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NASA-EP-338
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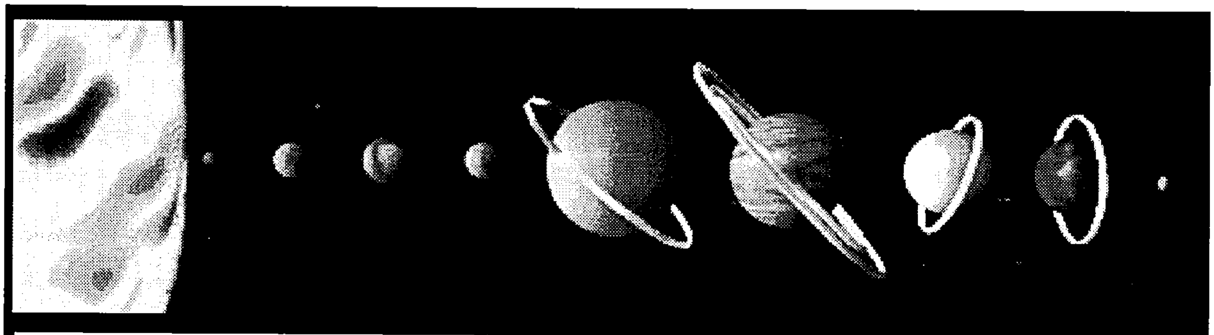
Solar System Litho

for Earth and Space Science



This set contains the following materials:

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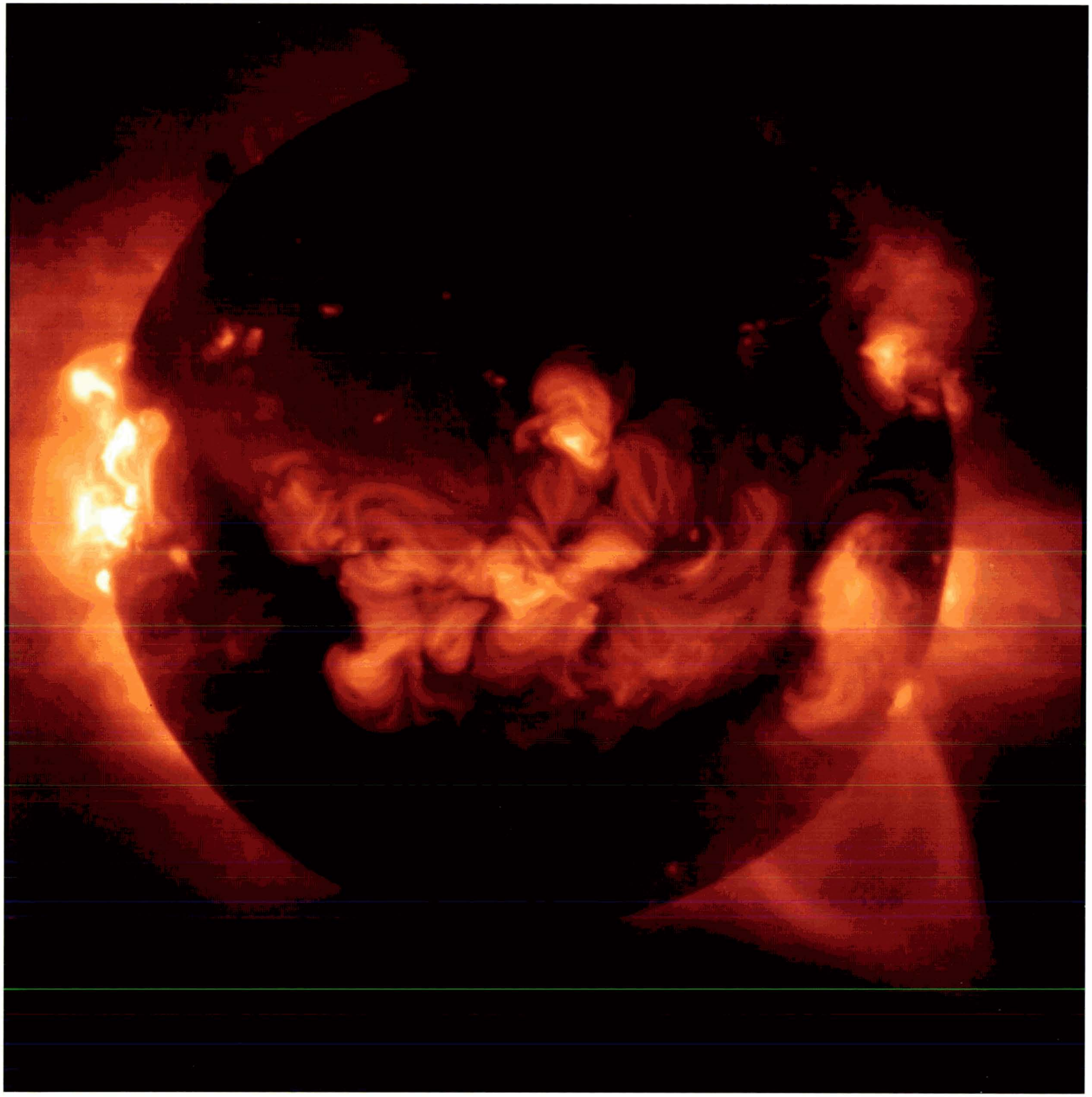

Our Star — The Sun ⊙

The Sun is a huge, bright sphere of mostly ionized gas about 5 billion years old. The closest star to Earth, it is 145 million km distant (this distance is called an 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 = 1.99×10^{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 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 and a convective zone. From the edge of the core outward, first through the radiative 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 corora ("crown"), extending outward from the Sun in the form of the "solar wind" to the edge of the solar system. The corora is extremely hot — millions of degrees K. 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.

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	1.99×10^{30} Kilograms
Composition	Hydrogen 71%, Helium 26.5%, Other 2.5%
Effective Surface Temperature	5,770 K
Energy Output (Luminosity)	3.83×10^{33} ergs/sec
Solar Constant	0.1368 Watts/cm^2
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 gases even though the temperature of the regions are 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 flow past Earth and through the solar system at about 700 kilometers per second.

Significant Dates

585 BC	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 and 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 occured
1959	First direct observations of solar wind made by Mariner 2
1963	First observations of solar gamma rays made by Orbiting Solar Observatory 1 (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

References

1. "The Sun," Educational Brief EB-106, NASA Headquarters, Washington, DC. 3/92.
2. "The Yohkoh Mission," Space Physics Topic, NASA Headquarters, Washington, DC. 10/93.

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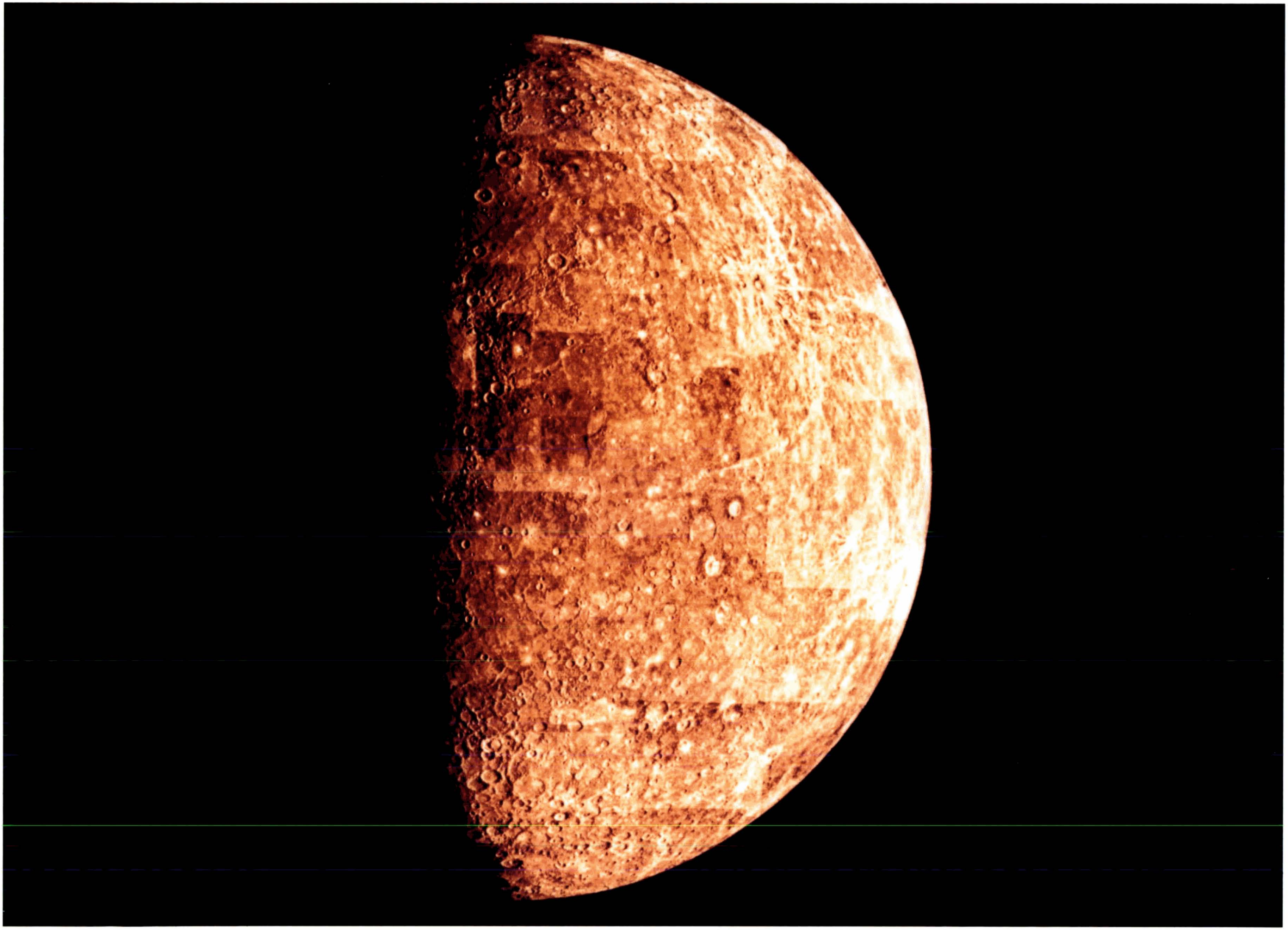
Mercury ☿



Mercury is the planet closest to the Sun. Of all the planets, it has the most elliptical orbit, except for Pluto. Because of its elliptical orbit, Mercury's closest distance to the Sun is only 46 million km while its greatest distance is 70 million km. Another unique aspect of Mercury is its rotational and orbital period. Mercury rotates on its axis once every 58.9 days and circles the Sun once every 87.9 days. As a result Mercury rotates exactly three times around its axis for every two orbits around the Sun. If you wanted to stay up for a solar day on Mercury (sunrise to sunrise), you would be awake for two Mercurian years (a total of 176 Earth days.) Because Mercury is so close to the Sun, its surface temperature has the greatest temperature range of any planet or satellite in the solar system. The surface temperature reaches a maximum of 427° Celsius on the side closest to the Sun, and -183°C on the night side. Mercury's atmosphere is tenuous and like a vacuum. The 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.

