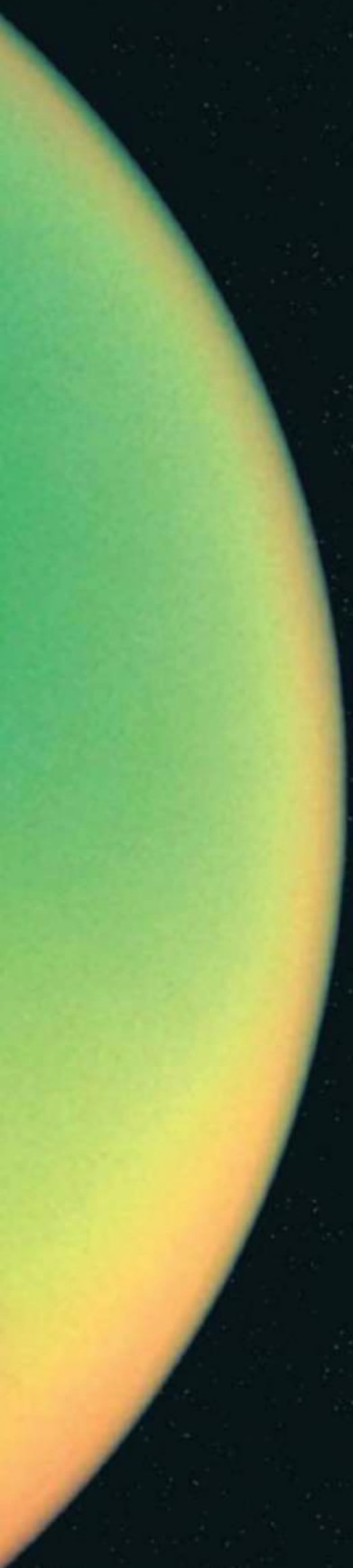
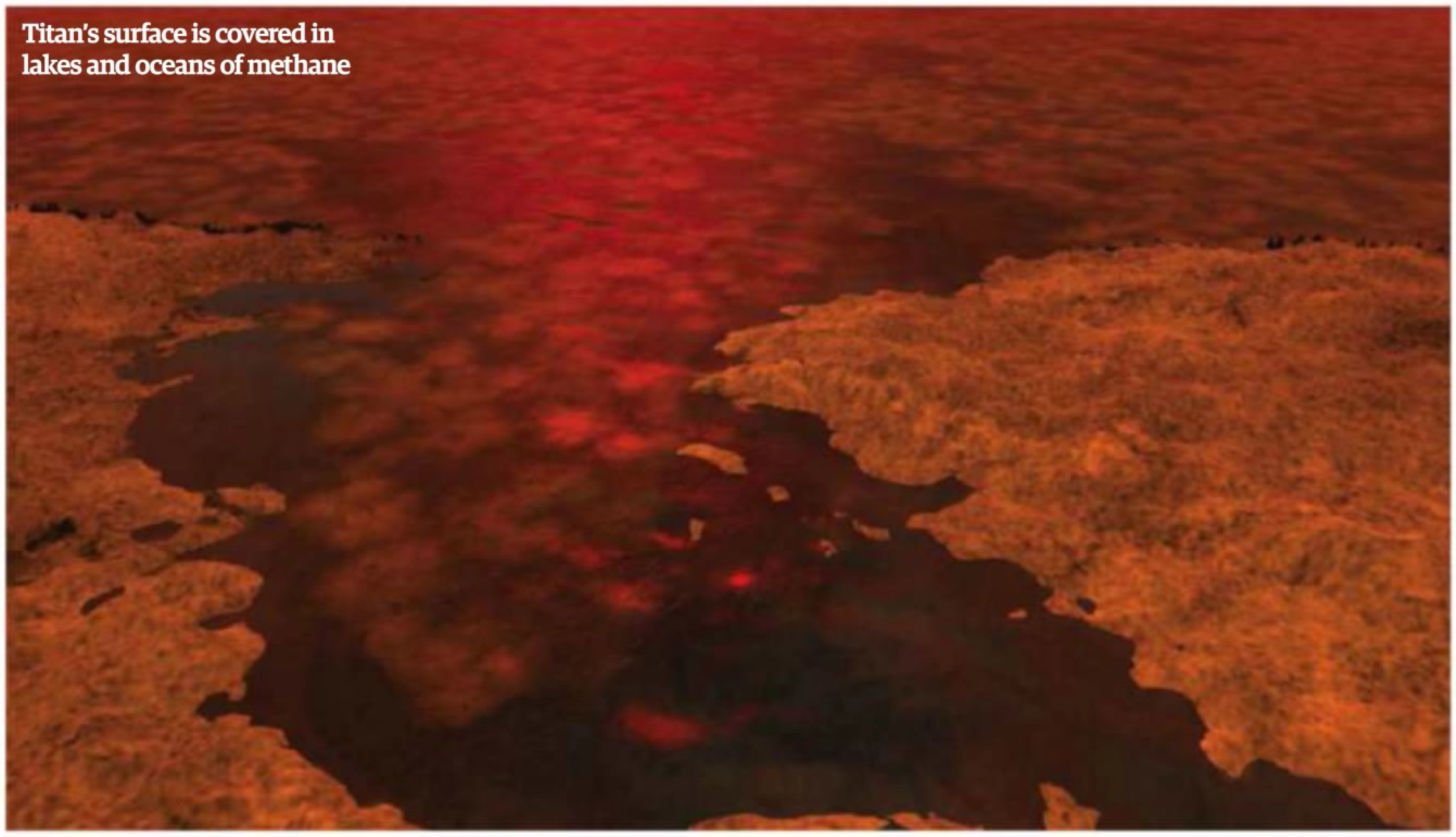


All About...
TITAN

Written by Shanna Freeman

Titan is considered the most planet-like of our Solar System's moons for many reasons, but could it really harbour life of its own or support a human colony?


Titan's surface is covered in lakes and oceans of methane

Saturn has more than 62 known moons (53 named ones) and numerous moonlets. But despite orbiting the same planet, these moons can be incredibly different from each other. One moon, Titan, stands out from the crowd for more than a few reasons. It's both the largest moon of Saturn and the second-largest known moon in the Solar System. It has a diameter of about 5,150 kilometres (3,200 miles) and is larger than both the Earth's Moon and the planet Mercury, although Mercury has a greater mass. Titan is also the only moon found to have a dense atmosphere. It's actually nitrogen-based, just like the Earth's atmosphere. The moon is also believed to have a differentiated interior, familiar surface features, including volcanoes and liquid lakes, a methane cycle that operates similarly to the Earth's water cycle, and four distinct seasons. For all of these reasons, Titan is often known as the most 'planet-like' or 'Earth-like' moon.

Titan orbits Saturn once every 15 days and 22 hours, and its rotational period is the same length. This means that much like the Earth's Moon, Titan is tidally locked with its planet Saturn – the same side of the moon always faces the planet. There is a sub-Saturnian point on the surface of Titan, so that if you were standing on the moon, it would appear that the planet is hanging directly above you. The moon is a distance of just over 1.2 million kilometres (745,000 miles) from Saturn on average, the sixth closest of the gas giant's larger moons. Titan has a high orbital eccentricity of just 0.0288, and its orbital plane is inclined about 0.35 degrees relative to the equator of Saturn.

There's another way in which Titan is not at all Earth-like; it's incredibly cold. On average, Titan is about -180 degrees Celsius (-290 degrees Fahrenheit). Its distance from the Sun means that it just doesn't get enough sunlight to get any warmer. Weather-wise, Titan has both wind and rain. The wind seems to circulate in a single cell in which warm air rises over the hemisphere experiencing summer and cold air sinks into the atmosphere over the hemisphere experiencing winter. Rain over Titan isn't water; it's methane and ethane, and it appears to fall more often in the spring, filling up lakes, rivers and oceans on the surface.

Neither the temperatures nor the apparent lack of water have stopped us from wondering about whether there could be life on Titan. The Cassini-Huygens probe, which first flew by Titan in 2004, has sent back data indicating that in some ways, Titan is like a sort of early Earth that didn't get a chance to evolve into a planet. With the exception of water vapour, the atmosphere is probably similar to that of primordial Earth. The moon also contains the materials to form complex organic compounds that could be considered the 'building blocks' of life. If there were some kind of extraterrestrials on Titan, they would probably have to be methane-based – a type of life form that as yet hasn't been found – and perhaps live in the liquid lakes or even the subsurface ocean. But the cold and the lack of atmospheric carbon dioxide make it unlikely.

How about colonising the moon ourselves, if it's so planet-like? There are several obstacles to this idea. Again, the frigid temperatures and atmosphere are both deterrents; we'd need to be able to maintain both a tolerable temperature and breathable air. Titan's gravity is less than the Moon's at 0.14 g, so the negative effects of low gravity could also be significant. Positives include the shielding from radiation provided by the haze. There is no magnetosphere on Titan, but it spends most of its time within Saturn's and is pretty well protected from the solar wind. So what would drive us to colonise Titan? Natural resources. Data from the Cassini probe indicates that Titan has more liquid hydrocarbons than all the known resources of natural gas and oil on Earth. Some speculate that even if Titan seems inhospitable now, that could change in the future – about five billion years into the future, that is. At that point the Sun should become a red giant, and its increasing heat could warm up Titan enough to set in motion some of the processes that allowed life to form on Earth.

> "Titan, the largest of Saturn's moons, may provide glimpses into conditions on primordial Earth"

The major moons of Saturn

Titan lies 1.2 million km (745,000 miles) from Saturn on average, **and 1.4** billion km (870 million miles) from the Sun

Titan's seasons

Summer
In whichever hemisphere is experiencing summer at the time, the single pole-to-pole circulation cell present on Titan shifts gases upwards into the atmosphere in that hemisphere.

Winter
Titan has seasons just like the Earth, but each one lasts about 7.5 Earth years. The pole experiencing winter has an icy cloud hanging over it. Cassini also observed a reddish area over the pole during its winter.

