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#215 APRIL 2023

Sky at Night

THE UK'S BEST-SELLING ASTRONOMY MAGAZINE

SEARCHING FOR LIFE AT JUPITER

MISSION TO THE ICY MOONS

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THIS MONTH*

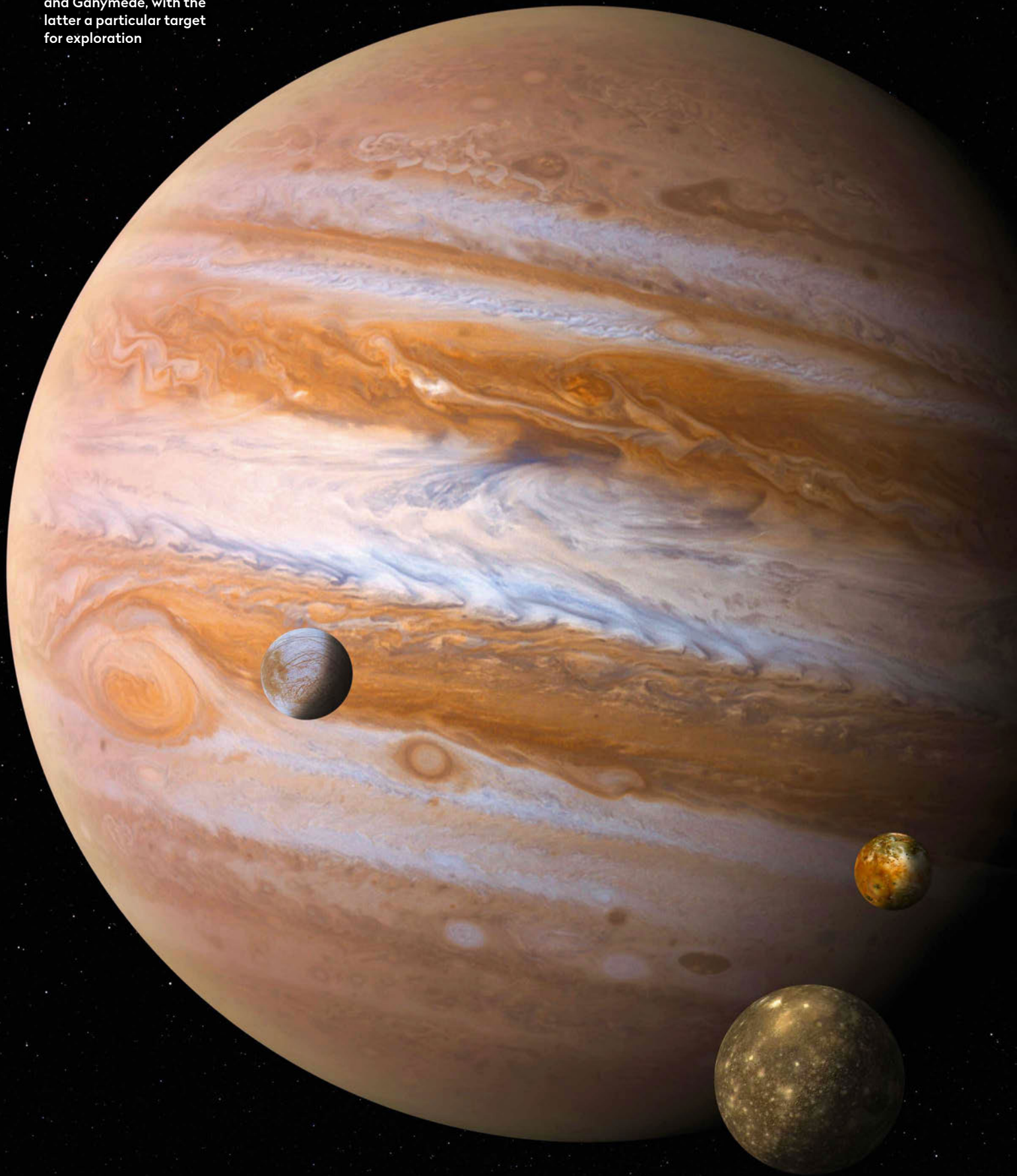
*WHERE IS THE EDGE
OF THE UNIVERSE?*

*HOW TO MASTER THE
ART OF AVERTED VISION*

*SOLVING THE CHALLENGES
OF THE NEW SPACE AGE*

*NEW HIGH-POWER
BINOCULARS STAR-TESTED*

JUICE will visit all of the Galilean moons, (left to right) Europa, Callisto, Io and Ganymede, with the latter a particular target for exploration



