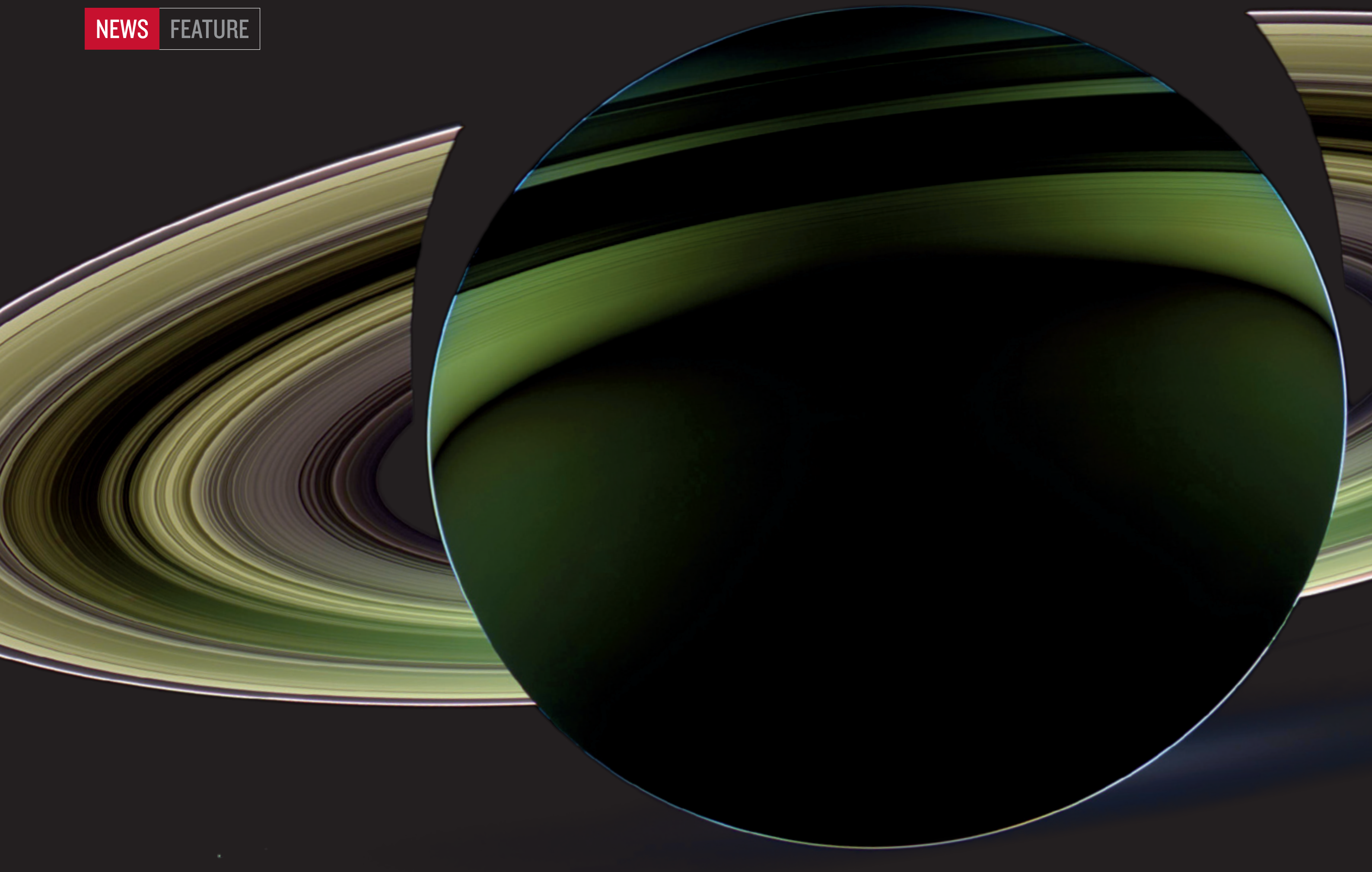

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CAUGHT IN THE ACT

We may be seeing some of the Solar System's most striking objects during rare moments of glory.

