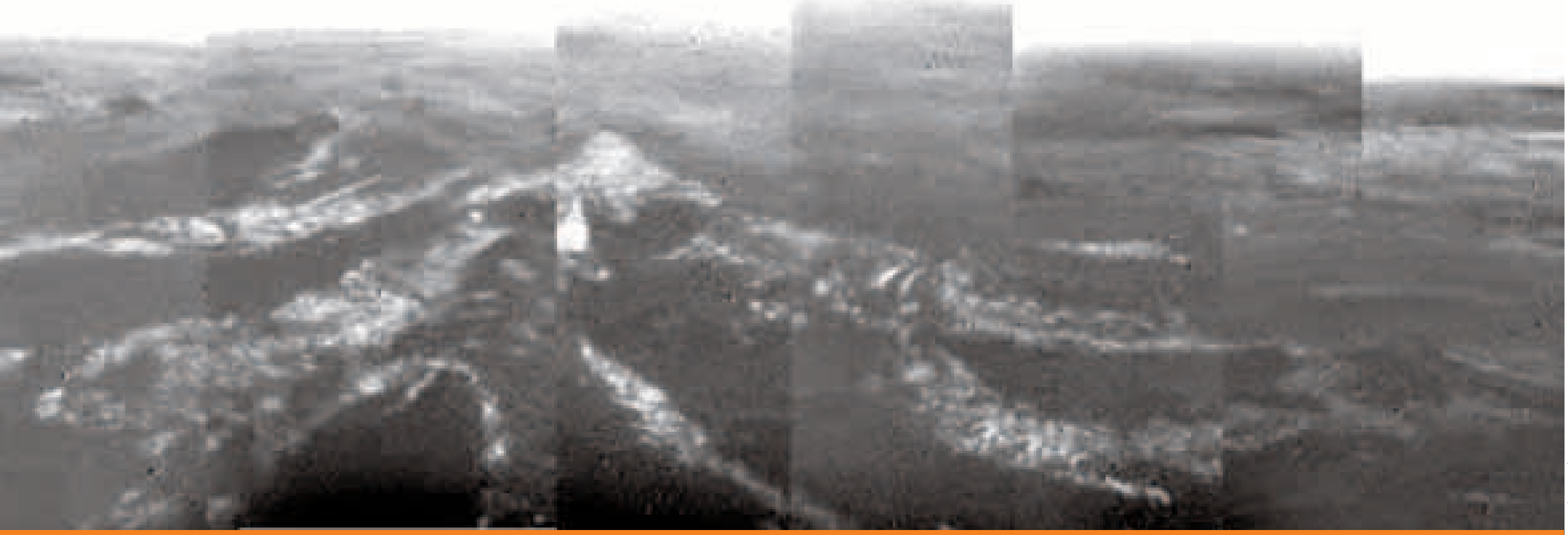
Titan: A Whole New WORLD

By David Tytell

TITAN'S SURFACE LOOKS eerily familiar. Streams, springs, and deltas — it's as if we we're looking at aerial images of river networks here on Earth. When the European Space Agency's Huygens probe landed on Saturn's largest moon on January 14th, perhaps the biggest surprise of all was just how closely Titan's terrain resembled home. "The way Titan manifests itself in Earth-like pictures takes one aback," said planetary scientist Caitlin Griffith (University of Arizona). After the first week of analyzing results from Huygens's half-dozen instruments, a coherent story began to take shape. "Our new picture of Titan is very fascinating," said Huygens project scientist Jean-Pierre Lebreton in a press conference on landing day. "There are Earth-like processes on Titan, but the ingredients are somewhat different."

Falling with Style

On Christmas Day, as Huygens detached from the Cassini orbiter and headed for its rendezvous with Titan, the astronomical community's excitement reached a fever pitch. Voyager spacecraft images, ground-based telescopic views, countless computer and laboratory models, and even Cassini's 1,200-kilometer-distant flyby of the cloud-enshrouded moon last October hadn't solved Titan's lingering mysteries. But the earlier observations did provide some background. Before Huygens arrived, astronomers knew that the moon was the only large solar-system body — other than Earth — to harbor a predominantly nitrogen atmosphere. They knew that the atmosphere was home to complex hydrocarbon chemistry that could potentially yield



