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June 2004

CASSINI-HUYGENS

Unique Insights into a Ringed World

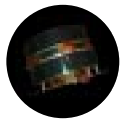
European Space Agency
Agence spatiale européenne

About ESA

The European Space Agency (ESA) was formed on 31 May 1975. It currently has 15 Member States: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

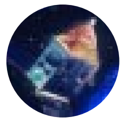
The ESA Science Programme has launched a series of innovative and successful missions. Highlights of the programme include:

Cluster, which is a four-spacecraft mission to investigate in unprecedented detail the interaction between the Sun and the Earth's magnetosphere.

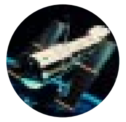


Double Star, following in the footsteps of the Cluster mission, with its two spacecraft it studies the effects of the Sun on the Earth's environment.

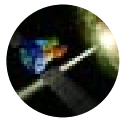
Giotto, which took the first close-up pictures of a comet nucleus (Halley) and completed flybys of Comets Halley and Grigg-Skjellerup.



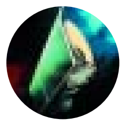
Hipparcos, which fixed the positions of the stars far more accurately than ever before and changed astronomers' ideas about the scale of the Universe.



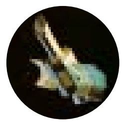
Hubble Space Telescope, a collaboration with NASA on the world's most important and successful orbital observatory.



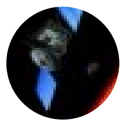
Integral, which is the first space observatory that can simultaneously observe celestial objects in gamma rays, X-rays and visible light.



ISO, which studied cool gas clouds and planetary atmospheres. Everywhere it looked, it found water in surprising abundance.

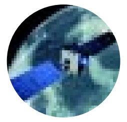


IUE, the first space observatory ever launched, marked the real beginning of ultraviolet astronomy.



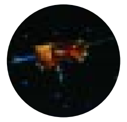
Mars Express, Europe's first mission to Mars, which consists of an orbiter and a lander looking for signs of water and life on the Red Planet.

Rosetta, Europe's comet chaser, will be the first mission to fly alongside and land on a comet, probing the building blocks of the Solar System in unprecedented detail.

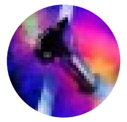


SMART-1, Europe's first mission to the Moon, which will test solar-electric propulsion in flight, a key technology for future deep-space missions.

SOHO, which is providing new views of the Sun's atmosphere and interior, revealing solar tornadoes and the probable cause of the supersonic solar wind.



Ulysses, the first spacecraft to fly over the Sun's poles.



XMM-Newton, with its powerful mirrors, is helping to solve many cosmic mysteries of the violent X-ray Universe, from enigmatic black holes to the formation of galaxies.

For further information on the ESA Science Programme please contact the Science Programme Communication Service on (tel.) +31-71-5653223; (fax) +31-71-5654101

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Cassini-Huygens

Unique Insights into a Ringed World

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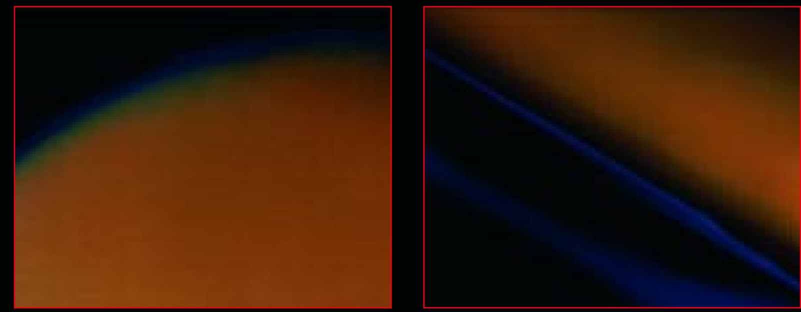
Solving the puzzles of Saturn and Titan

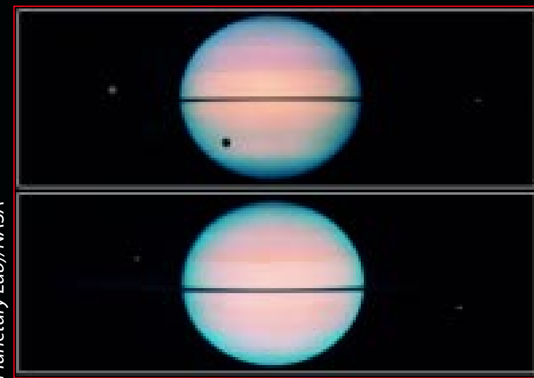
Courtesy NASA/JPL-Caltech



The typical orange-coloured atmosphere of Titan.

Top: During this ring plane crossing observed by Hubble, Titan is casting a shadow on Saturn. The other moons appear white because of their bright, icy surfaces. Bottom: The planet with its rings slightly tilted. Two other moons appear on the lower right and the upper left.

© E.Karkoscha (Arizona Univ. & Planetary Lab)/NASA



When the first space missions flew past Saturn at the end of the 1970s, very little was known about this mysterious and beautiful world. The most distant planet that could be seen by ancient astronomers, Saturn had appeared for centuries to be just another bright star in the night sky. Only when the telescope was invented at the beginning of the 17th century could human eyes see for the first time that this celestial body was actually a planet.

Courtesy NASA/JPL-Caltech

The so-called 'Cassini division' is visible in this picture of Saturn's ring taken by Voyager 1.

To Galileo Galilei, the planet appeared as a 'triplet' (a planet and two large moons), but in 1659 Dutch scientist Christiaan Huygens saw that the two 'moons' were in fact a thin flat ring surrounding the planet. It later became clear that this ring was really a system of rings. Italian astronomer Jean-Dominique Cassini discovered in 1675 that the 'ring' consisted of an outer ring and an inner ring, separated by a darker band, now known as the 'Cassini Division'. Nearly two centuries later, the English physicist James Clerk Maxwell proved that the rings had to consist of many small particles, all orbiting Saturn like individual moons.

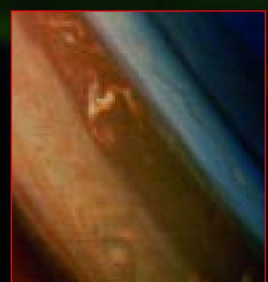
Of all the planets, Saturn still has the highest number of satellite bodies, currently counted at 31. The largest moon, Titan, was discovered by Huygens in 1655. Four more were first observed by Cassini and, thanks to better telescopes, nine more moons were known by the beginning of the 20th century. Titan has its own atmosphere, and in 1944 Dutch-born astronomer Gerard Kuiper discovered that it contained methane. This made Titan unique in the Solar System. A relatively thin atmosphere has only ever been found on two other large moons, Jupiter's Io and Neptune's Triton.

The space age is transforming our knowledge of Saturn and Titan

Saturn and Titan still had many secrets. Before the late 1970s, ground observations had shown Saturn itself to be a large ball of hydrogen and helium, flattened at the poles due to its rapid rotation. Occasionally, light and dark spots could be seen in the vague bands of cloud running parallel to the planet's equator. Virtually nothing was known about the moons, except for their orbits, orbital periods and approximate sizes.

The US Pioneer 11 spacecraft provided sensational discoveries in 1979. Cassini's 'division' was not empty, but consisted of a myriad of thin dust rings. Outside the outermost known ring, yet another ring was found. Saturn proved to have a strong magnetic field, much more powerful than that of Earth. This meant that, like Jupiter, it had to have a core of liquid hydrogen and helium compressed so much that the mixture has the properties of a metal. Strangely, the axis of this magnetic field almost coincides with the planet's axis of rotation; this is unique in the Solar System. Finally, Pioneer 11 discovered that Saturn radiates more heat than it receives from the Sun. Originally it was thought, as with Jupiter, that this was due to the slow shrinking of the planet. However, from detailed calculations it emerged that Saturn cannot shrink any further and had already reached its current size 2000 million years ago.

