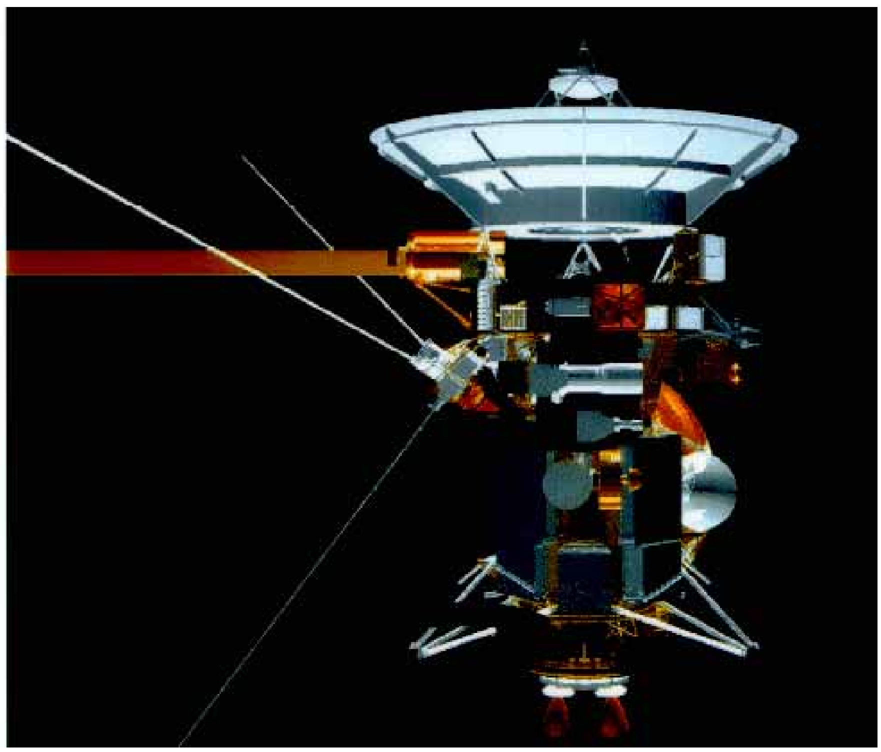
CHAPTER 9

# Tools of Discovery

The 18 scientific instruments carried by the Cassini–Huygens spacecraft have been designed to perform the most detailed studies ever of the Saturn system. Twelve instruments are mounted on the Cassini Orbiter and six are carried inside the Huygens Probe. Each instrument will make its own unique measurements, providing comprehensive, synergistic information on Saturn, its rings, its satellites and its magnetosphere. Cassini–Huygens' scientific investigations will build on the wealth of data provided by Pioneer 11 and Voyager 1 and 2.

**Orbiter Instruments Overview**

The Cassini–Huygens mission is a cooperative, international endeavor. In addition to the United States' involvement, a number of other countries have provided instrument hardware and software as well as investigators to the instrument teams. The United States' international partners in one or more elements of the Cassini–Huygens mission are Austria, Belgium, the Czech Republic, Denmark, the European Space Agency, Finland, France, Germany, Hungary, Ireland, Italy, The Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom. There are 12 scientific instruments aboard the Cassini Orbiter, which will spend four years studying the Saturn system in detail.



The Cassini–Huygens spacecraft stands almost seven meters tall and over four meters wide. In launch-ready configuration, the spacecraft weighs over 5600 kilograms.

All 12 Orbiter instruments are body-fixed to the spacecraft; some have articulating platforms that allow them to scan a portion of the sky without having to move the spacecraft. Each instrument has one or more microprocessors for internal control and data handling. The Orbiter experiments can be divided into three basic categories — optical remote sensing, microwave remote sensing and fields, particles and waves — and comprise a total of 27 sensors. The total mass of the science payload is 365 kilograms.

**Orbiter Instrument Descriptions**

***Optical Remote Sensing***

*Imaging Science Subsystem.* The optical remote-sensing Imaging Science Subsystem (ISS) will photograph a wide variety of targets — Saturn, the rings, Titan, the icy satellites and star fields — from a broad range of observing distances for various scientific purposes. General science objectives for the ISS include studying the atmospheres of Saturn and Titan, the rings of Saturn and their interactions with the planet's satellites and the surface characteristics of the satellites, including Titan. The following tasks are involved:

- Map the three-dimensional structure and motions in the Saturn and Titan atmospheres.

- Study the composition, distribution and physical properties of clouds and aerosols.
- Investigate scattering, absorption and solar heating in the Saturn and Titan atmospheres.
- Search for evidence of lightning, aurorae, airglow and planetary oscillations.
- Study gravitational interactions among the rings and the satellites.
- Determine the rate and nature of energy and momentum transfer within the rings.
- Determine ring thickness and the size, composition and physical nature of ring particles.
- Map the surfaces of the satellites, including Titan, to study their geological histories.
- Determine the nature and composition of the icy satellites' surface materials.
- Determine the rotation states of the icy satellites.

The ISS comprises a narrow-angle camera and a wide-angle camera. The narrow-angle camera provides high-resolution images of the target of interest, while the wide-angle camera provides extended spatial coverage at lower resolution. The cameras can also obtain optical navigation frames, which are used to keep the spacecraft on the correct trajectory.

The Cassini–Huygens imagers differ primarily in the design of the optics. The wide-angle camera has refractive optics with a focal length of 200 millimeters, a focal length–diameter ratio ($f$ number) of 3.5 and a 3.5-degree-square field of view (FOV). Refractive rather than reflective optics were chosen primarily to meet mass and cost constraints; these optics were available in the form of spares from the Voyager mission.

The narrow-angle camera has Ritchey–Chretien reflective optics with a 2000-millimeter focal length, an $f$ number of 10.5 and a 0.35-degree FOV.

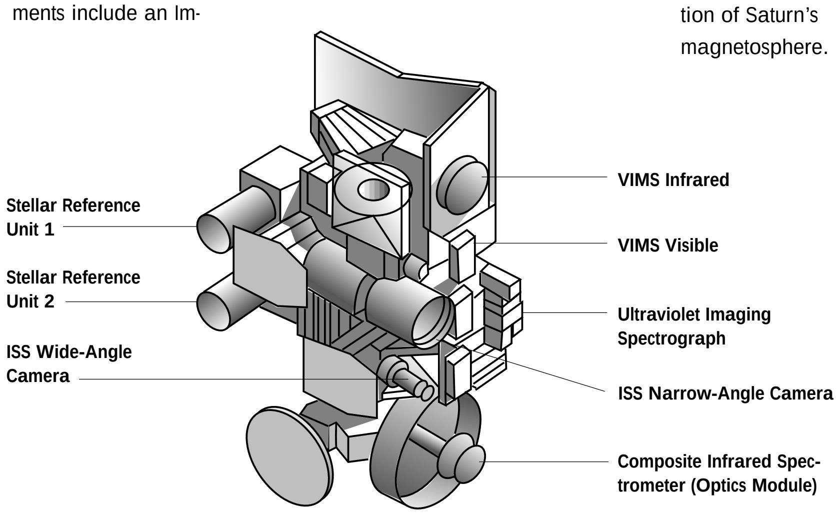
Filters are mounted in two rotatable wheels per camera; they have a two-wheel filter-changing mechanism whose design is derived from that of the Hubble Space Telescope's Wide Field and Planetary Camera 2. The wide-angle camera has 18 filters covering the range 380–1100 nanometers; the narrow-angle camera has 24 filters covering the range 200–1100 nanometers.

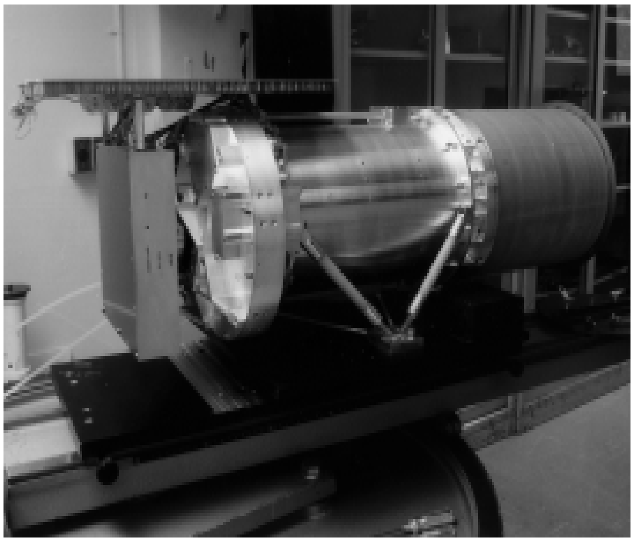
Shutters of the same type used on both Voyager and Galileo missions control exposure times: The shortest planned is five milliseconds and the longest is 20 minutes. The sensing element of each camera is a 1024 $\times$ 1024–element, solid-state array, or charge-coupled device (CCD). The CCD is phosphor-coated for ultraviolet response and radiator-cooled to 180 kelvins to reduce dark current (residual current in the CCD beyond that released by incident light).

*Visible and Infrared Mapping Spectrometer.* The Visible and Infrared Mapping Spectrometer (VIMS) will

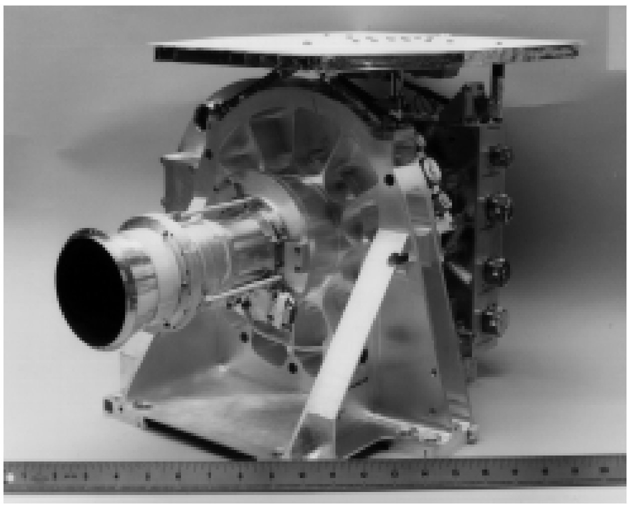
## OPTICAL REMOTE SENSING

Four optical remote-sensing instruments are mounted on a fixed, remote-sensing pallet, with their optical axes coaligned. The entire spacecraft must be rotated to point these instruments at the target of interest. The instruments include an Imaging Science Subsystem (ISS) comprising narrow- and wide-angle cameras, a Visible and Infrared Mapping Spectrometer (VIMS), a Composite Infrared Spectrometer (CIRS) and an Ultraviolet Imaging Spectrograph (UVIS). A fifth remote-sensing instrument, the imaging portion of the Magnetospheric Imaging Instrument (MIMI), is mounted on the upper equipment module, not far from the remote-sensing platform, and is also boresighted with the optical remote-sensing instruments. This experiment has the capability to image the charged particle population of Saturn's magnetosphere.