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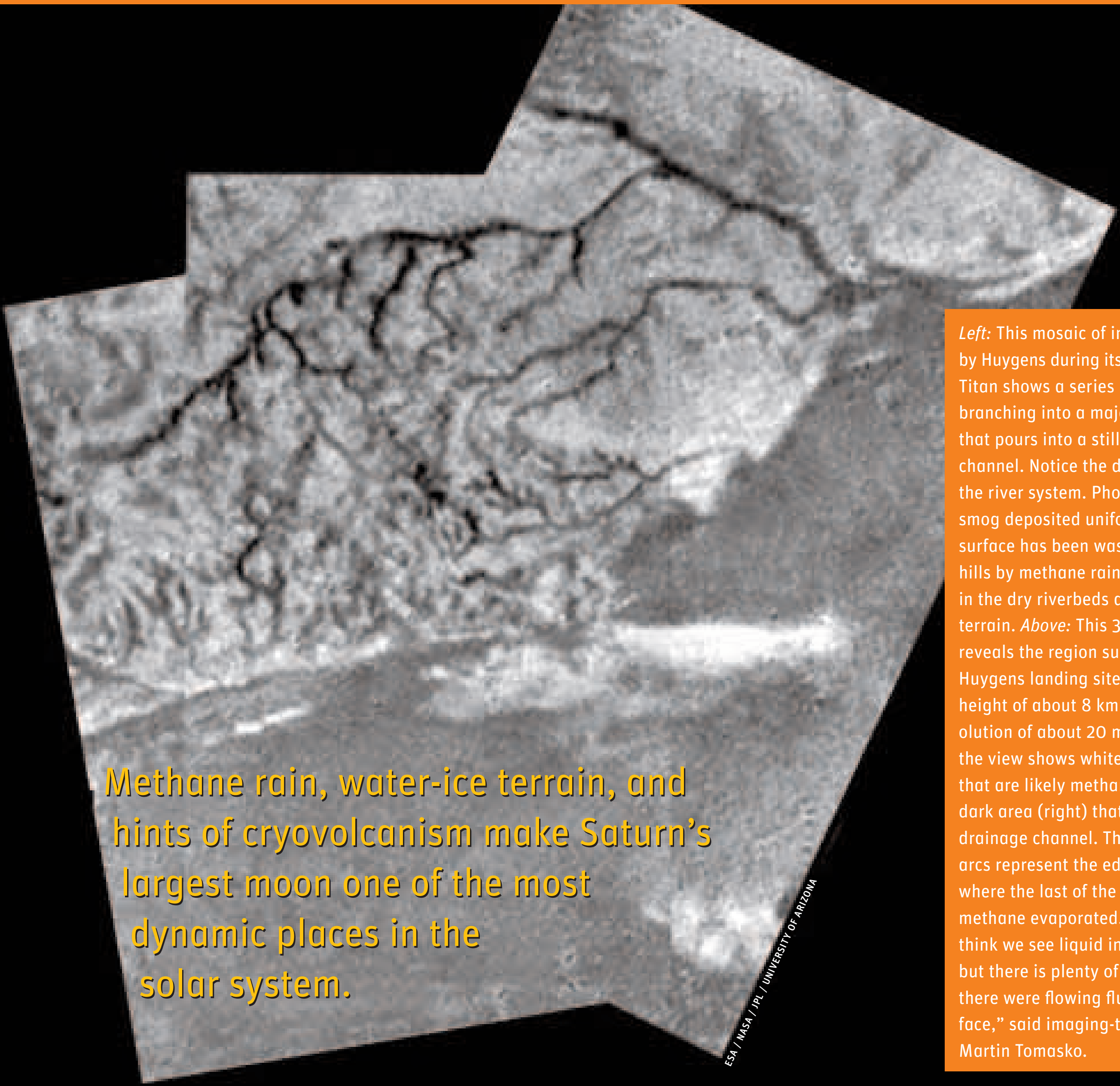

