.jpl.nasa.gov/
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Earth ⊕

EARTH, our planet, is the only planet in the solar system known to harbor life. All of the things we need to survive are provided under a thin layer of atmosphere that separates us from the uninhabitable void of space. Earth is made up of complex, interactive systems that are often unpredictable. Air, water, land, and humans themselves combine forces to create a constantly changing world that we are striving to understand.

NASA, in partnership with other U.S. and international agencies, has been studying Earth as an integrated system. Viewing Earth from the unique perspective of space provides the opportunity to see Earth as a whole. Scientists around the world have discovered many things about our planet by working together and sharing their findings.

Some facts are well known. For instance, 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. Our planet rotates on its axis at a surface speed of approximately 0.5.km/sec at mid-latitudes, while orbiting the Sun at a speed about 30 km/sec. We experience these motions as the daily routine of sunrise and sunset and the slower change of the seasons. The four seasons are a result of Earth's axis of rotation being tilted more that 23 degrees.

The changing nature of the planet's systems are the mysteries that scientists study today. For instance, the North American continent continues to move west over the Pacific Ocean basin, roughly at a rate equal to the growth of our fingernails. We are made aware of this movement when it is interrupted by earthquakes. Scientists notice a distinctive pattern to those earthquakes, leading them to conclude that Earth is dynamic, with its spherical surface separated into moving caps or plates. Earthquakes result when plates grind past one another, ride up over one another, collide to make mountains, or split and separate. These movements are known as plate tectonics. Developed within the last thirty years, this explanation has unified the results of centuries of study of our planet, long believe to be static.

Oceans at least 4 km deep covers nearly 70% of Earth's surface. Water exists in the liquid phase only within a narrow temperature span (0 degrees to 100 degrees C). 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 the Earth's weather.

On the surface, we are enveloped by an ocean of air that consists of 78% nitrogen, 21% oxygen, and 1% other constituents. Earth's atmosphere 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. Satellites have revealed that the upper atmosphere, which was thought to be calm and uneventful, actually swells by day and contracts by night due to solar activity. The upper atmosphere contributes to Earth's weather and climate and protects us from the Sun's harmful ultraviolet radiation.

Besides affecting Earth's weather, solar activity gives rise to a dramatic visual phenomenon in our atmosphere. 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 auroras, or the Northern and Southern lights.

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. The magnetic field does not fade off into space, but has definite boundaries.

As you observe Earth's finite boundaries, depicted on the front of this lithograph, consider the many unanswered questions and discoveries yet to be made on our own home planet.

Significant Dates

1957— Sputnik 1 U.S.S.R. became the first artificial satellite of the Earth.
1959— Luna 1 U.S.S.R. was the first successful mission to the Moon and the first spacecraft to leave Earth's gravity.
1960— NASA launched TIROS I, the first weather satellite.
1961— Vostok 1 U.S.S.R. carried the first human, Yuri Gagarin, into space. Alan Shepard became the first U.S. astronaut in space.
1962— John Glenn, Jr. was the first American to orbit Earth.
1964— Nimbus I began a series of missions to study Earth's atmosphere, geology, and oceans.
1968— The first humans orbited the Moon (U.S.).
1969— Apollo 11 (U.S.) became the first manned lunar landing.
1972— NASA began the Landsat satellite series to observe Earth's land surfaces.
1973— Skylab, the first space station (U.S.), was launched.
1976— LAGEOS I tracked movements of Earth's surface to increase understanding of earthquakes and other geological activity.
1978— The TOMS instrument, launched on Nimbus VII, recorded continuous data on Earth ozone layer.
1984— Earth Radiation Budget Satellite began studies of Earth's reaction to the Sun's energy.
1991— The UARS comprehensive data on chemistry and physics of the atmosphere provides evidence that human-made chemicals are responsible for the Antarctic ozone hole.
1992— The OPEX/Poseidon satellite details links between Earth's oceans and climate.
1998— NASA will launch first satellite of Earth Observing System (EOS) series, continuing through the first decade of the 21st century.

Fast Facts

Equatorial Diameter	12,756 km
Mean Distance from Sun	1.52 X 108 km
Mass	5.976 X 1023 kg
Density	5.52 g/cm^3
Mean Orbital Velocity	29.79 km/s
Tilt of Equator to Orbit	23.45º
Rotational Period	23.93 hours
Eccentricity of Orbit	0.017
Number of Satellites	1
Orbit Period	365.26 days

About the Image

This Apollo 10 view of Earth was taken during a journey to the Moon in May 1969. While clouds obscure the Yucatan Peninsula, nearly all of Mexico north of the Isthmus of Tehuantepec is clearly visible. The Gulf of California, Baja, and the San Joaquin Valley of California are identifiable as well. In the upper right corner, the northern polar cap appears with pressure fronts emanating to the south.

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1) Views of the Solar System—Earth http://bang.lanl.gov/solarsys/earth.htm
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Moon

The **MOON**, Earth's only natural satellite, is unusually large in relation to its planet, having a diameter roughly 1/4 that of Earth's. Thus, the two bodies are sometimes referred to as a double-planet system. This situation suggests an unusual origin for the Moon. Some proposed origin theories include separation from Earth, independent formation, and capture from elsewhere in the solar system. The theory that seems to explain most of our observations, however, is that a Mars-sized body once hit Earth and the resulting debris (from both Earth and the impacting body) accumulated to form the Moon. Whatever the origin, we know the Moon was formed over 4.5 billion years ago (the age of the oldest collected lunar rocks).

During the Moon's formation, very high temperatures caused extensive melting of its outer layers. The melting resulted in the formation of the lunar crust, probably from a planet-wide "magma ocean." The rocks found on the Moon's highlands are at least 4.5 billion years old, and are rich in light-colored minerals, called feldspar. These rocks, called anorthosites, give the lunar highlands their bright color. In the years since the rocks were formed, innumerable meteorites have hit the Moon, producing a crust that is intensely crated and fragmented.

About 4 billion years ago, a series of major impacts occurred, forming huge craters. These craters are now the sites of basins called maria (e.g., Mare Imbrium, Mare Serenitatis). Between 4 and 2.5 billion years ago, volcanic activity filled these basins with dark-colored lavas, called basalts. After this time of volcanism, the Moon cooled down, and has since been relatively inactive, except for the occasional "hits" of meteorites and comets. The Moon has not undergone the continual mountain-building associated with the movement of crustal plates and volcanic activity that characterized Earth; it is a fossil planet on which the earliest stages of geologic evolution are preserved.

The Moon, however, is not completely inactive. Seismometers emplaced by the Apollo astronauts have recorded small quakes (more properly called "moonquakes") at depths of several hundred kilometers. The quakes are probably triggered by tides resulting from Earth's gravitational pull. Small eruptions of gas from some craters, such as Aristarchus, have also been reported. Local magnetic areas have been detected around craters, but there is no planet-wide magnetic field resembling Earth's. It has also been determined that the deep interior of the Moon is still hot and perhaps partially molten.

The Moon's shape is unusual. It is slightly eggshaped, with the small end of the "egg" pointing toward Earth. This position causes the Moon to keep the same face toward Earth at all times. The far side, which cannot be observed from Earth, has days and nights just like those on the near side. The lunar gravity field is also unusual.
A surprising discovery from the tracking of the Lunar Orbiter photographic spacecraft in the 1960's revealed strong areas of high gravitational acceleration located over the circular maria.

The "mascons" (mass concentrations) are thought to be caused by layers of denser, basaltic lavas that fill the mare basins. Much remains to be learned about our Moon, beginning with its origin. Active research still continues to yield information about our nearest neighbor in space using the samples and data returned by Apollo and other missions. Speculation has begun on how the Moon might be used to support lunar bases and other human activities in the next century.

Fast Facts

Diameter	3,476 Kilometers
Mass	1/81 the /mass of Earth
Density	3.3 Grams/Cubic Centimeter
Rotation Period	27.3 Days
Surface Gravity	1/6 g
Escape Velocity	2.4 Kilometers/Second
Oldest Rocks	4.5 Billion Years
Atmosphere	None

Significant Dates

1610—Italian astronomer Galileo Galilei made the first telescopic observations of the Moon.
1959—Soviet spacecraft Luna 2 reached the Moon, impacting near the crater Autolycus.
1959—Soviet spacecraft Luna 3 flew by the moon and photographed the far side for the first time.
1961—President John F. Kennedy proposed a manned lunar program.
1964—Ranger 7 produced the first close-up TV pictures of the lunar surface.
1966—Luna 9 made the first soft landing on the Moon.
1967—Lunar Orbiter missions completed photographic mapping of the Moon (begun in 1966).
1968—Apollo 8 made the first manned flight to the Moon, circling it 10 times before returning to Earth.
1969—Apollo 11 mission made the first manned (human crew) landing on the Moon and return samples.
1972—Apollo 17 made the last manned landing of the Apollo Program.
1976—Soviet Luna 24 returned the last sample of the Moon.
1990—Gaileo spacecraft obtained multispectral images of the western limb and part of the far side of the Moon.
1994—Clementine mission conducted multispectral mapping of the Moon.
1998—Lunar Prospector will survey mineral composition of the Moon.

About the Image

This photograph of the Moon was taken in December 1972 by the Apollo 17 mission—shortly after the spacecraft left the Moon to return to Earth. The view shows the full Moon. The region at the right (about two-thirds of the total) is part of the Moon's far side, the side never seen from Earth. The dark regions are the maria, which are covered with dark-colored basalt lava flows. The dark, nearly circular mare region at the upper left is called Mare Crisium. Below it and to the left is Mare Fecunditatis, with the large white crater Langrenus. The light-colored regions are the lunar highlands, which are made of older rocks and contain extensive large craters made by large projectiles that struck the Moon more than 4 billion years ago. The bright, rayed crater near the upper-right rim is Giordano Bruno, a fresh crater formed by a much younger impact event.

