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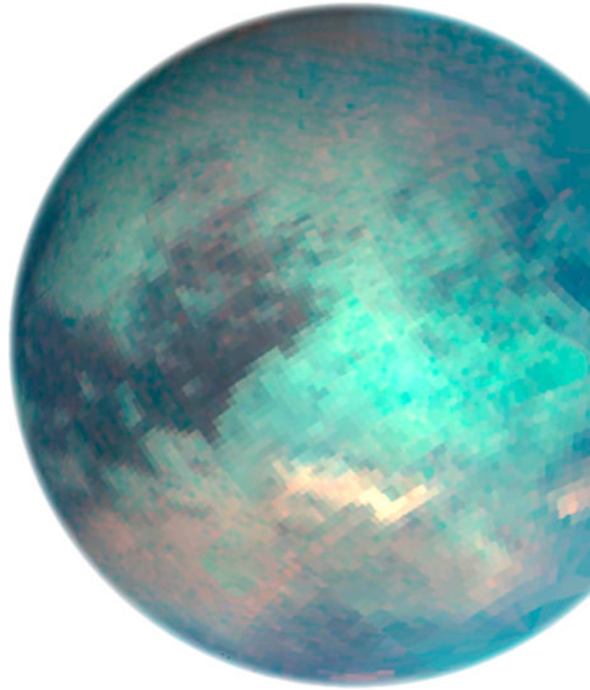
Secrets from Titan's seas



By probing "magic islands" and seafloors, astronomers are learning more than ever about the lakes and seas on Saturn's largest moon. **by Alexander G. Hayes**

These images show Titan, from left to right, in October and December 2005 and January 2006. The view from December is roughly the opposite side of the moon from the October and January flybys, but careful inspection of Titan's polar regions shows how dynamic and variable the polar weather can be. NASA/JPL/UNIVERSITY OF ARIZONA

IMAGINE YOURSELF standing at the shoreline of a picturesque freshwater lake, surrounded by soft grass and leafy trees. Perhaps you are enjoying a peaceful lakefront vacation. In the calm water, you see the mirror-like reflection of a cloudy sky just before it begins to rain. Now, let the surrounding vegetation disappear, leaving behind a landscape you might more reasonably expect to see in the rocky deserts of the southwestern United States. The temperature is dropping too, all the way down to a bone-chilling –295° F (92 kelvins). The air around you feels thicker, although you yourself feel seven times lighter, courtesy of reduced gravity. As the clouds pass overhead, you notice that the lake surface now reflects a hazy orange sky with the brightness of early twilight. After the clouds have moved on, you finally begin to feel rain hitting your hands. However, the rain falls much slower than normal and the drops are bigger, with large splashes following each impact. The ground you stand on is a loose sandy mixture of broken-up water ice and organic material like plastic shavings or Styrofoam beads. On closer inspection, the lake holds not water, but a liquid not unlike natural gas. And you'd better be holding your breath because the surrounding air has no oxygen.

If you can picture all of this, welcome to the surface of Saturn's largest moon, Titan.

Titan is the only extraterrestrial body known to support standing bodies of liquid on its surface and the only moon with a dense atmosphere. It is also an explorer's utopia, supporting landscapes that are uncannily similar to those found on Earth while also presenting a seemingly endless supply of intriguing mysteries, with fresh questions following each new discovery. Two recent findings in particular have revolutionized our understanding of Titan's lakes and seas: their unexpected transparency to microwave radiation and the appearance of mysterious "magic islands," which our research team has been privileged to bring to light. But Titan's environment amazed well before these latest discoveries.

