Solar System Lithograph Set
for Space Science

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- Our Solar System
- Our Star—The Sun
- Mercury
- Venus
- Earth
- Moon
- Mars
- Asteroids
- Jupiter
- Moons of Jupiter
- Saturn
- Uranus
- Neptune
- Pluto and Charon
- Comets
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       Phone: (973) 425-6000
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     - VA: Virginia Tech
       Phone: (540) 231-6000
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     - SC: University of South Carolina
       Phone: (803) 777-1000
     - SC: Clemson University
       Phone: (864) 656-5000
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     - GA: Georgia Tech
       Phone: (404) 385-1000
     - GA: Emory University
       Phone: (404) 727-1000
   - Florida:
     - FL: University of Florida
       Phone: (352) 392-1000
     - FL: Florida State University
       Phone: (850) 644-1000
   - Alabama:
     - AL: University of Alabama
       Phone: (205) 348-2000
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       Phone: (334) 844-2000
   - Mississippi:
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       Phone: (662) 325-1000

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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 goddess 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 Mars and Jupiter, 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 all of the planets—and some of the moons—have atmospheres. 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 at least 91 natural satellites (also called moons) around the various planets in our solar system, ranging from bodies larger than our own Moon down to small pieces of debris. Many of these were discovered by planetary spacecraft. Some of these moons 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 a 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 they 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 the Sun. Little by little, we are charting the universe, and obvious questions arise: 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 the development of yet more powerful observing tools and techniques.

The illustration on the reverse side is an artistic representation of the planets' sizes and distances.

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 of 65,000 kilometers 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. How large does 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.

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<td>Earth</td>
<td>149,600,000</td>
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<td>Jupiter</td>
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<td>Uranus</td>
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<tr>
<td>Neptune</td>
<td>4,504,300,000</td>
<td>1</td>
</tr>
</tbody>
</table>

References

1) Views of the Solar System—Solar System http://www.solarviews.com
3) Stardate: http://stardate.org
Mission: Genesis 7) observed Sun, discovered coronal holes. 1973–74
http://vestige.lmsal.com/TRACE

First direct observations of solar wind made by
Transition Region and Coronal Explorer 6) 1998

Corona temperature discovered to be 1,000,000 K. 1959
http://sohowww.nascom.nasa.gov

Helium lines first observed in solar spectrum. 1868
http://ulysses.jpl.nasa.gov

First solar eclipse successfully predicted. 585 BC
http://www-istp.gsfc.nasa.gov/istp/outreach

About the Images

SOHO/Extreme Ultraviolet Imaging

SOHO/MDI

SOHO/EIT

SOHO/Transition Region and Coronal Explorer (TRACE)

SOHO/MDI

SOHO/Extreme Ultraviolet Imaging

SOHO

SUN

Our SUN has inspired mythology in almost all cultures, including ancient Egyptians, Aztecs, Native Americans, and Chinese. We now know that the Sun is a huge, bright sphere of mostly ionized gas, about 4.6 billion years old, and is the closest star to Earth at a distance of about 150 million km. The next closest star—Proxima Centauri—is roughly 266,000 times farther away. There are millions of similar stars in the Milky Way Galaxy (and billions of galaxies in the universe). Our Sun supports life on Earth. It powers photosynthesis in green plants and is ultimately the source of all food and fossil fuel. The connection and interaction between the Sun and the Earth drive the seasons, currents in the ocean, weather, and climate.

The Sun is some 333,400 times more massive than Earth 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, with a density about 100 times that of water).

At the core, the temperature is 10 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 a gaseous form. The total energy released is 382 billion trillion kilowatts, which is equivalent to the energy generated by 10 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 edge of the core outward, first through the radiative zone and then through the convective zone, the temperature decreases from 0 million to 700 K. It takes a few hundred thousand years for photons to escape from the dense core and reach the surface.

The Sun’s “surface,” known as the photosphere, is just the middle 500-km-thick layer from which most of the Sun’s radiation and light finally escape, and it 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. Since it is physically impossible to transfer thermal energy from the cooler surface of the Sun to the much hotter corona, the source of coronal heating has been a scientific mystery for more than 50 years. Scientists believe that energy transfer has to be in the form of waves or magnetic energy. Likely solutions have emerged from recent SOHO and TRACE satellite observations, which found evidence for the upward transfer of magnetic energy from the Sun’s surface toward the corona above. Researchers in NASA Sun-Earth Connection Space Science theme study these impressive phenomena.

Fast Facts

Spectral Type of Star: G2 V
Age: 4.5 billion years
Mean Distance to Earth: 150 million km
Rotation Period (at equator): 26.8 days
Rotation Period (at poles): 36 days
Diameter: 1.4 million km
Mass: 1.99 x 10^30 kilograms
Composition (number of atoms): 92.1% Hydrogen, 7.8% Helium
Temperature (photosphere): 5,780 K
Energy Output (luminosity): 3.83 x 10^26 ergs/sec

Significant Dates

58 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 terrestrial weather.
1868 Helium lines first observed in solar spectrum.
1946 Corona temperature discovered to be 1,000,000 K.
1959 Solar and Heliospheric Observatory (SOHO) launches.
1991 Japan’s Yohkoh satellite studies X rays and gamma rays.
1994–95 ESA/NASA’s Transition Region and Coronal Explorer (TRACE) satellites view the Sun in X rays.
1995 ESA/NASA’s Solar and Heliospheric Observatory (SOHO) studies the solar interior, atmosphere, and wind.
1998 NASA’s Ulysses mission studies polar regions of Sun.

References
1) Sun-Earth Connection Education Forums: http://sunearth.gsfc.nasa.gov/education/2
4) TRACE satellite: http://solwind.lmsal.com/TRACE
6) Transition Region and Coronal Explorer (TRACE): http://TRACE.lmsal.com/TRACE

By: 03. Sun 9/4/01 12:29 PM Page 1
The small and rocky planet MERCURY is the closest planet to the Sun; it spends around the Sun in a wildly elliptical (non-circular) orbit that takes it as close as 47 million km and as far as 70 million km from the Sun. Mercury completes a trip around the Sun every 88 days, speeding through space at nearly 50 km per second, faster than any other planet. Because it is so close to the Sun, temperatures on its surface can reach a scorching 467 degrees Celsius. But because the planet has barely any atmosphere to keep it warm, nighttime temperatures can drop to a frigid -183 degrees Celsius.

Because Mercury is so close to the Sun, it is hard to see from Earth except during heliogaps. Until 1965, scientists thought that the same side of Mercury always faced the Sun. Then, astronomers discovered that Mercury completes three rotations for every two orbits around the Sun. If you wanted to stay up for a Mercury day, you'd have to stay up for 176 Earth days!

Like our Moon, Mercury has almost no atmosphere. What little atmosphere exists is made up of atoms blasted off its surface by the solar wind and has less than a million-billionths of the pressure on Earth's atmosphere at sea level. It is composed chiefly of oxygen, sodium, and helium. Because of Mercury's extreme surface temperature, these atoms quickly escape into space and are constantly replenished. With no atmosphere to protect the surface, there has been no erosion from wind or water, and meteorites do not burn up due to friction as they do in other planetary atmospheres.

Mercury's surface very much resembles Earth's Moon, scarred by thousands of impact craters resulting from collisions with meteors. While there are areas of smooth terrain, there are also cliffs, some towering upwards of one mile high, formed by ancient impacts.

The Caloris Basin, one of the largest features on Mercury, is about 1,300 km in diameter. It was the result of an asteroid impact on the planet's surface early in the solar system's history, the probable cause of the strange surfaces on the opposite side of the planet. Over the next billion years, Mercury actually shrank in radius from 2 to 4 km as the planet cooled from its formation. The outer crust, called the lithosphere, was compressed and grew strong enough to prevent the planet's magma from reaching the surface, effectively ending the planet's period of geologic activity. Evidence of Mercury's active past is seen in the smooth plains in the Caloris basin.

Mercury is the second smallest planet in the solar system, larger only than Pluto, the most distant planet in our solar system. If Earth were the size of a baseball, Mercury would be the size of a golf ball. Viewed from Mercury, the Sun would look almost three times as large as it does from Earth. Mercury is the second densest body in the solar system after Earth, with an interior made of a large iron core with a radius of 1,800 to 1,900 km, nearly 75 percent of the planet's diameter and nearly the size of Earth's Moon. Mercury's outer shell, comparable to Earth's outer shell (called the mantle) is only 50 to 600 km thick.