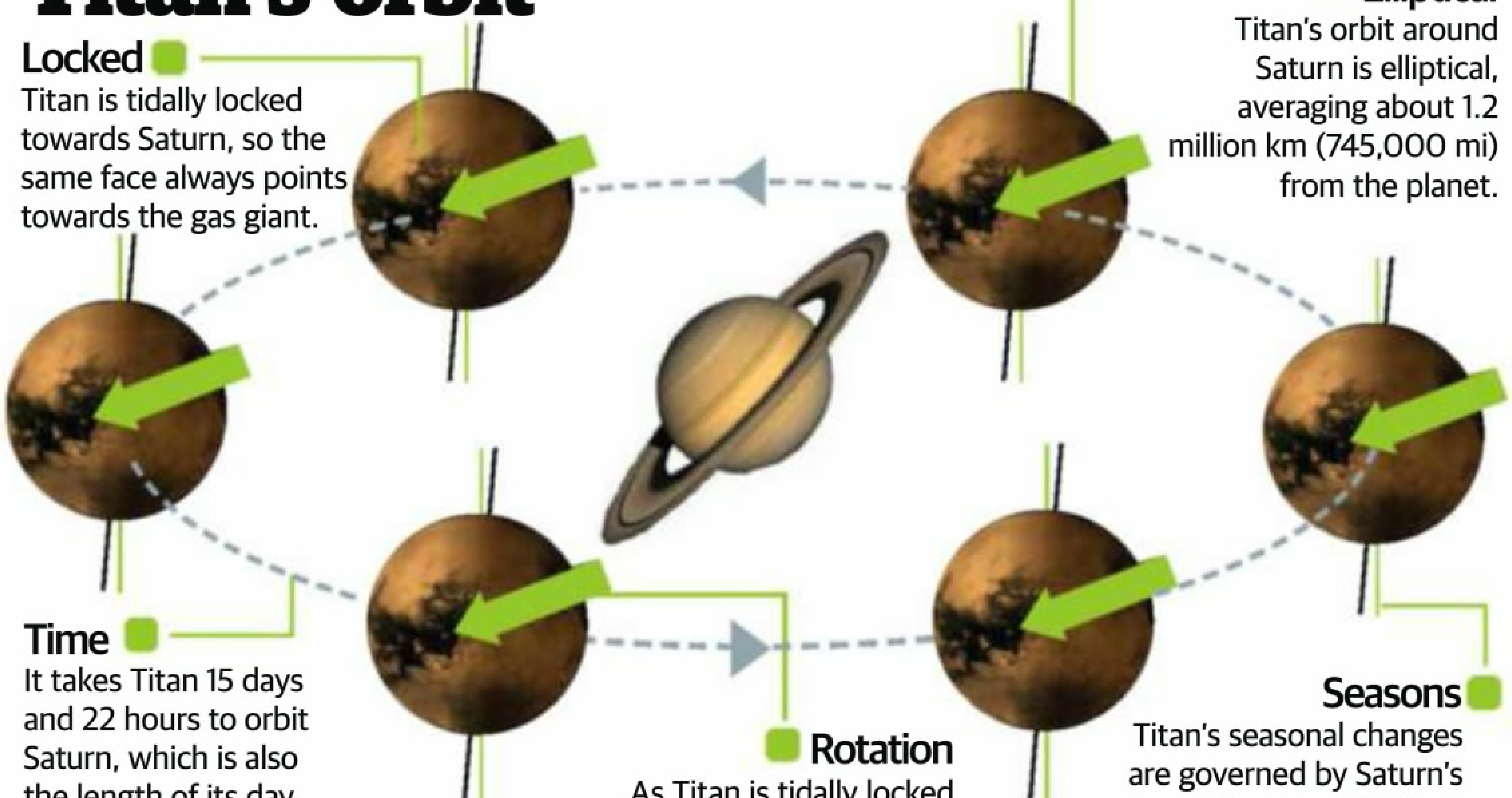
Spring
Spring means the clearing of the ice clouds in the pole that had been going through winter. However, this clearing is a slow and very gradual process; it may take until summer for the clouds to completely dissipate.

Autumn
Cassini has observed that as autumn arrives in each hemisphere, the polar ice cloud begins to form as gases circulate to the area and sinks. Again, it's a slow and lingering process that continues throughout the season.

Titan's orbit

Locked
Titan is tidally locked towards Saturn, so the same face always points towards the gas giant.

Elliptical
Titan's orbit around Saturn is elliptical, averaging about 1.2 million km (745,000 mi) from the planet.



Time
It takes Titan 15 days and 22 hours to orbit Saturn, which is also the length of its day.

Rotation
As Titan is tidally locked to Saturn, it rotates in the same time it takes to orbit.

Seasons
Titan's seasonal changes are governed by Saturn's orbit around the Sun.

Titan has been unusual from its beginning. As Saturn formed, other materials around it coalesced into moons. But for some reason, Saturn did not form multiple large moons with regular orbits. It ended up instead with a very massive moon, Titan, along with many smaller moons. Some scientists speculate that there were once several larger moons orbiting the planet, but then giant impacts with other bodies caused destruction. Titan and some of the mid-sized moons formed from these collisions. This sort of destructive beginning can also account for Titan's eccentric orbit.

Titan is bigger than our Moon – about 1.5 times bigger radius-wise, 3.3 times bigger by volume, and 1.8 times bigger by mass. Titan's radius is 0.4 times that of the Earth's, while its volume is 0.06 that of Earth's, and its mass is 0.02 of Earth's

Titan by numbers

Fascinating facts and figures about Saturn's largest moon

96%

Titan comprises 96 per cent of the total mass in orbit around Saturn, including all 61 of its remaining moons with known orbits

20

Titan dominates Saturn's moon system, but there are 20 named moons closer to the planet than it is

3¼

Three and a quarter Earth moons could fit inside Titan

60%

Titan's atmospheric pressure is 60 per cent stronger than Earth's – the same pressure found at the bottom of a swimming pool

400km (250 miles)

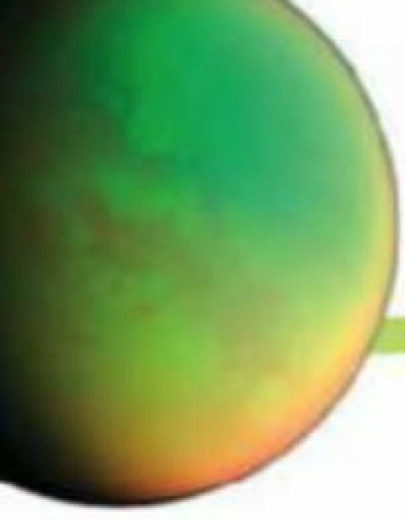
The length of the longest river discovered on Titan by Cassini; it stretches from 'headwaters' to a large sea

3:4

Titan is locked into a 3:4 orbital resonance with its neighbour Hyperion. For every three Hyperion rotations, Titan has four