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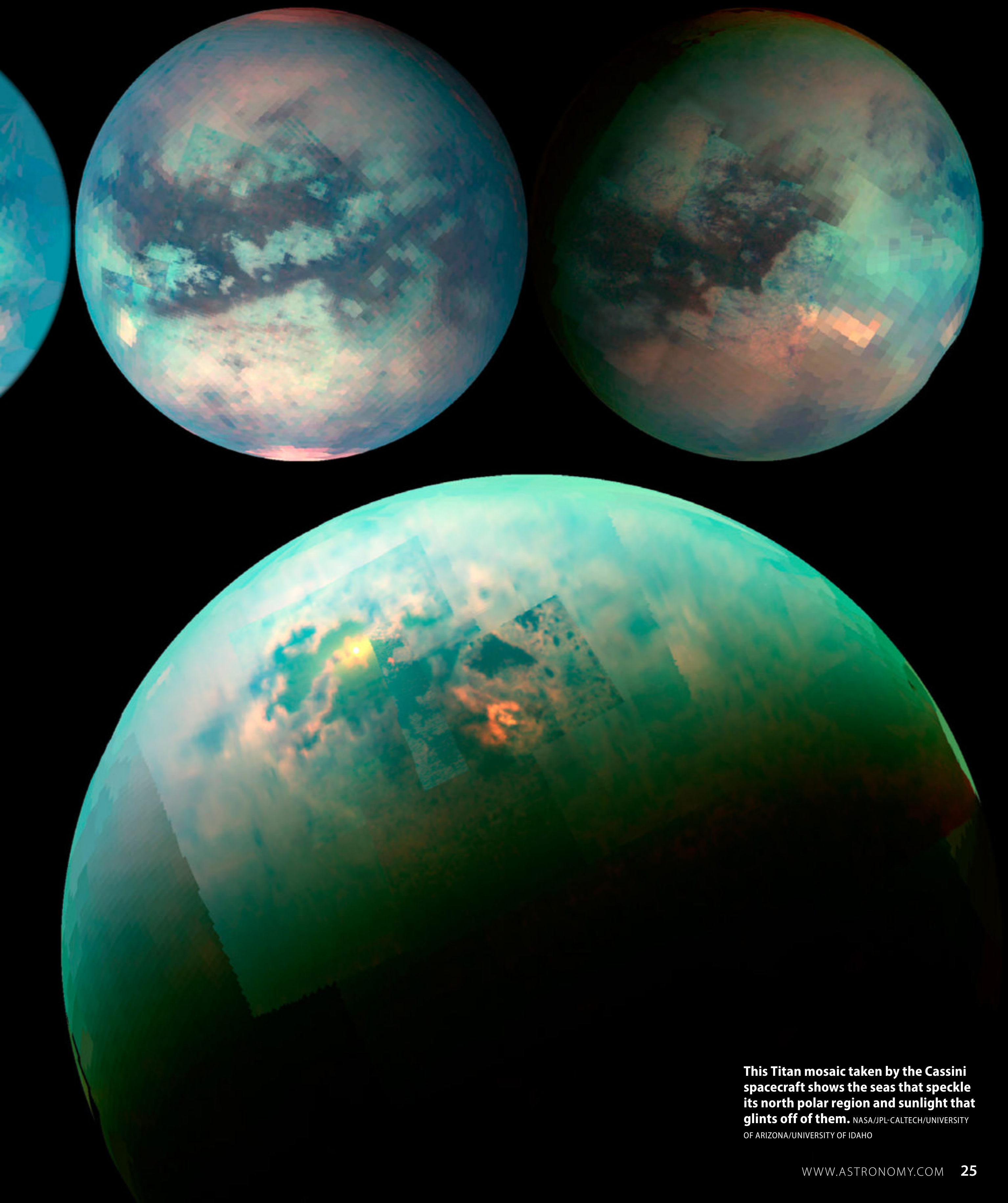
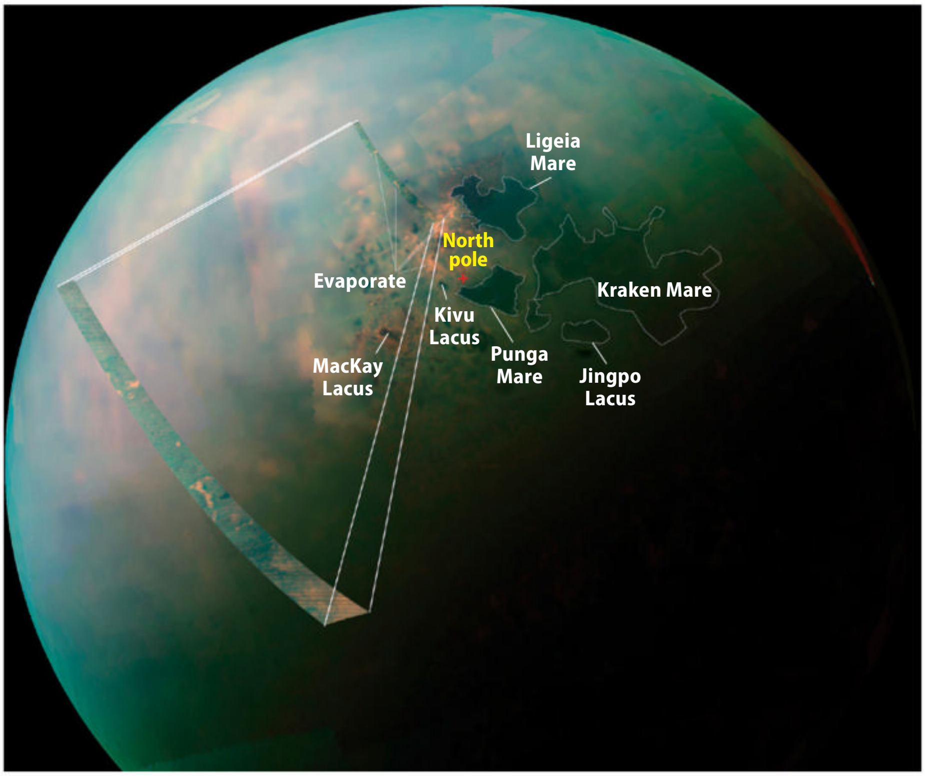
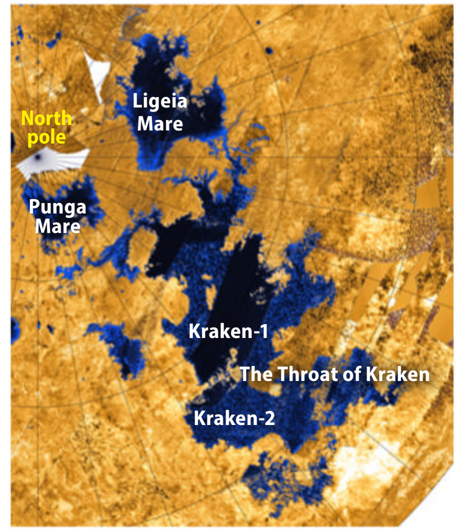
Strange but familiar

