

NASA Facts

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109



Cassini Mission to Saturn

The Cassini mission to Saturn is the most ambitious effort in planetary space exploration ever mounted. A joint endeavor of NASA, the European Space Agency (ESA) and the Italian space agency, Agenzia

Spaziale Italiana (ASI), Cassini is sending a sophisticated robotic spacecraft to orbit the ringed planet and study the Saturnian system in detail over a four-year period. Onboard Cassini is a scientific probe called Huygens that will be released from the main spacecraft to parachute through the atmosphere to the surface of

Saturn's largest and most interesting moon, Titan.

Launched in 1997, Cassini will reach Saturn in 2004 after an interplanetary cruise spanning nearly seven years. Along the way it is flying past Venus, Earth and Jupiter in "gravity-assist" maneuvers designed to increase the speed of the spacecraft.

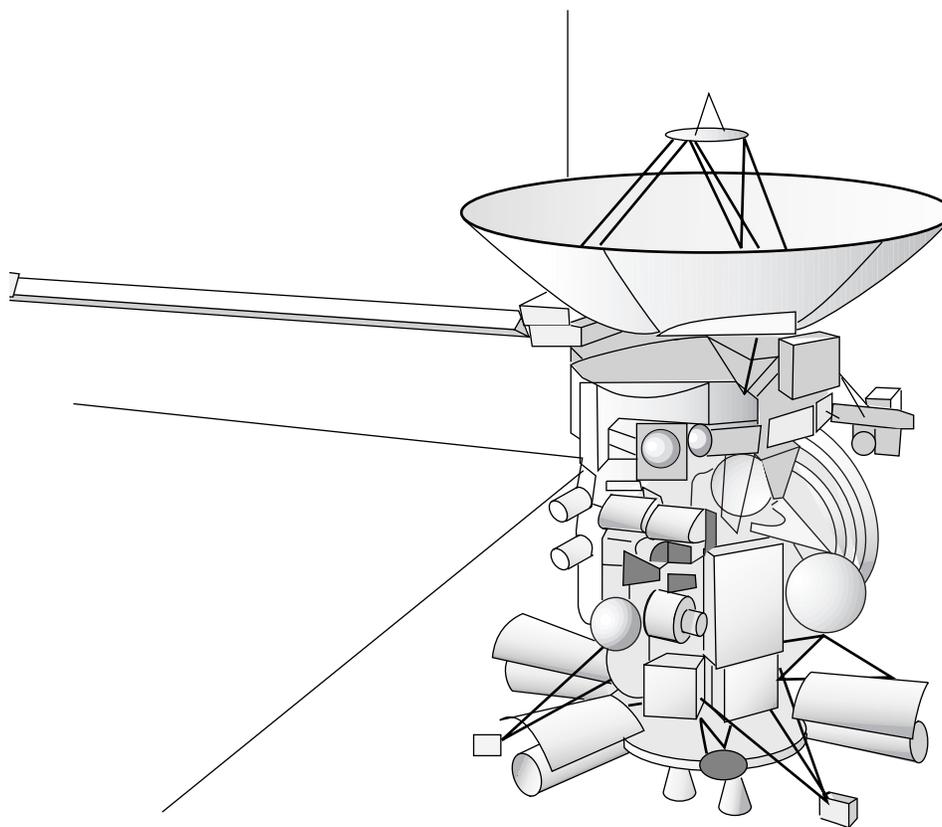
Saturn is the second largest planet in the solar sys-

tem. Like the other gaseous outer planets – Jupiter, Uranus and Neptune – its atmosphere is made up mostly of hydrogen and helium. Saturn's distinctive, bright rings are made up of ice and rock particles

ranging in size from grains of sand to boxcars. More moons of greater variety orbit Saturn than any other planet. So far, observations from Earth and by spacecraft have found Saturnian satellites ranging from small asteroid-size bodies to the aptly named Titan, which is larger than the planet Mercury.