Only one spacecraft has ever visited Mercury: Mariner 10 in 1974–75. Mariner 10’s discovery that Mercury has a very weak magnetic field, similar to but weaker than Earth’s, was a major surprise. In 1991, astronomers using radar observations showed that Mercury may have water ice at its north and south poles. The ice exists inside deep craters. The floors of these craters remain in perpetual shadow, so the Sun cannot melt the ice.

NASA is planning a new mission to Mercury called MESSENGER, an acronym for Mercury Surface, Space Environment, Geochemistry, and Ranging, which will orbit Mercury toward the end of this decade. MESSENGER will investigate key science questions using a set of miniaturized instruments: Why is Mercury so dense? What is the geographic history of Mercury? What is the structure of Mercury’s core? What is the nature of Mercury’s magnetic field? What are the unusual materials at Mercury’s poles? What volatiles are important on Mercury?

### Fast Facts

**Namesake:** Messenger of the Roman Gods

**Mean Distance from Sun:** 57.9 million km

**Orbital Period:** 88 days

**Orbital Eccentricity:** 0.206

**Orbital Inclination to Ecliptic:** 7

**Inclination of Equator to Orbit:** 0

**Rotational Period:** 58 d 39 m

**Diameter:** 4,879 km

**Mass:** 0.05 of Earth

**Density:** 5.43 g/cm³

**Gravity:** 0.35 of Earth’s

**Atmosphere (primary components):** Oxygen, Sodium, Helium

**Temperature Range:** -183°C (night) to +467°C (day)

**Number of Moons:** 0

**Number of Rings:** 0

### 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 that 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 flyby within 705 km of Mercury.
- **1975** Mariner 10 made its third and final flyby of Mercury at 327 km.

### About the Images

(Left) Mariner 10, taken the first spacecraft picture of Mercury from the lunar surface.

(Right, top) Caloris Basin was undoubtedly produced from a tremendous impact. A circular mountain range surrounding the wrinkled terrain at left defines the basin's main rim (Mariner 10).

(Right, bottom) Photomosaic of Mercury's southern hemisphere (Mariner 10).

### References

1. MESSENGER Mission: http://www.jhuapl.edu/MESSENGER
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 there the similarities end. Venus has no oceans. Venus is covered by thick, rapidly spinning clouds that trap surface heat, creating a scorching greenhouse-like world with temperatures hot enough to melt lead and pressure so intense that standing on Venus would feel like the pressure felt 900 meters deep in Earth’s oceans. These clouds reflect sunlight in addition to trapping heat. Because Venus reflects so much sunlight, it is usually the brightest planet in the sky.

The atmosphere consists mainly of carbon dioxide (the same gas that produces fizzy soda), droplets of sulfuric acid, and virtually no water vapor—not a great place for people or plants! In addition, the thick atmosphere allows the Sun’s heat in but does not allow it to escape, resulting in surface temperatures over 460 °C, hotter than the surface of the planet Mercury. Venus’s thick clouds are very close to the Sun. The high density of the atmosphere results in a surface pressure 90 times that of Earth, which is why probes that have landed on Venus have only survived several hours before being crushed by the incredible pressure. In the upper layers, the clouds move faster than hurricane-force winds on Earth.

Venus sluggishly rotates on its axis once every 243 Earth days, while it orbits the Sun every 225 days—in a day longer than its year! Besides that, Venus rotates retrograde, or “backwards,” spinning in the opposite direction of its orbit around the Sun. From its surface, the Sun would seem to rise in the west and set in the east.

Earth and Venus are similar in density and chemical compositions, and both have relatively young surfaces, with Venus appearing to have been completely resurfaced 500 to 900 million years ago.

The surface of Venus is covered by about 20 percent broadleaf plains, 70 percent rolling uplands, and 10 percent highlands. Volcanism, impacts, and deformation of the crust have shaped the surface. No direct evidence of currently active volcanoes has been found, although large variations of sulfur dioxide in the atmosphere lead some scientists to suspect that volcanoes may be active.

Although no rainfall, oceans, or strong winds exist to erode surface features, some weathering and erosion does occur. The surface is breached by gentle winds, no stronger than a few kilometers per hour, enough to move grains of sand, and radar images of the surface show wind streaks and sand dunes. In addition, the corrosive atmosphere probably chemically alters rocks.

Impact cratering is also affected by the dense atmosphere: craters smaller than 1.5 to 2 km across do not exist on Venus, largely because small meteors burn up in Venus’ dense atmosphere before they can reach the surface.

More than 1,000 volcanoes or volcanic centers larger than 20 km in diameter dot the surface of Venus. There may be close to a million volcanic centers that are over 1 km in diameter. Much of the surface is covered by vast lava flows. In the north, an elevated region named Bilia Terra is a scarsilled basin larger than the continental United States. Near the equator, the Aphrodite Terra highlands, more than half the size of Africa, extend for almost 10,000 kilometers. Volcanic flows have also produced long, narrow channels extending for hundreds of kilometers.

With few exceptions, features on Venus are named for accomplished women from all of Earth’s cultures.

Venus’s interior is probably very similar to that of Earth, containing an iron core about 3,000 km in radius and a molten rocky mantle covering the majority of the planet. Recent results from the Magellan spacecraft suggest that Venus’ crust is stronger and thicker than had previously been thought.

Venus has no satellites and no intrinsic magnetic field, but the solar wind rushing by Venus creates a pseudo-field around the planet.

**Fast Facts**

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**Significant Dates**

- 1962: Mariner 2 (U.S.) flies by Venus; verifies high temperatures.
- 1972: Venera 9 (U.S.S.R.) lands on Venus; transmits data in less than one hour.
- 1974: Mariner 10 (U.S.) provides coverage for Venus; tracked global atmospheric circulation with visible and ultraviolet imagery.
- 1975: Pioneer Venus Orbiter (U.S.) takes first surface pictures of Venus on its orbit.
- 1978: Pioneer Venus (U.S.) radar maps Venus; Pioneer Venus Multiprobe (U.S.) drops four probes through Venusian clouds.
- 1983: Pioneer Venus Orbiter and Multiprobe (U.S.) provide high-resolution mapping radar and atmospheric analyses.

**About the Images**

- (Left) Only radar can penetrate Venus’s thick clouds to reveal its topography. (Ava is low area; hills are high area). Aphrodite Terra, a bright highland north of the site of Mariner 10’s flyby, makes the area appear to be slightly elevated compared to its surroundings.
- (Right, top) Venus’s thick clouds of carbon dioxide produce a “mature greenhouse effect.” The -shaped cloud patterns indicate wind speeds up to 500 km per hour in the upper layers of the atmosphere. (Pioneer Venus microwave radiometer image).
- (Right, center) This cluster of large craters in an area the size of Michigan range in diameter from 50 to 35 km. (Multiprobe).
- (Right, bottom) These steep-sided and flat-topped domes of lava have oozed onto the plains east of Alpha Regio. They average 25 km in diameter with maximum heights of 790 meters. (Multiprobe).
- (Forenight) Bright areas on ancient lava blankets the flanks of the 6-km-high volcano Maat Mons. The volcanic area in this image has been exaggerated 23 times to enhance small features and aid analysis of the area. The color is simulated based on data from the Soviet (U.S.) spacecraft Magellan.

**References**


-National Aeronautics and Space Administration

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**VENUS**

**Madame de Pompadour**

**Fast Facts**

- Human Goddess of Love and Beauty
- Mean Distance from Sun: 0.72 AU
- Orbital Period: 224.69 days
- Orbital Eccentricity: 0.007
- Orbital Inclination to Ecliptic: 3.4°
- Inclination of Equator to Orbit: 177.5°
- Rotational Period: 243 d (synchronous)
- Diameter: 12,104 km
- Mass: 0.82 of Earth’s
- Density: 5.24 g/cm³
- Gravity: 0.91 of Earth’s
- Atmosphere (primary component): Carbon Dioxide
- Mean Temperature at Solid Surface: 462°C
- Number of Moons: 0
- Number of Rings: 0

---

**Significant Dates**

- 1962: Mariner 2 (U.S.) flies by Venus; verifies high temperatures.
- 1972: Venera 9 (U.S.S.R.) lands on Venus; transmits data in less than one hour.
- 1974: Mariner 10 (U.S.) provides coverage for Venus; tracked global atmospheric circulation with visible and ultraviolet imagery.
- 1975: Pioneer Venus Orbiter (U.S.) takes first surface pictures of Venus on its orbit.
- 1978: Pioneer Venus (U.S.) radar maps Venus; Pioneer Venus Multiprobe (U.S.) drops four probes through Venusian clouds.
- 1983: Pioneer Venus Orbiter and Multiprobe (U.S.) provide high-resolution mapping radar and atmospheric analyses.