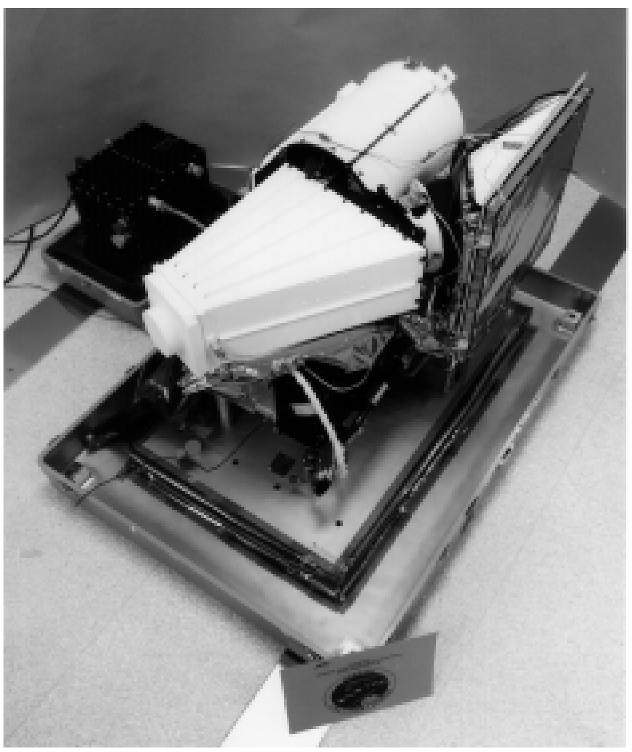




The Imaging Science Subsystem (ISS) narrow-angle camera.



The Imaging Science Subsystem (ISS) wide-angle camera.



The Visible and Infrared Mapping Spectrometer (VIMS).

map the surface spatial distribution of the mineral and chemical features of a number of targets, including the rings and satellite surfaces and the atmospheres of Saturn and Titan. The VIMS science objectives are as follows:

- Map the temporal behavior of winds, eddies and other features on Saturn and Titan.
- Study the composition and distribution of atmospheric and cloud species on Saturn and Titan.
- Determine the composition and distribution of surface materials on the icy satellites.
- Determine the temperatures, internal structure and rotation of Saturn's deep atmosphere.
- Study the structure and composition of Saturn's rings.
- Search for lightning on Saturn and Titan and active volcanism on Titan.
- Observe Titan's surface.

The VIMS comprises 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. The VIMS is an optical instrument that splits the light received from objects into its component wavelengths. The instrument uses a diffraction grating for this purpose.

The VIMS obtains information over 352 contiguous wavelengths from 0.35 to 5.1 micrometers. The instrument measures the intensities of individual wavelengths. The data are used to infer the composition and other properties of the object that emitted the light (such as a distant

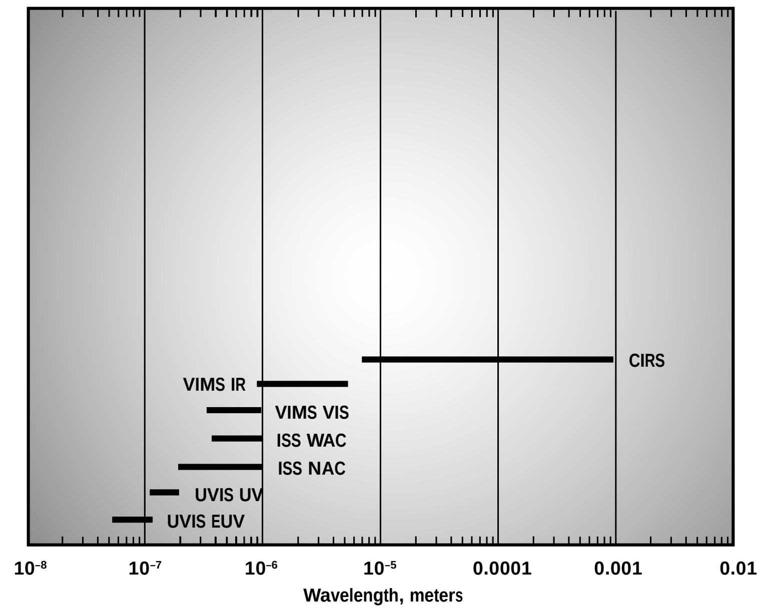
The bar charts at right show the operating wavelength coverage for the optical remote-sensing investigations (above) and energy range for the fields, particles and waves investigations (below).

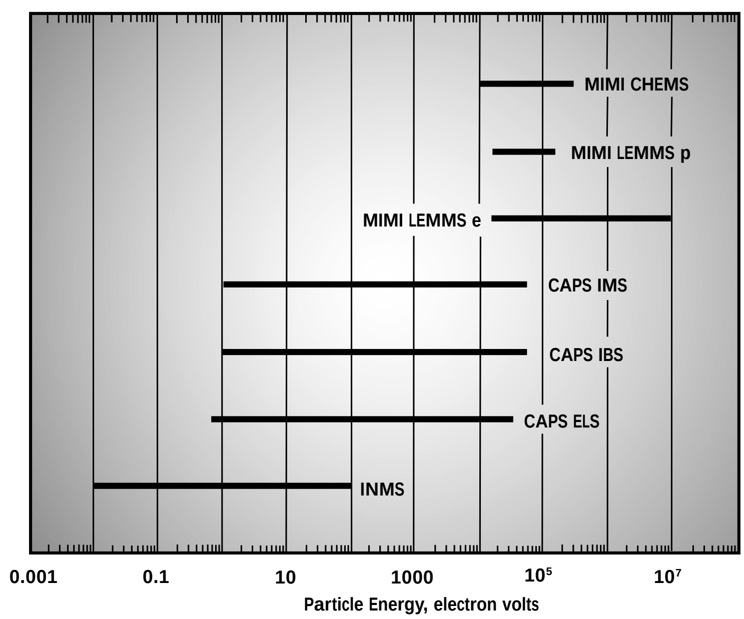
star), that absorbed specific wavelengths of the light as it passed through (such as a planetary atmosphere), or that reflected the light (such as a satellite surface). The VIMS provides images in which every pixel contains high-resolution spectra of the corresponding spot on the ground.

The VIMS has separate infrared and visible sensor channels. The infrared channel covers the wavelength range 0.85–5.1 micrometers. Its optics include an $f/3.5$ Ritchey–Chretien telescope that has an aperture of 230 millimeters, and a secondary mirror that scans on two axes to produce images varying in size from 0.03 degree to several degrees.

Radiation gathered by the telescope passes through a diffraction grating, which disperses it in wavelength. A camera refocuses it on to a linear detector array. The detector array is radiator-cooled to as low as 56 kelvins; the spectrometer's operating temperature is 125 kelvins.

The visible channel produces multispectral images spanning the spectral range 0.35–1.05 micrometers. It utilizes a Shafer telescope and a grating spectrometer. The silicon CCD array is radiator-cooled to 190 kelvins.




*Composite Infrared Spectrometer.* The Composite Infrared Spectrometer (CIRS) will measure infrared emissions from atmospheres, rings and surfaces. The CIRS will retrieve 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 (upper atmospheres). The CIRS instrument will also gather information on the thermal properties and compositions of Saturn's rings and icy satellites.

The CIRS science objectives are as follows:

- Map the global temperature structure in the Saturn and Titan atmospheres.
- Map the global gas composition in the Saturn and Titan atmospheres.
- Map global information on hazes and clouds in the Saturn and Titan atmospheres.
- Collect information on energetic processes in the Saturn and Titan atmospheres.
- Search for new molecular species in the Saturn and Titan atmospheres.
- Map the global surface temperatures at Titan's surface.

• Map the composition and thermal characteristics of Saturn's rings and icy satellites.

The CIRS is a coordinated set of three interferometers designed to measure infrared emissions from atmospheres, rings and surfaces over wavelengths from 7 to 1000 micrometers. The CIRS uses a beamsplitter to divide incoming infrared light into two paths. The beamsplitter reflects half 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 at a rate that depends on their wavelengths. This information can be used to construct an infrared spectrum.

The CIRS data will be collected by two of the instrument's three interferometers, which are designed to make precise measurements of wavelength within a specific range of the electromagnetic spectrum. The CIRS far infrared interferometer covers the spectral range 17–1000 micrometers; its FOV is circular and 0.25 degree in diameter.

The CIRS mid infrared interferometer is a conventional Michelson instrument that covers the spectral range of 7–17 micrometers. The third CIRS interferometer is used for internal reference. Light enters the instrument through a 51-centimeter-diameter telescope and is sent to the interferometers. The mid infrared detectors consist of two $1 \times 10$ linear arrays. Each square detector in the arrays is 0.015 degree on a side. The mid infrared arrays are cooled to 70 kelvins by a passive radiator. The remainder of the instrument, including the infrared detectors, is cooled to 170 kelvins.

*Ultraviolet Imaging Spectrograph.* The Ultraviolet Imaging Spectrograph (UVIS) 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 UVIS will measure the fluctuations of sunlight and starlight as the Sun and stars move behind the rings and atmospheres of Saturn and Titan, and will determine the atmospheric concentrations of hydrogen and deuterium.

The UVIS science objectives involve the following:

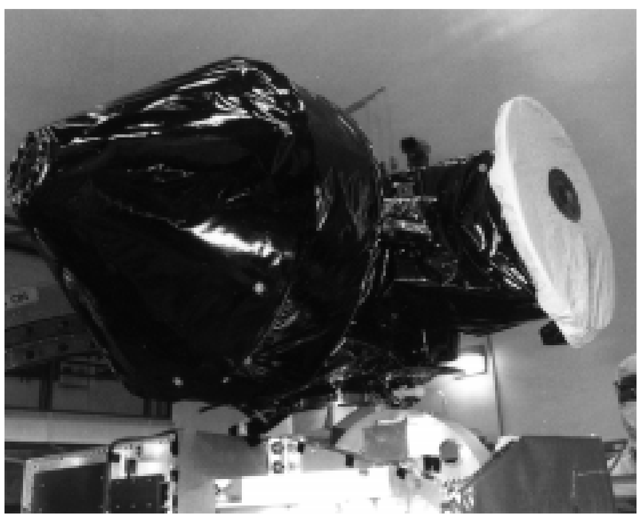
• Map the vertical and horizontal compositions of the Saturn and Titan upper atmospheres.