Courtesy NASA/JPL-Caltech



High-speed winds blow parallel to Saturn's equator.

NASA/R. Beebe/D. Gilmore, L. Bergeron, STScI/NASA

Storms on Saturn as seen by the Hubble Space Telescope.

When Voyager-1 encountered the planet in 1980, it saw cloud cover, storms and weather systems. To everyone's surprise, the clouds above the equator appeared to travel with the highest velocity ever measured in the Solar System – up to 1800 kilometres an hour! Polar auroral lights were also observed for the first time. Both Voyagers photographed the moons known at that time, and discovered some new ones; most consisted mainly of ice and rock, and were strewn with craters sometimes so big that they would cover a large proportion of the moon's surface. They observed a breathtaking collection of 'ringlets', bands often no thicker than a few tens of metres in a subtle balance between the gravity of the planet and that of nearby moons. The particles in the rings ranged in size from near-invisible dust grains to icebergs the size of a house.

Saturn has also been a frequent target of the NASA/ESA Hubble Space Telescope, which has produced stunning views of long-lived hurricane-like storms in the planet's atmosphere. The world's major telescopes, including Hubble, were recently trained on Saturn to observe an event known as a 'ring plane crossing' when the rings are seen edge-on from Earth. During these crossings, faint objects near the planet are easier to see. Many of Saturn's known moons were discovered during these crossings.

Titan was also observed by the two Voyagers, as well as other telescopes. Both spacecraft could observe its mysterious orange atmosphere, rich in nitrogen, methane and other organic compounds. In 1998 ESA's Infrared Space Observatory (ISO) discovered the presence of water vapour in Titan's atmosphere. Basically Titan exhibits many similarities to conditions that may well once have prevailed on Earth before life appeared.

Cassini-Huygens, named after the two celebrated scientists, is the joint NASA/ESA/ASI mission to Saturn and its giant moon Titan. It is designed to shed light on many of the unsolved mysteries arising from those previous observations.

- What is the source of heat inside Saturn that produces 87% more energy than the planet absorbs from sunlight?
- What is the origin of Saturn's rings?
- Where do the subtle colours in the rings come from?
- Are there any more moons?
- Why has the moon Enceladus such an abnormally smooth surface? (Has recent melting erased craters?)
- What is the origin of the dark organic material covering one side of the moon Iapetus?
- Which chemical reactions are occurring in Titan's atmosphere?
- What is the source of the methane, a compound associated with biological activity on Earth, which is so abundant in Titan's atmosphere?
- Are there any oceans on Titan?
- Do more complex organic compounds and 'pre-biotic' molecules exist on Titan?

High ambitions for an outstanding planetary mission

In many respects, a journey to Saturn is a journey back to the origins of the Solar System. Saturn's rings and moons are a model of the archetypal Solar System, when fragments of rock and ice collided with each other and melted on a grand scale. Titan, Saturn's most interesting moon, is similar to the primeval Earth in its frozen state. Perhaps the building blocks of life have been preserved there? This environment is certainly an intriguing place where time appears to have stood still for billions of years.

Cassini-Huygens is the most ambitious effort in planetary space exploration ever mounted. The mission calls for a sophisticated robotic spacecraft to orbit the ringed planet over a four-year period and a scientific probe called 'Huygens' to be released from the main spacecraft, parachuting through the atmosphere of Titan and eventually landing on its surface.

Cassini-Huygens is a masterpiece of collaboration that, from the initial vision in the early 1980s to the completion of the nominal mission in July 2008, will span nearly 30 years. It is a joint endeavour by the US National Aeronautics and Space Administration (NASA), providing the Cassini orbiter, the European Space Agency (ESA), providing the Huygens probe, and the Agenzia Spazio Italiana (ASI) that, through a bilateral agreement with NASA, is providing hardware systems for the Cassini orbiter and instruments.

The twelve scientific instruments on the Cassini orbiter will conduct in-depth studies of the planet, its rings, atmosphere, magnetic environment and a large number of its moons. The six instruments on the Huygens probe will provide our first direct and detailed sampling of Titan's atmospheric chemistry and the first photographs of its hidden surface.

Courtesy NASA/JPL-Caltech

The complex Saturnian system resembles an archetypal Solar System.

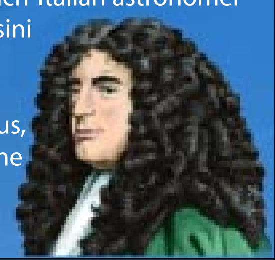
Courtesy NASA/JPL

Artist's impression of the Cassini-Huygens mission at Saturn and Titan.

© ESA

The Huygens probe descending onto Titan

The Mission at a Glance

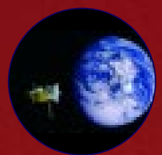
	Cassini Orbiter	Huygens Probe
Mission name	Named after the French-Italian astronomer Jean-Dominique Cassini (1625-1712), who discovered the four major moons – Iapetus, Rhea, Tethys and Dione – and the 'Cassini Division' 	Named after the Dutch scientist Christiaan Huygens (1629-1695), who discovered Saturn's rings and Titan. 
Destination	Saturn and its moons	Titan
Objectives	In-depth studies of Saturn, its atmosphere, rings, magnetic environment and moons	First direct sampling of Titan's atmospheric chemistry and first photographs of the surface
Experiments	12 instruments, led by the USA, Germany and United Kingdom	6 instruments, led by France, Italy, Germany, the United Kingdom and the USA
Launch date	15 October 1997, from Cape Canaveral (Florida, USA)	
Launcher	Titan-IVB/Centaur	
Expected operational lifetime	Four years, from 1 July 2004 (Saturn Orbit Insertion) to 1 July 2008	22 days, including up to 2.5 hours of descent through Titan's atmosphere and a few hours on its surface
Ground operations	NASA JPL, using stations of NASA's Deep Space Network in California, Spain and Australia.	ESA's European Space Operations Centre (ESOC) in Darmstadt, Germany.

A long and rich journey

Cassini-Huygens has taken almost seven years to reach its final destination, the Saturnian planetary system, which lies more than 1200 million kilometres from Earth. Based on the alignment of the planets and the capabilities of the launch vehicle, the spacecraft was launched in October 1997. The launch boosted the spacecraft into a Venus-Venus-Earth-Jupiter gravity-assist trajectory to reach Saturn on 1 July 2004. During each planetary fly-by, the spacecraft increased its speed relative to the Sun and gained the cumulative boosts it needed to reach its target. The long journey also provided an excellent opportunity to make scientific observations of several targets on the way. Once at Saturn, Cassini-Huygens will make 75 orbits around the planet, fly-bys of several of its moons, including Phoebe, Enceladus, Rhea, Dione, Hyperion and Iapetus, with 45 encounters with Titan.

- **15 October 1997: Launch**, at 08:43 UT, from Cape Canaveral by a Titan IVB/Centaur rocket. After being placed in a parking orbit around Earth, the Centaur upper stage was fired to send the spacecraft on an interplanetary trajectory to Saturn.

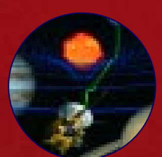
- **27 April 1998: 1st Venus fly-by**, at 287 km from the planet. The spacecraft searched for radio emissions from lightning in Venus's atmosphere.
- **24 June 1999: 2nd Venus fly-by**, at 600 km from the planet. The spacecraft studied the chemical composition of the Venusian environment and detected energetic neutral atoms escaping from Venus's atmosphere. No evidence of radio emission from lightning was observed.



