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Hidden kingdom

The discovery of another 100 moons around Saturn could help us solve the mystery of how the planet's rings formed, finds **Jonathan O'Callaghan**

PLANET VOLUMES/UNSPLASH

Saturn now has 274 known moons – more than Jupiter

IN THE far reaches of the solar system, the planetary neighbourhood seems quiet. Beyond Jupiter, the sun is no longer a blazing disc, but a cold, white lamp. The planets are separated by gulfs of darkness. Light takes just 8 minutes to get from the sun to Earth, but typically more than an hour to cross the yawning chasm between Uranus and Neptune.

But in the middle of what seems like an uneventful part of the solar system, astronomers recently made a mammoth discovery: a hidden population of more than 100 moons that, until recently, remained almost invisible. From Earth, they appear as faint, fast-moving points of light, easily lost in their planets' glare.

They aren't moons as we imagine them – grand worlds like our own pale satellite, Jupiter's volcanic Io or Saturn's haze-wrapped Titan. They are smaller, darker and far more unruly. Astronomers call them irregular moons, and with their numbers now so high, their hidden kingdom has become harder to ignore. "We have had this huge influx in the last year, [including an] eye opener at Saturn," says Marina Brozovic at NASA's Jet Propulsion Laboratory in California.

But it's not just the discovery of these moons that has astronomers excited. For one thing, they may hint that the outer part of our solar system might not be enjoying a quiet retirement, but instead has seen periods of incredible turbulence surprisingly recently. For another, these hidden moons may help us solve a mystery about one of our solar system's most iconic sights: how did Saturn get its rings?

What is a moon, exactly? If you looked up at our night sky, you would see our own natural satellite, more than 3400 kilometres across, keeping stately company with Earth. Many of the solar system's other moons fit that picture, too: big, round worlds circling close to their host planet, usually moving with that planet's spin.

But there is another kind of moon. These are small, misshapen things, often only a few kilometres wide, following distant, tilted and sometimes backwards paths. These are irregular moons and, for a long time, they were easy to overlook.

One of the first irregular moons to be recognised was Phoebe around Saturn in 1898, the largest of the planet's irregular moons at 213 km across. It was the herald of many more to come. As telescopes and digital cameras improved, especially from the early 2000s, astronomers began seeing smaller and smaller irregular moons around giant planets in droves. Then came last year's deluge. In 2025, researchers announced 128 new moons around Saturn alone, pushing the known total of solar system moons above 450.

For astronomer Scott Sheppard at the Carnegie Institution for Science in Washington DC, who has helped lead many of these searches, the broad pattern didn't come as a surprise. Astronomers were always sure there were more moons to be found around the gas giants, he says; telescopes just couldn't pick up such faint signals until recently.

Still, the scale of discoveries last year caught many off guard. "Everybody was surprised," says Brozovic. Astronomers had expected maybe a few dozen more moons to be found around these outer planets, but instead hundreds or even thousands are now thought to be awaiting discovery. "It really is starting to be pretty busy out there in the solar system," says Brozovic.

These moons might be small, but their implications are large. Their oddly elongated orbits suggest that they didn't form in the same place as their host planets, the way larger moons did. Many also travel in loose families, following similar paths around their planet (see "A family affair", page 37) – a pattern that seems to suggest they are the fragments of larger parent moons hundreds of kilometres across that broke apart in collisions long ago.

Thanks to these irregular moons, astronomers now think they can reconstruct this violent history and its role in shaping the solar system, says Jonti Horner at the University of Southern Queensland, Australia. "They are relics of the solar system's formation," he says.

To reconstruct this history, we need to first ask a pivotal question: how exactly did these irregular moons end up around these gas giants? For decades, astronomers thought the answer lay in the solar system's first flush of youth, because there just isn't an easy way for a planet to capture a passing object in the settled solar system we see today, says Sheppard. A comet or asteroid can wander briefly into a planet's gravitational grip, but unless something slows it down, it would simply fly out again. "The only way to capture a moon is to dissipate energy from its orbit," he says.

"IT REALLY IS STARTING TO BE PRETTY BUSY OUT THERE IN THE SOLAR SYSTEM"

However, soon after the birth of our solar system – about 4.5 billion years ago – there

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Hyperion (left) and Iapetus (above) are two of Saturn's more unusual moons

were several possible mechanisms of capture. One involved the atmospheres of the gas giants themselves, which were more swollen and extended back then. Asteroids or comets flying through them could have been slowed enough to be captured into the wild orbits we see today. But while that works for smaller bodies, it struggles to explain how planets captured the suspected parent bodies of irregular moons, which were later smashed apart.

A violent past

A more promising avenue for that is the Nice model, the most accepted picture of solar system evolution. It says Jupiter, Saturn, Uranus and Neptune didn't originally form where we see them now. They were packed much closer together when the solar system first took shape, before gravitational interactions sent them migrating outward. Their combined gravitational interactions during their migration could also have helped slow passing objects, including the larger progenitors of the irregular moons we see today.