The 12 sci-

entific instruments on the Cassini orbiter will conduct in-depth studies of the planet, its moons, rings and magnetic environment. The six instruments on the Huygens probe, which will be dispatched from Cassini during its first orbit of Saturn, will provide our first direct sampling of Titan's atmospheric chemistry and the first photographs of its hidden surface.



Saturn's butterscotch-colored face appears placid at the surface, but it masks a windswept atmosphere where an equatorial jetstream blows at 1,800 kilometers per hour (1,100 miles per hour) and swirling storms roil beneath the cloudtops. Early explorations by NASA's Pioneer 11 spacecraft in 1979, and the Voyager 1 and 2 spacecraft in 1980 and 1981, found Saturn to possess a huge and complex magnetic environment where trapped protons and electrons interact with each other, the planet, the rings and the surfaces of many of the satellites. The bright rings for which Saturn is best known were found to consist of not just a few monolithic bands but thousands of rings and ringlets broad and thin, with particles sometimes herded into complicated orbits by the gravitational interaction of small moons previously unseen from Earth.

Haze-covered Titan offers a tantalizing mix of an Earth-like, nitrogen-based atmosphere and a surface that many scientists believe probably features chilled lakes of ethane and a surface coated with sticky brown organic condensate that has rained down from the atmosphere. Standing on Titan's surface beneath an orange sky, a visitor from Earth likely would find a cold, exotic world with a pungent odor reminiscent of a petroleum processing facility. Because Titan and Earth share so much in atmospheric composition, Titan is thought to hold clues to how the primitive Earth evolved into a life-bearing planet.

The Saturnian system offers more variety in scientific targets for study than any other planet in our solar system. Over the course of Cassini's four-year mission, and through the the studies of Titan by the Huygens probe, scientists expect to reveal new discoveries and enrich our understanding of phenomena in fields including biology, atmospheric chemistry and physics, climatology, volcanism, tectonics, the physics of disc systems such as galaxies and solar systems in formation, and more.

Launch

Cassini was launched October 15, 1997, at 4:43 a.m. Eastern Daylight Time (0843 Universal Time) from Cape Canaveral Air Station in Florida aboard a Titan IVB/Centaur launch system – the most powerful launch vehicle in the U.S. fleet. After Cassini was been placed in a parking orbit around Earth, a Centaur upper stage fired to send Cassini on the inter-

planetary trajectory that will deliver the spacecraft to Saturn.

The Mission

In maneuvers called gravity-assist swingbys, Cassini will fly twice past Venus, then once each past Earth and Jupiter. The spacecraft's speed increases as it approaches and swings around each planet, giving Cassini the cumulative boost it needs to reach Saturn. The spacecraft will arrive at Saturn on July 1, 2004, when it will enter orbit and begin its detailed scientific observations of the Saturnian system. Cassini's four-year long prime mission ends July 1, 2008.

Cassini executed its first Venus flyby April 26, 1998, at an altitude of 287.2 kilometers (178.5 miles). The second Venus flyby will take place June 24, 1999, at an altitude of 617 kilometers (383 miles). Two months later, the swingby of Earth occurs August 18, 1999, at an altitude of 1,173 kilometers (729 miles). The swingby of Jupiter occurs December 30, 2000, at an altitude of 9,800,000 kilometers (6,080,000 miles) from the planet.

Upon reaching Saturn on July 1, 2004, Cassini will fire its main engine for 96 minutes to brake the spacecraft's speed and allow it to be captured as a satellite of Saturn. Passing through the dusty, outermost E-ring, Cassini will swing in close to the planet – to an altitude only one-sixth the diameter of Saturn itself – to begin the first of some five dozen orbits during the rest of its four-year mission.

On November 6, 2004, Cassini will release the European-built Huygens probe toward Titan. On November 27, the 2.7-meter-diameter (8.9-foot) Huygens will enter Titan's atmosphere, deploy its parachutes and begin its scientific observations during a descent of up to two and a half hours through that moon's dense atmosphere. Instruments onboard will measure the temperature, pressure, density and energy balance in the atmosphere. As the probe breaks through the cloud deck, a camera will capture pictures of the Titan panorama. Titan's surface properties will be observed, and about 1,000 images of the clouds and surface will be returned. In the final moments of descent, a spotlight will illuminate the surface for the imaging instrument onboard.