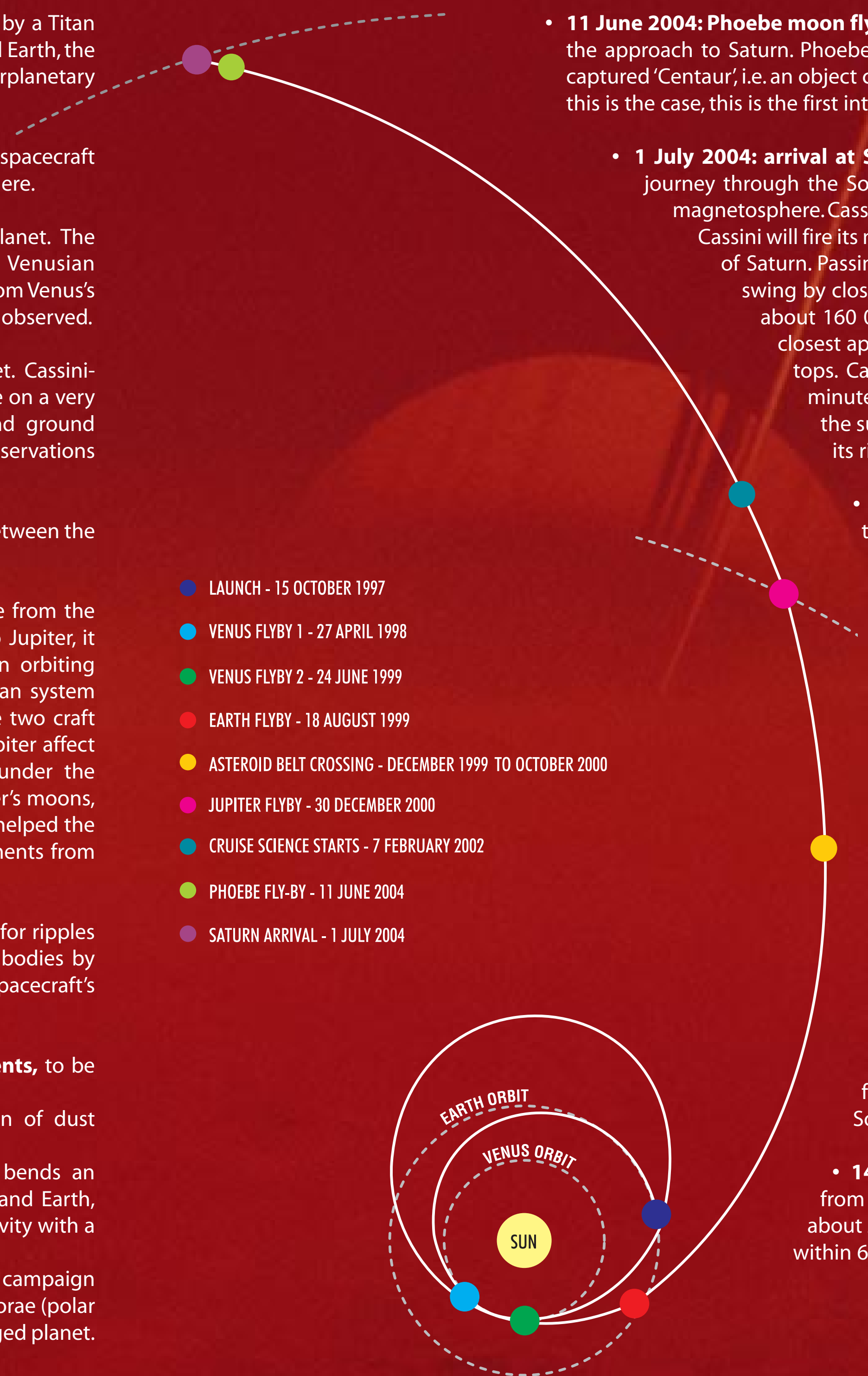
- **18 August 1999: Earth fly-by**, at 1171 km from the planet. Cassini-Huygens provided a unique view of the Earth's magnetosphere on a very short time scale and, in combination with other space and ground observatories, participated in an international campaign of observations of Earth's space environment.

- **December 1999-October 2000: crossing the asteroid belt**, between the orbits of Mars and Jupiter.

- **30 December 2000: Jupiter fly-by** at 9.7 million km distance from the planet. During the six months in which Cassini was closest to Jupiter, it collaborated with NASA's Galileo spacecraft, which had been orbiting Jupiter since 1995, for the rare opportunity to study the Jovian system from two different nearby perspectives at the same time. The two craft monitored how fluctuations in the solar wind approaching Jupiter affect the planet's magnetosphere, a vast region of ionised gas under the influence of Jupiter's magnetic field. They also examined Jupiter's moons, rings and storm clouds. During this phase, the Huygens probe helped the Cassini high-gain antenna to shield the orbiter and its instruments from solar radiation.
- **2001-2003: Gravitational-wave experiments.** Cassini looked for ripples in the fabric of space caused by the acceleration of massive bodies by studying possible - almost imperceptible - fluctuations in the spacecraft's speed relative to Earth.



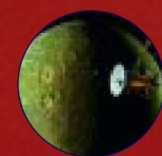
- **February 2002: Cassini started its cruise-science experiments,** to be concluded on arrival at Saturn:
  February 2002: interplanetary dust detection, and detection of dust streams coming from Jupiter.
  Summer 2002: by measuring how much the Sun's gravity bends an electromagnetic beam propagating between the spacecraft and Earth, Cassini tested the validity of Einstein's Theory of General Relativity with a precision 50 times higher than previous measurements.
  January-June 2004: approach science. In a joint observation campaign with the Hubble Space Telescope, Cassini observed Saturn's aurorae (polar lights), upstream of solar wind and radio emissions from the ringed planet. It also observed the planet's atmosphere, rings and Titan.



- **11 June 2004: Phoebe moon fly-by** at about 2000 km from the moon. This fly-by marked the beginning of the approach to Saturn. Phoebe's darkness and irregular, retrograde orbit suggest that it is most likely a captured 'Centaur', i.e. an object coming from a region of the outer Solar System known as the 'Kuiper Belt'. If this is the case, this is the first intensive opportunity scientists will have to study a Kuiper-Belt object.

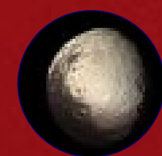
- **1 July 2004: arrival at Saturn.** Saturn Orbit Injection (SOI) will mark the end of the spacecraft's journey through the Solar System, and the beginning of its tour of Saturn, its rings, moons and magnetosphere. Cassini-Huygens will approach Saturn from below the ring plane. On 1 July 2004, Cassini will fire its main engine for 96 minutes to brake and allow it to be captured as a satellite of Saturn. Passing through the large gap between the F-ring and G-ring, Cassini will then swing by close to the planet to begin the first of 75 orbits. Cassini-Huygens will then be about 160 000 km from Saturn's centre. One hour later the spacecraft will achieve its closest approach of the whole mission, passing less than 18 000 km above the cloud tops. Cassini-Huygens will then coast above the rings for another hour and 44 minutes before descending back through the ring plane. The SOI burn is critical to the success of the mission. In this phase, the spacecraft's proximity to Saturn and its rings provides a unique opportunity for a close-range study.

- **26 October 2004: 1st Titan fly-by** at 1200 km distance. Cassini will make the first direct sampling of Titan's atmosphere and the first radar probing of its surface.
- **13 December 2004: 2nd Titan fly-by** at 2350 km distance.

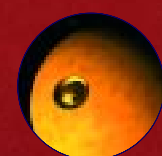


- **15 December 2004: Dione fly-by** at 84 000 km altitude, to study the moon's icy surface and its irregular features, and investigate its formation process.

- **25 December 2005: Huygens release window opens.** After three revolutions around Saturn, the Huygens probe will be released to enter Titan's atmosphere and will then coast for a maximum of 22 days before arriving at Titan on 14 January 2005. No systems will be active during this coasting phase except for the timer that will wake up the probe and its instruments 4 hours before the initial encounter with the outer fringes of Titan's atmosphere. In the meantime, five days after Huygens' release, Cassini will perform a deflection manoeuvre to position itself with the proper geometry to collect the data during the Huygens mission.



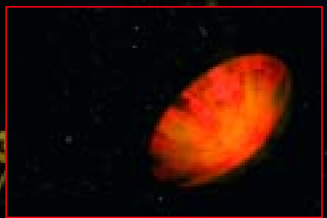
- **1 January 2005: Iapetus fly-by** at 64 000 km distance, to study this 'two-faced' moon covered on one side with some of the darkest material in the Solar System, and very bright on the other side.