In many ways, Titan's landscapes are eerily similar to their terrestrial counterparts. You can find sand dunes similar in both



This Titan mosaic taken by the Cassini spacecraft shows the seas that speckle its north polar region and sunlight that glints off of them. NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA/UNIVERSITY OF IDAHO





▲ Cassini's RADAR instrument took this detailed image of Titan's north pole and the many lakes and seas that cover its surface. NASA/JPL-CALTECH/ASI/USGS

◄ Many of Titan's intriguing details are visible in this Cassini infrared image. The surface appears largely in green, while dry lakebeds show up in orange. The lakes and seas that dot Titan's northern hemisphere are the darkest regions. NASA/JPL-CALTECH/UNIVERSITY OF ARIZONA/UNIVERSITY OF IDAHO

size and shape to the largest in the dune fields of the Saharan and Namibian sand seas of Africa. Alluvial fans (cone-shaped sediment flows left behind by rivers, streams, and landslides) resemble those found in the Atacama Desert of central Chile, and mountain chains are formed by tectonic forces similar to those responsible for the Himalayas that span southern Asia. Perhaps most astonishingly, lakes and seas scatter the polar landscape with shoreline features reminiscent of both marine and freshwater coastal environments found across our planet.

However, the dunes are not silicate sand; they are instead organic materials more like plastic than quartz. Rather than rock fragments delivered by flowing water, alluvial fans on Titan are a mixture of water ice and organic sediment delivered by flowing hydrocarbon liquids (methane and ethane). The mountains are broken-up sections of dirty water ice, and the lakes and seas are vast pools of liquid hydrocarbons. Despite these differences, the same mechanisms (such as wind and rain) sculpt and transport sediment across the landscape on Titan as they do on Earth. The similarities make Titan a natural laboratory for studying the processes that shape our own planet, including extreme conditions impossible to recreate in earthbound laboratories.

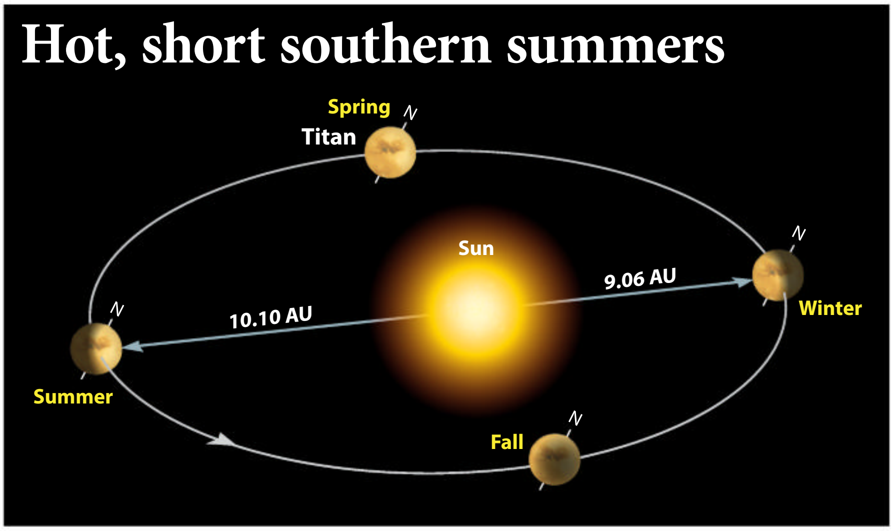
The forces that sculpt Titan's landscapes resemble Earth's water cycle, except that the key liquid is methane. Near the surface, methane makes up 5 percent of Titan's nitrogen-dominated atmosphere and, like water on Earth, condenses out of the atmosphere as rain and can persist as a liquid on the surface. If all of the methane in Titan's atmosphere were to fall down to the surface, it would make a global layer 23 feet (7 meters) deep. If you were to do the same thing to the water in Earth's atmosphere, the layer would be only 1 inch (3 centimeters) thick. On Titan, methane rain falls from the sky, flows on the surface, cuts channels into the bedrock, and fills depressions to form polar lakes and seas.

