NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Cassini-Huygens Saturn Arrival

Press Kit
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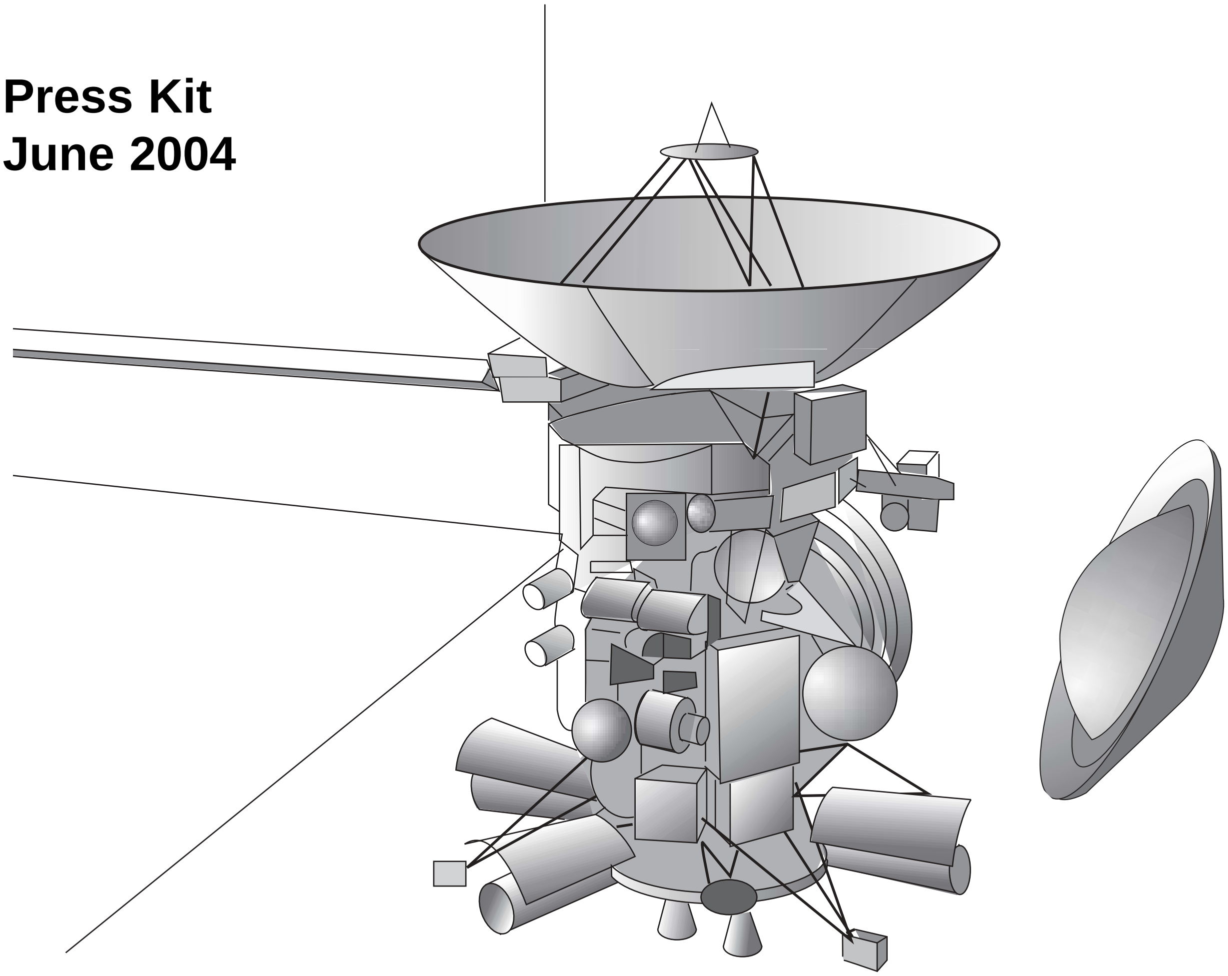

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Contents

GENERAL RELEASE:

CASSINI-HUYGENS WILL UNLOCK SATURN'S SECRETS

The international Cassini-Huygens mission is poised to begin an extensive tour of Saturn, its majestic rings and 31 known moons. After a nearly seven-year journey, Cassini is scheduled to enter orbit around Saturn at 10:30 p.m. EDT June 30, 2004.

"The Saturn system represents an unsurpassed laboratory, where we can look for answers to many fundamental questions about the physics, chemistry and evolution of the planets and the conditions that give rise to life," said Dr. Ed Weiler, associate administrator for space science at NASA Headquarters, Washington.

Launched Oct. 15, 1997, on a journey covering 3.5 billion kilometers (2.2 billion miles), Cassini is the most highly instrumented and scientifically capable planetary spacecraft ever flown. It has 12 instruments on the Cassini orbiter and six more on the Huygens probe. The mission represents the best technical efforts of 260 scientists from the United States and 17 European nations. The cost of the Cassini mission is approximately $3 billion.

The Cassini-Huygens mission is a four-year study of Saturn. The 18 highly sophisticated science instruments will study Saturn's rings, icy satellites, magnetosphere and Titan, the planet's largest moon.

For the critical Saturn orbit insertion maneuver, the spacecraft will fire its main engine for 96 minutes. The maneuver will reduce Cassini's speed and allow it to be captured into orbit as a satellite of Saturn. Cassini will pass through a gap between two of Saturn's rings, called the F and G rings. Cassini will swing close to the planet and begin the first of 76 orbits around the Saturn system. During Cassini's four-year mission, it will execute 52 close encounters with seven of Saturn's 31 known moons.

There are risks involved with orbit insertion, but mission planners have prepared for them. There is a backup engine in case the main engine fails. The region of passage through the ring plane was searched for hazards with the best Earth- and space-based telescopes.

Particles too small to be seen from Earth could be fatal to the spacecraft, so Cassini will be turned to use its high-gain antenna as a shield against small objects.

Saturn is the sixth planet from the sun. It is the second largest planet in our solar system, after Jupiter. The planet and ring system serve as a miniature model for the disc of gas and dust surrounding the early sun that formed the planets. Detailed knowledge of the dynamics of interactions among Saturn's elaborate rings and numerous moons will provide valuable data for understanding how each of the solar system's planets evolved.

The study of Titan, Saturn's largest moon, is one of the major goals of the mission. Titan may preserve, in deep-freeze, many of the chemical compounds that preceded life on Earth. Cassini will execute 45 flybys of Titan, coming as close as approximately 950 kilometers (590 miles) above the surface. This will permit high-resolution mapping of the moon's surface with an imaging radar instrument, which can see through the opaque haze of Titan's upper atmosphere.

"Titan is like a time machine taking us to the past to see what Earth might have been like," said Dr. Dennis Matson, Cassini project scientist at NASA's Jet Propulsion Laboratory, Pasadena, Calif. "The hazy moon may hold clues to how the primitive Earth evolved into a life-bearing planet," he said.

On Dec. 25, 2004 (Dec. 24 in U.S. time zones) Cassini will release the wok-shaped Huygens probe on its journey toward Titan. Huygens will be the first probe to descend to the surface of a moon of another planet. It will also make the most distant descent by a robotic probe ever attempted on another object in the solar system. On Jan. 14, 2005, after a 20-day ballistic freefall, Huygens will enter Titan's atmosphere. It will deploy parachutes and begin 2.5 hours of intensive scientific observations. The Huygens probe will transmit data to the Cassini spacecraft, which will relay the information back to Earth.

JPL designed, developed and assembled the Cassini orbiter. The European Space Agency managed the development of Huygens and is in charge of operations of the probe from its control center in Darmstadt, Germany. The Italian Space Agency provided the high-gain antenna, much of the radio system and elements of several of Cassini's science instruments. JPL manages the overall program for NASA's Office of Space Science, Washington.

For information about the Cassini-Huygens mission to Saturn and Titan on the Internet, visit:

http://www.nasa.gov/cassini

http://www.esa.int/Cassini-Huygens

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Media Services Information

NASA Television Transmission

NASA Television is broadcast on the satellite AMC-9, transponder 9C, C Band, 85 degrees west longitude, frequency 3880.0 MHz, vertical polarization, audio monaural at 6.8 MHz. The schedule for television transmissions for Saturn arrival will be available from the Jet Propulsion Laboratory, Pasadena, Calif., and NASA Headquarters, Washington.

Media Credentialing

News media representatives who wish to cover the Cassini-Huygens Saturn arrival from NASA's Jet Propulsion Laboratory must be accredited through the JPL Media Relations Office. Journalists may phone the newsroom at 818/354-5011 for more information.

Briefings

Frequent news briefings will be held at JPL during Saturn arrival. Information about upcoming briefings will be available on the Internet on the JPL Web site, http://www.jpl.nasa.gov .

Internet Information

Extensive information on Cassini, including an electronic copy of this press kit, press releases, fact sheets, status reports and images, is available at **http://www.nasa.gov/cassini** .

Detailed information about the mission for a general public audience is available on the Cassini project Web site at **http://saturn.jpl.nasa.gov** . The European Space Agency’s Cassini-Huygens website is at **http://saturn.esa.int** .

Quick Facts

Cassini Orbiter

Dimensions: 6.7 meters (22 feet) high; 4 meters (13.1 feet) wide

Weight: 5,712 kilograms (12,593 pounds) with fuel, Huygens probe, adapter, etc; 2,125 kilograms (4,685 pounds) unfueled orbiter alone

Orbiter science instruments: composite infrared spectrometer, imaging system, ultraviolet imaging spectrograph, visual and infrared mapping spectrometer, imaging radar, radio science, plasma spectrometer, cosmic dust analyzer, ion and neutral mass spectrometer, magnetometer, magnetospheric imaging instrument, radio and plasma wave science

Power: 885 watts (633 watts at end of mission) from radioisotope thermoelectric generators

Huygens Probe

Dimensions: 2.7 meters (8.9 feet) in diameter

Weight: 320 kilograms (705 pounds)

Probe science instruments: aerosol collector pyrolyser, descent imager and spectral radiometer, Doppler wind experiment, gas chromatograph and mass spectrometer, atmospheric structure instrument, surface science package

Mission

Launch vehicle: Titan IVB/ Centaur
Weight: 1 million kilograms (2.2 million pounds)
Launch: October 15, 1997, from Cape Canaveral Air Force Station, FL.
Earth-Saturn distance at arrival: 1.5 billion km (934 million mi) (10 times Earth to Sun distance)
Distance traveled to reach Saturn: 3.5 billion km (2.2 billion mi)
Saturn's average distance from Earth: 1.43 billion km (890 million mi)
One-way speed-of-light time from Saturn to Earth at Cassini arrival: 84 minutes
One-way speed-of-light time from Saturn to Earth during orbital tour: 67 to 85 minutes
Venus flybys: April 26, 1998 at 234 km (176 mi); June 24, 1999 at 600 km (370 mi)
Earth flyby: August 18, 1999 at 1,171 km (727 mi)
Jupiter flyby: December 30, 2000 at 10 million km (6 million mi)
Saturn arrival date: June 30, 2004 PDT (July 1, 2004, UTC)
Primary mission: 4 years
Huygens probe Titan release date: December 24, 2004
Huygens probe Titan descent date: January 14, 2005
Huygens' entry speed into Titan's atmosphere: about 20,000 kph (12,400 mph)

Program

Partners: NASA, European Space Agency (ESA), Italian space agency Agenzia Spaziale Italiana (ASI); total of 17 countries involved

U.S. states in which Cassini work was carried out: 33

Number of people who worked on some portion of Cassini-Huygens: More than 5,000

Cost of mission: $1.422 billion pre-launch development; $710 million mission operations; $54 million tracking; $422 million launch vehicle; $500 million ESA; $160 million ASI; total about $3.27 billion, of which U.S. contribution is $2.6 billion and European partners' contribution $660 million

Saturn at a Glance

General

- ☐ One of five "naked eye" planets known to the ancients. Saturn is named for the Roman god of agriculture, also linked to Kronos, Greek god of time, father of Jupiter and king of the gods
- ☐ Yellowish color; at times the 3rd brightest planet in night sky

Physical Characteristics

- ☐ Second largest planet in the solar system, after Jupiter.
- ☐ Equatorial diameter 120,536 kilometers (74,898 miles) at cloud tops; polar diameter 108,728 kilometers (67,560 miles), making it the most oblate (flattened) planet.
- ☐ Density 0.69 (water = 1), the least dense planet and the only one lighter than water
- ☐ Volume 764 times that of Earth, but only 95 times more massive
- ☐ Chemical composition primarily hydrogen and helium, thus accounting for its low density

Orbit

- ☐ Sixth planet from the Sun, between Jupiter and Uranus
- ☐ Mean distance from Sun 1.43 billion kilometers (890 million miles), approximately 10 times the distance from Earth to the sun
- ☐ Brightness of sunlight at Saturn 1 percent of that at Earth
- ☐ Length of a Saturn year is 29.42 Earth years
- ☐ Length of a Saturn day is 10 hours, 39.4 minutes
- ☐ Poles tilted 29 degrees relative to the plane of its orbit around the Sun

Environment

- ☐ Saturn's atmosphere above clouds is approximately 94 percent hydrogen and 6 percent helium
- ☐ Winds near Saturn's equator blow toward east at 500 meters per second (1,100 miles per hour), making Saturn the windiest planet
- ☐ Temperature at Saturn's cloud tops -139 C (-218 F)

Previous Exploration

- ☐ Pioneer 11 flyby September 1, 1979
- ☐ Voyager 1 flyby November 12, 1980
- ☐ Voyager 2 flyby August 25, 1981

Rings

- ☐ Saturn's main ring system would barely fit in the space between Earth and its Moon
- ☐ Ring names are alphabetical in order of their discovery
- ☐ B ring often contains radial spokes of dust-sized material; their appearance changes with time as they appear, change and disappear frequently
- ☐ "Cassini Division" between the B ring and A ring is sparsely populated with ring material
- ☐ E ring is densest at the orbit of Enceladus and may be fed by Enceladus eruptions

Moons

- ☐ Saturn has 31 known moons, 13 of which were discovered after Cassini launched
- ☐ Titan is the largest of Saturn's moons, and is larger than the planets Mercury and Pluto

Saturn's Rings and Moons

Rings

Ring	Distance	Width
D	66,970 km (41,610 mi)	7,540 km (4,690 mi)
C	74,510 km (46,300 mi)	17,490 km (10,870 mi)
B	92,000 km (57,170 mi)	25,580 km (15,890 mi)
A	122,170 km (75,910 mi)	14,610 km (9,080 mi)
F	140,180 km (87,100 mi)	50 km (30 mi)
G	170,180 km (105,740 mi)	500 to several 1,000s km (300 to several 1,000s mi)
E	181,000 km (112,000 mi)	302,000 km (188,000 mi)

(Distance is from Saturn's center to closest edge of ring)

The Known Moons of Saturn (31)

Moon	Diameter	Distance	Discoverer
Pan	20 km (12 mi)	133,583 km (83,004 mi)	1990: Showalter
Atlas	32 km (20 mi)	137,640 km (85,530 mi)	1980: Terrile (Voyager)
Prometheus	100 km (62 mi)	139,350 km (86,590 mi)	1980: Collins (Voyager)
Pandora	84 km (52 mi)	141,700 km (88,040 mi)	1980: Collins (Voyager)
Epimetheus	119 km (74 mi)	151,422 km (94,089 mi)	1966: Walker
Janus	178 km (111 mi)	151,472 km (94,120 mi)	1966: Dolfus
Mimas	392 km (244 mi)	185,520 km (115,280 mi)	1789: Herschel
Enceladus	499 km (310 mi)	238,020 km (147,900 mi)	1789: Herschel
Tethys	1,060 km (659 mi)	294,660 km (183,090 mi)	1684: Cassini
Telesto	22 km (14 mi)	294,660 km (183,090 mi)	1980: Smith
Calypso	20 km (12 mi)	294,660 km (183,090 mi)	1980: Smith
Dione	1,120 km (696 mi)	377,400 km (234,500 mi)	1684: Cassini
Helene	35 km (22 mi)	378,400 km (235,100 mi)	1980: Laques & Lecacheux
Rhea	1,528 km (949 mi)	527,040 km (327,490 mi)	1672: Cassini
Titan	5,150 km (3,200 mi)	1,221,850 km (759,220 mi)	1655: Huygens
Hyperion	283 km (176 mi)	1,481,100 km (920,300 mi)	1848: Bond
Iapetus	1,436 km (892 mi)	3,561,300 km (2,212,900 mi)	1671: Cassini
Phoebe	220 km (137 mi)	12,952,000 km (8,048,000 mi)	1898: Pickering
Kiviuq	14 km (9 mi)	11,365,000 km (7,061,900 mi)	2000: Gladman
Ijiraq	10 km (6 mi)	11,440,000 km (7,108,500 mi)	2000: Gladman
Paaliaq	19 km (12 mi)	15,199,000 km (9,444,300 mi)	2000: Gladman
Skadi	6.4 km (4 mi)	15,647,000 km (9,722,600 mi)	2000: Gladman
Albiorix	26 km (16 mi)	16,404,000 km (10,193,000 mi)	2000: Holman
Erriapo	8.6 km (5 mi)	17,616,000 km (10,946,100 mi)	2000: Gladman
Siarnaq	32 km (20 mi)	18,160,000 km (11,284,100 mi)	2000: Gladman
Tarvos	13 km (8 mi)	18,247,000 km (11,338,200 mi)	2000: Gladman
Mundilfari	5.6 km (3.4 mi)	18,709,000 km (11,625,300 mi)	2000: Gladman
S/2003 S1	6.6 km (4 mi)	18,719,000 km (11,631,500 mi)	2003: Sheppard & Jewitt
Suttung	5.6 km (3.4 mi)	19,463,000 km (12,093,800 mi)	2000: Gladman
Thrym	5.6 km (3.4 mi)	20,382,000 km (12,664,800 mi)	2000: Gladman
Ymir	16 km (10 mi)	23,096,000 km (12,351,200 mi)	2000: Gladman

The discoverer of a moon has the privilege of suggesting a name, which is then submitted to the International Astronomical Union for final approval. Names are to be chosen from mythology, and have historically been taken most often from Greek and Roman mythology.

Pan "PAN"
Atlas "AT-luss"
Prometheus "pro-MEE-thee-uss"
Pandora "pan-DOR-uh"
Epimetheus "epp-ee-MEE-thee-uss"
Janus "JANE-uss"
Mimas "MY-muss"
Enceladus "en-SELL-uh-duss"
Tethys "TEE-thiss"
Kiviuq "kee-VYOOK"
Paaliaq "pa-lee-AK"
Albiorix "AL-bee-or-icks"
Siarnaq "syar-NAK"
Mundilfari "mun-dill-far-ee"
Thrym "thrim"
Telesto "tel-LESS-toe"
Calypso "kuh-LIP-soh"
Dione "die-OH-nee"
Helene "huh-LEE-nee"
Rhea "REE-uh"
Titan "TIE-tun"
Hyperion "high-PEER-ee-on"
Iapetus "eye-APP-eh-tuss"
Phoebe "FEE-bee"
Ijiraq "ee-gee-RAK"
Skadi "SKA-dee"
Erriapo "air-ee-A-po"
Tarvos "TAR-vos"
Suttung "SOOT-toong"
Ymir "EE-mer"

Why Saturn?

Saturn offers a rich scientific environment to explore. While the other giant planets, Jupiter, Uranus, and Neptune, have rings, the rings of Saturn are unique in the solar system in their extent and brightness. They are the signature feature by which Saturn is known. The planet and the ring system serve as a physical model for the disc of gas and dust that surrounded the early Sun and from which the planets formed. The success of searches for other planetary systems elsewhere in our galaxy partly depends upon how well we understand the early stages of formation of planets.

Detailed knowledge of the history and processes now occurring on Saturn's elaborately different moons may provide valuable data to help understand how each of the solar system's planets evolved to their present states. Represented among Saturn's collection of moons is a huge variety of chemical, geologic and atmospheric processes. Physics and chemistry are the same everywhere, and the knowledge gained about Saturn's magnetosphere or Titan's atmosphere will have applications here on Earth.

Chief among Cassini's goals within Saturn's system is the unmasking of Titan. Titan is the only moon in the solar system that possesses a dense atmosphere (1.5 times denser than Earth's). The fact that this atmosphere is rich in organic material and that living organisms as we know them are composed of organic material is particularly intriguing. ("Organic" means only that the material is carbon-based, and does not necessarily imply any connection to living organisms.) Forty-five of Cassini's 76 orbits through the Saturnian system will include Titan flybys, and the Huygens probe is dedicated to study of Titan's atmosphere.

After decades of speculation and experiment in the modern age, scientists still seek fundamental clues to the question of how life began on Earth. Most experts suspect that life arose by chance combinations of complex carbon compounds in a primeval soup. But all studies of life's origin are hampered by ignorance about the chemical circumstances on the young Earth. We need to know what starting material was present at the beginning of life on Earth. Cassini-Huygens' study of Titan may go far toward providing the answer to that question.