If the probe survives landing at a fairly low speed of about 25 kilometers per hour (15 miles per hour), it

can possibly return data from Titan's surface, where the atmospheric pressure is 1.6 times that on Earth. The probe could touch down on solid ground, ice or even splash down in a lake of ethane or methane. One instrument on board will discern whether Huygens is bobbing in liquid, and other instruments on board would tell the chemical composition of that liquid. Throughout its mission, Huygens will radio data collected by its instruments to the Cassini orbiter to be stored and then relayed to Earth.

If it lands in liquid ethane, Huygens will not be able to return data for long because the extremely low temperature of this liquid (about -180 degrees Celsius (-290 degrees Fahrenheit)) would prevent the batteries from operating. In addition, if liquid ethane permeated the probe science instrument packages, the radio would be badly tuned and probably not be operable.

If the battery-powered probe continues to send data to Cassini from Titan's surface, it will be able to do so for only about 30 minutes, when the probe's battery power is expected to run out. With the end of the Huygens probe portion of the mission, Cassini's focus will shift to taking measurements with the orbiter's 12 instruments and returning the information to Earth.

During the course of the Cassini orbiter's mission, it will execute some three dozen close flybys of particular bodies of interest – including more than 30 encounters of Titan and at least four of selected icy moons of greatest interest. In addition, the orbiter will make at least two dozen more distant flybys of the Saturnian moons. Cassini's orbits will also allow it to study Saturn's polar regions in addition to the planet's equatorial zone.

Saturn

Saturn is the outermost planet in the solar system readily visible to the naked eye, and was recognized as a slow-moving point of bright yellow light in the sky by ancient cultures around the world. It was not until the invention of the telescope, however, that Saturn's characteristic rings began to come into focus. Italian astronomer Galileo was the first to look at Saturn through a telescope in 1609 and 1610. Saturn, viewed through Galileo's crude instrument was a puzzling sight. Unable to make out the rings, he thought

what he saw were two sizable companions close to the planet. Having recently discovered the major moons of Jupiter, it seemed to follow, he supposed, that Saturn could have large moons, too. "... [T]o my very great amazement, Saturn was seen to me to be not a single star, but three together, which almost touch each other," he wrote at the time. He was even more astonished when he again looked at Saturn through his telescope two years later to find that the companion bodies had apparently disappeared. "I do not know what to say in a case so surprising, so unlooked for and so novel," Galileo wrote in 1612. The rings were simply invisible because he was now viewing them edge-on. Two years later, they again reappeared, larger than ever. He concluded that what he saw were some sort of "arms" that grew and disappeared for unknown reasons. He died never knowing that he'd been the first to observe Saturn's rings.

Nearly half a century later, the Dutch scientist Christiaan Huygens solved the puzzle that had vexed Galileo. Thanks to better optics, Huygens was able to pronounce in 1659 that the companions or arms decorating Saturn were in fact a set of rings. The rings were tilted so that, as Saturn orbited the Sun every 29 years, the sheet of rings would occasionally seem to vanish as viewed on-edge from Earth.

While observing Saturn, Huygens also discovered the moon Titan. A few years later, the Italian-French astronomer Jean-Dominique Cassini (also known as Gian Domenico Cassini in his native Italy) added several other key Saturn discoveries. Using new telescopes, Cassini discovered Saturn's four other major moons – Iapetus, Rhea, Tethys and Dione. In 1675, he discovered that Saturn's rings are split largely into two parts by a narrow gap, known since as the "Cassini Division." In the 19th century, J.E. Keeler, pursuing theoretical studies by James Clerk Maxwell, showed that the ring system was not a uniform sheet but made up of small particles that orbit Saturn.