JUICE TAKES FLIGHT

Set to launch this month, the European-led JUICE spacecraft will explore the frozen worlds orbiting the gas giant Jupiter. **Will Gater** reports on the exciting flagship mission

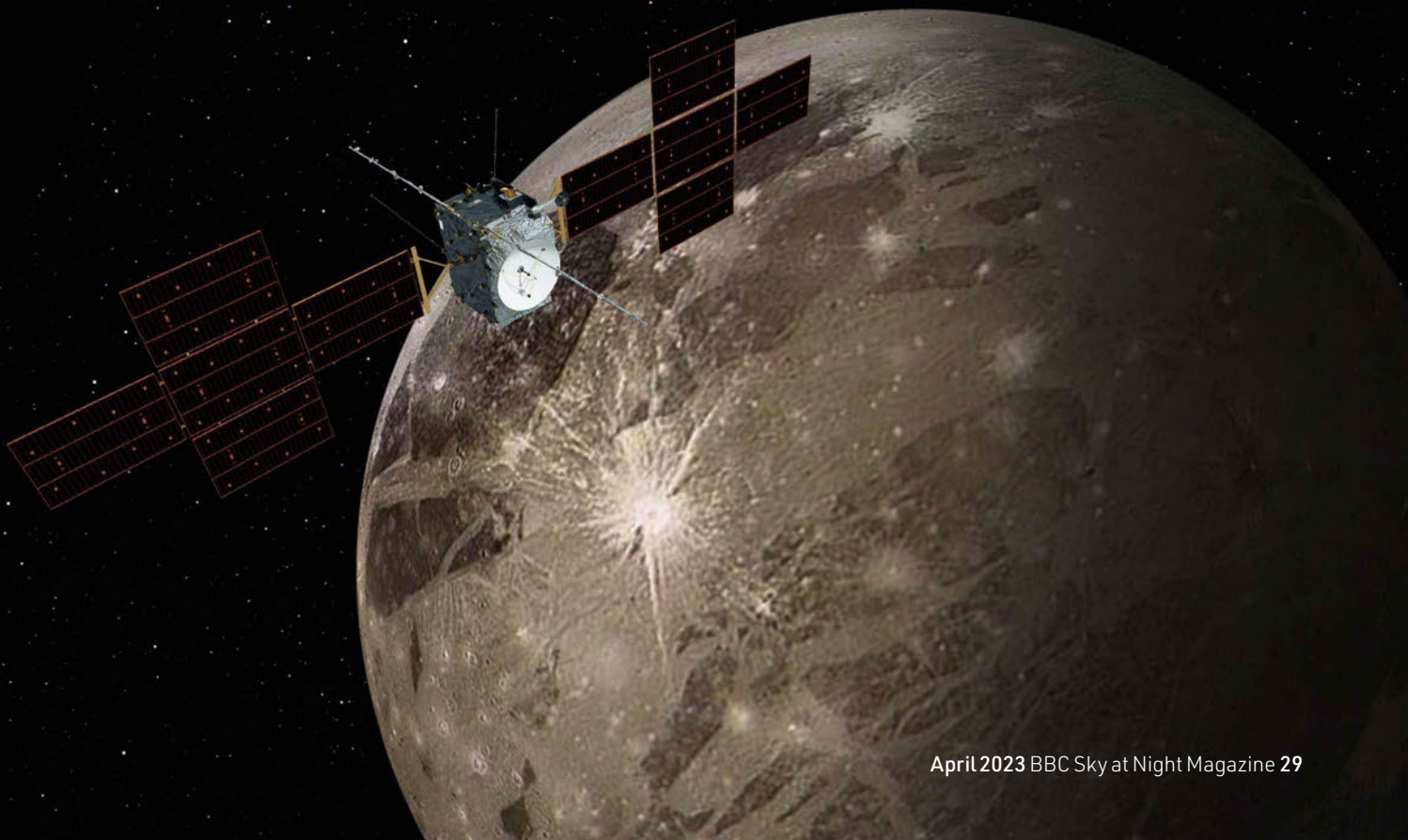
This month ESA's JUICE mission is due to thunder into the skies, carried aloft by a mighty Ariane 5 rocket. As the venerable European launcher soars above the palm trees around the spaceport in French Guiana, JUICE – the Jupiter Icy Moons Explorer