In our solar system, only Earth and Titan have atmospheres rich in nitrogen. Earth's siblings in the inner solar system, Venus and Mars, possess carbon-dioxide atmospheres, while Jupiter and Saturn resemble the Sun in their high content of hydrogen and helium. Hydrocarbons like the methane present on Titan may have been abundant on the young Earth.

The importance of Titan in this connection is that it may preserve, in deep-freeze, many of the chemical compounds that preceded life on Earth. Some scientists believe we will find that Titan more closely resembles the early Earth than Earth itself does today.

The results from Cassini's instruments and the Huygens probe, along with the results of our continuing explorations of Mars, Europa and the variety of life-bearing environments on Earth, will significantly enhance scientific efforts to solve the mystery of our origins.

Cassini and Planetary Exploration

The Cassini-Huygens mission is an enterprise that, from the initial vision to the completion of the mission, will span nearly 30 years. The formal beginning was in 1982, when a joint working group was formed by the Space Science Committee of the European Science Foundation and the Space Science Board of the National Academy of Science in the United States. The charter of the group was to study possible modes of cooperation between the U.S. and Europe in the field of planetary science. Their precept was that the mission would be beneficial for the scientific, technological and industrial sectors of their countries. As a result of their involvement in the studies, European scientists proposed a Saturn orbiter and Titan probe mission to the European Space Agency (ESA), suggesting a collaboration with NASA.

In 1983, the U.S. Solar System Exploration Committee recommended that NASA include a Titan probe and radar mapper in its core program and also consider a Saturn orbiter. In 1984-85, a joint NASA/ESA assessment of a Saturn orbiter-Titan probe mission was completed. In 1986, ESA's Science Program Committee approved Cassini for initial Phase A study, with a conditional start in 1987.

In 1987-88, NASA carried out further work on designing and developing the standardized Mariner Mark II spacecraft and a set of outer planets missions that would be accomplished with the new spacecraft line. The program was an early effort to reduce the costs of planetary exploration by producing multiple spacecraft for different missions but made with the basic spacecraft components off the same assembly line. Cassini and the Comet Rendezvous/Asteroid Flyby were the first two missions chosen for further study. At the same time in Europe, a Titan probe Phase A study was carried out by ESA in collaboration with a European industrial consortium led by Marconi Space Systems. The Titan probe was renamed Huygens by ESA as its first medium-sized mission of its Horizon 2000 space science program.

In 1989, funding for Cassini and the comet-asteroid mission was approved by the U.S. Congress. NASA and ESA simultaneously released announcements of opportunity for scientists to propose scientific investigations for the missions. In 1992, a funding cap was placed on the Mariner Mark II program, effectively ending the new spacecraft line and, at the same time, canceling the Comet Rendezvous/Asteroid Flyby mission. Cassini was restructured to cut the cost of the mission and to simplify the spacecraft and its operation.

The design of Cassini is the result of extensive tradeoff studies that considered cost, mass, reliability, durability, suitability and availability of hardware. Moving parts were eliminated from the spacecraft wherever the functions could be performed satisfactorily without them. Thus, early designs that included moving science instrument platforms or turntables were discarded in favor of instruments fixed to the spacecraft body, whose pointing requires rotation of the entire spacecraft. Tape recorders were replaced with solid-state recorders. Mechanical gyroscopes were replaced with hemispherical resonator gyroscopes. An articulated probe relay antenna was discarded in favor of using the high-gain antenna to capture the radio signal of the Huygens probe. A deployable high-gain antenna of the type used for the Galileo mission was considered and abandoned.

Project engineers, both those who designed and built the hardware and those who operate the spacecraft, relied heavily on extensive past experience to provide a spacecraft design more sophisticated and reliable than any other spacecraft ever built for exploration of the planets. Because of that care in design, the Cassini spacecraft will return more scientific data about its targets than has been possible in any previous planetary mission.

The research and development that Cassini has funded has provided key technologies that have enabled many of NASA's new "faster, better, cheaper" missions. All of NASA's new Discovery class missions to date, such as Mars Pathfinder, have used innovative technology derived from Cassini, and spacecraft being developed for NASA's New Millennium Program rely heavily upon fundamental new technologies brought forth by Cassini.

It is the ability to perform synergistic science that sets Cassini apart from other missions. The very complex interactions that are in play in systems such as those found at Jupiter and Saturn can best be addressed by instrument platforms such as Galileo and Cassini. Many phenomena to be studied are sensitively dependent upon a large number of parameters; a measurement might have to take into account simultaneous dependencies on location, time, directions to the Sun and planet, the orbital configurations of certain moons, magnetic longitude and latitude and solar wind conditions. To deal with such complexity, the right types of instruments must be on the spacecraft to make all the necessary and relevant measurements, and all the measurements must be made essentially at the same time. Identical conditions very seldom recur. A succession or even a fleet of less well equipped spacecraft could not obtain the same result. The need for a broadly based, diverse collection of instruments is the reason why the Cassini-Huygens spacecraft is so large.

The Cassini and Huygens missions, featuring the intertwined work of NASA, ESA and ASI, have become models for future international space science cooperation.

The Saturn System

Saturn is easily visible to the naked eye, and was known to ancient peoples around the world. It was not until the invention of the telescope, however, that Saturn's characteristic rings began to come into focus.

Historical Observations

The Italian astronomer Galileo was the first to look at Saturn through a telescope in 1609-10. Viewed through Galileo's crude instrument, Saturn was a puzzling sight. Unable to make out the rings, Galileo thought he saw two sizable companions close to the planet. Having recently discovered the major moons of Jupiter, 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.

Galileo was even more astonished when, two years later, he again looked at Saturn through his telescope only 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," he 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 had been the first to observe Saturn's rings.

Nearly half a century later, the Dutch scientist Christiaan Huygens solved the puzzle that vexed Galileo. Thanks to better optics, Huygens was able to pronounce in 1659 that the companions or arms decorating Saturn were not appendages, but rather the planet "is surrounded by a thin, flat ring, which nowhere touches the body." His theory was received with some opposition, but was confirmed by the observations of Robert Hooke and Italian-French astronomer Jean Dominique Cassini.

While observing Saturn, Huygens also discovered the moon Titan. A few years later, Cassini added several other key Saturn discoveries. Using new telescopes, Cassini discovered Saturn's four other major moons - Iapetus, Rhea, Tethys and Dione.

In 1675, Cassini 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 developed by James Clerk Maxwell, showed that the ring system was not a uniform sheet but made up of small particles that orbited 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 Saturn's 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 at least 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 instruments confirmed a finding from ground-based instruments 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 Earth's perspective on May 22 and August 10, 1995, and on February 11, 1996. Ring plane crossings provide astronomers with unique views of Saturn's system.

These observations showed that the ring plane was not absolutely flat; the tilt of the F ring distorts the appearance of the rings, causing one side to appear brighter than the other during ring plane crossings. Searches for new moons turned up several suspects, but most are now believed to be bright "knots" in the F ring. Of particular interest were these ring arcs, natural "satellites" in the F ring that appeared cloud-like and spread over a small area, instead of sharp pinpoints. The origin of these clumps of material in the F ring is not well understood.

The faint, outermost E ring is also easier to detect when viewed edge-on due to the greater amount of material in the line-of-sight. Thus, observations made over the course of the ring plane crossing provided new information on the thickness of the rings. New information gathered on the location and density of material in the rings was used by designers to plan the most advantageous and safest course for Cassini's flight through the gap between Saturn's F and G rings before Saturn arrival in 2004.

The Hubble Space Telescope is an important tool for studying Saturn, its rings, moons and magnetosphere in support of the Cassini-Huygens mission. Hubble observations of Saturn's atmosphere were made after storms were discovered by ground-based observers. First in 1990 and again in 1994, apparent upwellings of ammonia clouds appeared and then were spread around the planet by prevailing winds.

Hubble observations of Titan indicate that color differences in Titan's hemispheres seen during the Voyager flybys in 1980 and 1981 have since reversed themselves. Some Hubble observations have studied chemical processes in Titan's atmosphere. Images made in the infrared have looked through Titan's clouds and allowed some mapping of its surface. Hubble has also contributed new information about the processes in Saturn's magnetosphere through ultraviolet measurements of Saturn's auroras.

Scientists using Hubble expect to study the planet and the ring system as it opens up to our view during the course of Cassini's cruise to the planet. Hubble investigations will place Cassini results in the context of the decades-long studies of the planet and help direct Cassini instruments for studies of Saturn's system during its orbital tour.

Saturn's Place in the Solar System

Studies of star formation indicate that our solar system formed within a giant collection of gases and dust, drawn together by gravitational attraction and condensed over many millions of years into many stars. The giant gas cloud condensed into rotating pools of higher density in a process called gravitational collapse. These rotating pools of material condensed more rapidly until their temperatures and densities were great enough to form stars. Surrounding each new star, the leftover material flattened into a disc rotating approximately in the plane of the star's equator. This material can eventually form planets - and this is apparently what occurred in our solar system.

The composition of the planets is largely controlled by their temperatures, which in turn is determined by their distances from the Sun. Compounds with high melting points were the first to condense, followed by silicates. These formed the rocky cores of all the planets.

While hydrogen is the predominant element in the universe and in our solar system, other gases are present, including water, carbon dioxide and methane. These predominate in the cooler outer solar system in the form of ices. Gases also collected as envelopes around the planets and moons. (Where conditions are right, large quantities of water in its liquid state can form, as exhibited by Earth's oceans, Mars' flood plains and a possible ocean beneath the surface of Europa, a moon of Jupiter.)

The large outer planets contain much of the primordial cloud gases not trapped by the Sun. Hydrogen is the most abundant material in the Sun and in all the large gaseous planets - Jupiter, Saturn, Uranus and Neptune. Each of these giant planets has many moons. These moons form systems of natural satellites, creating the equivalent of miniature solar systems around the gas giants. They are believed to have been formed by processes similar to those responsible for the planetary system around the Sun.

Saturn is similar to Jupiter in size, shape, rotational characteristics and moons, but Saturn is less than one-third the mass of Jupiter and is almost twice as far from the Sun. Saturn radiates more heat than it receives from the Sun. This is true of Jupiter as well, but Jupiter's size and cooling rate suggest that it is still warm from the primordial heat generated from condensation during its formation. Slightly smaller Saturn, however, has had time to cool - so some other mechanism, such as helium migrating to the planet's core, is needed to explain its continuing radiation of heat.

Voyager measurements found that the ratio of helium to molecular hydrogen in Saturn is 0.06, compared to Jupiter's value of 0.13 (which is closer to the abundance in the Sun and in the primordial solar nebula). Helium depletion in Saturn's upper atmosphere is believed to result from helium raining down to the lower altitudes. This supports the concept of helium migration as the heat source in Saturn. Cassini's measurements of Saturn's energy, radiation and helium abundance will help to explain the residual warmth.

Saturn's visible features are dominated by atmospheric clouds. They are not as distinct as Jupiter's clouds, primarily because of a haze layer covering the planet that is a result of cooler temperatures due to the weaker incoming sunlight. This reduced solar radiation, and correspondingly greater influence from escaping internal heat, lead to greater wind velocities on Saturn. Both Saturn's and Jupiter's weather are thus driven by heat from below.

The Planet Saturn

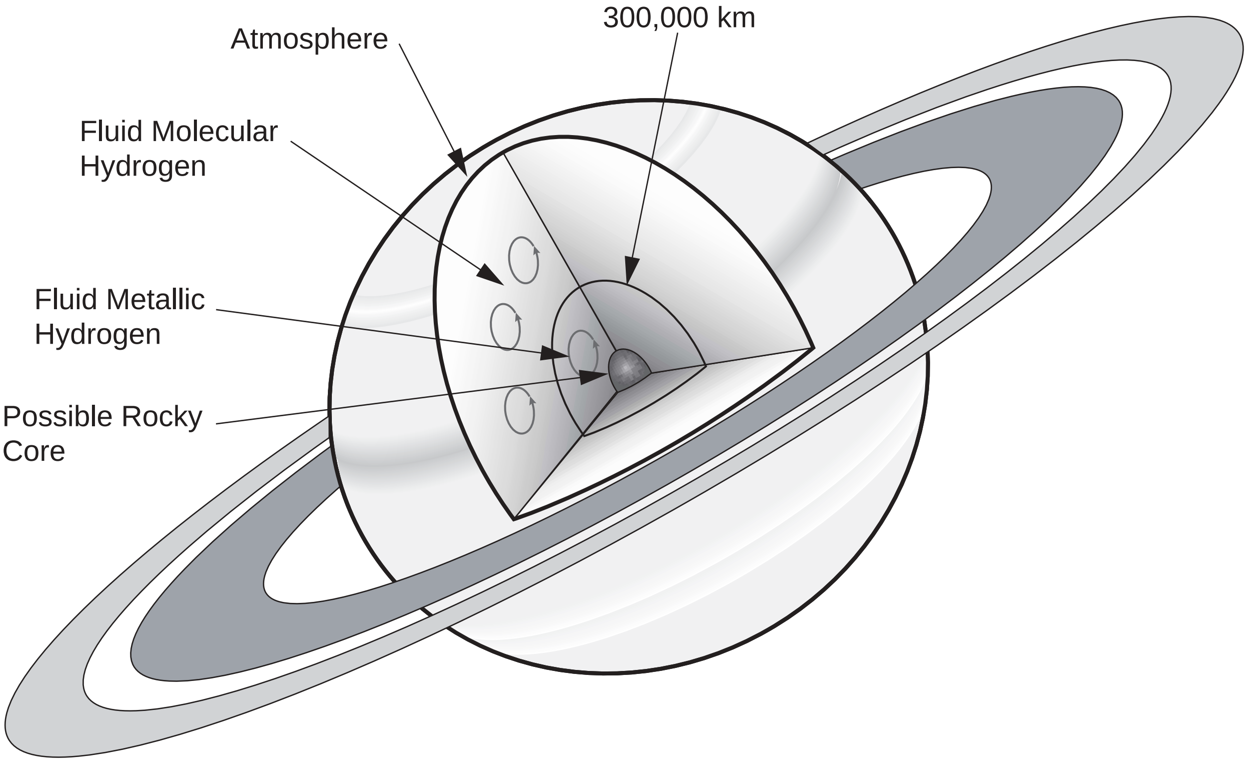
Saturn is the sixth planet from the Sun. Compared with Earth, Saturn is 9.5 times farther away from the Sun. From Saturn, the Sun is about 1/10th the size of the Sun we see from Earth. Sunlight spreads as it travels through space; an area on Earth receives 90 times more sunlight than an equivalent area on Saturn. Because of this fact, the same light-driven chemical processes in Saturn's atmosphere take 90 times longer than they would at Earth. The farther away from the Sun, the slower a planet travels in its orbit, and the longer it takes to complete its orbit about the Sun. Saturn's year is equal to 29.46 Earth years.

Saturn's orbit is not circular but slightly elliptical in shape; as a result, Saturn's distance from the Sun changes as it orbits the Sun. This elliptical orbit causes a small change in the amount of sunlight that reaches the surface of this gaseous planet at different times in the Saturn year, and may affect the planet's upper atmospheric composition over that period.

Saturn's period of rotation around its axis depends on how it is measured. The cloud tops show a rotation period of 10 hours, 15 minutes at the equator, but the period is 23 minutes longer at higher latitudes. A radio signal that has been associated with Saturn's magnetic field shows a period of 10 hours, 39.4 minutes.

This high rotation rate creates a strong centrifugal force that causes an equatorial bulge and a flattening of Saturn's poles. As a result, Saturn's cloud tops at the equator are about 60,330 kilometers (37,490 miles) from the center, while the cloud tops at the poles are only about 54,000 kilometers (33,550 miles) from the center. Saturn's volume is 764 times the volume of Earth.

Saturn has the lowest density of all the planets because of its vast, distended, hydrogen-rich outer layer. Like the other giant planets, Saturn contains a liquid core of heavy elements including iron and rock of about the same volume as Earth, but having three



Saturn's interior

or more times the mass of Earth. This increased density is due to compression resulting from the pressure of the liquid and atmospheric layers above the core, and is caused by gravitational compression of the planet.

The core of molten rocky material is believed to be covered with a thick layer of metallic liquid hydrogen and, beyond that, a layer of molecular liquid hydrogen. The great overall mass of Saturn produces a very strong gravitational field, and at levels just above the core the hydrogen is compressed to a state that is liquid metallic, which conducts electricity. (On Earth, liquid hydrogen is usually made by cooling the hydrogen gas to very cold temperatures, but on Saturn, liquid hydrogen is very hot and is formed under several million times the atmospheric pressure found at Earth's surface.) This conductive liquid metallic hydrogen layer, which is also spinning with the rest of the planet, is believed to be the source of Saturn's magnetic field. Turbulence or convective motion in this layer of Saturn's interior may create Saturn's magnetic field.

One unusual characteristic of Saturn's magnetic field is that its axis is the same as that of the planet's rotation. This is different from that of five other notable magnetic fields: those of Mercury, Earth, Jupiter, Uranus and Neptune. Current theory suggests that when the axes of rotation and magnetic field are aligned, the magnetic field cannot be maintained. Scientists do not understand the alignment of Saturn's strong magnetic field with its rotation axis, which does not fit with theories of how planets' magnetic fields are generated.

On Earth, there is a definite separation between the land, the oceans and the atmosphere. Saturn, on the other hand, has only layers of hydrogen that transform gradually from a liquid state deep inside into a gaseous state in the atmosphere, without a well-defined boundary. This is an unusual condition that results from the very high pressures and temperatures found on Saturn. Because the pressure of the atmosphere is so great, the atmosphere is compressed so much where the separation would be expected to occur that it actually has a density equal to that of the liquid. This condition is referred to as "supercritical." It can happen to any liquid and gas if compressed to a point above critical pressure. Saturn thus lacks a distinct surface. When making measurements of gas giant planets, scientists use as a "surface" reference point the altitude where the pressure is 1 bar (or one Earth atmosphere). This pressure level is near Saturn's cloud tops.

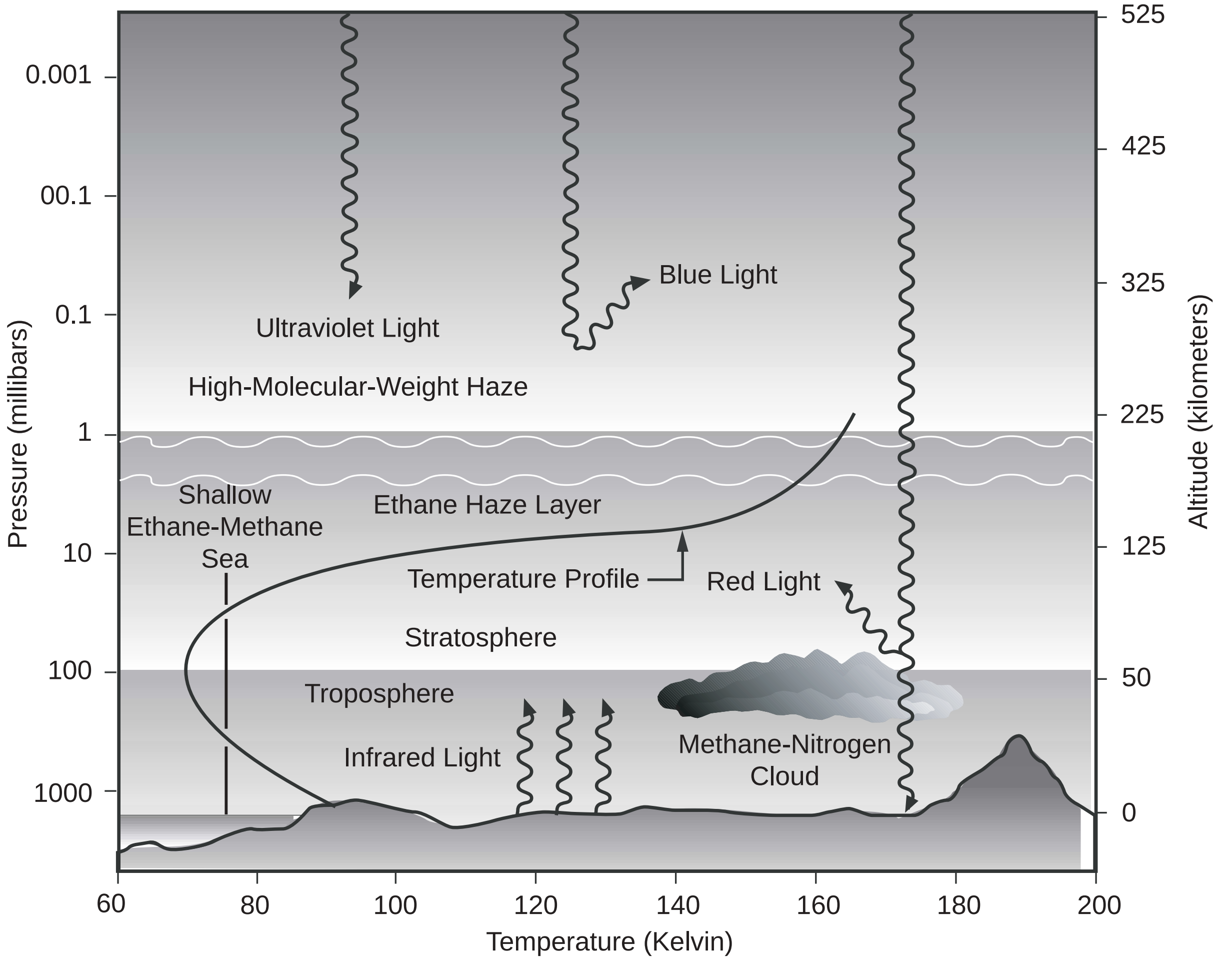
The major component of Saturn's atmosphere is hydrogen gas. If the planet were composed solely of hydrogen, there would not be much of interest to study. However, the composition of Saturn's atmosphere includes 6 percent helium gas by volume; in addition, 1/10,000th of 1 percent is composed of other trace elements. Using spectroscopic analysis, scientists find that these atmospheric elements can interact to form ammonia, phosphine, methane, ethane, acetylene, methylacetylene and propane. Even a small amount is enough to freeze or liquefy and make clouds of ice or rain possessing a variety of colors and forms.