The first detection of Saturn's magnetic field came with the flyby of Saturn by NASA's Pioneer 11 spacecraft in 1979. Then in 1980 and 1981, the NASA Voyager 1 and Voyager 2 spacecraft flew through the Saturnian system to reveal storms and subtle latitudinal banding in the planet's atmosphere, several more small moons, and a breathtaking collection of thousands of ringlets. The Voyagers found ring particles

ranging in size from nearly invisible dust to icebergs the size of a house. The spacing and width of the ringlets were discovered to be orchestrated in part by gravitational tugs from a retinue of orbiting moons and moonlets, some near ring edges but most far beyond the outermost main rings. Voyager's instruments showed that the rings contain water ice, which may cover rocky particles.

Saturn has been a frequent target of the Hubble Space Telescope, which has produced stunning views of long-lived hurricane-like storms in Saturn's atmosphere. The world's major telescopes, including Hubble, were recently trained on Saturn to observe the phenomenon known to astronomers as a Saturn ring plane crossing. The rings were seen edge-on from the Earth's perspective on May 22, 1995, August 10, 1995 and February 11, 1996. Ring plane crossings provide astronomers with unique views of the Saturnian system. With the rings temporarily invisible as viewed from Earth, faint objects near the planet are easier to see. Two new moons observed during these recent opportunities are now believed to be particle swarms within the narrow F-ring. The majority of Saturn's 18 known moons have been discovered during past ring plane crossings.

We now know that Saturn is one of four giant gaseous (and ringed) planets in the solar system, the others being Jupiter, Uranus and Neptune. Second in size only to Jupiter, Saturn is shaped like a ball squeezed from opposite sides; its diameter pole-to-pole is only 108,728 kilometers (67,560 miles), compared to about 120,536 kilometers (about 74,898 miles) for the equatorial diameter. This oblateness is caused in part by Saturn's very rapid rotation rate. Combined with the planet's low density, the fast rotation tends to promote a bulge of material near the equator. Saturn's volume would enclose more than 750 Earths. Even so, its mass is only 95 times that of Earth; with a density less than that of water, it would float in an ocean if there were one big enough to hold it.

Unlike rocky inner planets such as Earth, Saturn and the other gas giants have no surface on which to land. A spacecraft pilot foolhardy enough to descend into its atmosphere would simply find the surrounding gases becoming denser and denser, the temperature progressively hotter; eventually the craft would

be crushed and melted. Detailed analysis of Saturn's gravitational field leads astronomers to believe that the deepest interior of Saturn must consist of a molten rock core about the same size as Earth, but much more massive than Earth. This rock core may also be surrounded by a layer of melted ices.

Spectroscopic studies by the Voyager spacecraft found Saturn to be made up of about 94 percent hydrogen and 6 percent helium. Hydrogen and helium are the primary constituents of all the giant gas planets, the Sun and the stars.

A day on Saturn is about 10-2/3 hours, and a Saturnian year is about 29-1/2 Earth years.

A fast equatorial flow like a giant jet stream has been clocked on Saturn. This high-velocity wind of 1,800 kilometers per hour (1,100 mile per hour) remains fairly constant over decades. Saturn also has storms like those seen in the atmosphere of Jupiter, but they are much less visible and perhaps less frequent. They may represent Saturnian weather systems that resemble hurricanes on Earth. On Saturn, however, these storms last much longer, perhaps because they do not encounter continents, which reduce their energy sources. On Earth, hurricane-like storms tend to lose their energy as they come into contact with land.

Saturn is colder than Jupiter, but the colors of Saturn's cloud layers are due to the same basic cloud chemistry as on Jupiter. Near the top of the atmosphere, the ammonia becomes cold enough to crystallize into ice particle clouds, much like high cirrus clouds in Earth's skies. These ammonia clouds are the visible part of Saturn. The primary reason why Saturn is more uniformly colored than Jupiter is because this outermost cloud layer is much deeper in the atmosphere than on Jupiter. The haze layers above the clouds therefore hide or mute the colors of the clouds. Latitudinal banding can be seen on Saturn, but they lack the distinct color contrasts seen between atmospheric bands on Jupiter.