Physically, Mercury is smaller than any other planet except Pluto, measuring about one-third the size of Earth. However, Mercury's density (5.4 g/cm^3) is about the same as Earth's; therefore, scientists assume that the planet has an enormous iron core that composes some 75 percent of Mercury's diameter (42 percent of the volume). The core is surrounded by a rocky mantle and crust only about 600 km thick. Aside from Earth, Mercury is the only terrestial planet with a magnetic field. Although the magnetic field is considerably weaker than Earth's, its presence is strong evidence that the outer core is fluid at the present time.

To date the only spacecraft to explore Mercury was *Mariner 10* in 1974-75. It imaged about half the planet on its three encounters, so half of the planet is still unexplored. Although the surface of Mercury superficially resembles that of 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. Mercury also 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 bombarded 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 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 of the planet. Afterward, eruption of lava within and surrounding the Caloris, and other large basins formed the smooth plains. 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 a unique global system of fractures. As this occurred, volcanism ceased when compressive stresses in the lithosphere became strong enough to close off magma sources. Since that time, only occasional impacts of comets and asteroids have occurred.

Significant Dates

1610 - Italian astronomer Galileo Galilei made first telescopic oberservation of Mercury.
1631 - French astronomer Pierre Gassendi made first telescopic obervations 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 circle the Sun.
1841 - German astronomer, Johann Franz Encke made the first mass determination using 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 the 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 - Third and final fly-by of Mercury by *Mariner 10*.

References

1. *Charting the Planets*, Educational Brief, EB-111, NASA Headquarters, Washington, DC. 12/92.
2. *Our Solar System at a Glance*, Information Summaries, PMS 010-A, Jet Propulsion Laboratory, Pasadena, CA. 6/91.

Fast Facts

Namesake	Messenger of the Roman Gods
Diameter	4878 km
Mean Distance from Sun	57.8 million km
Mass	6/100 the mass of 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
Eccentricity of Orbit	0.206
Rotational Period (1 Mercury Day)	58.6 Earth days

About the Image

This false color photomosaic of Mercury is composed of images taken by 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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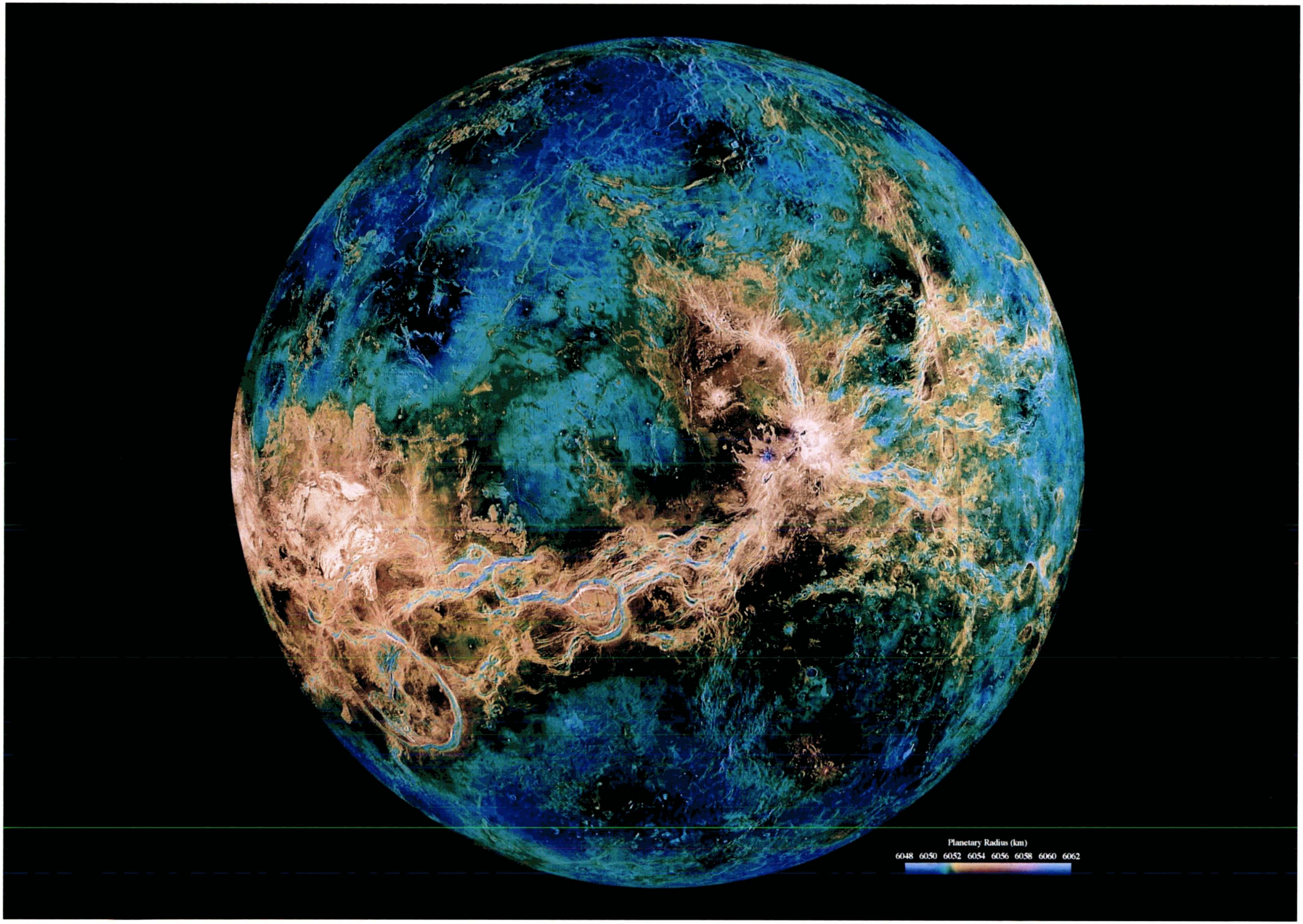
Venus ♀



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 twins' similarities end there. Venus has no oceans, and its scorching surface temperature 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. Venus' 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 fly by 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 Venus' large-scale surface features, but many more questions remained unanswered about the extent to which Venus' 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*. It was named after the early Portuguese explorer Ferdinand Magellan, whose fleet was the first to circumnavigate Earth.

Magellan began its radar mapping on September 15, 1990. Within 243 Earth days, the spacecraft had achieved and even exceeded its primary objective: to map 70 percent of the planet's surface. After three complete 243-day cycles, *Magellan* had mapped 98 percent of Venus. *Magellan* began a fourth 243-day cycle—a global gravity survey—on September 15, 1992. This survey will help scientists map the internal structure of Venus.

Magellan is unveiling on Venus a tortured surface shaped by a history of geological violence, tectonic deformation, volcanism, and impact cratering. At least 85 percent of Venus is covered by volcanic rock—mostly lava flows that form the planet's vast plains. Mountains deformed by repeated geologic activity cover much of the remaining surface areas. Because no rainfall, oceans, or strong winds exist on Venus, little erosion occurs.

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 (1 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 (1 Venusian Day)	243 Earth Days (Retrograde)
Inclination of Axis	177.2°

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.