With the first pictures of Saturn taken by the Voyager spacecraft in 1980, the clouds and the winds were seen to be almost as complex as those that Voyager found on Jupiter just the year before. Scientists have made an effort to label the belts and zones seen in Saturn's cloud patterns. The banding results from convective flows in the atmosphere driven by temperature - very much the same process that occurs in Earth's atmosphere, but on a grander scale and with a different heat source.

Saturn has different rotation rates in its atmosphere at different latitudes. Differences of more than 900 miles per hour (1,500 kilometers per hour) were seen between the equator and nearer the poles, with higher speeds at the equator. This is five times greater than the wind velocities found on Jupiter.

Saturn's cloud tops reveal the effects of temperature, winds and weather many kilometers below. Hot gases rise. As they rise, they cool and can form clouds. As these gases cool, they begin to sink: this convective motion is the source of the billowy clouds seen in the cloud layer. Cyclonic storms observed in the cloud tops of Saturn are much like the smaller versions we see in weather satellite images of Earth's atmosphere.

Temperature variations in Saturn's atmosphere are the driving force for the winds and thus cloud motion. The lower atmosphere is hotter than the upper atmosphere, causing



Model of Titan's atmosphere

gases to move vertically, and the equator is warmer than the poles because it receives more direct sunlight. Temperature variations, combined with the planet's rapid rotation rate, are responsible for the fast horizontal motion of winds in the atmosphere.

Titan

Titan presents an environment which appears to be unique in the solar system, with a thick organic hazy atmosphere containing organic (or carbon-based) compounds, an organic ocean or lakes and a rich soil filled with frozen molecules similar to what scientists believe led to the origin of life on Earth. In the three centuries since the discovery of Titan we have come to see it as a world strangely similar to our own, yet located almost 900 million miles (1.5 billion kilometers) from the Sun. With a thick, nitrogen-rich atmosphere, possible seas and a tar-like permafrost, Titan is thought to harbor organic compounds that may be important in the chain of chemistry that led to life on Earth.

Titan has been described as having an environment similar to that of Earth before biological activity forever altered the composition of Earth's atmosphere. The major difference on Titan, however, is the absence of liquid water and Titan's very low temperature. Thus there is no opportunity for aqueous chemistry at Earth-like temperatures - considered crucial for the origin of life as we know it. Scientists believe that the surface temperatures on Titan are cold enough to preclude any biological activity whatsoever at Titan.

As on Earth, the dominant atmospheric constituent in Titan's atmosphere is nitrogen. Methane represents about 6 percent of the atmospheric composition. Titan's surface pressure is 1.6 bars -- 1.6 times that on Earth, despite Titan's smaller size. The surface temperature was found by Voyager to be -179 C (-290 F), indicating that there is little greenhouse warming.

The opacity of Titan's atmosphere is caused by naturally produced photochemical smog. Voyager's infrared spectrometer detected many minor constituents produced primarily by photochemistry of methane, which produces hydrocarbons such as ethane, acetylene and propane. Methane also interacts with nitrogen atoms, forming "nitriles" such as hydrogen cyanide. With Titan's smoggy sky and distance from the Sun, a person standing on Titan's surface in the daytime would experience a level of daylight equivalent to about 1/1,000th the daylight at Earth's surface.

What is the source of molecular nitrogen, the primary constituent of Titan's atmosphere as we see it today? Was the molecular nitrogen accumulated as Titan formed, or was is it the byproduct of ammonia that was present when Titan formed? Did it come from comets? This important question can be investigated by looking for argon in Titan's atmosphere. Both argon and nitrogen condense at similar temperatures. If molecular nitrogen from the solar nebula - the cloud of gas that formed the Sun - was the source of nitrogen on Titan, then the ratio of argon to nitrogen in the solar nebula should be preserved on Titan. Such a finding would mean that we have truly found a sample of the "original" planetary atmosphere.

Some of the hydrocarbons found at Titan are in the form of aerosol haze in the atmosphere that obscures the surface. Many small molecules of compounds such as hydrogen cyanide and acetylene combine to form larger chains in a process called polymerization, resulting in additional aerosols. Eventually they drift to Titan's surface. Theoretically the aerosols should accumulate on the surface and, over the life of the solar system, produce a global ocean of ethane, acetylene, propane and other constituents with an average depth of up to 1 kilometer (about two-thirds of a mile). A large amount of liquid methane mixed with ethane could theoretically provide an ongoing source of methane in the atmosphere, similar to the way oceans on Earth supply water to the atmosphere. Radar and near-infrared data from ground-based studies show, however, that there is no global liquid ocean on Titan, although there could be lakes and seas.

Titan appears to have winds. However, the ability to study winds from Earth is tenuous at best. Instruments carried on board the Huygens probe will provide us with wind measurements.

The surface of Titan was not visible to Voyager at the wavelengths available to Voyager's cameras. What knowledge exists about the appearance of the surface of Titan comes from Earth-based radar measurements and more recent images acquired with the Hubble Space Telescope at wavelengths longer than those of Voyager's cameras. Hubble images from 1994 and later reveal brightness variations suggesting that Titan has a large continent-sized region on its surface that is distinctly brighter than the rest of the surface at both visible and near-infrared wavelengths.

Preliminary studies suggest that a simple plateau or elevation change of Titan's surface cannot explain the image features; the brightness differences must be partly due to a different composition and/or roughness of material. Like other moons in the outer solar system, Titan is expected to have a predominantly water ice crust. Water at the temperatures found in the outer solar system is as solid and strong as rock. There are weak spectral features that suggest ice on Titan's surface, but some dark substance is also present. Scientists conclude that something on the surface is masking the water ice.

Titan's size alone suggests that it may have a surface similar to Jupiter's moon Ganymede - somewhat modified by ice tectonics, but substantially cratered and old. If Titan's tectonic activity is no more extensive than that of Ganymede, circular crater basins may provide storage for lakes of liquid hydrocarbons. Impacting meteorites would create a layer of broken, porous surface materials, called regolith, which may extend to a depth of about 1 to 3 kilometers (1 to 2 miles). This regolith could provide subsurface storage for liquid hydrocarbons as well. In contrast to Ganymede, Titan may have incorporated as much as 15 percent ammonia as it formed in the colder region of Saturn's orbit. As Titan's water-ice surface froze, ammonia-water liquid would have been forced below the surface. This liquid will be buoyant relative to the surface water-ice crust; ammonia-water magma thus may have forced its way along cracks to the surface, forming exotic surface features. Density measurements suggest that Titan is made up of roughly half rocky silicate material and half water ice. Methane and ammonia could have been mixed with the water ice during Titan's formation. The formation of Titan by accretion was at temperatures warm enough for Titan to differentiate; rocky material sank to form a dense core, covered by a mantle of water, ammonia and methane ices.

The mixture of ammonia with water could ensure that Titan's interior is still partially unsolidified, as the ammonia would effectively act like antifreeze. Radioactive decay in the rocky material in the core could heat the core and mantle, making it possible that a liquid layer could exist today in Titan's mantle.

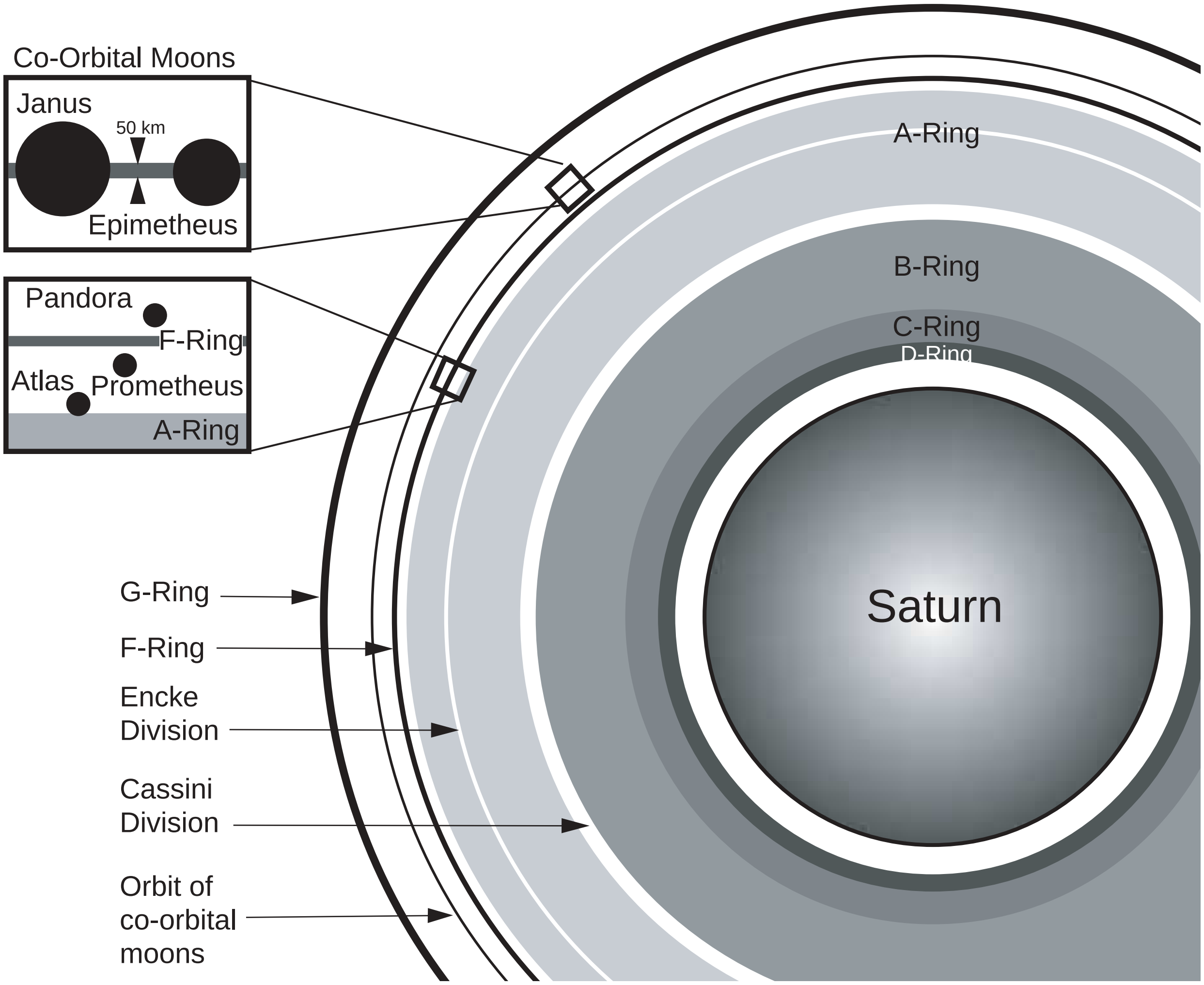
Methane could be trapped in Titan's water ice crust, which could provide a possible long term source for the methane in Titan's atmosphere if it were freed by ongoing volcanic processes. Voyager was prevented from viewing the surface by Titan's thick natural smog, and the images showed a featureless orange face. Spectroscopic observations by Voyager's infrared spectrometer revealed traces of ethane, propane, acetylene and other organic molecules in addition to methane. These hydrocarbons are produced by the combination of solar ultraviolet light and electrons from Saturn's rapidly rotating magnetosphere striking Titan's atmosphere. Hydrocarbons produced in the atmosphere should eventually condense out and rain down on the surface, thus there may exist lakes of ethane and methane, perhaps enclosed in the round bowls of impact craters. Titan's hidden surface may have exotic features such as mountains sculpted by hydrocarbon rain, and perhaps rivers, lakes and "waterfalls" of exotic liquids. Water and ammonia magma from Titan's interior may occasionally erupt, spreading across the surface.

Titan's orbit takes it both inside and outside the magnetosphere of Saturn. When Titan is outside the magnetosphere and exposed to the solar wind, its interaction may be similar to that of other bodies in the solar system such as Mars, Venus or comets (these bodies have substantial interaction with the solar wind, and, like Titan, have atmospheres but no strong internal magnetic fields).

The interaction of Titan with the magnetosphere provides a way for both the magnetospheric plasma to enter Titan's atmosphere and for atmospheric particles to escape Titan. Voyager results suggested that this interaction produces a torus of neutral particles encircling Saturn, making Titan a potentially important source of plasma to Saturn's magnetosphere. The characteristics of this torus are yet to be explored, and will be studied by the Cassini orbiter. The interaction of ice particles and dust from Saturn's rings will play a special role as the dust moves out towards Titan's torus and becomes charged by collisions. When the dust is charged it behaves partially like a neutral particle orbiting Titan according to Kepler's laws (gravity driven), and partially like a charged particle moving with Saturn's magnetosphere. The interaction of dust with Saturn's magnetosphere will provide scientists with a detailed look at how dust and plasma interact.

Electrical storms and lightning may exist in Titan's skies. Cassini will search for visible lightning and listen for "whistler" emissions that can be detected when lightning discharges a broad band of electromagnetic emission, part of which can propagate along Saturn's magnetic field lines. These emissions have a decreasing tone with time (because the high frequencies arrive before the low frequencies). Lightning whistlers have been detected in the magnetospheres of both Earth and Jupiter. They can be detected by radio and plasma-wave instruments from large distances and also can be used to estimate the frequency of lightning.

Titan may have its own internally generated magnetic field. Results from the Galileo spacecraft at Jupiter indicate the possibility of an internally generated magnetic field associated with the moon Ganymede. For Titan there are two possibilities: A magnetic field could be induced from the interaction of Titan's substantial atmosphere with the flow of Saturn's magnetosphere (like Venus's interaction with the solar wind); or a mag-



Saturn's rings

netic field could be generated internally from dynamo action in a metallic molten core (like Earth's). (Under the dynamo theory, a magnetic field is created by the circling motion of electrically conductive material in the core.) In addition to being important to understanding the Titan interaction with Saturn's magnetosphere, a Titan magnetic field, if generated internally, would help scientists define the natural satellite's interior structure.

The Rings

From a distance, the majestic rings of Saturn look like symmetrical hoops surrounding the planet. Up close, however, from the views provided by the Voyager spacecraft, the rings turn out to be a still splendid but somewhat unruly population of ice and rock particles jostling against each other or being pushed and pulled into uneven orbits by bigger particles and by Saturn's many moons.

The mass of all the ring particles measured together would comprise a moon about the size of Mimas, one of Saturn's medium-small moons. The rings may, in fact, be at least partly composed of the remnants of such a moon or moons, torn apart by gravitational forces.

Their precise origin is a mystery. It is not known if rings formed around Saturn out of the initial solar system nebula, or after one or more moons were torn apart by Saturn's gravity. If the rings were the result of the numerous comets captured and destroyed by Saturn's gravity, why are Saturn's bright rings so different in nature from the dark rings of neighboring planets? Over the lifetime of the rings, they must have been bombarded continually by comets and meteors - and therefore they should have accumulated a great amount of carbonaceous and silicate debris - yet water ice is the only material positively identified in spectra of the rings.

The effects of torque and gravitational drag -- along with the loss of momentum through collisions -- should have produced a system only one-tenth to one-hundredth the age of the solar system itself. If this hypothesis is correct, then we cannot now be observing a ring system around Saturn that formed when the solar system formed.

Saturn's rings, as well as the rings of all the other large planets, may have formed and dissipated many times since the beginning of the solar system. An extraordinarily complex structure is seen across the entire span of Saturn's ring system. The broad B ring, for instance, often contains numerous "spokes" -- radial, rotating features that may be caused by a combination of magnetic and electrostatic forces. The individual rings themselves defy definition; the count in high-resolution images suggests anywhere from 500 to 1,000 separate rings. Named in order of discovery, the labels that scientists have assigned to the major rings do not indicate their relative positions. From the planet outward, they are known as the D, C, B, A, F, G and E rings.

The possibility of numerous, small natural satellites within Saturn's ring system was a puzzle the Voyager mission had hoped to solve. Voyager's best-resolution studies of the ring system were aimed at revealing any bodies larger than about 6 miles (about 10 kilometers) in diameter; but only three were found and none were located within the main ring complex.

The Voyager high-resolution studies did, however, detect signs of small moonlets not actually resolved in the images. When a small, dense body passes near a section of low-density ring material, its gravitational pull distorts the ring and creates what are known as "edge waves."

Cassini will be able to perform a number of the experiments that Voyager used to detect other gravitational effects on Saturn's ring material. One experiment involves "watching" as a beam of light (or, in one case, radio waves) passes through the ring, then observing the effects of the ring material on the beam. As the beam passes through the ring material, it may be attenuated or even extinguished. This "occultation" experiment provides an extremely high-resolution study of a single path across the rings -with resolutions up to about about 100 meters (330 feet), Cassini will obtain far more detailed information on ring structures than the Voyager instruments.

Voyager's instruments did detect many minute ring structures and found that the F ring was far more complex than images had suggested. The data set, furthermore, showed that the B ring was quite opaque in regions, and the Cassini "division" was not at all empty. It also provided a direct measurement of the maximum thickness of the ring system in several locations, finding it to be as little as 100 meters (330 feet).

Many narrow ringlets were found with slightly eccentric, non-circular shapes and orbits. These eccentric ringlets generally lie in gaps in the mass of nearly circular rings that make up the majority of Saturn's ring system. Voyager also found very few truly empty "gaps" in the ring system. Moonlets inside the rings do appear to clear lanes within the ring plane, giving the rings their grooved appearance.

Voyager cameras found shepherd moons that tend to contain ring particles that would otherwise spread. Also seen were density waves that move though portions of the ring plane like a crowd starting a "wave" in a stadium. This phenomenon is due to the effects of one or more moons or moonlets gravitationally tugging on ring particles.

Gravitational interactions with moons seem to create most of the structure visible in the rings, but some structural detail exists even where there is no gravitational interaction with a moon. Some poorly understood fluid physics may be responsible for some unexplained structure in the rings. Other ring features may be explained by moonlets or large particles in the rings that have gone undetected.

Voyager images showed dark, radial structures on the rings. These so-called "spokes" were seen as they formed and rotated about the planet. Spokes seemed to appear rapidly - as a section of ring rotated out of the darkness near the dawn side -- and then dissipate gradually, rotating around toward the dusk side of the ring. A spoke's formation time seemed to be very short; in some imaging studies they were seen to grow more than about 6,000 kilometers (3,700 miles) in distance in just five minutes.

The spokes in Saturn's rings have an unexplained link with the planet's magnetic field, and are likely to be just one visible manifestation of many interactions the rings have with Saturn's electromagnetic fields.

Ground-based infrared studies of the spectra of the A and B rings show that they are composed largely, perhaps even exclusively, of water ice. The spectral characteristics of the rings are also very similar to those of several of Saturn's inner moons.

Studies of the main rings show that the ring system is not completely uniform in its makeup, and that some sorting of materials within the A and B rings exists. Why such a non-uniform composition exists is unknown. The E ring is somewhat bluish in color -

and thus different in makeup from the main rings. It is believed that the moon Enceladus is the source of E-ring material.

Since ring particles larger than about 1 millimeter represent a considerable hazard to the Cassini spacecraft, the mission plan will include efforts to avoid dense particle areas of Saturn's ring plane. The spacecraft will be oriented to provide maximum protection for itself and its sensitive instrumentation packages. Even with such protective measures, passage through the ring plane out beyond the main rings will allow Cassini's instruments to make important measurements of the particles making up the less dense regions of the ring plane. These studies could provide considerable insight into the composition and environment of the ring system and Saturn's icy natural satellites.

