NEWS & VIEWS

PLANETARY SCIENCE

Huygens rediscovers Titan

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The first analyses of data sent by the Huygens probe from Saturn's largest moon Titan are flooding in. They paint a picture of a 'Peter Pan' world — potentially like Earth, but with its development frozen at an early stage.

Ever since the two Voyager spacecraft passed the Solar System's sixth planet in 1980 and 1981, Saturn — with its beautiful rings and retinue of more than 30 satellites cocooned in a complex, pulsating magnetosphere — has insistently called on us to return. The joint NASA and European Space Agency (ESA) Cassini–Huygens mission, launched from Cape Canaveral on 15 October 1997, was the answer to that call. In this issue, an overview[1] is given of the descent of the Huygens probe through the atmosphere of the largest saturnian moon, Titan, and its subsequent landing on the satellite's surface. The first results[2–7] from the six instruments on board are also presented. These data, even at such an early stage of analysis, are highly enlightening — and are generating exciting questions.

To reach this stage, the Cassini–Huygens mission had first to overcome numerous political and technical challenges. The hardware that was needed to investigate Saturn — an orbiter and at least one atmospheric probe — was beyond the means of any one space agency, calling for a new form of international partnership. So NASA constructed the Cassini orbiter (named after the astronomer Giovanni Domenico Cassini, who discovered four of Saturn's moons), which would carry a range of instruments to investigate the entire Saturn system. ESA, meanwhile, built the Huygens probe (named after Christiaan Huygens, the Dutch physicist and astronomer who discovered Titan) that would enter Titan's atmosphere and descend to its surface. Scientists and engineers from both sides participated in all phases of the project, contributing instruments to both orbiter and probe.

This bold initiative has proved brilliantly successful: after a seven-year journey and insertion into orbit around Saturn, Cassini released Huygens on 25 December 2004. The probe entered Titan's atmosphere on 14 January 2005 and successively deployed its parachutes, taking 2 hours, 27 minutes to descend to the satellite's surface. Once there, it transmitted data via Cassini and a network of antennas around the Earth to the mission's command centre in Darmstadt, Germany, for a further 69 minutes. These were the first signals from the icy surface of a satellite that lies ten times farther from the Sun than does Earth. The reaction of the waiting scientists and engineers is best reflected in the words Huygens himself used as he attempted to imagine Galileo's feelings on discovering Jupiter's satellites: "No small rapture."

But why Titan? Because of its immense distance from the Sun, Titan's development was frozen at a very early stage — where it will remain until the Sun develops into a red giant star and melts it. Larger than the planet Mercury, Titan is a world massive enough and cold enough to have a nitrogen-dominated atmosphere ten times thicker than our own (Fig. 1). Its extremely low temperature keeps water frozen, so that even water vapour is missing from the atmosphere. In contrast, on the warmer inner planets Mars, Earth and Venus, where water vapour is active, carbon compounds become quickly oxidized.

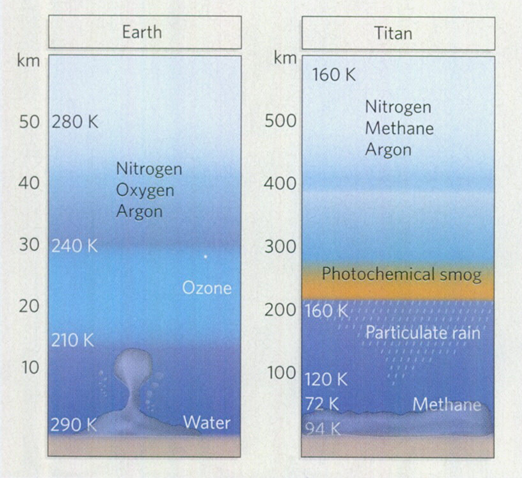

Figure 1 | Comparison between the atmospheres of Earth and Titan. The descent of the Huygens probe[1–7] has allowed the first detailed study of the atmosphere of Saturn's moon Titan, revealing startling parallels — and stark contrasts — with that of Earth. Both atmospheres are nitrogen-dominated, but the low temperature of Titan means that the carbon-carrying gas in its atmosphere is methane (1.6% of the total) rather than carbon dioxide (present at only 345 parts per million). Photochemical reactions involving this methane produce a smog at middle altitudes, and an organic rain of methane and nitrogen-containing aerosols falls steadily onto the satellite's surface, creating an Earth-like terrain of extended river networks. Radiogenic argon (^{40}Ar), which makes up 1% of Earth's atmosphere, is in short supply on Titan (just 43 parts per million). The still smaller amount of primordial argon (^{36}Ar) suggests that the nitrogen in the atmosphere must have arrived in the form of compounds such as ammonia, rather than as molecular nitrogen.