• Determine the atmospheric chemistry occurring in the Saturn and Titan atmospheres.

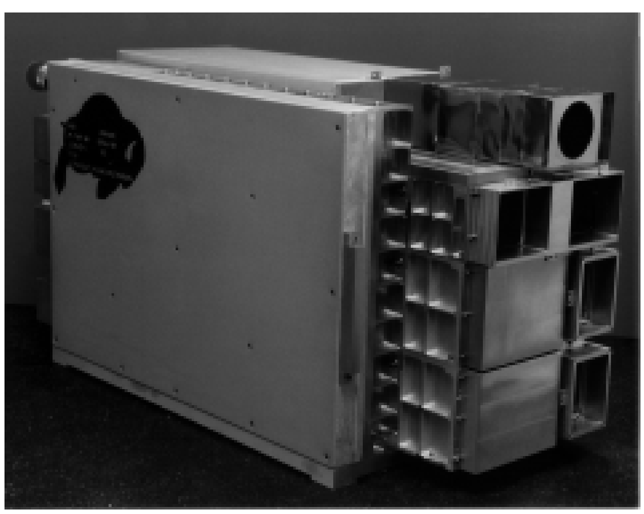
• Map the distributions and properties of aerosols in the Saturn and Titan atmospheres.

• Infer the nature and characteristics of circulation in the Saturn and Titan atmospheres.

• Map the distributions of neutrals and ions in Saturn's magnetosphere.



The Composite Infrared Spectrometer (CIRS).



The Ultraviolet Imaging Spectrograph (UVIS).

- Study the radial structure of Saturn's rings by means of stellar occultations.
- Study surface ices and any tenuous atmospheres associated with the icy satellites.

The UVIS instrument is a two-channel imaging spectrograph (far and extreme ultraviolet) that includes a hydrogen–deuterium absorption cell and a high-speed photometer. An imaging spectrograph is an instrument that records spectral intensity information in one or more wavelengths of energy and then outputs digital data that can be displayed in a visual form, such as a false-color image.

Each of the two spectrographic channels utilizes a reflecting telescope, a grating spectrometer and an imaging, pulse-counting detector. The telescopes have a focal length of 100 millimeters and an FOV of 3.67 × 0.34 degrees. The far ultraviolet channel has a wavelength range of 115–190 nanometers; the range of the extreme ultraviolet channel is 55–115 nanometers. Spectral resolution ranges from 0.21 to 0.24 nanometers. For solar occultation observations, the extreme ultraviolet channel includes a mechanism that allows sunlight to enter when the Sun is 20 degrees off the telescope axis.

The absorption cell channel is a photometer that measures hydrogen and deuterium concentrations. The high-speed photometer measures undispersed light from its own parabolic mirror with a photomultiplier tube detector. The wavelength range for this photometer channel is 115–185 nanometers. The FOV is 0.34 × 0.34 degrees. The time resolution is 2 milliseconds.

***Microwave Remote Sensing***

*Cassini Radar.* The Cassini Radar (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 RADAR uses the five-beam $K_u$-band (13.78 gigahertz) antenna feed on the high-gain antenna (HGA) to send RADAR transmissions toward targets. These signals, after reflection from the target, will be captured by the HGA and detected by the RADAR. The RADAR will also operate in a passive mode wherein the instrument will measure the blackbody radiation emitted by Titan. Science objectives of the RADAR include the following:

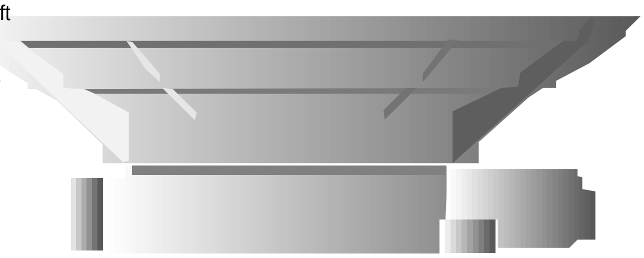
- Determine if large bodies of liquid exist on Titan, and if so, determine their distribution.
- Investigate the geological features and topography of Titan's solid surface.
- Acquire data on other targets (rings and icy satellites) as conditions permit.

The RADAR will take four types of observations: imaging, altimetry, backscatter and radiometry. In imaging synthetic aperture radar (SAR) mode, the instrument will record echoes of microwave energy off the surface of Titan from different incidence angles. The recorded echoes will allow construction of visual images of the target surface with a surface resolution of 0.35–1.7 kilometers.

Radar altimetry similarly involves bouncing microwave pulses off the subsatellite 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 pre-

## MICROWAVE REMOTE SENSING

Two microwave remote-sensing experiments, the Cassini Radar (RADAR) and the Radio Science Instrument (RSS), share the spacecraft's high-gain antenna (HGA). This antenna receives spacecraft commands from Earth and sends science and spacecraft data back to Earth; it is also used for communications with the Huygens Probe. Some RADAR components are housed in equipment bays in the upper equipment module, below the HGA; one piece, the radio frequency electronics subsystem (RFES), sits in a penthouse-like attachment between the upper equipment module and the HGA. The RSS components are housed in the spacecraft bays; the instrument also includes radio receiver elements located at NASA's Deep Space Network stations on Earth.



cise distance between the surface features of Titan and the spacecraft.

When these data are combined with the spacecraft ephemeris, a Titan topography map (altitude of surface features) can be created. The altimeter resolution is 24–27 kilometers horizontal, 90–150 meters vertical.

In scatterometry mode, the RADAR will bounce pulses off Titan's surface and then measure the intensity of the energy returning. This returning energy, or backscatter, is always less than the original pulse since surface features inevitably reflect the pulse in more than one direction. From the variations in these backscatter measurements, scientists can infer the composition and roughness of the surface.

Finally, in radiometry mode, the RADAR will operate as a passive instrument, simply recording the energy emanating from the surface of Titan. This information will tell scientists about Titan's surface properties. In the interferometry and scatterometry modes, the low-resolution (0.35-degree) data will be acquired from large amounts of Titan's surface by scanning the HGA.

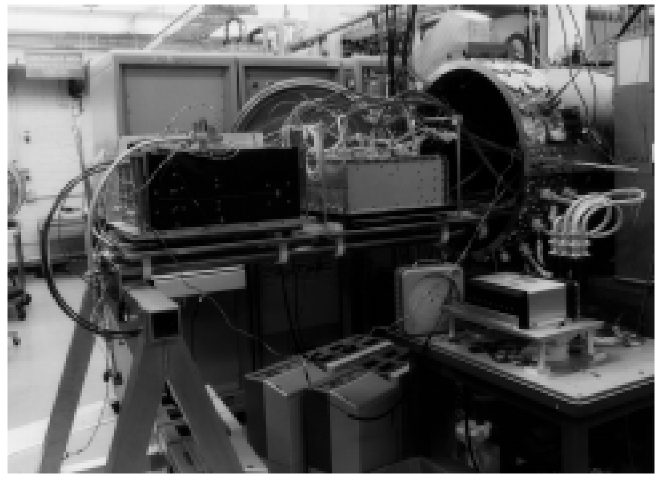
The RADAR can operate at altitudes below approximately 100,000 kilometers. From 100,000 to 25,000 kilometers, the RADAR will operate in radiometry mode only to gather data about surface temperature and emissivity that is related to composition.

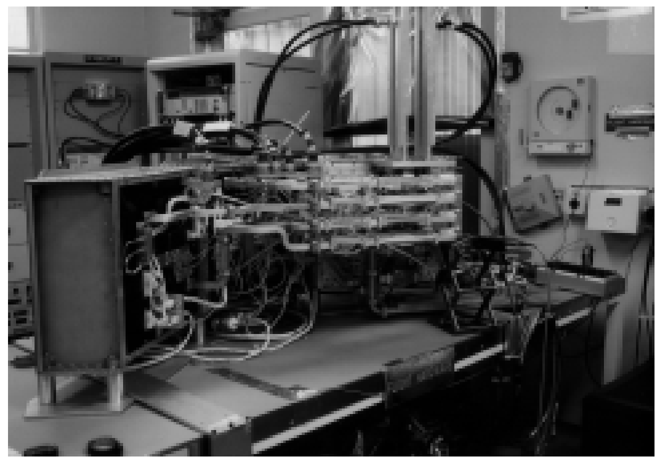
Between 22,500 and 9000 kilometers, the RADAR will switch between scatterometry and radiometry to obtain low-resolution global maps of Titan's surface roughness, backscatter intensity and thermal emissions. At altitudes between 9000 and 4000 kilometers, the instrument will switch between altimetry and radiometry, collecting surface altitude and thermal emission measurements along the suborbital track. Below 4000 kilometers, the RADAR will switch between imaging and radiometry.

At the RADAR's lowest planned altitude, 950 kilometers, the maximum image resolution will be 540 × 350 meters. In imaging mode, the RADAR will use all five beams in a fan shape to broaden the swath to approximately six degrees.

*Radio Science Instrument.* The Radio Science Instrument (RSS) will use the spacecraft radio and ground antennas — such as those of NASA's Deep Space Network (DSN) — to study the compositions, pressures and temperatures of the atmospheres and ionospheres of Saturn and Titan; the radial structure of Saturn's rings and the particle size distribution within the rings; and planet–satellite masses, gravity fields and ephemerides within the Saturn system. During the long interplanetary cruise to Saturn, the RSS will also be used — near solar oppositions to search for gravitational waves coming from beyond our solar system, and near solar conjunctions to test general relativity and study the solar corona. The instrument's science objectives include the following:

- Search for and characterize gravitational waves coming from beyond the solar system.
- Study the solar corona and general relativity when Cassini passes behind the Sun.
- Improve estimates of the masses and ephemerides of Saturn and its satellites.
- Study the radial structure of and particle size distribution in Saturn's rings.
- Determine temperature and composition profiles within the Saturn and Titan atmospheres.
- Determine temperatures and electron densities in the Saturn and Titan ionospheres.





The Cassini Radar (top) and the Radio Science Instrument (RSS).

The RSS instrument is unique in that it consists of elements on the ground as well as on the spacecraft (see the sidebar on the next page). The ground elements are DSN 70-meter and 34-meter high-efficiency and beam waveguide stations.

On the spacecraft, the elements of the RSS are contained in the radio frequency subsystem and in the radio frequency instrument subsystem. A body-fixed HGA with its boresight along the spacecraft's *z*-axis will be pointed by moving the spacecraft. The HGA will be configured to operate at S-band, X-band and $K_a$-band to support radio science.