1 PER CENT

Titan gets just one per cent of the sunlight that the Earth receives

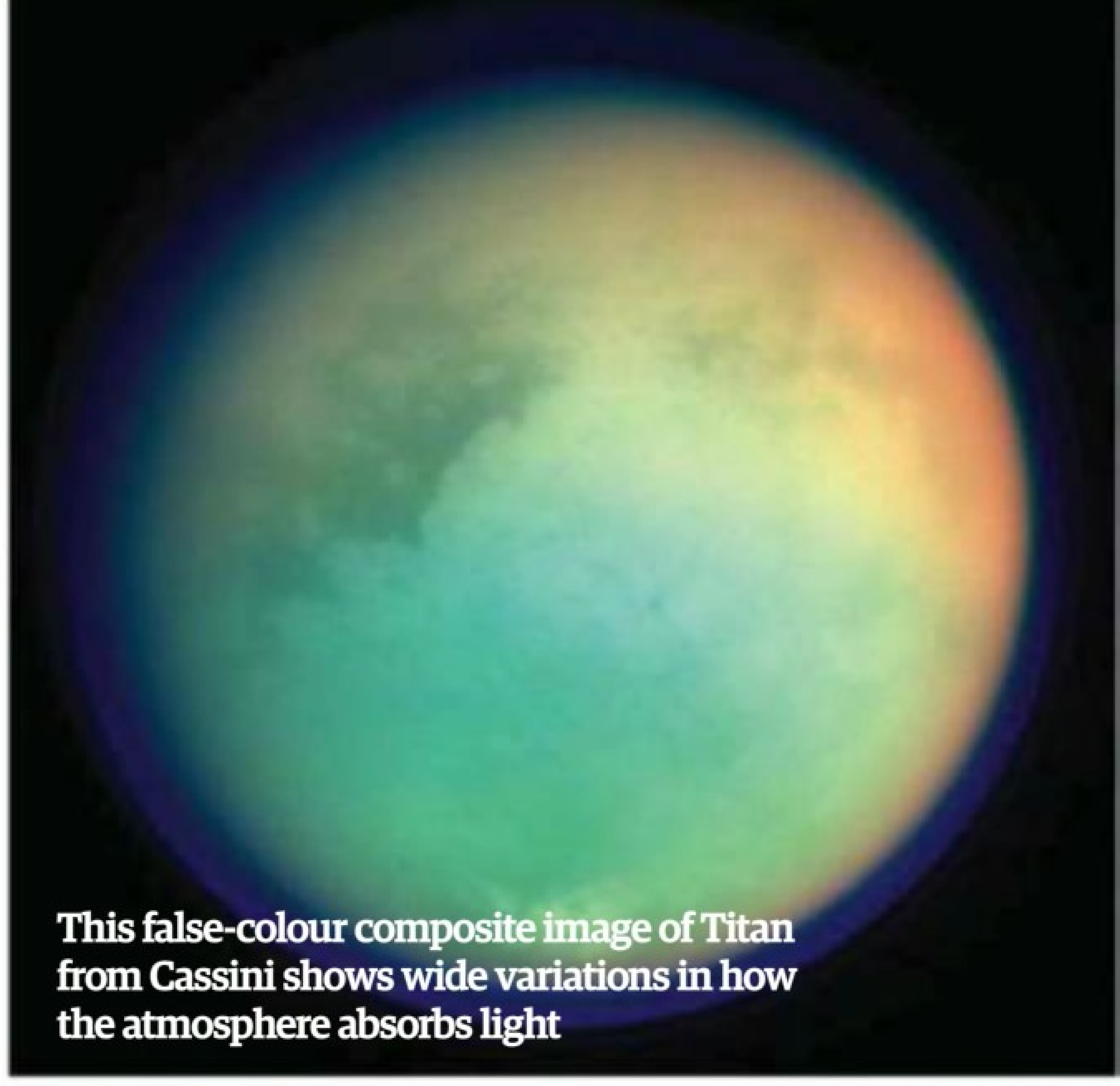


Titan inside and out

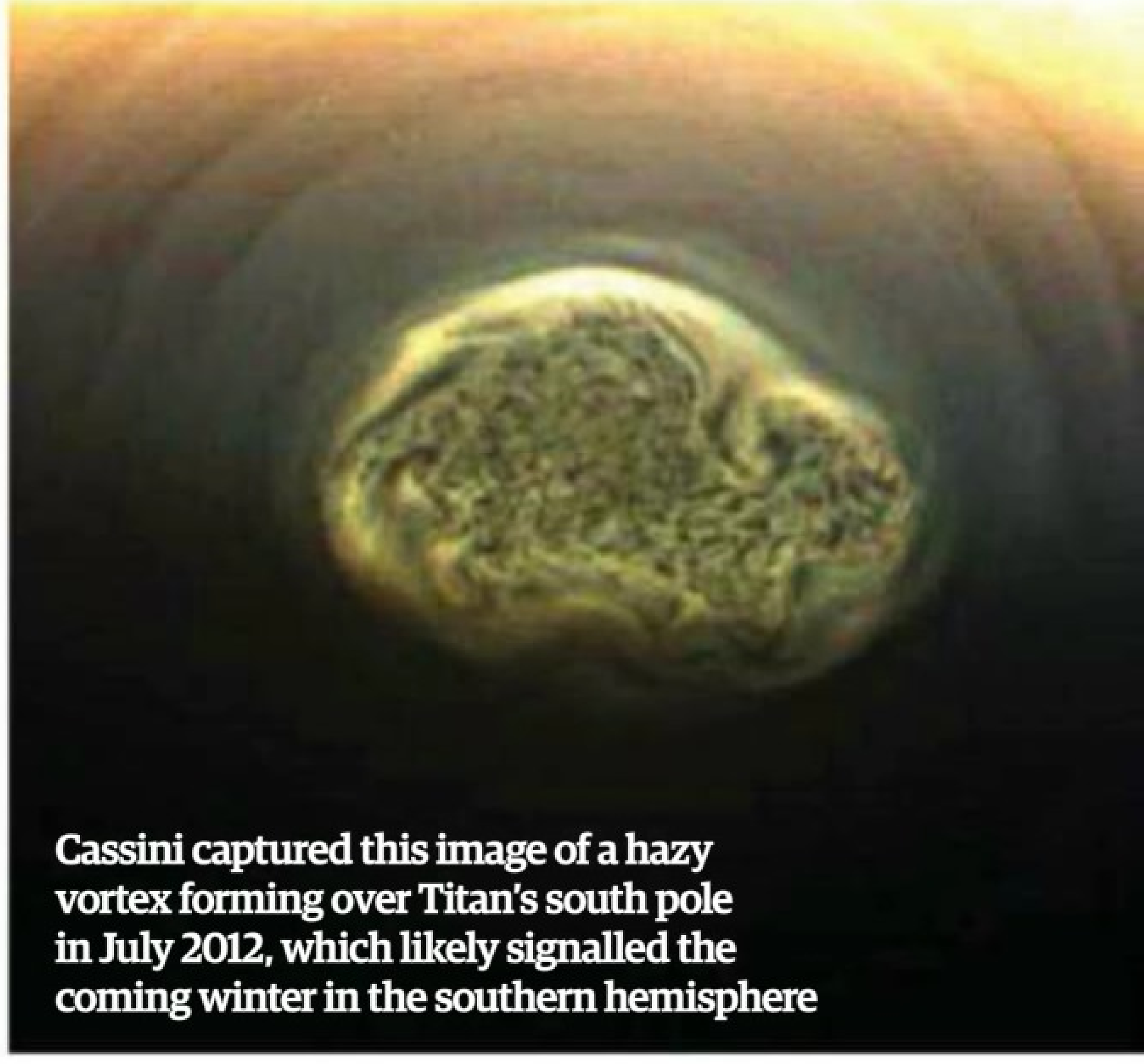
We knew that Titan was icy, but until Cassini's visit we didn't know about its hidden ocean

The interior of Titan appears to be quite icy and prior to the Cassini probe's visit, it was thought that the moon may not have a differentiated interior at all, but a disorganised one of ice and rock. Recent data indicates that the moon probably has a differentiated interior that is mainly composed of ice and liquid in different layers, with a rocky core. The core itself is less dense than one might expect, though, leading us to think that there must be some ice or liquid along with the silicates. This definitely makes Titan different from terrestrial planets like Earth (which have dense iron cores), but its big atmosphere and potentially large stores of liquid on the surface also set the moon apart from other icy moons.

Between the surface of the moon and its core lie three layers - an ice one that lies underneath the surface, which floats atop a liquid ocean, and then another hard icy shell. Titan's composition may help explain the huge levels of methane in its atmosphere - it has to be coming from somewhere, because otherwise the surface methane would have long ago been depleted via interactions with ultraviolet light from the Sun. If cryovolcanism is taking place on the moon, then methane stored underneath the surface may be outgassed that way. A liquid ocean could provide the storage, but the methane may also come up through the crust as the liquid (which would also contain ammonia) bubbles up. ■

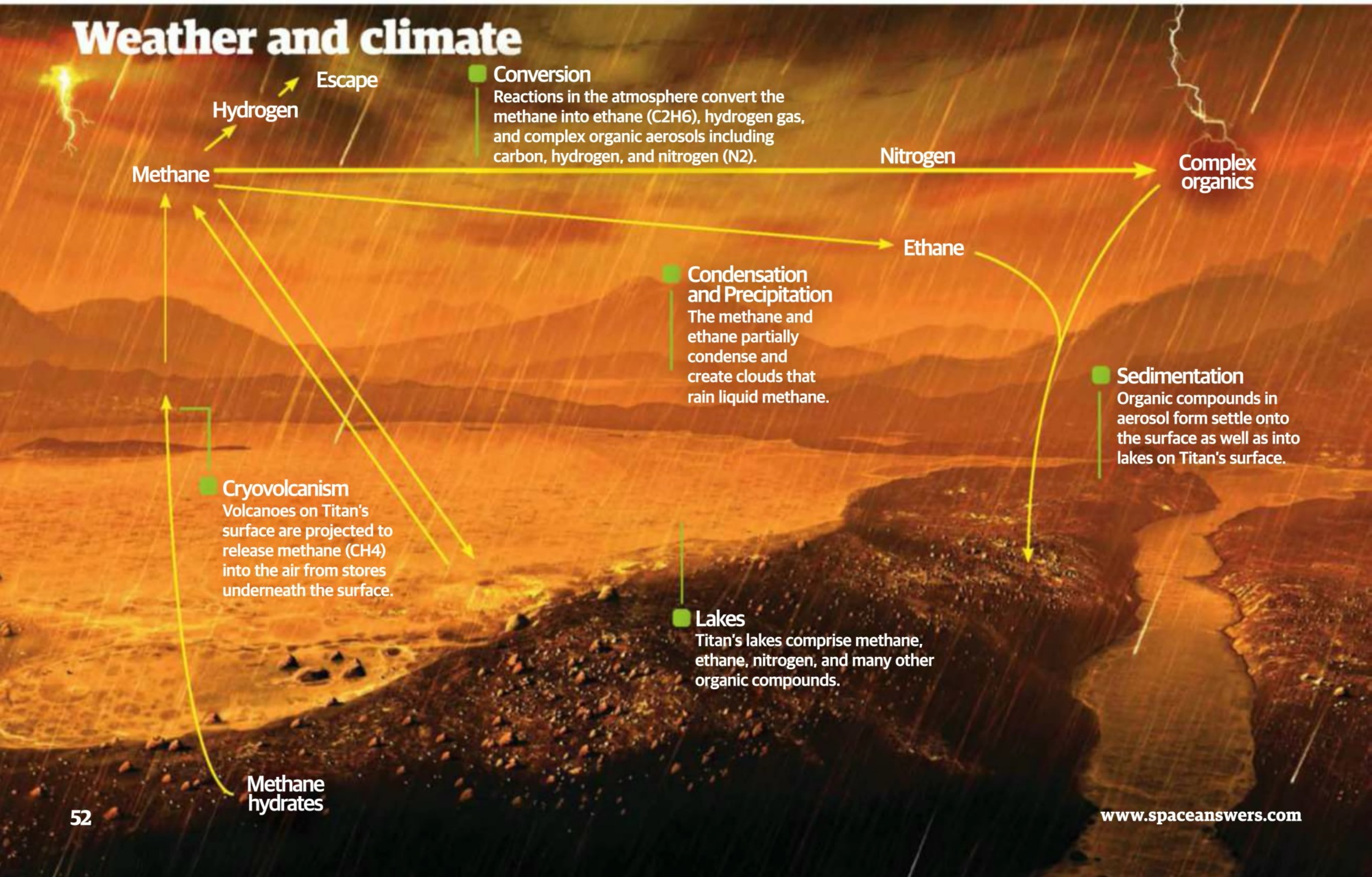


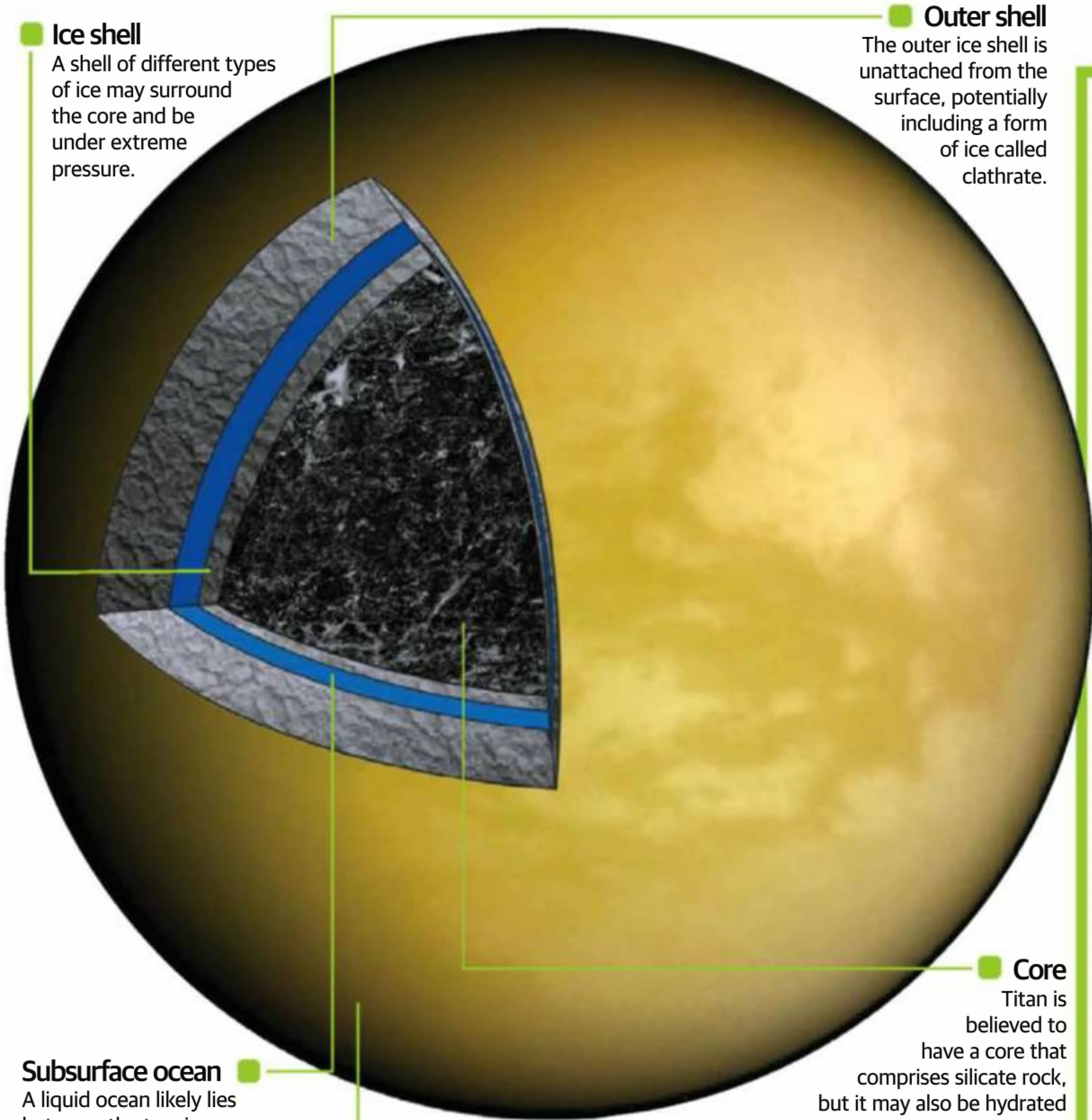
This false-colour composite image of Titan from Cassini shows wide variations in how the atmosphere absorbs light

