Introduction

Jupiter has captured the attention of sky watchers since prehistoric times**.** One of the seven objects that "wandered" across the evening sky according to ancient astronomers, Jupiter has been studied for centuries. In 1610, Galileo Galilee discovered Jupiter's four largest satellites: Io, Europa, Ganymede, and Callisto. These four satellites are now collectively called the Galilean satellites. This discovery was the first observational evidence of a center of motion not apparently centered on the Earth. This observation was a major argument in favor of Copernicus's heliocentric theory of the motions of the planets, which was an unpopular theory in early seventeenth century theology. Galileo's support of the Copernican theory got him arrested by the Inquisition and led to his life imprisonment under house arrest.

Heliocentric Theory: In the sixteenth century, Polish astronomer Nicolaus Copernicus proposed a theory that the planets revolve around the Sun and not the Earth, as was commonly believed at the time. Copernicus formed this theory based on watching the annual movements of the planets against the star field. An observer standing on Earth watches the stars rise in the east and travel westward across the sky, setting at the western horizon over the course of a night. Through the course of a year, the stars follow this westward movement at a slower pace. However, during the course of a year, the planets, Sun, and Moon generally drift eastward with respect to the star fields. Observed variability in planetary motion combined with the general eastward movement required complex explanations to satisfy the sixteenth century belief that the planets, Sun, and Moon revolve around the Earth.

Destination Jupiter

While the red and gold bands circling the planet are inviting, care must be taken when planning a visit to Jupiter. A good understanding of the fifth planet's dynamic environment is required before setting off on the journey.

Jupiter is the fourth brightest object in the sky (after the Sun, Earth's Moon, and Venus). This is not surprising since Jupiter is the largest planet in the Solar System. Its diameter is more than eleven times Earth's, totaling 141,592 kilometers (88,000 miles) at the equator and 128,720 kilometers (80,000 miles) at the poles. Jupiter's rapid rotation of 9.8 hours is so fast that the planet is actually squashed by the rotational force. Thus Jupiter is larger around the equator than the poles.

Jupiter is composed primarily of hydrogen (90%) and helium (10%) with traces of methane, water, ammonia, other volatile chemicals, and "rock." This composition is very similar to that of the solar nebula from which the solar system was formed. The main bulk of the planet is in the form of liquid metallic hydrogen. This exotic form of hydrogen consists of protons and electrons and can only form at pressures exceeding 4 million bars (the average atmospheric pressure at Earth's surface is 1.013 bars). The high pressure in Jupiter's interior allows the hot metallic hydrogen to exist in liquid form. This hydrogen is an electrical conductor and is the source of Jupiter's vast magnetic field.

Area Facts

Mass	1.9×10^{27} kilograms (3.178×10^{2} Earth Masses)
Equatorial Diameter	141,592 kilometers (88,000 miles)
Polar Diameter	128,720 kilometers (80,000 miles)
Average Distance From Sun	5.2 astronomical units (778,330,000 km)
Rotation Period (length of day in Earth hours)	9.8 hours
Revolution Period (length of year in Earth years)	11.86 years
Number of Rings	3 known
Number of Moons	17 known
Mean Density	1.33 grams/cubic centimeter (water has a density of 1 gm/cc)

Jupiter is more than twice as massive as the other eight planets combined. Compared to Earth, Jupiter is 318 times more massive!

The outer layers of Jupiter's atmosphere are composed primarily of molecular hydrogen and helium. In addition, water, carbon dioxide, methane, and other chemicals are also present.

Jupiter radiates more energy into space than it receives from the Sun. Its interior has a sustained temperature of approximately 20,000° Kelvin. The interior heat is generated by the slow gravitational compression of the planet. This heat flows outward from the planet's core, driving the circulation present in the Jovian atmosphere. This circulation involves the rise of hot gas from the Jovian interior to higher atmospheric layers where it cools and flows back down. This process is called convection.

Jupiter rotates very rapidly, completing one rotation (one Jovian day) in 9 hours and 50 minutes. This fast rotation combines with convection to drive the planet's global winds patterns through a mechanism called the Coriolis Effect. Light and dark bands that are visible through telescopes provide the visible evidence of these processes. The white zones are colored by ammonia ice crystals while the dark belts are colored by unknown materials, collectively called chromophores. Theoretical studies indicate there are three cloud layers in the upper reaches of Jupiter's atmosphere. From the top down, the clouds are composed of ammonia ice, ammonium hydrosulfide, and water ice.

The Coriolis Effect

To understand the Coriolis Effect, it is important to first learn the distinction between angular and linear velocity. Linear velocity is velocity along a straight line and is analogous to driving a car at constant speed down a straight highway. The Earth rotates eastward at a constant angular velocity completing one 360° rotation in a 24-hour period (one day). However, different latitudes rotate at different linear velocities. This is a subtle difference, but it is crucial to the understanding of the Coriolis Effect. Consider two vacationers: one at the equator in the Amazon and one at the North Pole. Both will see the Sun move across the sky from noon to noon, making one complete loop over the course of 24 hours. Thus, both vacationers move at the same angular velocity. But the vacationer in the Amazon must travel the Earth's circumference of 40,074 kilometers (24,906 miles) in one day. But the vacationer standing 10 meters (33 feet) from the North Pole must travel 62.8 meters (206 feet) over the same 24-hour period.

When an object like a bullet moves from north to south (and is not attached to the ground), it maintains its initial eastward speed as it moves. During the course of the bullet's journey, however, it travels across different latitude lines which have their own unique linear velocities that are higher than the bullet's. The bullet, which maintains the linear velocity of its latitude of origin, looks as if it is curving toward the west as it travels southward, because the ground beneath it is moving faster (since its eastward linear velocity was lower than further south). From the bullet's point of view, the ground is moving northward, with more and more eastward motion as it gets further and further south.