Occultation experiments measure the refractions, Doppler shifts (frequency shifts) and other modifications to radio signals that occur when the spacecraft is "occulted" by (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 the rings.

Cruise experiments and gravity field measurements use Doppler and ranging two-way measurements. The signal is generated from a reference on the ground, transformed to the transmitting frequencies, amplified and radiated through a Deep Space Network antenna. The spacecraft telecommunications subsystem receives the carrier signal, transforms it to downlink frequencies coherent with the uplink, amplifies it and returns it to Earth. The signal is detected through a ground antenna, amplified and saved for later analysis.

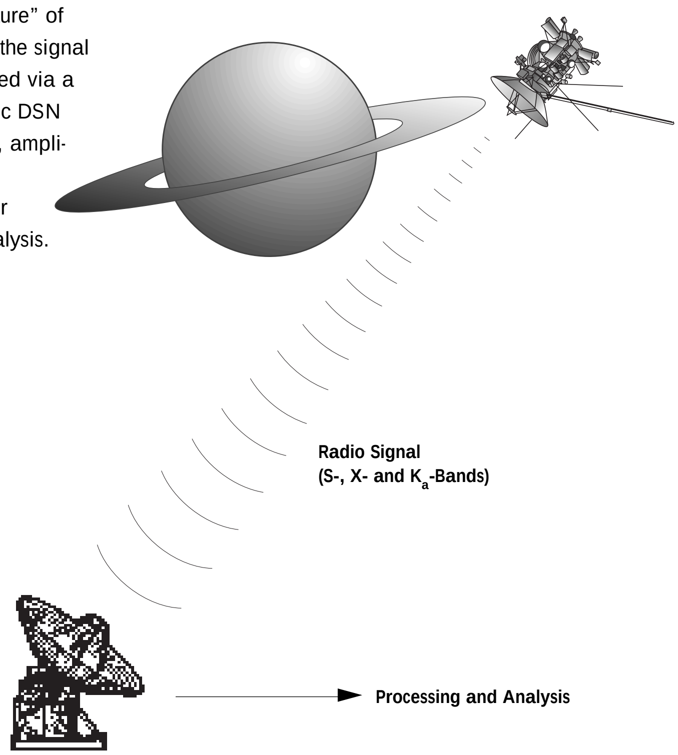
***Fields, Particles and Waves***

*Cassini Plasma Spectrometer.* The Cassini Plasma Spectrometer (CAPS) will measure the composition, density, flow velocity and temperature of ions and electrons in Saturn's magnetosphere. The CAPS science objectives are as follows:

- Measure the composition of ionized molecules originating from Saturn's ionosphere and Titan.
- Investigate the sources and sinks of ionospheric plasma — ion inflow/outflow and particle precipitation.
- Study the effect of magnetospheric and ionospheric interaction on ionospheric flows.
- Investigate auroral phenomena and Saturn kilometric radiation (SKR) generation.
- Determine the configuration of Saturn's magnetic field.
- Investigate plasma domains and internal boundaries.
- Investigate the interaction of Saturn's magnetosphere with the solar wind and solar-wind driven dynamics within the magnetosphere.
- Study the microphysics of the bow shock and magnetosheath.
- Investigate rotationally driven dynamics, plasma input from the satellites and rings and radial transport and angular momentum of the magnetospheric plasma.
- Investigate magnetotail dynamics and substorm activity.
- Study reconnection signatures in the magnetopause and tail.
- Characterize the plasma input to the magnetosphere from the rings.
- Characterize the role of ring–magnetosphere interaction in ring particle dynamics and erosion.
- Study dust–plasma interactions and evaluate the role of the magnetosphere in species transport between Saturn's atmosphere and rings.

## RADIO SCIENCE INSTRUMENT

Occultation experiments use one-way measurements. The radio signal is generated by an ultrastable oscillator aboard the spacecraft. The spacecraft radio frequency subsystems condition and amplify the signal for transmission to Earth. After passing through the "feature" of interest, the signal is detected via a parabolic DSN antenna, amplified and saved for later analysis.



• Study the interaction of the magnetosphere with Titan's upper atmosphere and ionosphere.

• Evaluate particle precipitation as a source of Titan's ionosphere.

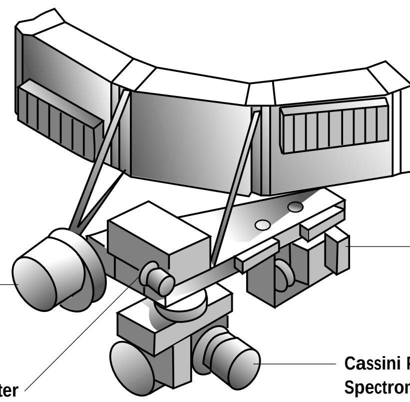
• Characterize plasma input to the magnetosphere from icy satellites.

• Study the effects of satellite interaction on magnetospheric particle dynamics inside and around the satellite flux tube.

The CAPS will measure the flux (the number of particles arriving at the CAPS per square centimeter per second per unit of energy and solid angle) of ions in Saturn's magnetosphere. The CAPS 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 azimuth about the –*y*-symmetry axis of the Cassini Orbiter.

## FIELDS, PARTICLES AND WAVES

Six instruments designed to study magnetic fields, particles and waves are mounted in a variety of locations on the spacecraft. The fields and particles pallet holds the Cassini Plasma Spectrometer (CAPS), an Ion and Neutral Mass Spectrometer (INMS) and two additional components of the Magnetospheric Imaging Instrument (MIMI). The Cosmic Dust Analyzer (CDA) and the Radio and Plasma Wave Science (RPWS) antennas and the magnetic search coils, also part of the RPWS, are attached to various locations on the upper equipment module. The RPWS also includes a Langmuir probe. The Dual Technique Magnetometer sensors are located on an extendible boom.




The electron spectrometer makes measurements of the energy of incoming electrons; its energy range is 0.7–30,000 electron volts. The sensor's FOV is 5 × 160 degrees. 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; its FOV is 1.5 × 160 degrees. The ion-mass spectrometer provides data on both the energy-to-charge and mass-to-charge ratios. Its mass range is 1–60 atomic mass units (amu); its energy range is 1 electron volt to 50 kilo–electron volts; its FOV is 12 × 160 degrees.

*Ion and Neutral Mass Spectrometer.* The Ion and Neutral Mass Spectrometer (INMS) will determine the composition and structure of positive ion and neutral species in the upper atmosphere of Titan and magnetosphere of Saturn, and will measure the positive ion and neutral environments of Saturn's icy satellites and rings. The science objectives are as follows:

• Measure the in situ composition and density variations, with altitude, of low-energy positive ions and neutrals in Titan's upper atmosphere.

• Study Titan's atmospheric chemistry.

• Investigate the interaction of Titan's upper atmosphere with the magnetosphere and the solar wind.

• Measure the in situ composition of low-energy positive ions and neutrals in the environments of the icy satellites, rings and inner magnetosphere of Saturn, wherever densities are above the measurement threshold and ion energies are below about 100 electron volts.

The INMS 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. It will also determine gas velocity.

The principal components of the INMS include an open source (for both ions and neutral particles), a closed source (for neutral particles only) and a quadrupole mass analyzer and detector.

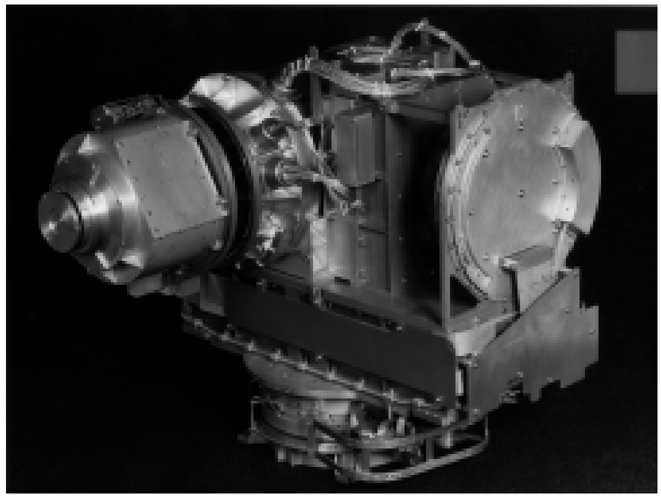
The open source analyzes ions as they enter, but the neutral gases must first be ionized within the instrument by the impact of electrons from an electron gun. The closed source measures neutrals along the direction of incoming atomic and molecular species. In both ion sources, the neutrals are ionized by electron impact.

Ions emerging from the ion sources are directed into the quadrupole mass analyzer; as the ions exit the analyzer, they go into an ion detector and are counted.

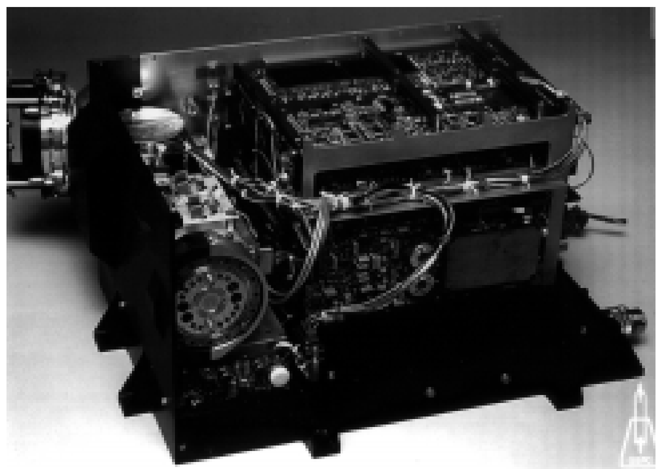
The FOV of the open source for neutral species is 16 degrees; the closed source has a hemispherical FOV. The mass range of the INMS is 1–8 amu and 12–99 amu.