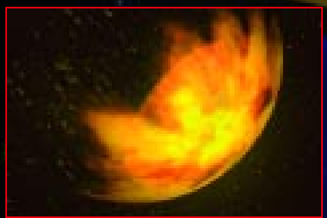
- **14 January 2005: Huygens descent.** No later than 22 days after its release from Cassini, Huygens will start its descent through Titan's atmosphere to land about 2.5 hours later. Meanwhile, Cassini will fly-by Titan for the third time, passing within 60 000 km at its closest approach.

Enceladus as seen by Voyager 2.

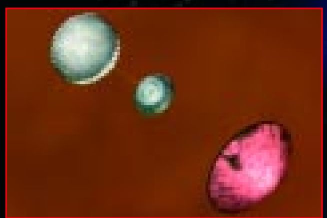
Huygens descent profile



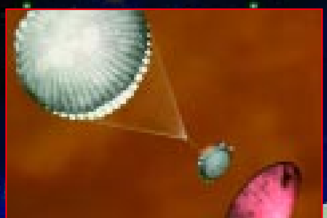
Instruments awoken, and radio link activated so that the orbiter can listen to the probe for the next 4.5 hours (after that Cassini will disappear behind Titan's horizon).



During the first three minutes inside Titan's atmosphere, Huygens will decelerate from 18 000 to 1400 km/h. The temperature of the gas heated by friction with the Huygens heatshield may reach 8000°C.

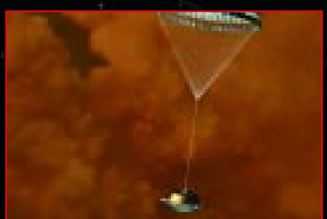


Pilot parachute automatically deployed to pull out the main parachute at a speed of about 1500 km/h. Speed reduced to less than 300 km/h within a minute.



The shell of the descent module falls away and exposes the scientific instruments to Titan's atmosphere at a height of about 160 km. The atmospheric temperature may then be about -120°C.

15 minutes later at about 120 km, the main parachute will be cut away and replaced by a smaller one, designed to allow a steady descent at about 20 km/h.
At about 45 km altitude, the probe will go through the coldest layer of the atmosphere, at about –200°C.



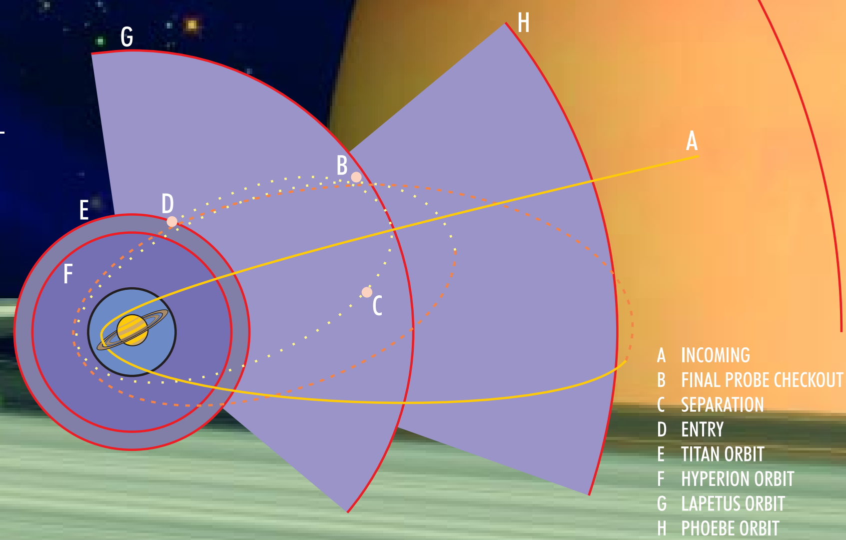
A radar altimeter will measure the probe's altitude during the last 10-20 km. During its descent, the probe's camera will capture images of Titan's cloud deck and surface. Data from Huygens will be relayed to Cassini passing overhead for later playback to Earth.

Cassini's exploration of Saturn continues

After the Huygens portion of the mission, Cassini's focus will shift to making measurements with the orbiter's 12 instruments and returning the information to Earth. Cassini will study Saturn's polar regions in addition to the planet's equatorial zone. Observations of seven selected icy moons will be made, plus at least two dozen more-distant fly-bys of other moons and there will be more than 44 encounters with Titan (also used for gravity-assist orbit changes that shape the Cassini orbital tour).

- **15 February 2005:** 4th Titan fly-by at about 950 km altitude.
- **17 February 2005:** 1st Enceladus fly-by at about 2900 km altitude. This smooth moon is ten times as bright and reflective as the Earth's moon. Its orbit is embedded in the thickest part of the E-ring.
- **9 March 2005:** 2nd Enceladus fly-by at about 750 km altitude.
- **2005-2008:** Cassini continues Saturn observations and Titan fly-bys.
- **1 July 2008:** Nominal end of the Cassini-Huygens mission.

Cassini will also study Rhea (top), Saturn's second largest satellite after Titan, and Tethys (bottom). They are both icy, densely cratered satellites.



History of a mission scenario

When a communications test on the Huygens probe was performed in February 2000, nobody foresaw the dramatic impact that its results would have on the Cassini-Huygens mission. An unexpected anomaly in the probe's communications system meant that, during the descent to Titan, most of the scientific data would have been lost, unless the two spacecraft were moving at relative velocities quite different from those initially planned.

This was due to a design flaw in the Huygens receiver, which meant it was unable to compensate for the frequency shift between the signal emitted by the probe and the one received by the moving orbiter, the so-called 'Doppler' shift. Given the impossibility of fixing an anomaly in the hardware on a spacecraft speeding towards Saturn, the Cassini-Huygens engineers faced a huge challenge to save the Huygens mission. After six months of intensive work, the ESA/NASA Huygens Recovery Task Force came up with a solution: the first two Cassini orbits around Saturn would be shortened and an additional orbit, much higher than originally planned, would be inserted. The dates of the first two Titan fly-bys had to be delayed, with Huygens being released during a third fly-by (25 December 2004) from which the probe would get to Titan in a maximum of 22 days, seven weeks later than originally planned.

In addition, the probe and instrument software had to be modified to cope with the earlier wake-up of Huygens.

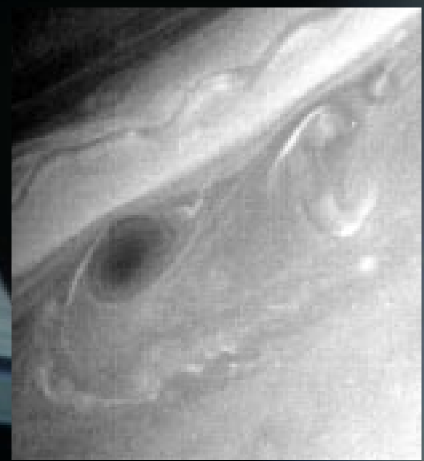
With this new scenario, Cassini will be able to receive Huygens' data and to resume its original trajectory in February 2005. This solution has been achieved at the cost of reducing by only a quarter the amount of fuel available for Cassini to possibly extend its four-year mission. Pioneering space exploration is all about thrilling moments - problems can easily arise, and a measure of a team's excellence is the manner in which it solves them!

What lies beneath?


© NASA/JPL-Caltech

Saturn's cloud structure.

Saturn, the second most massive planet in the Solar System after Jupiter, is a treasure - trove of opportunities for discovery. The Cassini orbiter has a host of investigations and experiments to perform once in orbit. It will study the planet itself, the ring structure, the moons, the magnetic field and Titan. Not only will it determine the present state of these bodies and the processes operating on or in them, but it is also equipped to uncover the interactions that occur between them.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Atmosphere of Saturn.