This would help explain why today's irregular moons don't seem to have a common origin, instead resembling a cosmic jumble from across the solar system, according to papers published last year that used observations from the James Webb Space Telescope.

The chaotic nature of this early period was thought to also be when some of the once-larger irregular moons might have crashed together, creating the much smaller objects around the planets we see today.

But then came a puzzling discovery in 2025. A team led by Edward Ashton at Academia Sinica in Taiwan took a closer look at the Mundilfari group, a clutch of some 100 newly discovered small moons looping around Saturn.

At first glance, this strange family looks like the debris trail of some ancient cosmic smash-up. But when Ashton's team modelled their sizes, that timing didn't quite add up. If these fragments had been circling Saturn since the early days of the solar system, many of the smaller moons should have fallen into the planet by now, tugged inward by its gravity.

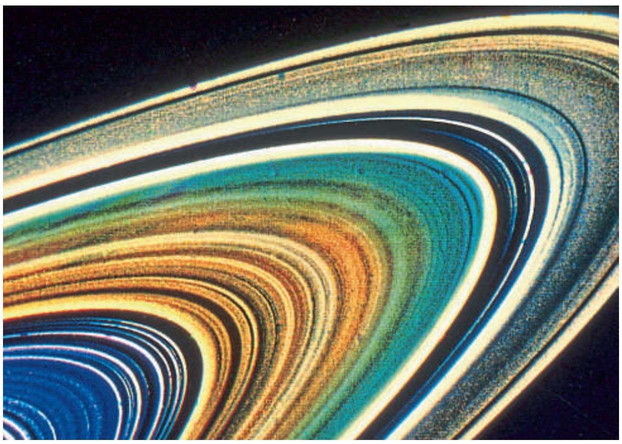
Instead, Ashton's team argued that the Mundilfari group may have formed in a collision just 100 million years ago. "[That might mean] these collisional processes are still alive and well," says Brozovic. If these collisions really were surprisingly recent, that would suggest the outer solar system is still being dramatically reshaped today, long after the main drama of planet formation was thought to be over.

Such collisions could be linked to other events, too. Ashton's paper was published in December 2025 and piqued the interest of Yifei Jiao at the University of California, Santa Cruz, because the age of the Mundilfari group seems suspiciously close to another number: the suspected age of Saturn's rings. Could the two be related?

For all their fame, Saturn's rings remain oddly hard to explain. We have seen them through telescopes for more than 400 years, yet the most important mystery lingers: how did they form? For a long time, Saturn's rings looked like an ancient ornament, a bright, almost permanent fixture that had circled the planet since the solar system's youth. The simplest story was that they formed early, perhaps from leftover material around Saturn or from a moon that shattered billions of years ago.

Then measurements from NASA's Cassini mission complicated things. In its final months, before it plunged into Saturn in 2017, the spacecraft repeatedly threaded the narrow gap between the planet and its rings. Those dives revealed rings that were surprisingly low in mass and remarkably clean. That was hard to square with great age: over billions of years, micrometeoroids should have darkened the ice and worn the system down. Instead, photos taken by Cassini made the rings look suspiciously fresh – perhaps only a few hundred million years old. That leaves a difficult question: what could have made them so recently?

The new moons may offer a way in. We already know that irregular moons can make a mess as they collide into each other or are struck by passing comets and asteroids. They can explode into clouds of dust that gradually fall towards their host planet. We already see evidence for this on Saturn's moon Iapetus, the outermost of the planet's regular moons, which has a strange, two-toned colouration. Its leading side – the face that ploughs forward



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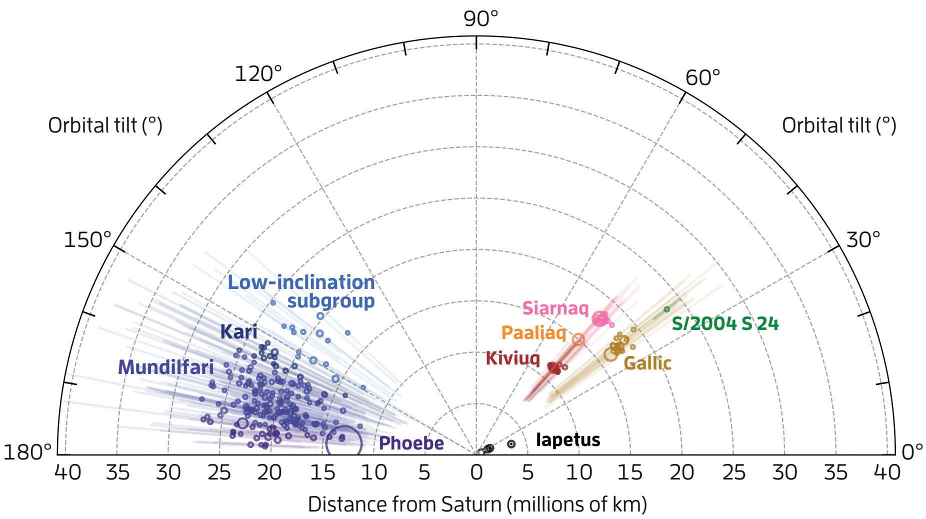
Saturn's iconic rings are hard to explain

A family affair

Plotted by orbital tilt and orbital distance from Saturn, many of the planet's irregular moons fall into distinct families. These clusters suggest the moons are fragments of once-larger bodies smashed apart in ancient collisions



through space – is extremely dark, while the trailing side is nice and bright. Sheppard says that Iapetus could be running through the reddish, carbon-rich dust shed by irregular moons "like a bulldozer".