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National Aeronautics and
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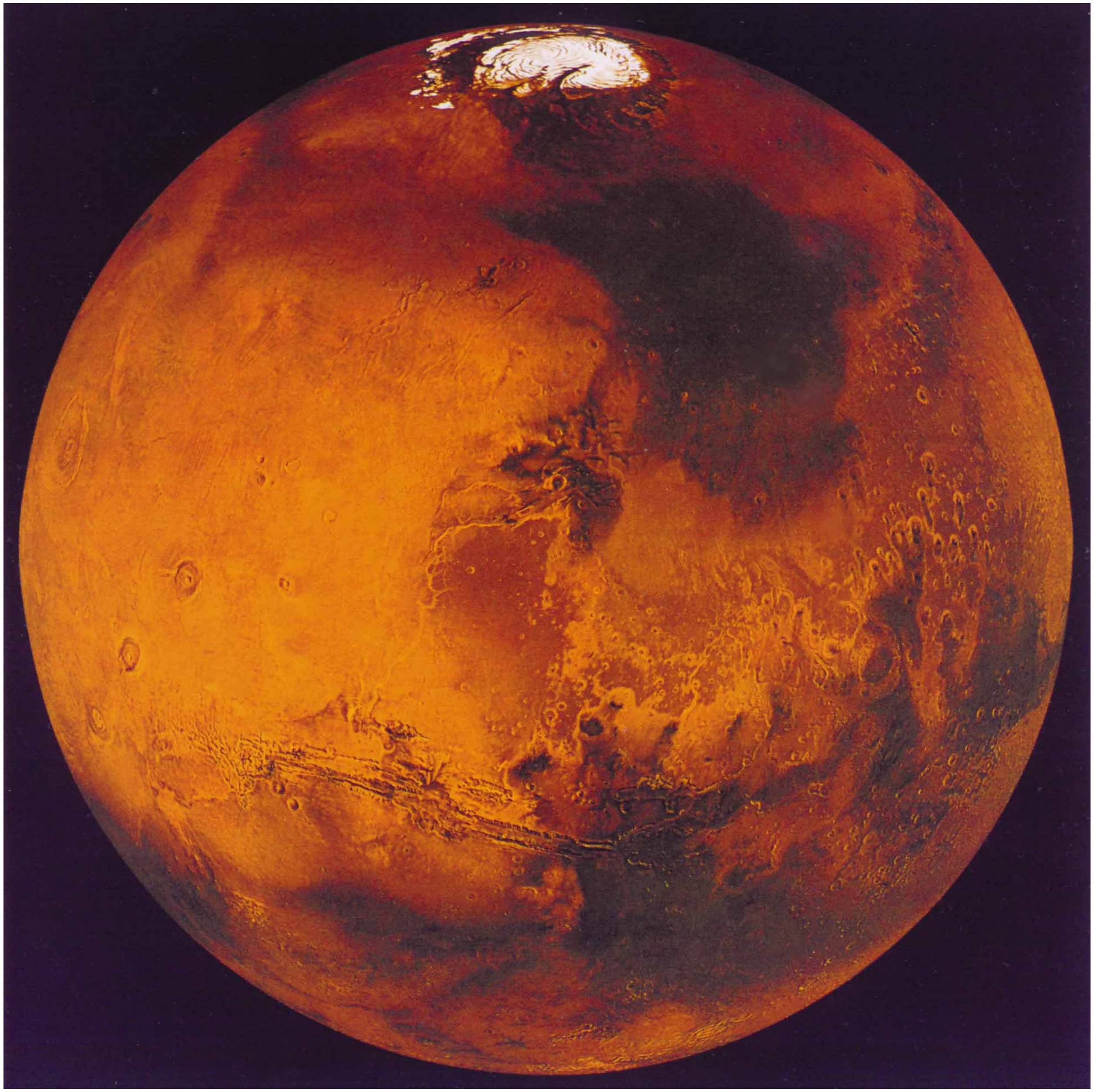
Mars ♂



National Aeronautics and
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Mars ♂

MARS, the Red Planet, has inspired wild flights of imagination over the centuries, and an intense scientific interest. Fancied to be the source of hostile invaders of Earth, the home of a dying civilization, and a rough-and-tumble mining colony of the future, Mars has proved to be fertile ground for science fiction writers, based on seeds planted by centuries of scientific observation. Mars has shown itself to be the most Earth-like of all the planets; it has polar ice caps that grow and recede with the change of seasons, and markings that appear to be similar to water channels on Earth.

American and Russian orbiters did not disclose any canals on Mars, but did find evidence of surface erosion and dried riverbeds, indicating the planet was once capable of sustaining liquid water. For millions of years, the Martian surface has been barren of water, and not subjected to the erosions and crustal plate movement that continually resurface Earth. Mars is too cool and its atmosphere is too thin to allow liquid water to exist. There is no evidence of civilizations, and it is unlikely that there are any extant life forms, but there may be fossils of life-forms from a time when the climate was warmer and there was liquid water.

Mars is a small rocky planet that developed relatively close to the Sun and has been subjected to some of the same planetary processes associated with the formation of the other “terrestrial” planets (Mercury, Venus, and Earth), including: volcanism, impact events, and atmospheric effects. Unlike Earth, Mars retains much of the surface record of its evolution. Layered terrains near the Martian poles suggest that the planet’s climate changes have been periodic, perhaps caused by a regular change in the planet’s orbit. Martian tectonism-the geological development and alteration of a planet’s crust-differs from Earth’s. Where Earth tectonics involve sliding plates that grind against each other or spread apart in the seafloors, Martian tectonics seem to be vertical, with hot lava pushing upwards through the crust to the surface. Periodically, great dust storms occur that engulf the entire planet. The effect of the storms are dramatic, including dunes, wind streaks, and wind-carved features.

Mars has some remarkable geological characteristics including: the largest volcanic mountain, Olympus Mons (27 km high and 600 km across), in the solar system; volcanoes in the northern Tharsis region that are so huge they deformed the planet’s sphericity; and a gigantic equatorial rift valley, the Vallis Marineris. This canyon system stretches a distance equivalent to the distance from New York to Los Angeles; Arizona’s Grand Canyon could easily fit into one of the side canyons of this great chasm.

Significant Dates

1965— Mariner 4 made first close-up pictures of the surface during flyby.
1969— Mariner 6 and Mariner 7 flybys resulted in high resolution images of the equatorial region and southern hemisphere.
1971— Mariner 9 became first satellite to orbit another planet.
1973— U.S.S.R. Mars 3 and Mars 5 first attempt to land on Mars.
1976— U.S.A. Vikings 1 and 2 orbited Mars. Viking Lander 1 provided first sustained surface science. Viking Lander 2 discovered water frost on the surface.
1988— U.S.S.R. probe Phobos returned detailed pictures of Phobos.
1996— Launch Mars Global Surveyor and Mars Pathfinder.
1997— Mars Pathfinder lands on Mars. Mars Global Surveyor arrives at Mars to map the surface from orbit.

Fast Facts

Namesake	Roman God of War
Distance from Sun	
Maximum	249 million km
Minimum	206 million km
Distance from Earth	
Maximum	399 million km
Minimum	56 million km
Rotational Period	24.6 hours
Equatorial Diameter	6,786 km
Equatorial Inclination to Ecliptic	25.2º
Gravity	0.38 of Earth’s
Atmosphere	
Main Component	Carbon Dioxide
Pressure at Surface	-8 millibars (vs 1,000 on Earth)
Temperature Range	143ºC to +17ºC
Moons (2)	Phobos (Fear), 21 km diameter Deimos (Panic), 12 km diameter
Rings	None
Orbital Eccentricity	0.093
Orbital Inclination to Ecliptic	1.85º
Magnetic Field Density	To be determined. Very weak, if any.

About the Image

This full-disk view of Mars is a merge of a morphologic mosaic and a color/brightness mosaic taken by Viking Orbiter 1 in 1980. The view centers at 20ºN, 60ºW. Note the north pole residual ice cap (top), Tharsis Montes (left), chaotic terrain, and Chryse outflow channels (NE of Valles Marineris). Kasei Valles appears at the center of Mars. The large dark region NE of Kasei Valles is Acidalia Planitia. Valles Mariners (bottom center) is a canyon system that stretches over 5,000 km in length and up to 8 km in depth. North of the eastern end of the Valles Marineris is the Chryse Planitia where Viking 1 landed. West of the Valles Marineris lie three of Mars’ huge volcanoes, the Tharsis volcanoes, which appear as dark reddish spots. Each volcano is about 27 km high, over 350 km in diameter, and has a central crater at its summit. To the upper left of these three huge volcanoes is the most famous member, Olympus Mons, which is about 600 km across.

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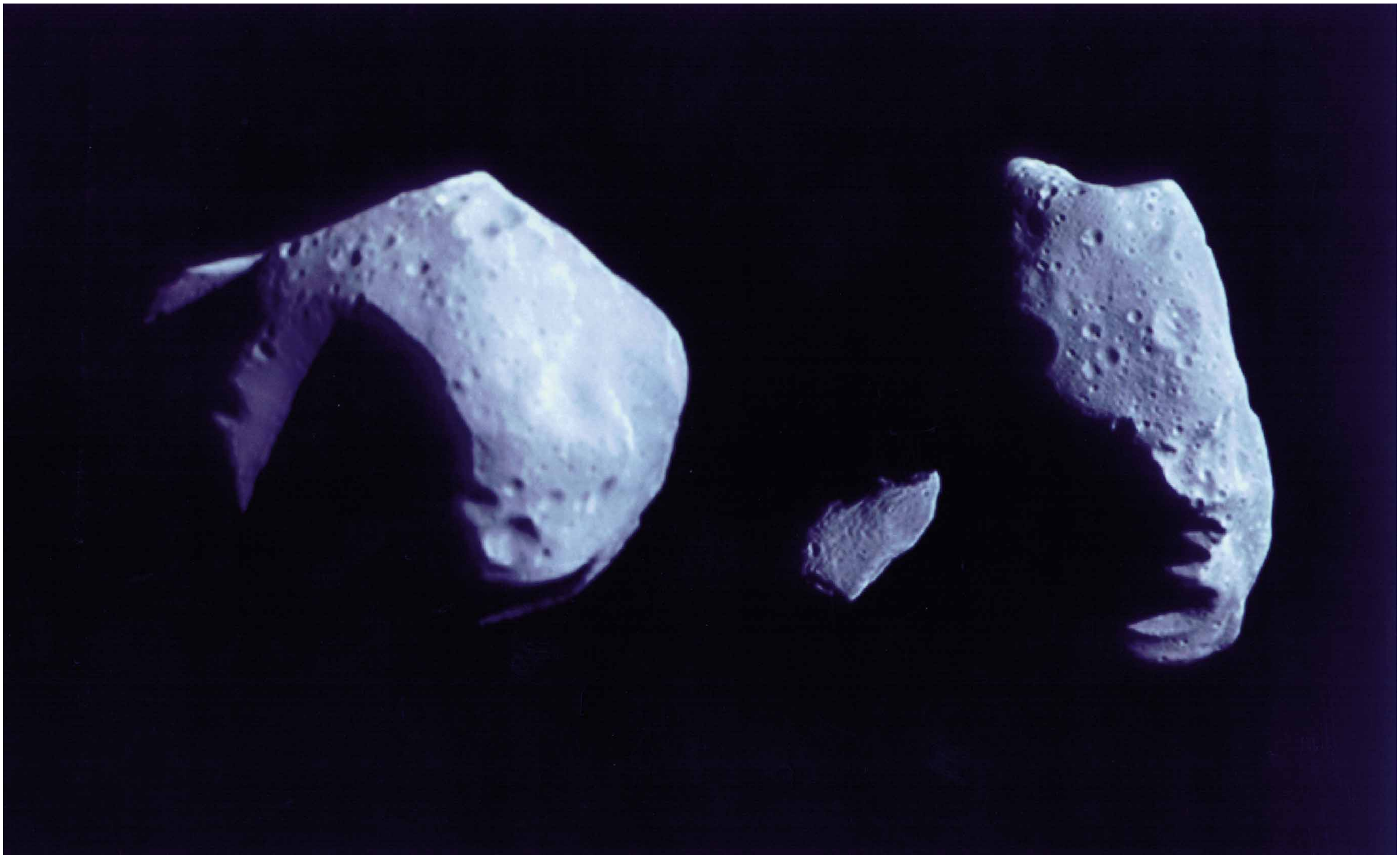
Asteroids: Mathilde, Gaspra, Ida



Asteroids: Mathilde, Gaspra, Ida

ASTEROIDS are rocky fragments left over from the formation of the solar system about 4.5 billion years ago. Most of these fragments of ancient space rubble—sometimes referred to by scientists as minor planets—can be found orbiting the Sun in a belt between Mars and Jupiter. This region in our solar system, called the Asteroid Belt or Main Belt, contains thousands of asteroids ranging widely in size from Ceres, which at 940 km (580 miles) in diameter is about a quarter the size of our moon, to bodies that are less than 1 km (0.5 miles) across.

