# Intensive Titan Exploration Begins

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**The Cassini Orbiter spacecraft first skimmed through the tenuous upper atmosphere of Titan on 26 October 2004. This moon of Saturn is unique in our solar system, with a dense nitrogen atmosphere that is cold enough in places to rain methane, the feedstock for the atmospheric chemistry that produces hydrocarbons, nitrile compounds, and Titan's orange haze. The data returned from this flyby supply new information on the magnetic field and plasma environment around Titan, expose new facets of the dynamics and chemistry of Titan's atmosphere, and provide the first glimpses of what appears to be a complex, fluid-processed, geologically young Titan surface.**

More than two decades ago, the Voyagers 1 and 2 spacecraft encountered Saturn on their grand tour of the solar system. In the summer of 2004, the Cassini mission—a sophisticated, heavily instrumented robotic platform—returned from Earth for a more systematic study of this gas giant with its complex system of satellites and icy rings. The mission had Titan (Fig. 1), Saturn's biggest moon, firmly in its sight.

The European Space Agency (ESA) and the Italian Space Agency collaborated with NASA on the Cassini mission. NASA's Jet Propulsion Laboratory led the development of the Cassini Orbiter and the ESA, that of the Huygens Probe of Titan's atmosphere. Instruments from both sides of the Atlantic were developed for both the Orbiter and Probe payloads. After a 7-year interplanetary cruise, the Huygens Probe was finally released from the Orbiter and successfully parachuted into Titan's atmosphere on 14 January 2005. During descent, it transmitted data back to the Orbiter and even continued to send back data for some time after it landed on Titan's surface. The Huygens data are still being analyzed, but data collected from several instruments on the Cassini Orbiter before, during, and after the first Titan flyby on 26 October 2004 are published in this issue (*1–7*); some reports include data from the second Titan flyby on 13 December 2004.

The orbital tour of a distant giant planet system is an ambitious undertaking. The first such endeavor, the Galileo mission, orbited Jupiter from 1995 to 2003 and sent a probe into its atmosphere. The mission demonstrated that such an in-depth study could provide astonishing discoveries, such as the likely existence of an ocean beneath the surface ices of the jovian moon Europa (*8*).

The Cassini spacecraft was launched in 1997 to study Saturn and its icy rings and at least 34 moons. From the start, the mission put a special focus on the moon Titan. This satellite is a unique object in our solar system (*9*), with a surface pressure 1.5 times as high as that at the surface of Earth and near-surface atmospheric temperatures below 100 K. The nominal mission length of 4 years should allow more than 70 orbits about Saturn; the resulting 44 close flybys of Titan will allow extensive study of its atmosphere and its surface. Close flybys of the moons Enceladus, Phoebe, Hyperion, Dione, Rea, and Iapetus are also part of Cassini's grand saturnian tour (*10*).

Voyager imaged Titan and obtained ultraviolet and infrared spectra from its atmosphere, but was unable to penetrate the orange hydrocarbon haze to get a clear view of the surface. Voyager measurements and stellar occultations suggested that the atmosphere might be cold enough to turn even its highly volatile methane into rain droplets, but speculation regarding possible hydrocarbon lakes or even a global hydrocarbon ocean awaited future validation. Eventually, both the Hubble space telescope and Earth-based radar were able to penetrate the haze and demonstrate that Titan's surface is heterogeneous. But it was left to the Cassini mission to examine this surface in detail.

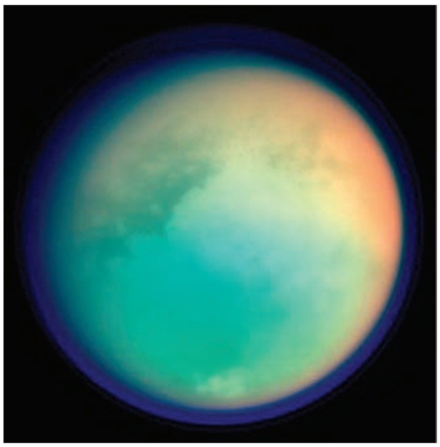

**Fig. 1.** A false-color view of Titan. This false-color image of Titan, derived from multiple wavelengths, was acquired during the first close flyby. Red and green colors (denoting infrared wavelengths) highlight methane, whereas the blue color (ultraviolet) shows the high atmosphere and detached hazes. Clouds are apparent near Titan's South Pole. [Credit: NASA/JPL]

About 1% of Titan's surface was imaged by the Cassini radar on the first flyby. On page 970, Elachi *et al.* (*1*) report a complex, crater-poor surface with evidence of surface flows. Based on these early results, the authors argue that Titan may be cryovolcanically active. The radar is not the only tool available from the Orbiter to view the Titan surface. Future comparison of radar data with imaging data, using spectral bands that penetrate the haze, will facilitate interpretation of surface features. The high-resolution images of the surface obtained by the Huygens Probe just before landing provide ground truth to the Orbital data at one surface location.

The primary constituent of the Titan atmosphere is nitrogen, with several percent of methane and trace amounts of stratospheric hydrocarbons and nitriles. Such a reducing environment may resemble that on early Earth, before microbial activity transformed Earth's atmosphere into a more oxidized state. The simple chemical building blocks of life, such as the amino acids that form proteins, contain both carbon and nitrogen, and knowledge of the prebiotic chemistry on Titan may help to elucidate chemical processes related to early life on Earth. The simplest molecule that contains both nitrogen and hydrogen (HCN) and heavier nitriles are found in Titan's atmosphere.