This difference in linear velocities at different latitudes is the cause of global wind patterns on Earth as well as other planets. The prevailing wind direction in the northern hemisphere is to the east and a low pressure system in the northern hemisphere rotates counterclockwise (toward the west). The exact opposite is true for the southern hemisphere. The Coriolis Effect was first described by the French mathematician Gaspard Coriolis in the early 19th century.

In the Neighborhood – The Jovian System

Exploring Jupiter is like travelling to London and only seeing the city center. It is when the traveller ventures out into the suburbs that a true flavor of the culture and history of London can be enjoyed. A visit to Jupiter is not complete without spending some time exploring the dark and tenuous rings, the vast magnetic field, and its seventeen known moons.

Jupiter's rings are very dark with an albedo of about 0.05 (5% of the sunlight falling on the rings is reflected back) and thin. Because of this combination, the rings remained hidden from human discovery until the Voyager 1 spacecraft saw them in 1979. Their dark appearance has led scientists to believe that they are composed of grains of rocky material and contain little or no ice. This is in contrast to Saturn's vast ring system which is primarily water ice in composition.

Atmospheric and magnetic drag doesn't allow particles in Jupiter's rings to remain in orbit for long. Data from the Galileo spacecraft shows that ring material is being constantly resupplied by dust formed through micrometeorite impacts on Jupiter's four inner satellites.

Jovian Ring Data

Ring	Distance from Jupiter*	Ring Width
Halo	92,000 km (57,178 miles)	30,500 km (18,956 miles)
Main	122,500 km (76,134 miles)	6,440 km (4,002 miles)
Gossamer	128,940 km (80,136 miles)	100,000 km (62,150 miles)

* Distance is measured from Jupiter's center to the ring's inner edge

While the four Galilean Satellites, Io, Europa, Ganymede, and Callisto, are Jupiter's best known satellites, the planet has 17 known satellites in total. Each of the 17 moons has its own unique environment.

Places Near the Center – Close Satellites

Metis [MEE-tis] is the innermost known satellite of Jupiter. Named after a Titaness who was the first wife of Zeus (Jupiter), the satellite was discovered through data collected by the Voyager 1 flyby in 1979. Metis lies within Jupiter's main ring and may be the source of material for the ring. Very little is known about Metis.

Metis
Orbit (from Jupiter) = 128,000 km (79,550 miles)
Diameter = 40 km (24.86 miles)
Mass = 9.56×10^{16} kg (1.59×10^{-8} Earth masses)
Orbital Period = 0.295 days

Andrastea
Orbit (from Jupiter) = 129,000 km (80,173 miles)
Diameter = 20 km (12.43 miles)
Mass = 1.91×10^{16} kg (3.19×10^{-9} Earth masses)
Orbital Period = 0.298 days

Adrastea [a-DRAS-tee-uh] is the second innermost known satellite of Jupiter. Adrastea was the daughter of Jupiter and Ananke and the distributor of rewards and punishments. Adrastea and Metis lie within Jupiter's main ring and may be the source of material for the ring. The satellite was discovered discovered through data collected by the Voyager 1 flyby in 1979 Very little is known about Adrastea.

Amalthea
Orbit (from Jupiter) = 181,300 km
(112,678 miles)
Diameter = 270 km x 166 km x 150 km
Mass = 7.17 x 10^{18} kg
(3.19 x 10^{-9} Earth masses)
Orbital Period = 0.498 days

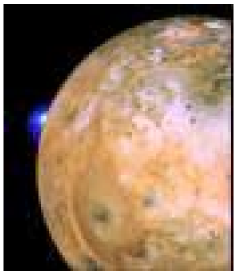
Amalthea [am-al-THEE-uh] is one of Jupiter's smaller moons. It was named after the nymph who nursed the infant Jupiter with goat's milk. The last moon in the solar system to be discovered through direct visual observation, Amalthea was discovered in 1892 by the American astronomer Edward Emerson Barnard while making observations from the Lick Observatory with a 36 inch (91 centimeter) refractory telescope. It was also the first moon of Jupiter to be discovered since Galileo's discovery of the four Galilean moons in 1610.

Amalthea is extremely irregular, having dimensions of about 270x165x150 kilometers in diameter. It is heavily scarred by craters, some of which are extremely large relative to the size of the moon. The surface is dark and reddish in color apparently caused by a dusting of sulfur originating from Io's volcanoes. Bright patches of green appear on the major slopes of Amalthea. The nature of this color is currently unknown.

Amalthea rotates synchronously with its long, blunt axis pointed towards Jupiter. Because of Amalthea's close proximity to Jupiter, it is exposed to the intense Jovian radiation field. It continuously receives high doses of energetic ions, protons, and electrons produced by the Jovian magnetosphere. In addition it is bombarded with micrometeorites, and heavy sulfur, oxygen, and sodium ions that have been stripped away from Io.

Thebe
Orbit (from Jupiter) = 222,000 km
(137,973 miles)
Diameter = 100 km x 90 km
Mass = 7.77 x 10^{17} kg
(1.3 x 10^{-7} Earth masses)
Orbital Period = 0.675 days

Thebe [THEE-bee] is the fourth known satellite of Jupiter. Thebe was a nymph and the daughter of the river god Asopus. Thebe rotates synchronously around Jupiter. It was discovered through data collected by the Voyager 1 flyby in 1979. Very little is known about this moon.



Io [EYE-oh or EE-oh] can be classified as one of the most unusual moons in our solar system. Active volcanism on Io was the greatest unexpected discovery at Jupiter. It was the first time active volcanoes had been seen on another body in the solar system. The Voyagers observed the eruption of nine volcanoes on Io altogether. There is also evidence that other eruptions occurred between Voyager encounters. Plumes from the volcanoes extend to more than 300 kilometers (190 miles) above the surface, with material being ejected at speeds up to a kilometer (.6 mile) per second.

Io's volcanoes are apparently due to heating of the satellite by tidal pumping. Io is perturbed in its orbit by Europa and Ganymede, two other large satellites nearby, then pulled back again into its regular orbit by Jupiter. This tug-of-war results in tidal bulging as great as 100 meters (330 feet) on Io's surface.