Without water as a source of oxygen, primitive, hydrogen-rich conditions have existed on Titan for billions of years, as signalled by the fact that the dominant carbon-carrying gas is not carbon dioxide, but methane (CH_4). In this atmosphere, photochemical reactions produce thick layers of organic smog that prevent Titan's surface from being viewed at visible wavelengths. The surface temperature of Titan measured by the Huygens Atmospheric Structure Instrument (HASI)[2] is just 94 K, or −179 °C; this would allow the existence of lakes and rivers of liquid methane. Yet this exotic, highly flammable world may offer illuminating insights into the hidden history of the early Earth.

The basic physical characteristics of Titan's atmosphere were determined by HASI and the Doppler Wind Experiment during the Huygens probe's descent. The latter instrument established that the winds at lower altitudes in Titan's atmosphere blow on average in the direction in which Titan is rotating[3], reaching a maximum of 120 metres per second (430 km h^{-1}) at an altitude of about 120 km. This 'super-rotation', also seen in Venus's atmosphere, confirms both Earth-based observations of Titan and theoretical models[8]. HASI found that the winds at Titan's surface are, in contrast, very weak, with speeds of around 1 metre per second (3.6 km h^{-1}) or less[3]. The challenge raised by this observation is to find out whether such light winds can account for the observed wind-induced features on Titan's surface, or whether stronger gusts are required.

The Huygens probe's Aerosol Collector and Pyrolyser (ACP)[4] captured and heated aerosols

— suspended liquid and solid particles — in Titan's atmosphere during descent, sending the effluent to the Gas Chromatograph Mass Spectrometer (GCMS)[5] for analysis. Preliminary evidence indicates the presence of nitrogen-containing organic compounds, which may include amino, imino and nitrile groups (further analysis is being carried out to determine the precise compounds present). These aerosols must fall steadily as a kind of organic rain on Titan's surface, producing a global layer with a potential thickness of 1 kilometre or more[9]. This means that the information from the ACP can be used to predict what additional compounds might be formed on the surface. Relatively recent depositions probably cause the dark patches seen on Titan's surface in infrared images[10]. The process removes atmospheric methane; indeed, methane would disappear completely from Titan's atmosphere in just 10 million to 20 million years without some (as yet undiscovered) source to replace it, either continuously or episodically.

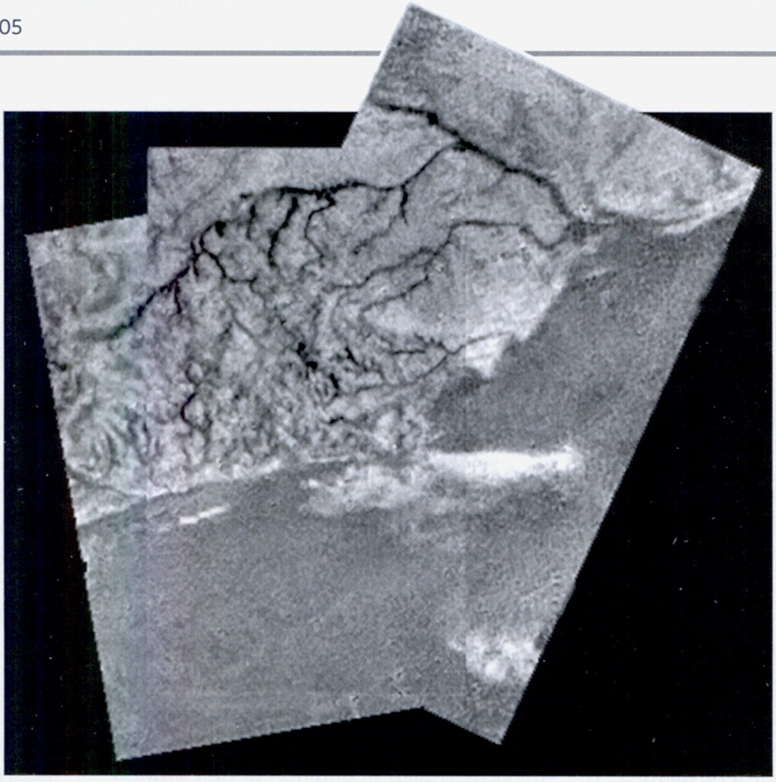

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Figure 2 | Rivers of methane. A mosaic of three frames of Titan's surface, taken by the Huygens probe from an altitude of 16 km, showing a system of converging river channels.