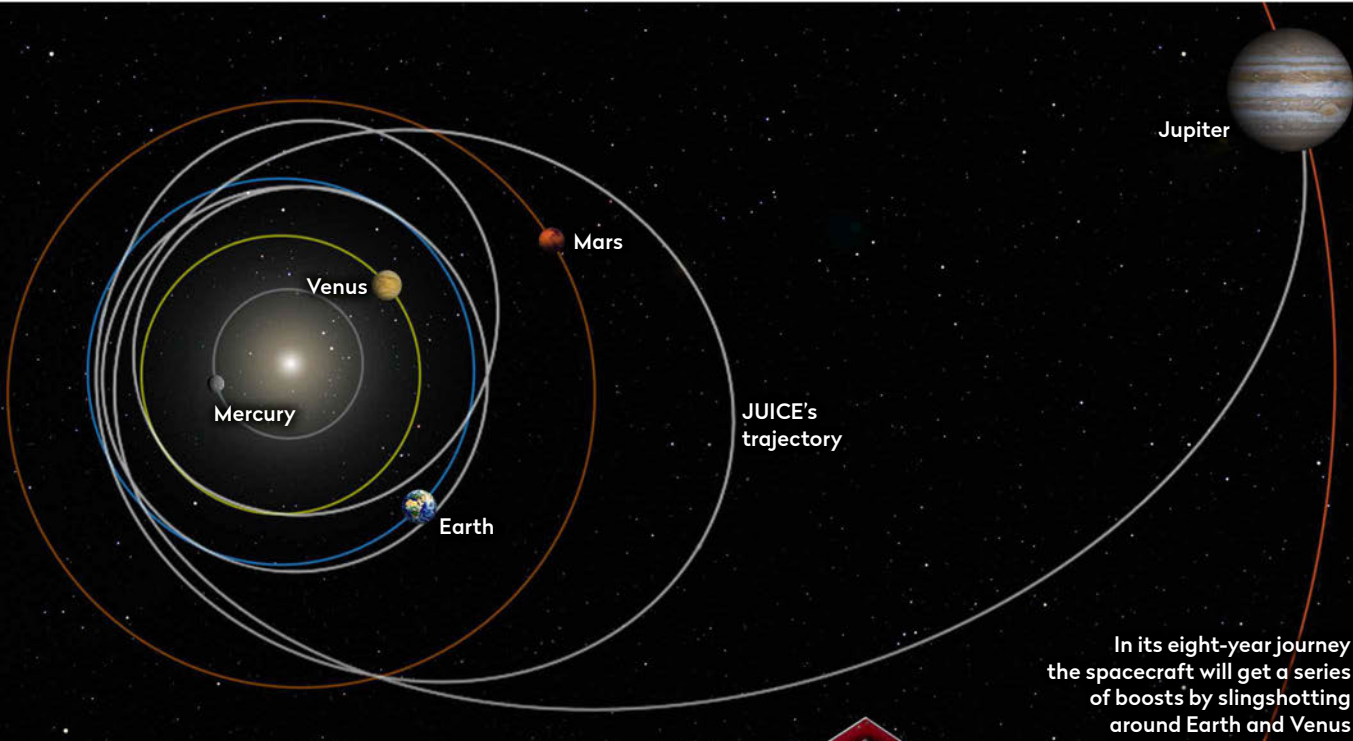
– will be some eight years from its final destination: Jupiter, the largest planet in the Solar System, and its enigmatic collection of satellites.

Through a series of fly-bys of both Earth and Venus, the mission will slingshot its way across the Solar System, crossing the gulf between our

world and the Jovian system to arrive there in the summer of 2031. It's a voyage only a small number of spacecraft have ever achieved. Once at Jupiter, JUICE will swoop past the three icy moons Callisto, Ganymede and Europa multiple times, before settling into orbit around Ganymede in 2034. For those working ►

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In its eight-year journey the spacecraft will get a series of boosts by slingshotting around Earth and Venus

► on JUICE, it will be a chance to dive deep into the secrets of worlds whose mystery has only grown the more humanity has learnt about them.