Revolving around the Sun in eccentric (that is, elliptical rather than circular) orbits, asteroids occasionally collide with each other, knocking themselves out of the Main Belt and hurtling into space across the orbits of the planets. Scientists believe that stray asteroids or fragments of asteroids may have slammed into Earth in the past, playing a major role both in altering the geological history of our planet and in the evolution of life on it. Some even surmise the extinction of the dinosaurs 65 million years ago may have been linked to a devastating asteroid impact near the Yucatan peninsula in Mexico.

It was only in the early 1800s that asteroids were first observed with telescopes by astronomers, and it was in 1802 that astronomer William Herschel first used the word “asteroid,” which means “starlike” in Greek, to describe these celestial bodies. Most of what we have found out about asteroids in the past 200 years has been derived from telescopic observation. Ground-based telescopes are used to watch asteroids that orbit close to Earth, not only to detect new ones or keep track of them, but to watch for any asteroids that might collide with Earth in the future. Two of these ground-based telescopes are the Near Earth Asteroid Tracking telescope on the rim of the Haleakala Crater, in Maui, Hawaii and the Spacewatch telescope on Kitt Peak in Arizona.

In the last few decades, astronomers have used instruments called spectroscopes to determine the chemical and mineral composition of asteroids by analyzing the light reflected off the asteroids’ surfaces. Another means scientists use to study the makeup of asteroids is by examining meteorites. Meteorites are chunks of space debris that fall to Earth and are believed to be of asteroidal or cometary origin.

What do asteroids look like? The first close-up images of asteroids were captured in 1991 and 1993 by NASA’s spacecraft *Galileo* when it flew by two asteroids in the Main Belt on its way to Jupiter. Its pictures of asteroids Gaspra and Ida showed them to be irregularly shaped objects, rather like potatoes, riddled with craters and fractures, 19 km (12 miles) long and 52 km (32 miles) long respectively. *Galileo* also discovered that Ida has its own moon, Dactyl, a tiny body in orbit around the asteroid that may be a fragment from past collisions.

In order to learn more about these intriguing primordial bodies that hold clues to the origin and evolution of our solar system and the history of Earth, NASA has planned a number of missions to study asteroids. Its *Near-Earth Asteroid Rendezvous (NEAR)* spacecraft, which was launched in February 1996, is the first dedicated scientific mission to an asteroid. *NEAR’s* primary goal is to rendezvous with asteroid Eros in January 1999, to study its surface, orbit, mass, composition, and magnetic field (if any). During its journey to Eros, *NEAR* passed by asteroid Mathilde in June 1997. *NEAR* came within 1200 km (745 mi) of Mathilde (the closest encounter with an asteroid to date) and returned close-up images of the carbon-rich, irregularly-shaped asteroid. NEAR’s investigations of Eros will directly address some of the mysteries of asteroids, their relation to comets and meteorites, and ultimately the place of asteroids in the history of planets.

Through the New Millennium Program, NASA will launch the *Deep Space 1* spacecraft in July 1998, to test advanced technologies as it flies by asteroid McAuliffe (named in honor of schoolteacher Christa McAuliffe) in January 1999. The probe will fly between 5 -10 km (3 - 6 mi) from the asteroid, which is the closest any spacecraft has ever flown by a celestial body, and will image and study the asteroids surface. In January 2002, the Japanese will launch their *MUSES-C* spacecraft, which will arrive at asteroid Nereus in May 2003. The spacecraft will carry a tiny NASA rover, the *MUSES-CN*, which will be dropped off the spacecraft onto the asteroid to travel across and investigate the surface of the asteroid.

Fast Facts

	Gaspra	Ida	Mathilde
Distance from Sun (At Perihelion) (A.U.)	1.82	2.74	1.94
Period of Revolution	3.28 Years	4.84 Years	4.31 Years
Length	19 km	52 km	61 km
Inclination of Orbit to Ecliptic	4.10°	1.14°	6.71°
Eccentricity of Orbit	.173	.042	.266
Rotational Period (Hours: Minutes)	7:03	4:38	417:36
Absolute Magnitude	12.9	11.05	10.2
Asteroid Type	S	S	C

Significant Dates

1801— First asteroid, Ceres, discovered by Piazzi
1884— Asteroid Ida discovered by Palisa
1898— Asteroid Eros discovered by Witt
1916— Asteroid Gaspra discovered by Neujmin
1991— *Galileo* captures first close-up images of asteroid (Gaspra)
1994— *Galileo* discovers first satellite (Dactyl) of an asteroid (Ida)
1996— *NEAR* launched; encounters asteroid Mathilde
1998— *DS-1* launched
1999— *NEAR* and *DS-1* encounter asteroids Eros and McAuliffe
2002— *MUSES-C* launched (Japanese)
2003— *MUSES-C/N* rover lands on asteroid Nereus

About the Image

These are views of the three asteroids that have been imaged at close range by the Galileo and Near Earth Asteroid Rendezvous (NEAR) spacecraft. The image of Mathilde (left) was taken by the NEAR spacecraft on June 27, 1997. Images of the asteroids Gaspra (middle) and Ida (right) were taken by the Galileo spacecraft in 1991 and 1993, respectively. All three objects are presented at the same scale. The visible part of Mathilde is 59 km wide by 47 km high (37x29 miles). Mathilde has more large craters than the other two asteroids. The relative brightness has been made similar for easy viewing; Mathilde is actually much darker than either Ida or Gaspra.

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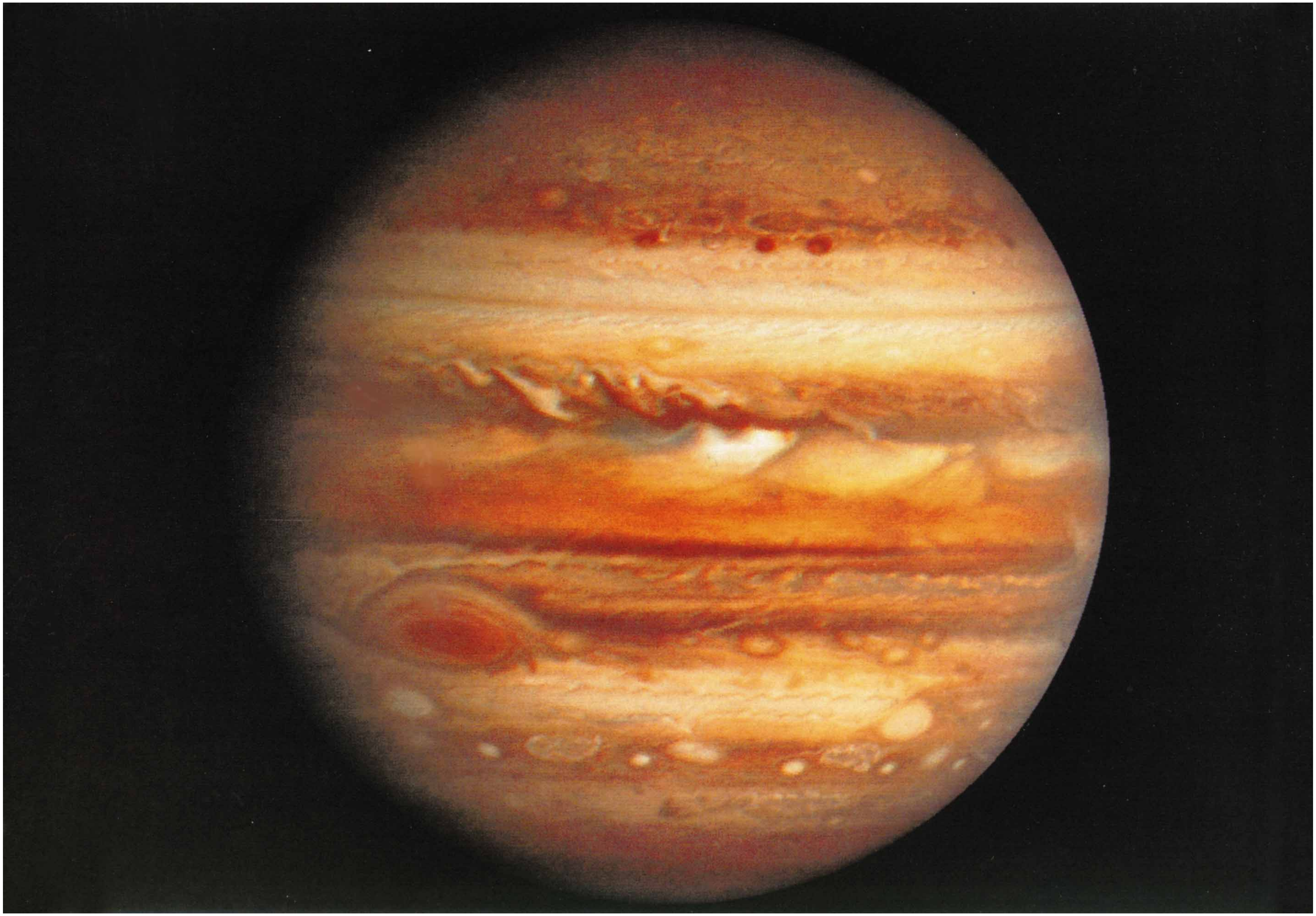

Jupiter ♃

JUPITER reigns supreme among the nine planets, containing two-thirds of the planetary mass of the solar system. In composition it resembles a small star. Its interior pressure may reach 100 million times the surface pressure on Earth. Jupiter's magnetic field is immense, even in proportion to the size of the planet, stretching million of miles into the solar system. Electrical activity in Jupiter is so strong that it pours billions of watts into Earth's own magnetic field every day.

Jupiter is endowed with 16 moons, a ring system, and an immense, complex atmosphere. Its atmosphere bristles with lightning and swirls with huge storm systems, including the Great Red Spot (giant "eye-looking" feature at lower-left of image), a storm that has persisted for at least 100, and perhaps as long as 300 years. Some scientists theorize that beneath the atmosphere there is no solid mass at the center of Jupiter, but that the planet's unique temperature and pressure conditions sustain a core whose density is more like liquid or slush.

In March 1972, NASA launched the Pioneer spacecraft to observe the asteroid belt and Jupiter. Arriving at Jupiter in December 1973, Pioneer 10 revealed Jupiter's intense radiation output, its tremendous magnetic field, and the probability of a liquid interior. One year later, *Pioneer 11* flew by Jupiter on its way to Saturn, providing even more detailed imagery and measurements, including our first close-up look at the giant planet's polar regions. Then, in August and September 1977, NASA launched the two *Voyager* spacecraft to the outer solar system. The *Voyagers*' 1979 encounters with Jupiter provided startling, beautiful imagery, revealing thousands of features never before seen. Swirling multicolored turbulence surrounded the Great Red Spot. Rising plumes and spinning eddies formed and dissipated, suggesting a strong source of heat bubbling up from within the planet.

Voyager imagery told us that Jovian dynamics were extremely complex. Yet many of these features resemble effects we know of in our own atmosphere, magnified by the enormity and extremity of the Jovian environment. In studying Jupiter, we can learn more about atmospheric effects and interactions that are subtle on Earth, such as magnetosphere-atmosphere interactions. Subsequent missions to Jupiter will help us understand the chemistry and behavior of Earth's own relatively thin, but very precious, atmosphere.

Sixteen Jovian moons have been discovered. Some are icy, some rocky, some cratered, and some smooth. Io, the fifth moon from Jupiter, is actively volcanic. The Voyager flybys witnessed a total of nine spectacular volcanic eruptions, the first time any such geologic activity had been seen outside of the Earth.