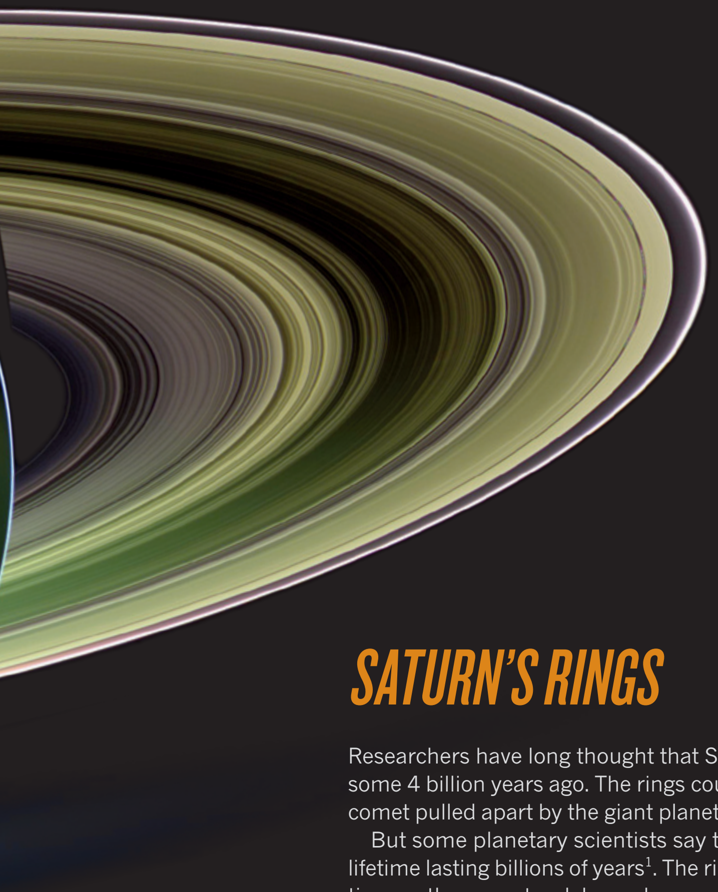
BY MAGGIE MCKEE

Ever since Copernicus evicted Earth from its privileged spot at the centre of the Solar System, researchers have embraced the idea that there is nothing special about our time and place in the Universe. What observers see now, they presume, has been going on for billions of years — and will continue for eons to come.

But observations of the distant reaches of the Solar System made in the past few years are challenging that concept. The most active bodies out there — Jupiter's moon Io and Saturn's moons Enceladus and Titan — may be putting on limited-run shows that humans are lucky to witness. Saturn's brilliant rings, too, might have appeared relatively recently, and could grow dingy over time. Some such proposals make planetary researchers uncomfortable, because it is statistically unlikely that humans would catch any one object engaged in unusual activity — let alone several.

The proposals also go against the grain of one of geology's founding principles: uniformitarianism, which states that planets are shaped by gradual, ongoing processes. "Geologists like things to be the same as they ever were," says Jeff Moore, a planetary scientist at the NASA Ames Research Center in Moffett Field, California. The unchanging world is "philosophically comforting because you don't have to assume you're living in special times", he says.

But on occasion, the available evidence forces researchers out of their comfort zone. Here, *Nature* looks at some of the frozen worlds that may be putting on an unusual spectacle.



SATURN'S RINGS

Researchers have long thought that Saturn acquired its dazzling adornments early in its life, some 4 billion years ago. The rings could be the glistening remnants of a shattered moon or a comet pulled apart by the giant planet's gravity.

But some planetary scientists say that the rings' resplendence is hard to reconcile with a lifetime lasting billions of years[1]. The rings' particles are 90% water ice and should darken over time as they are struck by carbonaceous dust shed from comets and asteroids. "If you look at the rings of all the other planets — Jupiter, Uranus and Neptune — those rings are all very dark," says Jeff Cuzzi, a planetary scientist at Ames. "That's kind of what you'd expect from heavily polluted material."