**About the Images**

- (Left) Only radar can penetrate Venus’s thick clouds to reveal its topography. (Ava is low area; hills are high area). Aphrodite Terra, a bright highland north of the site of Mariner 10’s flyby, makes the area appear to be slightly elevated compared to its surroundings.
- (Right, top) Venus’s thick clouds of carbon dioxide produce a “mature greenhouse effect.” The -shaped cloud patterns indicate wind speeds up to 500 km per hour in the upper layers of the atmosphere. (Pioneer Venus microwave radiometer image).
- (Right, center) This cluster of large craters in an area the size of Michigan range in diameter from 50 to 35 km. (Multiprobe).
- (Right, bottom) These steep-sided and flat-topped domes of lava have oozed onto the plains east of Alpha Regio. They average 25 km in diameter with maximum heights of 790 meters. (Multiprobe).
- (Forenight) Bright areas on ancient lava blankets the flanks of the 6-km-high volcano Maat Mons. The volcanic area in this image has been exaggerated 23 times to enhance small features and aid analysis of the area. The color is simulated based on data from the Soviet (U.S.) spacecraft Magellan.

**References**

Earth, our home planet, is the only planet in our solar system known to harbor life—life that is incredibly diverse. 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 life—including humans—combine forces to create a constantly changing world that we are striving to understand.

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. The four seasons are a result of Earth’s axis of rotation being tilted more than 23 degrees.

Oceans at least 4 km deep cover nearly 70 percent of Earth’s surface. Fresh water exists in the liquid phase only within a narrow temperature span (0 degrees to 100 degrees Celsius). This temperature span is especially narrow when contrasted with the full range of temperatures found within the solar system. The presence and distribution of water vapor in the atmosphere is responsible for much of Earth’s weather. Near the surface, an ocean of air that consists of 78 percent nitrogen, 21 percent oxygen, and 1 percent other ingredients cools us. This atmosphere affords Earth’s long-term climate and short-term local weather, shields us from nearly all harmful radiation coming from the Sun, and protects us from meteors as well—most of which burn up before they can strike the surface. Satellites have revealed that the upper atmosphere actually swirls by day and contracts by night due to solar activity.

Our planet’s rapid spin and metal-nickel-iron core give rise to a magnetic field, which the solar wind distorts into a constantly changing magnetic field. Charged particles from the solar wind become trapped in Earth’s magnetic field, collide with air molecules above our planet’s magnetic poles. These air molecules then begin to glow and are known as the aurora, or the Northern and Southern Lights. Earth’s land surfaces are also in motion. For example, the North American continent continues to move west over the Pacific Ocean basin, roughly at a rate equal to the growth of our fingernails. Earthquakes result when plates grind past one another, ride up over one another, collide to make mountains, or split and separate. These movements are known as plate tectonics. Developed within the last 30 years, this explanation has unified the results of centuries of study of our planet, long believed to be unmovable.

From the vantage point of space we are able to observe our planet globally, as we do other planets, using similar sensitive instruments to understand the delicate balance among its oceans, air, land, and life.

### Fast Facts

<table>
<thead>
<tr>
<th>Description</th>
<th>Information</th>
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<tr>
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<td><strong>Orbital Period</strong></td>
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<td><strong>Orbital Inclination to Ecliptic</strong></td>
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<tr>
<td><strong>Rotational Period</strong></td>
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<td><strong>Diameter</strong></td>
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<td><strong>Mass</strong></td>
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<td><strong>Density</strong></td>
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<td><strong>Gravity</strong></td>
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<tr>
<td><strong>Atmosphere (primary components)</strong></td>
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<tr>
<td><strong>Mean Temperature at Surface</strong></td>
<td>15 °C</td>
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<tr>
<td><strong>Number of Moons</strong></td>
<td>0</td>
</tr>
<tr>
<td><strong>Number of Rings</strong></td>
<td>0</td>
</tr>
</tbody>
</table>

### Significant Dates

- **1957** Sputnik (U.S.S.R.) becomes Earth’s first artificial satellite.
- **1960** NASA launches Tiros, first weather satellite.
- **1968** GOES series of weather satellites begins.
- **1972** Landsat satellite series begins to observe Earth’s land surfaces.
- **1991** EARS provides evidence that human-made chemicals are responsible for the Antarctic ozone hole.
- **1992** U.S./French satellite TOPEX/Posidron details links between Earth’s oceans and climate.
- **1999** Terra Earth-observing satellite begins studying global climate change.
- **2000** Shuttle Radar Topography Mission (SRTM) maps 80 percent of Earth’s surface at 50-meter resolution.

### About the Images

(Left) Earth is an ocean planet. The complex interplay between oceans and air affects our climate and weather (NOAA GOES-7/late color). (Right, top) Plants use chlorophyll during photosynthesis. Chlorophyll concentrations around the world indicate the distribution and abundance of vegetation. Since most animal life relies on vegetation for nutrition, directly or indirectly, these images are snapshots of Earth’s biosphere (Stoilova). (Right, center) The temperatures of the surfaces of Earth’s oceans are used to help predict weather patterns, to track ocean currents, and to monitor El Niño and La Niña. Warm water (red) is higher, while cold water (blue) is lower (NOAA). (Right, bottom left) Spaceborne radar allows us to observe regions that are hard to reach. This false-color radar image of central Africa shows the Virunga Volcano chain along the borders of Rwanda, Zaire, and Uganda. This area is home to the endangered mountain gorillas (Shuttle Imaging Radar D-4). (Right, bottom right) Global maps of ozone in Earth’s stratosphere show the role of chlorine monoxide in the destruction of stratospheric ozone; especially over the cold polar regions (Microwave Limb Sounder on Upper Atmosphere Research Satellite).
The regular daily and monthly rhythms of Earth's only natural satellite, the Moon, have guided timekeepers since ancient times. Its influence on Earth's cycles, notably tides, has also been channeled by many cultures in many ages. More than 70 spacecraft have been sent to the Moon, 12 astronauts have walked upon its surface and brought back 382 kg of lunar rock and soil to Earth.

The presence of the Moon stabilizes Earth's wobble. This has led to a much more stable climate over billions of years, which may have affected the course of the development and growth of life on Earth.

How did the Moon come to be? The leading theory 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. Scientists believe that the Moon was formed approximately 4.5 billion years ago (the age of the oldest collected lunar rocks). When the Moon formed, its outer layers melted under very high temperatures, forming the lunar crust, probably from a global "magma ocean."

From Earth, we see the same face of the Moon all the time because the Moon rotates just once on its own axis in very nearly the same time that it travels once around Earth. This is known as "synchronous rotation." Patterns of dark and light features on the nearside have given rise to the fanciful "Man in the Moon" description. The light areas are lunar highlands. The dark features, called maria, are impact basins that were filled with dark lava between 4 and 3.5 billion years ago.

After this time of volcanism, the Moon cooled down, and has since been nearly unchanged, except for a steady rain of "hits" by meteorites and comets. The Moon's surface is charcoal gray and sandy; with much fine soil. This powdery blanket is called the lunar regolith, a term for mechanically produced debris layers on planetary surfaces. The regolith is thin, ranging from about 2 meters on the youngest maria to perhaps 20 meters on the oldest surfaces in the highlands.

Unlike Earth, the Moon does not have moving crustal plates or active volcanoes. However, seismometers placed by the Apollo astronauts in the 1970s have recorded small quakes 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 anomalies have been detected around craters, but the Moon does not have a magnetic field resembling Earth's.

A surprising discovery from the tracking of the Lunar Orbiter spacecraft in the 1960s revealed strong areas of high gravitational acceleration located over the circular maria. These mass concentrations (mascons) may be caused by layers of denser, basaltic lavas that fill the maria basins.