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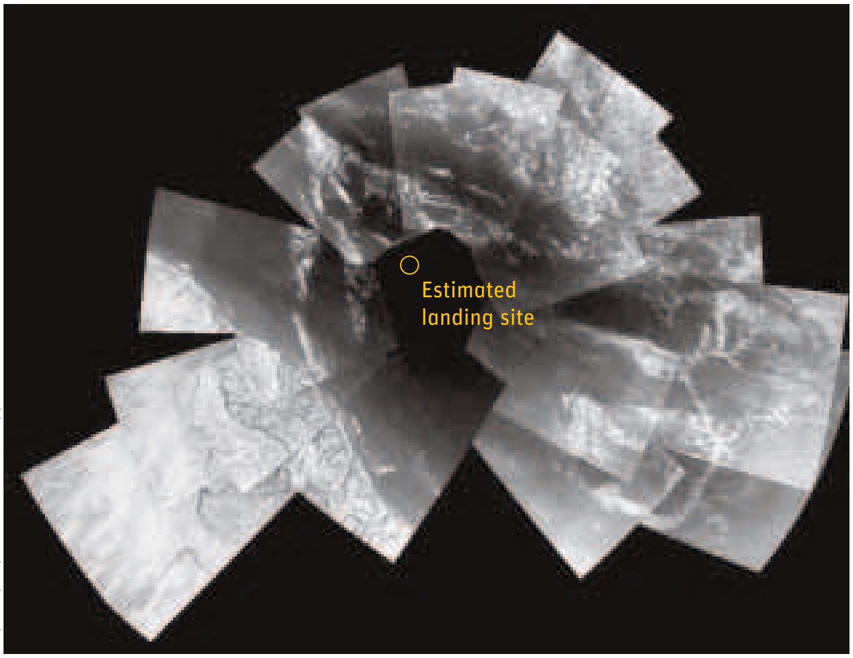
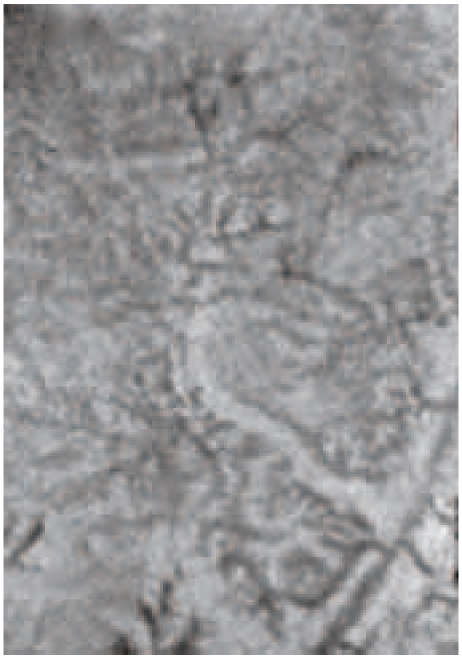
Methane rain, water-ice terrain, and hints of cryovolcanism make Saturn's largest moon one of the most dynamic places in the solar system.

Left: This mosaic of images snapped by Huygens during its descent toward Titan shows a series of streams branching into a major river channel that pours into a still-larger outflow channel. Notice the darker hue of the river system. Photochemical smog deposited uniformly across the surface has been washed off the hills by methane rains and collected in the dry riverbeds and low-lying terrain. *Above:* This 360° panorama reveals the region surrounding the Huygens landing site. Seen from a height of about 8 km and with a resolution of about 20 meters per pixel, the view shows white streaks (left) that are likely methane fog and a dark area (right) that is probably a drainage channel. The parabolic arcs represent the edges of pools where the last of the surface methane evaporated. "We don't think we see liquid in these areas, but there is plenty of evidence that there were flowing fluids on the surface," said imaging-team leader Martin Tomasko.





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Left: This 30-picture mosaic looking down upon the Huygens landing site shows features with a resolution of about 20 meters (65 feet) per pixel. River networks and outflow channels appear at lower left in these images shot from between 8 and 13 km above the surface. *Right:* The white streak near the center of this image is a region where water ice appears to have extruded from under the surface of Titan. It's possible that cryovolcanism like this might provide the surface with a constant supply of methane produced deep within the moon's interior. Also notice the short, stubby channels. Scientists believe they may be methane springs and outflows from the sides of hills.

methane (CH_4) and ethane (C_2H_6) oceans. Furthermore, they thought that the shores of the oceans could have outcrops of water ice.

The arrival was flawless — with one notable exception (see page 38) — and the instruments each worked to perfection. Huygens unfurled a series of parachutes as it slowly drifted toward the surface (*S&T:* July 2004, page 38). It descended for 2 hours 27 minutes before touching down at a gentle 5 meters per second (11 miles per hour). Cassini listened as Huygens transmitted data from the surface for 1 hour 12 minutes, and radio telescopes on Earth detected Huygens's broadcasts for more than four hours after touchdown — a testimonial to the life span of the probe's batteries, which survived on the 94° Kelvin (–290°F) soil much longer than anticipated.