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 ultraviolet 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 & 16* (U.S.S.R.) provided high-resolution mapping radar and atmospheric analyses

1984 — *Vegas 1 & 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)

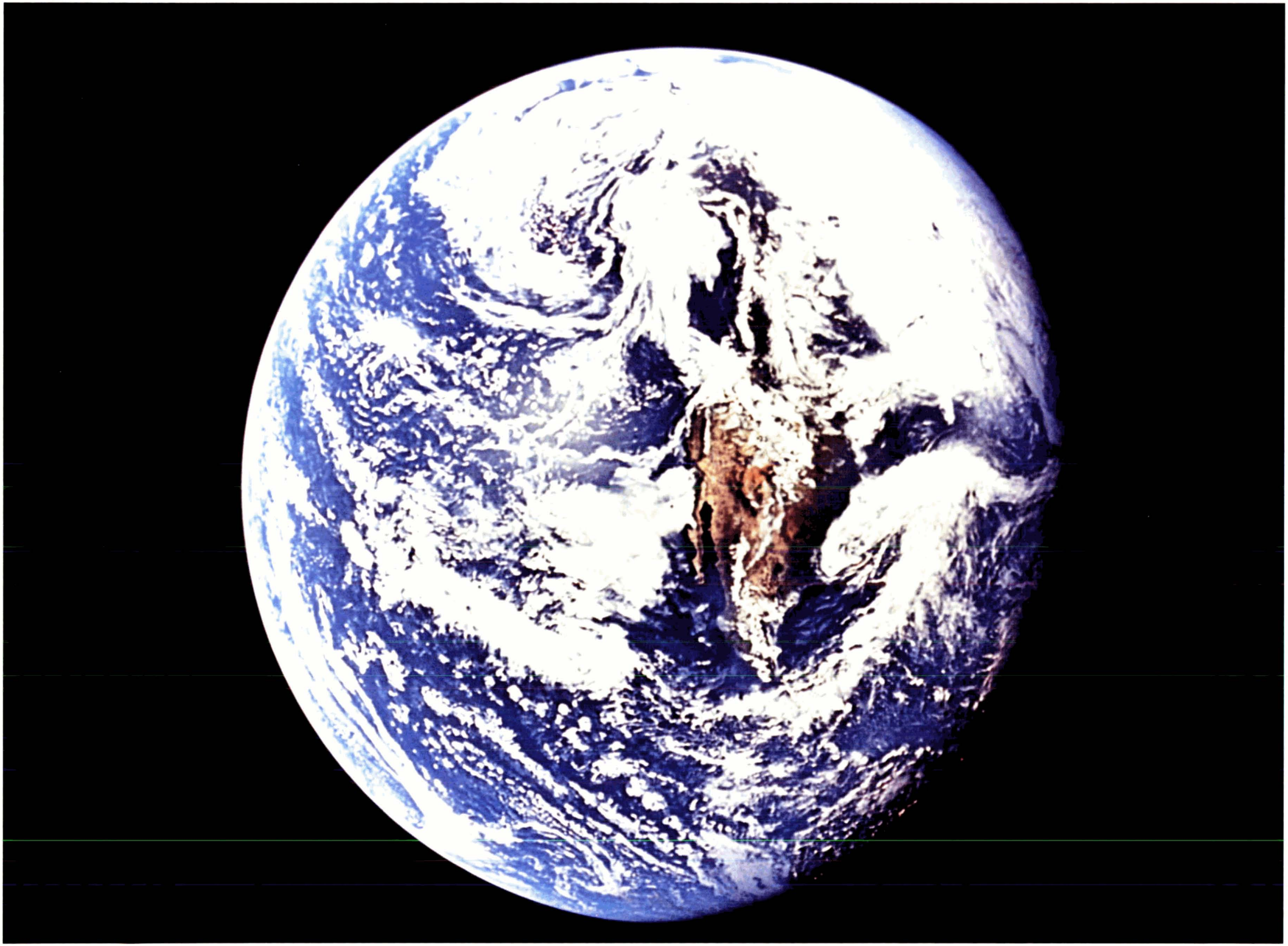
1990 — *Magellan* arrived at Venus (8/10/90)

References

1. "Charting the Planets" Educational Brief EB-111, NASA Headquarters, Washington, DC. 12/92.
2. "Magellan: Revealing the Face of Venus," JPL 400-494. Jet Propulsion Laboratory, Pasadena, CA. 3/93.
3. "Our Solar System: A Geologic Snapshot," NP 157, NASA Headquarters, Washington, DC. 5/92.

National Aeronautics and Space Administration

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 noticed 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 believed 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.

Fast Facts

Equatorial Diameter	12,756 km
Mean Distance from Sun	1.52×10^8 km
Mass	5.976×10^{23} kg
Density	5.52 g/cm^3
Mean Orbital Velocity	29.79 km/s
Tilt of Equator to Orbit	23.45°
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.*

For more information on planet Earth, access NASA Spacelink—NASA's electronic information system designed to provide current educational information to teachers, faculty, and students.

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Gopher:	spacelink.msfc.nasa.gov
Anonymous FTP:	spacelink.msfc.nasa.gov
Internet TCP/IP address:	192.149.89.61

Significant Dates

- 1957 Sputnik 1 (USSR) became the first artificial satellite of the Earth.
- 1959 Luna 1 (USSR) 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 (USSR) 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 First humans to orbit the Moon (U.S.).
- 1969 Apollo 11 (U.S.) became the first manned lunar landing.
- 1972 NASA began 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 TOMS instrument launched on Nimbus VII, recorded continuous data on Earth's ozone layer.
- 1984 Earth Radiation Budget Satellite began studies of Earth's reaction to Sun's energy.
- 1991 UARS comprehensive data on chemistry and physics of the atmosphere provides evidence that human-made chemicals are responsible for the Antarctic ozone hole.
- 1992 TOPEX/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 21st century.

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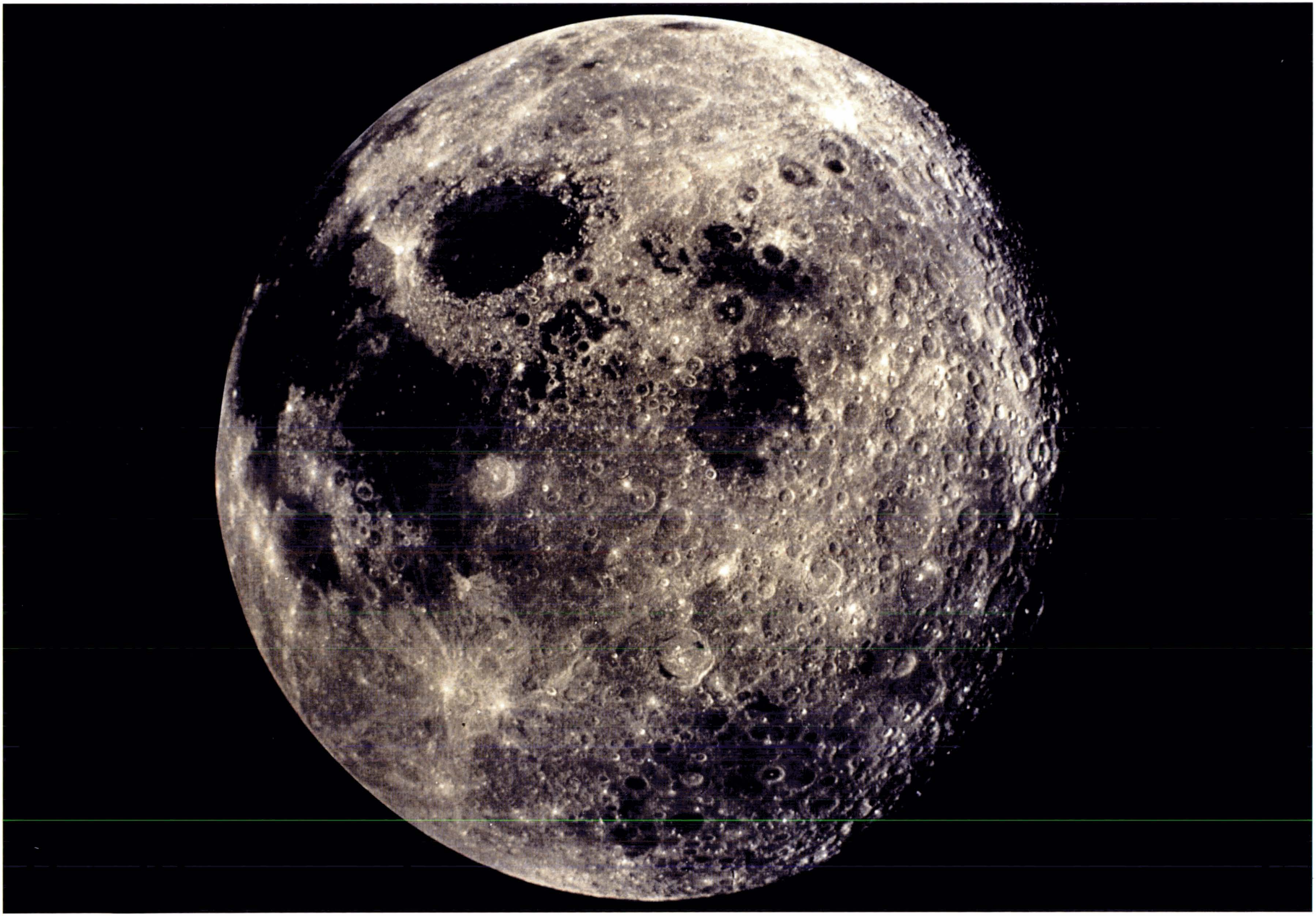
Moon



National Aeronautics and Space Administration

Moon

Earth's only natural satellite, the Moon, 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 they were formed, innumerable meteorites have hit the Moon, producing a crust that is intensely cratered 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 and volcanic activity that characterize Earth; it is a fossil planet on which the earliest stages of geologic evolution are preserved.

The Moon, however, is not completely dead. Seismometers emplaced by the *Apollo* astronauts have recorded small earthquakes (more properly called "moonquakes") at depths of several hundred kilometers. The quakes are probably triggered by tides caused by Earth. Small eruptions of gas from some craters, such as *Aristarchus*, have also been reported. We know the deep interior of the Moon is still hot, and perhaps partially molten. Although there are local magnetic areas in the lunar crust associated with some craters, there is no planet-wide magnetic field; the Moon lacks Earth's molten core.

The Moon's shape is unusual. It is slightly egg-shaped, 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 revealed strong areas of high gravitational acceleration located over the circular maria. These "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

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.*

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*

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 landing on the Moon and returned 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 — *Galileo* 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

References

1. *Our Solar System: A Geologic Snapshot*, NP 157, NASA Headquarters, Washington, DC. 5/92.
2. *Information Summaries: Our Solar System at a Glance*, PMS 010-A, Jet Propulsion Laboratory, Pasadena, CA. 6/91.
3. *Apollo Expeditions to the Moon*, NASA SP-350, NASA Headquarters, Washington, DC. 1975.