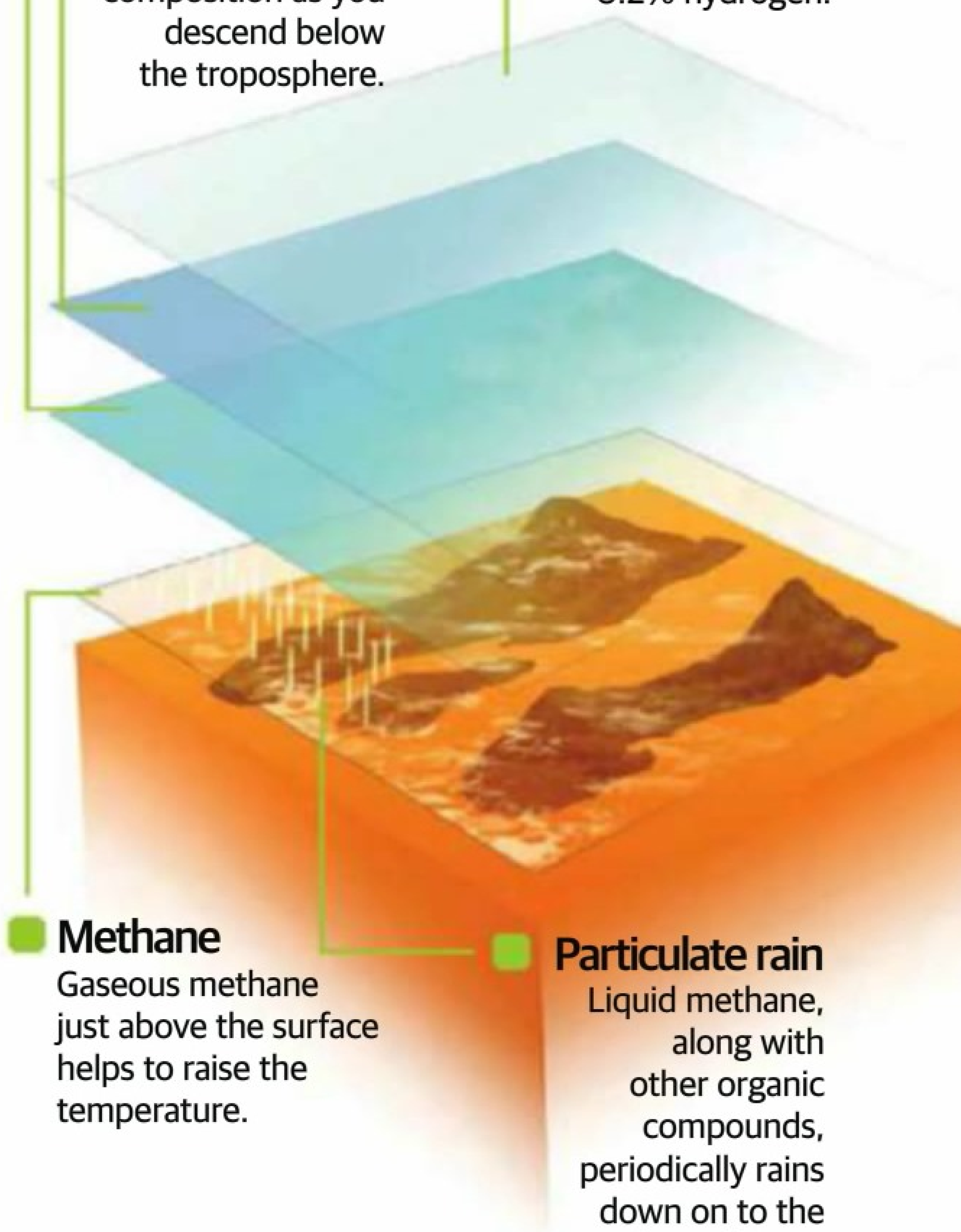


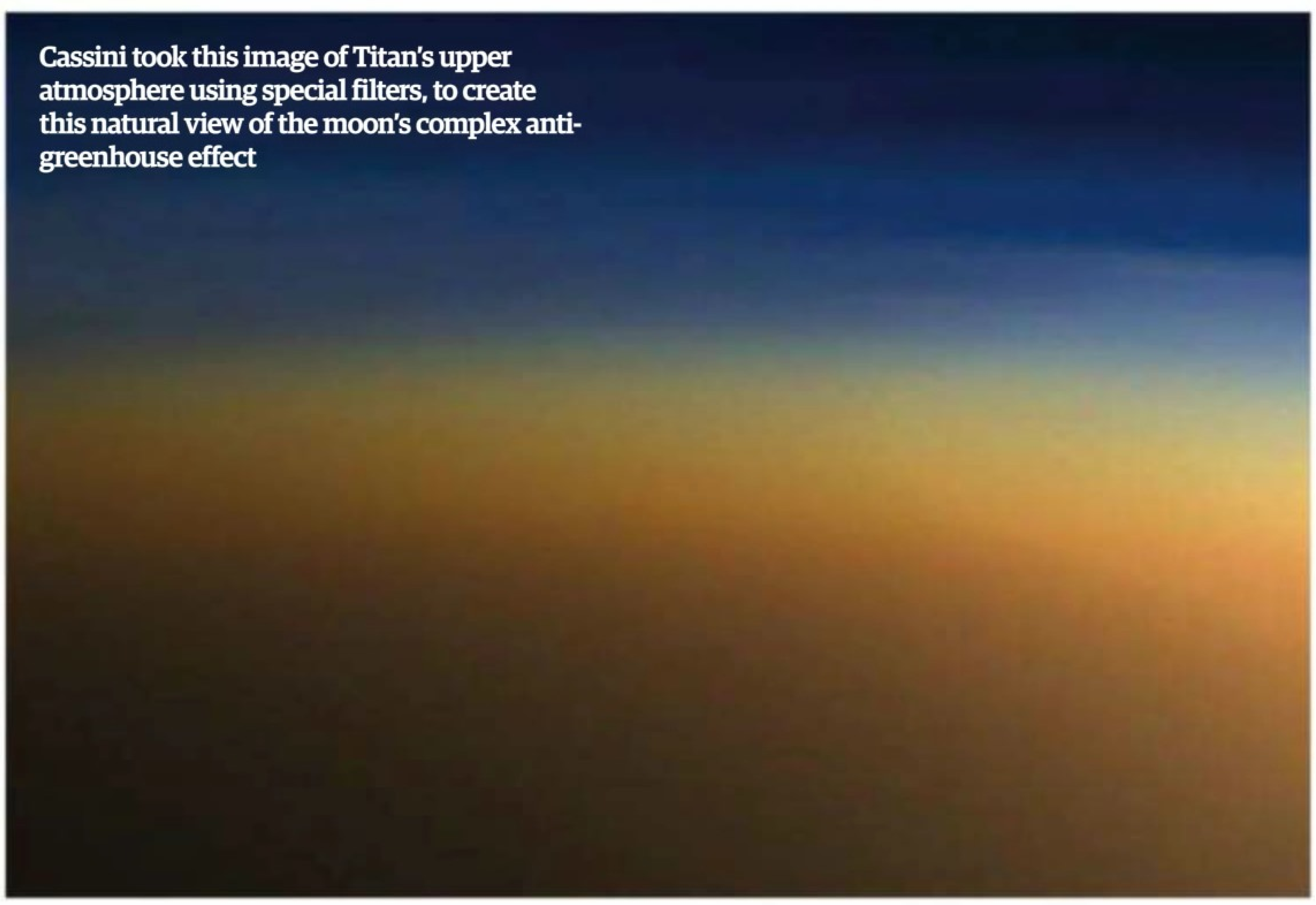
Cassini captured this image of a hazy vortex forming over Titan's south pole in July 2012, which likely signalled the coming winter in the southern hemisphere

Weather and climate







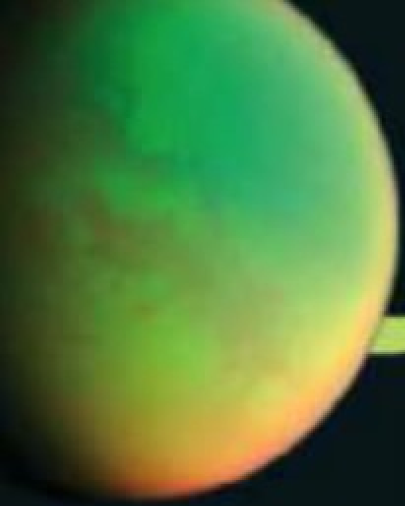


Cassini took this image of Titan's upper atmosphere using special filters, to create this natural view of the moon's complex anti-greenhouse effect

Titan's atmosphere

Titan possesses the only known nitrogen-dense atmosphere in the Solar System other than Earth's. It is actually denser and more massive than the Earth's atmosphere thanks to its hazy layers. Titan's lower gravity (0.85 that of the Moon's) also means that its atmosphere extends much further from the planet than the Earth's does – more than 600 kilometres (373 miles).

The dominating players in Titan's atmosphere are nitrogen and methane. Nitrogen makes up more than 98 percent in the highest regions, with the methane percentage increasing as the altitudes decrease. It's responsible for the thick haze that had prevented us from getting a clear view of the moon's surface until the Cassini-Huygens probe. Titan's atmosphere also has both a greenhouse effect and an anti-greenhouse effect. The methane in the upper atmosphere creates a greenhouse effect, keeping Titan warmer than it would be otherwise. However, the layer of haze actually reflects sunlight away from the moon. Ultimately the temperature of the moon is warmer than it would be without these concentrations of methane in the atmosphere.