Gravity at the top of Saturn's clouds is similar to the gravity near the surface of the Earth. The temperature near the cloudtops is about -139 degrees Celsius (-218 degrees Fahrenheit). The temperature increases with depth due to increased atmospheric pressure. At the core, Saturn's temperature is predicted to be about 10,000 degrees Celsius (18,000 degrees Fahrenheit).

Saturn is 9-1/2 times farther from the Sun than Earth is, so it receives only about 1 percent as much sunlight per square meter as does Earth. Saturn reflects a somewhat smaller fraction of sunlight received than does Earth (34.4 percent compared to 40 percent for Earth, computed across all wavelengths of light). Thus, Saturn absorbs 65.4 percent of the energy it receives from the Sun. Mysteriously, Saturn emits 87 percent more energy than it absorbs from sunlight. Unlike the rocky Earth and the more massive Jupiter, Saturn should not have any heat left over from its original formation. Therefore there must be a source of heat inside Saturn to produce the excess energy. One theory is that the energy comes from the friction of liquid helium raining through lighter liquid hydrogen in the interior of the planet. Cassini scientists will examine Saturn's energy balance for answers to this puzzle.

The Rings

Although the best telescopes on Earth show three nested main rings about Saturn, we now know that the ring system is collection of thousands of ringlets. They are not solid but rather are made up of countless unconnected particles, ranging in size from nearly invisible dust to icebergs the size of a house. The spacing and width of the ringlets are orchestrated by gravitational tugs from a retinue of orbiting moons and moonlets, some near ring edges but most far beyond the outermost main rings. The rings contain water ice, which may cover rocky particles. There are ghostly dark "spokes" in the rings that flicker on and off. Scientists believe they may be electrically charged particles, but we do not really know. Where do the subtle colors in Saturn's rings come from? The Cassini mission may well provide the answers.

And what is the origin of the rings themselves? One theory is that they are the shattered debris of moons broken apart by repeated meteorite impacts. Scientists believe that Saturn's ring system may even serve as a partial model for the disk of gas and dust from which all the planets formed about the early Sun. The Cassini mission will undoubtedly provide important clues to help determine the answers.

Mysterious Moons

Saturn has the most extensive system of moons of any planet in the solar system – ranging in diameter

from about 20 kilometers (12 miles) to 5,150 kilometers (3,200 miles), larger than the planet Mercury. Most are icy worlds heavily studded with craters caused by impacts very long ago.

Eighteen moons have been confirmed in orbit at Saturn. There are likely many more moons, and Cassini will probably discover heretofore unseen satellites.

The moon Enceladus poses a mystery. Although covered with water ice like Saturn's other moons, it displays an abnormally smooth surface; there are very few impact craters on the portions seen by Voyager. Has much of the surface of Enceladus recently melted to erase craters? Scientists now believe that Enceladus is the likely source for particles, spewed by ice volcanoes, that create Saturn's outermost E-ring.

Saturn's moon Iapetus is equally enigmatic. On one side – the trailing side in its orbit – Iapetus is one of the brightest objects in the solar system, while its leading side is one of the darkest. Scientists surmise that the bright side is water ice and the dark side is an organic material of some kind. But how the dark material got there is a mystery. Did it rise up from the inside of the moon, or was it deposited from the outside? The puzzle is compounded by the fact that the dividing line between the two sides is inexplicably sharp.

Titan

Titan is by far the most intriguing natural satellite of Saturn, and one of the most fascinating in the solar system. Titan lies hidden beneath an opaque atmosphere more than 50 percent denser than Earth's. Titan has two major components of Earth's atmosphere – nitrogen and oxygen – but the oxygen is likely frozen as water ice within the body of the moon. If Titan received more sunlight, its atmosphere might more nearly resemble that of a primitive Earth.