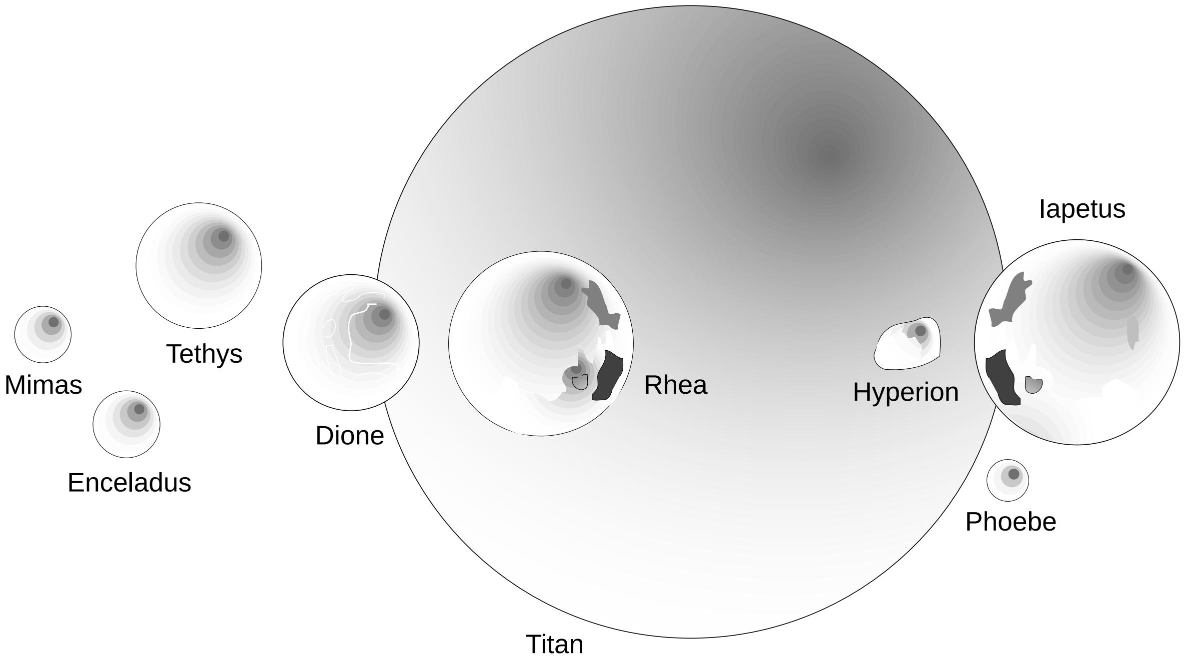
The Icy Moons

The moons of Saturn are diverse - ranging from the planet-like Titan to tiny, irregular objects only tens of kilometers (or miles) in diameter. These bodies are all (except perhaps Phoebe) believed to hold not only water ice, but also other components such as methane, ammonia and carbon dioxide.

Many of the smallest moons were discovered during the Voyager spacecraft flybys. During Saturn's ring plane crossings, Saturn's bright rings dim as they move to an edge-on orientation from Earth's perspective, making these ideal times for discovering new moons. At the time of Cassini's launch there were 18 known moons; now, nearly seven years later, there are 31. It is likely that Cassini will discover additional small natural satellites orbiting Saturn.

Before the advent of robotic spacecraft exploration, scientists expected the moons of the outer planets to be geologically dead. They assumed that heat sources were not sufficient to have melted the moons' mantles enough to provide a source of liquid, or even semi-liquid, ice or ice silicate slurries. The Voyager and Galileo spacecraft have radically altered this view by revealing a wide range of geological processes on the moons of the outer planets. For example, Saturn's moon Enceladus may be feeding material into the F ring, suggesting the existence of current activity such as geysers or volcanoes. Several of Saturn's medium-sized moons are large enough to have undergone internal melting with subsequent differentiation and resurfacing.

Many moons in the outer solar system show the effects of tidal interactions with their parent planets, and sometimes with other moons. This happens when the moon has an elliptical orbit, thus experiencing a varying gravitational force as it orbits the parent body. The resulting tidal forces can heat a moon's interior, much as a ball of dough becomes warm when kneaded, and this can cause tectonic, volcanic or geyser-like phenomena. Another factor is the presence of non-ice components, such as ammonia hydrate or methanol, which lower the melting point of near-surface materials. Partial melts of water ice and various other components, each with their own melting point



Saturn’s major moons

and viscosity, provide potential for a wide range of geological activity.

Because the surfaces of so many moons of the outer planets exhibit evidence of geological activity, planetary scientists have begun to think in terms of unified geological processes occurring on the planets and their moons. For example, partial melts of water ice with other materials could produce flows of liquid or partially molten slurries similar to lava flows on Earth that result from the partial melting of silicate rock mixtures. The ridged and grooved terrains on moons such as Saturn's Enceladus and Tethys may have resulted from tectonic activities. The explosive volcanic eruptions possibly occurring on Enceladus may be similar to those occurring on Earth.

Several of Saturn's moons underwent periods of melting and active geology within a billion years of their formation and then became quiescent. For nearly a billion years after their formation, the moons all underwent intense bombardment and cratering. The bombardment tapered off to a slower rate, but still continues. By counting the number of craters on a moon's surface, and making certain assumptions about the amount and frequency of impacting material, geologists are able to estimate when a specific portion of a moon's surface was formed.

Meteorites bombarding icy bodies change the surfaces by excavating and exposing fresh material. Impacts can also cause some surface or subsurface materials to turn to vapor, and the subsequent escape of those vaporized materials can create a slag deposit enriched in opaque, dark materials. Both the moons of Jupiter and the medium-sized moons of Saturn tend to be brighter on the hemispheres leading in the direction of orbital motion (each moon's so-called "leading" side, as opposed to its "trailing" side); this effect is thought to be due to the roughing-up and coating that the leading side receives from meteor bombardment.

Saturn's six largest moons after Titan are smaller than Titan and Jupiter's giant Galilean moons, but they are still sizable and represent a unique class of icy satellite. Tethys, Rhea, Iapetus, Mimas and Enceladus are thought to be largely water ice, possibly mixed with ammonia or other volatiles. They have smaller amounts of rocky silicates than the Galilean moons.

☐ Saturn's innermost, medium-sized moon, **Mimas**, is covered with craters, including one named Herschel that covers a third of the moon's diameter. There is a suggestion of grooves in its surface that may be features caused by the impact that created Herschel. The craters on Mimas tend to be high-rimmed, bowl-shaped pits. The crater record of Mimas suggests that it has undergone several episodes of resurfacing.

☐ The next moon outward from Saturn is **Enceladus**, an object known from telescope measurements to reflect nearly 100 percent of the visible light it receives. This leads scientists to believe Enceladus' surface is probably pure water ice. Voyager 2 images reveal a surface that had been subjected to extensive resurfacing in the recent geological past. Grooved formations similar to those on the Galilean moon Ganymede are prominent.

The lack of impact craters on part of Enceladus leads scientists to conclude the age of its surface is less than a billion years. Some form of ice volcanism may be currently occurring on Enceladus. One possible source of heating is tidal interactions, perhaps with the moon Dione.

Enceladus is possibly responsible for the formation of Saturn's E ring. This ring is a tenuous collection of icy particles that extends from inside the orbit of Enceladus to beyond the orbit of Dione, but is much much thicker than Saturn's other rings. The maximum thickness position of the ring coincides with the orbital position of Enceladus. If some form of volcanism is occurring on the surface, it could provide a source of particles for the ring.

☐ **Tethys** is covered with impact craters, including Odysseus, an enormous impact structure more than 400 kilometers (250 miles) in diameter, or more than one-third of the moon's diameter of 1,060 kilometers (658 miles). The craters tend to be flatter than those on Mimas or Earth's Moon, probably because they have been smoothed out over the eons under Tethys' gravity. Evidence for episodes of resurfacing is seen in regions that have fewer craters and higher reflectivity. In addition, there is a huge trench formation, the Ithaca Chasm, which may be a degraded form of the grooves found on Enceladus.

❑ **Dione** is about the same size as Tethys but more dense, and shows a wide variety of surface features. Next to Enceladus among Saturn's moons, it has the most extensive evidence for internal activity. It has enough rocky material in its makeup to produce heat from natural radioactivity, which could be the cause of its internal activity. Most of the surface is heavily cratered, but gradations in crater density indicate that several periods of resurfacing occurred during the first billion years of Dione's existence. The leading side of the moon is about 25 percent brighter than the trailing side, which may be due to its history of micrometeoroid bombardment. Wispy streaks, which are about 50 percent brighter than the surrounding areas, are believed to be the result of internal activity and subsequent flows of erupting material.

❑ **Rhea** appears to be superficially very similar to Dione. Bright, wispy streaks cover one hemisphere. However, no resurfacing events seem to have occurred in its early history. Some regions lack large craters, while other regions have a preponderance of such impacts. The larger craters may be due to a population of larger debris that was more prevalent during an earlier era of collisions.

❑ When the astronomer Cassini discovered **Iapetus** in 1672, he noticed almost immediately that at one point in its orbit around Saturn it was very bright, but on the opposite side of the orbit, the moon nearly disappeared. He correctly deduced that the trailing hemisphere is composed of highly reflective material, while the leading hemisphere is strikingly darker. (This sets Iapetus apart from Saturn's other moons and the moons of Jupiter, which tend to be brighter on their leading hemispheres.) Voyager images show that the bright side, which reflects nearly 50 percent of the light it receives, is fairly typical of a heavily cratered icy satellite. The leading side is coated with a much darker, redder material that has a reflectivity of only about 3 to 4 percent.

Scientists still do not agree on whether the dark material originated from an outside source or was created from Iapetus' own interior. One scenario for the outside deposit of material would involve dark particles being ejected from the little moon Phoebe and drifting inward to coat Iapetus. The major problem with this model is that the dark material on Iapetus is redder than Phoebe, although the material could have undergone chemical changes that made it redder after its expulsion from Phoebe. One observation lending credence to an internal origin is the concentration of material on crater floors, which implies that something is filling in the craters. In one model proposed by scientists, methane could erupt from the interior and then become darkened by ultraviolet radiation.

Iapetus is odd in other respects. It is the only large Saturn moon in a highly inclined orbit, one that takes it far above and below the plane in which the rings and most of the moons orbit. It is less dense than objects of similar brightness, which implies it has a higher fraction of ice or possibly methane or ammonia in its interior.

Small Moons

The Saturn system has a number of unique, small moons. Two types of objects have been found only in Saturn's system: the co-orbital moons and the Lagrangians. A third type of object, shepherding moons, have been found only at Saturn and Uranus. All three groups of moons are irregularly shaped and probably consist primarily of ice.

Three shepherds -- Atlas, Pandora and Prometheus -- are believed to play a key role in defining the edges of Saturn's A and F rings. The orbit of Atlas lies several hundred miles (or kilometers) from the outer edge of the A ring. Pandora and Prometheus, which orbit on either side of the F ring, constrain the width of this narrow ring and may cause its kinky appearance.

The co-orbital moons Janus and Epimetheus, discovered in 1966 and 1978, respectively, exist in an unusual dynamic situation. They move in almost identical orbits. Every four years, the inner moon (which orbits slightly faster than the outer one) overtakes its companion. Instead of colliding, the moons exchange orbits. The four-year cycle then begins again. Perhaps these two moons were once part of a larger body that disintegrated after a major collision.

The three other small moons of Saturn -- Calypso, Helene and Telesto -- orbit in the Lagrangian points of larger moons, one associated with Dione and two with Tethys. The Lagrangian points are locations within an object's orbit in which a less massive body can move in an identical, stable orbit. The points lie about 60 degrees in front of and behind the larger body. (Although no other known moons in the solar system are Lagrangians, the Trojan asteroids orbit in two of the Lagrangian points of Jupiter. Mars also has an asteroid at one Lagrangian point.)

Telescope observations showed that the surface of Hyperion, which lies between the orbits of Iapetus and Titan, is covered with ice. Because Hyperion is not very reflective, its ice must be mixed with a significant amount of darker, rocky material. The color of Hyperion is similar to that of the dark side of Iapetus and D-type asteroids: all three bodies may be rich in primitive material containing organic compounds. Although Hyperion is only slightly smaller than Mimas, it has a highly irregular shape that, along with a battered appearance, suggests that it has been subjected to intense bombardment and fragmentation. There is also evidence that Hyperion is in a chaotic rotation, probably the result of tidal forces during close passages of nearby Titan.

One of Saturn's outer moons, Phoebe, is a dark object with a surface composition probably similar to that of C-type asteroids, and is in a wrong-way orbit compared to the other moons (such a motion, opposite to the direction of Saturn's rotation, is called a "retrograde" orbit). The orbit is also highly inclined, taking Phoebe high above and below the plane on which the rings and most of the moons orbit. These peculiar orbital characteristics suggest that Phoebe may be a captured asteroid. Voyager images show a mottled appearance. Although it is smaller than Hyperion, Phoebe has a nearly spherical shape.

Pan, the last known moon when Cassini launched, was discovered in 1990 in Voyager 2 images that were taken in 1981. This small object is embedded within the A ring and helps to clear the particles out of the Encke division.

Since the launch of Cassini, 13 new moons of Saturn have been discovered. Not much is known about them. Estimates of their sizes range from 3 to 16 kilometers (2 to 10 miles) across. Discovered from ground-based telescopes on Earth, the moons appear as faint dots of light moving around the planet. They have been officially named by the International Astronomical Union after giants from Norse, Inuit and Gallic mythology. The orbits of these natural satellites are highly irregular, with several of them moving in retrograde orbits. Their orbits are also inclined to the plane of Saturn's equator. Scientists are not sure whether these small moons are fragments from larger satellites, if they were captured by Saturn, or if they are debris left over from Saturn's formation 4.65 billion years ago.

The Magnetosphere

Saturn, its moons and rings sit inside an enormous bubble in the solar wind created by the planet's strong magnetic field. This "sphere of influence" of Saturn's magnetic field -- called a magnetosphere -- resembles a similar, but smaller, one surrounding Earth. Magnetospheres also surround Jupiter and several other bodies in the solar system that have permanent magnetic fields. A supersonic "solar wind" of electrically charged particles blows outward from the Sun. The pressure of this solar wind against a planet's magnetosphere compresses the sunward side of the sphere and blows past the planet, giving the magnetosphere a drawn-out shape like that of a comet.

Inside Saturn's vast magnetospheric bubble is a mixture of particles including electrons, various species of ions and neutral atoms and molecules, several populations of very energetic charged particles (like those in Earth's Van Allen Belts) and charged dust grains. The charged particles and dust grains all interact with both the steady and the fluctuating electric and magnetic fields present throughout the magnetosphere. The primary sources of particles in Saturn's magnetosphere are thought to be the moons Dione and Tethys, which are bombarded by the more energetic particles. But the solar wind, ionosphere, rings, Saturn's atmosphere, Titan's atmosphere and the other icy moons are sources as well.

The mysterious "spokes" in the rings of Saturn are probably caused by electrodynamic interactions between the tiny charged dust particles in the rings and the magnetosphere -- but could also be caused by meteoroid impacts. Aurora, which exist on Saturn as well as Earth, are produced when trapped charged particles spiral down along magnetic field lines leading to the planet and collide with gases in the atmosphere. Scientists generally agree that the internal magnetic fields of the giant planets arise from an electrical field generated somewhere inside the planets' liquid interiors.

Saturn's interior is probably quite exotic because of the great pressures caused by its large size. There may be a molten rocky core, but wrapped around this core scientists would expect to find layers of uncommon materials such as liquid metallic hydrogen and perhaps liquid helium. Metallic (electrically conductive) hydrogen is not known on Earth, but is believed to be a possible stable form of that element under the intense conditions of temperature and pressure that exist in the interiors of Jupiter and Saturn.

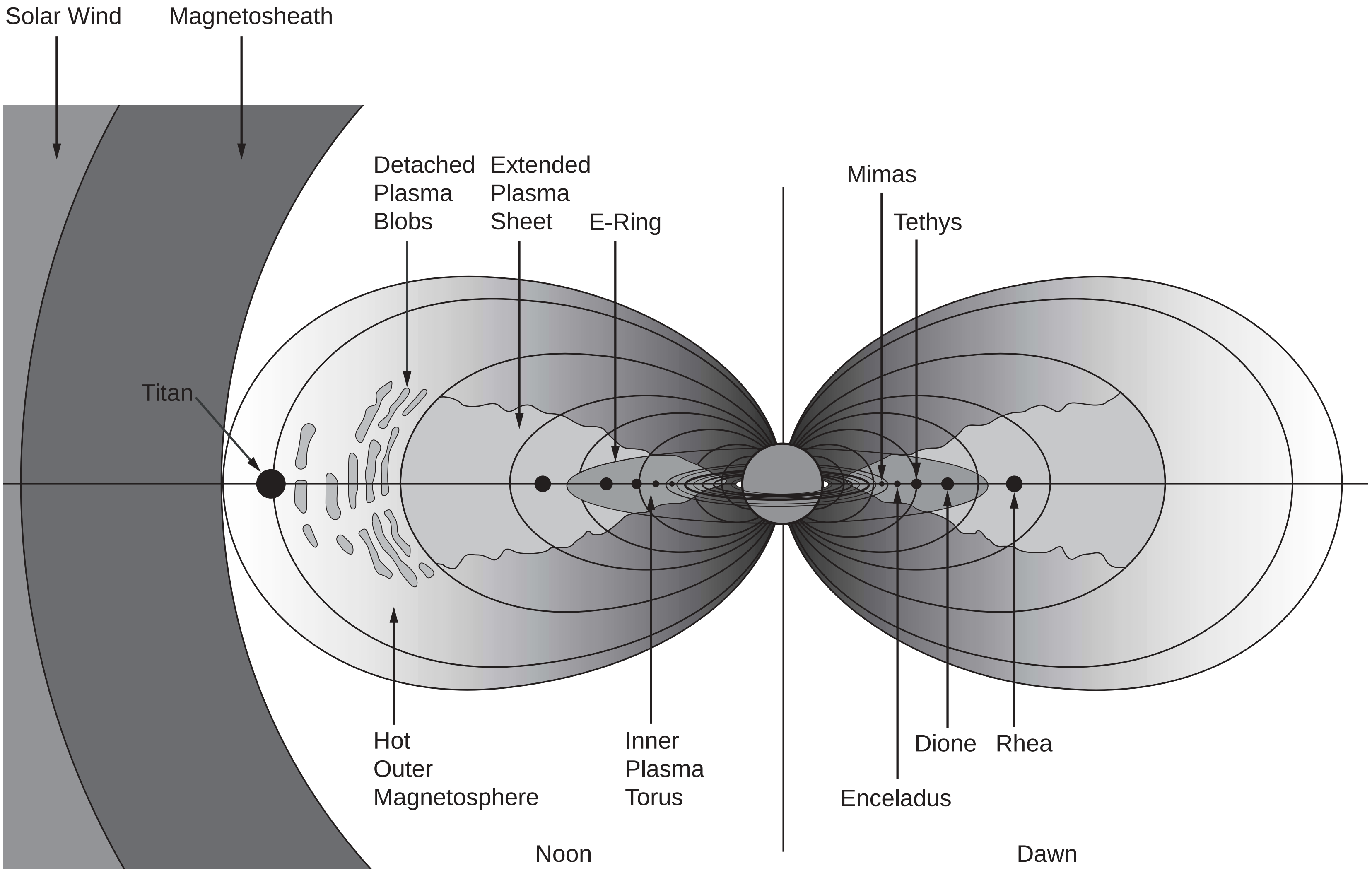
Making measurements close to the planet over a wide range of latitudes and longitudes, Cassini will measure the details of the gravitational and magnetic field and tell us more about Saturn's interior. The spacecraft's magnetometer will measure the strength and direction of the magnetic field throughout the magnetosphere - close to the planet where the field is nearly dipolar, and farther from the planet where electrical currents create a non-dipolar field. The magnetometer will measure the planet's magnetic field with sufficient accuracy to determine if it is indeed symmetrical. If so, the basic tenets of the dynamo theory invented to explain planetary magnetic fields may need to be reexamined.

Among all the planets with magnetic fields, there are two main sources of energy driving magnetospheric processes: the planet's rotation and the solar wind. In turn there are two types of large-scale plasma flow within the magnetosphere - co-rotation and convection. The nature of the large-scale circulation of particles in the magnetosphere depends on which source is dominant. At Earth, the energy is derived primarily from the solar wind; at Jupiter it is derived from the planet's rapid rotation rate. Saturn's magnetosphere is especially interesting because it is somewhere in between; both energy sources should play an important role.

The rotation of Saturn's magnetic field with the planet creates a large electric field that extends into the magnetosphere. The combination of this electric field and Saturn's magnetic field create electromagnetic forces that cause charged plasma particles to "co-rotate" (rotate together with Saturn and its internal magnetic field) as far out as Rhea's orbit.

The other large-scale flow of charged particles, convection, is caused by the solar wind pulling the lines of the magnetic field toward the tail of the magnetosphere. This leads to a plasma flow from dayside to nightside on open field lines, as well as a return flow from nightside to dayside on closed field lines (particularly near the equatorial plane).

Saturn has an ionosphere, a thin layer of partially ionized gas at the top of the sunlit atmosphere. Collisions between particles in the atmosphere and the ionosphere create a frictional drag that causes the ionosphere to rotate together with Saturn and its atmosphere.



Saturn’s magnetosphere

Mission Overview

The Cassini-Huygens mission will answer fundamental questions about the evolution of planets through an extensive study of Saturn, its famous rings, its magnetosphere, Titan, and its other icy moons.