Io
Orbit (from Jupiter) = 422,000 km
(262,273 miles)
Diameter = 3630 km (2256 miles)
Mass = 8.93 x 10^{22} kg
(1.5 x 10^{-2} Earth masses)
Orbital Period = 1.77 days

Io is composed primarily of rocky material with very little iron. Io is located within an intense radiation belt of electrons and ions trapped in Jupiter's magnetic field. As the magnetosphere rotates with Jupiter, it sweeps past Io and strips away about 1,000 kilograms (1 ton) of material per second. The material forms a torus, a doughnut shaped cloud of ions that glow in the ultraviolet. The torus's heavy ions migrate outward, and their pressure inflates the Jovian magnetosphere to more than twice its expected size. Some of the more energetic sulphur and oxygen ions fall along the magnetic field into the planet's atmosphere, resulting in auroras.

Named in honor of a maiden who was loved by Zeus, Io was discovered by Galileo Galilee in 1610.

Europa [yur-ROH-pah] is a strange looking moon of Jupiter with a large number of intersecting features. It is unlike Callisto and Ganymede with their heavily cratered crusts. Europa has almost a complete absence of craters as well as almost no vertical relief. There is a possibility that Europa may be internally active due to tidal heating at a level one-tenth or less that of Io. Models of Europa’s interior show that beneath a thin 5 kilometer (3 miles) crust of water ice, Europa may have oceans as deep as 50 kilometers (30 miles) or more. The visible markings on Europa could be a result of global expansion where the crust could have fractured, filled with water and froze.

Europa
Orbit (from Jupiter) = 670,900 km
(416,020 miles)
Diameter = 3138 km (2256 miles)
Mass = 4.8 x 10^{22} kg
(8.03 x 10^{-3} Earth masses)
Orbital Period = 3.55 days

Europa was a Phoenician princess abducted to Crete by Zeus. The satellite was discovered by Galileo Galilee in 1610.

Ganymede [GAN-ee-meed] is the largest moon of Jupiter and is the largest in our solar system with a diameter of 5,262 kilometers (3,280 miles). If Ganymede orbited the Sun instead of Jupiter it could be classified as a planet. Like Callisto, Ganymede is most likely composed of a rocky core with a water/ice mantle and a crust of rock and ice.

Ganymede
Orbit (from Jupiter) = 1,070,000 km
(665,005 miles)
Diameter = 5262 km (3270 miles)
Mass = 1.48 x 10^{23} kg
(8.03 x 10^{-3} Earth masses)
Orbital Period = 7.15 days

Ganymede has no known atmosphere, but recently the Hubble Space Telescope detected ozone at its surface. The amount of ozone is small as compared to Earth. It is produced as charged particles trapped in Jupiter's magnetic field rain down onto the surface of Ganymede. As the charged particles penetrate the icy surface, particles of water are disrupted leading to ozone production. This chemical process hints that Ganymede probably has a thin tenuous oxygen atmosphere like that detected on Europa.

Ganymede has had a complex geological history. It has mountains, valleys, craters and lava flows. Ganymede is mottled by both light and dark regions. It is heavily cratered especially in the dark regions, implying ancient origin. The bright regions show a different kind of terrain - one which is grooved with ridges and troughs. These features form complex patterns and have a vertical relief of a few hundred meters and run for thousands of kilometers. The grooved features were apparently formed more recently than the dark cratered area perhaps by tension from global tectonic processes. The real reason is unknown; however, local crust spreading does appear to have taken place, causing the crust to shear and separate.

First discovered by Galileo Galilee in 1610, Ganymede was named for a Trojan boy of great beauty whom Zeus carried away to be cup bearer to the gods.

Callisto [kah-LISS-toe] is the second largest moon of Jupiter, the third largest in the solar system, and is about the same size as Mercury. It orbits just beyond Jupiter's main radiation belt. Callisto is the most heavily cratered satellite in the solar system. Its crust is very ancient and dates back 4 billion years, just shortly after the solar system was formed.

Callisto
Orbit (from Jupiter) = 1,883,000 km
(1,170,285 miles)
Diameter = 4800 km (2983 miles)
Mass = 1.08 x 10^{23} kg
(1.81 x 10^{-2} Earth masses)
Orbital Period = 16.7 days

Callisto has the lowest density (1.86 grams per cubic centimeter) of the Galilean satellites. From recent observations made by the Galileo spacecraft, Callisto appears to be composed of a crust about 200 kilometers (124 miles) thick. Beneath the crust is a possible salty ocean more than 10 kilometers (6 miles) thick. Beneath the ocean is an unusual interior. It is not entirely uniform nor does it vary dramatically. Prior to the Galileo mission, scientists believed that Callisto's interior was totally undifferentiated, but Galileo spacecraft data suggest that the interior is composed of compressed rock and ice, with the percentage of rock increasing as depth increases. Meteorites have punctured holes in Callisto's crust, causing water to spread over the surface and forming bright rays and rings around the crater.

Callisto was a nymph, beloved of Zeus and hated by Hera. Hera changed her into a bear and Zeus then placed her in the sky as the constellation Ursa Major. The satellite was discovered by Galileo Galilee in 1610.

Heat Generation on Io

New calculations suggest that Jupiter’s moon Io may be giving off so much heat, the best explanation would be that virtually the entire surface is covered with lava spewed so recently that it is still cooling. Flexing of material inside Io by large tides is what generates the heat. This flexing is similar to the manner in which tires get warm from flexing against the highway. In Io’s case, the fluctuation tides are caused by changes in the amount of gravitational tugging from Jupiter as Io repeatedly comes closer to the planet, then farther away again, in its eccentric orbit. The eccentric shape of Io’s orbit is maintained by the gravitational pull of Europa, Io’s next closest neighbor.