On page 975, Flasar *et al.* (*2*) derive temperature and wind profiles and provide a refined value for the abundance of $CH_4$ and CO in the atmosphere, based on data from the Cassini Fourier Transform Infrared Spectrometer. They also demonstrate seasonal variations in several trace hydrocarbon and nitrile species (such as $C_2H_4$, $C_3H_4$, $C_4H_2$, HCN, $HC_3N$, and $C_2N_2$) by comparison with abundances of the same species measured at a different time of year during the Voyager flyby. The interplay of atmospheric dynamics and heterogeneous or gas-phase chemistry that produce seasonal effects such as the terrestrial Antarctica ozone hole can now be systematically studied in another atmosphere with Cassini instruments.

Three other papers report imaging of energetic neutral atoms surrounding Titan [Mitchell *et al.*, page 989 (*4*)], measurements of magnetic fields along the path of the spacecraft [Backes *et al.*, page 992 (*3*)], and cold-plasma measurements in Titan's ionosphere [Wahlund *et al.*, page 986 (*5*)]. Together, these highly complementary data sets can be used to model the response of Titan's atmosphere to the input of energetic particles, primarily from the rapidly rotating Saturn magnetosphere. This process not only sends material from Titan into the magnetospheric system; it also provides one energy source for the continuous production of complex hydrocarbons, nitriles, and aerosols from the $N_2$ and $CH_4$ feedstock. On page 978, Shemansky *et al.* (*6*) describe the composition of Titan's upper atmosphere, derived from Cassini ultraviolet spec-

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trometer data using stellar occultations after the 13 December flyby. The chemical composition of the upper atmosphere of Titan along the spacecraft track, derived from mass spectrometer measurements, is reported by Waite *et al.* on page 982 (*7*).

The desire to understand the formation and evolution of extrasolar planetary systems also motivates the detailed study of the Saturn system. Cassini observations will not only test and validate models of the processes that shaped the saturnian system into its collection of rings, satellites, and plasma; they will also provide an improved theoretical basis for understanding the conditions necessary for the emergence of planetary systems around young stars.

The in situ measurements provided by Cassini's flight through the upper atmosphere of Titan may constrain models of how this moon formed (*11*). For example, if CO and $N_2$ were dominant in the formation region of Saturn, clathrates (inclusion compounds within a host lattice such as water) of these molecules, together with the primordial and chemically inert $^{36}Ar$ and $^{38}Ar$ that were present during Titan's formation, might be incorporated into the planet. Alternatively, the source of the present $N_2$ atmosphere might be $NH_3$ that was later transformed into nitrogen. Measurements of the $^{36}Ar$ and $^{38}Ar$ argon isotopes relative to the radiogenic $^{40}Ar$ (released later into this atmosphere from the decay of $^{40}K$) may distinguish between these alternatives. Likewise, tests of how much of Titan's atmosphere may have been lost over its history can come from measurements of the isotope ratios $^{15}N/^{14}N$, because loss to space fractionates these isotopes, with preferential loss of the lighter $^{14}N$. The Cassini Orbiter mass spectrometer data (*7*), combined with Huygens Probe mass spectrometer (*12*) measurements of these same isotope ratios in the deep atmosphere, will provide better observational constraints on models of Titan formation.

The Cassini Orbiter/Huygens Probe mission provides an extraordinary example of a successful international collaboration in space exploration. The navigation (*9*) of this sophisticated science platform precisely to its targeted destination in Titan's upper atmosphere, the successful deployment and entry of the Huygens Probe, the solid performance from the large number of instruments, and the demonstration of the ability to flawlessly plan and execute complex measurement sequences are a tribute to the skill, dedication, and perseverance of the multinational Cassini team. Future Titan flybys will incrementally build up the map of Titan's surface and sample the atmosphere at different locations and seasons. The data from the first flyby reported here (*1–7*) provide a preview of the insights that can be expected from the next several years of exploration and are the first steps toward a substantially deeper understanding of this distant world.

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10.1126/science.1113205

REPORT

# Cassini Radar Views the Surface of Titan

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**The Cassini Titan Radar Mapper imaged about 1% of Titan's surface at a resolution of ~0.5 kilometer, and larger areas of the globe in lower resolution modes. The images reveal a complex surface, with areas of low relief and a variety of geologic features suggestive of dome-like volcanic constructs, flows, and sinuous channels. The surface appears to be young, with few impact craters. Scattering and dielectric properties are consistent with porous ice or organics. Dark patches in the radar images show high brightness temperatures and high emissivity and are consistent with frozen hydrocarbons.**

Saturn's largest satellite, Titan, is the only moon and one of only four solid bodies in the solar system to host a thick atmosphere, uniquely distinguished by nitrogen and methane and a complex suite of organic products of these molecules. Its primitive chemistry may reveal clues about the prebiotic origin of materials that ultimately gave birth to life in our solar system. The mapping of Titan is an especially challenging puzzle because the most likely constituent materials (e.g., water-ammonia and other ices, hydrocarbons, tholins) in this chemical and temperature regime are likely to exhibit different scattering properties than at Earth and Venus, the only other worlds mapped by spaceborne radar (*1–3*).