High in Titan's atmosphere, sunlight breaks apart methane in a process called photolysis (this also happens to methane in Earth's upper atmosphere). The methane splits into hydrogen, which escapes into space, and highly reactive compounds that quickly recombine to form more complex hydrocarbons like ethane and propane. These hydrocarbons rain out onto the surface and, over geologic time, rework themselves into the solid particles that make up Titan's dunes and coat the world's surface. Carl Sagan referred to laboratory-generated versions of the kinds of compounds Titan's atmosphere generates as "tholins" and noted that they are similar to the organic material that may have been important to the development of life on Earth. On Titan, these tholin-like materials form haze layers that obscure the surface from visible-light cameras, such as those on board the Pioneer 11 and Voyager 1 spacecraft.

Close encounters

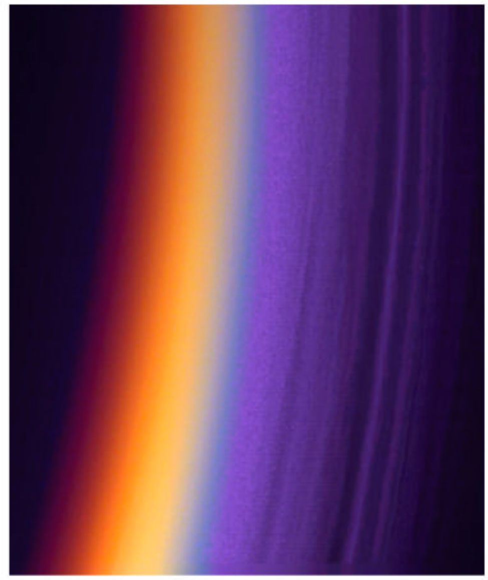
The presence of a thick atmosphere makes Titan unique among the moons in our solar system. It also made the saturnian moon one of the primary targets for exploration by Voyager 1. In fact, in order to reach Titan, Voyager 1 had to follow a specialized trajectory that eliminated the possibility of visiting Uranus or Neptune as Voyager 2 did on its "grand tour" of the solar system. While the cameras on Voyager 1 were not able to see down to Titan's surface, the spacecraft was able to use radio instruments to determine the surface pressure (1.5 times that of Earth) and temperature (92K). Following the Voyager encounter, scientists knew liquid methane and ethane were raining down and stable on Titan's surface but had no idea how they were distributed.

Prompted by the exciting results of the Voyager mission and the near two decades of ground-based imaging campaigns that followed, NASA and the European Space Agency (ESA) launched the Cassini/Huygens mission to Saturn in 1997. As a multipurpose mission, Cassini must divide its limited orbits around Saturn between many different moons (as well as the planet itself) and carefully allot its close flybys, but the spacecraft came specially prepared for Titan. In order to penetrate Titan's thick atmosphere,



ASTRONOMY: ROEN KELLY, AFTER NASA/JPL-CALTECH/UNIV. OF ARIZONA/CASSINI IMAGING & RADAR SCIENCE TEAMS

Seasons on both Earth and Titan are caused by each world's tilt, so that one side receives more direct sunlight. But on Titan, Saturn's eccentricity varies how far Titan orbits the Sun by more than an astronomical unit (AU; the average Earth-Sun distance), as well as speeding it up and down. This means the hemispheres don't share equal seasons, so the south has hotter, shorter summers than the north, driving liquid to the upper pole over eons.