The results from several of Huygens' instruments imply that methane is involved in a phase-change cycle on Titan similar to that of water on Earth. Both the GCMS and the Descent Imager/Spectral Radiometer (DISR)[6] detected a methane haze in the lower regions of the atmosphere, and the Surface-Science Package[7] found the ground at the landing site to have the consistency of damp sand — probably a mixture of ice chips, precipitated aerosols and some liquid. The liquid was identified as condensed methane by a sudden surge in the methane signal detected by the GCMS after the probe had landed. This higher signal level lasted for the remaining 69 minutes of communication with the Cassini orbiter[5].

It would therefore seem, to update Professor Higgins's exercise in elocution, that the titanian rain is mainly methane. But despite the fact that exotic materials produced it, the landscape near the probe is remarkably Earth-like: stunning images from the DISR reveal beautifully defined channel systems incised into the surrounding terrain[6] (Fig. 2). These river networks must have been cut into the bedrock of thick ice by some combination of methane rain and subsurface springs.

Another feature that Titan shares with Earth is the abundant nitrogen in its atmosphere. Relative to its abundance in Earth's atmosphere, however, the lighter nitrogen isotope ^{14}N is depleted on Titan, indicating that roughly five times the present amount of atmosphere has escaped from Titan since its formation[5]. (Escape into space is the only plausible way to selectively remove one isotope, and has been observed on Mars[11].) Carbon, which is present in methane, does not show such a large anomalous isotopic ratio — a further indication that methane must be continually replenished on Titan.

> "The brightest of Saturn's [satellites], it chanc'd to be my lot, with a telescope not above 12 foot long, to have the first light of in the year 1655. The rest we may thank the industrious Cassini for..."
> — Christiaan Huygens, 1685

One possible pathway for this methane replenishment is cryovolcanism, or a similar mechanism by which material would be exuded by Titan's interior. This possibility is supported by the discovery in Titan's atmosphere of the argon isotope ^{40}Ar, which originates solely from the decay of radioactive potassium; this potassium must exist in rocks predominantly below the satellite's ice-water mantle. In contrast, the atmosphere contains only a trace of the primordial isotope ^{36}Ar. This fact provides us with an important clue to the conditions under which Titan formed: it indicates that nitrogen originally arrived on Titan as a mixture of compounds such as ammonia (as indeed it came to Earth). Simple molecular nitrogen, N_2, is trapped only in icy planetesimals of the kind that created Titan at temperatures below 45 K, at which a large fraction of the ambient ^{36}Ar would also be trapped. Compounds such as ammonia can be trapped at much higher temperatures, without trapping primordial argon.

But it is not just the primordial noble gases that are missing in Titan's atmosphere — for any world to have a thick nitrogen atmosphere, an amount of carbon 4 to 20 times greater than that actually found must be hidden somewhere. (The range is given by the proportions found elsewhere in nature, the lower figure being given by the ratio of abundances in the Sun, and the higher figure by that found in comets and the atmospheres of the inner planets[12,13].) On Earth, the missing carbon is found in enormous deposits of carbonate rocks in the crust. On Titan, some might exist as ancient deposits of aerosols, buried under layers of ice that have successively resurfaced the satellite, hiding the impact craters that once dominated the landscape. But the need for a replenishing source of methane suggests that vast deposits of carbon may still be sequestered deep inside Titan, perhaps in the form of methane that was made in the satellite's mantle eons ago. This methane could now be held in cage-like structures of water molecules (a form known as a clathrate hydrate) at the bottom of an ocean hypothesized to lie beneath Titan's crust. Alternatively, a reservoir of carbon in its original form (organic compounds, carbon dioxide and grains) that is still being converted to methane might exist far below the surface[5].

The mystery of the missing methane is just one of many to be solved. Titan will have much to tell us even after the rich harvest of the Huygens data has been analysed. The region where the probe landed was named 'Antilia', after a mythical island once thought to lie between Europe and the Americas. That symbol of the international nature of the Cassini–Huygens endeavour should serve as an inspiration for the next mission to set sail for this fiercely frozen echo of the early Earth. ■

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