The *Voyagers* also revealed a thin ring around Jupiter. Composed of three bands, the ring is optically dark, suggesting it is made up of impact debris. The nature and source of this ring are among the questions to be answered by subsequent missions to Jupiter.

On October 18, 1989, NASA launched the *Galileo* spacecraft to Jupiter. After flying by Venus and Earth (Earth twice), and passing through the asteroid belt, *Galileo* arrived at Jupiter and deployed a probe into the Jovian atmosphere. The probe fell for nearly an hour, revealing that Jupiter's atmosphere is much drier than expected and does not exhibit the three-tiered cloud layers anticipated. Further, the atmosphere contained only one-half the expected helium. The probe also revealed previously unknown radiation belts and a virtual absence of lightning. Following the release of the probe, *Galileo* embarked on a tour of the Jovian system performing flybys of the largest moons 1000 times closer than the *Voyager* missions. *Galileo* has recorded volcanic activity on Io and revealed that the moon has an iron core almost one-half its diameter. Also, the moon Europa may have a layer of warm ice or liquid water beneath its cracked icy surface. Such observations promise to advance our understanding of small bodies of the outer solar system for decades to come.

Significant Dates

1610 — Italian astronomer Galileo Galilei discovered four moons orbiting Jupiter (Io, Europa, Ganymede, and Callisto-the Galilean Satellites).

1973 — *Pioneer 10* passed within 130,354 km of Jupiter (12/3/73); cloudtops and moons imaged.

1974 — *Pioneer 11* passed within 43,000 km of Jupiter (12/2/74) providing the first images of polar regions.

1979 — *Voyager 1* passed within 350,000 km of Jupiter (3/79) and discovered a faint ring and three moons.

1979 — *Voyager 2* passed within 650,000 km of Jupiter (7/79) providing detailed imagery of Jovian ring and Io volcanism.

1989 — *Galileo* spacecraft launched (10/18/89).

1995 — *Galileo* arrives at Jupiter (12/9/95); atmos pheric entry probe survives to pressure depth of 23 bars.

1999 — *Galileo* orbits in Jupiter's system, studying planet, rings, satellites, and magnetosphere.

Fast Facts

Namesake	King of the Roman Gods
Distance from Sun	778.3 Million Kilometers
Period of Revolution (One Jovian Year)	11.86 Earth Years
Equatorial Diameter	143,200 Kilometers
Atmosphere (Main Components)	Hyrogen and Helium
Moons (16) In Increasing Distance from Planet:	Metis, Adrastea, Amalthea, Thebe, Io, Europa, Ganymede, Callisto, Leda, Himalia, Lysithea, Elara, Ananke, Carme, Pasiphae, Sinope
Rings	1
Inclination of Orbit to Ecliptic	1.3˚
Eccentricity of Orbit	.048
Rotation Period (One Jovian Day)	9 Hours 55 Minutes
Inclination of Axis	3˚5

About the Image

This processed color image of Jupiter was produced in 1990 by the U.S. Geological Survey from a Voyager image captured in 1979. The colors have been enhanced to bring out detail. Zones if thought-colored, ascending clouds alternate with bands of dark, descending clouds. The clouds travel around the planet in alternating eastward and westward belts at speeds of up to 540 kilometers per hour. Tremendous storms big as Earthly continents surge around the planet. The Great Red Spot (oval shape toward the lower-left) is an enormous anticyclonic storm that drifts along its belt, eventually circling the entire planet.

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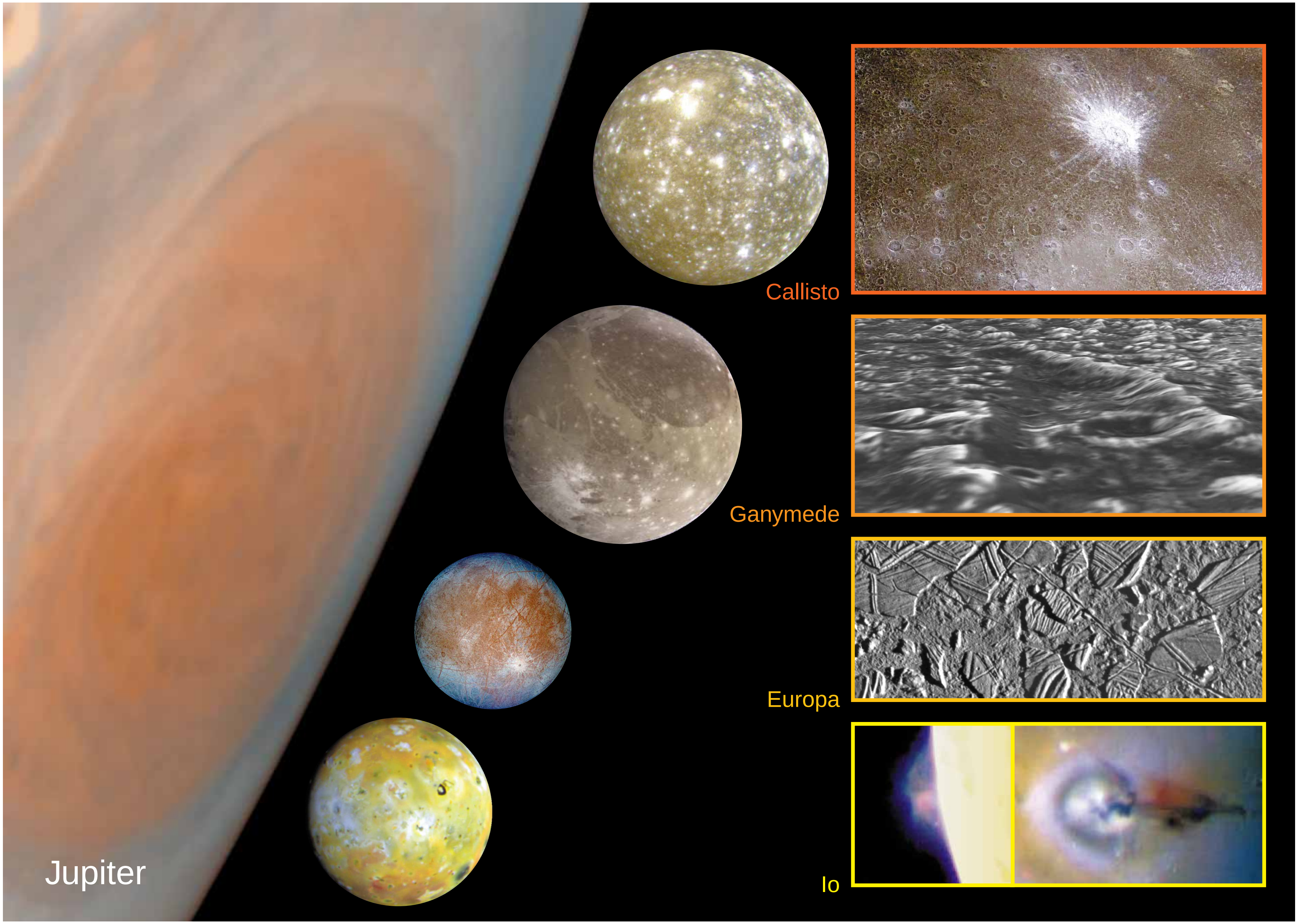
Moons of Jupiter



Moons of Jupiter

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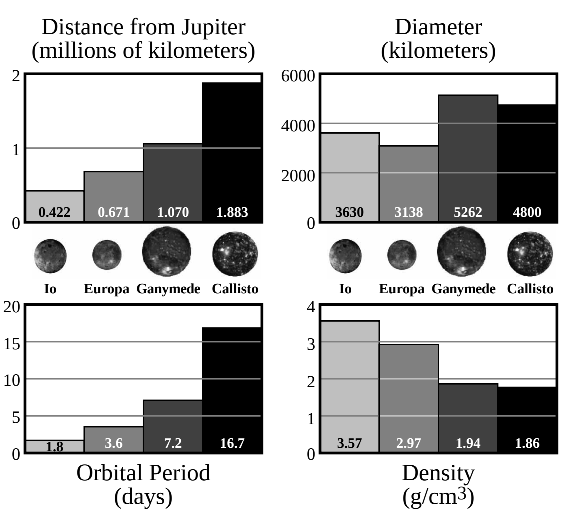
The planet Jupiter's four largest moons are called the Galilean satellites, after Galileo Galilei who discovered them in 1610. These moons, named **IO**, **EUROPA**, **GANYMEDE**, and **CALLISTO**, are particularly intriguing since each has its own amazing distinction in our solar system. Io is the most active volcanic body in the solar system, and parts of its surface often change within weeks. Europa's cratered surface is mostly water ice, and there is strong evidence that it may be covering an ocean of water or slushy ice. Ganymede is the largest moon in the solar system (larger than even the planet Mercury), and is the first moon known to have its own magnetic field. Callisto is extremely heavily cratered, but has surprised scientists with its lack of very small craters that should be visible in Galileo's close-up images - they appear to be covered with fine dust.

Though distinctive, the Galilean moons also have much in common. The surfaces of the outermost three moons are mostly water ice, mixed with rocky, probably carbon-rich, material. Io's surface is mainly sulfur in different colorful forms and sulfur dioxide. As Io travels in it's slightly elliptical orbit, Jupiter's immense gravity causes tides in the solid surface 100 meters high on Io, generating enough heat to drive the volcanic activity and drive off any water. Io, Europa, and Ganymede all have a layered interior structure (as does the Earth). Europa and Ganymede all have a core, a rock envelope around the core, a thick soft ice layer (which on Europa could be liquid), and a thin crust of impure water ice, Io has a core, and a mantle of at least partially molten rock, topped by a crust of solid rock coated with sulfur Compounds. On the other hand Callisto appears to be an ice-rock mix both inside and out. Under the influence of Jupiter's and each others gravity, the Galilean moons all keep the same face towards Jupiter as they orbit (as does our moon towards Earth), This means that each of the moons turns only once on its axis for every orbit about Jupiter.

Galileo originally assigned names I, II, III, and IV to these moons, which were later more artfully renamed for the lovers of Jupiter (also known as Zeus) from Greek mythology. They continued to be studied from Earth through telescopes until the Pioneer (in 1973) and Voyager (in 1979) spacecraft offered striking color views and a global perspective from their midrange flybys while surveying parts of the outer solar system. At present, the Galileo spacecraft flies in repeated comet-like eliptical orbits around Jupiter, flying over the surface of the Galilean moons as low as 261 kilometers (that's lower than the space shuttle orbits the earth, and much lower than most communications satellites). These close approaches result in images with unprecedented detail of selected portions of the moons' surfaces.