Facts about Saturn

Type of planet:	Gas giant
Average distance from Sun	9.6 AU (1 Astronomical Unit is the average distance from the Earth to the Sun, about 150 million kilometres)
Orbital period (Saturnian year)	29 years and 5.5 months
Rotation period around axis (Saturnian day)	10 hours and 39 minutes
Mass	95.2 Earth masses
Volume	More than 750 times that of the Earth
Diameter at equator	120 536 km (about 10 times the size of Earth). 1 Saturn radius is 60 268 km at the equator
Diameter pole to pole	108 728 km
Average density	0.7 g/cm3 (that of the Earth is 5.4 g/cm3)
Composition	Mainly hydrogen (96 %) and helium (4 %)
Temperature at cloud surface	-139°C
Temperature at core	Expected to be around 10 000°C
Width of ring system	From a few thousand to a few hundred thousand km above the cloud top
Average thickness of the ring system	Between 30 and 500 metres
Number of known moons	31 (13 discovered by ground telescopes after the launch of Cassini-Huygens)

Gas planet

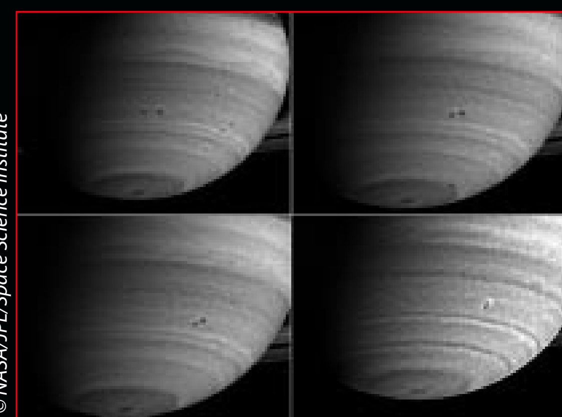
Saturn is a sister world to Jupiter and both are essentially gigantic balls of gas. It is mostly a mixture of hydrogen and helium, but many other chemical elements are present too. Saturn is the least dense of all of the planets and, if you could find an ocean big enough, Saturn would float on water.

Saturn spins very quickly - once every 10 hours and 39 minutes - so that the planet bulges at its equator. Unlike Jupiter, the colour of Saturn's cloud layers is muted and subtle. This is because a deep layer of haze sits above the visible cloud layers, and has the effect of 'washing-out' the colours. Computer simulations suggest that Saturn has no surface to land on; instead the atmosphere gets denser with depth until it begins behaving like a highly compressed liquid. Cassini will probe Saturn's interior indirectly by studying the effect of the planet's gravity on the spacecraft's trajectory and by measuring the planet's magnetic field.

Winds and weather

Despite its serene appearance, Saturn's atmosphere is a violent place. Cassini will therefore monitor the 'weather' as this will give clues to the chemistry of the atmosphere and the interior processes of the planet. Wind speeds have been clocked at a staggering 1800 km/h near the equator. Cassini will monitor these and also measure temperature variations across the planet.

Occasionally, white storms – bigger than Earth – erupt through the cloud layers. The last of these occurred in 1994 and was observed by the Hubble Space Telescope. Cassini scientists hope for another similar such event to take place when their spacecraft is at Saturn and thereby get a closer view.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Between February and March 2004 Cassini has observed two storms merging, both with diameters close to 1000 km.

The deep interior

Deep inside Saturn there must be a source of energy. Mysteriously, the planet radiates 87% more power than it absorbs. At ten times the distance of the Earth from the Sun, Saturn only receives 1% of the sunlight that we do. The planet reflects one third of it back into space, absorbing the rest. To

© Jon Williams/NASA/JPL

Saturn's ring particles in range in size from dust grains to rocks the size of a house.

account for the extra energy radiated by Saturn, scientists believe that helium may be 'raining' through the atmosphere, releasing energy as it sinks. Cassini can measure the precise amount of energy radiated by Saturn, perhaps helping to solve this mystery.

Puzzling rings

Saturn's rings are one of the wonders of the Universe. Although they are over 250 000 km in diameter, they are less than a kilometre thick. They are composed of dust grains and boulder-sized lumps of rock and ice. Pressed together, the rings would make a 'moon' only about 100 km in diameter.

Variations in chemical composition are possibly responsible for the colour of Saturn's rings enhanced in this image.

© NASA/JPL-Caltech

From Earth, the rings appear divided into three main bands, but in reality there are thousands of ringlets, all bunched together. Cassini therefore has plenty to do, mapping these ringlets and measuring their compositions. Scientists will be able to investigate why the rings are arranged like this and how they formed. They could be the debris of a shattered moon, or the leftovers from a moon that never formed.

Discovering Saturn's moons

In addition to Titan, Saturn has 30 more known moons, all of which are rocky and icy worlds. Phoebe is the most distant and orbits the 'wrong' way around the planet, indicating that it was probably captured from the Kuiper Belt.

On these moons, water freezes solid and so geological forces can sculpt it into mountains and impacts can leave craters. However, Enceladus is beautifully smooth, as if its features have been rubbed away. Iapetus is bright on one side but dark on the other. How did these contrasting surfaces come about?

Many of Saturn's moons resemble Jupiter's Europa, which has a global ocean under its icy crust, and many scientists expect to find similar oceans within some of Saturn's moons. Cassini will investigate the characteristics of many of the moons, and will look for clues concerning their formation and evolution.

The mystery of Saturn's magnetosphere

Saturn is surrounded by a giant magnetic field, aligned with the rotation axis of the planet. This cannot be explained by current theories. Cassini's data may explain how the puzzling magnetic field is generated. This field may also cause strange features in the rings called 'spokes'. These markings fall across the rings like spokes in a wheel, and may be caused by electrically charged particles caught up in the magnetic field, but there are as yet no detailed theories about them.

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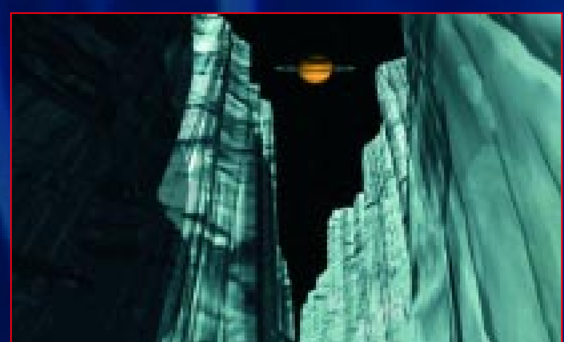

Large ice crevasse on the surface of Phoebe, the least known of all the Saturnian satellites.

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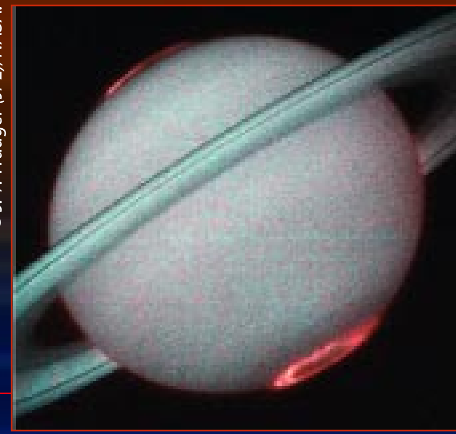

Auroral displays (polar lights) are primarily shaped and powered by a continual tug-of-war between Saturn's magnetic field and the flow of charged particles from the Sun. This image was taken by Hubble in 1997.