Earlier estimates of Io’s heat output summed the amounts from active volcanoes and other localized areas that are warmer than a measurement-difficulty threshold of approximately 135° Kelvin (-216° Farenheit). New calculations made by Dr. Dennis Matson of NASA’s Jet Propulsion Laboratory and four of his colleagues sets a lower limit to the total heat output, but excludes about nine-tenths of Io’s surface. Their calculation of the upper limit of Io’s heat output is approximately 13.5 watts of energy per square meter (approximately 1.3 watts per square foot) which is approximately five times as much as the heat output from the ground in the Yellowstone hot springs area Wyoming.

The calculated heat output does not include energy absorbed from the Sun, which is much greater on Earth than on Io. Recent nighttime temperature measurements of Io’s surface by NASA’s Galileo spacecraft, averaging 90° to 95° Kelvin (-297° to –288° Farenheit), correspond closely with new upper-limit estimates of the moon’s heat flow. The measurements do not vary much by latitude or time of night, implying that most of the heat comes from Io itself, rather than absorbed sunshine. That suggests Io’s actual total heat output is close to the new upper-limit calculation.

The JPL research team says that for Io to be emitting so much heat, its entire surface, with a few exceptions, such as high mountains, is likely covered with lava in various stages of cooling. Knowing the moon’s heat output is important for checking theories about the interiors of both Io and Jupiter, Dr. Matson said.

The Outer Environs

Jupiter's eight outer moons fall into two distinct orbital groups. Leda, Himalia, Lysithea, and Elara all orbit at approximately 11 million kilometers from Jupiter while Ananke, Carme, Pasiphae, and Sinope orbit at approximately 23 million kilometers. None of these eight outer satellites has been explored in any detail or with enough resolution to gain a full understanding of the nature of the terrain.

Leda [LEE-duh] is the ninth known and smallest satellite of Jupiter. Leda was the queen of Sparta and the mother of Helen and Pollux. The satellite was discovered by the astronomer C. Kowal in 1974.

Himalia [hih-MAL-yuh] is the 10th known satellite of Jupiter. Himalia was a nymph who bore three sons of Zeus (Jupiter). The satellite was discovered by the astronomer C. Perrine in 1904.

Lysithea [ly-SITH-ee-uh] is the 11th known satellite of Jupiter. Lysithea was a daughter of Oceanus and one of Zeus's lovers. The satellite was discovered by the astronomer S. Nicholson in 1938.

Elara [EE-lar-uh] is the 12th known satellite of Jupiter. Elara and Zeus were the parents of Tityus the giant. The satellite was discovered by the astronomer C. Perrine in 1905.

Ananke [a-NANG-kee] is the 13th known satellite of Jupiter. Ananke and Zeus were the parents of Adrastea. The satellite was discovered by astronomer S. Nicholson in 1951.

Carme [KAR-mee] is the 14th known satellite of Jupiter. Carme and Zeus were the parents of Britomartis, a Cretan goddess. The satellite was discovered by the astronomer S. Nicholson in 1938.

Pasiphae [pah-SIF-ah-ee] was the wife of Minos and the mother of the Minotaur. The satellite was first discovered by P. Melotte in 1908.

Sinope [sah-NOH-pee] was a woman said to have been unsuccessfully courted by Zeus. The satellite, the outermost of Jupiter, was discovered by the astronomer S. Nicholson in 1914.

S/1999 J1 is a new satellite of Jupiter that was discovered in 1999.

Jupiter's Outer Destinations

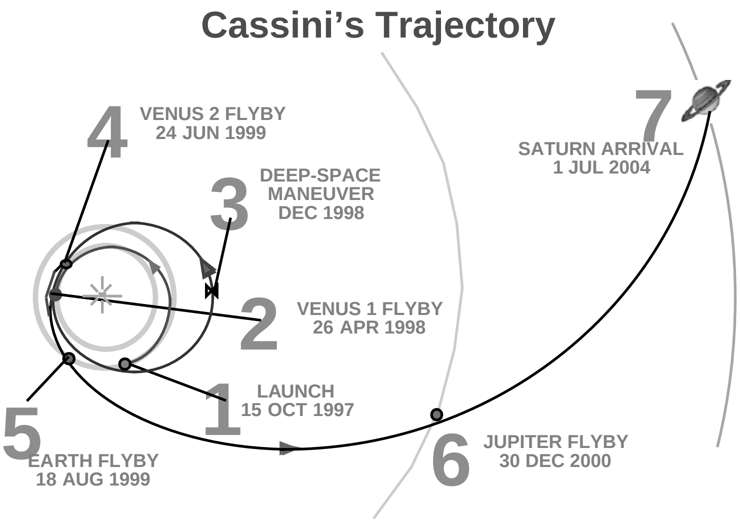
Satellite	**Orbit (from Jupiter)**	**Diameter**	**Mass**	**Orbital Period**
Leda	11,094,000 km (6,894,921 miles)	16 km (9.94 miles)	5.68×10^{15} kg (9.5×10^{-10} Earth Masses)	239 days
Himalia	11,480,000 km (7,134,820 miles)	186 km (115.6 miles)	9.56×10^{18} kg (1.59×10^{-6} Earth Masses)	251 days
Lysithea	11,720,000 km (7,283,980 miles)	36 km (22.37 miles)	7.77×10^{16} kg (1.3×10^{-8} Earth Masses)	260 days
Elara	11,737,000 km (7,294,546 miles)	76 km (47.2 miles)	7.77×10^{17} kg (1.3×10^{-7} Earth Masses)	260 days
Ananke	21,200,000 km (13,175,800 miles)	30 km (18.6 miles)	3.82×10^{16} kg (6.39×10^{-9} Earth Masses)	631 days
Carme	22,600,000 km (14,045,900 miles)	40 km (24.86 miles)	9.56×10^{16} kg (1.59×10^{-8} Earth Masses)	692 days
Pasiphae	23,500,000 km (14,605,250 miles)	50 km (31.1 miles)	1.91×10^{17} kg (3.2×10^{-8} Earth Masses)	735 days
Sinope	23,700,000 km (14,729,550 miles)	36 km (22.37 miles)	7.77×10^{16} kg (1.3×10^{-8} Earth Masses)	758 days
S/1999 J1	24,200,000 km (15,040,400 miles)	12 km (7.46 miles)	Unknown	774 days