Professor Michele Dougherty, a planetary scientist based at Imperial College London, is one of many researchers eager to explore the Jovian system. Her involvement in JUICE has been a long one, stretching back some 15 years to the early planning days, when it was going to be a joint US and European project. Now Dougherty is the lead scientist on the magnetometer that JUICE will carry with it to Jupiter. This instrument, built here in the UK, will examine the magnetic fields of the moons Callisto, Ganymede and Europa in unprecedented detail. And indeed it is those fields, or rather what they hint at, that are one of the biggest draws to exploring these icy worlds.

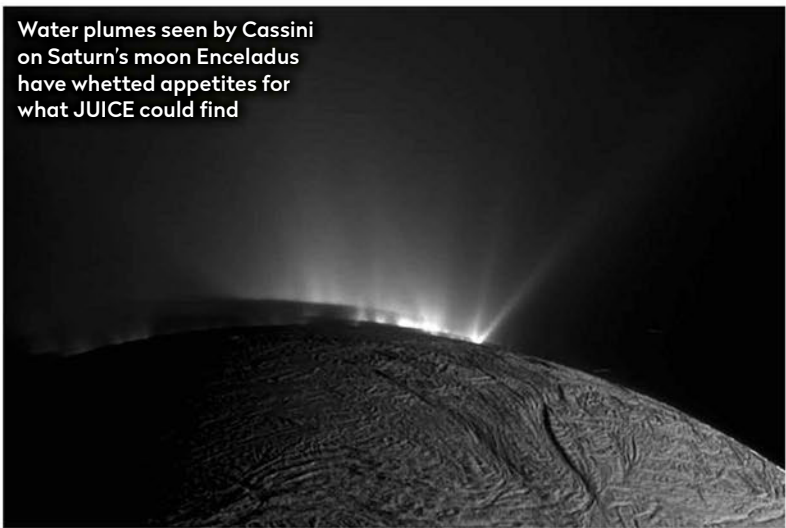
Four not of a kind

The magnetic fields were previously investigated by NASA's Galileo spacecraft, which carried out a ground-breaking study of the Jovian system in the late 1990s and early 2000s. Through fly-bys of the Galilean moons – Io, Europa, Ganymede and Callisto – the mission painted a remarkable portrait of the four largest moons of Jupiter, one that showed each satellite to be captivating in its own right. Galileo's pictures revealed the moons' surfaces in a level of detail never before seen: Io with its sulphurous yellow globe scarred by numerous volcanoes; Europa and its ice crust riven with immense fissures and fractures; and Ganymede and Callisto, the former larger than the planet Mercury, with their cratered, frozen forms.