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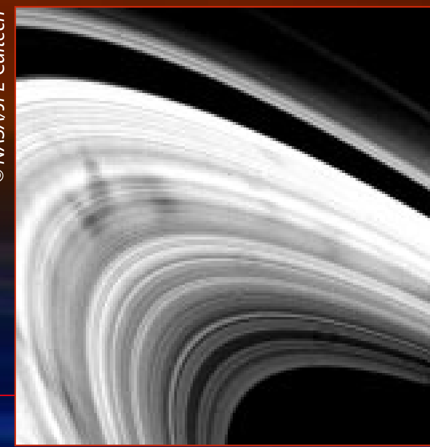


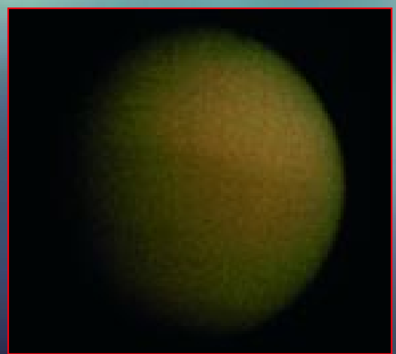
Spokes in Saturn' rings. Their sharp, narrow appearance suggests short formation times.

Science experiments on Cassini

There are twelve instruments mounted on the Cassini orbiter. The scientific experiments are primarily mounted on two platforms: one takes care of the photography and spectroscopy, and the other is equipped for measuring magnetic and electric fields and for detecting neutral and charged particles and dust. In addition, there are several instruments that are body-mounted.

Instrument	Purpose
Imaging Science Subsystem – ISS (USA, F, D, UK)	Takes pictures in visible, near-ultraviolet and near-infrared light.
Cassini radar – RADAR (USA, F, I, UK)	Maps surface of Titan using radar imager to pierce veil of haze. Also used to measure heights of surface features.
Radio Science Subsystem – RSS (USA, I)	Searches for gravitational waves in the Universe; studies the atmosphere, rings and gravity fields of Saturn and its moons by measuring telltale changes in radio waves sent from the spacecraft.
Ion and Neutral Mass-Spectrometer –INMS (USA, D)	Examines neutral and charged particles near Titan, Saturn and moons to learn more about their extended atmospheres and ionospheres.
Visible and Infrared Mapping Spectrometer – VIMS (USA, F, D, I)	Identifies the chemical compositions of the surfaces, atmospheres and rings of Saturn and its moons by measuring colours of visible light and infrared energy emitted or reflected.
Composite Infrared Spectrometer – CIRS (USA, F, D, I, UK)	Measures infrared energy from the surfaces, atmospheres and rings of Saturn and its moons to study their temperature and compositions.
Cosmic Dust Analyser – CDA (D, CZ, F, UK, USA, ESA)	Studies ice and dust grains in and near the Saturnian system.
Radio and Plasma-Wave Spectrometer – RPWS (USA, A, F, S, UK, N)	Investigates plasma waves (generated by ionised gases flowing out from the Sun or orbiting Saturn), natural emissions of radio energy and dust.
Cassini Plasma Spectrometer – CAPS (USA, F, FIN, HU, N, UK)	Explores plasma (highly ionised gas) within and near Saturn's magnetic field.
Ultraviolet Imaging Spectrograph – UVIS (USA, F, D)	Measures ultraviolet energy from atmospheres and rings to study their structure, chemistry and composition.
Magnetospheric Imaging Instrument – MIMI (USA, F, D)	Images Saturn's magnetosphere and measures interactions between the magnetosphere and the solar wind, a flow of ionised gases streaming out from the Sun.
Dual-technique Magnetometer – MAG (UK, D, USA, HU)	Studies Saturn's magnetic field and its interactions with the solar wind, the rings and the moons of Saturn.

Mysterious Titan

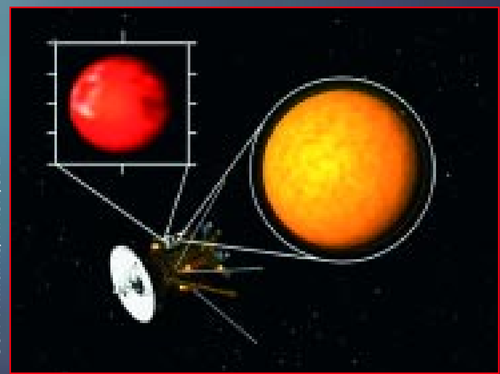


What secrets has Titan still to reveal?

Titan is a truly fascinating world. It is freezing cold, with temperatures reaching minus 180°C, and has a very thick atmosphere whose origin is still unknown, consisting mainly of nitrogen, just like Earth, but also very rich in organic compounds which are constantly reacting. In particular, a few percent of methane is continuously resupplied in Titan's atmosphere by a mechanism that is still a mystery.

Orange-coloured clouds and mist due to the organic haze are so opaque that the surface can hardly be seen. They are created by sunlight and cosmic rays breaking down the methane in the atmosphere, and producing a range of complicated organic compounds that float down to the surface to accumulate over time.

In this image of Titan taken in May 2004, Cassini has already surpassed the best views of the moon taken from Earth.



The Cassini spacecraft investigating Titan's atmosphere (left) and surface (right) from orbit.

Titan also has a 'greenhouse-warmed' climate, as does the Earth, but sustained by different gases. Volcanoes and impacts shape the surface and maybe provide energy to make even more complex organic molecules. Water cannot exist in liquid form because the surface is far too cold, unless it exists for relatively short periods because of the heat generated by volcanism or asteroid impacts. Very little is known about the moon's surface and scientists speculate that Huygens may find lakes or even oceans of a mixture of liquid ethane, methane and nitrogen, and possibly underground reservoirs. It seems that the pressure and temperature on Titan's surface are sufficient to liquefy these natural gases.

Distance from centre of Saturn	1 221 870 km (= 20.3 Saturn radii)
Orbital period (Titanic day)	About 16 Earth days
Diameter	5150 km (larger than Mercury - 4878 km, and slightly smaller than Jupiter's Ganymede – 5262; Earth's Moon is only 3476 km)
Atmospheric thickness	More than 1000 km
Mass	1/45 of Earth's mass (more massive than Pluto)
Expected surface temperature	About -180°C
Surface pressure	About 1.5 times higher than on Earth
Average density	About 1.9 times the density of water

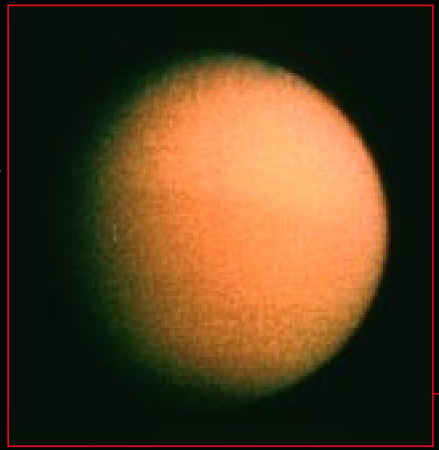
Both Cassini and Huygens will look at Titan, and their combined data will greatly improve our understanding of this mysterious moon. They will study its atmospheric chemistry and investigate the energy source that makes it so active. They will also look into Titan's 'weather', measuring winds and temperatures, cloud physics and circulation, lightning and seasonal changes, as well as possible climate changes.

The physics, topography and composition of the surface will all be investigated. By measuring possible magnetic changes around the moon, Cassini may be able to determine whether there are underground liquid-hydrocarbon reservoirs. Both Cassini and Huygens will provide clues about the moon's inner structure. Cassini will also see how Titan's upper atmosphere interacts with the magnetosphere of Saturn and if it has a significant magnetic field of its own. The combined observations of Cassini and Huygens will help constrain the possible scientific scenarios for the formation and the evolution of Titan and its unique atmosphere.