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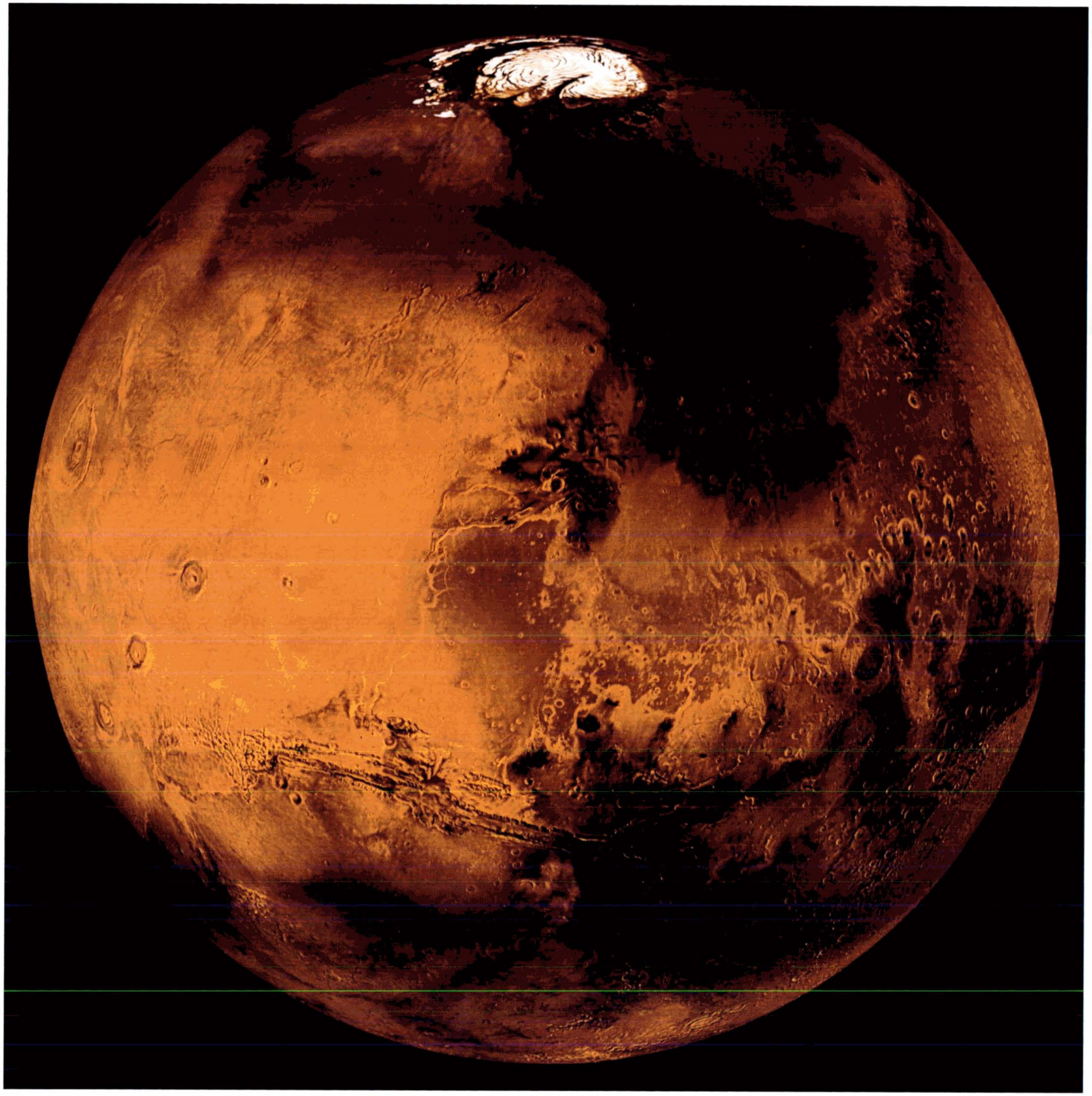
Mars ♂



Mars–the Red Planet, the Bringer of War–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 proven to be fertile ground for science fiction writers, based on seeds planted by centuries of scientific observation. Mars has shown itself to be most Earth-like of all the planets; it has polar ice caps that grew and receded with the change of seasons, and markings that looked, through 19th century telescopes, to be similar to human-made water canals on Earth, which fueled speculations that Mars was inhabited.

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 that has been subject to some of the same planetary processes associated with the formation of the other "terrestial" 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 effects of these 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 could easily fit the Grand Canyon inside it and stretches the distance equivalent from New York to Los Angeles.

Significant Dates

1965 - U.S.A. *Mariner 4* made first close-up pictures of the surface during flyby.

1969 - U.S.A. *Mariner 6* and *Mariner 7* flybys resulted in high-resolution images of the equatorial region and southern hemisphere.

1971 - U.S.A. *Mariner 9* 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. *Viking 1* orbited Mars. Lander provided first sustained surface science. U.S.A. *Viking 2* lander discovered water frost on the surface.

1988 - U.S.S.R. probe *Phobos* returned detailed pictures of Phobos.

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 20°N, 60°W. 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.

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	25.2°
Gravity	0.38 of Earth's
Atmosphere	
Main Component	Carbon Dioxide
Pressure at Surface	~8 millibars (vs 1,000 on Earth)
Temperature Range	-143°C to +17°C
Moons (2)	Phobos (Fear), 21 km diameter Deimos (Panic), 12 km diameter
Rings	None
Orbital Eccentricity	0.093
Orbital Inclination to Ecliptic	1.85°
Magnetic Field Density	To be determined. Very weak, if any.

References

1. *Discovering Mars*, PAM-537, NASA Headquarters, Washington, DC. 9/94.
2. *The Exploration of Mars*, EB-112, Educational Brief, NASA Headquarters, Washington, DC. 5/93.
3. *Charting the Planets*, EB-111, Educational Brief, NASA Headquarters, Washington, DC. 12/92.

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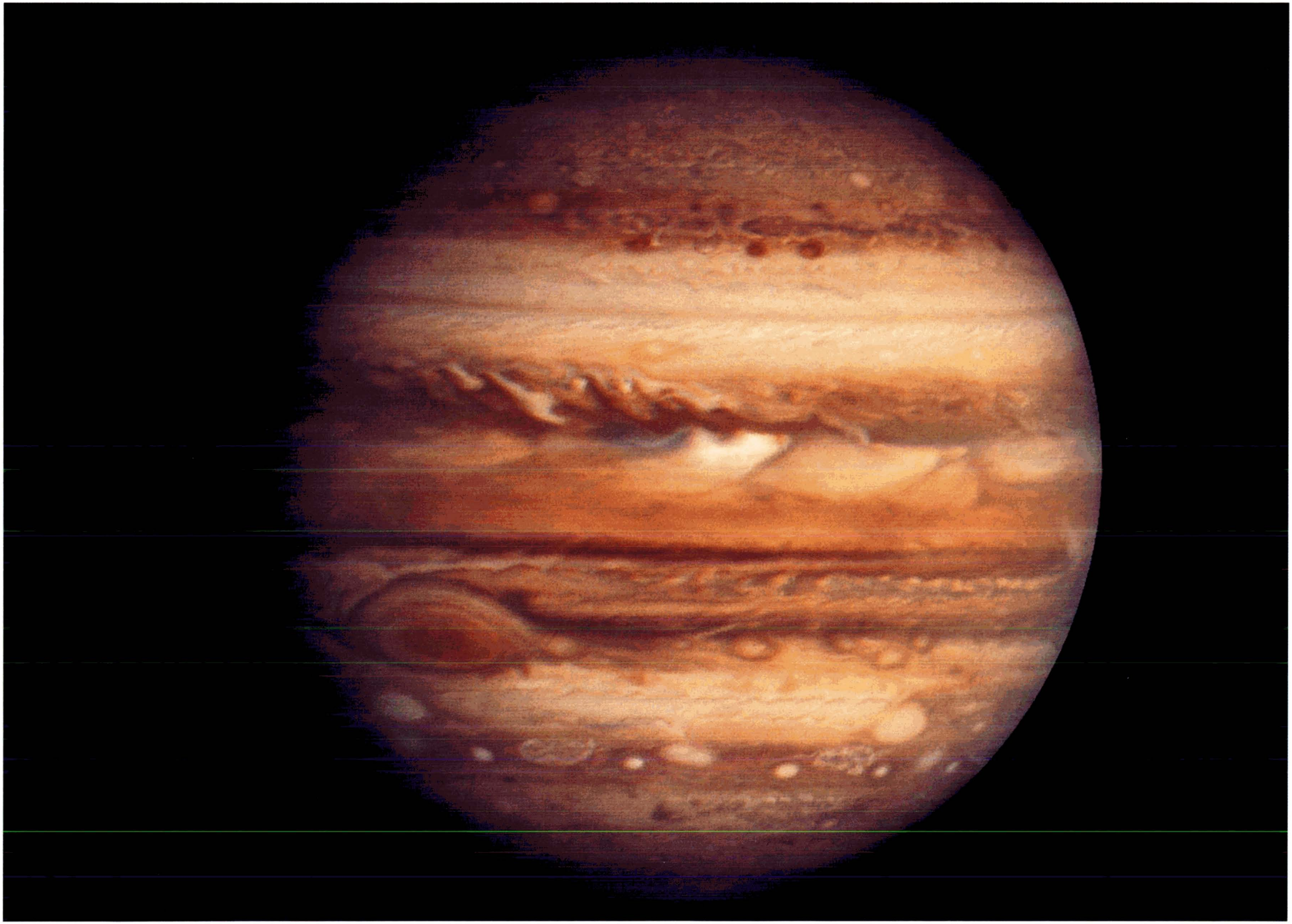

Jupiter ♃

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 millions 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.

Dynamic 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 us with 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* will arrive at Jupiter in December 1995. *Galileo* will investigate the chemical composition and physical state of Jupiter's atmosphere; will characterize the morphology, physical state, and dynamic properties of the Jovian satellites; and will analyze the structure and physical dynamics of the Jovian magnetosphere. The data obtained from *Galileo* will undoubtedly revolutionize our understanding of the complexities of Jupiter and the Jovian system.