"Vehicle Fleet at Jupiter"

Throughout the fall of 2000 and winter of 2001, two NASA spacecraft will be focused on Jupiter. Galileo, which has been in orbit since December 7, 1995, will be continuing its exploration of Jupiter's magnetosphere and will flyby Ganymede in December. Much further afield will be Cassini which will pass by Jupiter on its way to a 2004 rendezvous with Saturn. Cassini will make a very distant flyby of Jupiter, coming no closer then 9,721,846 kilometers (6,076,154 miles). This closest approach will occur on 30 December 2000 at 10:12 UTC (02:12 a.m. Pacific Standard Time). This is the first time two spacecraft are within the vicinity of Jupiter, simultaneously studying its environment. This unique opportunity allows scientists to gather data simultaneously using Galileo's vantage point deep within the magnetosphere and using Cassini's distant view.

"Getting There"
Gravity Assist - Cassini's Interplanetary Trajectory

Cassini's journey began on October 15, 1997 at 4:43 a.m. Eastern Daylight Time with the lift-off of a Titan IVB/Centaur rocket from Cape Canaveral, Florida. During the short duration of Cassini's launch into Earth orbit, the spacecraft received virtually all the propulsive power needed for its flight. In fact, Cassini will be in free-fall for nearly all of its nearly seven-year cruise, except for a large main engine burn that set up the Venus 2 flyby in June 1999 and some infrequent, small propulsive maneuvers (known as “trajectory correction maneuvers,” or TCMs), which make tiny adjustments in course or speed.



The launch vehicle didn’t speed Cassini on its way toward Saturn, rather the rocket actually slowed down the spacecraft. On the launch pad, Cassini was orbiting the Sun, just as we are right now. The Titan IVB launch and the first firing of its Centaur upper stage separated Cassini from Earth – Cassini still had the same momentum going around the Sun that it had while attached by gravity to Earth’s surface. Then the Centaur fired a second time, slowing the spacecraft so that Cassini would begin to lag a little behind Earth in its journey around the Sun. The amount of slowing imparted to Cassini was just enough so that as it continued around the Sun, it would fall inward about as far as the orbit of Venus.

Momentum is a measure of the ‘quantity of motion’ of an object, that is, an object’s mass multiplied by its velocity. A car travelling at 145 kilometers per hour (90 miles per hour) into a brick wall has a much different result compared to a baseball hitting the same wall at the same speed. The difference is their respective momentum since the baseball is much less massive than the car.

How can gravity “assist” a spacecraft? After Cassini’s launch, the spacecraft’s travel path dropped inward toward the Sun. When Cassini approached Venus, the spacecraft flew behind the planet. The planet’s gravity pulls at the spacecraft, but the spacecraft also has its own gravity, which pulls on the planet by a minute amount. This caused Venus to change its velocity in its solar orbit, while Cassini changed its velocity a great amount. The result was that Cassini was on a flight path that takes it out to just beyond the orbit of Mars (but not near the planet).

If mission engineers had allowed Cassini to continue on this flight path, the spacecraft would not have enough velocity to reach Saturn. Therefore, on December 3, 1998, the spacecraft’s main engine was used to change the flight path of Cassini and target it for the next planetary flyby. Cassini flew by Venus again on June 24, 1999 and then by Earth on August 18, 1999.

After the Earth swingby in August 1999, Cassini was headed toward the outer solar system where a final planetary assist by Jupiter will give the spacecraft the velocity necessary for it to reach Saturn.

Galileo's Legacy at Jupiter
Science Observations & Discoveries

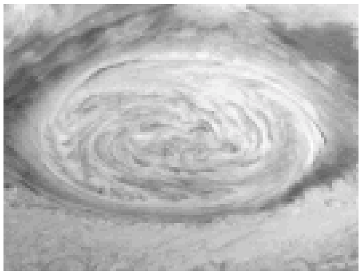
Galileo has been orbiting Jupiter since December 7, 1995. Originally launched from the Space Shuttle in October 1989, Galileo also used a gravity assist trajectory to achieve the required velocity to reach Jupiter. This is the same technique employed by Cassini on her journey to Saturn. On the way to Jupiter, Galileo flew past Venus, Earth (twice), and made two close flybys (without gravity assists) with main belt asteroids: Gaspra and Ida.

Galileo Mission Events

Mission Event	**Calendar Date**	**Comments**
Launch	18-Oct-89	Spacecraft was launched aboard the Space Shuttle Atlantis on manifest flight STS-34. Launch occurred at 12:53 p.m. Eastern Daylight Time (09:53 a.m. Pacific Daylight Time)
Venus flyby	10-Feb-90	Altitude = 16,000 km (10,000 miles) Closest Approach Time = 13:44 Universal Time (UTC) (05:44 a.m. Pacific Standard Time)
Earth flyby	8-Dec-90	Altitude = 960 km (597 miles) Closest Approach Time =20:30 UTC (2:30 p.m. Pacific Standard Time)
Earth flyby	8-Dec-92	Altitude = 303 km (188 miles)
Gaspra Asteroid Flyby	29-Oct-91	Closest Approach = 1,601 km (1,000 miles)
Ida Asteroid Flyby	28-Aug-93	Closest Approach = approximately 2,400 km (1,490 miles)
Shoemaker-Levy9 Observation	July-94	Galileo directly observed the fragments of Comet Shoemaker-Levy 9 plunge into the Jovian atmosphere.
Probe Release	13-Jul-95	The Probe began its five-month journey from the spacecraft to Jupiter.
Jupiter Orbit Insertion	7-Dec-95	Galileo's arrival at Jupiter.
Probe Mission	7-Dec-95	The Probe plunged into the Jovian atmosphere.