Ground Truth

The first instrument to touch Titan's surface was the penetrometer, essentially a stick fixed to the bottom of the probe designed to measure the force of impact and thus the strength of the material impacted. "As soon as the sensor touched the ground, it saw a rather high force," said John C. Zarnecki (Open University, England), lead scientist for the Surface Science Package (SSP), in a press conference. "As the probe entered the soil, it detected a much lower, rather constant force." When comparing these results to sample materials, added Zarnecki, "The closest match we could find was sand or clay along with something else to give the sharp beginning."

Once on the surface the SSP's accelerometer detected that the craft nestled an additional 10–15 centimeters before coming to rest. At that point Huygens's Gas Chromatograph and Mass Spectrometer (GCMS) began to analyze its new surroundings. The instrument, by design, can detect only gases. "We thought if we landed in a place where we could evaporate material, we could detect what was there," said GCMS team member Sushil Atreya (University of Michigan). "If we landed on solid rock, we wouldn't have seen any evaporation."

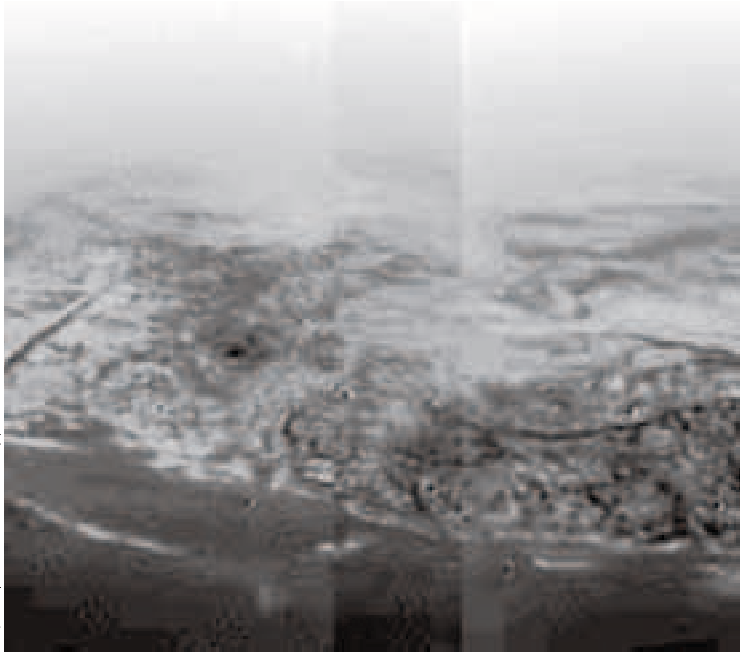
But Huygens *did* see evaporation — and plenty of it. Within the three minutes it took to heat the GCMS inlet, the methane concentration in the air jumped some 30 percent and remained at that level for the rest of the time that Huygens recorded data on the surface. This behavior is what was expected if the inlet were suspended above a reservoir of liquid located on or just below the surface. "This is a planet where the liquids are right there," said GCMS team member Tobias C. Owen (University of Hawaii) in a press conference. However, Atreya cautions, "We do not detect liquid methane; we are *inferring* liquid methane."

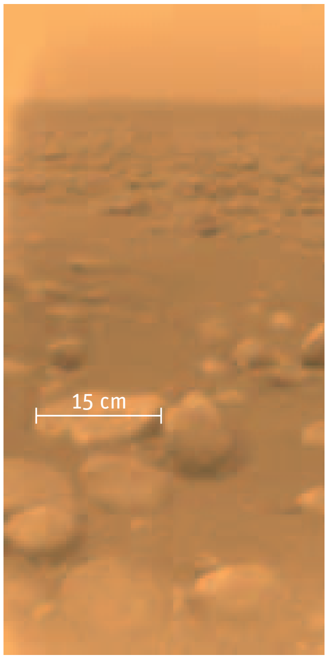
The Methane Cycle

Assuming that the probe did indeed land in "humid ground," as Griffith calls it, how did the liquid get there and saturate the soil? The answer, it seems, is that Titan sports a complete hydrological cycle, one where it rains methane.

Because the ground is so cold, methane stays in liquid form on the surface and acts very much like water does on Earth. It evaporates, condenses, forms clouds, and rains back down onto Titan, where it creates lakes, streams, creeks, and springs. In fact, as Huygens descended through an altitude of 17–20 km, according to Atreya it sensed a zone best characterized by a thick cloud or haze layer with 100 percent relative humidity — the maximum amount of methane that the air could hold, given its temperature.