In 1998, the Lunar Prospector spacecraft team reported finding water ice at both poles. Comet impacts deposited water on the Moon. Some of it migrated to very dark, very cold areas at the poles.

Much remains to be learned about our Moon. Researchers continue to study the samples and data returned by Apollo and other missions, as well as lunar meteorites.

### Fast Facts

**Mean Distance from Earth**: 384,400 km
**Orbital Period**: 27.3 days
**Orbital Eccentricity**: 0.05
**Orbital Inclination to Elliptic**: 18.5° – 28.6°
**Inclination of Equator to Orbit**: 6.6°
**Rotational Period**: 27.3 h 7.4 m (synchrotron)
**Diameter**: 3,475 km
**Mass**: 7.34 x 10^22 kg
**Density**: 3.34 g/cm^3
**Gravity**: 0.17 of Earth's
**Surface Rocks**: Basaltic and anorthositic
**Atmosphere**: None
**Mean Temperature at Surface**: 107 °C (day), -155 °C (night)

### Significant Dates

**1610**
Italian astronomer Galileo Galilei made the first telescope observations of the Moon.

**1959–60**
Luna 9, 10, 15 and 16 made the first soft landings on the Moon.

**1964**
Lunar Orbiter 7 data indicated that the lunar surface would be suitable for a polar landing.

**1966**
Surveyor 3 made the first soft landing on the Moon.

**1968**
Apollo 8, first piloted flight to the Moon, circled 10 times before returning to Earth.

**1969**
Apollo 11, first human landing on the Moon, returned rock and soil samples.

**1970**
Apollo 12 landed on the first of 5 Soviet missions to use a robotic rover to return lunar soil samples.

**1972**
Apollo 17 was the last of the Apollo missions to land astronauts and return samples from the Moon.

**1998**
Lunar Prospector made a geochemical map of the Moon and discovered ice at both poles.

### About the Images

![Moon](https://images.jsc.nasa.gov)

**Left** The familiar face of the Moon, taken by Apollo 11 astronauts from their way home, shows the dark maria and lighter highlands.

**Right, top center** Apollo 11 astronaut Neil Armstrong, on the last human mission to the Moon, steps toward the Moon's surface. The familiar face of the Moon, taken by Apollo 8 astronauts from their way home, shows the dark maria and lighter highlands.

**Right, top right** First piloted flight to the Moon, circled 10 times before returning to Earth.

**Right, bottom** Close-up view of Apollo 15 lunar sample number 15415 in the Lunar Receiving Laboratory at the Manned Spacecraft Center. This sample is the white anorthositic rock (nicknamed the Genesis Rock) that is 4.5 billion years old—as old as Earth.

#### References
2. Lunar Prospector mission: http://lunar.arc.nasa.gov
3. Clementine mission: http://www.sel.arc.nasa.gov/clementine
The red planet MARS has inspired wild flights of imagination over the centuries, as well as intense scientific interest. Whether fancied to be the source of hostile invaders of Earth, the home of a dying civilization, or a rough and tumble mining colony of the future, Mars provides fertile ground for science fiction writers, based on seeds planted by centuries of scientific observation.

We know that Mars is a small rocky body once thought to be very Earth-like. Like the other “terrestrial” planets—Mercury, Venus, and Earth—a surface has been changed by volcanism, impacts from other bodies, movements of its crust, and atmospheric effects such as dust storms. It has polar ice caps that grow and recede with the change of seasons; areas of layered soils near the Martian poles suggest that the planet’s climate has changed more than once; perhaps caused by a regular change in the planet’s orbit. Martian tectonics—the formation and change 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 engulf the entire planet. The effects of these storms are dramatic, including giant dust storms, wind streaks, and wind-carved features.

Scientists believe that 3.5 billion years ago, Mars experienced the largest known floods in the solar system. This water may even have pooled into lakes or shallow oceans. Yet the central question to carve Mars’ great channels and flood plains is not evident on the surface today. Recent images from NASA’s Mars Global Surveyor spacecraft suggest that underground reserves of water may break through the surface as springs. Unraveling the story of the water on Mars is important to unlocking its past climate history, which will help us understand the evolution of all planets, including our own. Water is also believed to be a central ingredient for the initiation of life; the evidence of past or present water on Mars is expected to hold clues about past or present life on Mars, as well as the potential for life elsewhere in the universe. And, before humans can safely go to Mars, we need to know much more about the planet’s environment, including the availability of resources such as water.

Mars has some remarkable geological characteristics, including the largest volcanic mountain in the solar system, Olympus Mons (27 km high and 600 km across); volcanoes in the northern Tharsis region that are so huge they deform the planet’s roundness; and a gigantic equatorial rift valley, the Valles Marineris. This canyon system stretches across the surface, 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.

Mars also has two small moons, Phobos and Deimos. Although no one knows how they formed, they may be asteroids snared by Mars’ gravity.

**Fast Facts**

<table>
<thead>
<tr>
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<th>Value</th>
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<tr>
<td>Namesake</td>
<td>Roman God of War</td>
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<tr>
<td>Mean Distance from Sun</td>
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<td>Diameter</td>
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<tr>
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<tr>
<td>Gravity</td>
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<td>Temperature Range</td>
<td>−143 °C to +17 °C</td>
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<tr>
<td>Moons (2) in Increasing Distance from Mars</td>
<td>Phobos, Deimos</td>
</tr>
<tr>
<td>Number of Rings</td>
<td>0</td>
</tr>
</tbody>
</table>

**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 4 first attempts to land on Mars.
- **1976**
- **1996**
  - Possible microbial fossils in Martian meteorite.
- **1997**
  - Mars Pathfinder lander on Mars. Sojourner Rover explores Mars’ Yarras area for three months.
- **1997–present**
  - Mars Global Surveyor maps the surface of Mars from orbit.
- **2001**
  - Mars Odyssey orbiter goes to Mars.

**About the Images**

- **Fast Facts**
  - Mars is about half the diameter of Earth. Here, bluish-white water ice clouds hang above the Tharsis volcanoes. The northern polar cap is visible, as is Yarras Marineris, a 4,000 km-long canyon system just below the equator and to the right of visitor (NASA/PIR/MSRS Mars Global Surveyor).
- **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**
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  - **1997**
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  - **1997–present**
    - Mars Global Surveyor maps the surface of Mars from orbit.
  - **2001**
    - Mars Odyssey orbiter goes to Mars.

**References**

4) Stardate: [http://stardate.org](http://stardate.org)
ASTEROIDS are rocky fragments left over from the formation of the solar system about 4.6 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 of our solar system, called the Asteroid Belt or Main Belt, probably contains millions of asteroids ranging widely in size from Ceres, which at 940 km in diameter is about one-quarter the diameter of our Moon, to bodies that are less than 1 km in across. There are more than 30,000 numbered asteroids.

As asteroids revolve around the Sun in elliptical orbits, giant Jupiter’s gravity and occasional close encounters with Mars or with another asteroid change the asteroids’ orbits, knocking them out of the Main Belt and hurling them into space across the orbits of the planets. For example, Mars’s moons Phobos and Deimos may be captured asteroids. Scientists believe that tiny asteroids or fragments of asteroids 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. The extinction of the dinosaurs 65 million years ago has been linked to a devastating impact near the Yucatan peninsula in Mexico.

Asteroids were first observed with telescopes in the early 1800s, and in 1802, the astronomer William Herschel first used the word “asteroid,” which means “starlike” in Greek, to describe these celestial bodies. Most of what we have learned about asteroids in the past 200 years has been derived from telescope observations. 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 also to watch for any asteroids that might collide with Earth in the future. Scientists define near-Earth asteroids (NEAs) as those whose orbits never take them farther than about 195 million kilometers from the Sun.

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 their surfaces. Scientists also examine meteorites—the remnants of comets or asteroids that can be found on Earth—for clues to the origins of these bodies. About three-quarters of asteroids are extremely dark and are similar to carbon-rich meteorites called carbonaceous chondrites (C-type). About one-sixth of asteroids are reddish, stony-iron bodies (S-type).

In 1997, instruments on the Hubble Space Telescope mapped Vesta, one of the largest asteroids, and found an enormous crater formed a billion years ago. Interestingly, Vesta is an uncommon asteroid type, yet meteorites having the same composition have been found on Earth. Could these be remnants from the collision that created Vesta’s giant crater?