A drop into the unknown

The whole of the Huygens scientific mission is to be carried out during just 2.5 hours of exciting descent through Titan's atmosphere and up to a few hours on its surface. Despite such a short mission duration, however, scientists will be able to gather a huge amount of scientific data that

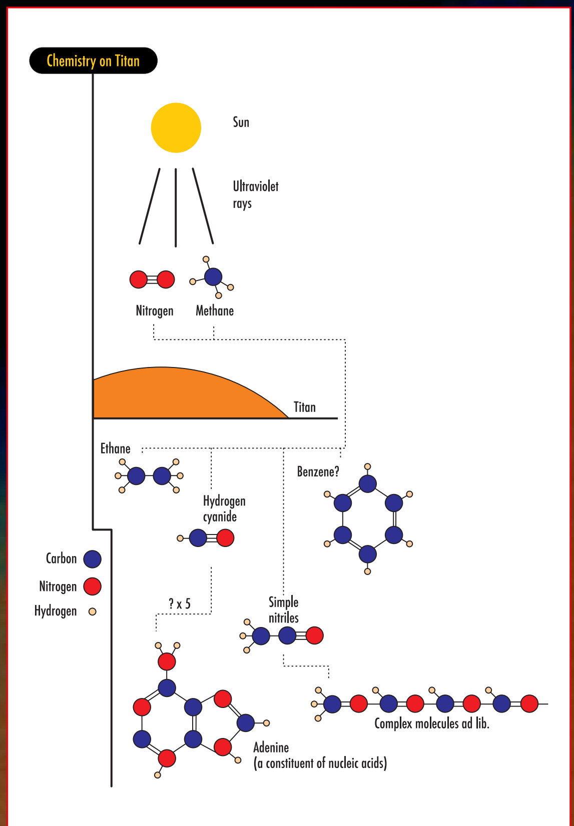
Huygens will be the first probe to descend to the surface of a world in the outer Solar System, and will make detailed studies of Titan.



Titan as seen by Voyager.

will make their enormous efforts worthwhile. Even if the probe does not survive the landing, the mission will be considered a tremendous success.

Is there a primeval Earth around the corner?



What chemical tricks can the Sun's rays play in Titan's atmosphere?

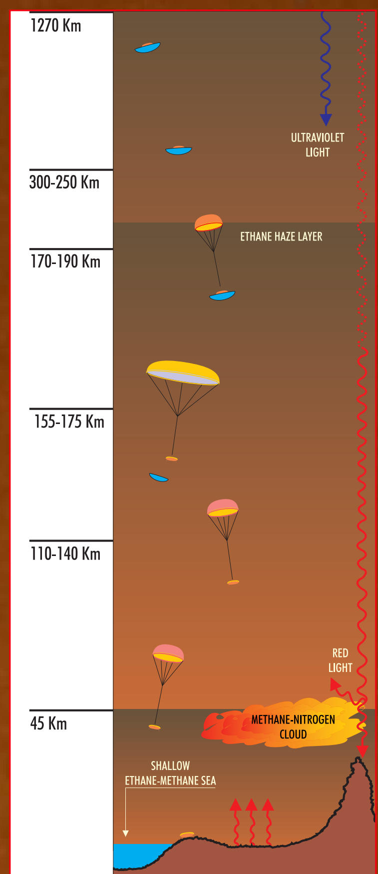
One of the main reasons for sending Huygens to Titan is because in some ways it is the closest analogue to Earth before life began. Its atmosphere and surface may contain many chemicals of the kind that existed on the young Earth, and stocked the primeval soup in which the first living organisms appeared. It is known that complicated carbon molecules are present in cosmic space, but ultraviolet light from the Sun, cosmic rays and lightning strokes could also manufacture carbon compounds on planets like Earth.

Huygens will investigate this 'home cooking' on Titan. It will identify the complex molecules by their masses, and by their speeds of transit through various filters. It will collect particles from the atmosphere and use an oven to vaporise them for identification. Even today, we still do not know how the self-sustaining assemblies of nucleic acids, proteins and fats at the basis of life came into existence. By identifying the likely chemical precursors that filled the primeval soup, Huygens will give a fresh impetus to the theories regarding the origin of life on the Earth.

Weather and chemistry in the haze

Meteorologists will be fascinated by the parallels and contrasts with the weather on Earth, in a world where clouds and raindrops are made of methane and nitrogen. Winds of 500 km/h, which are expected to diminish during the descent, will propel Huygens sideways when the main parachute opens. The probe will be able to deduce the prevailing wind speeds and provide detailed weather information, such as temperature and pressure. It will also be able to measure the electrical properties of the atmosphere and register radio pulses from lightning strokes, if they occur. A microphone will listen for thunderclaps.

Huygens will rotate as it drops, and its cameras will scan the scene over 360°, imaging the cloud layers. The view will be very fuzzy, with the Sun plainly visible, but its halo will allow the probe to measure the size and abundance of the haze particles, while the spectrometers will measure the heat flows inwards from the Sun and outwards from Titan into space. These instruments will tell us about the kind and number of molecules in the atmosphere, and will analyse aerosol (dust) particles distributed in two layers of Titan's atmosphere (between 150 and 40 km altitude, and at around 20 km altitude).



Hard landing or splashdown?

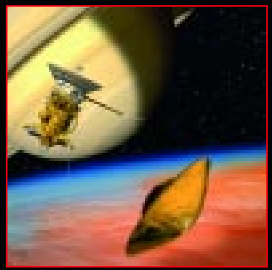
As the probe breaks through the cloud deck, its camera will take up to 1100 pictures of the panorama and observe surface properties. Perhaps 50 km above the surface, the haze may clear and give Huygens its first glimpse of the surface between fluffy cloud-tops. A radar altimeter will help to determine Titan's surface characteristics by listening for echoes. A special lamp, turned on for the final stage of the descent, will allow accurate measurement of the colours of the surface to help the probe's spectrographs analyse its composition.

Will Huygens land in an ocean of methane and ethane, with coloured organic icebergs, or on solid land with geysers spouting methane from underground reservoirs? Will it see volcanoes erupting with ammonia and water? If the probe survives the landing, the Surface Science Package will come into its own for the last phase of the mission. It will be able to tell whether it is in a liquid, and the chemical composition of that liquid. It may even detect waves and measure the depth. It will be able to deduce the ratio of methane to ethane in the liquid, which will give an indication of how long Titan has spent converting the one into the other. Scientists should then be able to judge whether the ocean is as old as Titan, or a later addition. On a dry surface, Huygens will be able to measure its hardness and whether the surface is level.

Huygens may splash down on a sea of hydrocarbons. Simulations have shown that waves produced by Titan's winds would be up to seven times higher than on Earth's oceans but would move more slowly.

Science experiments on Huygens

Instrument	Purpose
Gas Chromatograph and Mass-Spectrometer – GCMS (USA, A, F, D)	Measures the chemical composition of gas in the atmosphere
Aerosol Collector and Pyrolyser – ACP (F, A, USA)	Measures the chemical composition of aerosols (dust)
Descent Imager (panoramic camera) and Spectral Radiometer – DISR (USA, D, F, CH)	Takes images to study the distribution of aerosols (dust) and cloud droplets and to determine the nature of the surface. Makes spectral measurements to record the thermal properties of the atmosphere and measure its composition.
Huygens Atmosphere Structure Instrument – HASI (F, I, A, D, E, N, FIN, USA, UK, ESA, IS, P)	Measures the temperature, density and electrical properties of the atmosphere during the entry, descent and after landing. Research into lightning on Titan
Doppler Wind Experiment – DWE (D, I, USA)	Measures the vertical wind profile and the horizontal winds via the propagation of radio signals through the atmosphere
Surface Science Package – SSP (UK, F, PL, USA, ESA)	Studies the state (physical properties and composition) of the surface at the impact site