Fast Facts

Namesake	King of the Roman Gods
Distance from Sun	778.3 Million Kilometers
Period of Revolution (1 Jovian Year)	11.86 Earth Years
Equatorial Diameter	143,200 Kilometers
Atmosphere (Main Components)	Hydrogen and Helium
Moons (16)	In Ascending 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 (1 Jovian Day)	9 Hours 55 Minutes
Inclination of Axis	3°5'

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); first images of polar regions
1979 — *Voyager 1* passed within 350,000 km of Jupiter (3/79); discovered faint ring and three moons
1979 — *Voyager 2* passed within 650,000 km of Jupiter (7/79); provided detailed imagery of Jovian ring and Io volcanism
1989 — *Galileo* spacecraft launched (10/18/89)
1995 — *Galileo* to arrive at Jupiter (12/7/95)

References
1. "Discovering Jupiter," PAM-540, NASA Headquarters, Washington, DC. 6/93.
2. Galileo Fact Sheet, NASA Headquarters, Washington, DC. 3/92.
3. "Charting the Planets" Educational Brief EB-111, NASA Headquarters, Washington, DC. 12/92.

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 of light-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 as 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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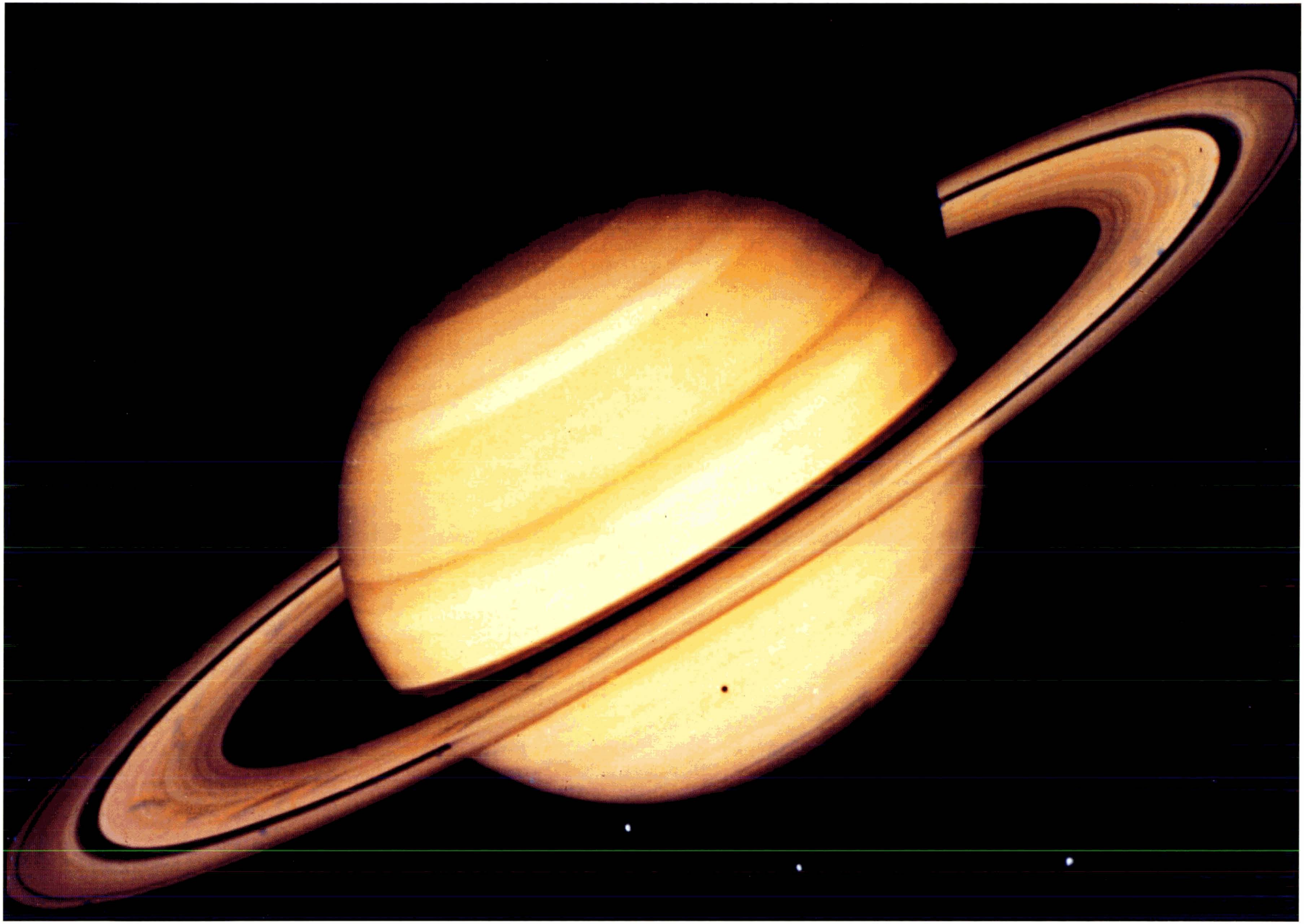
Saturn ♄



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 rings actually are 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 Cassini 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. 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 primordial Earth as well.

Cassini, 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's 4-year scientific mission is dual: to complete a multispectral, orbital surveillance of Saturn, and to investigate Titan. *Cassini* 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* 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 Kilometers
Period of Revolution (1 Saturnian Year)	29.46 Years
Equatorial Diameter	120,536 Kilometers
Atmosphere (Main Components)	Hydrogen and Helium
Moons (18)	Pan, Atlas, Prometheus, Pandora, Epimetheus, Janus, Mimas, Enceladus, Tethys, Telesto, Calypso, Dione, Helene, Rhea, Titan, Hyperion, Iapetus, 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 (1 Saturnian Day)	10 Hours 40 Minutes
Inclination of Axis	26°44′

About the Image

This true-color image was assembled from Voyager 2 images obtained August 4, 1981, from a distance of 21 million kilometers (13 million miles) from the spacecraft. Three of Saturn's icy moons (Tethys, Dione, and Rhea) are visible at the bottom of the image. The shadow of Tethys appears on Saturn's southern hemisphere. The pastel and yellow hues on the planet reveal many contrasting bright and darker bands in both hemispheres of Saturn's weather system.

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

1979 – *Pioneer 11* passed within 22,000 km of Saturn's cloudtops (9/1/79); first images of polar regions; imaged Titan; detected presence of internal source of heat in Saturn

1980 – *Voyager 1* passed within 125,000 km of Saturn's cloudtops (11/12/80); sent back 17,500 color images; measured high wind speeds in Saturn's equatorial region; imaged five moons; measured Titan's size

1981 – *Voyager* 2 passed within 101,000 km of Saturn's cloudtops (8/25/81); provided detailed imagery of rings; imaged intermediate sized moons; measured and made compositional studies of Titan's atmosphere

1997 – *Cassini* spacecraft will be launched toward the Saturnian system

2004 – Cassini to arrive at Saturn

References

1. "Discovering Saturn," PAM-541, NASA Headquarters, Washington, DC. 10/93.
2. "Charting the Planets" Educational Brief EB-111, NASA Headquarters, Washington, DC. 12/92.
3. Cassini Fact Sheet, NASA Headquarters, Washington, DC. 3/93.

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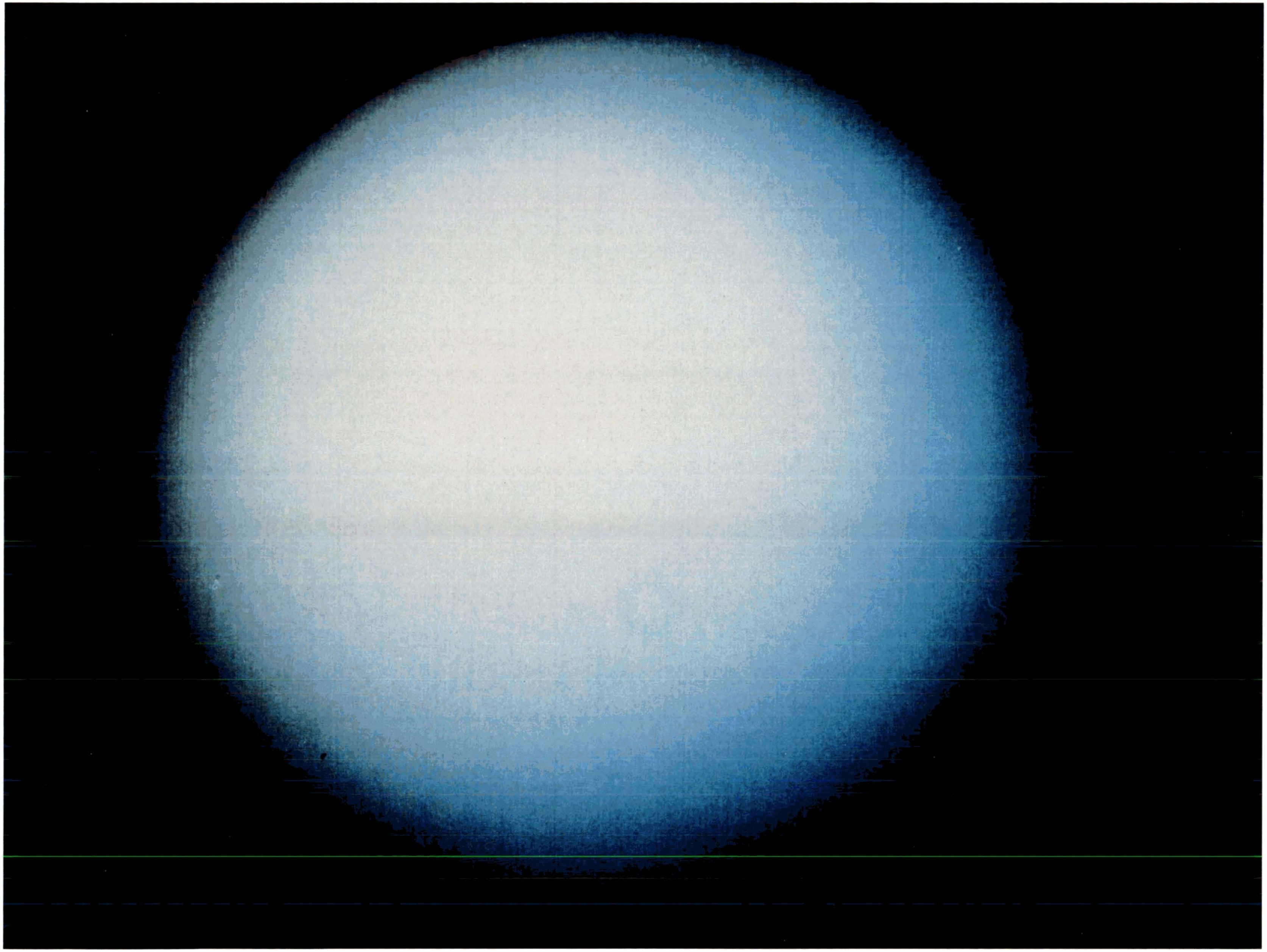

Uranus ♅

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.