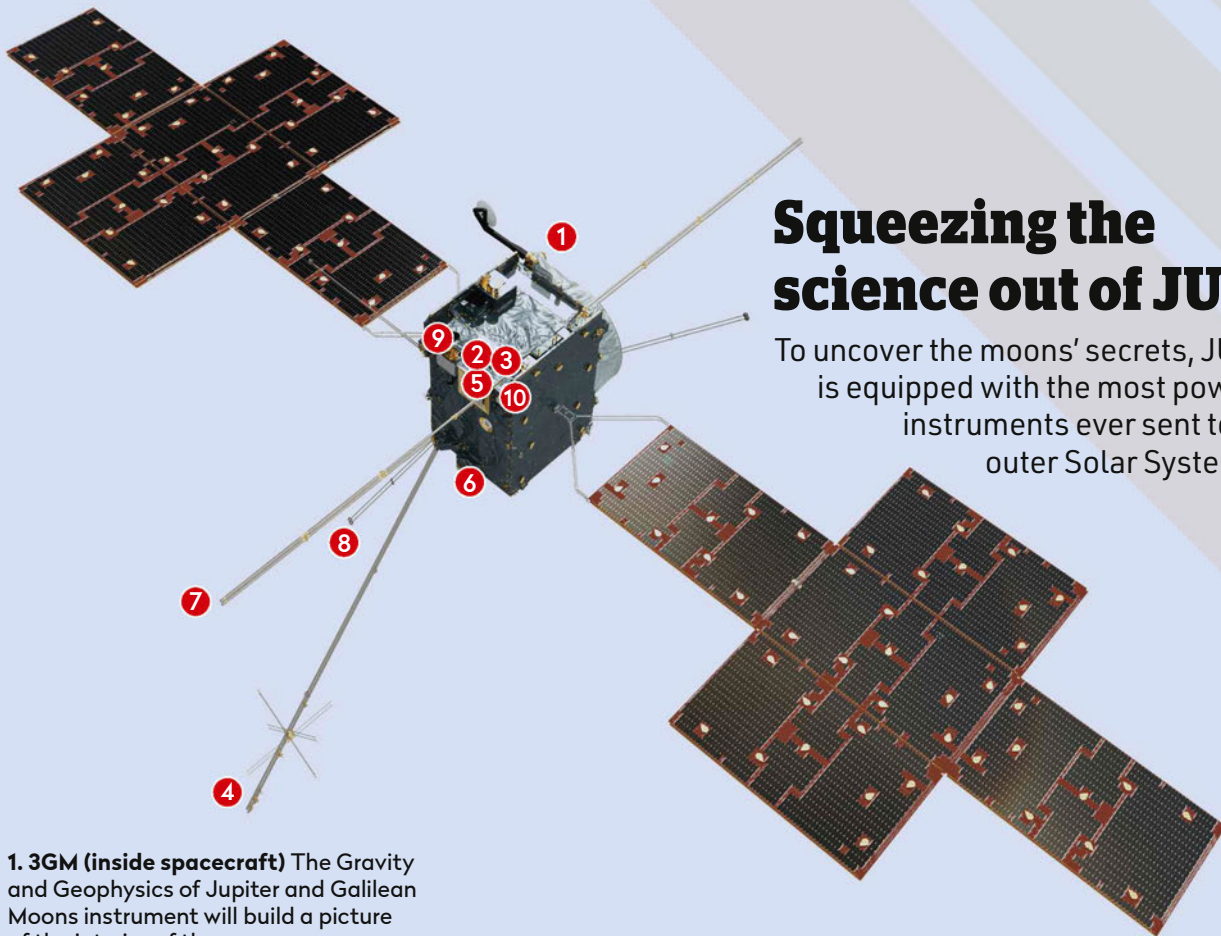
Yet it was the magnetic field data from the last three that particularly intrigued scientists. This seemed to suggest that deep beneath the frozen exteriors of these moons were salty, liquid water



After long years in development, in February JUICE arrived at the spaceport in French Guiana



Water plumes seen by Cassini on Saturn's moon Enceladus have whetted appetites for what JUICE could find



Squeezing the science out of JUICE

To uncover the moons' secrets, JUICE is equipped with the most powerful instruments ever sent to the outer Solar System

1. 3GM (inside spacecraft) The Gravity and Geophysics of Jupiter and Galilean Moons instrument will build a picture of the interior of the moon.

2. GALA The Ganymede Laser Altimeter will bounce a laser off the moon to create a detailed 3D model of its surface terrain.

3. JANUS The camera on board JUICE will take detailed images of the Jovian system. At Ganymede it should be able to pick out features just a few metres across.

4. J-MAG The UK-led magnetometer will measure the magnetic fields of both Jupiter and its moons, and which are key to understanding the nature of the internal oceans of Ganymede and Callisto.

5. MAJIS The Moons and Jupiter Imaging Spectrometer will examine the chemical fingerprints hidden within the light from its targets, revealing the composition of Callisto and Ganymede's surfaces.

6. PEP The Particle Environment Package will analyse the clouds of particles, plasma and gas that swirl around Jupiter, including the extremely tenuous outer atmospheres or 'exospheres' of Ganymede, Callisto and Europa.

7. RIME The Radar for Icy Moons Exploration instrument will probe the frozen crusts of Ganymede and Callisto to around nine kilometres below their surfaces.

8. RPWI Sensors on the Radio and Plasma Wave Investigation instrument will shed light on many processes, such as particles bombarding the surface and will even investigate any plumes.

9. SWI Jupiter and its churning atmosphere will be one of the key targets for the Sub-millimeter Wave Instrument, which can study the wind speeds in the gas giant's stratosphere.

10. UVS The UV Imaging Spectrograph will analyse the aurorae that dance around Jupiter's poles, as well as examining the exospheres of Ganymede and Callisto.

oceans. Given liquid water's link to habitable environments and life on Earth, the results were tantalising. What's more, the quantities may be substantial – some estimates suggest there could be more water within Ganymede than there is sloshing around on our own planet.