Still, those distant, irregular moons of Saturn weren't thought to have much to do with the planet's rings. But in April, Jiao and his team published a paper suggesting a potential link. They first built on the idea that Saturn once had an extra icy moon about 1000 km across, called Chrysalis. Over the 4.5-billion-year history of the solar system, it fell into a gravitational rhythm with Titan, Saturn's largest moon. The mutual tug between both elongated Chrysalis's orbit from a circular shape into an ellipse.

Ring in the changes

Then, about 100 million years ago, the moon's distorted orbit carried it past a threshold around Saturn known as the Roche limit, the boundary within which a planet's gravity can tear a moon apart. In one catastrophic pass, Saturn stripped away much of Chrysalis's ice, almost instantly shrinking the moon to half its size.

What would have happened next is uncertain. The rocky core of Chrysalis may have been cannibalised by Saturn or ejected entirely, although Jiao notes we "haven't found such a body" orbiting the sun somewhere else. The ice, meanwhile, would have spread like butter, forming a broad, bright disc over a few thousand years – Saturn's rings.

But not all the debris would have stayed close in. Some chunks could have been flung into Saturn's outer reaches, where one piece struck another moon and shattered it, forming

"SATURN'S RINGS AND SOME OF ITS HIDDEN MOONS MAY BE TWO REMNANTS OF THE SAME LOST WORLD"

the Mundilfari group of irregular moons at the same time. If so, Saturn's rings and some of its hidden moons may be two remnants of the same lost world, both formed about 100 million years ago.

"It is hard to imagine that all of these events occurred at the same time by coincidence," says Jiao. "I am quite excited about the possibility of linking the lost moon Chrysalis with the irregular satellite population."

While the timing adds up, there is some scepticism. "It's definitely a very cool study showing one way that the rings might have formed," says Horner. But he cautions that linking the destruction of Chrysalis to the formation of the Mundilfari irregular moons would require more evidence, such as impact scars on Saturn's other regular moons, which might also have been struck – something a future mission might be able to look for.

Brett Gladman at the University of British Columbia in Canada is also intrigued by the idea, although similarly not completely convinced. "It's certainly curious that these two wildly disparate events come out to be the same age, but that doesn't necessarily mean they have a causal connection," he says.

Jiao says that further modelling will be needed to test whether his idea is right. But Saturn's rings may be just one example where irregular moons are yielding fresh answers to old solar system puzzles. The next surprises may lie even further from the sun.

For a long time, astronomers expected Jupiter to be the solar system's great collector of irregular moons. It is the largest planet by far, with the strongest gravitational pull, so it seemed natural that it would have the biggest satellite system. But last year's discoveries put Saturn ahead, with 274 known moons compared with Jupiter's 115. That is surprising enough. But there is reason to question whether the solar system's other two outer planets may have even more.

As far as we know, Uranus and Neptune have far fewer moons – 29 and 16, respectively – but that may say more about the limits of our surveys than about what is really there. Both are distant, dim targets. Yet their position could make them rich hunting grounds. Their distance from the sun gives them vast regions of gravitational influence, known as Hill spheres, in which small bodies can remain bound; Neptune's stretches some 115 million km, almost twice Saturn's. Their proximity to the Kuiper Belt, a reservoir of icy debris, may also have given them plenty of material to capture.

"I fully expect that someday, a couple of decades away, we will find thousands of these objects at Uranus and Neptune," says Luke Dones at the Southwest Research Institute in the US.

If Uranus and Neptune end up on top of the league table, that could reveal how efficiently the ice giants gathered material from their surroundings. If they don't, that absence would be just as telling, hinting that something stripped those systems bare or prevented captures in the first place.

And we may soon even have a chance to see an irregular moon up close, the second time a spacecraft has ever visited an irregular moon after Cassini's brief visit to Saturn's satellite Phoebe in 2004. Tilmann Denk at the German Aerospace Center says the European Space Agency is considering whether to adjust the path of its Jupiter Icy Moons Explorer spacecraft so that it passes close to Kallichore, one of Jupiter's tiny irregular moons, in 2031. It would be a fleeting encounter with one of these small, dark objects, but a worthwhile one. These overlooked moons may be among the best records we have of how the giant planets came to be. ▮

Jonathan O'Callaghan is a science journalist based in London who specialises in stories on astronomy, astrophysics and space exploration