In 1997, NEAR Shoemaker spacecraft was the first to observe an asteroid close-up, flying by main-belt asteroids Gaspra and Ida in 1991 and 1993, respectively. Gaspra and Ida proved to be irregularly shaped objects, rather like potatoes, ridged with craters and fractures, 12 km long and 5 km 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.

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In 1997, NEAR Shoemaker captured first close-up images of asteroid (Gaspra).

In 1994, Galileo discovers first satellite (Dactyl) of an asteroid (Ida).

1996 NEAR Shoemaker studies asteroid Mathilde.

2000–01 NEAR Shoemaker orbits Eros for one year and then lands.

Facts

Fast Facts

(for some representative asteroids)

<table>
<thead>
<tr>
<th>Asteroid Type</th>
<th>Eros</th>
<th>Gaspra</th>
<th>Vesta</th>
<th>Ceres</th>
<th>Ida</th>
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<td>18 x 11 x 9</td>
<td>530</td>
<td>933</td>
<td>58 x 23</td>
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</table>

About the Images

(upper left) Asteroid Eros is about 35 kilometers long (NEAR Shoemaker).

(upper right) Surface of Eros is covered in rocks of all shapes and sizes (NEAR Shoemaker).

(right center) Color-coded map shows upland (red) and downland (blue) areas on Eros (NEAR Shoemaker).

(lower left) Mars’s moons Phobos (left) and Deimos (right) may be captured asteroids. Asteroid Gaspra (top) is shown at same scale.

(lower center) Asteroid Ida and its moon Dactyl (Galileo).

(lower right) Color-coded topography map of asteroid Vesta clearly shows a large crater with a central peak. (blue is low, red is high) (Hubble Space Telescope).

Significant Dates

1801 First asteroid, Ceres, discovered by Piazzi.

1807 Vesta discovered by Olbers.

1884 Asteroid 10195 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 Shoemaker studies asteroid Mathilde.

1997 Hubble Space Telescope studies Vesta.

2000–01 NEAR Shoemaker orbits Eros for one year and then lands.

References

1) NEAR Shoemaker mission to Eros: http://near.jhuapl.edu

2) Near Earth Object Program: http://www.jpl.nasa.gov/neo


4) National Space Science Data Center Asteroid information: http://nssdc.gsfc.nasa.gov/planetary/planets/asteroidpage.html

About the Images

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(lower center) Asteroid Ida and its moon Dactyl (Galileo).

(lower right) Color-coded topography map of asteroid Vesta clearly shows a large crater with a central peak. (blue is low, red is high) (Hubble Space Telescope).
With its numerous moons and several rings, the JUPITER system is a “mini-solar system.” Jupiter is the most massive planet in our solar system, and in composition it resembles a small star. In fact, if Jupiter had been between Earth and one hundred times more massive, it would have become a star rather than a planet.

On January 7, 1610, while stargazing from his garden in Padua, Italy, astronomer Galileo Galilei was surprised to see four small “stars” near Jupiter. He had discovered Jupiter’s four largest moons, now called Io, Europa, Ganymede, and Callisto. Collectively, these four moons are known today as the Galilean satellites.

Galileo would be astonished at what we have learned about Jupiter and its moons in the past 300 years. In the most volcanically active body in our solar system. Ganymede is the largest planetary moon and has its own magnetic field. A liquid ocean may be beneath the frozen crust of Europa. Its icy ocean may also be beneath the crust of Callisto. Jupiter also has at least 24 smaller moons. The 20 outer moons are probably asteroids captured by the giant planet's gravity.

At first glance, Jupiter appears striped. These stripes are dark belts and light zones created by strong east-west winds in Jupiter’s upper atmosphere. Within these belts and zones are storm systems that have raged for years. The southern hemisphere’s Great Red Spot has existed for at least 150 years, and perhaps longer, at Galileo reported seeing a similar feature nearly 400 years ago. Three Earths could fit across the Great Red Spot.

Jupiter’s core is probably not solid but a dense, hot liquid with a composition like that of Earth’s core. The pressure inside Jupiter may be 30 million times greater than the pressure at Earth’s surface.

As Jupiter rotates, a giant magnetic field is generated in its electrically conducting liquid interior. Trapped within Jupiter’s magnetosphere—the area in which magnetic field lines encircle the planet from pole to pole—are charged particles that make up the inner portion of Jupiter’s magnetosphere. The most deadly radiation environment of any of the planets, both for humans and for electronic equipment. The “tail” of Jupiter’s magnetic field—that portion stretched behind the planet as the solar wind rushes past—is thought to be the largest and most distant. Jupiter’s magnetic field can stretch more than a billion kilometers from pole to pole, creating a giant “cage” around the planet that is stretched behind the planet as the wind blows it. Jupiter’s strong magnetic field can affect the solar wind, causing it to be deflected from its normal path.

In December 1995, NASA’s Galileo spacecraft discovered a new ring in Jupiter’s atmosphere. Carrying six scientific instruments, the probe survived the crushing pressure and searing heat for nearly an hour, collecting the first direct measurements of Jupiter’s atmosphere, the first real data about the chemistry of a gas planet. Following the release of the probe, the Galileo spacecraft began a multi-year orbit of Jupiter, observing each of the largest moons from close range several times.

### Fast Facts

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### Significant Dates

- **1610**: Italian astronomer Galileo Galilei discovers four moons orbiting Jupiter—now called Io, Europa, Ganymede, and Callisto—the Galilean satellites.
- **1973**: Pioneer 10, the first spacecraft to reach Jupiter, passes within 358,534 km of Jupiter’s cloud tops.
- **1974**: Voyager 1 passes within 43,000 km of Jupiter’s cloud tops, providing first images of Jupiter’s rings.
- **1975**: Pioneer 11 arrives at Jupiter; atmospheric entry probe survives to arrive at Jupiter; uses Jupiter’s gravity to enter solar polar orbit.
- **1995**: Voyager 2 passes within 850,000 km of Jupiter’s center, providing first images of Jupiter’s rings and its inner moons.
- **1997**: Voyager 1 passes within 500,000 km of Jupiter’s center, providing first images of Jupiter’s rings and its outer moons.
- **1999**: Voyager 2 passes within 4,000 km of Jupiter’s cloud tops, providing first images of Jupiter’s rings.
- **2000**: Voyager 1 and Voyager 2 fly by Jupiter, providing images of Jupiter’s inner and outer moons.
- **2004**: Cassini-Huygens spacecraft arrives at Jupiter; atmospheric entry probe survives to arrive at Jupiter; provides images of Jupiter’s rings, moons, and magnetosphere.

### About the Images

- **(Left)** Strong east-west winds create material bands in Jupiter’s atmosphere (Galileo).
- **(Right, top)** Two of Jupiter’s moons, Io and Europa (above the Great Red Spot) and a hint of Ganymede’s ring and Io’s volcanic activity.
- **(Right, center)** Artist’s conception of magnetic field lines extending more than one billion kilometers behind Jupiter—"as far as Saturn's orbit." Jupiter’s core is probably not solid but a dense, hot liquid with a composition like that of Earth’s core. The pressure inside Jupiter may be 30 million times greater than the pressure at Earth’s surface.
- **(Right, bottom)** Artist’s conception of magnetic field lines extending more than one billion kilometers behind Jupiter—"as far as Saturn's orbit." Jupiter’s core is probably not solid but a dense, hot liquid with a composition like that of Earth’s core. The pressure inside Jupiter may be 30 million times greater than the pressure at Earth’s surface.

### References

5. Artist’s View: [http://www.nasa.gov/](http://www.nasa.gov/)

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LG-2001-08-534-HQ
The planet Jupiter’s four largest moons are called the Galilean satellites, after Italian astronomer Galileo Galilei who observed them in 1610. The moons were also observed then by German astronomer Simon Marius. 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 volcanically active body in the solar system, and parts of its surface change within weeks. Europa’s cracked 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 the planet Mercury), and it 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 closest 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 including sulfur dioxide. Io travels in its 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’s volatiles are driven by hot silicate, not water ice. Europa, and Ganymede, all have a layered interior structure (as does Earth). Europa and Ganymede both have a core; a rock envelope around the core; a thick, soft icy layer; and a thin crust of impermeable 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, Galileo appears to be an ice-rock mix both inside and out. Under the influence of Jupiter’s and each other’s gravity, the Galilean moons all keep the same face towards Jupiter as they orbit (as does one moon towards Earth). This means that each of the moons turns only once on its axis for every orbit about Jupiter.