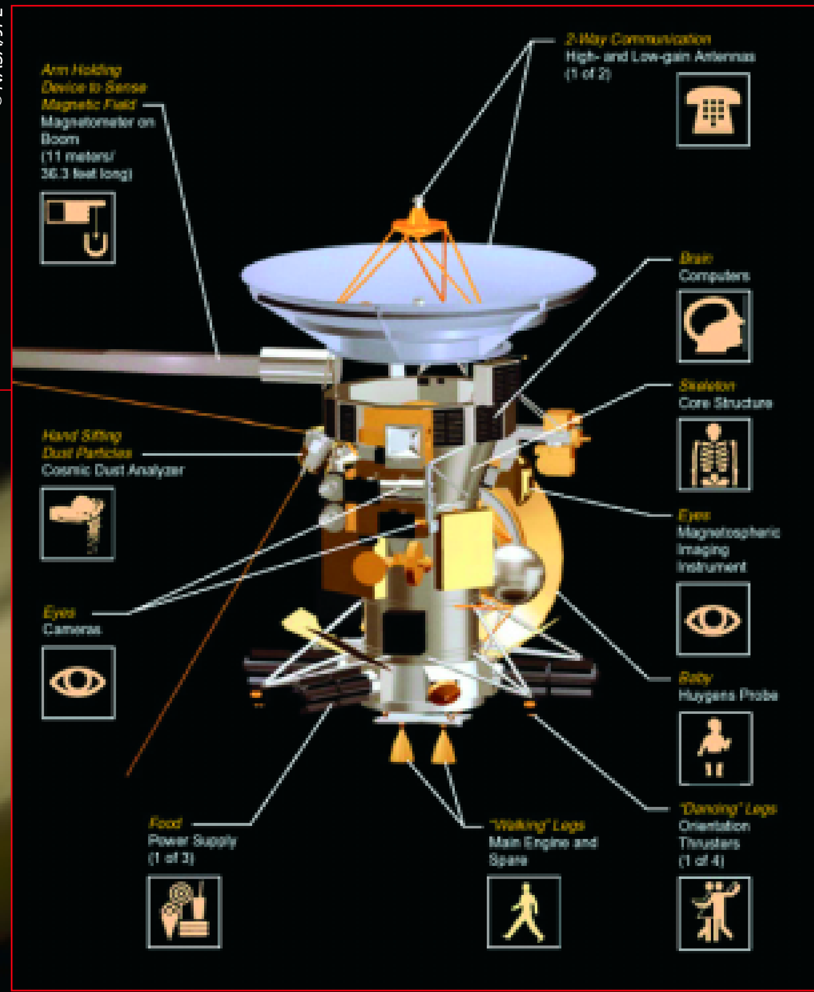
Vehicles of discovery

Cassini, including the Huygens probe, is the largest, heaviest and most complex interplanetary spacecraft ever built. With such a complicated space mission requiring many instruments to operate simultaneously, there is a major impact on spacecraft resources, such as electrical power. This demand – and the need for a broadly based, diverse collection of instruments – is the reason why the Cassini-Huygens spacecraft is so large. When it was built, Cassini was also the first inter-planetary spacecraft to have on-board solid-state recorders instead of tape recorders.

The antenna subsystem on the Cassini orbiter consists of the 4-m high-gain antenna and two low-gain antennas. The primary function of the high-gain antenna is to support communication with Earth and to receive Huygens' signals during its mission. It is also used for scientific experiments. During most of the early part of the journey, the high-gain antenna was directed towards the Sun, functioning like an umbrella to shield the spacecraft's instruments from harmful rays.

Huygens is attached to Cassini by a separation mechanism, which will push it off towards Titan at the right moment. The mechanism will also start the probe rotating, to make sure that it is stabilised and enters the atmosphere front-shield-first. Huygens is built like a shellfish, with a hard shell (carbon-fibre honeycomb covered by silica-fibre tiles) to protect its delicate interior from extreme temperatures (up to 8000°C) during the descent through Titan's atmosphere. The probe consists of two parts: the Entry Assembly Module and the Descent Module. The Entry Assembly Module carries the equipment to control Huygens after its separation from Cassini, and has a front shield that will act both as a brake and as thermal protection. The Descent Module contains the six scientific instruments. The probe will use three different parachutes in sequence during the descent.

	Cassini orbiter	Huygens probe
Dimensions	More than 6.7 m high and more than 4 m wide. Deployed appendages extend up to 11 m from the body of the spacecraft.	2.7 m in diameter
Launch mass	Total Cassini-Huygens mass at launch was 5.82 tonnes, including 3.1 tonnes of propellant	
	Cassini (dry) mass: 2125 kg	Huygens mass: 348 kg (=318 kg for the Huygens probe and 30 kg for the Probe Support Equipment which remains attached to the orbiter after separation)
Ground operations	NASA's JPL, using NASA's Deep Space Network stations in California, Spain and Australia.	ESA's European Space Operations Centre (ESOC) in Darmstadt, Germany.
Prime contractor	NASA's JPL, Pasadena, California. The high-gain antenna is provided by ASI.	Alcatel, France, managed by ESA (ESTEC, The Netherlands)
Cost	2245 MEuro* (2100 MEuro from NASA, plus 145 MEuro from ASI for the high-gain antenna and portions of three instruments) * Current economic conditions	460 MEuro* (360 MEuro from ESA for the Huygens probe, plus about 100 MEuro for the scientific instruments provided by European universities and research institutes funded by ESA Member States and NASA).



Cassini orbiter's main components.

Because of the very dim sunlight at Saturn's orbit, solar arrays were not an option on the Cassini orbiter, and so the electrical power needed to operate the spacecraft and its 12 instruments is supplied by a set of radio-isotope thermoelectric generators, which use heat produced by the harmless natural decay of plutonium-238. These power generators were also used on the ESA/NASA Ulysses mission. The energy to operate the Huygens probe is supplied by five onboard batteries, capable of generating 1800 Wh, which can power the mission for up to eight hours.

"Cassini-Huygens to ground control…"

During the early part of the interplanetary cruise, communication between the spacecraft and Earth for checkouts and manoeuvres took place via the two low-gain antennas onboard Cassini. Six months after the Earth fly-by in August 1999, as the spacecraft was getting far away from Earth, communications were switched to the high-gain antenna. During operations at Saturn, the scientific data collected by Cassini's instruments will be stored on the solid-state recorders for about 15 hours each day when the high-gain antenna is not pointed towards Earth. Then, for nine hours each day, the stored data will be relayed back to Earth.

The Huygens probe remains dormant until just before its entry into Titan's atmosphere. Contacts with Huygens during the cruise phase were only possible via an umbilical link with Cassini. This link has been used to subject the probe to periodic checkouts during the journey for health-monitoring and instrument-calibration purposes.

The setting of the timers that will wake up the probe about four hours before it reaches Titan's atmosphere will be the last

1 Heat Shield
2 Front Shield
3 Back Cover
4 Parachute Compartment
5 Descent Module with Scientific Intruments

The Huygens probe in cross-section.

© NASA/JPL

The Cassini spacecraft

commands sent from the ground. Thereafter, Huygens will have to work autonomously.

The probe's radio link with Cassini will be activated automatically in the early phase of the descent and the orbiter will listen to the probe for the next 4-5 hours, storing four identical copies (for redundancy) of the precious Huygens data in its memory units. Within a couple of hours after the end of this communication window, Cassini's high-gain antenna will be turned away from Titan and pointed towards Earth to download the Huygens data.

Cassini flight operations are being conducted from NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, using Deep Space Network stations in California, Spain and Australia. During a 'low-activity' day, Cassini can return approximately one gigabyte of data, while in a 'high-activity' day the volume of data sent back to Earth can reach four gigabits.

The Huygens flight operations are being conducted from ESA's European Space Operations Centre (ESOC) in Darmstadt, Germany. All of the probe's commands are prepared at ESOC and sent via NASA's Deep Space Network to Cassini, which stores them onboard for release to Huygens at a pre-determined time. Huygens data are received back via the reverse path, and distributed to the scientific teams by ESOC.

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The Huygens probe being assembled.

An international endeavour

Hundreds of scientists and engineers from 19 nations, including 17 European countries and the USA, make up the team responsible for designing, building, flying the Cassini-Huygens spacecraft and collecting their scientific data. Of these 19 countries, 17 have been active participants since the mission started.

The mission is managed by NASA's JPL, where the orbiter was designed and assembled. Development of the Huygens probe was managed by ESA. The prime contractor for the probe is Alcatel in France. Equipment and instruments for the mission have been supplied from many European countries and the USA.

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A full-size model of the Huygens probe was drop-tested and landed at Kiruna in Sweden in 1995 during a successful test of the parachutes.

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