The Saturn system represents an unsurpassed laboratory where scientists can look for answers to many fundamental questions about the physics, chemistry and evolution of the planets and the conditions that give rise to life.

Saturn may contain much of the primordial cloud's gases not trapped by the Sun. With 31 known moons, and rings that would barely fit in the space between Earth and its moon, Saturn could be considered the equivalent of a miniature solar system. Saturn's largest moon Titan is thought to harbor organic compounds that may be important in the chain of chemistry that led to life on Earth. Although too cold to support life now, it serves as a "frozen vault" to see what early Earth might have been like.

Cassini will be the first orbiter around Saturn when it conducts its extensive four-year tour of the ringed world. Six months after its arrival at Saturn, it will release its piggy-backed Huygens probe for a descent through Titan's thick atmosphere. The probe could impact in what may be a liquid methane ocean.

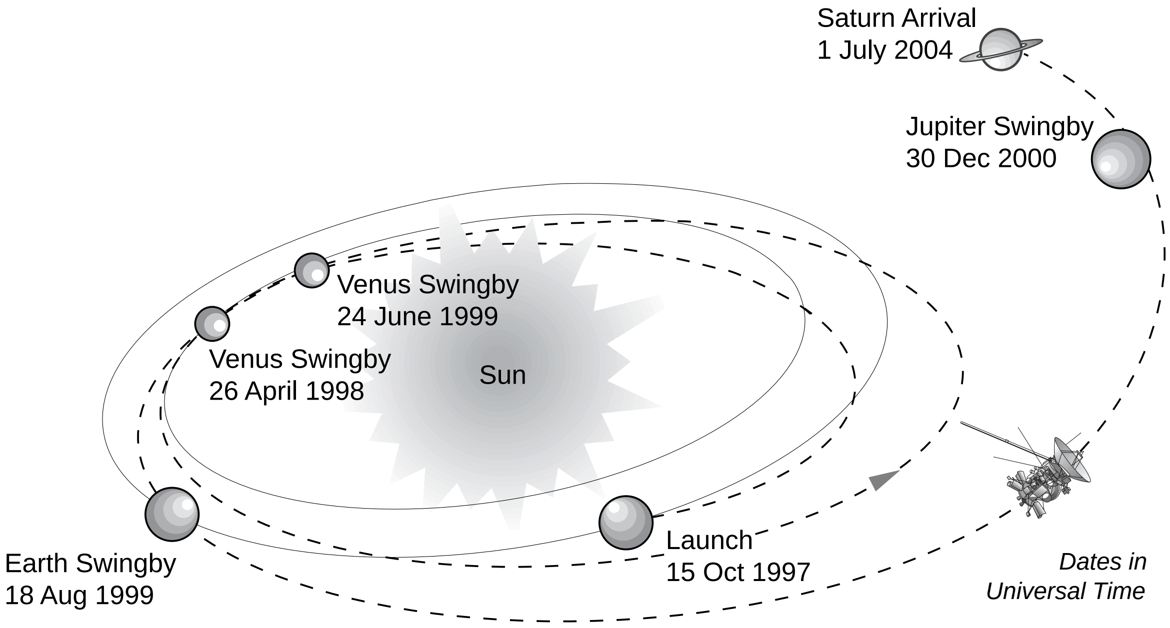
The Cassini spacecraft, including the orbiter and Huygens probe, is the most complex interplanetary spacecraft ever built. The orbiter has 12 sophisticated instruments, while the Huygens probe carries six more. They represent the best technical efforts of the United States and 17 European nations involved in the mission.

Launch

Cassini's journey to Saturn began on October 15, 1997, with launch on a Titan IVB/Centaur launch system from Florida's Cape Canaveral Air Force Station. The upper-stage booster accelerated the spacecraft out of Earth orbit towards Venus for the first of four planetary "gravity assists" designed to boost Cassini toward Saturn. In a gravity assist, the spacecraft flies close enough to a planet to be accelerated by its gravity, creating a "slingshot" effect to boost the speed of the spacecraft.

Venus, Earth and Jupiter Flybys

Cassini's mass is so large that it was not possible to use any available launch vehicle to send it on a direct path to Saturn. Four gravity assists were required to hurl the spacecraft to Saturn. Cassini used an interplanetary trajectory that took it by Venus twice, then past Earth and Jupiter. After flying past Venus twice at an altitude of 284 kilometers (176 miles) on April 26, 1998 and on June 24, 1999 at 600 kilometers (370 miles), the spacecraft swung past Earth at an altitude of 1,171 kilometers (727 miles)



Interplanetary Trajectory

on August 18, 1999. Given these three gravity assists, Cassini finally had enough momentum to reach the outer solar system. The fourth and final gravity assist was from Jupiter on December 30, 2000, at an altitude of 9,723,890 million kilometers (6,042,145 million miles) boosting Cassini all the way to Saturn.

Cruise Phase

Cassini carried out a low-activity flight plan during which only essential engineering and navigation activities such as trajectory correction maneuvers were performed. The science instruments were turned off except for a few maintenance activities. These included a single post-launch checkout of all of Cassini's science instruments, as well as calibration of Cassini's magnetometer during its subsequent Earth flyby. Huygens probe health checks occurred every six months. Science observations were conducted as the spacecraft passed Venus and Earth.

The Jupiter flyby posed a good opportunity for Cassini and the Galileo spacecraft to study several aspects of Jupiter and its surrounding environment from October 2000 through March 2001, before, during and after Cassini's closest approach to Jupiter on December 30, 2000. The scientific observations took advantage of having two different vantage points in the vicinity of the planet at the same time. Some of the objectives accomplished by the Cassini and Galileo joint studies included studying the shape of the magnetosphere and the effects of the solar wind on the magnetosphere and learning about the auroras at Jupiter.

During this flyby, most of the Cassini orbiter science instruments were turned on, calibrated and collected data. The joint studies served as good practice to check-out many of Cassini's instruments, three and a half years before Saturn arrival.

Saturn Arrival

After a nearly seven-year journey covering 3.5 billion kilometers (2.2 billion miles), Cassini will arrive at Saturn on July 1, 2004 (Universal Time; June 30 in U.S. time zones).

The most critical phase of the mission after launch is Saturn orbit insertion. When Cassini reaches Saturn, the spacecraft will fire its main engine at 7:36 p.m. PDT (Earth-received time) for 96 minutes to brake its speed and allow it to be captured as a satellite of Saturn. Passing through the a gap between Saturn's F and G rings, Cassini will swing close to the planet to begin the first of some six dozen orbits to be completed during its four-year primary mission.

Information gathered on the location and density of material in the rings was used by designers to plan the most advantageous and safest course for Cassini's flight path. The spacecraft will be oriented with the high-gain antenna used as a shield to provide maximum protection against any small particles that may be present in the region of the ring crossing.

The arrival period provides a unique opportunity to observe Saturn's rings and the planet itself, as this is the closest approach the spacecraft will make to Saturn during the entire mission.

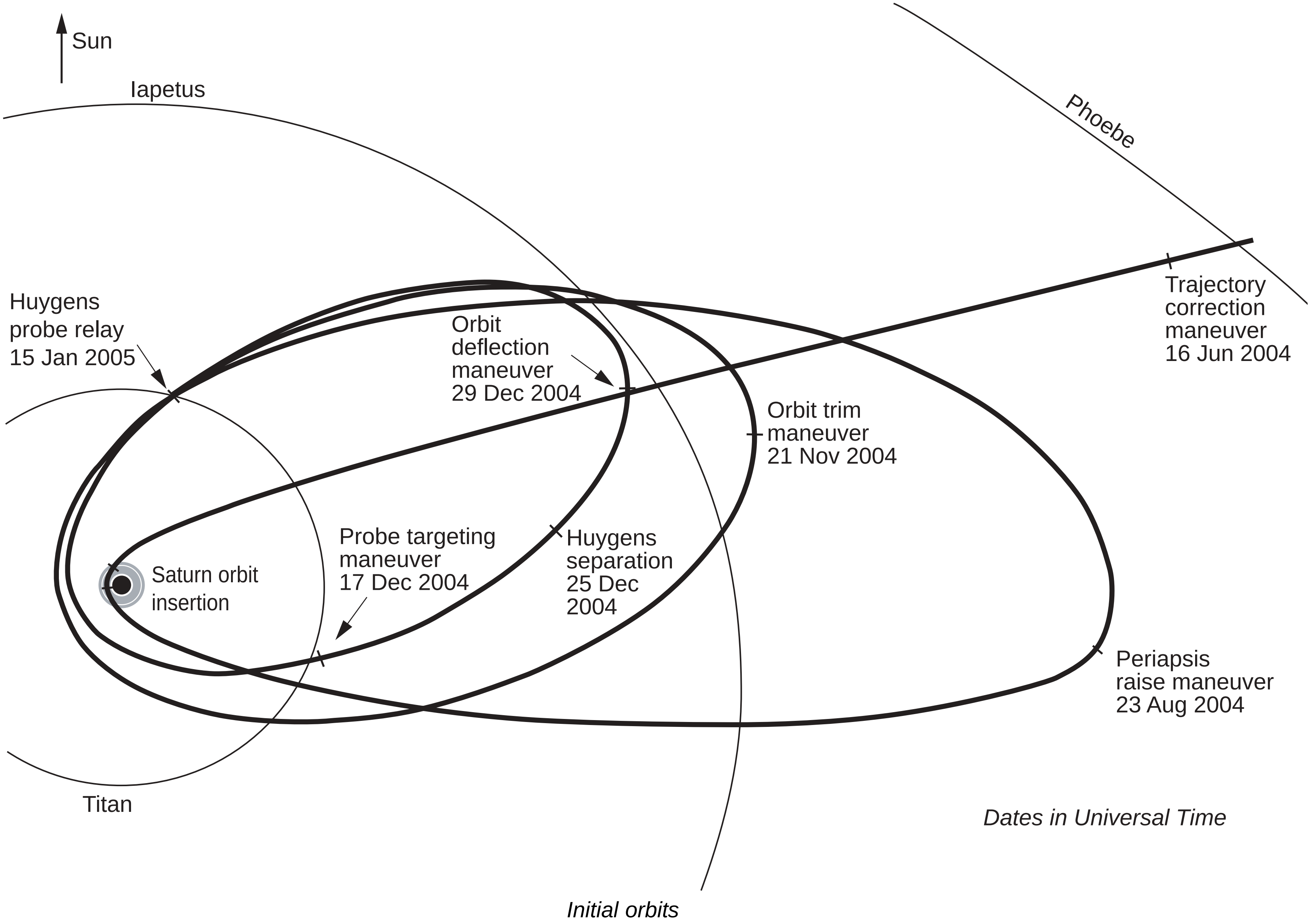
The Huygens Probe Mission

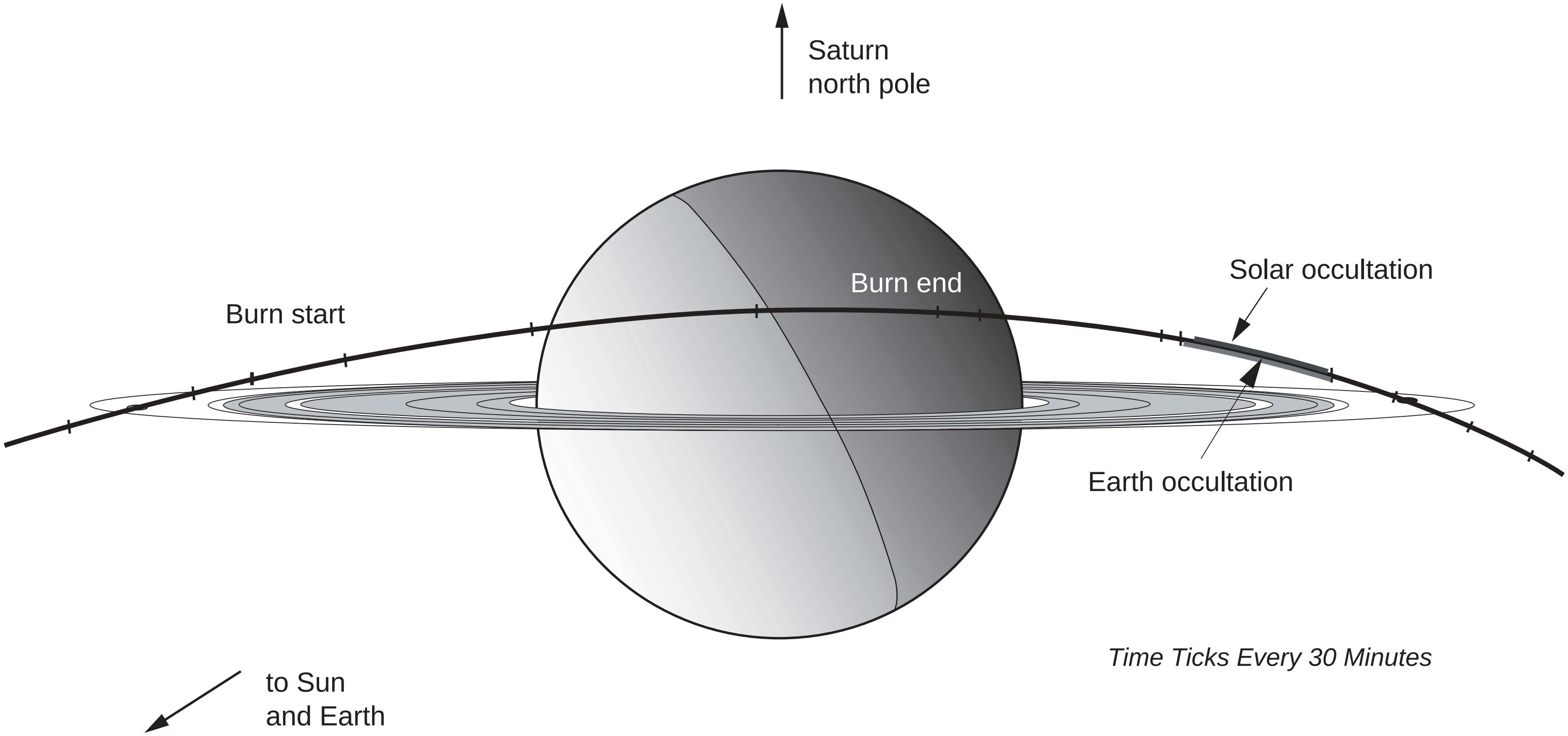
The Huygens probe will be carried to the Saturn system by Cassini. Bolted to Cassini and fed electrical power through an umbilical cable, Huygens will ride along during the nearly seven-year journey largely in a "sleep" mode, awakened every six months for three-hour instrument and engineering checkups.

Some 20 days before it hits the top of Titan's atmosphere, Huygens will be released from Cassini on December 24, 2004. With its umbilical cut and bolts released, Huygens will spring loose from the mother ship and fly on a ballistic trajectory to Titan. The probe will spin at about 7 rpm for stability. Onboard timers will switch on the probe systems before the probe reaches Titan's upper atmosphere.

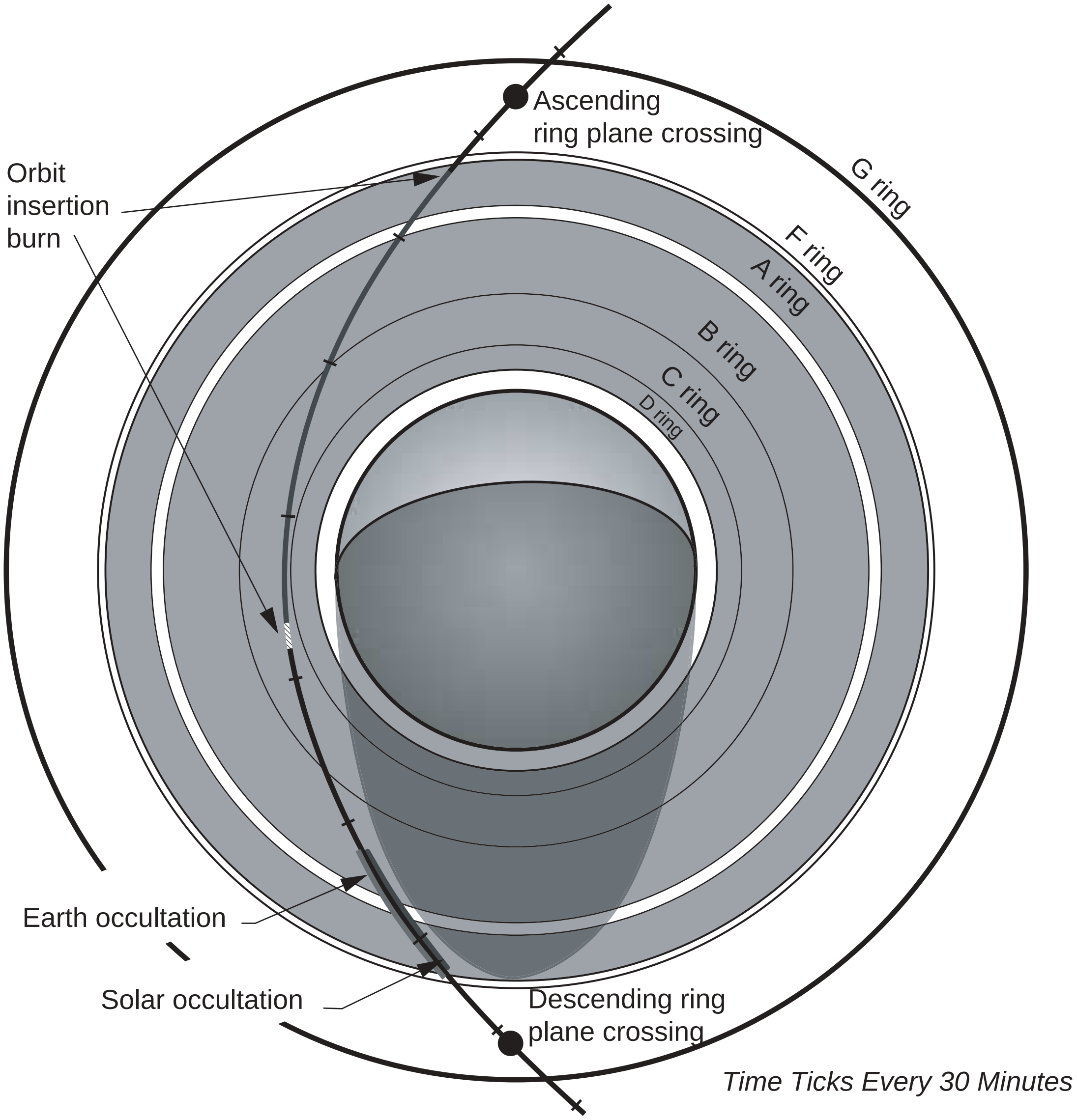
Two days after the probe's release, the orbiter will perform a deflection maneuver; this will keep Cassini from following Huygens into Titan's atmosphere. This maneuver will also establish the required geometry between the probe and the orbiter for radio communications during the probe descent.