Tipped Uranus behaves as 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 1 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 -220 °C.

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 50 °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 the 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 between 1.4 and 2.0 Uranian radii, with the tiny moon Cordelia orbiting inside the brightest, outermost ring. Nine other small moons orbit from 2.1 to 3.4 Uranian radii. The five outer moons, with diameters ranging from 13 to 15 percent the size of our Moon, revolve around the planet at distances from 4 to 15 radii, or 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.

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.

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 the rings of Uranus

1986 — *Voyager 2* discovered 10 small moons, 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 would 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.

Fast Facts

Namesake	Roman God, Father of the Titans
Distance from Sun	2.871 Billion Kilometers
Period of Revolution (1 Uranian Year)	84.01 Earth Years
Equatorial Diameter	51,118 Kilometers
Atmosphere (Main Components)	Hydrogen and Helium
Moons (15)	In Ascending 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	0.774°
Eccentricity of Orbit	0.046
Rotation Period (1 Uranian Day)	17 Hours 14 Minutes
Inclination of Axis	97.86°

References

1. *Our Solar System: A Geologic Snapshot*, NP 157, NASA Headquarters, Washington, DC. 5/92.
2. *Voyager at Uranus*, JPL 400-268, 1986.
3. *Information Summaries: Our Solar System at a Glance*, PMS 010-A, Jet Propulsion Laboratory, Pasadena, CA. 6/91.

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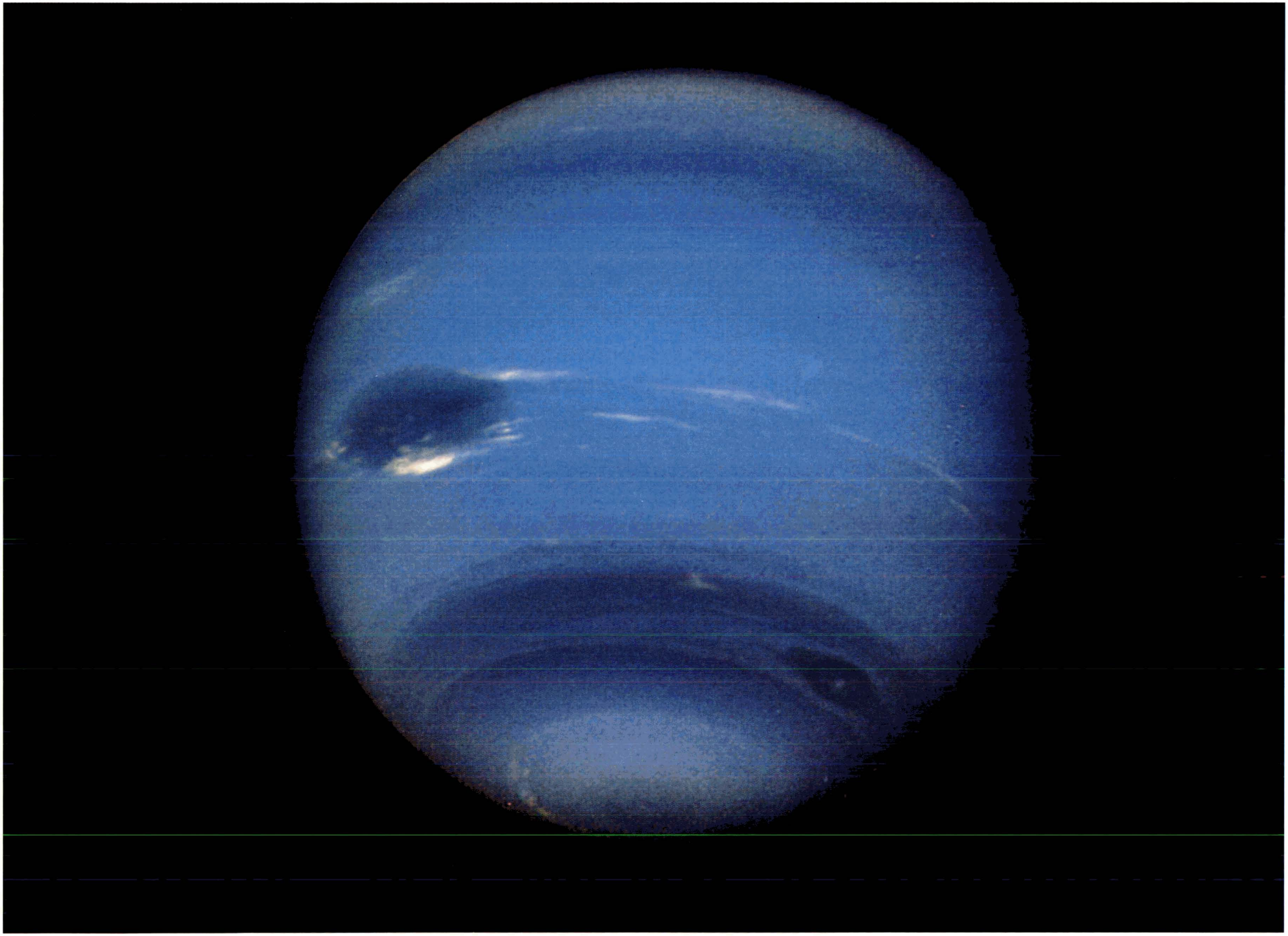
Neptune



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 of the hypothesized planet. Careful observations of this 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 there 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; this "scooter" 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. Aurorae were detected, but 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 proven 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 geologic 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 (1 Neptune Year)	164.79 Years
Equatorial Diameter	49,528 kilometers
Atmosphere (Main Components)	Hydrogen and Helium
Moons	Naiad, Thalassa, Depoina, Galatea, Larissa, Proteus, Triton, Nereid
Rings	Four thin rings of varying thickness
Inclination of Orbit to Ecliptic	1.77 degrees
Eccentricity of Orbit	0.009
Rotational Period	16.11 hours
Inclination of Axis	28.8 degrees

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.
1949	American astronomer Gerard Kuiper discovered Nereid.
1985	Rings of Neptune discovered by astronomers based on star occultations.
1989	*Voyager 2* discovered six small satellites: Naiad, Thalassa, Despoina, Galatea, Larissa, and Proteus.

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 appearances 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. *Charting the Planets*, Educational Brief, EB-111, NASA Headquarters, Washington, DC. 12/92.
2. *Our Solar System at a Glance*, Information Summaries, PMS 010-A, Jet Propulsion Laboratory, Pasadena, CA. 6/91.

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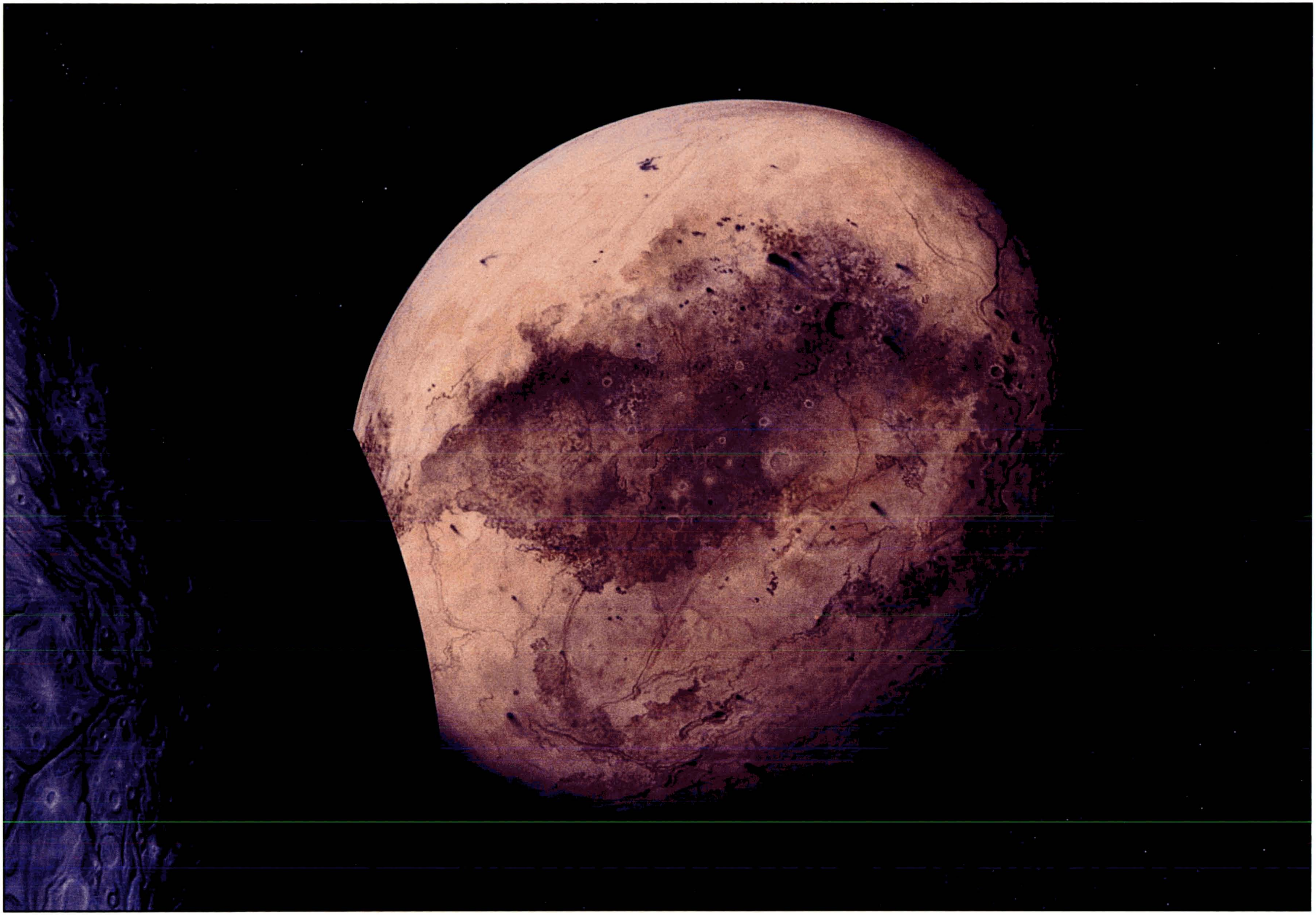
Pluto ♇