What fascinates scientists about Titan's atmosphere is that it is filled with a brownish orange haze made of complex organic molecules, falling from the sky to the surface. Thus in many ways it may be a chemical factory like the primordial Earth. Most scientists agree that conditions on Titan are too cold for life to have evolved – although there are theories concerning the possibility of lifeforms in covered lakes of liquid hydrocarbons warmed by the planet's internal

heat. Yet even if Titan proves to be lifeless, as expected, understanding chemical interactions on the distant moon may help us understand better the chemistry of the early Earth – and how we came to be.

Saturn has a magnetic field and extensive magnetosphere that shields much of the Saturnian system from the wind of charged particles that flows outward from the Sun. The behavior of charged and other particles trapped in this magnetic bubble around Saturn are of great interest to physicists. Cassini will help determine the similarities and differences between the magnetospheres of the planets and possibly moons in the solar system that generate such fields.

The Cassini Spacecraft

The Cassini spacecraft, including the orbiter and the Huygens probe, is one of the largest, heaviest and most complex interplanetary spacecraft ever built. The orbiter alone weighs 2,125 kilograms (4,685 pounds). When the 320-kilogram (705-pound) Huygens probe and a launch vehicle adapter were attached and 3,267 kilograms (7,203 pounds) of propellants were loaded, the spacecraft at launch weighed 5,712 kilograms (12,593 pounds). Only the two Phobos spacecraft sent to Mars by the former Soviet Union were heavier.

The Cassini spacecraft stands more than 6.7 meters (22 feet) high and is more than 4 meters (13.1 feet) wide. The magnetometer instrument is mounted on a 13-meter-long (42-foot) boom that extends outward from the spacecraft. Three other 10-meter (32-foot) rod-like booms that act as the antennas for the radio plasma wave subsystem extend outward from the spacecraft in a Y shape. The complexity of the spacecraft is necessitated both by its flight path to Saturn and by the ambitious program of scientific observations to be undertaken once the spacecraft reaches its destination. The spacecraft includes 22,000 wire connections and more than 12 kilometers (7.5 miles) of cabling. Because of the very dim sunlight at Saturn's orbit, solar arrays are not feasible and electrical power is supplied by a set of radioisotope thermoelectric generators, which use heat from the natural decay of plutonium-238 to generate electricity to run Cassini's systems. These power generators are of the same design as those used on the Galileo and Ulysses missions.

Equipment for a total of 12 science experiments is carried onboard the Cassini orbiter. Another six fly on the Huygens probe, which will detach from the orbiter to parachute through Titan's atmosphere to its surface

The Cassini orbiter has advanced and extended the United States' technology base with several innovations in engineering and information systems. Whereas previous planetary spacecraft used onboard tape recorders, Cassini has pioneered a new solid-state data recorder with no moving parts. The solid state recorder eventually will likely replace tape recorders used on space missions. Similarly, the main onboard computer that directs operations of the orbiter uses a novel design drawing on new families of electronic chips. Among them are very high-speed integrated circuit (VHSIC) chips developed under a U.S. government-industry research and development initiative. Also part of the computer are powerful new application-specific integrated circuit (ASIC) parts; each component replaces a hundred or more traditional chips.

Elsewhere on the Cassini orbiter, the power system benefits from an innovative solid-state power switch being developed for the mission. This switch will eliminate rapid fluctuations called transients that usually occur with conventional power switches, with a significantly improved component lifetime. The solid-state power switch holds great promise for use in numerous Earth-based applications as well.

Science Experiments

Orbiter

❑ **Imaging science subsystem:** Takes pictures in visible, near-ultraviolet and near-infrared light.

❑ **Cassini radar:** Maps surface of Titan using radar imager to pierce veil of haze. Also used to measure heights of surface features.

❑ **Radio science subsystem:** Searches for gravitational waves in the universe; studies the atmosphere, rings and gravity fields of Saturn and its moons by measuring telltale changes in radio waves sent from the spacecraft.

❑ **Ion and neutral mass spectrometer:** Examines neutral and charged particles near Titan, Saturn and the icy satellites to learn more about their

extended atmospheres and ionospheres.

❑ **Visible and infrared mapping spectrometer:** Identifies the chemical composition of the the surfaces, atmospheres and rings of Saturn and its moons by measuring colors of visible light and infrared energy given off by them.