According to Cuzzi, the sparkle of Saturn's rings suggests that something — perhaps an icy interloper from beyond Neptune or a large moon of Saturn itself — might have broken apart near the planet and formed the rings within the past few hundred million years, less than 10% of the planet's life so far. The brilliance would be fleeting, because the rings would "get duller and duller" over time, says Cuzzi.

But the idea of young rings presents its own puzzle. Large bodies of the kind that could have formed the bands flew helter-skelter through the Solar System during its first 700 million years or so, but they have grown much rarer since then. There is only a minuscule chance that such a large object whizzed past Saturn in the past one billion years, says Cuzzi. Likewise, he adds, it would be difficult to explain how a moon large enough to form the rings could have fallen close enough to the planet in that time frame.

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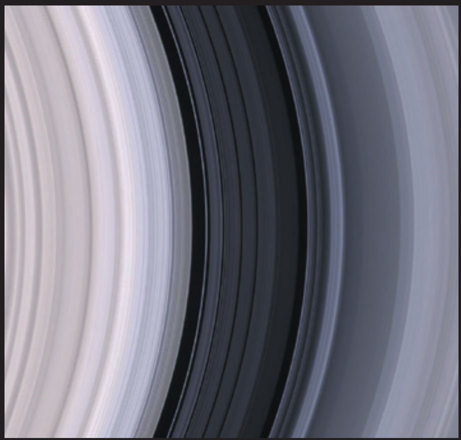

Saturn's B ring (left) is so bright that some researchers wonder whether it is relatively young.

Another possibility is that the rings formed billions of years ago, but somehow retained their youthful glow. That could be the case if they are at least ten times more massive than previously thought, so the dust has so far had little effect. "If you have a thimbleful of black paint, and you drop it into a gallon of white paint, you'll make it pretty dark," says Cuzzi. "But if you drop it into a swimming pool, you won't."

That explanation appeals to Robin Canup, associate vice-president of the planetary-science directorate at the Southwest Research Institute in Boulder, Colorado. "I know of no way to form the rings recently with any reasonable probability," she says.

There is no evidence of any missing mass yet. But it could be hiding in the biggest ring, dubbed the B ring, which is so opaque that researchers cannot study its contents by measuring how light passes through it. The solution to this puzzle could come soon from the Cassini spacecraft, which has been orbiting Saturn since 2004. In 2017, at the end of Cassini's planned lifetime, mission controllers will send it between the planet and the innermost D ring. Comparing the spacecraft's motion at different orbital distances will reveal the rings' mass with unprecedented precision, says Cuzzi.

But Canup warns that "if the Cassini results point to a low mass for the rings, it will be a real mystery".