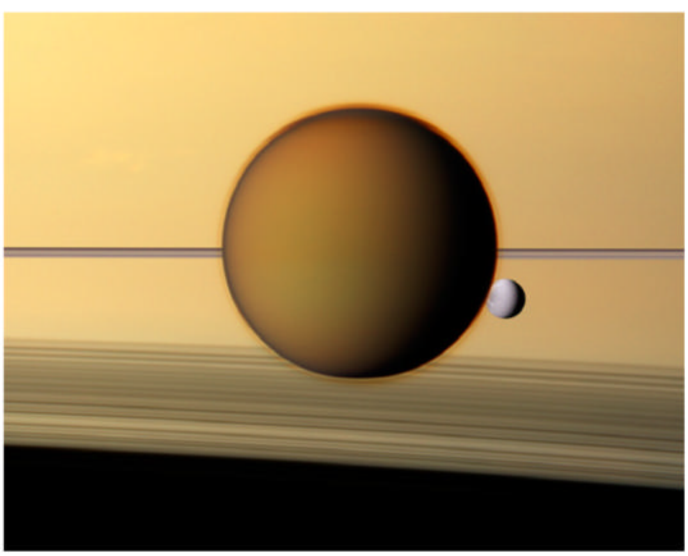
NASA/JPL/SPACE SCIENCE INSTITUTE

Titan's "purple haze" of an atmosphere is thanks to a thick shroud of methane, which separates into distinct layers upon closer inspection.

Cassini carries a radar mapper capable of obtaining images of the surface at a resolution of 1,000 feet (300m). The RADAR works by sending out bursts of microwave energy and measuring how much reflects back. Cassini contains two additional infrared instruments it uses to study Titan's surface, but their resolution is usually less than that of the RADAR. The Cassini orbiter also carried an ESA-provided probe, Huygens, which landed on Titan's surface in early 2005. Because at the time the surface of Titan was a mystery, engineers designed Huygens either to touch down on a solid surface or to land in an ethane sea. The probe touched down near Titan's equator on what appears to be a flood plain strewn with rounded cobblestones about 4 inches (10cm) in diameter.

Seasons and sunlight

The Saturn system tilts by 27° from the plane of its orbit, and thus Titan, like Earth, has seasons. Saturn and Titan, however, take 30 years to circle the Sun, so their seasons are 7.5 years long.



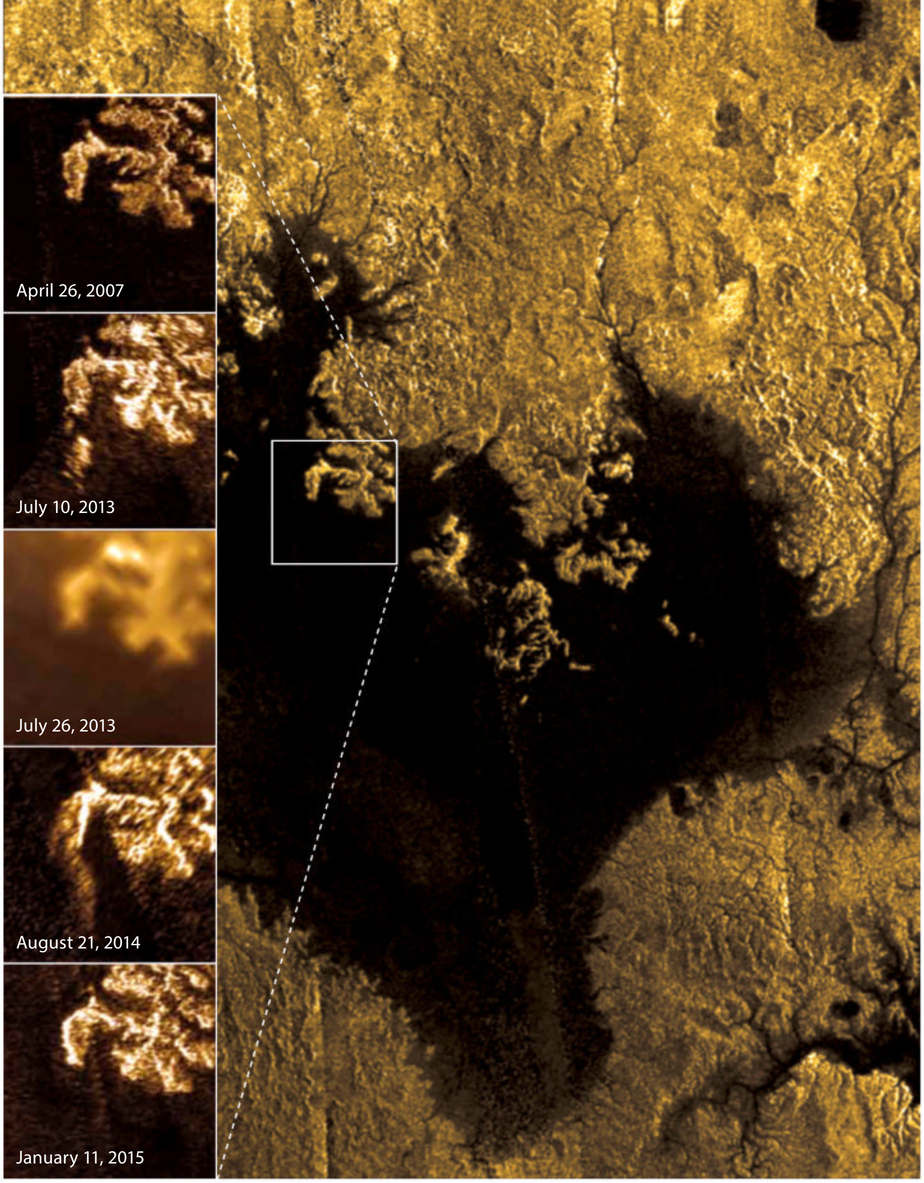
Titan poses here in front of Saturn's rings with its much smaller sibling moon Dione. The fuzzy outline of Titan is due to its thick, hazy atmosphere.
NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE

The Cassini RADAR discovered Titan's lakes and seas in the north polar region during a flyby in July 2006, during northern winter. Since then, Cassini has discovered more than 300 liquid-filled depressions that range in size from moderately sized lakes at the limits of detection (about 90 acres, or 0.4 square km) to vast bodies larger than Earth's Great Lakes. The three largest, Kraken Mare, Ligeia Mare, and Punga Mare, hold the title "mare," which is Latin for sea. Collectively, the lakes and seas cover 1 percent of Titan's surface and lie mostly in the northern hemisphere, where they cover 35 times more area than in the south. We believe Saturn's eccentric orbit around the Sun causes this contrast between north and south.

Saturn is closest to the Sun during summer in Titan's southern hemisphere, when it tilts areas below the equator toward our star's most direct light. Northern summer, on the other hand, happens to occur when the Saturn system is farther from the Sun. As a result, southern summers are both hotter and shorter, with more intense sunlight than their northern counterparts. Over many seasons and years, the stronger, hotter sunlight in the south drives methane and ethane toward the northern hemisphere. But if this is the explanation for Titan's lake distribution, we should also note that it changes with time. The position of Titan's seasons on Saturn's eccentric orbit varies over periods of 50,000 years. In fact, 35,000 years ago, the situation was the exact opposite of today's scenario: Northern summers were hotter and shorter than southern summers. This suggests that the liquid in Titan's polar regions shifts between the poles over timescales of 50,000 to 100,000 years. And, in fact, there are large-scale depressions in the south that include features reminiscent of old shorelines along their borders. These paleo-seas encompass an area similar to the northern maria and suggest that Titan's south pole once looked similar to the north. This orbitally driven mechanism is analogous to the cycles on Earth that drive the frequency and duration of the ice ages.

Wind and waves

For most of Cassini's mission, its instruments observed Titan's lakes and seas to be calm and flat, with vertical deviations of



Titan's "magic islands" appear and disappear in Ligeia Mare from one observation to the next. They are more likely to be debris, waves, or bubbles than any supernatural occurrence. CORNELL UNIV./JPL-CALTECH


Titan's surface (left) can bear striking resemblance to Earth, where eons of flowing liquid — hydrocarbons or water — have shaped their surfaces and scattered debris across the landscapes. NASA/JPL/ESA/UNIVERSITY OF ARIZONA AND S.M. MATHESON

less than a few millimeters. This was surprising because the lower gravity and reduced surface tension and viscosity of liquid methane, as compared to water on Earth, should make it easier to excite wind waves.

Furthermore, we know that winds blow near Titan's equator because we see dunes. So why don't we see waves in polar lakes? After applying modern theories of wind-wave generation to Titan, scientists realized the absence of waves was most likely a seasonal effect resulting from light winds during the fall and winter. Researchers expected winds to freshen as Titan approached northern summer, with predicted speeds sufficient to sporadically ruffle the faces of hydrocarbon lakes and seas. Now, as predicted, Cassini has recently started to see indications of wave activity, such as sunlight glinting off ripples on the surface. Spurred by these results, research groups — my own included — began actively searching for activity in the lakes and seas, and the effort is delivering rich and often unexpected rewards.