Close-up images taken by the Galileo spacecraft of portions of Europa's surface show places where ice has broken up and appeared to float apart, and where liquid seems to have come from below and frozen smoothly on the surface. The lack of many craters on Europa leads scientists to believe that the ocean existed 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 of Europa, due to a milder form of the tide forces that drives Io's volcanoes. The remarkable contrast between "Fire" and "Ice" on these two neighboring moons has prompted the continuation of the Galileo mission to the end of 1999. In this "Galileo Europa mission", Galileo will spend more than a year repeatedly studying Europa from as close as 200 kilometers, and will see details as small as 2 meters. Then the spacecraft will use the gravity of Callisto to direct its orbit in toward Io, and brave the intense radiation from being so close in to Jupiter, passing through the top of one of Io's volcanic phases and imaging the surface with unprecedented

Fast Facts



Significant Dates

1610— Italian astronomer Galileo Galilei discovers four moons orbiting Jupiter
1973— Pioneer 10 passed within 130,354 km of Jupiter; moons imaged
1979— Voyager 2 passed within 650,000 km of Jupiter; provid ed detailed imagery of Io volcanism
1989— Galileo spacecraft launched (10/18/89)
1995— Galileo began orbiting Jupiter
1996— First high resolution images of Ganymede, Callisto, and Europa
1997— Europa images suggests sub-surface ocean; Galileo Europa Mission begins
1999— First high resolution images of Io planned from 500 km

About the Images

In this composite of images, Jupiter's four largest moons are shown to scale, in order of increasing distance away from Jupiter (from bottom, Io, Europa, Ganymede, and Callisto). The limb of the gaseous giant planet in the region of the Great Red Spot is shown for comparison. All the images were taken by the Galileo spacecraft in 1996 and 1997 during its orbital tour of the Jovian system, except for the globe of Callisto, which was taken in 1979 by the Voyager spacecraft.

The insets are all images from Galileo, taken during several of its closest flybys to the Galilean moons in 1996 and 1997. Two of Io's plumes of cold sulfur dioxide gas and "snow" are shown on the moon's limb (Pillan Petera), and from overhead (Prometheus). Sunlight scattered by ice and dust in Pillan Petera's plume, spewing 140 kilometers above the surface, appears blue against the black of space. Prometheus' towering plume (75 kilometers high) casts a reddish shadow, and appears to have been active since the time of Voyager flybys. On Europa, ice rafts the size of small towns (up to 13 kilometers long) appear to have broken apart and "rafted" on soft ice or ice-crusted water. This image suggests the presence of an ocean underneath Europa's surface some time in recent geologic history. The stereo view of Galileo Regio is reconstructed from two images of Ganymede token on separate close flybys in 1996. Scientists use geometry to accurately compute the heights of features on the surface; the trench in the center of the image is 1 kilometer deep. Glileo Regio has ancient mottled craters and ridges, part of Ganymede's dark terrain. Callisto is famous for its numerous and varied craters. This multi-ringed impact crater named Asgard is surrounded by concentric rings up to 1700 kilometers in diameter. Newer craters, such as Burr in the upper right, are brighter because they expose fresh ice.

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3) Stardate, The University of Texas of Austin, McDonald Observatory, 2609 University Ave., #3.118, Austin, TX 78712

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National Aeronautics and
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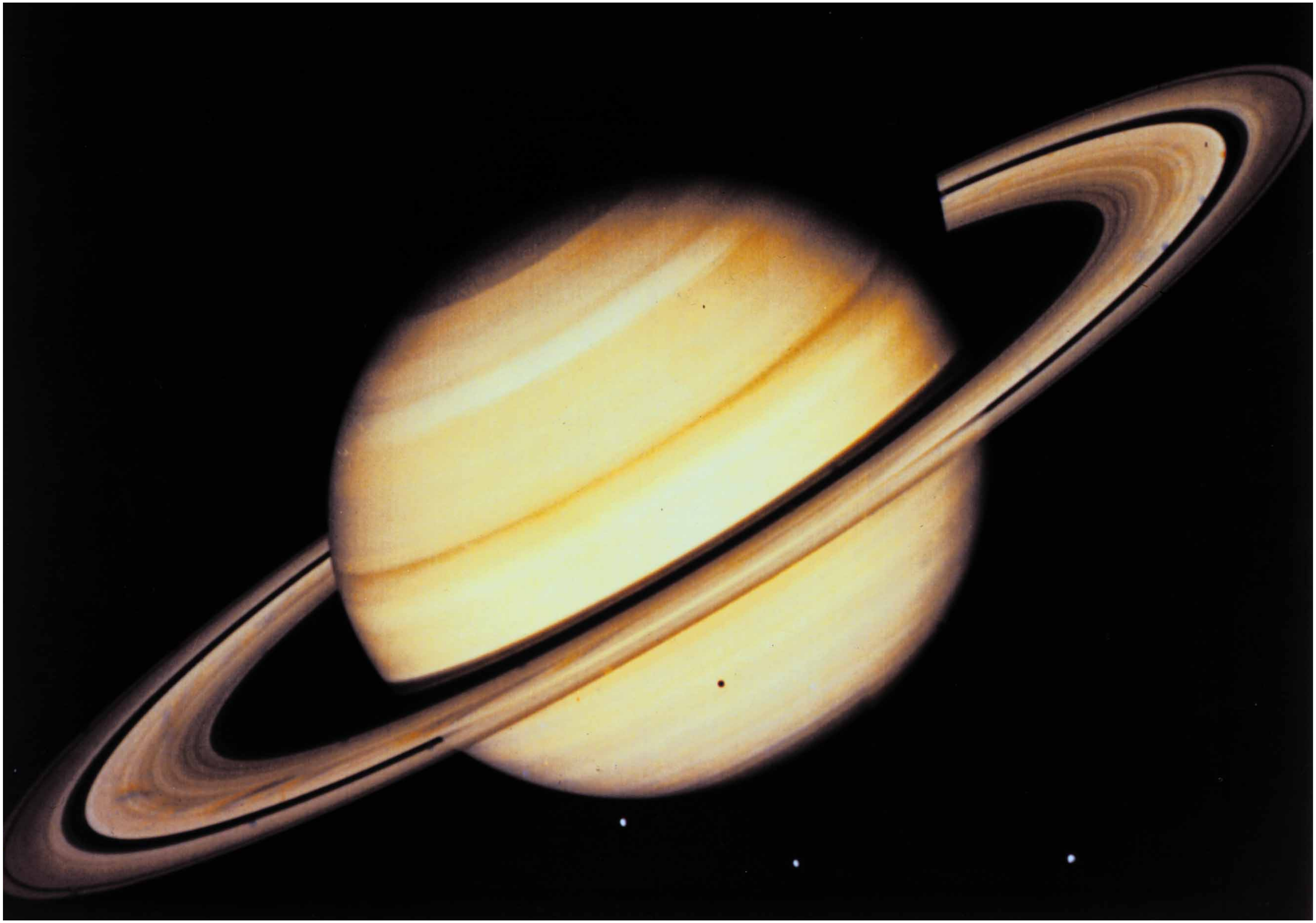
Saturn ♄



Saturn ♄

SATURN, the sixth planet from the Sun, is one of the five planets visible from Earth without a telescope. Since the 17th century, when Saturn's dazzling, complex ring system was first observed by the Italian astronomer Galileo Galilei, the planet has stood as a symbol of the majesty, mystery, and order of the physical universe. Over the past 20 years, we have discovered that Jupiter, Uranus, and Neptune also have rings; however, Saturn's ring system is the most extensive and brilliant. Although the origin of the rings is unknown, scientists hope to uncover clues by studying the planet's history.

A giant, gaseous planet, Saturn has an intriguing atmosphere. Alternate jet streams of east-west and west-east circulation can be traced in the motions of the cloud tops; the speeds of these jet streams reach as much as 1,000 miles per hour and are responsible for the banded appearance of the clouds. The atmosphere consists mostly of hydrogen and helium, but also includes trace amounts of other elements. Electrical processes and heat from internal planetary sources enrich the layered chemical mix of the atmosphere, which probably transitions from superheated water near the core to the ammonia ice clouds that are observed at the cloudtop. The planet's atmosphere also features storm structures similar to Jupiter's famous Great Red Spot.

Although Galileo was the first to see Saturn's rings (in 1610), it wasn't until 1659 that the Dutch astronomer Christiaan Huygens, using an improved telescope, observed that the are actually separate from the planet. In 1676, the French-Italian astronomer Jean Dominique Cassini first observed what appeared to be a division between the rings now known as the Cassino division. Improvements in telescopy over the next three centuries revealed much about the mysterious planet: the banded atmosphere, the storm "spots," and a very apparent "flattening" at the poles, three features Saturn was observed to share with Jupiter.

Over the past two decades, a series of spacecraft (see "Significant Dates") flew by Saturn, giving us our first close-up looks of the planet, and revealing to us a Saturnian magnetic field 1,000 times stronger than Earth's. Previously unobserved rings and moons were also discovered. Some moons were found to be covered with very smooth ice. Also, visible and infrared observations of Saturn showed us a surprising mix of thermal patterns among the cloud bands, suggesting internal processes yet to be understood. The *Voyager* spacecraft discovered hundreds of ringlets within Saturn's major rings. Some ringlets were found to be "braided." Some had small moons flanking them (called "shepherding" moons), and all gave the impression of great dynamism. Shadowy "spokes" were seen to develop and dissipate in the rings. Ring particles were found to be composed mostly of ice crystals, and to range in size from a few centimeters to a few meters.

Today we know Saturn to have 7 major ring divisions and 18 moons Space Telescope in 1995) (two and possibly four new moons were discovered by the Hubble Space Telescope in 1995.) The rings may be the remnants of moons destroyed by tidal interaction with Saturn's gravity. They may include remnants of comets that passed too close to Saturn and were likewise destroyed. Of the 18 known moons, Titan-the largest-has held the attention of scientists most. A bit larger than Mercury, Titan is shrouded by a thick nitrogen 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 primordal Earth as well.

Cassini/Huygens a joint U.S.-European orbiter/probe mission to Saturn and Titan, will be launched in October 1997, arriving at the Saturnian system in 2004. *Cassini/Huygens* 4-year scientific mission is dual: to complete a multispectral, orbital surveillance of Saturn, and to investigate Titan. *Cassini/Huygens* will measure the planet's magnetosphere, atmosphere, and rings, and observe some of its icy satellites and Titan during close flybys. The orbiter investigation of Titan will be augmented by an instrumented probe-called the Huygens Probe—that will descend through Titan's atmosphere and send back data about the atmosphere and surface. If the *Cassini/Huygens* mission goes as planned, theories of the solar system's evolution and chemical processes on primordial Earth may be improved.

Fast Facts

Namesake	Roman God of Agriculture
Distance from Sun	1,429.4 Million Kilmeters
Period of Revolution (One Saturnian Year)	29.46 Years
Equatorial Diameter	120,536 Kilometers
Atmosphere (Main Components)	Hydrogen and Helium

Moons (Known) in Increasing Distance from Planet: Pan, Atlas, Prometheus, Pandora, Epimetheus, Janus, Mimas, Enceladus, Tethys, Telesto, Calypso, Dione, Helene, Rhea, Titan, Hyperion, Lapetus, Phoebe

Rings (8)	D, C, B, A, F, G, E (The *Cassini* Division is Visible Between the B and A Rings.)
Inclination of Orbit to Ecliptic	2.5˚
Eccentricity of Orbit	0.056
Rotation Period (One Saturnian Day)	10 Hours 40 Minutes
Inclination of Axis	26˚44'

Significant Dates

1610 —Galileo Galilei discovered Saturn's rings.
1659 —Christiaan Huygens discovered that Saturn's rings were separate from the planet.
1676 —Jean Dominique Cassini discovered the *Cassini* division.
1679 —*Pioneer 11* passed within 22,00 km of Saturn's cloudtops (9/1/79) and provided the first images of polar regions, imaged Titan, and detected presence of internal source of heat in Saturn.
1980 —*Voyager 1* passed within 125,000 km of Saturn's cloud tops (11/12/80) and sent back 17,500 color images; measured high wind speeds in Saturn's equatorial region; imaged five moons; measured Titan; size.
1981 —*Voyager 2* passed within 101,000 km of Saturn's cloud tops (8/25/81) and provided detailed imagery of rings, imaged intermediate sized moons; measured and made compositional studies of Titan's atmosphere.
1997 —The *Cassini/Huygens* spacecraft will be launched toward the Saturnian system.
2004 —*Cassini/Huygens* to arrive at Saturn.