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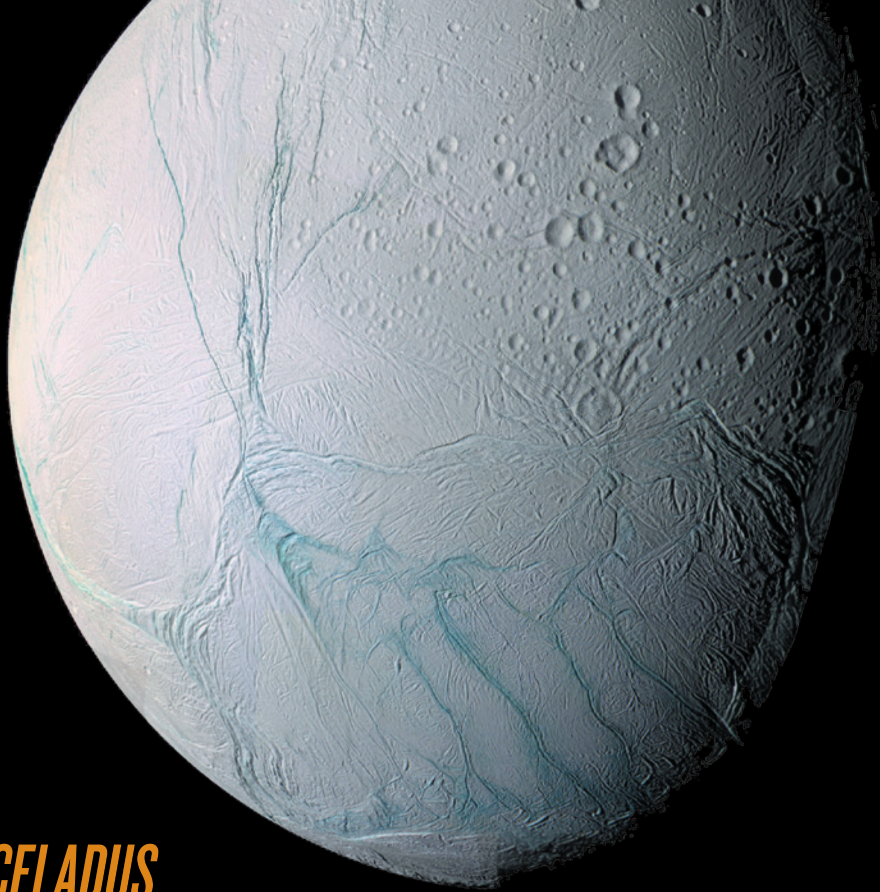

ENCELADUS

Enceladus's patchwork surface suggests that it has seen bouts of geological activity.

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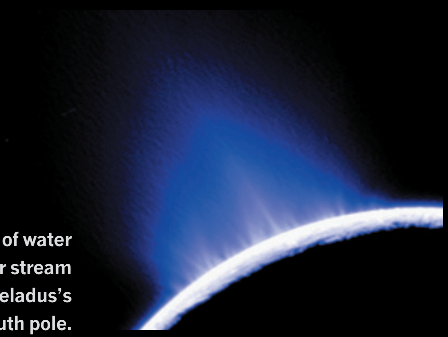
Enceladus is a fairy moon. As it orbits Saturn, it sprinkles a glittering trail of ice — the E ring — thanks to watery geysers that shoot from its south pole. But researchers have struggled to explain how it can sustain such activity. Enceladus seems to be giving off 16 gigawatts of heat: ten times as much as theorists think it should be able to produce from the decay of radioactive elements in its interior and from the simplest models of tidal heating, the kneading and flexing of the moon caused by Saturn's powerful gravity.

Several explanations have been put forward to account for this furious release of heat, but all rely on arguments that researchers are viewing the moon at a special time. One such proposal, advanced by planetary scientists Craig O'Neill of Macquarie University in Sydney, Australia, and Francis Nimmo of the University of California, Santa Cruz, suggests that over the course of between 100 million and 1 billion years, the internal stresses and strains from tidal forces could build up enough heat to crack the moon's crust, releasing energy and water vapour into space[2].



Jets of water vapour stream from Enceladus's south pole.

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Such activity would last for only about 10 million years before the crust cooled and the geysers died. Then the heat-storage cycle would start anew. "It seems like special pleading — we just happened to catch it in the act," says O'Neill, echoing criticisms that he has heard when presenting the model at conferences. But he points out that the cycle would be just like those of the geysers in Yellowstone National Park in the United States, except on a longer timescale.

Episodic tectonic activity could also explain another discrepancy: why parts of the moon appear to be different ages, with some areas heavily pockmarked by craters and other, fresh-faced regions that have presumably been plastered over by newer crust. A similar patchwork of surfaces is seen on a few other moons, including Jupiter's giant Ganymede and Uranus's small moon Miranda. If these have also gone through cycles of activity, it would make Enceladus less of an outlier. At any given time, there would be a good chance that at least one of them would be passing through a lively period, says O'Neill.