The Huygens probe carries two microwave S-band transmitters and two antennas, both of which will transmit to the Cassini orbiter during the probe's descent. One


Sun
Iapetus
Phoebe
Huygens
probe relay
15 Jan 2005
Orbit
deflection
maneuver
29 Dec 2004
Trajectory
correction
maneuver
16 Jun 2004
Orbit trim
maneuver
21 Nov 2004
Saturn orbit
insertion
Probe targeting
maneuver
17 Dec 2004
Huygens
separation
25 Dec
2004
Periapsis
raise maneuver
23 Aug 2004
Titan
Dates in Universal Time
Initial orbits



Arrival geometry

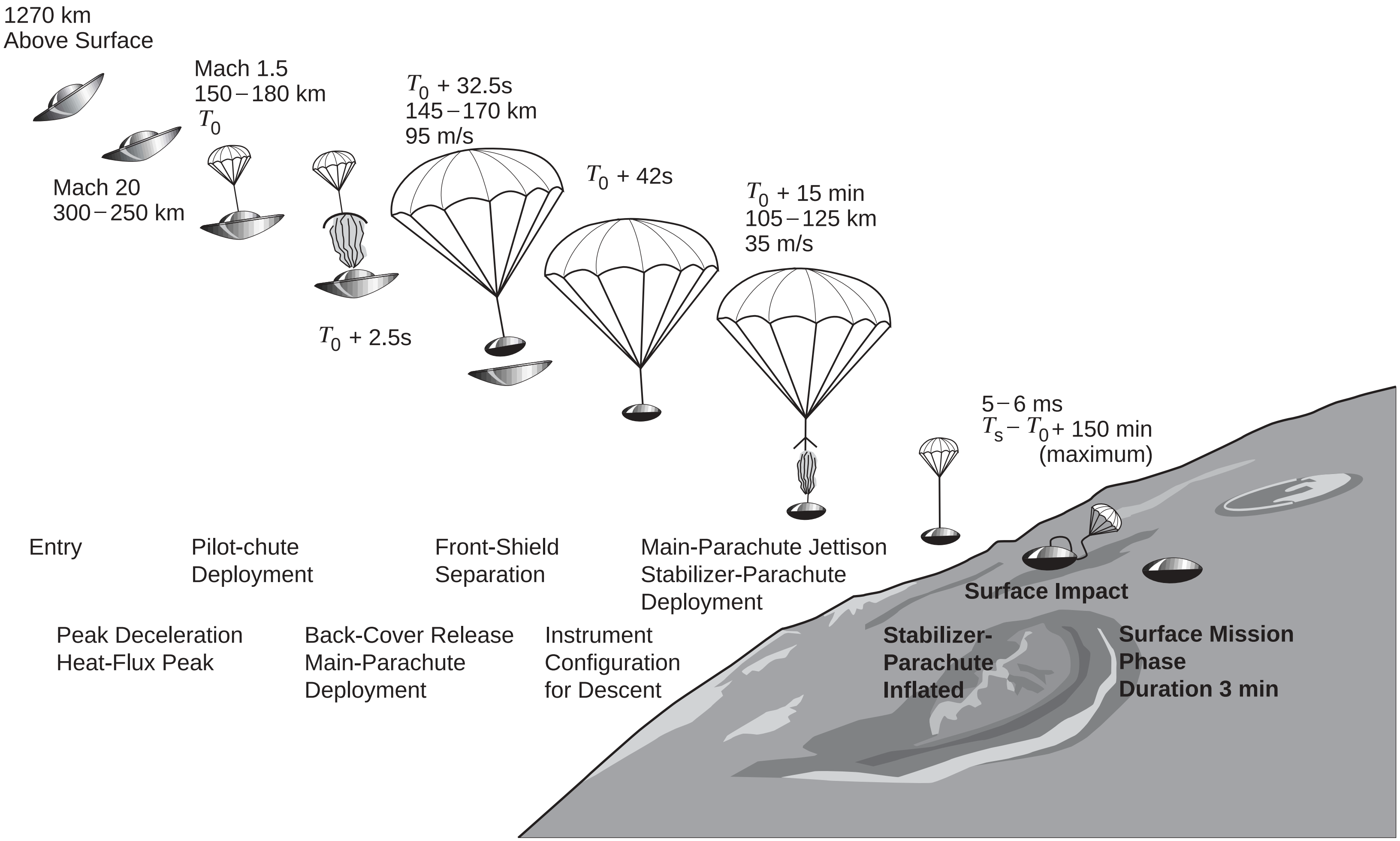


Arrival geometry

stream of telemetry is delayed by about six seconds with respect to the other to avoid data loss if there are brief transmission outages.

Probe descent will take place January 15, 2005 (Universal Time; January 14 in U.S. time zones). Huygens will enter Titan's atmosphere at a speed of about 20,000 kilometers per hour (12,400 miles per hour). It is designed to withstand the extreme cold of space (about -200 C (-330 F)) and the intense heat it will encounter during its atmospheric entry (more than 12,000 C (21,600 F).

Huygens' parachutes will further slow the descent so the probe can conduct an intensive program of scientific observations all the way down to Titan's surface. When the



Huygens' descent to Titan

probe's speed has moderated to about 1,400 kilometers per hour (870 miles per hour), the probe's cover will be pulled off by a pilot parachute. An 8.3-meter-diameter (27-foot) main parachute will then be deployed to ensure a slow and stable descent. The main parachute will slow the probe and allow the decelerator and heat shield to fall away when the parachute is released.

To limit the duration of the descent to a maximum of 2-1/2 hours, the main parachute will be jettisoned 900 seconds after the probe has entered the top of the atmosphere. A smaller, 3-meter-diameter (9.8-foot) drogue chute will deploy to support the probe for the remainder of the descent.

During the first part of the descent, instruments onboard the Huygens probe will be controlled by a timer. During the final 10 to 20 kilometers (6 to 12 miles) of descent, instruments will be controlled on the basis of altitude measured by the radar altimeter.

Throughout the descent, Huygens' atmospheric structure instrument will measure the physical properties of the atmosphere. The gas chromatograph and mass spectrometer will determine the chemical composition of the atmosphere as a function of altitude. The aerosol collector and pyrolyzer will capture aerosol particles -- fine liquid or solid particles suspended in the atmosphere -- heat them and send the resulting vapor to the chromatograph/spectrometer for analysis.

Huygens' descent imager and spectral radiometer will take pictures of cloud formations and Titan's surface, and also determine the visibility within Titan's atmosphere. As the surface looms closer, the instrument will switch on a bright lamp and measure the spectral reflectance of the surface. Throughout the descent, the Doppler shift of Huygens' radio signal will be measured by the Doppler wind experiment onboard the Cassini orbiter to determine Titan's atmospheric winds, gusts and turbulence. As the probe is shifted about by winds, the frequency of its radio signal would change slightly in what is known as the Doppler effect -- similar to how the pitch of a train whistle appears to rise and then fall as the train passes. Such changes in frequency can be used to deduce the wind speed experienced by the probe.

As Huygens nears impact, its surface science package will activate a number of sensors to measure surface properties. Huygens will impact the surface at about 25 kilometers per hour (15 miles per hour); the chief uncertainty is whether its landing will be a thud or a splash. If Huygens lands in liquid, these instruments will measure the liquid's properties while the probe floats for a few minutes.

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

Assuming Huygens continues to send data to Cassini from Titan's surface, it will be able to do so for a maximum of about 30 minutes, when the probe's battery power is expected to run out and the Cassini orbiter disappears over the probe's horizon.

The Orbital Tour

Upon arrival and orbit insertion, Cassini will begin its tour of the Saturn system with at least 76 orbits around Saturn, including 52 close encounters with seven of Saturn's 31 known moons. Cassini's orbits around Saturn will be shaped by gravity-assist flybys of Titan. Close flybys of Titan will permit high-resolution mapping of Titan's surface with the Titan imaging radar instrument, which can see through the opaque haze covering that moon to produce vivid topographic maps of the surface.

The size of these orbits, their orientation relative to Saturn and the Sun, and their inclination to Saturn's equator are dictated by various scientific requirements. These include: imaging radar coverage of Titan's surface; flybys of selected icy moons, Saturn or Titan; occultations by Saturn's rings; and crossings of the ring plane.

Cassini will make at least six close targeted flybys of selected icy moons of greatest interest -- Iapetus, Enceladus, Dione and Rhea. Images taken with Cassini's high-resolution telescopic cameras during these flybys will show surface features equivalent in size to a baseball diamond. At least two dozen more distant flybys (at altitudes of up to 100,000 kilometers (60,000 miles) will be made of the major moons of Saturn other than Titan. The varying inclination angle of Cassini's orbits also will allow studies of Saturn's polar regions in addition to the planet's equatorial zone.

Titan will be the subject of close investigations by Cassini. Cassini will execute 45 targeted close flybys of Titan, Saturn's largest moon, as close as about 950 kilometers (590 miles) above the surface. Titan is the only Saturn moon large enough to enable significant gravity-assist changes in Cassini's orbits. Accurate navigation and targeting of the point at which Cassini flies by Titan will be used to shape the orbital tour in the same way the Galileo mission used its encounters of Jupiter's large moons to shape its tour of Jupiter's system.

End of Prime Mission

The prime mission tour concludes on June 30, 2008, four years after Saturn arrival and 33 days after the last Titan flyby, which occurs on May 28, 2008. The aim point of the final flyby is chosen to position Cassini for a Titan flyby on July 31, 2008 -- providing the opportunity to proceed with more flybys during an extended mission, if resources allow. Nothing in the design of the tour precludes an extended mission.

Mission Operations

Two-way communication with Cassini will be through the large dish antennas of NASA's worldwide Deep Space Network. The spacecraft will transmit and receive in the microwave X-band using its parabolic high-gain antenna. The high-gain antenna is also used for radio and radar experiments and for receiving signals from the Huygens probe.

Because Cassini's science instruments are fixed and the entire spacecraft must be turned to point them, the spacecraft will be frequently reoriented by using either devices called reaction wheels or the spacecraft's set of small onboard thrusters. Consequently, most science observations will be made without a real-time communications link to Earth. Data will be stored on Cassini's two solid-state data recorders, each with a capacity of 2 gigabits.

Each of Cassini's science instruments is run by a microprocessor capable of controlling the instrument and formatting/packetizing data. Ground controllers will run the spacecraft with a combination of some centralized commands to control system-level resources, and some commands issued by the individual science instruments' microprocessors. Packets of data will be collected from each instrument on a schedule that may vary at different times. Data packets may be transmitted to Earth right away, or stored on Cassini's onboard solid-state recorders for later transmission. The science instruments have different pointing requirements. These often conflict with each other and with the need to point the spacecraft toward Earth to transmit data home. Periods during which the antenna points toward Earth have been carefully built in to the tour design.

Mission controllers, engineering teams and science teams will monitor telemetry from the spacecraft and look for anomalies in real time. The flight systems operations team retrieves engineering data to determine the health, safety and performance of the spacecraft, and processes the tracking data to determine and predict the spacecraft's trajectory. Data will normally be received by the Deep Space Network with one tracking pass by one antenna per day, with occasional extra coverage for special radio science experiments.

Cassini Encounters with Saturn's Moons

Orbit	Moon	Encounter Date	Altitude
0	Phoebe	June 11, 2004	1,997 km (1,241 mi)
A	Titan	October 26, 2004	1,200 km (746 mi)
B	Titan	December 13, 2004	2,358 km (1,465 mi)
B	Probe Release	December 24, 2004	n/a km (n/a mi)
C	Iapetus	January 1, 2005	65,000 km (40,398 mi)
C	Titan	January 14, 2005	60,000 km (37,290 mi)
3	Titan	February 15, 2005	950 km (590 mi)
3	Enceladus	February 17, 2005	1,179 km (733 mi)
4	Enceladus	March 9, 2005	500 km (311 mi)
5	Titan	March 31, 2005	2,523 km (1,568 mi)
6	Titan	April 16, 2005	950 km (590 mi)
11	Enceladus	July 14, 2005	1,000 km (622 mi)
12	Mimas	August 2, 2005	45,100 km (28,030 mi)
13	Titan	August 22, 2005	4,015 km (2,495 mi)
14	Titan	September 7, 2005	950 km (590 mi)
15	Tethys	September 24, 2005	33,000 km (20,510 mi)
15	Hyperion	September 26, 2005	990 km (615 mi)
16	Dione	October 11, 2005	500 km (311 mi)
17	Titan	October 28, 2005	1,446 km (899 mi)
18	Rhea	November 26, 2005	500 km (311 mi)
19	Titan	December 26, 2005	10,429 km (6,482 mi)
20	Titan	January 15, 2006	2,042 km (1,269 mi)
21	Titan	February 27, 2006	1,812 km (1,126 mi)
22	Titan	March 18, 2006	1,947 km (1,210 mi)
23	Titan	April 30, 2006	1,853 km (1,152 mi)
24	Titan	May 20, 2006	1,879 km (1,168 mi)
25	Titan	July 2, 2006	1,911 km (1,188 mi)
26	Titan	July 22, 2006	950 km (590 mi)
28	Titan	September 7, 2006	950 km (590 mi)
29	Titan	September 23, 2006	950 km (590 mi)

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Orbit	**Moon**	**Encounter Date**	**Altitude**
30	Titan	October 9, 2006	950 km (590 mi)
31	Titan	October 25, 2006	950 km (590 mi)
35	Titan	December 12, 2006	950 km (590 mi)
36	Titan	December 28, 2006	1,500 km (932 mi)
37	Titan	January 13, 2007	950 km (590 mi)
38	Titan	January 29, 2007	2,776 km (1,725 mi)
39	Titan	February 22, 2007	953 km (592 mi)
40	Titan	March 10, 2007	956 km (594 mi)
41	Titan	March 26, 2007	953 km (592 mi)
42	Titan	April 10, 2007	951 km (591 mi)
43	Titan	April 26, 2007	951 km (591 mi)
44	Titan	May 12, 2007	950 km (590 mi)
45	Titan	May 28, 2007	2,425 km (1,507 mi)
46	Titan	June 13, 2007	950 km (590 mi)
47	Tethys	June 27, 2007	16,200 km (10,068 mi)
47	Titan	June 29, 2007	1,942 km (1,207 mi)
48	Titan	July 19, 2007	1,302 km (809 mi)
49	Rhea	August 30, 2007	5,100 km (3,170 mi)
49	Titan	August 31, 2007	3,227 km (2,006 mi)
49	Iapetus	September 10, 2007	1,000 km (622 mi)
50	Titan	October 2, 2007	950 km (590 mi)
52	Titan	November 19, 2007	950 km (590 mi)
53	Titan	December 5, 2007	1,300 km (808 mi)
54	Titan	December 20, 2007	953 km (592 mi)
55	Titan	January 5, 2008	949 km (590 mi)
59	Titan	February 22, 2008	959 km (596 mi)
61	Enceladus	March 12, 2008	995 km (618 mi)
62	Titan	March 25, 2008	950 km (590 mi)
67	Titan	May 12, 2008	950 km (590 mi)
69	Titan	May 28, 2008	1,316 km (818 mi)

The Spacecraft

The Cassini spacecraft is a two-part structure, composed of the orbiter and the Huygens Titan probe. The orbiter is designed to enter orbit around Saturn, deliver Huygens to its destination and relay the probe's data, and conduct at least four years of detailed studies of Saturn's system. Huygens is designed to remain primarily dormant throughout Cassini's journey, then spring into action when it reaches the top of Titan's atmosphere. There, Huygens will deploy its parachutes and conduct 2-1/2 hours of intensive measurements as it descends through Titan's atmosphere, all the while transmitting its findings to the Cassini orbiter for relay back to Earth.

The Cassini Orbiter

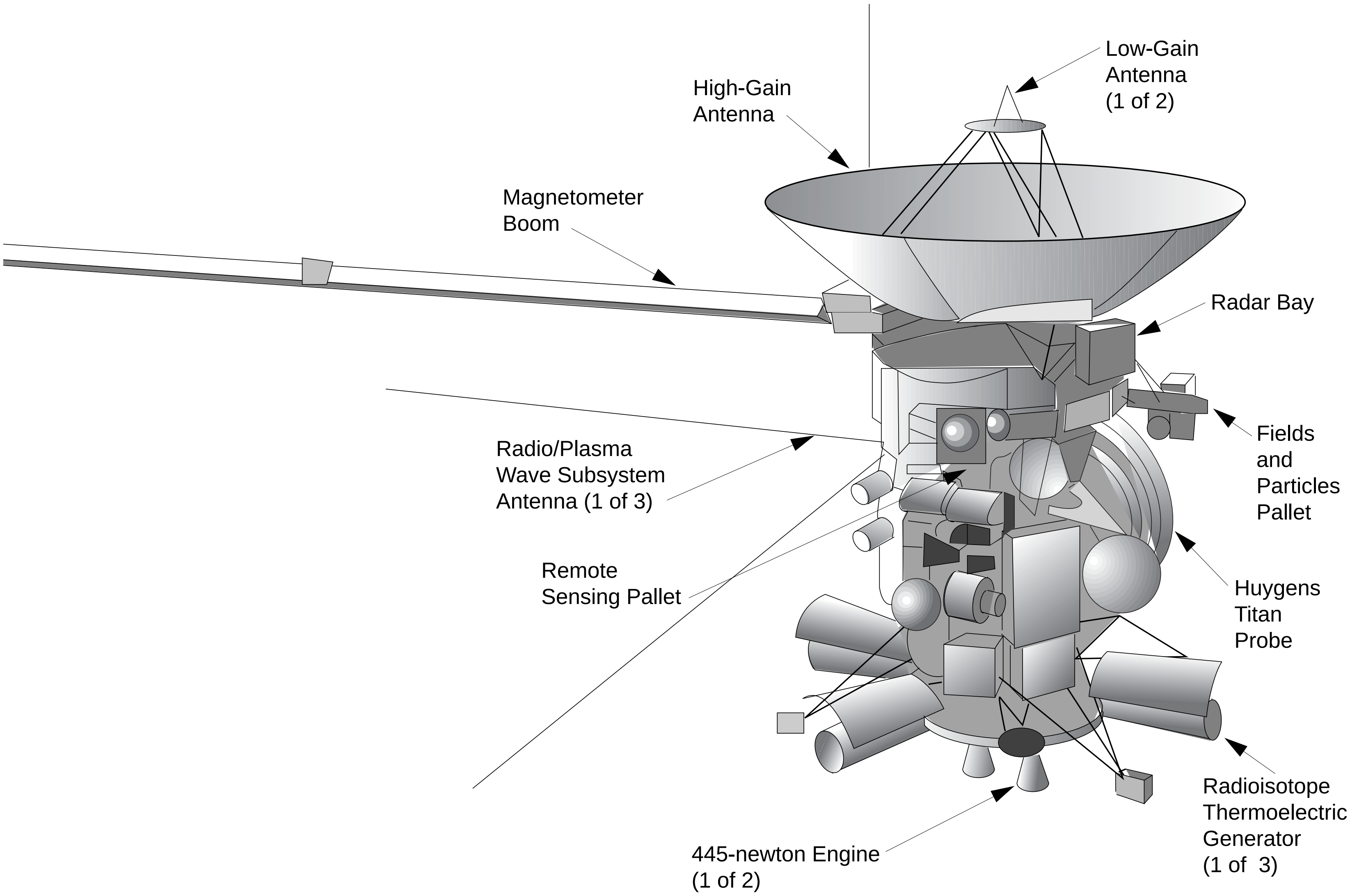
The Cassini orbiter alone weighs 2,125 kilograms (4,685 pounds). After addition of the 320-kilogram (705-pound) Huygens probe and a launch vehicle adapter, as well as 3,132 kilograms (6,905 pounds) of propellants, the spacecraft weight was 5,712 kilograms (12,593 pounds). More than half of the spacecraft's total mass at launch was propellant -- somewhat less than half of which is needed for Cassini's 96-minute main engine firing that brakes it into orbit around Saturn.

The spacecraft stands 6.8 meters (22.3 feet) high and is 4 meters (13 feet) wide. The magnetometer instrument is mounted on an 11-meter-long (36-foot) boom that extends outward from the spacecraft; three other rod-like antenna booms, each measuring about 10 meters (32 feet), extend outward from the spacecraft in a Y-shape. Most of the spacecraft and its instrument housings are covered with multiple-layered, shiny amber-colored or matte-black blanketing material. The blankets protect Cassini against the extreme heat and cold of space, and maintain the room temperature operating environment needed for computers and other electronic systems onboard. The blanketing includes layers of mylar to afford protection against dust-size particles called micrometeoroids that zip through interplanetary space.

The spacecraft's complexity is necessitated both by its flight path to Saturn and by the ambitious program of scientific observations to be accomplished at Saturn. Cassini has some 22,000 wire connections and more than 12 kilometers (7.5 miles) of cabling linking its instruments, computers and mechanical devices.

Cassini's cargo of science instruments, the Huygens probe and the amount of propellant the spacecraft carries make it one of the largest interplanetary spacecraft ever launched. Cassini's propellant mass alone is more than the mass of the Galileo and Voyager spacecraft combined.

The main body of the orbiter is a nearly cylindrical stack consisting of a lower equipment module, a propulsion module and an upper equipment module, and is topped by the fixed 4-meter-diameter (13-foot) high-gain antenna. Attached about halfway up the



Cassini spacecraft

stack are a remote sensing pallet, which contains cameras and other remote sensing instruments, and a fields and particles pallet, which contains instruments that study magnetic fields and charged particles. The two pallets carry most of the Cassini orbiter's science instruments. In general the whole spacecraft must be turned to point the instruments in the proper direction, though three of the instruments provide their own articulation about one axis.

Several booms were deployed early in Cassini's flight. These included three rod-like plasma wave antennas and an 11-meter (36-foot) spring-loaded magnetometer boom that extends from a canister mounted on the upper equipment module.

Software sequences - detailed instructions stored in the spacecraft's computer - direct the activities of the spacecraft. A typical sequence may operate Cassini for a month without the need for intervention from ground controllers. Onboard computers are designed to withstand the radiation environment of deep space, particularly when the Sun is at peak activity. Solar flares, which can last up to several days, can deliver radiation 1,000 times above the usual radiation levels in interplanetary space. Cassini's electronics have undergone customized radiation hardening to ensure that they won't be disrupted or destroyed by such events.

Sophisticated fault protection software resides in the spacecraft's computers to continuously sample and sense the health of the onboard systems. The fault protection system automatically takes corrective action when it determines the spacecraft is at risk due to any onboard failure.

The orbiter receives electrical power from three radioisotope thermoelectric generators. These generators produce power by converting heat into electrical energy. Heat is provided by the natural radioactive decay of plutonium dioxide. Devices called thermocouples convert the heat into electricity to run the spacecraft. Upon arrival at Saturn, the three generators will provide about 750 watts of power. Plutonium dioxide is also used as the heat source in 82 small radioisotope heater units on the Cassini orbiter and 35 on the Huygens probe; each produces about 1 watt of heat to keep nearby electronics at their operating temperatures. Similar heater units were most recently used on the Mars Exploration Rovers to keep their electronics warm during Martian nights. Both the generators and heater units have a long and safe heritage of use and high reliability in NASA's planetary exploration program, including the Voyager and Galileo missions.