NASA artwork by Pat Rawlings

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 so 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 on 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 the 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 far from the Sun. As a result, Pluto's atmosphere is thought to persist only for the part of each orbit when Pluto is closer to the Sun, as it is now.

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 is capable of mapping Pluto; in 1994 the newly repaired Hubble will undertake this project.

Today, questions such as "How were Pluto and Charon formed?" and "Why are they so small and different from all the 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. According to these plans, one or two small spacecraft would be launched at speeds as high as 160,000 kilometers per hour in 2000 or 2001, so that they could reach Pluto before 2010, when the planet's atmosphere is expected to begin collapsing onto the surface in a planet-wide snow storm.

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	17.2°
Eccentricity of Orbit	0.25
Rotation Period	6.387 Days
Inclination of Axis	~120°
Moon	Charon
Charon's Diameter	1,210 Kilometers

Significant Dates

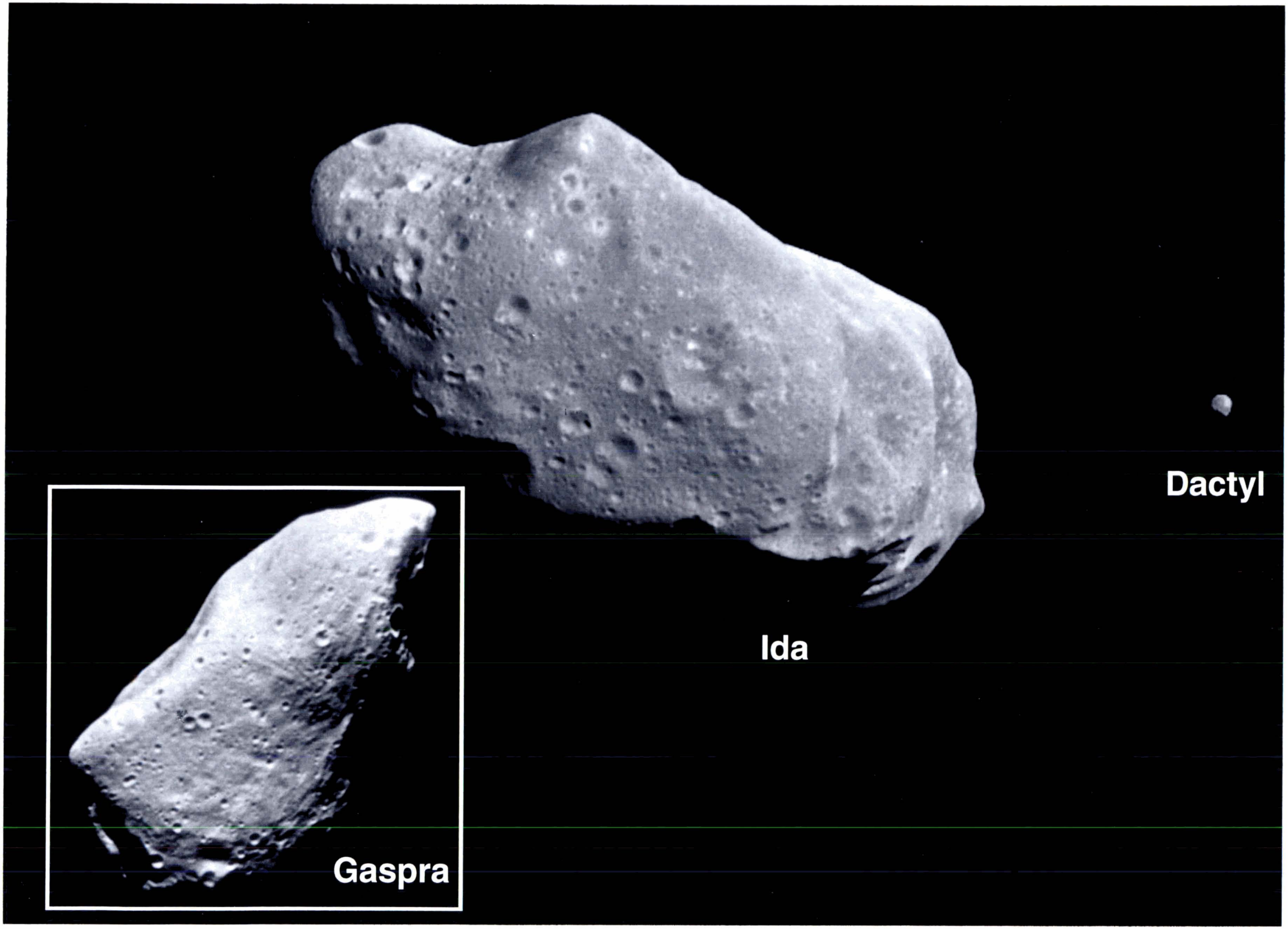
- 1930 — Pluto discovered
- 1955 — Pluto's 6.4 day rotation period discovered
- 1976 — Methane on Pluto's surface discovered
- 1978 — Charon discovered
- 1985 — Onset of Pluto-Charon eclipses (lasted 1985–1991)
- 1988 — Pluto's atmosphere discovered
- 1992 — Nitrogen and carbon monoxide on Pluto's surface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

About the Image

This artist's conception of the Pluto-Charon binary planet was conceived and executed by Pat Rawlings of Science Applications International Corporation. Pluto is represented in the background; Charon is in the foreground. The drawing depicts Pluto's true color, bright polar cap, tenuous atmosphere, and dark equatorial band. Notice how much brighter Pluto's surface is than Charon's. The craters and other geological features depicted are based on educated guesses about the kinds of features a flyby spacecraft might detect.

National Aeronautics and
Space Administration

Asteroids: Ida with Moon and Gaspra (Inset)



Asteroids: Ida with Moon and Gaspra (Inset)

The *Galileo* spacecraft, launched on October 18, 1989, has its primary mission reaching Jupiter's system; however, its carefully designed trajectory path allowed the spacecraft to accomplish two secondary missions: flying by two "minor planets"—Gaspra and Ida—and sending back to Earth our first-ever, close-up view of asteroids.

On October 29, 1991, *Galileo* passed within 1,600 kilometers of asteroid 951* Gaspra and, with incredible navigational accuracy, took pictures of it—pictures that reveal an irregular planetary body riddled with craters and fractures. To date, over 600 craters have been identified on the asteroid, the longest measuring about 1.5 kilometers across. The type of cracks seen—some more than 90-meters long—are similar to ones seen before only on the Martian moon Phobos. Some planetary scientists theorize that about 4 billion years ago, Gaspra probably measured about 97 kilometers across. But, after years of catastrophic collisions with other planetary objects, the asteroid now measures a mere 19 X 12 X 11 kilometers. This history may not be unusual for asteroids like Gaspra, many of which are believed to have accreted into relatively substantial minor planets during the formation of the solar system, only to be broken down in collisions over the ensuing billions of years.

On August 28, 1993, *Galileo* approached another asteroid—Ida. This 52-kilometer-long asteroid is more than twice as large as Gaspra. The images *Galileo* sent back reveal that numerous craters—many larger than those observed on Gaspra—pepper the surface of the asteroid. The extensive craters seem to dispel the once-believed theories that Ida's surface is geologically youthful. The sharp images of Ida also dispel a popular belief that Ida is a double body. Though Ida is not a double body in the sense that astronomers had thought, *Galileo* found that it has a moon. This tiny natural satellite, named Dactyl, is about 1.2 x 1.4 x 1.6 kilometers. It orbits Ida at a distance of about 100 km from Ida's center. Like Ida and Gaspra, Dactyl is a heavily cratered body. The largest crater observed on Dactyl is about 80 meters across. Remarkably, Dactyl appears to be composed of different materials than Ida.

Ida, like Gaspra, is an S-type asteroid, meaning that it is a reddish object composed of a mixture of the minerals pyroxene, olivine, and iron. Approximately one-sixth of all known asteroids fall within the S-type category. Gaspra and Ida like other S-class asteroids are the parent bodies of some types of basaltic meteorites.

Asteroids have long been recognized as the source of most meteorites. Our study of meteorites has taught us much about the solar system. With advances in telescopic instrumentation in the last 5 years, scientists have recognized the wealth of information that asteroids themselves may provide about the solar system's origin and evolution.