Galileo proposed that these moons be called the “Medicane stars” in honor of his patron, Cosimo II de Medici, Marius named the moons Io, Europa, Ganymede, and Callisto after the lovers of the Roman god Jupiter (who was known to the Greeks as Zeus). They continued to be studied from Earth through telescopes until the two Pioneer (in 1973–74) and two Voyager (in 1979) spacecraft offered striking color views and a global perspective from their midrange flybys while surveying parts of the outer solar system. In present, the Galileo spacecraft flew in repeated elliptical orbits around Jupiter, flying as low as 261 kilometers over the surface of the Galilean moons. That’s lower than the average Space Shuttle orbit over 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 low number of craters on Europa leads scientists to believe that the ocean existed in its current 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, from a mild form of the tidal forces that drive Io’s volcanoes.

Significant Dates

1610 Italian astronomer Galileo Galilei and German astronomer Simon Marius independently discover four moons orbiting Jupiter.

1973 Pioneer 10 is the first spacecraft to cross the asteroid belt and fly by Jupiter.

1974 Pioneer 11 flies by Jupiter.

1975 Voyager 1 discovers Io’s volcanoes and Jupiter’s ring.

1979 Voyager 2 and 3 discover Io’s volcanoes and Jupiter’s ring.


2000–01 Galileo and Galileo spacecraft jointly observe Jupiter.

About the Images

(Left) 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 (right) of the gas-giant planet in the region of the Great Red Spot is shown for comparison.

(Right) The image of the surfaces of the moons shows that each is unique.

(Bottom) In Europa, a volcanic plume of cold sulfur dioxide gas and “snow” rises 140 km above the moon’s surface. The close-up shows Punta Calans, a chain of volcanic calderas, in enhanced color with the bright lava curtain (a chain of lava basins) and surface flows added by the Galileo scientists, based on their knowledge of the area. Fountains of lava rise to heights of 1.5 km above the surface. The darkened terrain to the center of the image is almost surrounded by a moon that is about 1.4 km high.

(Bottom, middle) On Europa, ice The image size of small towns (up to 13 km long) appear to have broken apart and “rafted” on soft ice or sea-ice-covered water. This suggests the presence of an ocean under Europa’s ice surface.

(Top, middle) Ganymede has many diverse types of terrain, including the area of Nicholson Regio and Angel Regiones. The bright terrain of Angel Regiones is the youngest terrain here, slicing through the center of the image. It is fairly smooth and relatively high-covered. To the east (right) is the darkened Tethys area, rolling and relatively highly-covered Nicholson Regio. To the west (left) is a region of highly deformed gross terrain, intermediate in relative age. In the area of grooved terrain, stretching and normal faulting of Nicholson Regio has deformed it beyond recognition.

(Bottom) Callisto is famous for its numerous and varied craters. This multi-ringed impact crater named Asgard is surrounded by concentric rings up to 1,700 km in diameter. Newer craters, such as Burr in the upper right, are brighter because they expose fresh ice.

Fast Facts

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SATURN is the most distant of the five planets known to ancient stargazers. In 1610, Italian Galileo Galilei was the first astronomer to gaze at Saturn through a telescope. To his surprise, he saw a pair of objects on either side of the planet, which he later drew as “two handles” attached to the planet on each side. In 1655, Dutch astronomer Christiaan Huygens announced that this was a ring encircling the planet. In 1675, Italian-born astronomer Jean Dominique Cassini discovered a gap between what are now called the A and B rings.

Like the other giant planets—Jupiter, Uranus, and Neptune—Saturn is a gas giant made mostly of hydrogen and helium. Its volume is 75,000 times greater than Earth’s. Winds in the upper atmosphere reach 500 meters per second in the equatorial region. In contrast, the strongest hurricane-force winds on Earth top out at about 110 meters per second. These super-fast winds, combined with heat rising from within the planet’s interior, cause the yellow and gold bands visible in its atmosphere.

Saturn’s ring system is the most extensive and complex in our solar system; it extends hundreds of thousands of kilometers from the planet. In fact, Saturn and its rings would just fit in the distance between Earth and the Moon. In the early 1980s, NASA’s two Voyager spacecraft revealed that Saturn’s rings are made mostly of water ice, and they found “branched” rings, ripples, and “spokes”—dark features in the rings that seem to circle the planet at different rates from that of the surrounding ring material. Some of the small moons orbit within the ring system as well. Material in the rings ranges in size from a few micrometers to several tens of meters. Saturn has at least 30 moons. The largest, Titan, is a bit bigger than Earth’s moon.

In addition to Titan, Saturn has many smaller “sky” satellites. From Enceladus, which shows evidence of surface changes, to Iapetus, with one hemisphere darker than asphalt and the other as bright as snow, each of Saturn’s satellites is unique.

Saturn, the rings, and many of the satellites lie tidally within Saturn’s enormous magnetosphere, the region of space in which the behavior of electrically charged particles is influenced more by Saturn’s magnetic field than by the solar wind. Recent images by NASA’s Hubble Space Telescope show that Saturn’s polar regions have aurorae similar to Earth’s Northern and Southern Lights. Aurorae occur when charged particles spiral into a planet’s atmosphere along magnetic field lines.

The next chapter in our knowledge of Saturn is already underway, as the Cassini/Huygens spacecraft began its journey to Saturn in October 1997 and will arrive on July 1, 2004. The Huygens probe will descend through Titan’s atmosphere in late November 2004 to collect data on the atmosphere and surface of the moon. Cassini will orbit Saturn more than 70 times during a four-year study of the planet, its moons, rings, and magnetosphere. Cassini/Huygens is a joint NASA-European Space Agency mission.

**Fast Facts**

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<td>Saturn’s polar regions have aurorae similar to Earth’s Northern and Southern Lights. Aurorae occur when charged particles spiral into a planet’s atmosphere along magnetic field lines. Cassini/Huygens is a joint NASA-European Space Agency mission.</td>
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Once considered one of the blander-looking planets, **Uranus** (pronounced YOOR un nus) has been revealed as a dynamic world with some of the brightest clouds in the outer solar system and a fragile ring system that wobbles like an unbalanced wagon wheel. Uranus gets its blue-green color from methane gas above the deeper cloud layers (methane absorbs red light and reflects blue light).

Uranus was discovered in 1781 by astronomer William Herschel, who at first believed it to be a comet. This seventh planet from the Sun is so distant that it takes 84 years to complete an orbit.

The third largest planet in our solar system, Uranus is classified as a “gas giant” planet because it has no solid surface. The atmosphere of Uranus is hydrogen and helium, with a small amount of methane and traces of water and ammonia. The bulk (80 percent or more) of the mass of Uranus is contained in an extended liquid core consisting primarily of “icy” materials (water, methane, and ammonia), with higher-density material at depth.

In 1986, Voyager 2 observed faint cloud markings in the southern latitudes blowing westward between 100 and 600 km/hr. In 1998, the *Hubble Space Telescope* observed as many as 20 bright clouds at various altitudes in Uranus’ atmosphere. The bright clouds are probably made of crystals of methane, which condense as warm bubbles of gas well up from deep in the atmosphere of Uranus.

Uranus currently moves around the Sun with its rotation axis nearly horizontal with respect to the ecliptic plane. This unusual orientation may be the result of a collision with a planet-sized body early in the planet’s history, which apparently changed Uranus’s rotation radically.

Uranus’s magnetic field is unusual in that the magnetic axis is tilted 60 degrees from the planet’s axis of rotation and is offset from the center of the planet by one-third of the planet’s radius.

Uranus is so far from the Sun that, even though tipped on its side and experiencing seasons that last over twenty years, the temperature differences on the sunnier and darker sides of the planet do not differ that greatly. Near the clouds, the temperature of Uranus is near -215 °C.