Propulsion for major changes to Cassini's trajectory is provided by one of two main engines. These powerful engines use monomethylhydrazine as the fuel and nitrogen tetroxide as the oxidizer. Sixteen smaller thrusters use hydrazine to control Cassini's orientation and to make small adjustments to the spacecraft's flight path.

Guidance and control is governed by sensors that recognize reference stars and the Sun, and by onboard computers that determine the spacecraft's orientation. Using a new type of gyroscope called an inertial reference unit, the spacecraft can perform turns, twists and propulsion firings while retaining continuous knowledge of its own position. The Cassini orbiter is stabilized along all three axes and thus does not normally rotate during its long cruise to Saturn.

The mission's trajectory posed a challenge for controlling the spacecraft's temperature in the first several years of the mission because of its proximity to the Sun. During this time, the high-gain antenna was pointed at the Sun and used as a sunshade to shield the rest of the orbiter and probe. Special paints were used on the antenna to reflect and radiate much of the sunlight received.

Communications with the spacecraft during its passage through the inner solar system were through one of the orbiter's two low-gain antennas. In late January 2000, as Cassini entered the cooler climes of the asteroid belt and beyond, it turned its high-gain antenna toward Earth and will conduct telecommunications through it for the remainder of the mission.

As Cassini moves farther from the Sun, extreme cold becomes a concern. At Saturn's distance, the intensity of sunlight is approximately 1 percent of that at Earth.

Heat within the spacecraft is retained by using lightweight, multiple-layered insulating blankets that have been tailor-made for the instrument housings and other areas of the orbiter. The blanket's outer layer is a three-ply membrane composed of a Kapton core with an aluminized inner surface and a metallic outer surface. The translucent Kapton has a yellow color, and when backed by a shiny aluminum layer, results in an amber appearance. Up to 26 layers of material are used in the blankets, which also afford protection against dust-size micrometeoroids which, traveling at speeds of 5 to 40 kilometers per second (roughly 10,000 to 90,000 miles per hour), could potentially penetrate portions of the spacecraft.

Orbiter Subsystems

The Cassini orbiter contains 12 engineering subsystems that govern spacecraft features and functions including wiring, electrical power, computing, telecommunications, guidance and propulsion.

❑ The **structure subsystem** is the skeleton that provides mechanical support and alignment for all flight equipment, including the Huygens probe. In addition, it provides an equipotential container -- an electrical grounding reference -- which provides a shield from radio frequency interference, and protection from space radiation and micrometeoroids. The structure subsystem consists of the upper equipment module, which contains the 12-bay electronics bus assembly, instrument pallets and the magnetometer boom; the lower equipment module; plus all the brackets and structure used to attach the Huygens probe, the low-gain and high-gain antennas, electrical generators, main rocket engines, reaction control thrusters and other equipment.

❑ The **radio frequency subsystem** provides the telecommunications facilities for the spacecraft, and is also used as part of the radio science instrument. For communications, it produces an X-band carrier signal at a frequency of 8.4 GHz; modulates it with data received from the command and data subsystem; amplifies the X-band carrier power to produce 20 watts from the traveling wave tube amplifiers; and delivers the signal to the antenna subsystem. From the antenna subsystem, the radio frequency subsystem takes signals transmitted from Earth at a frequency of 7.2 GHz in the microwave X-band; demodulates them; and delivers the commands and data to the command and data subsystem for storage and/or execution.

❑ Regulated electrical power and various small pyrotechnic devices on the spacecraft are controlled by the **power and pyrotechnics subsystem**. Operating on command from the central computer system, this subsystem distributes electrical power to instruments and other subsystems on the spacecraft at 30 volts DC. The subsystem also regulates a shunt radiator that can be used to dispose of excess heat. Pyrotechnics include squib devices that will be fired to cut cables and other links that hold the Huygens probe onto the orbiter.

❑ The **command and data subsystem** is Cassini's nervous system -- the central processing and delivery clearinghouse of the spacecraft for commands received from the ground and data sent back to Earth. All elements of the subsystem are duplicated with redundant components that can be used in the event of a component failure. The subsystem receives ground commands and data from the radio frequency subsystem, processes the information and distributes it to other subsystems. The command and data subsystem uses two redundant solid-state recorders and flight computers, which are programmed in the Ada programming language. Memory capacity for each solid-state recorder is 2 gigabits.

Scientific and engineering data from science instruments destined for transmission to Earth are first forwarded to the command and data subsystem for processing and formatting for telemetry, and delivery to the radio frequency subsystem. The command and data subsystem contains software routines that protect the spacecraft in the event of a fault. The software also allows the spacecraft to autonomously respond to faults needing immediate action. Memory for the command and data subsystem is 512 kilo-words of random-access memory (RAM) and 8 kilo-words of programmable read-only memory (PROM).

❑ The **attitude and articulation control subsystem** is the spacecraft's inner ear, continuously sensing and measuring the spacecraft's orientation on its three axes and the spacecraft's position in space relative to Earth, Sun, Saturn and other targets. It provides measurements and controls pointing for spacecraft instruments, including scans that require the spacecraft to roll while an instrument performs an observation. The attitude and articulation control subsystem encompasses a number of sensors including redundant Sun sensor assemblies; stellar reference units, or star trackers; a

Z-axis accelerometer; and two 3-axis gyro inertial reference units. Each unit consists of four gyros, three orthogonal to each other and the fourth skewed equidistant to the other three. The subsystem also contains actuators for the main rocket engine gimbals and for the redundant reaction wheel.

With two redundant computers programmed in Ada, the subsystem processes commands from the command and data subsystem and produces commands to be delivered to attitude control actuators and/or spacecraft thrusters or main engines to control Cassini's attitude and to make trajectory changes. The attitude and articulation control subsystem memory has 512 kilobytes of RAM and 8 kilobytes of PROM.

☐ All power and data cabling, except for coaxial cabling and waveguides, makes up the **cabling subsystem**. This network of cabling conducts power from the three electrical generators to the power and pyrotechnics subsystem and to the power shunt radiator. It also conducts data between the command and data subsystem and the other subsystems and assemblies on the spacecraft. In addition, cabling allows engineers to access Cassini's electronics during spacecraft integration and testing.

☐ The **propulsion module subsystem** controls the spacecraft's thrust and changes in its attitude. It works under the command of the attitude and articulation control system. Attitude control is provided by the reaction control subsystem, which consists of four clusters of four hydrazine thrusters each. These move the spacecraft to or maintain it in its desired orientation and are used to point the instruments at their targets. The thrusters are also used for executing small spacecraft maneuvers. For larger changes in the spacecraft velocity, the main rocket engine is used. Cassini has a primary and redundant pressure-regulated main engine. Each engine is capable of a thrust of approximately 100 pounds of force (445 newtons). The bipropellant main engines burn nitrogen tetroxide and monomethylhydrazine. The engines are gimbaled so that the thrust vector can be maintained through the shifting center of mass of the spacecraft. A retractable cover, mounted below the main engines, was used during cruise to protect the main engines from micrometeoroids. The main engine cover can be extended and retracted multiple times (at least 25 times), and has a pyro-ejection mechanism to jettison the cover should there be a mechanical problem with the cover that interferes with main engine operation. During cruise, when the main engines were not used, the cover remained closed.

☐ The **temperature control subsystem** keeps temperatures of the various parts of the spacecraft within allowable limits through a variety of thermal control techniques, many of which are passive. Automatically positioned reflective louvers are located on Cassini's 12-bay electronics bus. Radioisotope heater units are used where constant heat is required. Multilayer insulation blankets cover much of the spacecraft and its equipment. Electric heaters are used in several locations under control of the spacecraft's main computer. Temperature sensors are located at many sites on the spacecraft, and their measurements are used by the command and data subsystem to adjust the heaters. The entire spacecraft body and Huygens probe are shaded when necessary by the high-gain antenna.

❑ The **mechanical devices subsystem** provides a pyrotechnic separation device that releases the spacecraft from the launch vehicle adapter. Springs then push the spacecraft away from the adapter. The subsystem includes a self-deploying 10.5-meter (40-foot) coiled mast stored in a canister which supports the magnetometers. It also includes an articulation system for a backup reaction wheel assembly, a "pin puller" for the rod-like antennas of the radio plasma wave spectrometer's Langmuir probe, and louvers for venting or holding heat from the radioisotope heater units.

❑ The **electronic packaging subsystem** consists of the electronics packaging for most of the spacecraft in the form of the 12-bay electronics bus.

❑ The **solid-state recorder**, with no moving parts, is the primary memory storage and retrieval device for the orbiter. The spacecraft is equipped with two recorders, each with a capacity of 2 gigabits. Data such as spacecraft telemetry, and memory loads for various subsystems, may be stored in separate files, or partitions, on the recorder. All data recorded to, and played back from, the solid-state recorder are handled by the command and data subsystem.

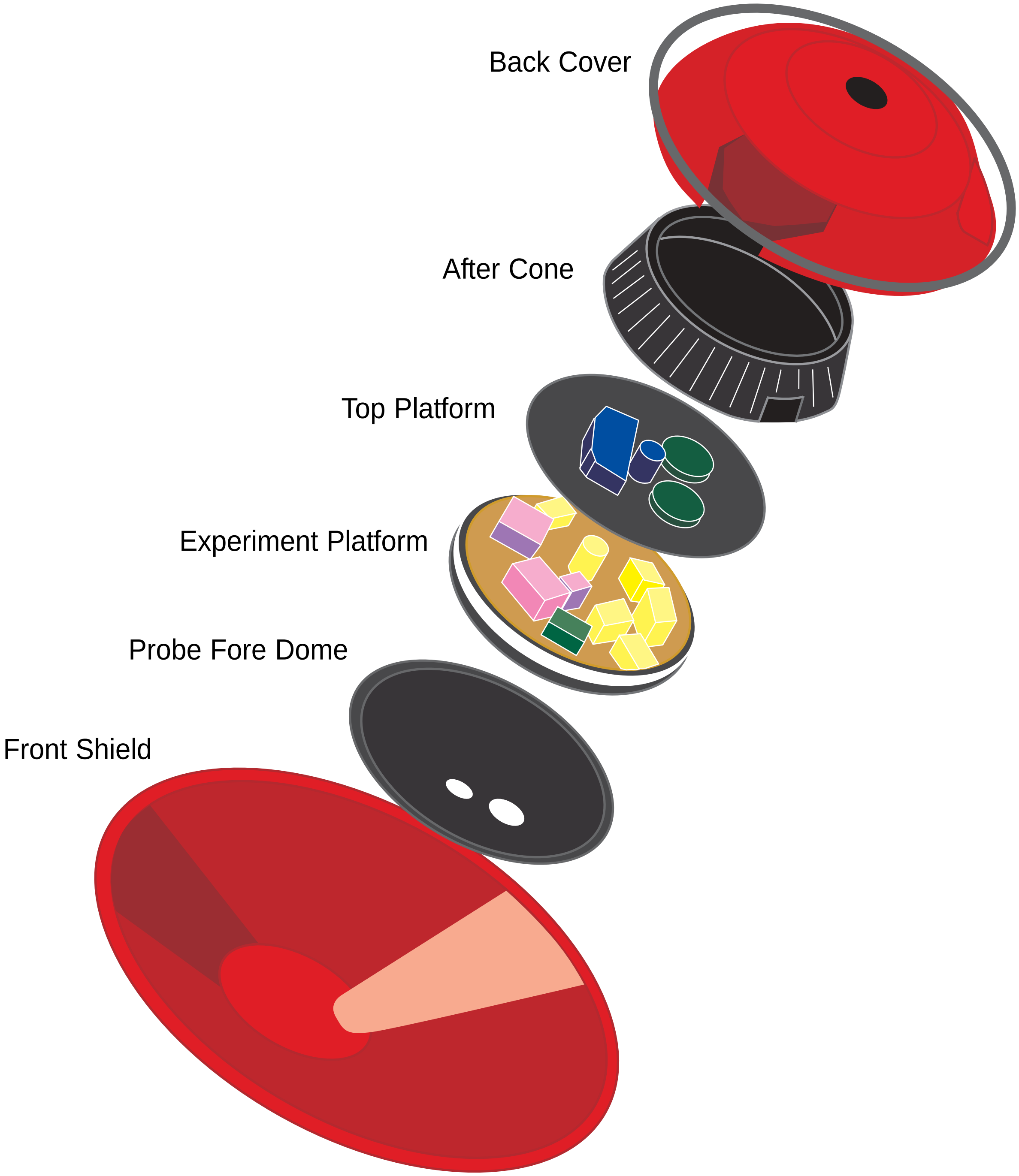
❑ The **antenna subsystem** provides a directional high-gain antenna that can transmit and receive on four different bands in the microwave spectrum - X, Ka, S and Ku. The high-gain antenna and one of two low-gain antennas were provided by the Italian space agency. One low-gain antenna is located on the dish structure of the high-gain antenna. The other low-gain antenna is located on the Cassini orbiter body below the attachment point for the Huygens probe. During the inner solar system cruise, the high-gain antenna was pointed toward the Sun to provide shade and prevent overheating of the spacecraft. The two low-gain antennas allow for one or the other to transmit and receive signals in the microwave X-band to and from Earth when the spacecraft is Sun-pointed. The low-gain antennas also provide an emergency telecommunications capability while Cassini is at Saturn.

The Huygens Probe

The Huygens probe system includes the probe itself, which enters the Titan atmosphere, and support equipment that remains attached to the orbiter. The probe weighs 320 kilograms (705 pounds) and consists of three main elements:

❑ A **spin-eject device**, which uses springs to propel the probe away from the orbiter with a relative velocity of about 0.3 to 0.4 meter per second (1 foot per second) and simultaneously causes the probe to spin about its axis at 7 rpm. This device is part of the support equipment.

❑ A **front shield**, 2.7 meters (8.8 feet) in diameter, covered with a special thermal protection material called AQ60, a low-density mat of silica fibers, to protect the



Huygens probe

probe from the enormous heat generated during entry into Titan's atmosphere.

☐ An **aft cover** that uses thermal protection materials to ensure a slow and stable descent. The main parachute slows the probe and allows the decelerator to fall away when it is released. To limit the duration of the descent to a maximum of 2.5 hours, the main parachute is jettisoned at 900 seconds after atmospheric entry, and is replaced by an approximately 3-meter-diameter (10-foot) drogue chute for the remainder of the descent.

The probe's interior consists of two aluminum honeycomb platforms and an aluminum shell. It is linked by fiberglass struts and pyrotechnically operated release mechanisms to the front shield and aft cover. The central equipment platform carries the boxes containing the electrical subsystems and the experiments. The upper platform carries the stowed parachute and the transmitter used to radio data in the microwave S-band to the Cassini orbiter.

At different phases of the mission, Huygens will be subjected to extremes of heat and cold requiring a variety of passive controls to maintain the required temperature conditions. When Cassini left the inner solar system, the temperature environment of the probe was greatly reduced. After separation from the Cassini orbiter, Huygens will be at its coldest. To ensure that the equipment stays operational, 35 radioisotope heater units are placed in the system. Each heater unit, which contains radioactive plutonium dioxide, produces about 1 watt of heat.

During entry into Titan's atmosphere, the front shield may reach temperatures above 1,500 C (2,700 F). Layers of insulation will ensure that the equipment inside stays below 50 C (122 F). Once the chutes are deployed, the probe instruments will be exposed to the cold Titan atmosphere at a temperature of -200 C (-330 F). The internal temperature will be kept within operating limits by thick foam insulation filling the probe and by power dissipation in the experiments and subsystems.

While it is still attached to the Cassini orbiter, the Huygens probe will obtain power from the orbiter via an umbilical cable. After separation, electrical power is provided by five lithium sulfur dioxide batteries, each with 23 cells. A small part of the battery power is used to power the Huygens probe's timer for the 22 days of coasting to Titan.

Huygens' command and data management subsystem controls the timing and execution of a number of critical events. It keeps time during the coast phase and switches on the probe just before entry. It controls deployment of various components during descent. It distributes commands to other subsystems and to the experiments. It distributes to the experiments a timeline of conditions that instruments can use to schedule operations. And it collects scientific and engineering data and forwards them to the orbiter during the cruise to Saturn and during the Huygens mission.

The probe data relay subsystem provides the one-way communications link between the Huygens probe and the Cassini orbiter, and includes equipment installed in each spacecraft. Elements that are part of the probe support equipment on the Cassini orbiter include radio frequency electronics (including an ultra-stable oscillator) and a low-noise amplifier. For backup, the Huygens probe carries two S-band transmitters, both of which transmit during probe descent, each with its own antenna. The telemetry in one link is delayed by about six seconds with respect to the other to avoid data loss if there are brief transmission outages. Reacquisition of the probe signal would normally occur within this interval.

New Technology

A wealth of new technology was developed and qualified for spaceflight by or for the Cassini program. Much of this new technology has already been adopted by other space science programs, in some cases at a discounted cost directly attributable to Cassini. This has enabled the development of new classes of low-cost, high-efficiency spacecraft, such as the Discovery and New Millennium spacecraft.

The Cassini orbiter advances and extends the technology base of the United States and its partners with several innovations in engineering and information systems. Each of the innovations described below was revolutionary at the time of Cassini's launch in 1997, however the pace of technology is so fast that they may not seem so today.

Cassini pioneered the use of solid-state data recorders with no moving parts. This is now standard on all spacecraft.

Similarly, the main onboard computer that directs operations of the orbiter used a novel design that draws 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. The Cassini application GVSC 1750A computer was the first civilian spacecraft application of this technology. The computer system also used new application-specific integrated circuit (ASIC) parts; each component replaced one hundred or more traditional chips. The ASIC chips allowed the development of a data system for Cassini 10 times more efficient than earlier spacecraft designs, but at less than one-third the mass and volume. Two spacecraft under NASA's Discovery program, Mars Pathfinder and the Near Earth Asteroid Rendezvous mission, used these chips directly off the Cassini production line.

Elsewhere on the Cassini orbiter, the power system benefits from an innovative solid-state power switch developed for the mission. This switch eliminates rapid fluctuations called transients that usually occur with conventional power switches, with a significantly improved component lifetime. The power switch holds great promise for use in numerous Earth-based applications. A low mass, low power, radiation-hardened X-band radio transponder (a combined receiver and transmitter) was developed by the Cassini program. Both Mars Pathfinder and the Near Earth Asteroid Rendezvous mission used radio transponders built on the Cassini mission's production line.

The inertial reference units to be used on Cassini represent the first space version of a revolutionary new gyro called the hemispherical resonator gyroscope. Gyros commonly used in spacecraft, aircraft and ships are large, very delicate mechanical devices whose many moving parts make them susceptible to failure. This new gyro, which eventually may be used on other spacecraft, promises greater reliability and less vulnerability to failure because it uses no moving parts. A slightly modified Cassini gyro was incorporated into the Near Earth Asteroid Rendezvous spacecraft.

Cassini Signature Disc

In August 1997, a small digital versatile disc (DVD) was installed aboard the Cassini spacecraft during processing at the Kennedy Space Center. The disc contains a record of 616,400 handwritten signatures from 81 countries around the globe. Signatures were received from people of all ages and backgrounds.

Mail came from individuals, families and, often, from entire schools of students. Signatures came from the very young, just learning to write, and from the very old, whose hands were no longer steady. Signatures were sent on behalf of loved ones who had died in the recent past. Even the signatures of Jean-Dominique Cassini and Christiaan Huygens were obtained from letters they wrote during the 17th century.

Sorting, counting and scanning the signatures was performed over the course of a year by volunteers from the Planetary Society, Pasadena, CA. The disc's cover, designed by Charles Kohlhase of the Cassini project, depicts a golden eagle wing feather and various Cassini mission elements to symbolize the signature experience. The feather was chosen to represent both the beauty and power of flight, as well as the quill pen that was used for nearly 14 centuries in writing and signing.

Science Objectives

Cassini's payload represents a carefully chosen set of interrelating instruments that will address many major scientific questions about the Saturn system. The data they return will be analyzed by a team of nearly 260 scientists from the United States and Europe. The Cassini and Huygens mission science objectives are as follows:

Saturn

☐ Determine the temperature field, cloud properties and composition of Saturn's atmosphere.

☐ Measure the planet's global wind field, including waves and eddies; make long-term observations of cloud features to see how they grow, evolve and dissipate.

☐ Determine the internal structure and rotation of the deep atmosphere.

☐ Study daily variations and relationship between the ionosphere and the planet's magnetic field.

☐ Determine the composition, heat flux and radiation environment present during Saturn's formation and evolution.

☐ Investigate sources and nature of Saturn's lightning.

Titan

☐ Determine the relative amounts of different components of the atmosphere; determine the mostly likely scenarios for the formation and evolution of Titan and its atmosphere.

☐ Observe vertical and horizontal distributions of trace gases; search for complex organic molecules; investigate energy sources for atmospheric chemistry; determine the effects of sunlight on chemicals in the stratosphere; study formation and composition of aerosols (particles suspended in the atmosphere).

☐ Measure winds and global temperatures; investigate cloud physics, general circulation and seasonal effects in Titan's atmosphere; search for lightning.