The methane cycle does have a leak. When this molecule





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Far left: When seen at an oblique angle from 8 km up, the boundary between the lighter-colored uplifted terrains and the photochemical smog collected in the low-lying delta appears much like a shoreline. *Left:* This colorized image represents Huygens's first view from the surface of Titan. The "rocks" are not like the silicate rocks one finds on Earth — they are stones of frozen-solid water ice. The "soil" surrounding the probe is also different. "Instead of silicate sands like we have on Earth, this is probably crushed and chipped ice with organic material in it," said Tomasko. The colored sky and landscape closely match what your eyes would see, and the haziness may be due to methane fog.

reaches the uppermost parts of the atmosphere, it is broken apart by ultraviolet light. The resulting hydrocarbon byproducts of this reaction combine to produce complex organic molecules ranging from ethane to benzene (C_6H_6). The former falls out of the atmosphere as a liquid. The latter, and other complex microscopic particles like it, make up Titan's photochemical smog layer and give the moon's sky its orange hue. Those same molecules eventually coat the surface below.

Without a continuous source replenishing the methane supply, the moon would run dry in only 10 million years. Therefore, many scientists believe that methane is being manufactured within Titan's interior and is outgassing through geological processes. Perhaps Titan experiences some form of upwelling or cryovolcanism on its surface. GCMS measurements did record the signature of argon-40, a byproduct of the radioactive decay of potassium. But Huygens found no evidence for Earth-like potassium-bearing rocks on the surface. Theory suggests that if they are present, they're buried deep within the moon's middle from when Titan first formed and differentiated. The detection of argon-40 means other molecules and elements could be outgassing too.

It seems Huygens landed in a dry environment. Despite the evidence of rivers, springs, and lakes, no rain or standing liquid was seen on January 14, 2005.

"We know very little about the time interval between the rains," said Descent Imager and Spectral Radiometer (DISR) team leader Martin G. Tomasko (University of Arizona) in a press conference. "The place we examined was dry at the moment, but there was liquid within a few centimeters of the surface indicating that it must have rained not very long ago. Does that mean yesterday, or the day before, or the week before? We don't really know."

The View from Above

When the DISR peered down onto Titan's surface, the images it saw matched up perfectly with the putative hydrologic cycle suggested by the GCMS data. There were vast dark and light regions, 100-meter-tall ridges with bright spots atop them, dark elliptical arcs, and what appeared to be rivers, streams, and deltas.

"The branching dendritic channels are evidence of rain, and the dark material in the bottom of the channels is very likely photochemical smog that falls out of the atmosphere, coats the whole terrain, and gets preferentially washed off the top of the ridges," Tomasko said. "The dark material is concentrated at the bottom of these drainage channels." Moreover, spectral reflectivity measurements indicate that the ridges themselves aren't made of silicate rocks like those found on Earth; they are "frozen-hard water ice," said Tomasko.

As for the dark elliptical regions, they are most likely evaporated lakes. Other images show spots where water ice appears to have extruded from under the surface — perhaps demonstrating the release of internal methane and argon-40.

STEFAN SEIP

On January 14th an international group of scientists, engineers, space administrators, and reporters filled the European Space Operations Centre in Darmstadt, Germany, to hear the first status report on the Huygens space probe.

The Future of Huygens

As planetary scientists continue to analyze the data from the craft's six instruments, they are wrestling with several unanswered questions:

- **Where is the ethane?**

The GCMS detected a faint signature of ethane, but present analysis shows it's nowhere near the abundances that models predict given the chemistry of the upper atmosphere. "It may still be there on the surface, but not evaporating as readily as methane, perhaps due to its lower volatility," said Atreya. Huygens visited only one spot on Titan. The ethane "may condense out somewhere else."

- **Where are the global oceans?**

For years models have predicted they should be there, but Huygens didn't see any, ground-based radar observations haven't uncovered big reservoirs or ponds, and radar from Cassini has thus far been inconclusive.