On the surface

Titan is covered with a network of interesting features that we're only just now discovering thanks to Cassini

Titan is called planet-like for more than just its atmosphere; the moon also has numerous features on its surface that are similar to those on Earth. The surface of Titan is much younger than the moon itself, between 100 million and one billion years old (the moon is almost as old as the Solar System, about 4.6 billion years old). This relative youth may be due to volcanism and other geologic processes within it.

Titan is believed to be mostly smooth, with a surface consistency like that of wet sand. Because of the cold temperatures, it might be more accurate to say frozen sand. On average, the elevation is about 150 metres (492 feet), but there are some tall mountains as well. Other surface features include plains, dunes, lakes and seas.

Because of the difficulty in penetrating Titan's atmosphere, only recently have we begun to learn about its surface features. But before we explore those, let's look at one of the first things you notice when viewing a map of the surface: its large, contrasting areas of light and dark. Even the lighter regions appear to have dark lines running through them, indicating potential tectonic activity or channels cut by streams. There are also smaller light areas, called faculae, as well as smaller dark ones, called maculae. The lighter areas are likely ice, from methane or ethane, while the dark ones are plains.

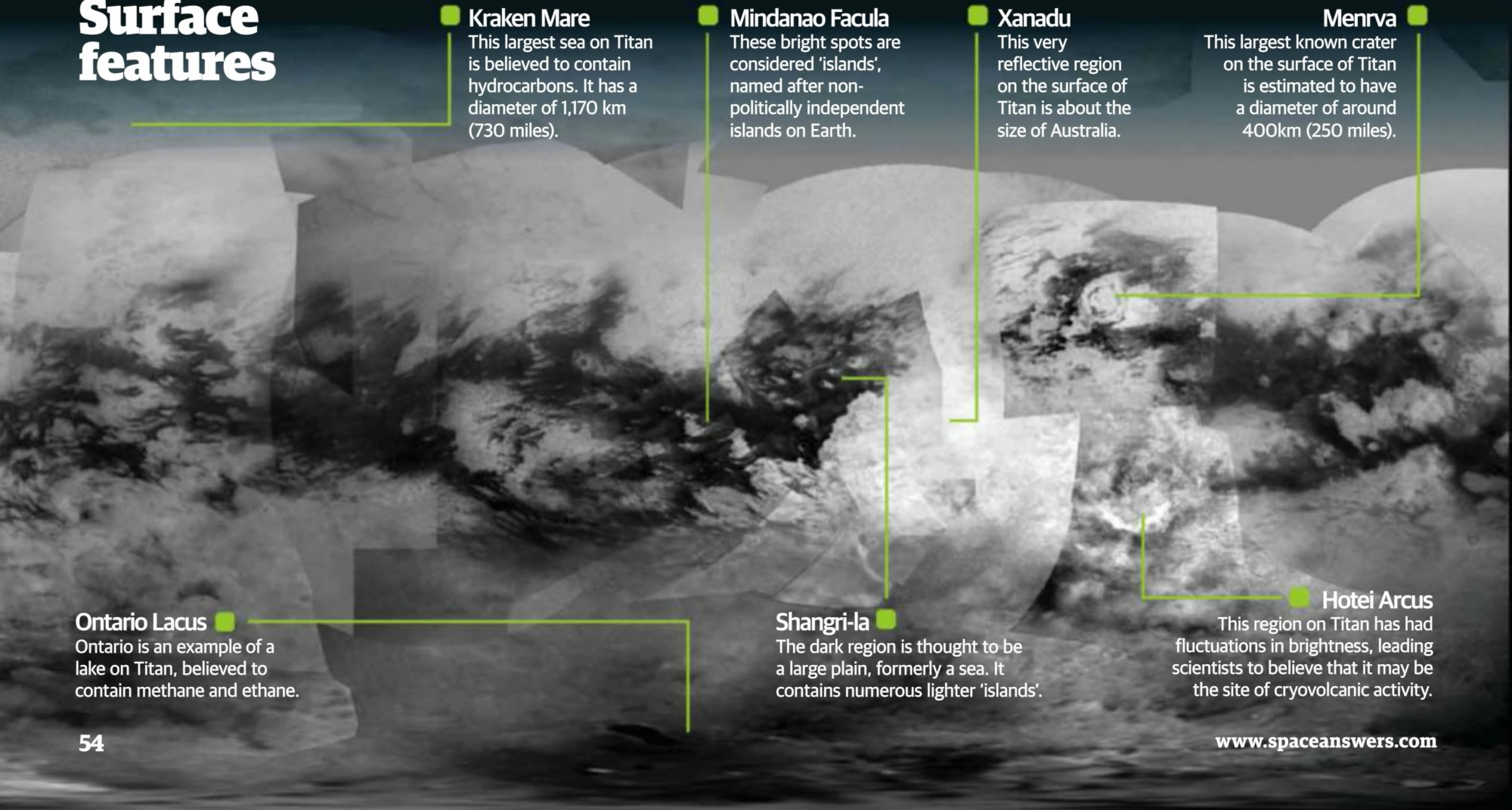
Many other moons, including our own, have smaller dark areas that astronomers initially believed to be liquid lakes or seas. In most cases, these turned out to be another material. Titan, however, appears to actually have liquid in its lakes. The larger areas are known as maria, or seas, and the smaller ones are lacūs, or lakes. Cassini confirmed the existence of these liquid lakes when it observed reflections that indicated smooth, mirror-like surfaces. These appear to be mainly around the poles, where they can't be evaporated by sunlight, but there are others that are potentially fed by underground stores. The lakes are hydrocarbon-based, mostly ethane and methane, and are the first stable, liquid bodies found somewhere other than Earth. The largest of these, Kraken Mare, may be as big as the Caspian Sea. So we know that they're big and liquid, but we aren't sure about things like the exact ratios of hydrocarbons, or the viscosity. Some data indicates that they may be thick and tar-like.

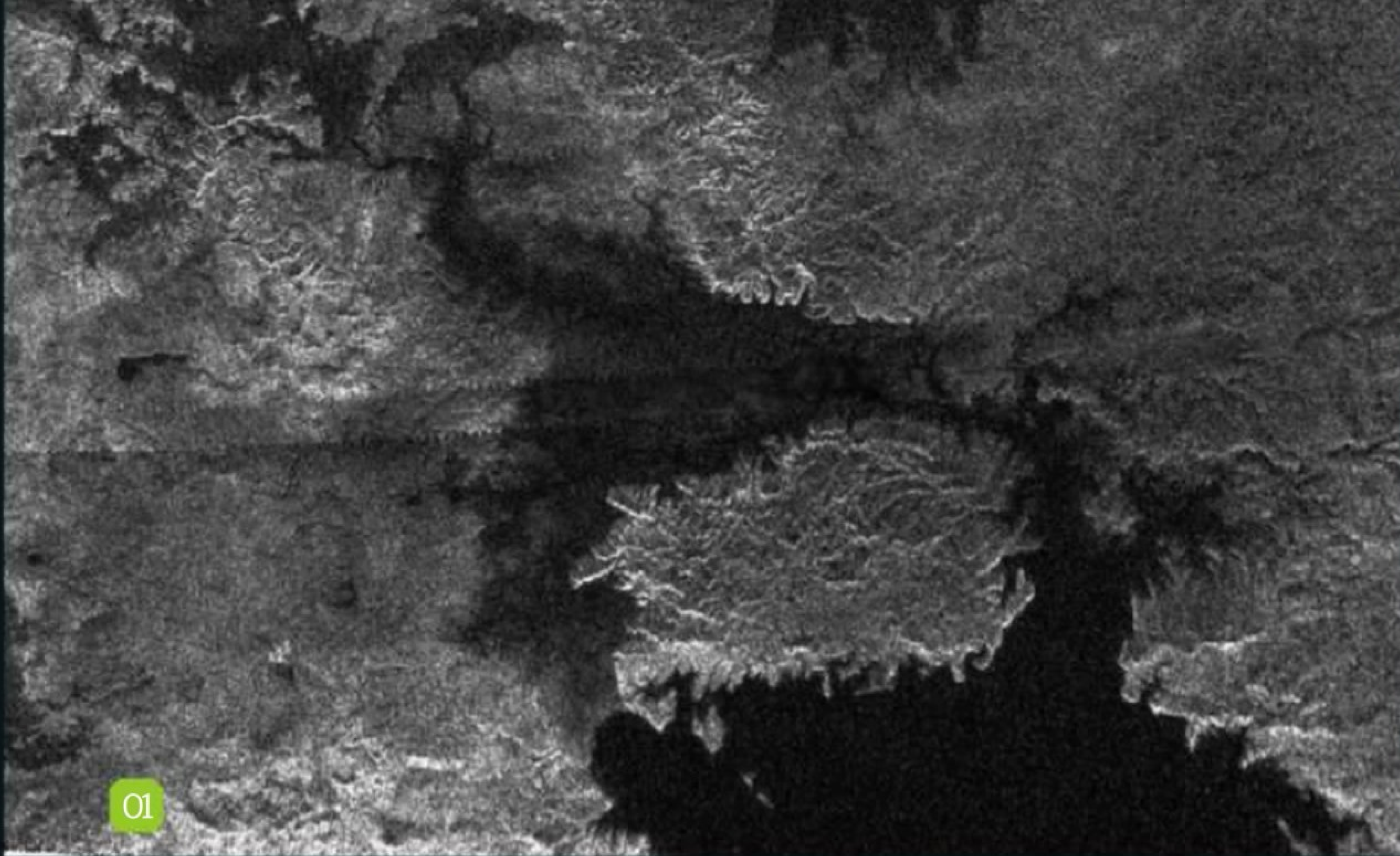
The origins of mountains on Titan can't be confirmed, but one theory is that they are cryovolcanoes, or ice volcanoes. Because Titan is much cooler than Earth, its volcanoes would probably expel ammonia and liquid along with hydrocarbons. The strongest possibility for a cryovolcano is Sotra Patera, a two-peaked mountain. The taller of its two peaks is estimated at 1,500 metres (4,900 feet) high. Other scientists believe that Titan is geologically inactive, and the mountains are just the remnants of large impact craters that have degraded, or even caused by the moon contracting as its interior cooled.