*Cosmic Dust Analyzer.* The Cosmic Dust Analyzer (CDA) 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 satellites and magnetosphere of Saturn. The CDA science objectives are as follows:

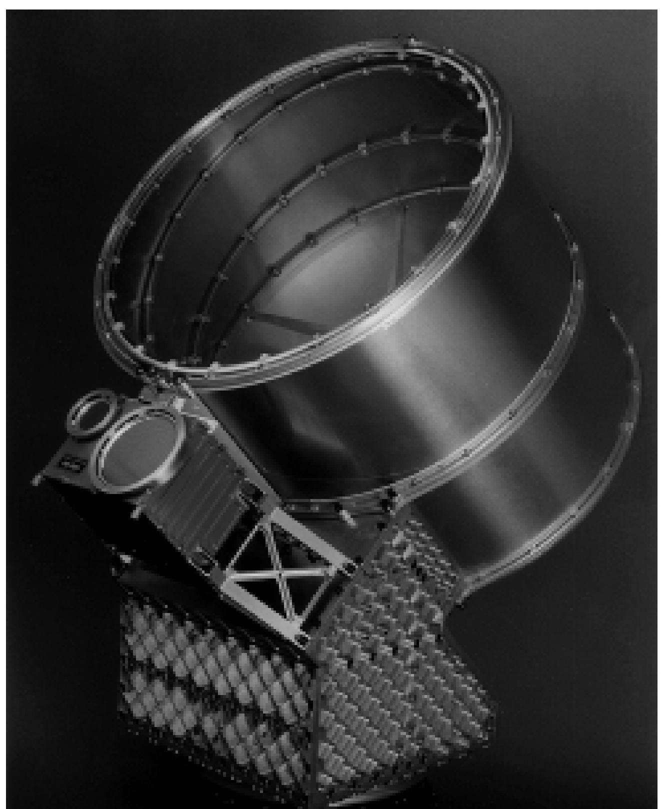
- Extend studies of interplanetary dust (sizes and orbits) to the orbit of Saturn.
- Define dust and meteoroid distribution (sizes, orbits, composition) near the rings.
- Map the size distribution of ring material in and near the known rings.
- Analyze the chemical compositions of ring particles.



The Cassini Plasma Spectrometer (CAPS).



The Ion and Neutral Mass Spectrometer (INMS).



The Cosmic Dust Analyzer (CDA).

• Study the erosional and electromagnetic processes responsible for E-ring structure.

• Search for ring particles beyond the known E-ring.

• Study the effect of Titan on the Saturn dust complex.

• Study the chemical composition of icy satellites from studies of ejecta particles.

• Determine the role of icy satellites as a source of ring particles.

• Determine the role of dust as a charged-particle source or sink in the magnetosphere.

The CDA measures the flux, velocity, charge, mass and composition of dust and ice particles in the mass range from $10^{-16}$ to $10^{-6}$ gram. 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, giving the integral flux of dust particles above the mass threshold of each detector. The threshold varies with impact velocity, but since ring particle orbits are nearly circular, their velocity at a given point does not vary much.

The dust analyzer determines the electric charge carried by dust particles, the flight direction and impact speed and the mass and chemical composition, at rates up to one particle per second, and for speeds of 1–100 kilometers per second. Some dust particles strike a separate chemical analyzer in the dust analyzer and also produce impact ionization. A grid accelerates positive ions; ions reaching the grid signal the start time for the time-of-flight mass spectrometer. Other dust particles pass through into the spectrometer and eventually reach the ion collector and electron multiplier. Their time of flight is an inverse function of the ion mass. The distribution of ion masses (atomic weights) gives the chemical composition of the dust particle. The mass resolution of the ion spectrum is approximately 50.

An articulation mechanism allows the entire CDA instrument to be rotated or repositioned, relative to the Cassini Orbiter body.

*Dual Technique Magnetometer.* The Dual Technique Magnetometer (MAG) will determine planetary magnetic fields and study dynamic interactions in the planetary environment. The MAG science objectives include the following:

• Determine the internal magnetic field of Saturn.

• Develop a three-dimensional model of Saturn's magnetosphere.

• Determine the magnetic state of Titan and its atmosphere.

• Derive an empirical model of Titan's electromagnetic environment.

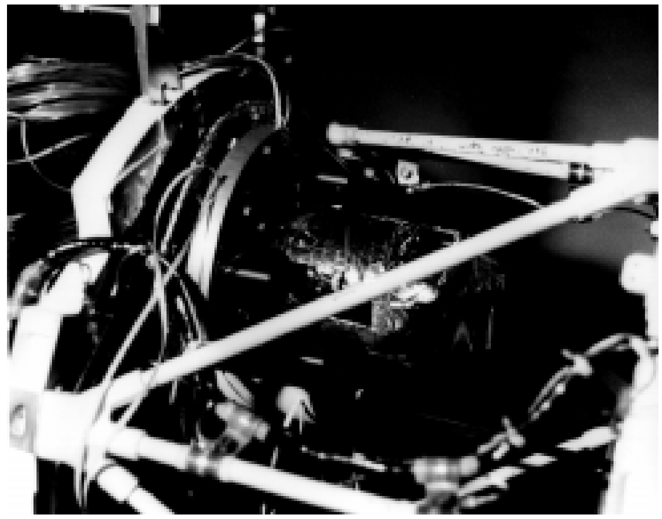
• Investigate the interactions of Titan with the magnetosphere, magnetosheath and solar wind.

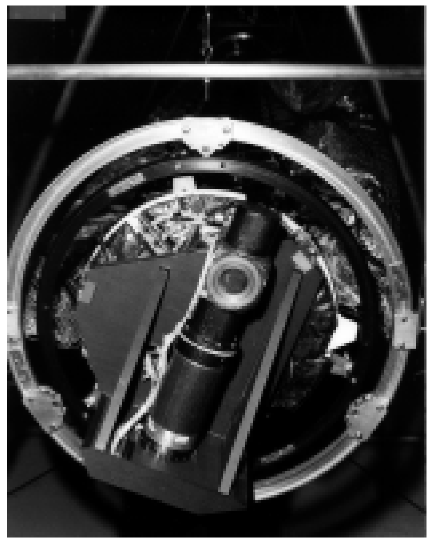
• Survey ring and dust interactions with the electromagnetic environment.

• Study the interactions of the icy satellites with Saturn's magnetosphere.

• Investigate the structure of the magnetotail and the dynamic processes therein.

The MAG consists of direct-sensing instruments that detect and measure





The Dual Technique Magnetometer (MAG) comprises the flux gate magnetometer (above) and the vector / scalar helium magnetometer (left).

the strength of magnetic fields in the vicinity of the spacecraft. The MAG comprises both a flux gate magnetometer and a vector / scalar helium magnetometer. The flux gate magnetometer is used to make vector field measurements. The vector / scalar helium magnetometer is used to make vector (magnitude and direction) and scalar (magnitude only) measurements of magnetic fields.

Since magnetometers are sensitive to electric currents and ferrous components, they are generally placed on an extended boom, as far from the spacecraft as possible. On Cassini, the flux gate magnetometer is located

## CASSINI ORBITER INSTRUMENTS

| | Measurements | Techniques | Partner Nations |
|---|---|---|---|
| **Optical Remote Sensing** | | | |
| Composite Infrared Spectrometer – CIRS | High-resolution spectra, 7–1000 µm | Spectroscopy using 3 interferometric spectrometers | US, France, Germany, Italy, UK |
| Imaging Science Subsystem – ISS | Photometric images through filters, 0.2–1.1 µm | Imaging with CCD detectors; 1 wide-angle camera (61.2 mr FOV); 1 narrow-angle camera (6.1 mr FOV) | US, France, Germany, UK |
| Ultraviolet Imaging Spectrograph – UVIS | Spectral images, 0.055–0.190 µm; occultation photometry, 2 ms; H and D spectroscopy, 0.0002-µm resolution | Imaging spectroscopy, 2 spectrometers; hydrogen–deuterium absorption cell | US, France, Germany |
| Visible and Infrared Mapping Spectrometer – VIMS | Spectral images, 0.35–1.05 µm (0.073-µm resolution); 0.85–5.1 µm (0.166-µm resolution); occultation photometry | Imaging spectroscopy, 2 spectrometers | US, France, Germany, Italy |
| **Radio Remote Sensing** | | | |
| Cassini Radar – RADAR | $K_u$-band RADAR images (13.8 GHz); radiometry resolution less than 5 K | Synthetic aperture radar; radiometry with a microwave receiver | US, France, Italy, UK |
| Radio Science Instrument – RSS | $K_a$-, S- and X-bands; frequency, phase, timing and amplitude | X- and Ka-band transmissions to Cassini Orbiter; $K_a$-, S- and X-band transmissions to Earth | US, Italy |
| **Particle Remote Sensing & In Situ Measurement** | | | |
| Magnetospheric Imaging Instrument – MIMI | Image energetic neutrals and ions at less than 10 keV to 8 MeV per nucleon; composition, 10–265 keV/e; charge state; directional flux; mass spec: 20 keV to 130 MeV ions; 15 keV to greater than 11 MeV electrons, directional flux | Particle detection and imaging; ion-neutral camera (time-of-flight, total energy detector); charge energy mass spectrometer; solid-state detectors with magnetic focusing telescope and aperture-controlled ~45° FOV | US, France, Germany |
| **In Situ Measurement** | | | |
| Cassini Plasma Spectrometer – CAPS | Particle energy/charge, 0.7–30,000 eV/e; 1–50,000 eV/e | Particle detection and spectroscopy; electron spectrometer; ion-mass spectrometer; ion-beam spectrometer | US, Finland, France, Hungary, Norway, UK |
| Cosmic Dust Analyzer – CDA | Directional flux and mass of dust particles in the range $10^{-16}$–$10^{-6}$ g | Impact-induced currents | Germany, Czech Republic, France, The Netherlands, Norway, UK, US |
| Dual Technique Magnetometer – MAG | B DC to 4 Hz up to 256 nT; scalar field DC to 20 Hz up to 44,000 nT | Magnetic field measurement; flux gate magnetometer; vector–scalar magnetometer | UK, Germany, US |
| Ion and Neutral Mass Spectrometer – INMS | Fluxes of +ions and neutrals in mass range 1–66 amu | Mass spectrometry | US, Germany |
| Radio and Plasma Wave Science – RPWS | E, 10 Hz–2MHz; B, 1 Hz–20 kHz; plasma density | Radio frequency receivers; 3 electric dipole antennas; 3 magnetic search coils; Langmuir probe current | US, Austria, France, The Netherlands, Sweden, UK |

midway out on the magnetometer boom, and the vector / scalar helium magnetometer is located at the end of the boom. The boom itself, composed of thin, nonmetallic rods, will be folded during launch and deployed long after the spacecraft separates from the launch vehicle and shortly before the Earth flyby. The magnetometer electronics are in a spacecraft bay.

The use of two separate magnetometers at different locations aids in distinguishing the ambient magnetic field from that produced by the spacecraft. The helium magnetometer has full-scale flux ranges of 32–256 nanoteslas in vector mode and 256–16,000 nanoteslas in scalar mode. The flux gate magnetometer's flux range is 40–44,000 nanoteslas.