The mystery, then, is why Saturn's moon Mimas, which lies closer to the giant planet than Enceladus and therefore experiences greater tidal forces, shows no sign of tectonic activity. Nimmo says that Mimas may have a different internal composition, making it too rigid to deform, but he acknowledges that this is just one possibility. "Mimas should be producing more heat than Enceladus and it doesn't, and we don't really understand why," he says.

Cassini will collect more clues when it snaps images of Enceladus's south pole between 2015 and 2017, gathering measurements that could refine estimates of the geysers' heat output.

“IT’S POSSIBLE WE SIMPLY DON’T UNDERSTAND THEM.”

Io’s orbit may be shutting down the moon’s volcanoes, such these erupting craters.

ABOVE AND RIGHT: NASA/JPL/UNIV. ARIZONA

IO

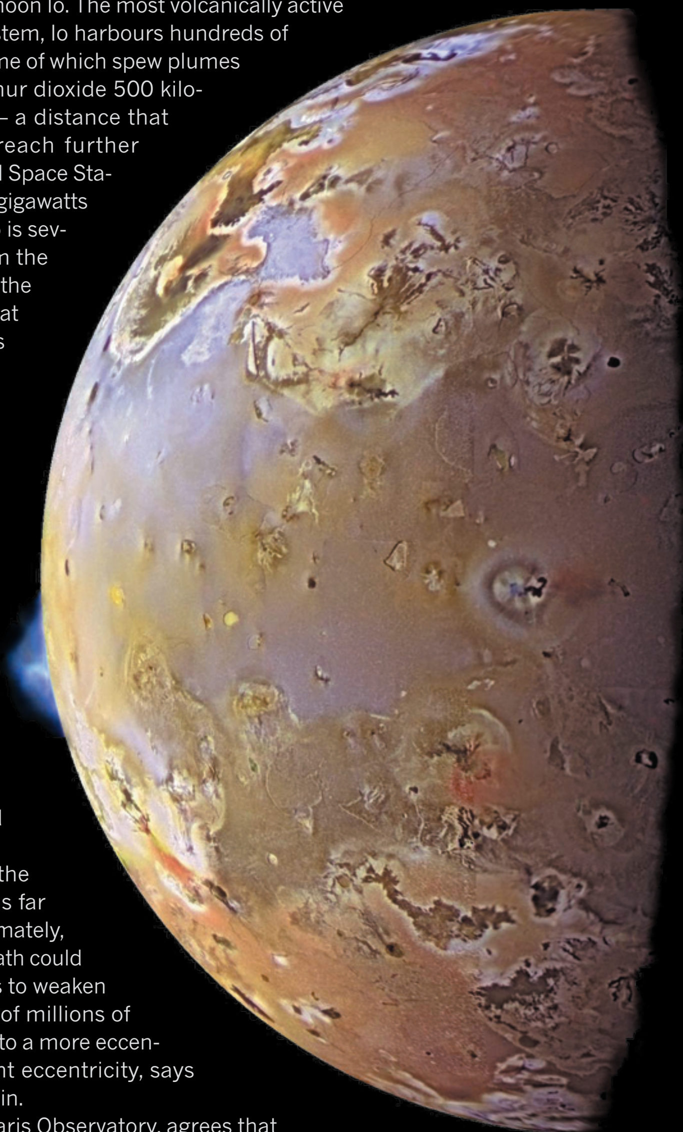
In terms of heat, Enceladus is a firefly in comparison with the furnace of Jupiter’s moon Io. The most volcanically active body in the Solar System, Io harbours hundreds of volcanic features, some of which spew plumes of sulphur and sulphur dioxide 500 kilometres into space — a distance that from Earth would reach further than the International Space Station. But the 90,000 gigawatts of heat released by Io is several times more than would be expected from the simplest models of tidal interactions between the moon and Jupiter. That mismatch suggests that “Io is more volcanically active in some periods than others”, says David Stevenson, a planetary scientist at the California Institute of Technology in Pasadena.