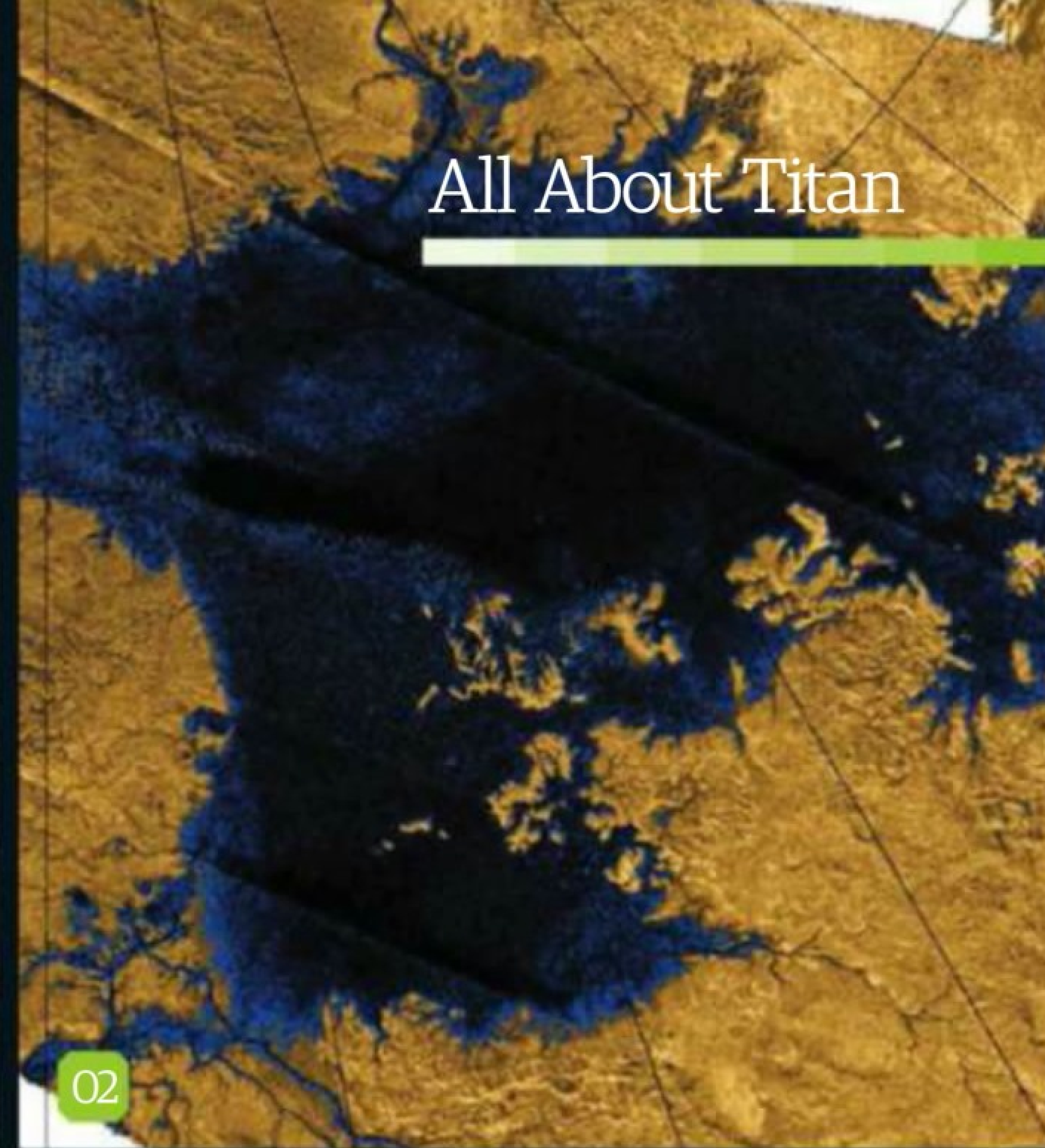
Speaking of impact craters, Titan doesn't have many of them. Some craters may have been filled in by materials from cryovolcanoes or sediment blown in by tidal winds. Titan might also not get as many heavy impacts because of its thick atmosphere.

Due to the freezing temperatures, Titan's surface might seem hostile to life. However, there are several things that allow for the possibility. There's the large amount of organic compounds present, which are potential building blocks for life. There's also the possibility of hydrocarbon ice blocks floating on lake surfaces and the potential for a subsurface ocean. Cassini continues to send back information about the surface as it observes Titan's seasonal changes, so we may have more information soon.

Surface features







1. Kraken Mare
Cassini took this radar image of Kraken, the largest known liquid body on Titan. It appears to contain an island about the size of Hawaii's largest island.

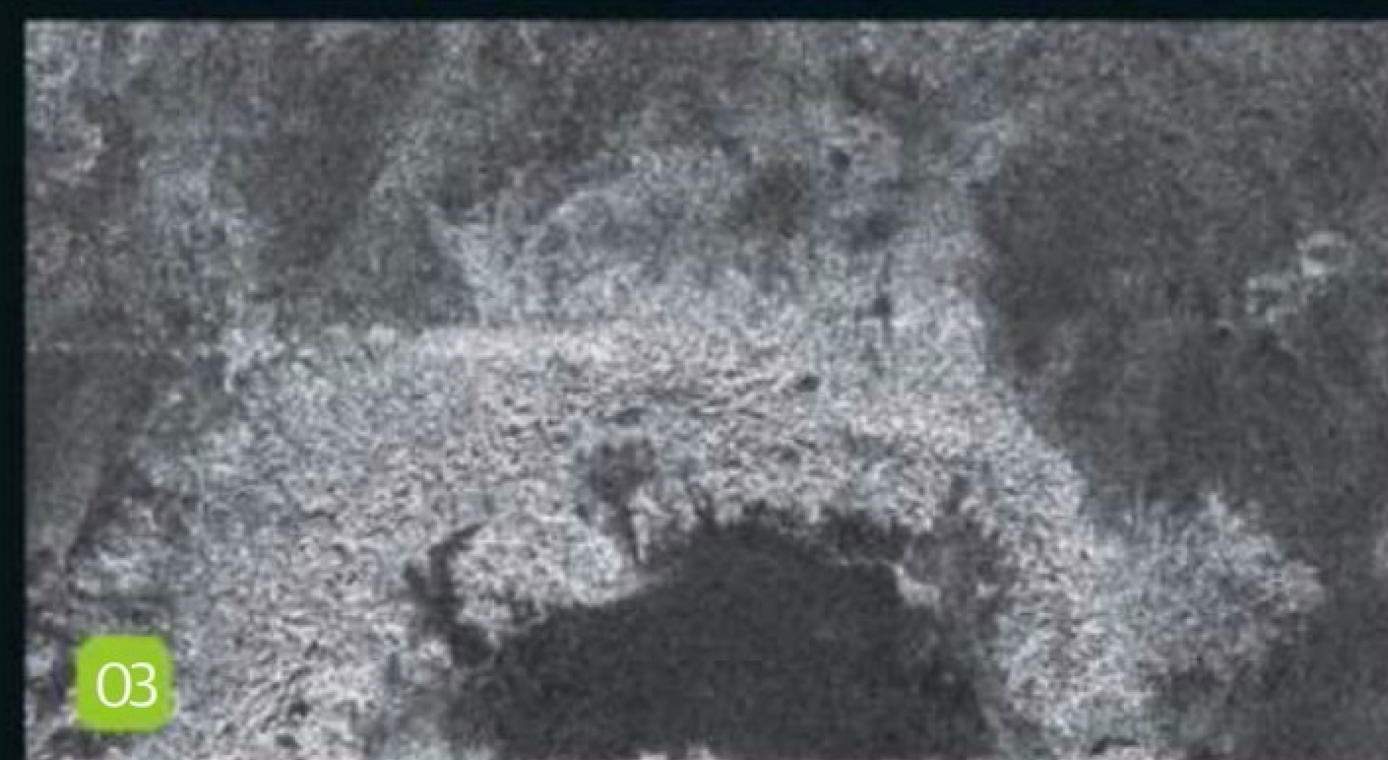
2. Ligeia Mare
This mosaic image from Cassini shows Ligeia Mare, a sea on the surface in the north polar region. It is the second-largest body of water after Kraken Mare.

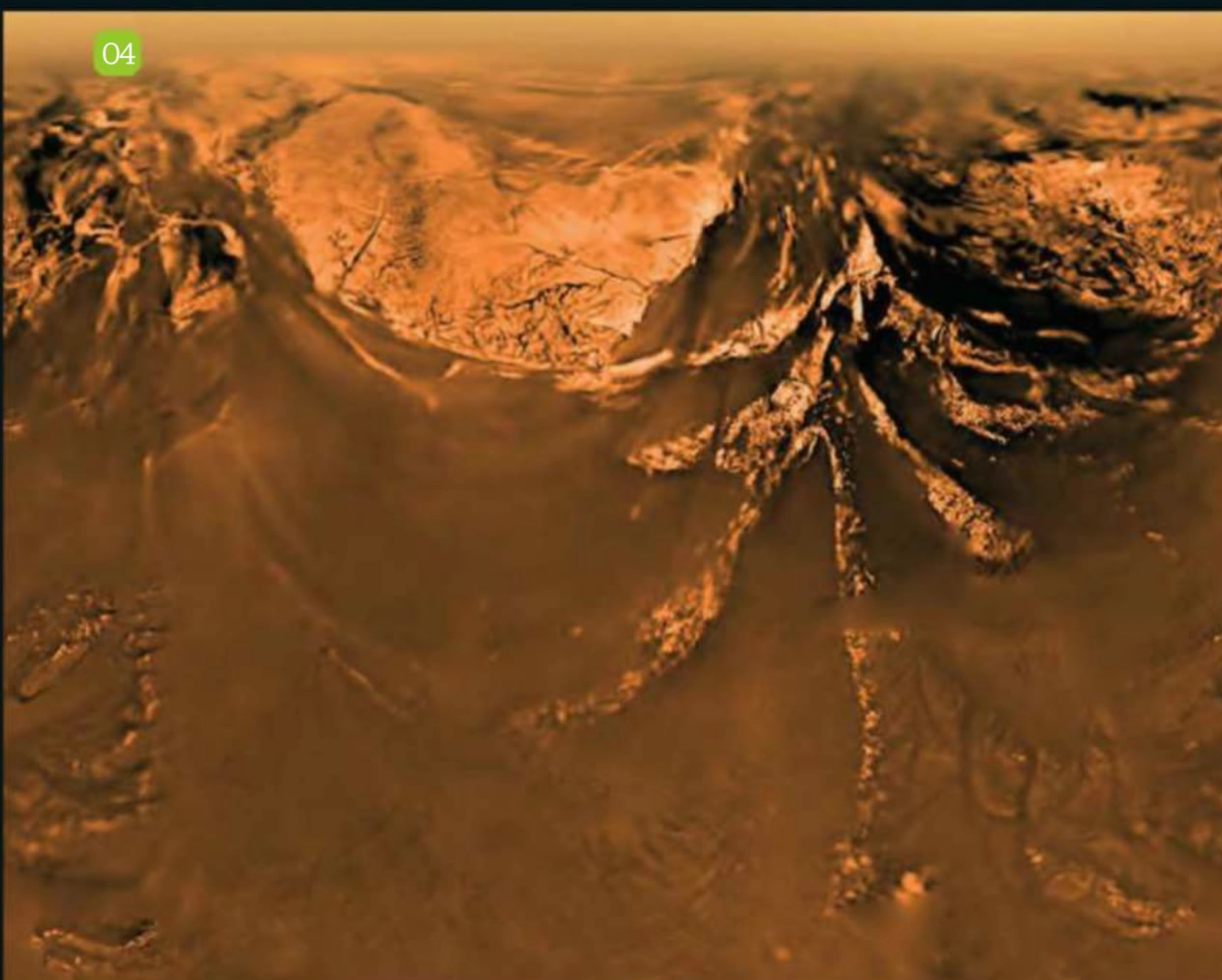
3. Impact crater
This radar image, taken by Cassini during a flyby, appears to contain part of an impact crater.