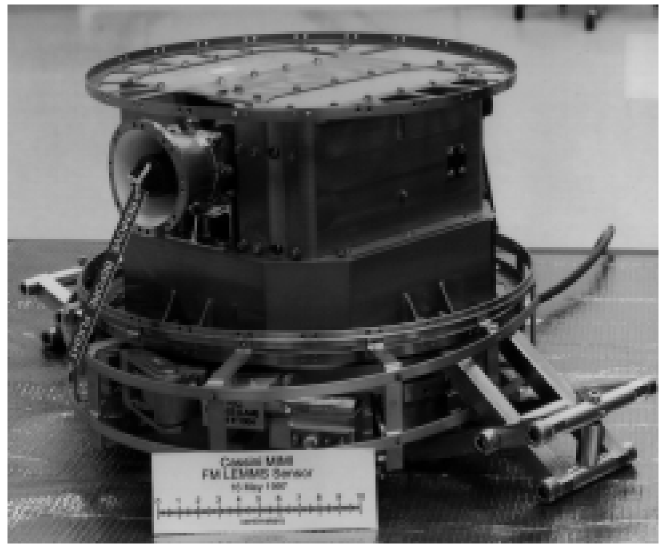
*Magnetospheric Imaging Instrument.* The Magnetospheric Imaging Instrument (MIMI) is designed to measure the composition, charge state and energy distribution of energetic ions and electrons; detect fast neutral species; and conduct remote imaging of Saturn's magnetosphere. This information will be used 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 satellites. The science objectives are as follows:

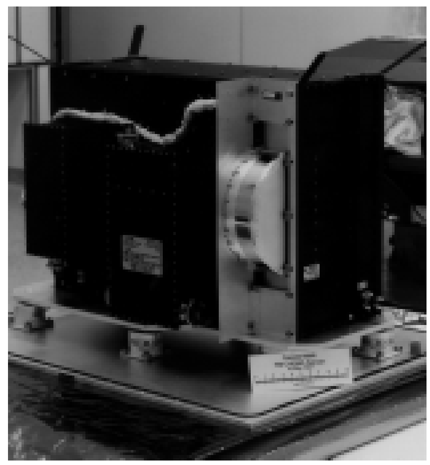
- Determine the global configuration and dynamics of hot plasma in the magnetosphere of Saturn.
- Monitor and model magnetospheric, substorm-like activity and correlate this activity with Saturn kilometric radiation observations.
- Study magnetosphere / ionosphere coupling through remote sensing of aurora and measurements of energetic ions and electrons.
- Investigate plasma energization and circulation processes in the magnetotail of Saturn.
- Determine through imaging and composition studies the magnetosphere–satellite interactions at Saturn, and understand the formation of clouds of neutral hydrogen, nitrogen and water products.
- Measure electron losses due to interactions with whistler waves.
- Study the global structure and temporal variability of Titan's atmosphere.
- Monitor the loss rate and composition of particles lost from Titan's atmosphere due to ionization and pickup.
- Study Titan's interaction with the magnetosphere of Saturn and the solar wind.
- Determine the importance of Titan's exosphere as a source for the atomic hydrogen torus in Saturn's outer magnetosphere.
- Investigate the absorption of energetic ions and electrons by Saturn's rings and icy satellites.
- Analyze Dione's exosphere.

The MIMI will provide images of the plasma surrounding Saturn and determine ion charge and composition. The MIMI has three sensors that perform various measurements: the low-energy magnetospheric measurement system (LEMMS), the charge-energy-mass spectrometer (CHEMS) and the ion and neutral camera (INCA).

The LEMMS will measure low- and high-energy proton, ion and electron angular distributions (the number of particles coming from each direction). The LEMMS sensor is mounted on a scan platform that is capable of turning 180 degrees. The sensor provides directional and energy information on electrons from 15 kilo–electron volts to 10 mega–electron volts, protons at 15–130 mega–electron volts and other ions from 20 kilo–electron volts to 10.5 mega–electron volts per nucleon. The LEMMS head is double-ended, with oppositely directed FOVs of 15 and 45 degrees.

The CHEMS uses an electrostatic analyzer, a time-of-flight mass spectrometer and microchannel plate detectors to measure the charge and composition of ions at 10–265 kilo–electron volts per electron. Its mass / charge



The Magnetospheric Imaging Instrument (MIMI) low-energy magnetospheric measurement system, LEMMS (above), and the MIMI charge-energy-mass spectrometer, CHEMS (left).

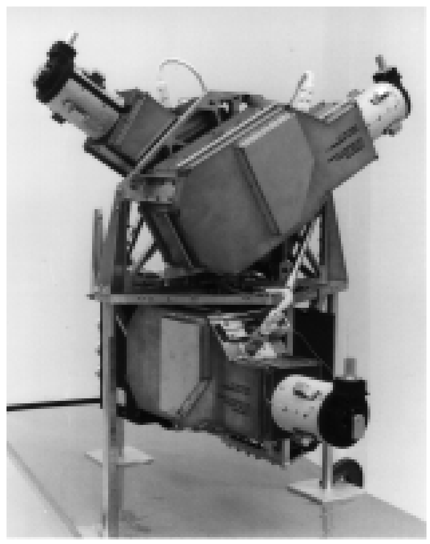
The MIMI ion and neutral camera, INCA (right), and the Radio and Plasma Wave Science (RPWS) instrument (below).

range is 1–60 amu / e (elements hydrogen–iron); its molecular ion mass range is 2–120 amu.

The third MIMI sensor, the INCA, makes two different types of measurements. It will obtain three-dimensional distributions, velocities and the rough composition of magnetospheric and interplanetary ions with energies from 10 kilo–electron volts to about eight mega–electron volts per nucleon for regions with low energetic ion fluxes. The instrument will also obtain remote images of the global distribution of the energetic neutral emission of hot plasmas in the Saturn magnetosphere, measuring the composition and velocities of those energetic neutrals. The FOV is $120 \times 90$ degrees.

The MIMI sensors share common electronics and provide complementary measurements of energetic plasma distribution, composition and energy spectrum, and the interaction of that plasma with the extended atmosphere and satellites of Saturn.

*Radio and Plasma Wave Science.* The Radio and Plasma Wave Science (RPWS) instrument will measure the electrical and magnetic fields in the plasma of the interplanetary medium and Saturn's magnetosphere, as well



as electron density and temperature. Science objectives of the RPWS instrument include the following:

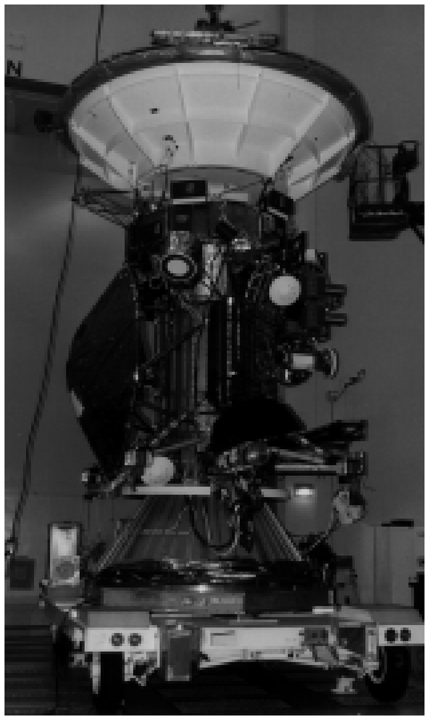
- Study the configuration of Saturn's magnetic field and its relationship to Saturn kilometric radiation (SKR).
- Monitor and map the sources of SKR.
- Study daily variations in Saturn's ionosphere and search for outflowing plasma in the magnetic cusp region.
- Study radio signals from lightning in Saturn's atmosphere.
- Investigate Saturn electric discharges (SED).
- Determine the current systems in Saturn's magnetosphere and study the composition, sources and sinks of magnetospheric plasma.
- Investigate the dynamics of the magnetosphere with the solar wind, satellites and rings.
- Study the rings as a source of magnetospheric plasma.
- Look for plasma waves associated with ring spoke phenomena.
- Determine the dust and meteroid distributions throughout the Saturn system and interplanetary space.
- Study waves and turbulence generated by the interaction of charged dust grains with the magnetospheric plasma.
- Investigate the interactions of the icy satellites and the ring systems.
- Measure electron density and temperature in the vicinity of Titan.
- Study the ionization of Titan's upper atmosphere and ionosphere and the interactions of the atmosphere and exosphere with the surrounding plasma.
- Investigate the production, transport, and loss of plasma from Titan's upper atmosphere and ionosphere.
- Search for radio signals from lightning in Titan's atmosphere, a possible source for atmospheric chemistry.
- Study the interaction of Titan with the solar wind and magnetospheric plasma.
- Study Titan's vast hydrogen torus as a source of magnetospheric plasma.
- Study Titan's induced magnetosphere.

The RPWS instrument will be used to investigate electric and magnetic waves in space plasma at Saturn. The solar wind is a plasma; plasma may be "contained" within magnetic fields (that is, the magnetospheres) of bodies such as Saturn and Titan. The RPWS instrument will measure the electric and magnetic fields in the interplanetary medium and planetary magnetospheres and will directly measure the electron density and temperature of the plasma in the vicinity of the spacecraft.

The major components of the RPWS instrument are an electric field sensor, a magnetic search coil assembly and the 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 is rolled up during launch and subsequently unrolled to its 10-meter length by a motor drive.

The magnetic search coil assembly includes three orthogonal coils about 25 millimeters in diameter and 260 millimeters long. The magnetic search coils are mounted on a small platform attached to a support for the HGA. The Langmuir probe, which measures electron density and temperature, is a metallic sphere 50 millimeters in diameter. The probe is attached to the same platform by a one-meter deployable boom.

Signals from the sensors go to a number of receivers, which provide low and high time and frequency resolution measurements. The instrument ranges are one hertz to 16 megahertz for electric fields; one hertz to 12.6 kilohertz for magnetic fields; electron densities of 5–10,000 electrons per cubic centimeter; and electron temperatures equivalent to 0.1–4 electron volts.



The Cassini–Huygens spacecraft, with thermal blankets on, in its flight-ready state.

**Probe Instruments Overview**
The Huygens Probe, provided by the European Space Agency (ESA), will fly to the Saturn system aboard the Cassini–Huygens spacecraft. Carrying six science instruments, the Probe will study the atmosphere and surface of Saturn's largest satellite, Titan, descending through Titan's atmosphere and landing — either on solid land or in a liquid lake or ocean.