Prior to the spacecraft's arrival at Jupiter, Galileo released its atmospheric probe, which plunged into Jupiter, studying the composition and structure of the Jovian atmosphere. Almost 5 months after the probe release, Galileo arrived at Jupiter. Upon arrival, Galileo's main engine was fired to slow it down and the spacecraft used a gravity assist with Jupiter's closest moon, Io, to place itself in an orbit around Jupiter. Since that day in December 1995, Galileo has made more then 25 orbits around the planet, taking detailed science data of Jupiter, its tenuous rings, its satellites, and magnetospheres.

Some of the discoveries made by the Galileo spacecraft include:



Jupiter's Storms - Using data from the probe mission, scientists have discovered that Jupiter has thunderstorms many times larger than Earth's. These storms result from the vertical circulation of water in the top layers. There are areas where water rises to form thunderstorms, leaving areas where air descends and becomes dry. Lightning many times stronger than average bolts on Earth are common.

Jupiter's Rings **–** Unlike the rings of Saturn, which are composed primarily of water ice, Galileo data has shown that Jupiter's rings are made principally of small dust grains. Dust material is fed into the rings through the collision of meteoroids with Jupiter's four innermost satellites: Metis, Adrastea, Amalthea, and Thebe (all of which orbit closer to Jupiter than the innermost Galilean satelllite, Io).

Io **–** Io's volcanoes were first discovered by Voyager 1 in 1979. The volcanoes are activated by strong tidal forces caused by Jupiter as well as the satellites Europa and Ganymede. Tides as high as 100 meters or 328 feet exist on Io's solid surface. Temperature measurements taken by the Galileo spacecraft reveal that some of Io's volcanoes are hotter than those found on Earth. This information allows scientists to gain better insight into the material that erupts from these volcanoes and has led to the belief that silicate material rich in magnesium erupts from below Io's surface. Such hot volcanism has not been present on Earth for approximately 3.5 billion years.

Europa **–** Galileo's study of Europa has uncovered one of the most intriguing science discoveries of the mission. The satellite's icy, cracked, and frozen surface shows evidence of repeated surface melt and refreeze. Galileo images have revealed that Europa possesses more water than the total amount found on Earth. Some may be liquid trapped beneath the satellite's icy crust. In addition, the satellite has a thin oxygen atmosphere and an ionosphere.

Ganymede **–** Galileo data have revealed that Ganymede, the largest satellite in the solar system, has its own magnetic field. This magnetic field is believed to be generated by tidal friction which caused the separation of material inside the satellite.

Callisto **–** Scientific data show evidence of a subterranean ocean on Callisto. Electric field flow from Callisto's subterranean ocean generated by Jupiter's magnetic field could be the cause of the satellite's magnetic field. Callisto's surface is ancient and completely filled with craters.

Cassini's Itinerary – Flyby Science

While Cassini's actual flyby of Jupiter doesn't occur until December 30, 2000, the instruments will begin collecting data in early October. On October 1, 2000 the spacecraft will begin executing a five-day repeating sequence that combines collection of data using a variety of on-board instruments. During this time, the Imaging Science Subsystem (ISS), Cosmic Dust Analyzer (CDA), and Cassini Plasma Spectrometer (CAPS) instruments will be the primary operators while the other science instruments operate in a "ride-along" mode. This means that the science collection from the ISS, CAPS, and CDA instruments will dictate how the spacecraft is operated.

The weeks surrounding closest approach will be a busy time for Cassini. The on-board instruments will be collecting data to study:

1. Jupiter's atmospheric composition and dynamics, including the aurora, and heat flow
2. Jupiter's rings
3. Observe Jupiter's moons Europa and Callisto at opposition (when they are exactly on the Sun-Cassini-moon line
4. Jupiter's moon Himalia and determine the satellite's rotation period
5. Observe Jupiter's moon Io in eclipse
6. Jupiter's magnetosphere and its interaction with the solar wind
7. Io's dust stream
8. Jupiter's synchrotron radiation (natural radio emission caused by spiraling electrons)

Synchrotron Radiation

Jupiter's magnetic field is a dynamic environment. When charged particles encounter Jupiter's magnetic field, the particles get caught and spiral in the magnetic field. This rapid spiraling causes the charged particles to emit radio energy. This energy is called synchrotron radiation.

As Cassini leaves Jupiter's vicinity in early 2001, science data will continue to be collected on Jupiter's environment. At the end of March 2001, Cassini will turn away from the fifth planet and set its sights on the destination ahead: Saturn.

Cassini-Galileo Joint Science Observations

Throughout the fall, Cassini and Galileo (the NASA spacecraft orbiting and studying Jupiter since December 1995) will jointly be collecting science data. Prior to closest approach, Cassini will be outside Jupiter's magnetosphere collecting measurements on the solar wind while Galileo will be within Jupiter's magnetic field. Data will be collected simultaneously by both spacecraft, allowing scientists, for the first time, to observe both the environments outside and within the planetary magnetic field of a gas giant planet. Data collected from Galileo's 5-year tour of Jupiter suggest that magnetospheric dynamics, including fluctuations in Jupiter's aurora, interaction between Jupiter and Io, and changes in Jupiter's magnetotail, could be caused by changes in solar wind conditions. These data will allow researchers to gain understanding of how the solar wind interacts with a planetary magnetic field.

What's a magnetotail? The magnetosphere of a planet is not a sphere. The pressure of the solar wind distorts it. The solar wind is a free-flowing plasma blowing out from the Sun. A plasma is an electrically-charged gas, like the one in a fluorescent light. As the solar wind reaches a planet on the sunward side, the planet's magnetic field is compressed towards the planet. Where the solar wind "bumps into" the magnetic field and is deflected around it is called the bow shock. On the side away from the Sun, magnetic interactions with the solar wind drag the magnetosphere deep into the interplanetary environment. This elongated extension is termed the "magnetotail." The resulting magnetosphere shape loosely resembles a comet.