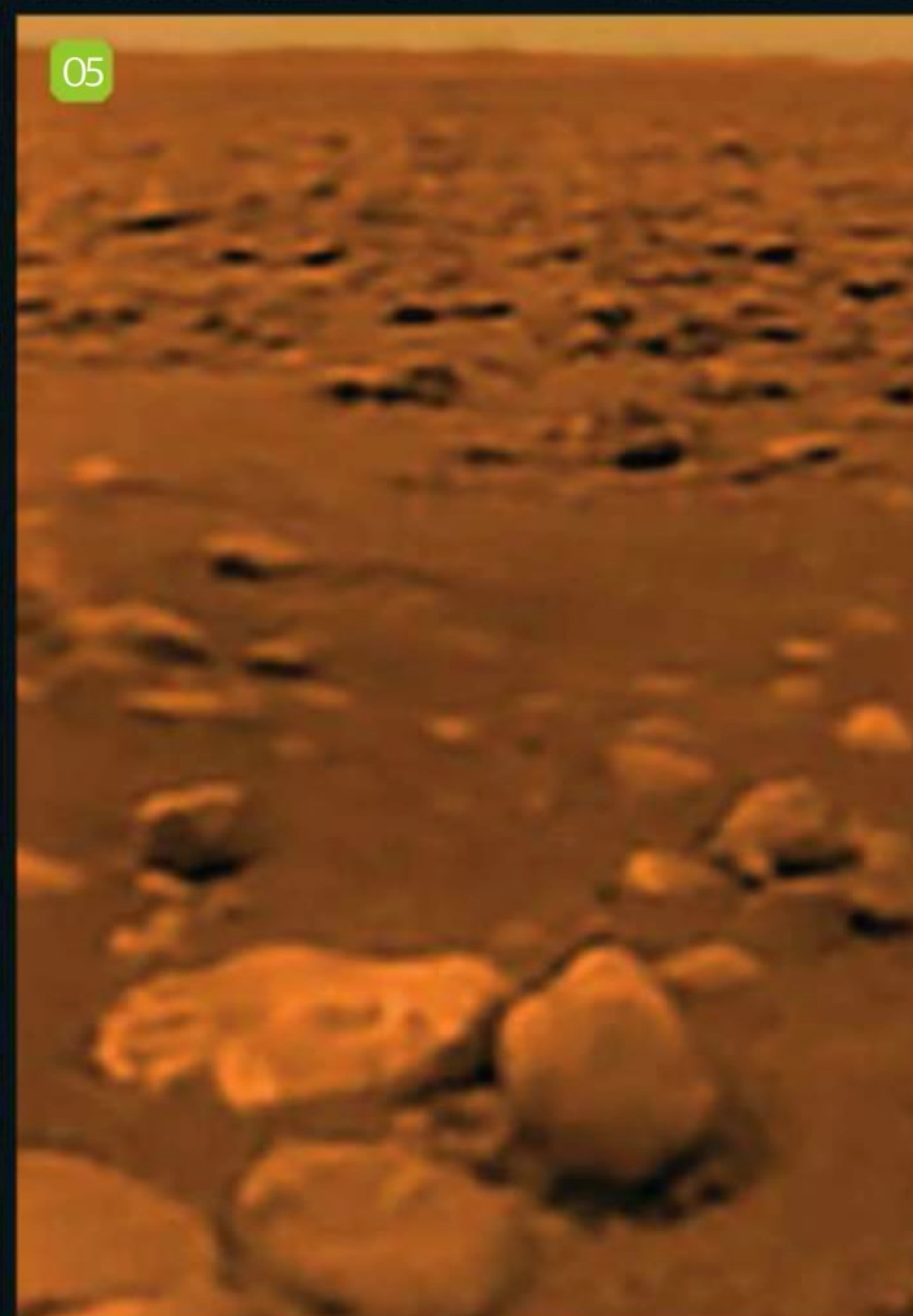
4. Titan from Huygens
During its descent to Titan's surface in January 2005, the Huygens probe sent back the images that make up this flattened projection.

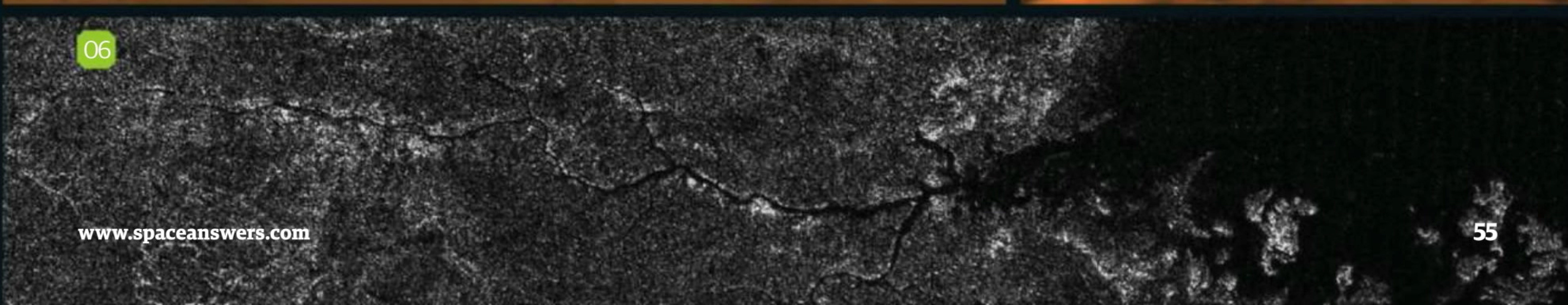
5. Huygens probe image
Extensive data processing of this image taken by the Huygens probe in January 2005 reveals pebble-sized rocks, possibly ice, on Titan's surface.

6. Hydrocarbon river
Cassini sent back this image of an extensive river system on Titan's surface in September 2012.









Exploring Titan

Titan remained a hazy mystery until the Cassini-Huygens spacecraft penetrated its dense atmosphere, however, it appears that future explorations are currently on hold

Because Titan is so close to Saturn, it can be difficult for amateurs to observe from Earth. The planet's brightness and rings can overwhelm the view. However, it can be seen with small telescopes or powerful binoculars. Astronomers often use an occulting bar on their telescopes – this band placed on the eyepiece is used to block brighter objects in the sky so that dimmer ones can be more easily seen. Another obstacle to exploring Titan has been its thick, hazy atmosphere, which has proven difficult to penetrate.

Titan was discovered in 1655 by Dutch astronomer Christiaan Huygens, and was originally thought to be larger than it actually is due to its thick atmosphere. Spanish astronomer Josep Comas i Solà claimed to observe light and dark patches on the moon in 1907, giving us our first piece of evidence that it might have an atmosphere. In 1944, Dutch astronomer Gerard Kuiper formally confirmed the presence of the moon's atmosphere when he spotted bands of methane.

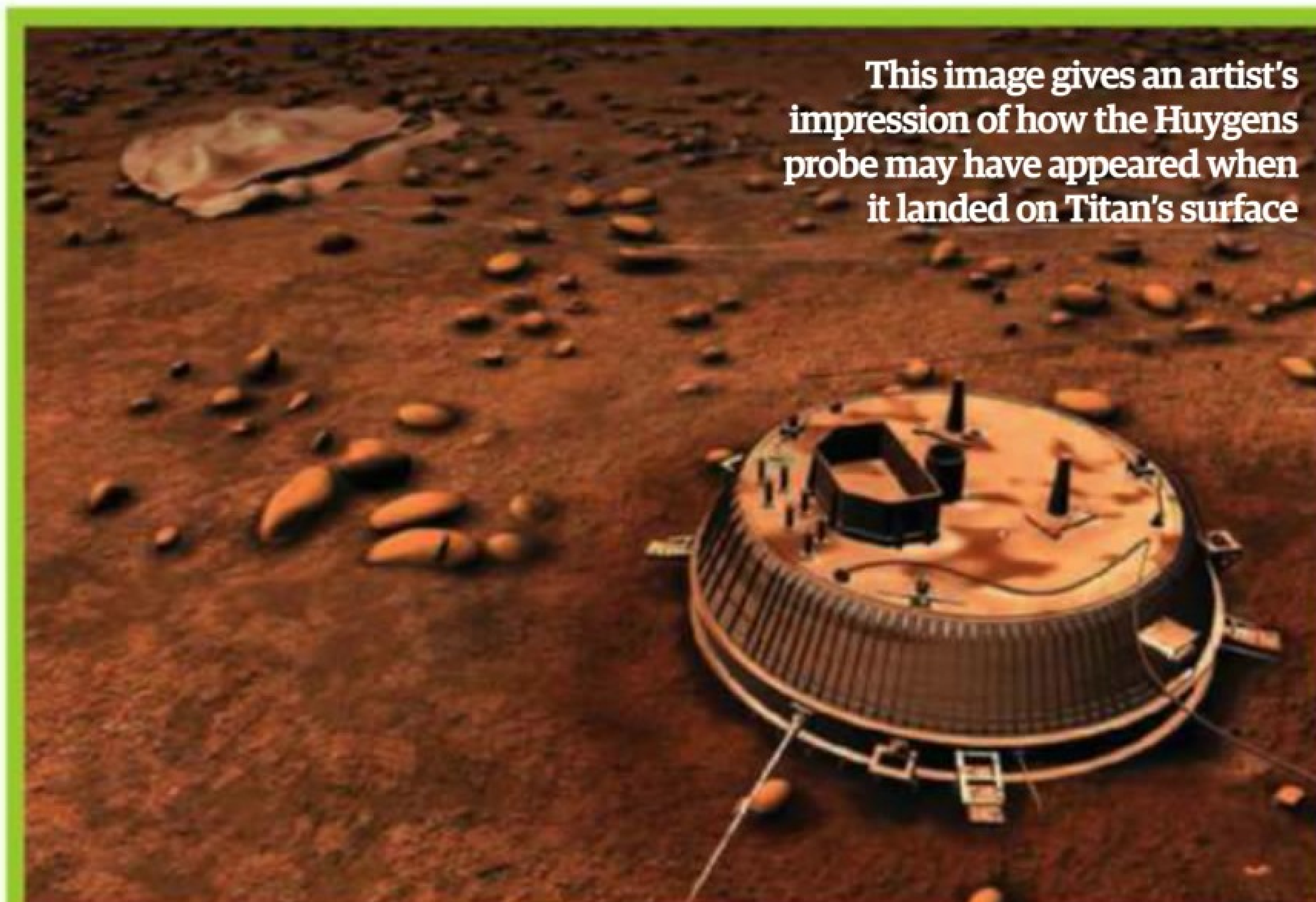
Little more was learned about the moon until the first spacecraft visited the Saturnian system in 1979 – the Pioneer 11 probe. It took some of the first images of the moon and determined that Titan was likely too cold to support life, but most of the images weren't high-quality ones. Voyagers 1 and 2 both visited Titan as well. In 1981, Voyager 1 specifically flew by to observe the moon, but didn't have instruments capable of finding many details in the haze. Digital processing of the Voyager 1 images much later did reveal some features, but these had already been observed by the Hubble Space Telescope. Voyager 2 didn't bother getting too close to Titan based on Voyager 1's experience, instead choosing to head out to Uranus and Neptune. All we knew was that it likely had a planet-like atmosphere.