❑ **Composite infrared spectrometer:** Measures infrared energy from the surfaces, atmospheres and rings of Saturn and its moons to study their temperature and composition.

❑ **Cosmic dust analyzer:** Studies ice and dust grains in and near the Saturn system.

❑ **Radio and plasma wave spectrometer:** Investigates plasma waves (generated by ionized gases flowing out from the Sun or orbiting Saturn), natural emissions of radio energy and dust.

❑ **Cassini plasma spectrometer:** Explores plasma (highly ionized gas) within and near Saturn's magnetic field.

❑ **Ultraviolet imaging spectrograph:** Measures ultraviolet energy from atmospheres and rings to study their structure, chemistry and composition.

❑ **Magnetospheric imaging instrument:** Images Saturn's magnetosphere and measures interactions between the magnetosphere and the solar wind, a flow of ionized gases streaming out from the Sun.

❑ **Dual technique magnetometer:** Studies Saturn's magnetic field and its interactions with the solar wind, the rings and the moons of Saturn.

Huygens Probe

❑ **Descent imager and spectral radiometer:** Makes images and measures temperatures of particles in Titan's atmosphere and on Titan's surface.

❑ **Huygens atmospheric structure instrument:** Explores the structure and physical properties of Titan's atmosphere.

❑ **Gas chromatograph and mass spectrometer:** Measures the chemical composition of gases and suspended particles in Titan's atmosphere.

❑ **Aerosol collector pyrolyzer:** Examines clouds and suspended particles in Titan's atmosphere.

❑ **Surface science package:** Investigates the

physical properties of Titan's surface.

❑ **Doppler wind experiment:** Studies Titan's winds from their effect on the probe during its descent.

The International Team

Hundreds of scientists and engineers from 16 European countries and 33 states of the United States make up the team that has designed, fabricated, assembled and will fly and collect data from the Cassini orbiter and Huygens probe.

The Cassini mission is managed by NASA's Jet Propulsion Laboratory in Pasadena, California, where the orbiter was designed and assembled. JPL is a division of the California Institute of Technology. Development of the Huygens Titan probe is managed by the European Space Technology and Research Center (ESTEC). ESTEC 's prime contractor for the probe is Aerospatiale in France. Equipment and instruments for the probe have been supplied by many countries, including the United States.

The Cassini program is an 18-year endeavor; the program received a new start from U.S. Congress in 1990, and the prime mission extends through July 2008. The Cassini orbiter and its instruments represent a \$1.422 billion investment by NASA. The agency has budgeted a total of \$755 million will support the cruise and orbital operations phase of the mission. Other contributions include \$54 million in NASA tracking costs and about \$144 million from the U.S. Department of Energy in support of the radioisotope thermoelectric generators and radioisotope heater units for the mission. The launch vehicle, provided to NASA by the U.S. Air Force, cost \$422 million.

The European Space Agency's contribution to the Cassini program totals approximately \$500 million for the Huygens probe, its instruments and probe science and engineering operations. The Italian Space Agency has contributed the Cassini orbiter's dish-shaped high-gain antenna as well as significant portions of three science instruments; its contribution is \$160 million.

The Centaur upper stage and launch vehicle performance analysis were managed by NASA's Lewis Research Center, Cleveland, Ohio.

Communications with Cassini during the mission

are carried out through stations of NASA's Deep Space Network in California, Spain and Australia. Data from the Huygens probe will be received at an operations complex in Darmstadt, Germany.

At NASA Headquarters, the Cassini program director is Dr. Earle K. Huckins, the Cassini program executive is Mark Dahl and the program scientist is Dr. Henry C. Brinton. At JPL, Robert T. Mitchell became Cassini program manager in June 1998, replacing Richard J. Spehalski, who retired after leading the mission for 6-1/2 years. Ronald Draper is deputy program manager, Dr. Dennis Matson of JPL is Cassini project scientist and Dr. Linda Spilker is deputy project scientist.

8-98 MBM