In addition to studying Jupiter's magnetosphere, Galileo and Cassini will collect simultaneous data on Jupiter's rings, the atmosphere, and Io. Near Cassini's closest approach to Jupiter, both spacecraft will measure the Io dust stream. This stream of electrically charged dust flows outward continuously from Jupiter, under the control of Io. Dust ejected from the system will first be measured by Galileo, and then will be measured by Cassini. The data will be correlated so that the dust velocity distribution and particle compositions and masses will be measured for the first time.

Ground-Space Joint Science Observations

Telescopes on the ground will join Cassini and Galileo in studying Jupiter. Amateur astronomers around the world will focus their eyepieces on the fifth planet this fall. Meanwhile, Jupiter's synchrotron radiation will be studied in the radio wavelengths using the Very Large Array radio telescope in Socorro, New Mexico. A bit farther afield, in Earth orbit, the Hubble Space Telescope will be watching Jupiter as well. Observations coordinated between Cassini and Hubble will study Jupiter's aurora.

Students participating in the Goldstone Apple Valley Radio Telescope (GAVRT) Project will also be watching Jupiter in radio wavelengths. GAVRT students will collect ground-based observations of Jupiter throughout fall-winter 2000-2001 using two radio telescopes located in Goldstone, California. GAVRT students perform radio astronomy research projects by remotely operating the GAVRT radio telescope, and for the Cassini-Jupiter Microwave Observing Campaign, a second radio telescope, from their classrooms. These data will be combined with Cassini and Galileo observations to model the radiation environment of Jupiter's magnetosphere.

What's Next?

Galileo will be completing its orbital tour of Jupiter in 2001**.** While details about the culmination of Galileo's tour are not finalized, the spacecraft will be making more observations of the fifth planet over the next months prior to the end of its mission.

Cassini will continue its journey to Saturn. General Relativity enthusiasts might want to check out Cassini's Gravitational Wave Experiments, planned for the next three years. During this time, Cassini will be performing a series of Gravitational Wave Experiments (GWE) in an effort to search for low-frequency waves of space-time distortion generated by massive astrophysical systems.

To accomplish this, scientists treat the Earth and the spacecraft as separated test masses. A radio signal with a very stable frequency is transmitted between the Earth and the spacecraft. By measuring any change in frequency, the relative spacecraft velocity change with respect to the Earth is measured. If a gravitational wave occurs, it leaves a "signature" in the Doppler signal, either of a momentary increase or decrease in the spacecraft's speed.

On July 1, 2004 Cassini will enter the Saturn system and commence a four-year tour of the sixth planet from the Sun. On November 6, 2004, the Huygens probe will be released from the Cassini orbiter. The probe will parachute to the surface of Titan, Saturn's largest moon, on November 27, 2004, during Thanksgiving weekend. During the probe mission, data will be collected on Titan's atmosphere, winds, and surface conditions. Data from the probe mission will be sent back to Earth using the Cassini orbiter as a relay.

Cassini will operate in orbit around Saturn during a four-year orbital tour of the Saturn system. Using the spacecraft's 12 on-board instruments, data will be collected on Saturn, the rings, the magnetosphere, Titan, and Saturn's 17 smaller, icy moons.

Cassini Mission Events

Mission Events	Calendar Date	Days from Launch	Comments
Launch	15-Oct-97	0	Launch occurred at 4:43 a.m. Eastern Standard Time (1:43 a.m. Pacific Standard Time)
Venus flyby	26-Apr-98	193	Altitude = 337 km; Speed = 11.7 km / sec Closest Approach Time = 13:44 UTC (06:44 a.m. Pacific Daylight Time)
Deep Space Maneuver	3-Dec-98	414	Adjusted Cassini's trajectory for a return to Venus
Instrument	28-Dec-98	439 to 464	Integrated checkout of all 12 orbiter science

Mission Events	**Calendar Date**	**Days from Launch**	**Comments**
Checkout	to21-Jan-99		instruments.
Venus flyby	24-Jun-99	617	Altitude = 623 km; Speed = 13.6 km/sec Closest Approach Time =20:30 UTC (3:30 p.m. Pacific Daylight Time)
Earth flyby	18-Aug-99	672	Altitude = 1157 km; Speed = 19.0 km/sec Closest Approach Time = 03:28 UTC (8:28 p.m. Pacific Daylight Time on 17 August)
Enter Asteroid Belt	11-Dec-99	787	Sun range ≈ 2.2 AU
Masursky Flyby (distant)	23-Jan-00	830	Closest Approach = 1.5 million km, Closest Approach Time = 09:35 UTC (1:35 a.m. Pacific Standard Time)
High Gain Antenna Operations Begin	1-Feb-00	839	Cassini is now far enough from the Sun that the High Gain Antenna can be pointed toward Earth and used for communications (it was shading the spacecraft in the inner Solar System)
Exit Asteroid Belt	12-Apr-00	910	Sun range ≈ 3.3 AU
Jupiter flyby	30-Dec-00	1172	Altitude = 9721846 km; Speed = 11.6 km/sec Closest Approach Time = 10:03 UTC (2:03 a.m. Pacific Standard Time)
Gravitational Wave Experiment	26-Nov-01 to 5-Jan-02	1503 to 1543	Searching for low-frequency waves in the space-time continuum.
Conjunction Experiment	6-Jun-02 to 6 –Jul-02	1695 to 1725	Study affects of solar corona on transmissions to/from Cassini.
Gravitational Wave Experiment	7-Dec-02 to 16-Jan-03	1879 to 1919	Searching for low-frequency waves in the space-time continuum.
Conjunction Experiment	16-Jun-03 to 16-Jul-03	2070 to 2100	Study affects of solar corona on transmissions to/from Cassini.
Gravitational Wave Experiment	15-Dec-03 to 4-Jan-04	2252 to 2292	Searching for low-frequency waves in the space-time continuum.
Phoebe flyby	11-Jun-04	2431	Closest Approach = 2,000 km
Saturn Orbit Insertion	1-Jul-04	2451	Main rocket engine burn takes Cassini from its interplanetary trajectory into orbit around Saturn
Huygens Probe Separation	6-Nov-04	2579	The Huygens probe begins its solo 3-week journey to Titan
Huygens Probe Mission	27-Nov-04	2600	The Huygens probe parachutes to the surface of Titan.
Titan 1 flyby	27-Nov-04	2600	This first flyby of Titan will be dedicated to returning the data from the Huygens probe mission and collecting atmospheric data necessary for the rest of the orbiter mission.
End Of Mission	1-Jul-08	3912	End of 4-year tour