One possible explanation is that the shape of Io’s orbit changes periodically. Io currently takes a slightly elongated, or eccentric, path around Jupiter, thanks to the gravitational influence of two other moons, Europa and Ganymede. Every time Io makes a circuit of Jupiter, the other moons give it a push, “just like a child on a swing”, says Stevenson, preventing Jupiter’s gravity from pulling Io into a perfectly circular orbit. The eccentric path intensifies the tidal warping, which deforms Io’s surface by about 10 metres on each orbit. The frictional heat from all that warping gets released through volcanic eruptions.

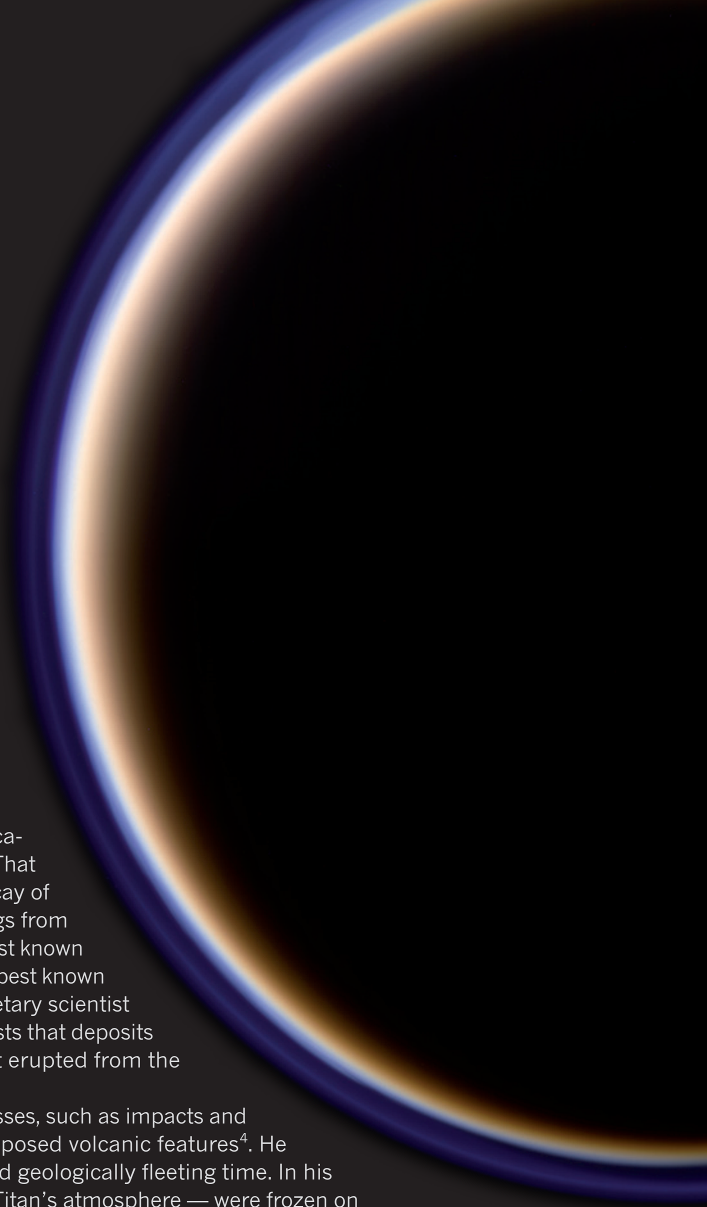
But the same process steals energy from the orbit, so that Io might not be able to swing as far away from Jupiter on subsequent rounds. Ultimately, as energy is drained into internal heating, Io’s path could become more circular, causing the tidal forces to weaken and the moon to cool. Then, over the course of millions of years, Europa and Ganymede could push Io into a more eccentric orbit — one with several times its current eccentricity, says Stevenson — and the process could begin again.

Valéry Lainey, a planetary scientist at the Paris Observatory, agrees that there may be cyclical variations in Io’s orbit. Some support for that hypothesis comes from observations of Io over more than a century, which show that its orbit may be growing more circular[3]. If so, the moon’s raging volcanic activity might be on the wane.