☐ Determine the physical state, topography and composition of Titan's surface; characterize its internal structure.

☐ Investigate Titan's upper atmosphere, its ionization and its role as a source of neutral and ionized material for the magnetosphere of Saturn.

Magnetosphere

☐ Determine the configuration of Saturn's magnetic field, which is nearly symmetrical with Saturn's rotational axis. Also study its relation to the modulation of Saturn kilometric radiation - a radio emission from Saturn that is believed to be linked to the way electrons in the solar wind interact with the magnetic field at Saturn's poles.

☐ Determine the current systems, composition, sources and concentrations of electrons and protons in the magnetosphere.

☐ Characterize the structure of the magnetosphere and its interactions with the solar wind, Saturn's moons and rings.

☐ Study how Titan interacts with the solar wind and with the ionized gases within Saturn's magnetosphere.

The Rings

☐ Study configuration of the rings and dynamic processes responsible for ring structure.

☐ Map the composition and size distribution of ring material.

☐ Investigate the interrelation of Saturn's rings and moons, including embedded moons.

☐ Determine the distribution of dust and meteoroid distribution in the vicinity of the rings.

☐ Study the interactions between the rings and Saturn's magnetosphere, ionosphere and atmosphere.

Icy Moons

☐ Determine general characteristics and geological histories of Saturn's moons.

☐ Define the different physical processes that have created the surfaces, crusts or subsurfaces of the moons.

☐ Investigate compositions and distributions of surface materials, particularly dark, organic-rich materials and condensed ices with low melting points.

☐ Determine the bulk compositions and internal structures of the moons.

☐ Investigate interactions of the moons with Saturn's magnetosphere and ring system and possible gas injections into the magnetosphere.

In addition to the science objectives at Saturn, the Cassini spacecraft will also conduct a gravitational wave search through the ASI-provided high-gain antenna during its interplanetary cruise.

Orbiter Science Instruments

The Cassini orbiter carries a total of 12 science instruments. Two pallets carry most of the instruments; four instruments are located on the remote sensing experiments pallet, and three are located on the fields and particles experiments pallet. Others are fixed at independent locations on the spacecraft. The experiments include:

☐ **Imaging Science Subsystem**, or Cassini's cameras, will photograph a wide variety of targets - Saturn, the rings, Titan and the icy moons - from a broad range of observing distances for various scientific purposes. General science objectives include studying the atmospheres of Saturn and Titan, the rings of Saturn and their interactions with the planet's moons and the surface characteristics of the moons, including Titan. The instrument includes both a narrow-angle and a wide-angle camera. The narrow-angle camera provides high-resolution images of targets of interest, while the wide-angle camera provides more extended spatial coverage at lower resolution. The cameras can also obtain optical navigation frames -- images of Saturn's moons against a star background -- which are used to keep the spacecraft on the correct trajectory. Team leader is Dr. Carolyn C. Porco of the Space Science Institute, Boulder, Colo.

☐ **Visible and Infrared Mapping Spectrometer** will map the surface spatial distribution of the mineral and chemical features of a number of targets, including Saturn's rings, surfaces of the moons, and the atmospheres of Saturn and Titan. The instrument includes a pair of imaging grating spectrometers that are designed to measure reflected and emitted radiation from atmospheres, rings and surfaces to determine their compositions, temperatures and structures. A spectrometer is an optical instrument that splits the light received from objects into its component wavelengths; each chemical has a unique spectral signature and thus can be identified. The instrument obtains information over 352 contiguous wavelengths from 0.35 to 5.1 micrometers; it will measure intensities of individual wavelengths and use the data to infer the composition and other properties of the object that emitted the light. The mapping function of the instrument will provide images in which every pixel contains high-resolution spectra of the corresponding spot on the target body. Team leader is Dr. Robert H. Brown of the University of Arizona, Tucson, Ariz.

☐ **Composite Infrared Spectrometer** will measure infrared emissions from atmospheres, rings and surfaces. This spectrometer will create vertical profiles of temperature and gas composition for the atmospheres of Titan and Saturn, from deep in their tropospheres (lower atmospheres), to high in their stratospheres (middle atmospheres). The instrument will also gather information on the thermal properties and composition of Saturn's rings and icy moons. The instrument is a coordinated set of three interferometers designed to measure infrared emissions over wavelengths from 7 to 1000 micrometers in the mid- and far-infrared range of the electromagnetic spectrum. Each interferometer uses a beam splitter to divide incoming infrared light into two paths. The beam splitter reflects half of the energy toward a moving mirror and transmits half to a fixed mirror. The light is recombined at the detector. As the mirror moves, different wavelengths of light alternately cancel and reinforce each other in a pattern, called an interferogram, that depends on their wavelengths and intensities. This information can be used to determine the infrared spectrum. Principal investigator is Dr. Michael Flasar of NASA's Goddard Space Flight Center, Greenbelt, Md.

☐ **Ultraviolet Imaging Spectrograph** is a set of detectors designed to measure ultraviolet light reflected by or emitted from atmospheres, rings and surfaces to determine their compositions, distributions, aerosol content and temperatures. The instrument will also measure fluctuations of sunlight and starlight as the Sun and stars move behind the rings of Saturn and the atmospheres of Saturn and Titan, and will determine the atmospheric concentrations of hydrogen and deuterium. The instrument includes a two-channel, far- and extreme-ultraviolet imaging spectrograph that studies light over wavelengths from 55.8 to 190 nanometers. It also has a hydrogen deuterium absorption cell and a high-speed photometer. An imaging spectrograph records spectral intensity information in one or more wavelengths of light and then outputs digital data that can be displayed in a visual form, such as a false-color image. (False-color images are not what the eye would see, but are often more useful because enhanced contrast brings out scientifically meaningful details.) The hydrogen-deuterium absorption cell will measure the quantity of deuterium, a heavier form (isotope) of hydrogen. Hydrogen-deuterium ratio varies widely throughout the solar system and is an important piece of data in understanding planetary evolution. The high-speed photometer determines the radial structure of Saturn's rings by watching starlight that passes through the rings. Principal investigator is Dr. Larry L. Esposito of the University of Colorado, Boulder, Colo.

☐ **Cassini Radar** will investigate the surface of Saturn's largest moon, Titan. Titan's surface is covered by a thick, cloudy atmosphere that is hidden to normal optical view, but can be penetrated by radar. The instrument is based on the same imaging radar technology used in missions such as the Magellan mission to Venus and the Earth-orbiting Spaceborne Imaging Radar. Scientists hope to determine if oceans exist on Titan and, if so, determine their distribution; investigate the geological features and topography of Titan's solid surface; and acquire data on other targets, such as Saturn's rings and icy moons, as conditions permit.

The radar will take four types of observations: imaging, altimetry, backscatter and radiometry. In imaging mode, the instrument will bounce pulses of microwave energy off the surface of Titan from different incidence angles and record the time it takes the pulses to return to the spacecraft. These measurements, converted to distances by dividing by the speed of light, will allow construction of visual images of the target surface with a resolution ranging from about 0.3 to 1.7 kilometers (one-fifth mile to one mile).

Radar altimetry similarly involves bouncing microwave pulses off the surface of the target body and measuring the time it takes the "echo" to return to the spacecraft. In this case, however, the goal will not be to create visual images but rather to obtain numerical data on the precise altitude of surface features. The altimeter resolution is about 24 to 27 kilometers (14 to 16 miles) horizontally, and 90 to 150 meters (300 to 500 feet) vertically.

In backscatter mode, the radar will bounce pulses off Titan's surface and measure the intensity of the energy returning. This returning energy, or backscatter, is always less than the original pulse, because surface features reflect the pulse in more than one direction. Scientists can draw conclusions about the composition and roughness of the surface from the backscatter measurements.

In radiometry mode, the radar will operate as a passive instrument, simply recording the heat energy emanating from the surface of Titan. This information will be used to determine the amount of heat absorption by gases and aerosols, (such as methane) in Titan's atmosphere, a factor that has an impact on the accuracy of the other measurements taken by the instrument.

The radar will be used in different ways at different altitudes. At altitudes between about 22,500 to 9,000 kilometers (14,000 and 5,600 miles), the radar will switch between scattering measurements and radiometry in order to obtain low-resolution global maps of Titan's surface roughness, backscatter intensity and thermal emissions. At altitudes between about 9,000 to 4,000 kilometers (5,600 and 2,500 miles), the instrument will switch between altimetry and radiometry, collecting surface altitude and thermal emission measurements. Below about 4,000 kilometers (2,500 miles), the radar will switch between imaging and radiometry. Team leader is Dr. Charles Elachi of NASA's Jet Propulsion Laboratory, Pasadena, Calif.

☐ **Radio Science** will use the spacecraft's radio and the ground antennas of NASA's Deep Space Network to study the composition, pressures and temperatures of the atmospheres and ionospheres of Saturn and Titan; the radial structure of and particle size distribution in Saturn's rings; and the masses of objects in the Saturn system and the mass of Saturn's ring system as a whole. Radio science will also be used to search for gravitational waves coming from beyond our solar system. Some of these experiments measure Doppler shifts (frequency shifts) and other changes to radio signals that occur when the spacecraft passes behind planets, moons, atmospheres or physical features such as planetary rings. From these measurements, scientists can derive information about the structures and compositions of the occulting bodies, atmospheres and rings. Team leader is Dr. Arvydas J. Kliore of NASA's Jet Propulsion Laboratory, Pasadena, Calif.

❑ **Cassini Plasma Spectrometer** will measure the composition, density, flow velocity and temperature of ions and electrons in Saturn's magnetosphere. The instrument consists of three sensors: an electron spectrometer, an ion beam spectrometer and an ion mass spectrometer. A motor-driven actuator rotates the sensor package to provide 208-degree scanning in the azimuth of the Cassini orbiter. The electron spectrometer makes measurements of the energy of incoming electrons; its energy range is 0.7 to 30,000 electron volts. The ion beam spectrometer determines the energy to charge ratio of an ion; its energy range is 1 electron volt to 50 kilo-electron volts. The ion mass spectrometer's energy range is 1 electron volt to 50 kilo-electron volts. Principal investigator is Dr. David T. Young of the Southwest Research Institute, San Antonio, Texas.

❑ **Ion and Neutral Mass Spectrometer** will determine the composition and structure of positive ions and neutral particles in the upper atmosphere of Titan and the magnetosphere of Saturn, and will measure the positive ion and neutral environments of Saturn's icy moons and rings. The instrument will determine the chemical, elemental and isotopic composition of the gaseous and volatile components of the neutral particles and the low energy ions in Titan's atmosphere and ionosphere, Saturn's magnetosphere and the ring environment. Principal investigator is Dr. J. Hunter Waite of the University of Michigan, Ann Arbor, Mich.

❑ **Cosmic Dust Analyzer** will provide direct observations of small ice or dust particles in the Saturn system in order to investigate their physical, chemical and dynamic properties and study their interactions with the rings, icy moons and magnetosphere of Saturn. The instrument measures the amount, velocity, charge, mass and composition of tiny dust and ice particles. It has two types of sensors -- high-rate detectors and a dust analyzer. The two high-rate detectors, intended primarily for measurements in Saturn's rings, count impacts up to 10,000 per second. The dust analyzer will determine the electric charge carried by dust particles, the flight direction and impact speed, mass and chemical composition, at rates up to 1 particle per second, and for speeds of up to 100 kilometers per second (about 60 miles per second). An articulation mechanism allows the entire instrument to be rotated or repositioned relative to the body of the Cassini orbiter. Principal investigator is Dr. Ralf Srama of the Max Planck Institute für Kernphysik, Heidelberg, Germany.

❑ **Dual Technique Magnetometer** will determine the magnetic fields of the planet and moons and study dynamic interactions between different magnetic fields in the planetary environment. The instrument consists of direct-sensing instruments that detect and measure the strength of magnetic fields in the vicinity of the spacecraft. The experiment includes both a flux gate magnetometer and a vector/scalar helium magnetometer. They are used to measure the magnitude and direction of magnetic fields. Since magnetometers are sensitive to electric currents and ferrous metal components, they are generally placed on an extended boom, as far from the spacecraft as possible. On Cassini, the flux gate magnetometer is located midway out on the 11-meter

(36-foot) magnetometer boom, and the vector/scalar helium magnetometer is located at the end of the boom. The boom itself, composed of thin, nonmetallic rods, was folded during launch and deployed about two years after launch. The magnetometer electronics are located in a bay in the Cassini orbiter's spacecraft body. Principal investigator is Dr. David J. Southwood of the Imperial College of Science & Technology, London, England.

❑ **Magnetospheric Imaging Instrument** is designed to measure the composition, charge state and energy distribution of energetic ions and electrons; detect fast neutral particles; and conduct remote imaging of Saturn's magnetosphere. It is the first instrument ever designed to produce an image of a planetary magnetosphere. This information will be used to study the overall configuration and dynamics of the magnetosphere and its interactions with the solar wind, Saturn's atmosphere, Titan, rings and the icy moons. The instrument will provide images of the ionized gases, called plasma, surrounding Saturn and determine the charge and composition of ions. Like the Cassini plasma spectrometer, this instrument has three sensors that perform various measurements: the low-energy magnetospheric measurement system, the charge-energy-mass spectrometer and the ion and neutral camera. The low-energy magnetospheric measurement system will measure low- and high-energy proton, ion and electron angular distributions (the number of particles coming from each direction). The charge-energy-mass spectrometer uses an electrostatic analyzer, a time-of-flight mass spectrometer and microchannel plate detectors to measure the charge and composition of ions. The third sensor, the ion and neutral camera, makes two different types of measurements. It will obtain three-dimensional distributions, velocities and the rough composition of magnetospheric and interplanetary ions. Principal investigator is Dr. Stamatios M. Krimigis of Johns Hopkins University, Baltimore, Md.

❑ **Radio and Plasma Wave Science** instrument will measure electrical and magnetic fields in the plasma of the interplanetary medium and Saturn's magnetosphere, as well as electron density and temperature. Plasma is essentially a soup of free electrons and positively charged ions, the latter being atoms that have lost one or more electrons. Plasma makes up most of the universe and is created by the heating of gases by stars and other bodies in space. Plasma is distributed by the solar wind; it is also "contained" by magnetic fields (that is, the magnetospheres) of bodies such as Saturn and Titan. The major components of the instrument are an electric field sensor, a magnetic search coil assembly and a Langmuir probe. The electric field sensor is made up of three deployable antenna elements mounted on the upper equipment module of the Cassini orbiter. Each element is a collapsible beryllium-copper tube that was rolled up during launch and subsequently unrolled to its approximately 10-meter (33-foot) length by a motor drive. The magnetic search coils are mounted on a small platform attached to a support for Cassini's high-gain antenna. The Langmuir probe, which measures electron density and temperature, is a metallic sphere about 50 millimeters (2 inches) in diameter. The probe is attached to the same platform by an approximately 1-meter (3-foot) deployable boom. Principal investigator is Dr. Donald A. Gurnett of the University of Iowa, Iowa City, Iowa.

Huygens Probe Instruments

The Huygens descent probe contains a total of six science instruments. They are:

☐ **Descent Imager/Spectral Radiometer** uses 13 fields of view, operating at wavelengths of 350 to 1700 nanometers, to obtain a variety of imaging and spectral observations. Infrared and visible imagers will observe Titan's surface during the latter stages of the descent. By taking advantage of the Huygens probe's rotation, the imagers will build a mosaic of pictures around the landing site. A side-looking visible imager will view the horizon and the underside of any cloud deck. The spectral radiometer will measure concentrations of argon and methane in the atmosphere. It also will determine if the local surface is solid or liquid and, if solid, its topography. Solar aureole sensors will measure the light intensity around the Sun resulting from scattering by particles suspended in the atmosphere, permitting calculations of their size, number and density. Principal investigator is Dr. Martin G. Tomasko of the University of Arizona, Tucson, Ariz.

☐ **Huygens Atmospheric Structure Instrument** investigates the physical properties of Titan's atmosphere, including temperature, pressure and atmospheric density as a function of altitude, wind gusts and, in the event of a landing on a liquid surface, wave motion. Comprising a variety of sensors, the instrument will also measure the ion and electron conductivity of the atmosphere and search for electromagnetic wave activity. On Titan's surface, the instrument will be able to measure the conductivity of surface material. The instrument also processes the signal from the Huygens probe's radar altimeter to obtain information on surface topography, roughness and electrical properties. Principal investigator is Dr. Marcello Fulchignoni of the Paris Observatory, Meudon, France.

☐ **Aerosol Collector and Pyrolyzer** will trap particles suspended in Titan's atmosphere using a deployable sampling device. Samples will be heated to vaporize the ice particles and decompose the complex organic materials into their component chemicals. The products will then be passed to the gas chromatograph/mass spectrometer for analysis. The instrument will obtain samples at two altitude ranges. The first sample will be taken at altitudes down to about 30 kilometers (19 miles) above the surface. The second sample will be obtained at an altitude of about 20 kilometers (12 miles). Principal investigator is Dr. Guy M. Israel of the Service d'Aeronomie du Centre National de la Recherche Scientifique, Verrieres-le-Buisson, France.

☐ **Gas Chromatograph/Mass Spectrometer** will provide a quantitative analysis of Titan's atmosphere. Atmospheric samples will be transferred into the instrument by dynamic pressure as the Huygens probe descends through the atmosphere. The mass spectrometer will construct a spectrum of the molecular masses of the gas sampled by the instrument. Just before landing, the instrument's inlet port will be heated to vaporize material on contact with the surface. Following a safe landing, the instrument will be able to determine Titan's surface composition. The mass spectrometer serves as the detector for the gas chromatograph, for atmospheric samples and for samples provided by the aerosol collector and pyrolyzer. Portions of the instrument are identical in design to the Cassini orbiter's ion and neutral mass spectrometer. Principal investigator is Dr. Hasso B. Neimann of NASA's Goddard Space Flight Center, Greenbelt, Md.

☐ **Doppler Wind Experiment** uses two ultrastable oscillators, one on the Huygens probe and one on the Cassini orbiter, to give Huygens' radio relay link a stable carrier frequency. Orbiter measurements of changes in probe frequency caused by Doppler shift will provide information on the probe's motion. From this, scientists will be able to derive a height profile of wind and its turbulence. Principal investigator is Dr. Michael K. Bird of the University of Bonn, Germany.

☐ **Surface Science Package** contains a number of sensors to determine the physical properties and composition of Titan's surface. An acoustic sounder will measure the rate of descent, surface roughness and the speed of sound in any liquid. During descent, measurements of the speed of sound will give information on atmospheric composition and temperature. An accelerometer will record the deceleration profile at impact, indicating the hardness of the surface. Tilt sensors (liquid-filled tubes with electrodes) will measure any pendulum motion of the Huygens probe during descent, indicate the Huygens probe orientation after landing and measure any wave motion. If the surface is liquid, other sensors will measure its density, temperature, refractive index, thermal conductivity, heat capacity and electrical properties. A group of platinum resistance wires, through which a heating current can be passed, will measure temperature and thermal conductivity of the surface and lower atmosphere and the heat capacity of the surface material. If the probe lands in liquid, a transducer, pointed downward and operating at 15 kilohertz, will conduct an acoustic sounding of the liquid's depth. The instrument will also provide some crude topographic mapping of the surface as the probe descends the last few meters (or yards) through the atmosphere. Principal investigator is Dr. John C. Zarnecki of the University of Kent, England.

The International Team

The Cassini program is an international cooperative effort involving NASA, the European Space Agency (ESA) and the Italian space agency, Agenzia Spaziale Italiana (ASI), as well as several separate European academic and industrial contributors. The Cassini partnership represents an undertaking whose scope and cost would not likely be borne by any single nation, but is made possible through shared investment and participation. Through the mission, about 260 scientists from 17 countries hope to gain a better understanding of Saturn, its stunning rings, its magnetosphere, Titan and its other icy moons.

In the United States, the mission is managed for NASA's Office of Space Science by the Jet Propulsion Laboratory (JPL), Pasadena, CA. JPL is a division of the California Institute of Technology. At JPL, Robert T. Mitchell is the Cassini program manager, and Dr. Earl H. Maize is the deputy program manager. Dr. Dennis L. Matson is the Cassini project scientist and Dr. Linda J. Spilker is the deputy project scientist.

At NASA Headquarters, Mark Dahl is Cassini program executive and Dr. Denis Bogan is Cassini program scientist.

The major U.S. contractor is Lockheed Martin, whose contributions include the launch vehicle and upper stage, spacecraft propulsion module and the radioisotope thermoelectric generators.

Development of the Huygens Titan probe was managed by the European Space Technology and Research Center. The center's prime contractor, Aerospatiale (now Alcatel) in Cannes, France, assembled the probe with equipment supplied by many European countries. Huygens' batteries and two scientific instruments came from the United States. At ESA, Dr. Jean-Pierre Lebreton is the mission manager and project scientist.

At ASI, Enrico Flamini is the project manager for Cassini's radio antenna and other contributions to the spacecraft.

The U.S. Department of Energy provided Cassini's radioisotope thermoelectric generators.

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