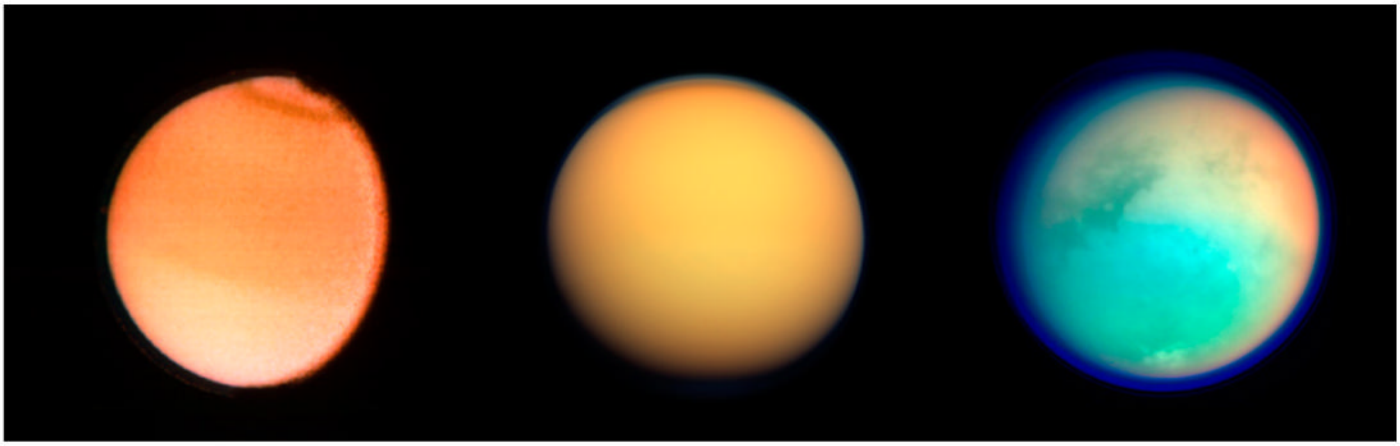
Old instrument, new tricks

In May 2013, the Cassini RADAR observed Ligeia Mare using its altimetry mode. In this mode, the instrument points straight down and measures the distance to Titan's surface by the round-trip travel time of the echo, similar to sonar. It also can read the roughness and composition of the surface through the intensity of the observed reflection. We intended this particular measurement to search for waves on the surface of Ligeia Mare.

While we didn't find any sign of waves, Cornell researcher Marco Mastrogiuseppe, an associate member of the Cassini RADAR team, re-examined the data and discovered two returns for each transmitted radio burst over the sea. The first return was from the surface of Ligeia, while the second was from the seafloor! The time delay between these two returns provided the first depth measurement of a Titan sea, showing that Ligeia Mare varied from 0 to 525 feet (160m) in depth along the observed range. This measurement is remarkable because it required the transmitted radio waves to pass through over 1,000 feet (300m) of liquid (to the floor and back again) without being completely absorbed. For comparison, the RADAR only would be able to penetrate 1 centimeter of seawater. The absorptivity of the liquid tells scientists what it is made of — primarily methane. This substance is four times less absorptive than ethane and 10,000 times less absorptive than seawater.

As a result of Mastrogiuseppe's discovery, the RADAR team redesigned two of Cassini's final three north polar flybys to obtain altimetry observations over the Kraken and Punga maria. These passes revealed the depth and composition of all three seas and proved that, contrary to expectations, methane, not ethane, is the dominant component. We have also applied Mastrogiuseppe's techniques to previous observations of the largest southern lake, Ontario Lacus, and showed it to be up to 300 feet (90m) deep and have 50 percent higher absorptivity then Ligeia. This increased absorption means the lake holds even more complex hydrocarbons, which may have slowly accumulated in Ontario with the transport of methane and ethane to the north over thousands of years.

These results have literally added a new dimension (liquid depth) to our understanding of Titan's lakes and seas and also showcase the adaptability and collaborative nature of the Cassini science team, who gave up long-standing observations of other key areas on Titan in order to accommodate these new altimetry