Six of Uranus’s rings were discovered in 1977 by scientists aboard NASA’s Kuiper Airborne Observatory who were watching a star pass behind Uranus. They noticed the starlight winking on and off as the star first appeared to move toward the planet, and then again as the star moved away from the planet. Perihelion Observatory found three more rings that same day, and Voyager 2 found two more rings in 1986, bringing the count to 11. The rings are in the planet’s equatorial plane, perpendicular to its orbit about the Sun. The 10 outer rings are dark, thin, and narrow, while the 11th ring is inside the other ten and is broad and diffuse. The rings of Uranus are very different from those surrounding Jupiter and Saturn. When viewed with the Sun behind the rings, faint dust can be seen scattered throughout all of the rings.

Uranus has at least 21 moons, named mostly for characters from the works of Shakespeare and Alexander Pope. Miranda is the strangest Uranian moon. The high cliffs and winding valleys of the moon may indicate partial melting of the interior, with icy material occasionally drifting to the surface.

### Significant Dates

- 1787: Sir William Herschel discovers Titania and Oberon.
- 1948: Gerald Kuiper (U.S.) discovers Miranda.
- 1977: James Elliot (U.S.) and others discover six rings; astronomers at Perihelion Observatory discover three additional rings.
- 1986: Voyager 2 discovers 10 small moons and 2 more rings, detects magnetic field, and measures length of Uranian day.

### About the Images

(Left) False-color image taken in the near-infrared of Uranus, 4 of its major rings, and 10 of its satellites ([*Hubble Space Telescope NICMOS*](http://solarystem.nasa.gov)).

(Right, center and right) Uranus appears nearly featureless in visible wavelengths, but through blue, orange, and green filters, a dark polar hood and zonal areas in the atmosphere are apparent ([*Voyager 2*](http://photojournal.jpl.nasa.gov)).

(Right, center) Voyager 2 revealed a continuous distribution of small particles throughout the Uranus ring system.

(Right, center and bottom) Miranda’s surface consists of two strikingly different major types of terrain. One is an old, heavily cratered, rolling terrain with relatively uniform ... and in the distinctive “chevron” feature above and to the right of center. The ice cliffs at right are 20 km high ([*Voyager 2*](http://photojournal.jpl.nasa.gov)).

### Fast Facts

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### References

Neptune

The eighth planet from the Sun, **NEPTUNE** was the first planet located through mathematical predictions rather than through regular observations of the sky. When Uranus didn’t travel exactly as astronomers expected it to, two mathematicians, working independently of each other, proposed the position and mass of another, as yet unknown planet that could account for Uranus’ orbit. Although “the establishments” ignored the predictions, a young astronomer decided to look for the predicted planet. Thus, Neptune was discovered in 1846. Seventeen days later, its largest moon, Triton, was also discovered.

Nearly 4.5 billion kilometers from the Sun, Neptune orbits the Sun once every 165 years, and therefore it has not quite made a full circle around the Sun since it was discovered. It is invisible to the naked eye because of its extreme distance from Earth. Interestingly, due to Pluto’s unusual elliptical orbit, Neptune is actually the farthest planet from the Sun for a 20-year period out of every 248 Earth years.

Neptune has the smallest diameter of our solar system’s giant gas planets (including Jupiter, Saturn, and Uranus), so called because they have no solid surfaces. From us, its volume could hold nearly 60 Earths. Neptune’s atmosphere extends to great depths, gradually merging into water and other “melted ices” over a heavier, approximately Earth-sized liquid core.

Neptune’s rotational axis is tilted 30 degrees to the plane of its orbit around the Sun. Its seasons last an incredible 41 years. During the southern summer, the south pole is in constant sunlight for about 41 years, and in northern summer, the north pole is in constant sunlight for about 40 years.

Neptune’s atmosphere is made up of hydrogen, helium, and methane; the last of these giving the planet its blue color (because methane absorbs red light). Despite its great distance from the Sun and lower energy input, Neptune’s winds are three times stronger than Jupiter’s and nine times stronger than Earth’s.

In 1989, Voyager 2 tracked a large oval dark storm in Neptune’s southern hemisphere. The hurricane-like “Great Dark Spot” was large enough to contain the entire Earth, spun counterclockwise, and moved westward at almost 1,200 km per hour. Recent images from the Hubble Space Telescope show no sign of the “Great Dark Spot,” although a comparable spot appeared in 1997 in Neptune’s northern hemisphere.

The planet has several rings of varying widths, confirmed by Voyager 2’s observations in 1989. The outermost ring, Adams, contains five distinct arcs (incomplete rings) named Liberté, Égalité 1, Égalité 2, Fraternité, and Courage. Next is an unnamed ring encircling with the moon Galatea, then Le Verrier, Lassell, Juno, and Galle. Neptune’s rings are believed to be relatively young and relatively short-lived.

Neptune has eight known moons, six of which were discovered by Voyager 2. The largest, Triton, orbits Neptune in a direction opposite to the planet’s rotation direction, and is gradually getting closer until it will collide with the planet in about 10 to 100 million years, forming vast rings around Neptune that will rival or exceed Saturn’s extensive ring system. Triton is the coldest body yet visited in our solar system; temperatures on its surface are about -235 °C. Despite the deep freeze, Voyager 2 discovered great geysers of gaseous nitrogen on Triton.

**Fast Facts**

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**Significant Dates**

- **1845** Mathematicians John Adams (Britain) and Jean Le Verrier (France) predict Neptune based on orbital motion of Uranus.
- **1846** German astronomer Johann Galle discovers Neptune using location predicted by Le Verrier.
- **1846** British astronomer William Lassell discovers Triton.
- **1949** American astronomer Gerard Kuiper discovers Nereid.
- **1985** Astronomers discover Neptune’s rings based on star occultations.
- **1989** Voyager 2 visits Neptune system.
- **1994** Hubble Space Telescope observes changes in Neptune’s atmosphere.

**About the Images**

(Left) Neptune’s blue color is due to methane, which absorbs red light and reflects blue light. In 1989, Voyager 2 tracked these three giant storms—the Great Dark Spot, Scooter, and Dark Spot 2.

(Right, top) Voyager 2 photographed Neptunian clouds that are 50 kilometers above the underlying cloud decks.

(Right, middle) Voyager 2 needed ten-minute exposures to capture images of Neptune’s main rings.

(Right, bottom) Nitrogen frost coats Neptune’s largest moon Triton. Bright and dark streaks are materials deposited by winds (NASA/Voyager 2).

**References**

1) NASA Solar System Exploration: [http://solarsystem.nasa.gov](http://solarsystem.nasa.gov)

L:\2001-08-536-HQ
Pluto and Charon

Long considered to be the smallest, coldest, and most distant planet from the Sun, PLUTO may also be the largest of a group of objects that orbit in a disk-like zone of comets beyond the orbit of Neptune.

Discovered by American astronomer Clyde Tombaugh in 1930, Pluto takes 248 years to orbit the Sun. Pluto's most recent close approach to the Sun was in 1989. Between 1979 and 1999, Pluto was actually closer to the Sun than Neptune, providing rare opportunities to study this small, cold, distant world and its companion moon, CHARON.

Most of what we know about Pluto we have learned since the late 1970s from Earth-based observations, the Infrared Astronomical Satellite (IRAS), and the Hubble Space Telescope. Many of the key questions about Pluto, Charon, and the outer fringes of our solar system await close-up observations by a robotic space flight mission.

Pluto and Charon orbit the Sun in a region where there may be a population of hundreds or thousands of similar bodies that were formed early in solar system history. The gravitational influence of the giant planets may have ejected these bodies to much larger distances from the solar system. The recent discovery of several bodies about the size of Charon in the region beyond Pluto has bolstered this theory. These objects are currently referred to interchangeably as trans-Neptunian objects, Edgeworth-Kuiper Disk objects, Kuiper Belt objects, or iced dwarves.

Pluto is about two-thirds the diameter of Earth's Moon and may have a rocky core surrounded by a mantle of water ice. Due to its lower density, its mass is about one-sixth that of the Moon. Most of Pluto's atmosphere freezes during the part of each orbit when it is traveling away from the Sun. During this time, the bulk of the planet's atmosphere freezes.

In 1978, American astronomers James Christy and Robert Harrington discovered that Pluto has a satellite (moon), which they named Charon. Charon is almost half the size of Pluto and shares the same orbit. Pluto and Charon are thus essentially a double planet. Charon's surface is covered with dry water ice and doesn't reflect as much light as Pluto's surface.