Many countries have participated in the development of the Huygens Probe's six instruments. The instruments are the Huygens Atmospheric Structure Instrument (HASI), the Aerosol Collector and Pyrolyser (ACP), the Gas Chromatograph and Mass Spectrometer (GCMS), the Descent Imager and Spectral Radiometer (DISR), the Doppler Wind Experiment (DWE) and the Surface Science Package (SSP). These instruments comprise 39 sensors; the total mass of the science payload is 48 kilograms.

Once the Probe has separated from the Orbiter, it is wholly autonomous. The instruments are turned on in a preprogrammed sequence after the Probe's heat shield is released. Probe instrument operation is controlled by timers, acceleration sensors, altimeters and a Sun sensor. All instruments use time-based operation from the beginning of the descent down to 20 kilometers. Three of the instruments, the DISR, the HASI and the SSP, use measured altitude below 20 kilometers. Up to three hours of Probe data will be relayed to the Orbiter for later transmission to Earth.

**Probe Instrument Descriptions**
*Huygens Atmospheric Structure Instrument.* The Huygens Atmospheric Structure Instrument (HASI) investigates the physical and electrical properties of Titan's atmosphere, including temperature, pressure and atmospheric density as a function of altitude and wind gusts — and in the event of a landing on a liquid surface — wave motion. Comprising a variety of sensors, the HASI will also measure the ion and electron conductivities of the atmosphere and search for electromagnetic wave activity.

Atmospheric pressure is measured by the deflection of a diaphragm. A tube inlet is mounted on a stub extending outside the Probe. Thermometers mounted on the stub measure atmospheric temperature.

## HUYGENS PROBE INSTRUMENTS

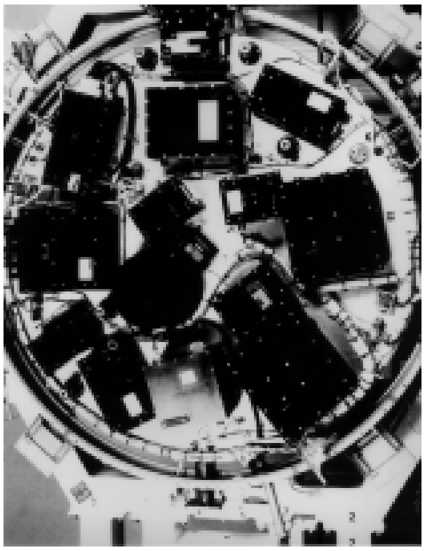
| | Measurements | Techniques | Partner Nations |
|---|---|---|---|
| Huygens Atmospheric Structure Instrument – HASI | Temp: 50–300 K; Pres: 0–2000 mbar; Grav: 1 μg–20 mg; AC E-field: 0–10 kHz, 80 dB at 2 $\mu Vm^{-1}$ $Hz^{-0.5}$; DC E-field: 50 dB at 40 mV/m; electrical conductivity: $10^{-15}$ Ω/m to ∞; relative permittivity: 1–∞; acoustic: 0–5 kHz, 90 dB at 5 mPa | Direct measurements using "laboratory" methods | Italy, Austria, Finland, Germany, France, The Netherlands, Norway, Spain, US, UK |
| Gas Chromatograph and Mass Spectrometer – GCMS | Mass range: 2–146 amu; Dynamic range: $>10^8$; Sensitivity: $10^{-12}$ mixing ratio; Mass resolution: $10^{-6}$ at 60 amu | Chromatography and mass spectrometry; 3 parallel chromatographic columns; quadrupole mass filter; 5 electron impact sources | US, Austria, France |
| Aerosol Collector and Pyrolyser – ACP | 2 samples: 150–45 km, 30–15 km altitude | 3-step pyrolysis; 20°C, 250°C, 650°C | France, Austria, Belgium, US |
| Descent Imager and Spectral Radiometer – DISR | Upward and downward spectra: 480–960 nm, 0.87–1.7 μm; resolution 2.4–6.3 nm; downward and side-looking images: 0.66–1 μm; solar aureole photometry: 550 nm, 939 nm; surface spectral reflectance | Spectrometry, imaging, photometry and surface illumination by lamp | US, Germany, France |
| Doppler Wind Experiment – DWE | (Allan Variance)1/2: $10^{-11}$ (in 1 s), $5 \times 10^{-12}$ (in 10 s), $10^{-12}$ (in 100 s), corresponding to wind velocities of 2 m/s to 200 m/s, Probe spin | Doppler shift of Huygens Probe telemetry signal, signal attenuation | Germany, France, Italy, US |
| Surface Science Package – SSP | Gravity: 0–100 g; Tilt: ±60°; Temp: 65–100 K; thermal conductivity: 0–400 mW $m^{-1}K^{-1}$; speed of sound: 150–2000 m/s; liquid density: 400–700 kg $m^{-3}$; refractive index: 1.25–1.45 | Impact acceleration; acoustic sounding, liquid relative permittivity, density and index of refraction | UK, Italy, The Netherlands, US |

To determine the density of the atmosphere, an accelerometer measures acceleration along the spin axis. Three additional accelerometers measure acceleration along all three axes of the Probe over a range of ±20 g. A microphone is also part of the HASI; it senses acoustic noise from sources such as thunder, rain or wind gusts.

A permittivity and wave analyzer, consisting of an array of six electrodes, is mounted on two deployable booms. Measurements of the magnitude and phase of the received signal give the permittivity and electronic conductivity of the atmosphere and the surface. Electromagnetic signals such as those of lightning can also be detected. The instrument also processes the signal from the Probe's radar altimeter to obtain information on surface topography, roughness and electrical properties.

*Aerosol Collector and Pyrolyser.* The Aerosol Collector and Pyrolyser (ACP) captures aerosol particles from Titan's atmosphere using a deployable sampling device extended in the air flow below the nose of the Probe. The samples are heated in ovens to vaporize the volatiles and decompose the complex organic materials. The products are then passed to the GCMS for analysis.

The ACP will obtain samples at two altitude ranges. The first sample, at



altitudes down to 40 kilometers above the surface, will be obtained primarily by direct impact of the atmosphere on a cold filter target. The second sample will be obtained at about 20 kilometers by pumping the atmosphere through the filter.

After each collection, the filter will be transferred to an oven and heated to three successively higher temperatures, up to about 650 degrees Celsius, to vaporize and pyrolyze the collected material. The product at each temperature will be swept up by nitrogen carrier gas and transferred to the GCMS for analysis.

*Gas Chromatograph and Mass Spectrometer.* The Gas Chromatograph and Mass Spectrometer (GCMS) provides a quantitative analysis of the composition of Titan's atmosphere. Atmospheric samples are transferred into the instrument by dynamic pressure as the Probe descends through the atmosphere. The Mass Spectrometer constructs a spectrum of the molecular masses of the gas driven into the instrument. Just prior to landing, the inlet port of the GCMS is heated to vaporize material on contact with the surface. Following a safe landing, the GCMS can determine Titan's surface composition.

The GCMS uses an inlet port to collect samples of the atmosphere and has an outlet port at a low pressure point. The instrument contains three chromatographic columns. One column has an absorber chosen to separate carbon monoxide, nitrogen and other gases. Another column has an absorber that will separate nitriles and other highly polar compounds. The third is to separate hydrocarbons up to $C_8$. The mass range is 2–146 amu.

The Mass Spectrometer serves as the detector for the Gas Chromatograph, for unseparated atmospheric samples and for samples provided by the ACP. Portions of the GCMS are identical in design to the Orbiter's INMS.

*Descent Imager and Spectral Radiometer.* The Descent Imager and Spectral Radiometer (DISR) uses several instrument fields of view and 13 sensors, operating at wavelengths of 350–1700 nanometers, to obtain a variety of imaging and spectral observations. The thermal balance of the atmosphere and surface can inferred by measuring the upward and downward flux of radiation.

Solar aureole sensors will measure the light intensity around the Sun resulting from scattering by aerosols, permitting calculations of the size and number density of suspended particles. Infrared and visible imagers will observe the surface during the latter stages of the descent. Using the Probe's rotation, the imagers will build a mosaic of pictures of the Titan landscape. A side-looking visible imager will view the horizon and take pictures of the clouds, if any exist. For spectral measurements of the surface, a lamp will be turned on shortly before landing to provide enough light for measuring surface composition.

The interior of the Huygens Probe, showing its science instruments.

The DISR will obtain data to help determine the concentrations of atmospheric gases such as methane and argon. DISR images will also determine if the local surface is solid or liquid. If the surface is solid, DISR will reveal topographic details. If the surface is liquid, and waves exist, DISR will photograph them.

DISR sensors include three framing imagers, looking downward and horizontally; a spectrometer dispersing light from two sets of optics looking downward and upward; and four solar aureole radiometers. The spectral range of the imagers is 660–1000 nanometers; the spectrometer's range is 480–960 nanometers; the aureole radiometers operate at 475–525 and 910–960 nanometers, with two different polarizations.

Separate downward- and upward-looking optics are linked by fiberoptic bundles to an infrared grating spectrometer. The infrared detectors have a spectral range of 870–1700 nanometers. There are also two violet photometers, looking downward and upward with a bandwidth of 350–470 micrometers.

To provide reference and timing for the other measurements, the DISR uses a Sun sensor to measure the solar azimuth and zenith angle relative to the rotating Probe.

*Doppler Wind Experiment.* The Doppler Wind Experiment (DWE) uses two ultrastable oscillators (USOs), one on the Probe and one on the Orbiter, to give Huygens' relay link a stable carrier frequency. Orbiter measurements of the shift in Probe frequency (Doppler shift) will provide information on the Probe's motion from which a height profile of the zonal wind (the component of wind along the line of sight) and its turbulence can be derived.

The output frequency of each USO is set by a rubidium oscillator. The signal (which is like a very high precision clock) received from the Probe is compared with that of the Orbiter USO, and the difference in frequency is recorded and stored for transmission to Earth. This information is used to determine the Doppler velocity between the Probe and the Orbiter. Modulation of this signal will provide additional data on the Probe spin rate, spin phase and parachute swing. Winds will be measured to a precision of one meter per second.

*Surface Science Package.* The Surface Science Package (SSP) contains a number of sensors to determine the physical properties and composition of Titan's surface. Some of the SSP sensors will also perform atmospheric measurements during descent.