NASA's Near Earth Asteroid Rendezvous (NEAR) mission, scheduled to launch in February 1996, will swing by Earth before reaching its main target—asteroid 433 Eros—in January1999. During its 1-year rendezvous period, NEAR will address such questions as: "Is Eros related to a known meteorite type?" "Is Eros related to comets?" (Some scientists believe near-Earth asteroids are extinct or dormant comets) and "Is there evidence that Eros is a fragment of a larger body?"

* The number assigned to an asteroid (e.g., 951) denotes the order in which the asteroid's orbit was catalogued.

Fast Facts

	951 Gaspra	243 Ida
Distance from Sun (At Perihelion) (A.U.)	1.82	2.74
Period of Revolution	3.28 Years	4.84 Years
Length	19 km	52 km
Inclination of Orbit to Ecliptic	4.10°	1.14°
Eccentricity of Orbit	.173	.042
Rotational Period (Hours: Minutes)	7:03	4:38
Absolute Magnitude	12.9	11.05
Asteroid Type	S	S

About the Image

Asteroid 243 Ida appears here with its moon, Dactyl (to the right). This image taken by Galileo in August 1993, provides conclusive evidence that natural satellites of asteroids exist. The asteroid 951 Gaspra (inset) image is a mosaic of two images taken by Galileo *from a range of 5,300 km some 10 minutes before closest approach, on October 29, 1991. Images are not to the same scale. These asteroids are located in the main asteroid belt between Mars and Jupiter.*

Significant Dates

1801	Piazzi discovered first asteroid, named 1 Ceres
1884	Palisa discovered asteroid 243 Ida
1898	Witt discovered asteroid 433 Eros
1916	Neujmin discovered asteroid 951 Gaspra
1991	*Galileo* encountered asteroid 951 Gaspra
1993	*Galileo* encountered asteroid 243 Ida
1994	Dactyl discovered on *Galileo* images data
1996	NEAR mission will launch
1999	NEAR will encounter asteroid 433 Eros

References

1. Galileo *Fact Sheet*, NASA Headquarters, Washington DC. 3/92.
2. *Our Solar System, a Geologic Snapshot*, NP-157, NASA Headquarters, Washington, DC. 5/92.
3. *Our Solar System at a Glance*, Information Summaries, PMS 010-A, Jet Propulsion Laboratory, Pasadena, CA. 6/91.

NASA Resources for Educators

For more information on NASA education programs for the classroom, teachers may contact the following:

NASA's Central Operation of Resources for Educators (CORE) was established for the national and international distribution of NASA-produced educational materials in audiovisual format. Educators can obtain a catalogue of these materials and an order form by written request, on school letterhead to:

NASA CORE
Lorain County Joint Vocational School
15181 Route 58 South
Oberlin, OH 44074
PHONE: (216) 774-1051, Ext. 293 or 294

Teacher Resource Center Network
To make additional information available to the education community, the NASA Education Division has created the NASA Teacher Resource Center (TRC) network. TRCs contain a wealth of information for educators: publications, reference books, slide sets, audio cassettes, videotapes, telelecture programs, computer programs, lesson plans, and teacher guides with activities. Contact the TRC in your region (see the listing below) for details on the services they provide:

AK, AZ, CA, HI, ID, MT, NV, OR, UT, WA, WY
NASA Teacher Resource Center
Mail Stop T12-A
NASA Ames Research Center
Moffett Field, CA 94035-1000
PHONE: (415) 604-3574

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

CO, KS, NE, NM, ND, OK, SD, TX
NASA Teacher Resource Room
Mail Code AP2
NASA Johnson Space Center
2101 NASA Road One
Houston, TX 77058-3696
PHONE: (713) 483-8696

FL, GA, PR, VI
NASA Educators Resource Laboratory
Mail Code ERL
NASA Kennedy Space Center
Kennedy Space Center, FL 32899-0001
PHONE: (407) 867-4090

KY, NC, SC, VA, WV
Virginia Air and Space Museum
NASA Teacher Resource Center for
NASA Langley Research Center
600 Settler's Landing Road
Hampton, VA 23669-4033
PHONE: (804) 727-0900 x 757

IL, IN, MI, MN, OH, WI
NASA Teacher 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 Teacher Resource Center for
NASA Marshall Space Flight Center
P.O. Box 070015
Huntsville, AL 35807-7015
PHONE: (205) 544-5812

MS
NASA Teacher Resource Center
Building 1200
NASA John C. Stennis Space Center
Stennis Space Center, MS 39529-6000
PHONE: (601) 688-3338

Serves inquiries related to space and planetary exploration
NASA Teacher Resource Center
Mail Stop CS-530
NASA Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109-8099
PHONE: (818) 354-6916

CA cities near the facility
Public Affairs Office (Trl. 42)
NASA Teacher Resource Center
NASA Dryden Flight Research Facility
Edwards, CA 93523-0273
PHONE: (805) 258-3456

VA and MD's Eastern Shores
NASA Teacher Resource Lab
Education Complex -Visitor Center
Building J-17
NASA Wallops Flight Facility
Wallops Island, VA 23337-5099
PHONE: (804) 824-2297/2298

Regional Teacher Resource Centers (RTRCs) offer more educators access to NASA educational materials. NASA has formed partnerships with universities, museums, and other educational institutions to serve as RTRCs in many states. Teachers may preview, copy, or receive NASA materials at these sites. A complete list of RTRCs is available through CORE.

NASA Spacelink is an electronic information system designed to provide current educational information to teachers, faculty, and students. Spacelink offers a wide range of computer text files, software, and graphics related to the space program.

The system may be accessed by computer though direct-dial modem or the Internet.

Modem line:	(205) 895-0028
Terminal emulation:	VT-100 required
Data format:	8-N-1
Telnet:	spacelink.msfc.nasa.gov

Spacelink fully supports the following Internet services:

World Wide Web:	http://spacelink.msfc.nasa.gov
Gopher:	spacelink.msfc.nasa.gov
Anonymous FTP:	spacelink.msfc.nasa.gov
Internet TCP/IP address:	192.149.89.61

For more information, contact: Spacelink Administrator, Education Programs Office, Mail Code CL01, NASA Marshall Space Flight Center, Huntsville, AL 35812-0001.
Voice phone: (205) 961-1225
E-mail: comments@spacelink.msfc.nasa.gov

NASA Educational Satellite Videoconferences
The Education Satellite Videoconference Series for Teachers is offered as an in-service education program for educators through the school year. The content of each program varies, but includes aeronautics or space science topics of interest to elementary and secondary teachers. NASA program managers, scientists, astronauts, and education specialists are featured presenters. The videoconference schedule is available on NASA Spacelink.

The videoconference series is free to registered educational institutions. To participate, the institution must have a C-band satellite receiving system, teacher release time, and an optional long distance telephone line for interaction. Arrangements may also be made to receive the satellite signal through the local cable television system. The programs may be videotaped and copied for later use.

For more information, contact: Videoconference Producer, NASA Teaching From Space Program, 308 A CITD, Oklahoma State University, Stillwater, OK 74078-8089
E-mail: nasaedutv@smtpgate.osu.hq.nasa.gov

How to Access NASA Education Materials and Services, PED-329 April 1995. This brochure serves as a guide to accessing a variety of NASA materials and services for educators. Copies are available through the TRC network.

August 1995

Electronic Resources for Educators

The following listing of Internet addresses will provide users with robust links to earth and space science educational materials throughout the WWW. NASA resources begins with sites that cover a range of topics and becomes increasingly science specific.

NASA Resources

NASA SpaceLink
http://spacelink.msfc.nasa.gov

NASA Home Page
http://www.nasa.gov/

NASA Goddard Space Flight Center
Space Science Education Home Page
http://www.gsfc.nasa.gov/education/education_home.html

NASA Mission To Planet Earth Home Page
http://www.hq.nasa.gov/office/mtpe

NASA Jet Propulsion Laboratory
Learning Link
http://learn.jpl.nasa.gov

Remote Sensing Public Access Center
http://www.rspac.ivv.nasa.gov

Public Access to NASA's Planetary Data
http://stardust.jpl.nasa.gov/public

Lunar and Planetary Institute
http://cass.jsc.nasa.gov/lpi.html

Astronomy On-line: Ask Dr. Sue
http://dlt.gsfc.nasa.gov/Ask

NASA/JPL Imaging Radar Home Page
http://southport.jpl.nasa.gov

Global Quest: The Internet in the Classroom
http://quest.arc.nasa.gov

Other Earth and Space Science Resources

American Geophysical Union
http://earth.agu.org/kosmos/homepage/html

Arizona Mars K-12 Educational Supplement and Guide
http://esther.la.asu.edu/cgi-bin/imagemap/tes_home?144,327

Astronomical Society of the Pacific
http://www.physics.sfsu.edu/asp/asp.html

Earth System Science Education Program
Universities Space Research Association
http://www.usra.edu/esse/Educational_Resources.html

The Planetary Society
http://planetary.org/tps/

Space Telescope Science Institute (STScI)
Hubble Space Telescope's Greatest Hits 1990-1995 Picture Gallery
http://www.stsci.edu/public.html

Space Telescope Science Institute Exploration in Education (EXInED) Picture Books
http://stsci.edu/exined-html/exined-home.html

Telescopes In Education
http://www.mtwilson.edu/tie.html

YAHOO
http://www.yahoo.com/Education

Educators and scientists at the National Aeronautics and Space Administration would appreciate your taking a few minutes to respond to the statements and questions below. Please return by mail.

SA	-	Strongly Agree
A	-	Agree
D	-	Disagree
SD	-	Strongly Disagree

Solar System Lithograph Set

1. The lithograph set is easily integrated into the curriculum.	SA	A	D	SD
2. It is helpful to me to have a complete set of planetary images.	SA	A	D	SD
3. The information on the back of the lithographs is both informative and educational.	SA	A	D	SD

4. a. What features of the lithographs are particularly helpful in your teaching?

____

b. What changes would make the set more effective for you?

____

5. I teach_____ grade. Subjects_______________________________

6. I used the guide with _____ (number of) students.

Additional comments: _______________________________________

____

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Today's Date: ______________