References
1) Views of the Solar System Saturn http://bang.1an1.gov/solarsys/saturn.htm
2) Planetary Photo Journal: http://photojournal.jpl.nasa.gov/
3) Stardate, The University of Texas of Austin, McDonald Observatory, 2609 University Ave., #3.118, Austin, TX 78712

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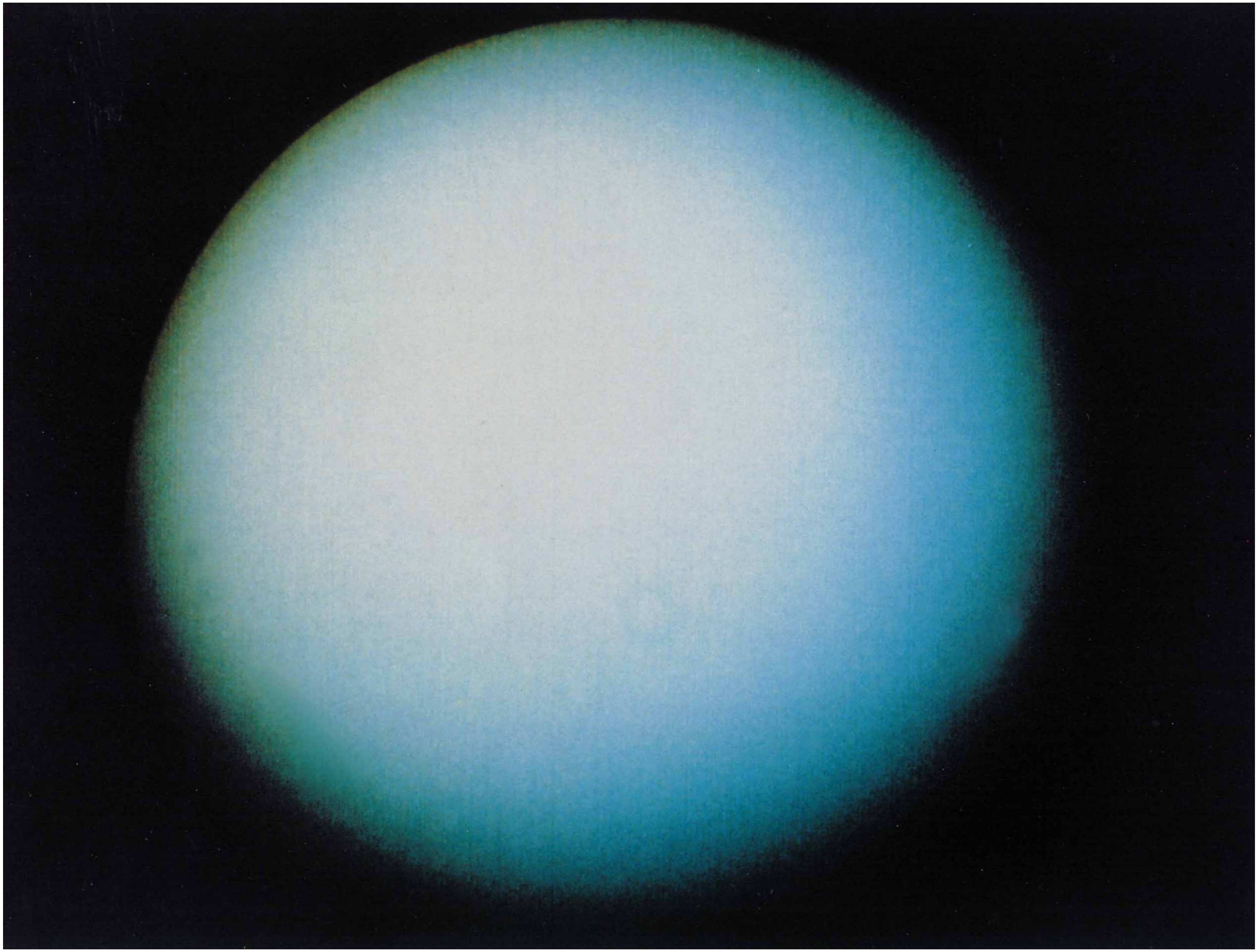
Uranus ⛢



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Uranus

While surveying the skies on a March evening in 1781, English astronomer Sir William Herschel discovered the planet **URANUS** at first mistaking it for a comet. After observing Uranus' path among the stars, astronomers determined that Uranus' orbit extends 19 times farther from the Sun than Earth's orbit. Although the diameter of the planet is four times greater than that of Earth, at this distance it appears in the sky as a faint disk spanning one thousandth of a degree, making it barely visible to the unaided eye only on clear, dark nights.

Early astronomers observed that the orbits of the four then-known Uranian moons were tipped 98 degrees relative to the planet's orbit around the Sun. These satellites, as well as Miranda (a Uranian moon discovered in 1948), and 10 small inner moons discovered by *Voyager 2* in 1986 (bringing the total number of Uranian moons to 15), all lie in Uranus' equatorial plane.

Uranus behaves like a giant top as it spins on an axis almost in the plane of the orbit. This motion leads to extreme seasonal variation in what sunlight is available. Over the period of one Uranian year (84 Earth years), the polar regions of the planet go through four seasons, as on Earth, with perpetual sunlight in the summer, and total darkness in the winter. Periods of alternating day and night are interspersed in the spring and fall.

With winters and summers extending for 21 Earth years, it would seem that Uranus should experience drastic temperature changes, but this is not the case. Uranus is so far from the Sun that its energy input per area is 360 times less than that on Earth; thus, little heating occurs during the summer. The rate of heat loss depends on the temperature of the region that is exposed to space; low cloud temperature leads to little heat loss during the winter. Despite Uranus' strange seasons, the temperature of the clouds shrouding the planet remain somewhat constant at -220ºC.

Only one spacecraft has observed Uranus at close range—*Voyager 2*. The *Voyager* spacecraft revealed that recurring patterns in radio signals from the planet indicated a rotation period (length of day) of 17.3 hours. *Voyager* scientists also discovered that, while the strength of Uranus' magnetic field is similar to Earth's, the Uranian poles are an amazing 60 degrees away from the rotational pole.

When *Voyager 2* flew by the planet, the spacecraft's cameras revealed an almost featureless atmosphere; however, faint cloud markings between 20 and 50º S latitude were recorded. The rotation rate of these clouds compared with the rotation of the magnetic field indicated wind speeds of 100–600 km/hr., which, unlike the winds of Jupiter and Saturn, blow westward.

In 1977, Uranus was observed passing in front of a star. During this observation, it was revealed that Uranus possesses a system of at least 11 thin, widely, separated rings, In 1986 *Voyager 2* confirmed that rings' existence.

Today, we know that the dimly lit Uranian system consists of a planet surrounded by a flat system of rings and satellites. Bits of debris are concentrated into thin rings that orbit the planet with the tiny moon Cordelia orbiting inside the brightest, outermost ring. Nine other small moons orbit outside the ring system. The five outer moons, with diameters ranging from 13 to 15 percent the size of our Moon, revolve around the planet at distances one-third to one-and-a-half times the distance between Earth and our Moon. *Voyager 2* revealed that a remarkable variety of surface features mark these larger satellites, including craters, fractures, and frozen water.

Fast Facts

Namesake	Roman God, Father of the Titans
Distance from Sun	2.871 Billion Kilometers
Period of Revolution (One Uranian Year)	84.01 Earth Years
Equatorial Diameter	51,118 Kilometers
Atmosphere (Main Components)	Hydrogen and Helium
Moons (15) In Increasing Distance from the Planet:	Cordelia, Ophelia, Bianca, Cressida, Desdemona, Juliet, Portia, Rosalind, Belinda, Puck, Miranda, Ariel, Umbriel Titania, Oberon
Rings	11
Inclination of Orbit to Ecliptic	0.774º
Eccentricity of Orbit	0.046
Rotation Period (One Uranian Day)	17 Hours 14 Minutes
Inclination of Axis	97.86

Significant Dates

1781 — Sir William Herschel discovered Uranus
1787 — Sir William Herschel discovered Uranian moons Titania and Oberon
1851 — William Lassell discovered Uranian moons Ariel and Umbriel
1948 — Gerard Kuiper discovered Uranian moon Miranda
1977 — James Elliot and others discovered rings around Uranus
1986 — *Voyager 2* discovered 10 small moons, and 2 more rings, detected the magnetic period, and measured the length of the Uranian day.

About the Image

This color image of Uranus was produced in 1986 by the Jet Propulsion Laboratory. Images obtained with blue, green, and orange filters were combined and the color balance adjusted to simulate what the eye wouyld normally see. The blue color is due to the absorption of red and orange light by methane gas in the planet's upper atmosphere. An obscuring haze gives Uranus a bland, velvety appearance. The darkening near the perimeter of the planet is typical of back-scattering of sunlight in a thick atmosphere.

Because no missions are currently being planned to return to Uranus, future information will need to be gained using ground-based or Earth-orbiting facilities.

References

1) Views of the Solar System—Uranus http://bang.1an1.gov/solarsys/uranus.htm
2) Planetary Photo Journal: http://photojournal.jpl.nasa.gov/
3) Stardate, The University of Texas of Austin, McDonald Observatory, 2609 University Ave., #3.118, Austin, TX 78712

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National Aeronautics and
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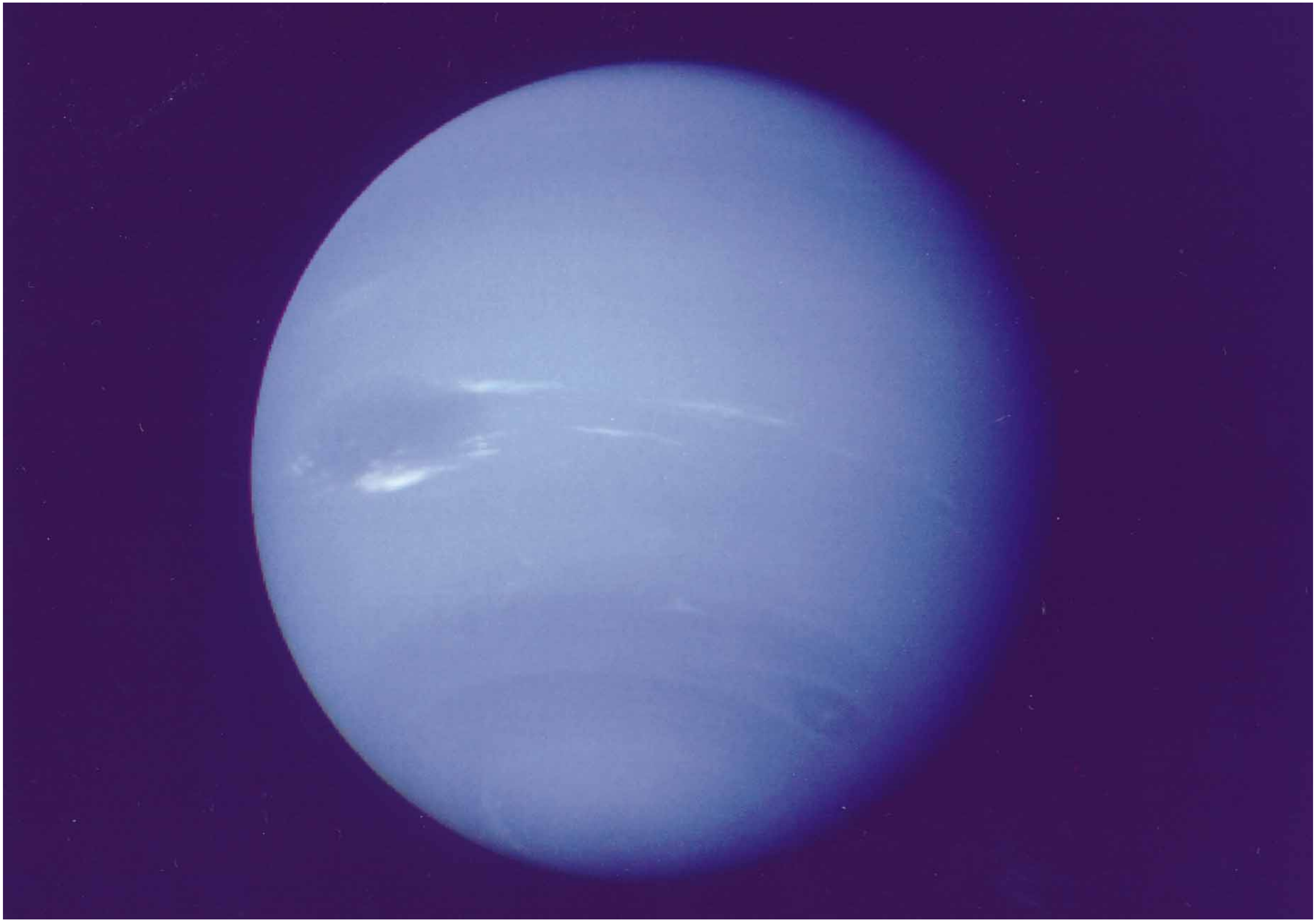
Neptune ♆