No spacecraft have ever visited Pluto. Because Pluto is so small and far away, it is difficult to observe from Earth. In the late 1990s, Pluto and Charon passed in front of each other repeatedly for several years. Observations of these rare events allowed astronomers to make crude maps of each body. From these maps it was learned that Pluto has polar caps, as well as large, dark spots near its equator.

Fast Facts

<table>
<thead>
<tr>
<th>Name</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Namesake</td>
<td>Roman God of the Underworld</td>
</tr>
<tr>
<td>Mean Distance from the Sun</td>
<td>6 billion km</td>
</tr>
<tr>
<td>Orbital Period</td>
<td>248 years</td>
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<td>Orbital Eccentricity</td>
<td>0.25</td>
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<td>Orbital Inclination to Ecliptic</td>
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<tr>
<td>Inclination of Equator to Orbit</td>
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<tr>
<td>Rotational Period</td>
<td>6 d 23 m (retrograde)</td>
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<tr>
<td>Diameter</td>
<td>2,390 km</td>
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<tr>
<td>Mass</td>
<td>0.0022 of Earth's</td>
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<tr>
<td>Density</td>
<td>1.1 g/cm^3</td>
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<tr>
<td>Gravity</td>
<td>0.06 of Earth's</td>
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<tr>
<td>Atmosphere (primary components)</td>
<td>Nitrogen, Carbon, Methane</td>
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<tr>
<td>Mean Temperature at Solid Surface</td>
<td>57° K</td>
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<tr>
<td>Moon</td>
<td>1 (Charon)</td>
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<tr>
<td>Charon's Diameter</td>
<td>1,186 km</td>
</tr>
<tr>
<td>Rings</td>
<td>None known</td>
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</table>

Significant Dates

- 1930 Clyde Tombaugh discovers Pluto.
- 1955 Pluto's 6.4-day rotation period is discovered.
- 1976 Methane on Pluto's surface is discovered.
- 1978 James Christy and Robert Harrington discover Charon.
- 1990 Pluto's atmosphere is discovered.
- 1992 Nitrogen and carbon monoxide are discovered on Pluto's surface.
- 2010–25 Predicted atmospheric collapse.

About the Images

(Bottom) The ability of the Hubble Space Telescope to distinguish Pluto's disk at a distance of 6.5 billion km is equivalent to seeing a baseball at a distance of 64 km. Pluto and its moon Charon are 394,400 km apart. The Hubble observations show that Charon is larger than Pluto. This means that both worlds have different surface composition and structure. A bright highlight on Pluto suggests it has a smoothly reflecting surface layer (NASA's Hubble Space Telescope/ European Space Agency's Spacecraft Object (Gomes)).

(Left, bottom) Pluto is mostly brown. This map was created by tracking brightness changes from Earth of Pluto during times when it was being partially eclipsed by its moon Charon. The map therefore shows the hemisphere of Pluto that faces Charon. Pluto's brown color is thought dominated by frozen methane deposits superimposed by faint but energized sunlight. The dark hand below Pluto's equator is seen to have rather complex coloring, however, indicating that some unknown mechanisms may have affected Pluto's surface (Young, Beaud, Grand/University of Texas McDonald Observatory).

(Center and right, bottom) Opposite hemispheres of Pluto are seen in these maps constructed through computer image processing performed on Hubble Space Telescope data. Pluto is an unusually complex object, with more large-scale contrasts than any planet except Earth, Venus and Mars, NASA's Hubble Space Telescope/European Space Agency's Spacecraft Object (Gomes).

References

1) Hubble Space Telescope: http://hubble.stsci.edu
3) Stardate: http://stardate.org/resources/ssguide/pluto.html

LG-2001-08-539-HQ
Throughout history, people have been both awed and alarmed by comets, stars with “long hair” that appeared in the sky unannounced and unpredictably. We now know that comets are dirty-ice leftovers from the formation of our solar system around 4.6 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. We can predict the orbits of many of them, but not all.

Around a dozen “new” comets are discovered each year. Short-period comets are more predictable because they take less than 200 years to orbit the Sun. Most come from a region of icy bodies beyond the orbit of Neptune. These icy bodies are variously called Kuiper Belt Objects, Edgeworth-Kuiper Belt Objects, or trans-Neptunian objects.

Less predictable are long-period comets, many of which arrive from a distant region called the Oort cloud about 100,000 astronomical units (that is, 100,000 times the mean distance between Earth and the Sun) from the Sun. These comets can take as long as 30 million years to complete one trip around the Sun. (It takes Earth only 1 year to orbit the Sun.) As many as a trillion comets may reside in the Oort cloud, orbiting the Sun near the edge of the Sun’s gravitational influence.

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. In its center, the nucleus may have a small, rocky core.

As a comet nears the Sun, it begins to warm up. The comet gets bright enough to see from Earth while its atmosphere—the coma—grows larger. The Sun’s heat causes ice on the comet’s surface to change to gases, which fluoresce like a neon sign. “Vents” on the Sun-warmed side may release fountains of dust and gas for tens of thousands of kilometers. The escaping material forms a coma that may be hundreds of thousands of kilometers in diameter.

The pressure of sunlight and the flow of electrically charged particles, called the solar wind, blow the coma materials away from the Sun, forming the comet’s long, bright tails, which are often seen separately as straight tails of electrically charged ions and an arching tail of dust. The tails of a comet always point away from the Sun.

Most comets travel a safe distance from the Sun itself. Comet Halley comes no closer than 89 million kilometers from the Sun, which is closer to the Sun than Earth is. However, some comets, called sun-grazers, crash straight into the Sun or get so close that they break up and vaporize.

Impacts from comets played a major role in the evolution of the Earth, primarily during its early history billions of years ago. Some believe that they brought water and a variety of organic molecules to Earth.

In September 2001, NASA’s Deep Space 1 spacecraft will fly by Comet Borrelly. In January 2004, NASA’s Stardust mission is expected to encounter Comet Wild 2. Coming within 190 kilometers of the comet, it will study the comet’s nucleus and the composition of comet dust, and it will capture dust samples to bring back to Earth in 2006. In 2005, NASA’s Deep Impact mission is scheduled to create a crater in Comet Tempel 1 and to study the freshly exposed material for clues to the early formation of the solar system. Another NASA mission, Contour, is scheduled to fly by comets Encke and Schwassmann-Wachmann-3 to study the diversity of comet nuclei.

Comets

Significant Dates

1618 First comet observed telescopically: Johann Baptist Cysat of Switzerland and John Bainbridge of England.
1858 First photograph of a comet: Comet Donati by William Usherwood.
1864 First comet examined by a spectroscope: Comet Tempel.
1985 First spacecraft to visit a comet: NASA’s ICE observes Comet Giacobini-Zinner.
1986 International Bottle of spacecraft observers Halley’s Comet.
1997 Comet Hale-Bopp easily observable to the naked eye.
1998 European Space Agency’s Solar and Heliospheric Observatory (SOHO) observes sun-grazing comets.

About the Image

(Left) Comet Hale-Bopp, with its bluish tail of ions and white tail of dust, is expected to be visible again from Earth in about 2,380 years (Jet Table Mountain Observatory image).
(Right, top and bottom) In July 1994, Comet Shoemaker-Levy 9 broke up into more than 20 pieces and collided with Jupiter over several days. Eight impact sites (brown dots stretching from lower left to upper right below Great Red Spot) can be seen in this image from NASA’s Hubble Space Telescope. This was the first time observers could actually watch a comet collide with another body. Shoemaker-Levy 9 fragments are false color.

References
1) Missions to Comets: http://cne.gid.name/missions/comet_missions/comet-stardust.html
2) Asteroids, Comets, and NASA Research: http://www.nasa.gov/mission/planets/comets.html
4) Comet Shoemaker-Levy 9 Collides with Jupiter: http://www.gid.name/eo/collides
6) Stardate: http://stardate.org

National Aeronautics and Space Administration
Solar System Lithograph Set

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   ______ K-4 ______ 5-8 ______ 9-12 ______ Community College
   College/University: ______ Undergraduate ______ Graduate

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

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

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

3. This is a valuable lithograph set?
   □ Strongly Agree □ Agree □ Neutral □ Disagree □ Strongly Disagree

4. I expect to apply what I learned in this lithograph set.
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   □ Workshop/Conference
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9. How can we make this lithograph set more effective for you?
   __________________________________________________

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    __________________________________________________

   Today's date: ____________________________

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