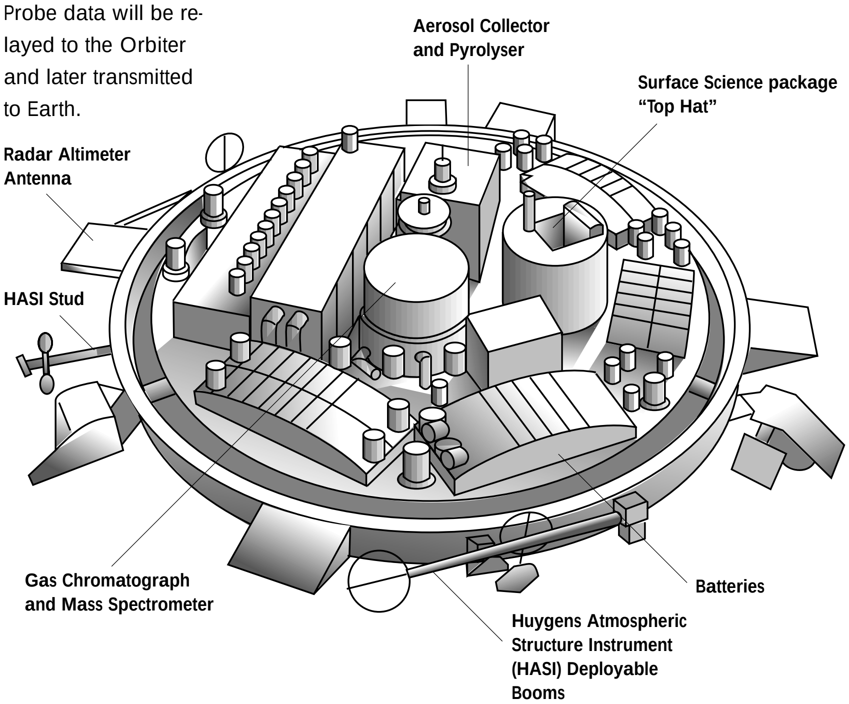
During descent, measurements of the speed of sound will give information on atmospheric composition and temperature. An accelerometer records the deceleration profile at impact, indicating the hardness of the surface. Tilt sensors (liquid-filled tubes with electrodes) will measure any pendulum motion of the Probe during descent, indicate the Probe orientation after landing and measure any wave motion.

If the surface is liquid, an opening at the bottom of the Probe body, with a vent extending upward along the Probe axis, will admit liquid, which will fill the space between a pair of electrodes. The capacitance between the electrodes gives the dielectric constant of the liquid; the resistance gives the electrical conductivity. A float with electrical position sensors determines the liquid's density.

A sensor to measure the refractive index of the liquid has light-emitting diode (LED) light sources, a prism with a curved surface and a linear photodiode detector array. The position of the light / dark transition on the detector array indicates the refractive in-

## PROBING TITAN'S DEPTHS

Like the Cassini Orbiter, Huygens represents an international collaboration. The partners involved in the Probe effort are Austria, Belgium, the European Space Agency, Finland, France, Germany, Italy, The Netherlands, Norway, Spain, the United Kingdom and the United States. The Huygens science instruments comprise a total of 39 sensors. The total mass of the Probe science payload is 48 kilograms. Once the Probe separates from the Orbiter, it is wholly autonomous. The instruments will turn on in a preprogrammed sequence after the Probe cover is released. Probe operation is controlled by timers, acceleration sensors, altimeters and a Sun sensor. As much as three hours of Probe data will be relayed to the Orbiter and later transmitted to Earth.



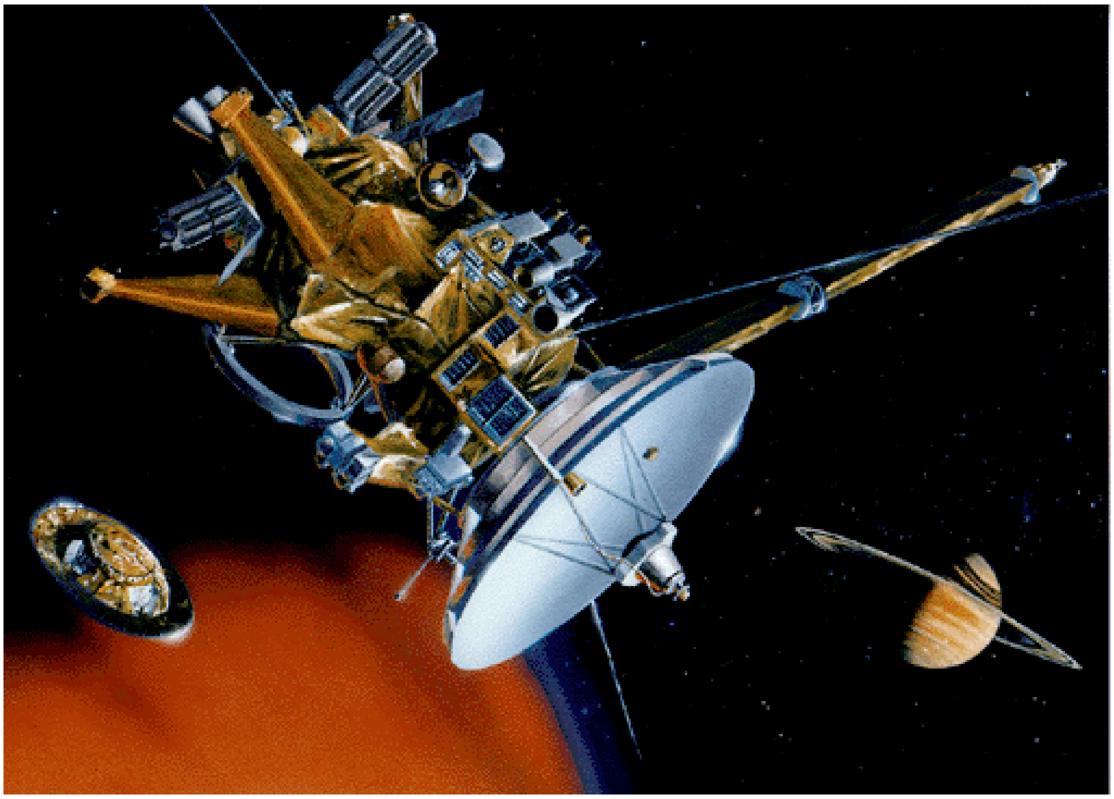
dex. A group of platinum resistance wires, two of which can be heated, will measure temperature and thermal conductivity of the surface and lower atmosphere and the heat capacity of the surface material. The acoustic sounder, which will then work as a sonar, will conduct an acoustic sounding of liquid depth — if the Probe lands in liquid.

**Instrument Operations**

*Cassini Orbiter.* The power available to the Cassini Orbiter is not sufficient to operate all the instruments and engineering subsystems simultaneously. Operations are therefore divided into a number of operational modes. For example, during much of the orbital tour of Saturn, 16 hours in remote-sensing mode will often alternate with eight hours in fields and particles and waves and downlink mode.

Other science modes will be used during satellite flybys, occultations, cruise to Saturn and so on. Instruments that are not gathering data will generally not turn off during the orbital tour, but will be in a low-power "sleep" state. This strategy is designed to reduce on–off thermal cycling, keep high voltages on (to avoid having to turn up voltage slowly each time it is required) and to preserve the onboard computer memories (to avoid having to reload them each time).

The operational modes differ in characteristics other than power. In remote sensing, for example, the Orbiter is oriented to point remote-sensing instruments toward their objects of interest. This means that the



The Huygens Probe is released on a trajectory to enter Titan's atmosphere.

HGA generally cannot be pointed toward Earth, so telemetry is stored in the solid-state recorders for later transmission.

In fields, particles, waves and downlink mode, the HGA is pointed toward Earth — permitting transmission of stored and real-time telemetry — and the Orbiter is rolled about the antenna axis to provide scanning about another axis in addition to the articulation axes of some instruments.

The bit rate available on the command and data subsystem databus is not high enough to permit all instruments to output telemetry simultaneously at their maximum rates. The Orbiter is switched among a number of different telemetry modes in which the available bit rate is allocated differently among the instruments.

Some of the instruments will adjust their operating state or parameters depending on the activities of the spacecraft or other instruments and the kind of environment the Orbiter is encountering. When these other conditions are predictable from the command sequence, commands for the instruments will be set accordingly.

When conditions are not predictable, or if it is simpler to handle the adjustment on board, the command and data subsystem relays information to the instruments that need it. Specifically, information on spacecraft attitude and its rate of change, warnings of thruster firings, measurements of the magnetic field vector and notices of operation of the sounder and Langmuir probe in the RPWS instrument are broadcast for use by the CAPS, CDA and MIMI.

*Huygens Probe.* There is no radio transmission link to the Huygens Probe after it separates from the Orbiter; the Probe is wholly autonomous. The instruments are turned on in a preprogrammed sequence after the Probe cover is released. The Probe goes through five successive power configurations in which the available power is allocated differently among the various instruments. Operation is controlled by timers, acceleration sensors, altimeters and a Sun sensor. The Probe's command and data management subsystem broadcasts altitude and spin-rate data to the instruments. Data collection involves three successive steps in which the available data rate is allocated differently among the instruments.

**Summary**

The Cassini–Huygens mission will carry 18 scientific instruments to the Saturn system. After the spacecraft is inserted into Saturn orbit, it will separate into a Saturn Orbiter and an atmospheric Probe, called Huygens, which will descend to the surface of Titan. The Orbiter will orbit the planet for four years, with close flybys of Enceladus, Dione, Rhea, Hyperion and Iapetus, and multiple close flybys of Titan.

The Orbiter is three-axis stabilized. Its 12 science instruments are body-mounted; the spacecraft must be turned to point them toward objects of interest. Optical instruments provide imagery and spectrometry at wavelengths from 55 nanometers to one millimeter. A radar instrument supplies synthetic aperture imaging, altimetry and microwave radiometry. S-band, X-band and $K_a$-band link measurements between the Orbiter and Earth will provide information about intervening material and gravity fields. Fields and particles instruments will measure magnetic and electric fields, plasma properties and the flux and properties of dust and ice particles. Cassini's maximum downlink rate from Saturn to Earth is 166 kilobits per second.

The Probe is spin-stabilized for the coast to Titan. A heat shield decelerates it and protects it from heat during entry into Titan's atmosphere. Parachutes then slow its descent to the surface and provide a stable platform for taking images and making other measurements. A set of small vanes on the bottom skirt of the Probe forces it to rotate, providing 360-degree viewing of the landscape.

The Probe carries six instruments, including sensors to determine atmospheric physical properties and chemical composition. Radiometric and optical sensors will provide data on temperatures and thermal balance and obtain images of Titan's atmosphere and surface. Doppler measurements over the radio link from Probe to Orbiter will provide wind profiles. Surface sensors are carried to measure impact acceleration, thermal properties of the surface material and, if the surface is liquid, its density, refractive index, electrical properties and acoustic velocity. The Probe returns its data via an S-band link to the Orbiter.