National Aeronautics and
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Neptune ♆

The discovery of **NEPTUNE** is an excellent example of the application of the scientific method on an international scale. Astronomers discovered Neptune as a result of their efforts to understand the orbit of Uranus. Observations of Uranus' orbit did not agree with theory, which led theorists to hypothesize about the existence of yet another planet, well beyond Uranus which perturbed the orbit of Uranus. Calculations were performed to reveal the approximate location followed by investigators at institutions in several countries confirmed the existence of the hypothesized planet—Neptune.

When *Voyager 2* flew within 5,000 km of Neptune on August 25, 1989, the planet was the most distant member of the solar system from the Sun. (In 1999, Pluto will once again become the most distant planet.) Neptune orbits the Sun every 165 years, and is the smallest of the solar system's gas giants. *Voyager 2* solved many of the questions scientists had about Neptune's rings. Searches for "ring arcs," or partial rings, showed that Neptune's rings actually are complete, but the thickness of the rings vary so that they cannot be fully viewed from Earth.

Even though Neptune receives only three percent as much sunlight as Jupiter does, it is a dynamic planet and surprisingly showed several large, dark spots reminiscent of Jupiter's hurricane-like storms. The largest spot, dubbed the Great Dark Spot, is about the size of Earth and is similar to the Great Red Spot on Jupiter. At low northern latitudes, *Voyager 2* captured images of cloud streaks casting their shadows on cloud decks below. The strongest winds on any planet were measured on Neptune. Most of the winds blow westward, opposite to the rotation of the planet. Near the Great Dark Spot, winds blow up to 2,000 km/hr. A small irregularly shaped, eastward-moving cloud was observed "scooting" around Neptune every 16 hours or so, which could be a cloud plume rising above a deeper cloud deck.

The magnetic field of Neptune, like that of Uranus, is highly tilted—47° from the axis of rotation. The magnetic fields of the two planets are similar. Scientists think the extreme orientation may be characteristic of flow in the interiors of both Uranus and Neptune. Studies of radio waves caused by Neptune's magnetic field revealed the length of a Neptunian day to be approximately 16 hours. Auroras were detected but are much weaker than those on Earth and other planets.

Neptune is now known to have eight satellites, six of which were found by *Voyager 2*. The new satellites are all small and remain close to Neptune's equatorial plane. Names selected from mythology's water deities have been given to Neptune's newest satellites by the International Astronomical Union.

Triton, the largest satellite of Neptune, has proved to be not only the most intriguing satellite of the Neptunian system, but also one of the most interesting in all the solar system. It shows evidence of a remarkable geological history, with active geyser-like eruptions spewing invisible nitrogen gas and dark dust particles several kilometers into the tenuous atmosphere. Triton's relatively high density and retrograde orbit offer strong evidence that Triton is not an original member of Neptune's family but is a captured object. If that is the case, tidal heating could have melted Triton in its originally eccentric orbit, and the satellite might even have been liquid for as long as one billion years after its capture by Neptune.

Fast Facts

Namesake	Roman god of the Sea
Distance from Sun	4,501.2 Million Kilometers
Period of Revolution	164.79 Years (One Neptune Year)
Equatorial Diameter	49,528 kilometers
Atmosphere	Hydrogen and Helium (Main Components)
Moons (8) In increasing distance from Planet	Naiad, Thalassa, Depoina, Galatea, Larissa, Proteus, Triton, Nereid
Rings	Four thin rings of varying thickness
Inclination of Orbit to Ecliptic	1.77˚
Eccentricity of Orbit	0.009
Rotational Period	16.11 hours
Inclination of Axis	28.8˚

Significant Dates

1845— Mathematicians John Adams (British) and Jean Leverrier (French) predict Neptune based on orbital motion of Uranus.
1846— German astronomer Johann Galle discovered Neptune using predicted location provided by Adams and Leverrier.
1846— British astronomer William Lassell discovers Neptune's largest satellite, Triton.
1849— American astronomer Gerard Kuiper discovered Nereid.
1885— Rings of Neptune discovered by astronomers based on star occultations.
1889— *Voyager 2* discovered six small satellites: Desponia, Galatea, Larissa, Naiad, Proteus, and Thalassa.

About the Image

During 1989, the Voyager 2 narrow-angle camera was used to photograph Neptune almost continuously for two days, recording approximately two and a half rotations of the planet. This image shows two of four cloud features Voyager 2 tracked including the Great Dark Spot and a smaller dark spot. The image has been processed to enhance the visibility of features, at some sacrifice of color fidelity. The Great Dark Spot near the left side of the planet circuits Neptune every 18.3 hours. The bright clouds immediately to the south and east of this oval are seen to substantially change their appearance in periods as short as four hours. The smaller dark spot at the lower right of the planet circuits Neptune every 16.1 hours.

References
1) Views of the Solar System—Neptune http://bang.lanl.gov/solarsys/neptune.htm
2) Planetary Photo Journal: http://photojournal.jpl.nasa.gov/
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National Aeronautics and Space Administration

Pluto and Charon

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Pluto and Charon

PLUTO is unique among the planets. It's the smallest, the coldest, and the farthest from the Sun. Its orbit is the most elliptical and tilted, and it's the only planet that has a moon close to its own size. Because of its great distance, Pluto remains the only planet that has never been visited by spacecraft.

Pluto wasn't discovered until 1930, when American astronomer Clyde Tombaugh first captured it in photographs. Because of its faintness, several decades elapsed before much was learned about Pluto. However, beginning in the late 1970s, as astronomical instrumentation and telescope technology began to advance rapidly, so did number of things known about Pluto.

We now know Pluto's diameter is much smaller than was believed at its discovery. In fact, Pluto is only about 2,400 kilometers across, which means that Pluto is smaller than Earth's moon! Pluto's surface, which is slightly reddish, is made up of exotic snows, including methane, nitrogen, and carbon monoxide. Evidence indicates that Pluto's interior consists primarily of rock and water ice. Above the planet's surface lies an atmosphere, which is not very dense; the atmospheric pressure on Pluto is just one millionth that on Earth. Although the atmosphere is much more tenuous than Earth's, Pluto's low gravity (about 6% of Earth's) causes the atmosphere to be much more extended in altitude than our planet's. Because Pluto's orbit is so elliptical, Pluto grows much colder during the part of each orbit when it is traveling away from the Sun. During this time, the planet's atmosphere collapses onto the surface in a planet-wide snow storm.

In 1978, American astronomers James Christy and Robert Harrington discovered that Pluto has a satellite (moon), which they named **CHARON**. Charon, which is almost half the size of Pluto, orbits the planet every 6.4 days, at an altitude of about 18,300 kilometers. Given the rough similarity of Pluto's size to Charon's, most planetary scientists refer to Pluto-Charon as a double, or binary, planet. Charon's surface differs from Pluto's; it is covered with dirty water ice and doesn't reflect as much light as Pluto's surface. Also, Charon's surface is devoid of strong color, and there is no confirmed evidence for an atmosphere on Charon.

In the late 1980s, Pluto and Charon underwent a set of mutual eclipses in which each body passed in front of the other repeatedly for several years. This pattern of events can be seen from Earth every 124 years, and will next begin in 2109 AD. Based on data from these eclipses and sophisticated computer models, it was possible to make crude maps of each body. From these maps it was learned that Pluto has polar caps, as well as large, dark spots nearer its equator. Because Pluto is so small and far away, it is impossible for any telescope on Earth to directly see these features. By getting above Earth's blurring atmosphere, the Hubble Space Telescope was capable of imaging Pluto and its moon Charon in early 1994.

Today, questions such as "How were Pluto and Charon formed?" Why are they so small and different from all other planets? still remain. One leading theory suggests that Pluto and Charon are relics of a population of hundreds or thousands of similar bodies that were formed early in solar system history. According to this hypothesis, most of these bodies were ejected to much larger distances from the solar system by the gravitational influence of the giant planets. The recent discovery of several bodies approaching the size of Charon in the region beyond Pluto has bolstered this theory.

Although no spacecraft mission has been sent to Pluto, NASA is presently working with scientists around the United States to discuss and evaluate plans for a mission to explore this strange double planet. The *Pluto-Kuiper Express* mission will entail using two highly miniaturized spacecraft to fly past the Pluto/Charon system and conduct a reconnaissance of the only major planet that has never been visited by a spacecraft. Projected to reach Pluto/Charon sometime around 2010 or later, the two flyby encounters will be timed to view opposite hemispheres of the slowly-rotating Pluto. Following the Pluto/Charon encounters, the spacecraft will be retargeted to survey a diverse collection of icy bodies, the so-called "Kuiper Belt Objects."

Fast Facts

Namesake	Roman God of the Underworld
Average Distance from the Sun	6 Billion Kilometers
Orbit Period	248 Years
Equatorial Diameter	2,400 Kilometers
Atmosphere (Main Constituents)	Nitrogen, Carbon Monoxide, Methane
Inclination of Orbit to Ecliptic	17.2º
Eccentricity of Orbit	0.25
Rotation Period	6.387 Days
Inclination of Axis	~120º
Moon	Charon
Charon's Diameter	1,210 Kilometers

Significant Dates

1930 — Pluto is discovered.
1955 — Pluto's 6.4. day rotation period is discovered.
1976 — Methane on Pluto's surface is discovered.
1978 — Charon is discovered.
1985 — Onset of Pluto-Charon eclipses (lasted 1985-1991).
1988 — Pluto's atmosphere is discovered.
1992 — Nitrogen and carbon monoxide on Pluto's surface is discovered.
1994 — First Hubble Space Telescope maps of Pluto.
2010 — Predicated atmospheric collapse.