The Cassini-Huygens spacecraft provided us with the first real opportunity to explore Titan in a serious way. Special filters on Cassini's cameras allowed them to get through the atmosphere to take some detailed images of the surface and show the moon's features. The Huygens probe also sent back images and other data about the composition of the moon's atmosphere and surface. Cassini is currently on its second extended mission, Solstice, which includes additional flybys of Titan.

The future of Titan exploration is uncertain, however; two different missions proposed by NASA and the European Space Agency (ESA) have gone nowhere, and the same is true of proposals by groups of scientists. A joint venture between NASA and the ESA called the Titan Saturn System Mission (TSSM) was put on hold after NASA decided to pull out in 2012. NASA had also proposed the Titan Mare Explorer (TiME), a potential lake lander, but has chosen to fund a probe to Mars instead.

A group of Spanish scientists presented another lake lander proposal called TALISE (Titan Lake In-situ Sampling Propelled Explorer) at the European Planetary Science Congress in autumn 2012, but so far it has not gone beyond the proposal stage. The same goes for a group of American scientists, whose proposal of an unmanned drone lander called Aerial Vehicle for In-situ and Airborne Titan Reconnaissance (AVIATR) was passed over for inclusion in The Decadal Survey. This document – created by NASA, the National Research Council, and the National Science Foundation – is a list of recommendations for future space exploration.

On 29 December 2006, Cassini captured images of a huge cloud system covering Titan's north pole



This image gives an artist's impression of how the Huygens probe may have appeared when it landed on Titan's surface

Huygens probe

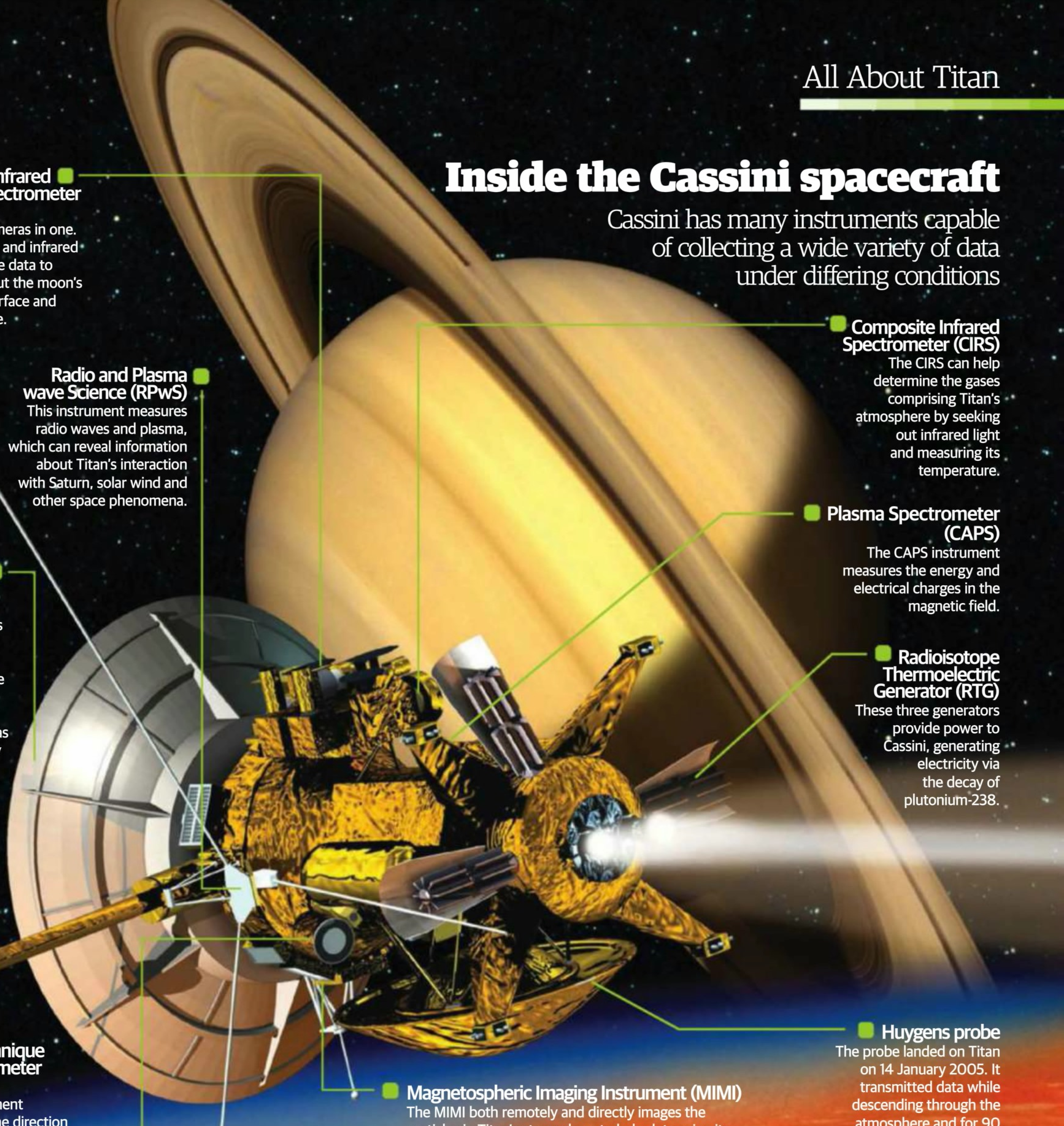
The European Space Agency (ESA) supplied the Huygens probe, which rode aboard the Cassini spacecraft until it reached Titan. Huygens was designed to parachute down to the moon's surface, gathering data along the way. There was no way of knowing exactly where it might land on Titan, so engineers designed it to withstand both an ocean splashdown and a surface impact. The probe weighed about 318 kilograms (700 pounds) and had a diameter of 1.3 metres (four feet) after ejecting its heat shield.

During the spacecraft's trip to Titan, the probe stayed dormant except for the occasional system check to be sure everything was in working order. The probe separated from Cassini on 25 December 2004, and Cassini stayed in orbit above the moon to support the probe and receive data. Huygens coasted for 22 days. Upon entering Titan's atmosphere, it deployed a parachute and descended to the surface. Images taken by Cassini about 1,200 kilometres (746 miles) above showed that Huygens landed on what is probably a shoreline.

Huygens was supposed to have a battery life of about three hours. It also had six different instruments on board to perform experiments. In the atmosphere, they measured particles, identified and measured chemicals, studied radiation levels, and measured wind speed, density and temperature. Another instrument sent back information about the surface of the moon where the probe landed. It took Huygens about two-and-a-half hours to descend and land on the surface, and it continued to send data for nearly 90 minutes. The probe's landing marked the first time a spacecraft has landed on a body in the outer Solar System.

Inside the Cassini spacecraft

Cassini has many instruments capable of collecting a wide variety of data under differing conditions



Visible and Infrared Mapping Spectrometer (VIMS)

VIMS is two cameras in one. The visible light and infrared cameras capture data to learn more about the moon's atmosphere, surface and overall structure.

Radio and Plasma wave Science (RPwS)

This instrument measures radio waves and plasma, which can reveal information about Titan's interaction with Saturn, solar wind and other space phenomena.

High Gain Antenna

Cassini's radar system bounces microwaves off surfaces to measure surface composition and image the landscape. It was built specifically to study Titan.

Dual Technique Magnetometer (MAG)

This instrument measures the direction and strength of Saturn's magnetic field.

Cosmic Dust Analyser (CDA)

The CDA observes tiny grains of dust on the planet's surface to detect their direction, size and speed.

Composite Infrared Spectrometer (CIRS)

The CIRS can help determine the gases comprising Titan's atmosphere by seeking out infrared light and measuring its temperature.

Plasma Spectrometer (CAPS)

The CAPS instrument measures the energy and electrical charges in the magnetic field.

Radioisotope Thermoelectric Generator (RTG)

These three generators provide power to Cassini, generating electricity via the decay of plutonium-238.

Huygens probe

The probe landed on Titan on 14 January 2005. It transmitted data while descending through the atmosphere and for 90 minutes after landing.

Magnetospheric Imaging Instrument (MIMI)

The MIMI both remotely and directly images the particles in Titan's atmosphere to help determine its magnetic field.

Mission Profile

Cassini spacecraft

Name: Cassini-Huygens
Launch: 15 October 1997
Orbital insertion: 1 July 2004
Launch vehicle: US Air Force Titan IVB/Centaur rocket
Vehicle mass (orbiter): 2,523kg (5,560lb)
Spacecraft dimensions (orbiter): 6.8m (22ft) high, 4m (13.1ft) wide
Missions: Cassini-Huygens, Cassini Equinox, Cassini Solstice
Flybys: Venus, Earth, Jupiter, Phoebe, Titan, Enceladus, Iapetus
Initial discoveries:
Once establishing an orbit around Saturn, Cassini went to work, immediately clocking up a string of new discoveries. This included seven new moons, superbly detailed shots of Phoebe, the discovery of water on Enceladus, the first radar images of the giant moon Titan's surface and the aftermath of Saturn's Great White Spot mega-storm.