- **Where are the primordial noble gases?**

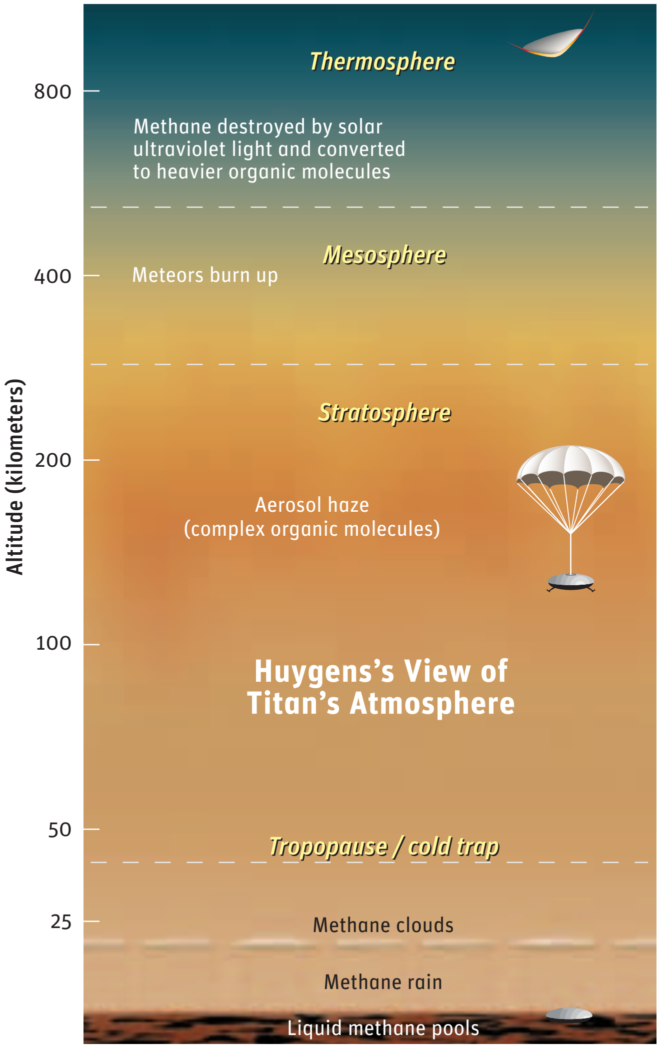
Aside from the argon-40 produced by radioactive decay, the GCMS found no evidence for noble gases. Their absence gives astronomers clues about Titan's formation. For noble gases such as argon, krypton, or xenon to be incorporated into the nascent Titan, they would have had to hitch a ride on icy blocks or frozen rocks colder than about 36°K. Since the rocks on Titan have differentiated toward the middle, and since argon-40 is bubbling out from their radioactive decay, any noble gases locked in the rocks should be seen along with the argon-40. In other words, it seems that cold planetesimals didn't combine to form Titan.

- **Where are the amino acids?**

Laboratory tests suggest that amino acids, the building blocks for life, are among the many complex organic molecules that can form in Titan's upper atmosphere. Yet spectroscopic observations from Earth and Cassini haven't seen them. Huygens's Aerosol Collector and Pyrolyser was designed to sample the atmosphere twice during descent, heat up the captured air — smog included — and run it through the GCMS for analysis. As of late January the ACP team was still sifting through its results.

Perhaps these remaining mysteries will be solved as scientists dig deeper into the trove of measurements returned by Huygens. But after just one frenzied week of analysis, Titan is finally coming into focus. "The story is pretty coherent," said Lebreton. "A new big picture of Titan is emerging." ✷

Associate editor David Tytell *learned to love smog growing up in Los Angeles.*



S&T: GREGG DINDERMAN AND STEVEN SIMPSON; SOURCES: RALPH LORENZ, ROGER YELLE, AND SUSHIL ATREYA

Huygens project scientist Jean-Pierre Lebreton holds a plot of the radio signal from the Titan probe moments after it was received on Earth.

GEORG DITTIE

The Radio Savior

Not everything about the Huygens mission went perfectly. Cassini was supposed to listen for Huygens's signal on two channels, but due to a programming error it only heard one channel of data. As a result half of the 700 images shot by the DISR were never relayed to Earth, nor were results from the Doppler Wind Experiment (DWE), an instrument designed to determine the speed and direction of Titan's winds during descent. European Space Agency science director David Southwood immediately launched an inquiry to investigate the mistake.

But all was not lost. Eighteen different radio telescopes on Earth were listening for Huygens's signal as it headed toward Titan. Their combined observations have fully recovered the DWE's data. But "it will require days, weeks, and months to analyze," said project scientist Jean-Pierre Lebreton, as scientists will have to compare and combine the observations of all 18 stations that acquired some part of Huygens's signal.

While the missing images are gone forever, the DISR team is managing. "We do have holes in our panoramic mosaics, but we have a lot of overlap in our coverage," said Martin G. Tomasko (University of Arizona). "I think the quality of the images will get better as we continue to solve for the geometry and assemble these mosaics in the days and weeks ahead."