About the Image

This is the clearest view yet of the distant planet Pluto and its moon, Charon, as revealed by NASA's Hubble Space Telescope (HST). The image was taken by the European Space Agency's Faint Object Camera on February 21, 1994 when the planet was 2.6 billion miles (4.4 billion kilometers) from Earth; or nearly 30 times the separation between Earth and the Sun.

References
1) Views of the Solar System—Pluto http://bang.lanl.gov/solarsys/pluto.htm
2) Planetary Photo Journal: http://photojournal.jpl.nasa.gov/
3) Stardate, The University of Texas of Austin, McDonald Observatory, 2609 University Ave., #3.118, Austin, TX 78712

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National Aeronautics and
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Comets

Comets

Throughout history, people have been both awed and alarmed by **COMETS**. Astronomers have long watched these periodic visitors including Englishman Edmond Halley, who first proved that comets are regular visitors of our solar system. Halley believed that several of the recorded bright comets might really be the same comet approaching the Sun at periodic intervals. He realized that one particularly bright comet was being sighted once every 76 years or so. It was recorded in 1531, also in 1607, and again in 1682. Halley predicted the comet's next appearance to be in late 1758. When the comet appeared as predicted, Halley's theory was proven correct and the comet was named in his honor. This was a rare occasion when a comet was named for the person who predicted its future appearance In most cases, comets are named for their discoverers. Comet Halley last approached the Sun in 1986 and will be back again in 2061.

Comets are dirty-ice leftovers from the formation of our solar-system around 4.5 billion years ago. They are among the least changed objects in our solar system, and, as such, may yield important clues about the formation of our solar system. 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.

Most comets arrive from a distant region called the Oort cloud about 100,000 astronomical units from the Sun (that is, 100,000 times the mean distance between the Earth and the Sun). As many as a trillion comets may reside in this cloud, orbiting the Sun near the edge of the Sun's gravitational tug. Thus, any star passing nearby can change a comet's orbit, flinging it into the inner solar system where we can see it. The large planets of our outer solar system are big enough that their gravity can also shift a comet into a different orbit.

In addition to the comets in the Oort Cloud, billions more orbit the Sun beyond the orbit of Pluto. This belt of comets is called the Kuiper Belt.

Around a dozen "new" comets are discovered each year. Most of them are long-period comets, meaning that they have orbits that can take as much as 30 million years to complete one trip around the Sun. (It takes Earth only 365 days to orbit the Sun.) Some are short-period comets, which can take less than 200 years to complete one orbit.

As a comet begins its inward pass toward the Sun, it begins to warm up and turns from a dark, cold object into one so bright that we can see it on Earth. This transformation occurs when the heat from the Sun vaporizes ice on the comet's surface, causing the resultant gases to glow. "Vents" on the sun-warmed side may squirt fountains of dust and gas for several thousand kilometers. All this escaping material forms a large, tenuous atmosphere called a coma, typically a few hundred thousand kilo-meters in diameter. Solar energy and the flow of electrically charged particles, called the solar wind, blow the coma materials away from the Sun, forming the comet's long, glowing tail, which is often split into a straight tail of electrically charged ions and an arching tail of dust. The tails of a comet always point away from the Sun.

Almost all comet orbits keep them safely away from the Sun itself. Comet Halley comes no closer than 89 million kilometers from the Sun, a distance well within our own Earth's orbit. However, there are some comets, called sungrazers, which may crash straight into the Sun or get so close they burn up.

NASA plans to launch several comet missions over the next few years. *Deep Space 1* will be launched in July 1998, and arrive at Comet West-Kohoutek-Ikemura in June 2000. The mission will come within 500 kilometers of the comet and study the size and shape of the nucleus and the effect of the solar wind on the gases leaving the comet. *Stardust* will be launched in February 1999, and encounter Comet Wild in January 2004. Coming within 150 kilometers of the comet, it will also study the comet's nucleus, the composition of comet dust, and bring a dust sample back to Earth in 2006. *Contour* will be launched July 2002, and will perform close flybys of comets Encke, Schwassman-Wachmann-3, and d'Arrest to study the diversity of comet nuclei. *Deep Space 4* will be launched in April 2003, and land on the surface of Comet Tempel 1 in December 2005. It will study the nucleus and map the surface of the comet, and bring surface samples back to Earth.

Significant Dates

1618— First comet to be observed telescopically by Johann Baptist Cysat of Switzerland and John Bainbridge of England.

1744— Comet with many tails seen was De Cheseaux's comet or Daytime Comet of 1744. It had 6-7 tails.

1858— First photograph of a comet [Comet Donati (1858 VI)] by William Usherwood on September 27th.

1864— First comet examined by a spectroscope was Comet Tempel (1864 II).

1985— First Comet visited by a spacecraft was Comet Giacobini-Zinner. The NASA ICE spacecraft flew by on September 11th.

1986— First comet nucleus (Halley's Comet) was imaged by the ESA's Giotto spacecraft in March.

1994— First time pieces of a comet (Shoemaker-Levy 9) were seen impacting with the atmosphere of Jupiter.

1997— Comet Hale-Bopp easily observable to the naked eye.

About the Image

This image of Comet Hale-Bopp was taken at the Jet Propulsion Laboratory Table Mountain Observatory in Southern California. The bluish tail is the comet's ion tail, while the white one is the dust tail. Comet Hale-Bopp is expected to be visible again from Earth in about 2,380 years.

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1) Views of the Solar System—Comets http://bang.lanl.gov/solarsys/comet.htm
2) Planetary Photo Journal: http://photojournal.jpl.nasa.gov/
3) Stardate, The University of Texas of Austin, McDonald Observatory, 2609 University Ave., #3.118, Austin, TX 78712

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Kennedy Space Center, FL 32899-0001
Phone: (407) 867-4090

KY, NC, SC, VA, WV
Virginia Air and Space Museum
NASA Educator Resource Center for
NASA Langley Research Center
600 Settler's Landing Road
Hampton, VA 23669-4033
Phone: (757) 727-0900 x 757

IL, IN, MI, MN, OH, WI
NASA Educator Resource Center
Mail Stop 8-1
NASA Lewis Research Center
21000 Brookpark Road
Cleveland, OH 44135-3191
Phone: (216) 433-2017

AL, AR, IA, LA, MO,TN
U.S. Space and Rocket Center
NASA Educator Resource Center for
NASA Marshall Space Flight Center
P.O. Box 070015
Huntsville, AL 35807-7015
Phone: (205) 544-5812

MS
NASA Educator Resource Center
Building 1200
NASA John C. Stennis Space Center
Stennis Space Center, MS 39529-6000
Phone: (228) 688-3338

NASA Educator Resource Center
JPL Educational Outreach
Mail Stop CS-530
NASA Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109-8099
Phone: (818) 354-6916

CA cities near the center
NASA Educator Resource Center for
NASA Dryden Flight Research Center
45108 N. 3rd Street East
Lancaster, CA 93535
Phone: (805) 948-7347

VA and MD's Eastern Shores
NASA Educator Resource Lab
Education Complex - Visitor Center
Building J-1
NASA Wallops Flight Facility
Wallops Island, VA 23337-5099
Phone: (757) 824-2297/2298

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

NASA On-line Resources for Educators provide current educational information and instructional resource materials to teachers, faculty, and students. A wide range of information is available, including science, mathematics, engineering, and technology education lesson plans, historical information related to the aeronautics and space program, current status reports on NASA projects, news releases, information on NASA educational programs, useful software, and graphics files. Educators and students can also use NASA resources as learning tools to explore the Internet, accessing information about educational grants, interacting with other schools that are already on-line, participating in on-line interactive projects, and communicating with NASA scientists, engineers, and other team members to experience the excitement of real NASA projects.

Access these resources through the NASA Education Home Page: *http://www.hq.nasa.gov/education*

NASA Television (NTV) is the Agency's distribution system for live and taped programs. It offers the public a front-row seat for launches and missions, as well as informational and educational programming, historical documentaries, and updates on the latest developments in aeronautics and space science. NTV is transmitted on the GE-2 satellite, Transponder 9C at 85 degrees West longitude, vertical polarization, with a frequency of 3880 megahertz and audio of 6.8 megahertz.

Apart from live mission coverage, regular NASA Television programming includes a Video File from noon to 1:00 p.m., a NASA Gallery File from 1:00 to 2:00 p.m., and an Education File from 2:00 to 3:00 pm (all times Eastern). This sequence is repeated at 3:00 p.m., 6:00 p.m., and 9:00 p.m., Monday through Friday. The NTV Education File features programming for teachers and students on science, mathematics, and technology. NASA Television programming may be videotaped for later use.

For more information on NASA Television, contact:
NASA Headquarters, Code P-2, NASA TV, Washington, DC 20546-0001
Phone: (202) 358-3572
NTV Home Page: *http://www.hq.nasa.gov/ntv.html*

How to Access NASA's Education Materials and Services, EP-1996-11-345-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 electronically via NASA Spacelink. NASA Spacelink can be accessed at the following address:
http://spacelink.nasa.gov

Solar System Lithograph Set
TEACHER REPLY CARD

To achieve America's goals in Educational Excellence, it is NASA's mission to develop supplementary instructional materials and curricula in science, mathematics, and technology. NASA seeks to involve the educational community in the development and improvement of these materials. Your evaluation and suggestions are vital to continually improving NASA educational materials.

Please take a moment to respond to the statements and questions below. You can submit your response through the Internet or by mail. Send your reply to the following Internet address:

http://ednet.gsfc.nasa.gov/edcats/lithograph_set

You will then be asked to enter your data at the appropriate prompt.

Otherwise, please return the reply card by mail. Thank you.

1. With what grades did you use the lithograph set?
   Number of Teachers/Faculty:
   ______ K-4 ______ Community College
   ______ 5-8 ______ College/University — Undergraduate
   ______ 9-12 ______ College/University — Graduate

   Number of Students:
   ______ K-4 ______ Community College
   ______ 5-8 ______ College/University — Undergraduate
   ______ 9-12 ______ College/University — Graduate

   Number of Others:
   ______ Administrators/Staff ______ Professional Groups
   ______ Parents ______ Civic Groups
   ______ General Public ______ Other ______________________

2. What is your home 5- or 9-digit zip code? __ __ __ __ __ — __ __ __ __

3. How was the quality of this lithograph set?

   ❏ Excellent ❏ Good ❏ Average ❏ Poor ❏ Very Poor

Fold along line and tape closed.

4. How did you use this lithograph set?

   ❏ Background Information
   ❏ Demonstrate NASA Materials
   ❏ Group Discussions
   ❏ Integration Into Existing Curricula
   ❏ Lecture
   ❏ Team Activities
   ❏ Critical Thinking Tasks
   ❏ Demonstration
   ❏ Hands-On Activities
   ❏ Interdisciplinary Activity
   ❏ Science and Mathematics Standards Integration
   ❏ Other: Please specify: ______________________________

5. Where did you learn about this lithograph set?

   ❏ NASA Educator Resource Center
   ❏ NASA Central Operation of Resources for Educators (CORE)
   ❏ Institution/School System
   ❏ Fellow Educator
   ❏ Workshop/Conference
   ❏ Other: Please specify: ______________________________

6. What features of this lithograph set did you find particularly helpful?

   ____
   ____
   ____

7. How can we make this lithograph set more effective for you?

   ____
   ____
   ____

8. Additional comments:

   ____
   ____
   ____

Today's Date: ______________________

EP-1997-11-371-HQ

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WASHINGTON DC 20546–0001

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