Such orbital transformations “would satisfy the data”, says Stevenson. But even though cyclical patterns abound in nature, he says, Io’s behaviour, like that of Enceladus, seems so strikingly variable “that it’s possible we simply don’t understand them”.



Io’s volcanoes produce sulphurous plumes up to 500 kilometres high.



NASA/JPL

TITAN

When Cassini dropped its Huygens probe through the haze-shrouded atmosphere of Saturn's biggest moon in 2005, it revealed a landscape of sinuous river channels that seems much like Earth's except for one big twist: The liquid that sculpts much of the surface is methane that rains down from hydrocarbon clouds. Yet the atmospheric methane — and its effects on the landscape — ought to be short-lived. Sunlight degrades methane, driving reactions that turn it into heavier hydrocarbons, which should deplete Titan's atmospheric reservoir in a few tens of millions of years. Either researchers are witnessing Titan at a rare moment, not long after a massive release of methane into the atmosphere, or — as many believe — something is replenishing what sunlight destroys.

Cassini revealed a number of what might be ice volcanoes that pump methane up from the moon's interior. That plumbing process could be driven by heat from the decay of radioactive elements inside the moon and from tidal tugs from Saturn. One of these candidate volcanoes is Titan's highest known mountain, Doom Mons, which lies beside the moon's deepest known pit in a region called Sotra Facula. Rosaly Lopes, a planetary scientist at NASA's Jet Propulsion Laboratory in Pasadena, suggests that deposits in that area were formed from methane-rich slush that erupted from the mountain, causing the nearby terrain to collapse.

Moore takes a different view, arguing that other processes, such as impacts and erosion by methane rivers, could have created the supposed volcanic features[4]. He thinks that researchers are seeing Titan at a unique and geologically fleeting time. In his view, methane and nitrogen — the main component of Titan's atmosphere — were frozen on the moon's surface until a few tens or hundreds of millions of years ago. At that point, the Sun, which has been growing warmer over its 4.6-billion-year life, vaporized these ices, forming a methane-rich atmosphere within a million years or so.

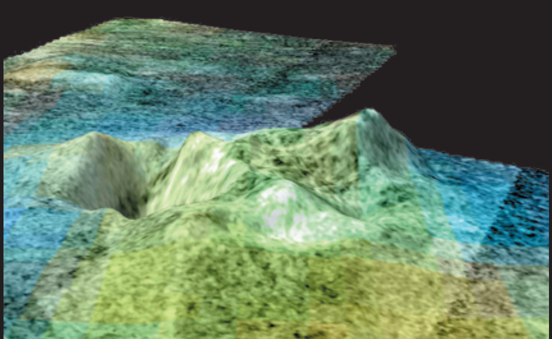
Methane then condensed from the atmosphere and "rained like hell" over the moon, creating the landscape features, says Moore. Gradually, sunlight turned the methane into heavier hydrocarbons, and the rain tapered off. In another 40 million years or so, says Moore, the methane could completely disappear, and Titan could revert to a nearly unchanging tableau, with blue, nitrogen-filled skies rising above a reddish, hydrocarbon-covered surface.

Ralph Lorenz of the Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland, argues that Moore's picture is too simplistic. Some evidence suggests, he says, that it would have taken billions of years for the destruction of atmospheric methane to form the hydrocarbon-filled dunes that cover 20% of Titan's surface. If that is so, the liquid-methane cycle has persisted for much of the moon's history.

Continuing observations by Cassini will reveal how much Titan's surface changes on timescales of a few years — allowing researchers to better estimate how long methane rain has been sculpting it.

"I think we have to have a much more nuanced view of Titan through time," says Lorenz. "Titan is bloody complicated." ■

The hydrocarbon haze in Titan's atmosphere may be a temporary feature.



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In Titan's Sotra Facula region, the 1.5-kilometre Doom Mons peak (right) sits next to a giant pit (left).

Maggie McKee *is a freelance writer in Boston, Massachusetts.*

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