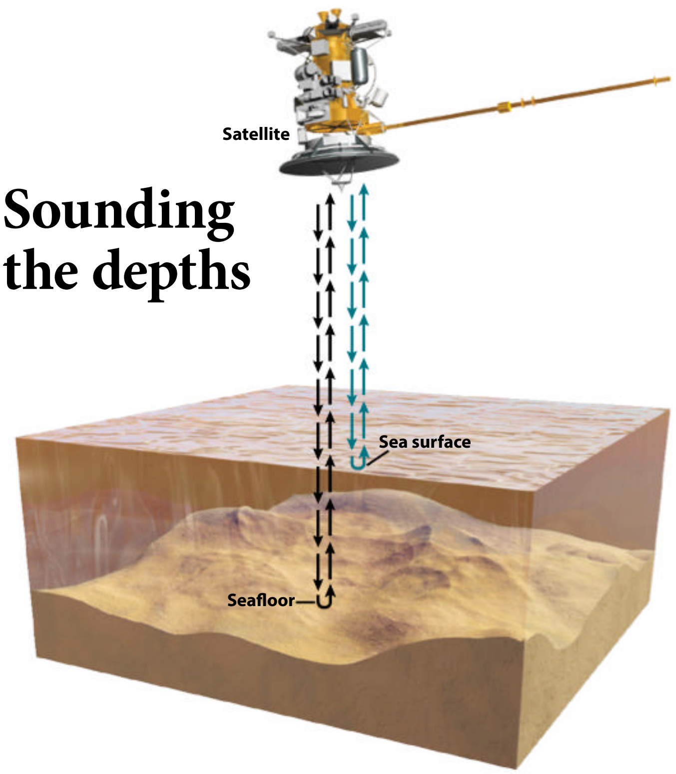
Views of Titan change dramatically from Voyager 2's flyby in 1981 (left) to Cassini, shown both in natural colors (center) and then peering through different cloud layers by using infrared and ultraviolet cameras. NASA/JPL (LEFT); NASA/JPL-CALTECH/SPACE SCIENCE INSTITUTE (CENTER, RIGHT)

observations. When considered collectively, the findings reveal that the surface liquid on Titan encompasses a volume of 17,000 cubic miles (70,000 cubic km), which is 15 times larger than the volume of Lake Michigan and equivalent to 300 times the mass of the entirety of the natural gas reserve on Earth.

"Magic islands"

Two months after the altimetry pass over Ligeia Mare, the RADAR re-observed the sea in imaging mode. Near a peninsula along the southeastern shoreline, it saw a 6-mile-long (10km) region of previously dark sea now to be nearly as bright as the surrounding shore.

Sounding the depths



Cassini's RADAR instrument operates in altimetry mode by bouncing radar signals off Titan's surface. By measuring the difference in timing between bounces off the sea's floor and surface, astronomers measured the changing depth of Titan's seas. *ASTRONOMY*: ROEN KELLY, AFTER SCRIPPS INSTITUTION OF OCEANOGRAPHY

At first, the RADAR team collectively dismissed the bright feature as merely a blip in the data. But it intrigued Jason Hofgartner, a Cornell University graduate student in our research group, who pursued the analysis. Hofgartner's work proved that the features were not a blip but represented real changes at Ligeia. Despite the significant resource reallocation required, the team modified several of the precious few remaining RADAR passes in order to re-observe the area and document its evolution.

During this campaign, transient features appeared and disappeared at both the Ligeia and Kraken maria. Researchers affectionately dubbed them Titan's "magic islands," and they highlight the moon's dynamic seasonality. While the origins of the islands remain unknown, the most likely hypotheses include waves, floating debris, or bubbles. Whatever their cause, without the tenacity and determination of a young scientist who was in elementary school when Cassini launched from Earth, we would have not discovered the magic islands at all.

Learning more

Just as Earth's history is tied to its oceans, Titan's origin and evolution are chronicled within the nature of its lakes and seas. Their discovery has shown us that oceanography is no longer just an Earth science. Despite vastly different environmental conditions, Titan is arguably the most Earth-like body yet discovered and presents a mirror — however distorted — through which we can learn about our own planet. While the Cassini/Huygens mission has provided a wealth of information on the location and depth of Titan's lakes and seas, it has only scratched the surface regarding their composition and interactions with the atmosphere. Addressing these fundamental questions requires visiting them close-up.

Various groups have proposed a wide range of concepts for future Titan missions, including exploration of its maria. While no missions are currently scheduled, NASA nearly selected a capsule called the Titan Mare Explorer (TiME) in 2010, and interest remains high. On-site exploration of Titan's lakes and seas would let us directly observe liquid-atmosphere interactions, read the history of the moon's evolution in its atmosphere and surface, and investigate a natural laboratory for the limits and requirements of life by examining trace organics in the seas. It is my enduring hope that, within our lifetimes, someone will write this article's sequel describing discoveries from the first extraterrestrial boat to explore a Titan sea.

LEARN MORE ABOUT HOW SATURN'S ORBIT CHANGES TITAN'S SEASONS AT **www.Astronomy.com/toc.**