During the planned four-year tour, Cassini will make over 70 orbits of Saturn, collecting data on all aspects of the Saturnian system. The orbits of the tour are planned for maximum science data collection. Therefore, the closest approach distance to Saturn, the inclination of the spacecraft to Saturn's equator, and the orbit length will all change throughout the tour. In addition, there are opportunities to make close observations of the majority of Saturn's satellites, including over 40 close passes of Titan.

Jupiter in the Night Sky

During Cassini's science flyby of Jupiter over the period autumn 2000 through winter 2001, observers on Earth can see Jupiter in the sky following the Seven Sisters (Pleiades) and above Orion, the large, familiar winter constellation with three bright stars marking his belt. Jupiter will be the brightest object in that area of the sky, looking like a brilliant white star to the unaided eye. To Jupiter's right, slightly fainter, gold-colored Saturn will be leading it during their nightly swing across the sky from east to west.

Dates when the Moon will be close to Jupiter & Saturn:

16 October 2000
12 November 2000
9, 10 December 2000
6 January 2001
2, 3 February 2001
2 March 2001
29 March 2001

Over the course of the autumn and winter, Jupiter will rise earlier and earlier due to Earth's orbital motion around the Sun. Early in autumn, Jupiter will just be on the eastern horizon around 9:00 p.m. By late autumn, observers will find it is visible in the east as soon as the sky is dark. In December at 9:00 p.m., Jupiter and Saturn will be very high above the southern horizon, with Orion trailing to their lower left. By 12:00 midnight during December, the planets will have moved to a position high in the western sky. In late winter, the Earth's changing position places the planets high in the west just after dark. The Moon will be close to Jupiter and Saturn on these nights, making them easier to identify.

While neither Cassini nor Galileo (in orbit around Jupiter) can be seen with telescopes from Earth (in fact, they can't even see each other), an earthbound observer with binoculars will be able to see Jupiter's four large satellites. In order outward, the moons are Io, Europa, Ganymede, and Callisto. Their orbital periods range from less than two days to more than 16 days. Over the course of one or more nights, their orbital minuets can be tracked. On some nights, as few as two moons may be visible.

Observers with small telescopes can see the movements of Jupiter's moons and will also be able to see some of the dark belts and bright zones marking Jupiter's cloud tops. Small telescopes will also show a dark band across Saturn, Saturn's rings, and its largest moon, Titan. Titan is comparable in size to Jupiter's largest moon, Ganymede, but it is almost twice as far away from Earth and much more mysterious.

Here are some interesting activities for students, amateur stargazers, and families:

1. Chart Earth's orbital motion in October and November. From the same place in your front or back yard, on a daily basis make note of the time of night that Jupiter first appears on the horizon each evening. Jupiter will appear above the horizon several minutes (how many?) earlier each day. Make a plot of the time of rising versus the date.

2. Chart Earth’s orbital motion through autumn and winter. Jupiter and Saturn are both in the constellation Taurus, the Bull, over the full period of visibility. Carefully sketch the positions of Jupiter and Saturn relative to the background stars. Use stars near them in the sky as reference points. The Seven Sisters (Pleiades) and the Hyades, the V-shaped collection of stars marking the head of Taurus (especially the bright, reddish star Aldebaran, one of Taurus’ eyes), are easy to see and the planets will be near them throughout the period. Their changing positions indicate Earth’s overtaking them during its annual revolution around the Sun.

3. Using binoculars or a small telescope, sketch the positions of the moons relative to Jupiter. By making nightly drawings over a period of a few weeks it is possible to sort out which moons are which, based on how frequently they circle Jupiter and their maximum apparent distance from the planet. Pretend you are Galileo in 1609 seeing the moons for the first time. How far from the planet does each one get? How fast does each go from side to side and back? Do you see any color differences between them? The astronomer Galileo made similar observations when he discovered the moons of Jupiter. Use a telescope and sketch Titan’s motion around Saturn. How long does it take to make a revolution around Saturn?

4. Compare the colors of Jupiter and Saturn to the colors of the brightest stars in Taurus and Orion. Reddish stars (actually salmon-colored) have temperatures of 3,000 to 4,000C and bluish stars have temperatures exceeding 10,000C. Jupiter’s naked-eye color matches the Sun’s. At what temperature would you conclude the Sun is?

Learn More

Adventurers of all ages will enjoy learning more about Jupiter and the Galileo and Cassini missions. A wealth of reading references, hands-on classroom activities, and supporting information on Jupiter and the Galileo Mission are available from the Galileo Mission web site at http://galileo.jpl.nasa.gov.

Those who are interested in the future journeys of Cassini and the mission at Saturn can find hands-on student activities as well as general and scientific information on the Saturn System and Cassini on the Cassini Mission web site at: http://www.jpl.nasa.gov/cassini.

Both sites are also accessible via the Jet Propulsion Laboratory's web site at: http://www.jpl.nasa.gov.

Classroom activities, optical viewing of Jupiter, and supporting information on the Goldstone Apple Valley Radio Telescope (GAVRT) Project can be accessed from the GAVRT web site at http://www.avstc.org/gavrt.

Visit the Telescopes in Education web site at http://tie.jpl.nasa.gov/ for information on the TIE program.

Happy trails!