Fast-forward to the findings of the more recent Cassini mission – which explored Saturn and its moons, observing immense plumes of water vapour jetting from the moon Enceladus and evidence for a liquid water ocean within Titan – and it becomes clear why interest in these icy satellites has only accelerated. "All of those discoveries have now focused our minds," says Dougherty. "If we're searching for habitability, we don't need to focus on Mars only, we can look further out in our Solar System."

It's in this context that JUICE now finds itself bound for distant Jupiter, not just to explore an intriguing collection of worlds, but to gain a deeper

understanding of potential environments for life in our planetary neighbourhood and, by extension, similar spots in other star systems.

Tooled up

When it arrives at Jupiter in 2031, JUICE will be fully equipped to scrutinise the moons it studies. As well as cameras, its onboard hardware includes a laser altimeter, an instrument for studying the gravity fields of its targets, spectrometers for establishing surface compositions, and the magnetometer that Dougherty and her colleagues have been working on.

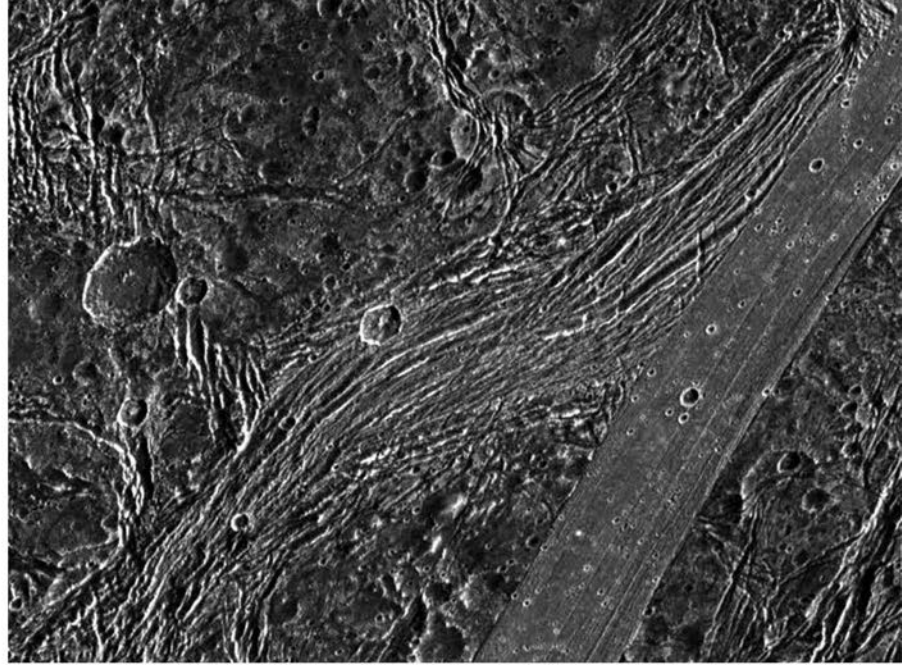
It will initially spend several years performing fly-bys of Europa, Callisto and Ganymede, examining them up-close. While Europa will get its own dedicated visitor in the coming decade in the form of NASA's Europa Clipper mission, it's Ganymede that JUICE has set its sights on. The spacecraft will enter into orbit around the 5,260km-wide moon in ►

► **Nine months will be dedicated to Ganymede, where JUICE will closely examine its magnetic field and aurorae, and map minerals on its surface**

► December 2034 and spend around nine months circling the satellite gathering an extraordinarily rich data set. It will be in this phase that Dougherty and her colleagues working on JUICE's magnetometer will really get a chance to pin down the internal structure of the moon and the nature of the water lying beneath its icy crust.

The instrument will be looking for what Dougherty calls 'induction signatures', signs of magnetic fields that arise from electrical currents – driven by Jupiter's own magnetic field – flowing through the subsurface ocean. And they can contain clues to the nature of the ocean itself, such as its depth and salt content. It will take considerable work, however, to pick these 'signatures' out from the other magnetic fields within the system, including that generated by Jupiter, one originating from an immense sheet-like cloud of plasma encircling the gas giant, and another emerging from Ganymede itself. Each of these fields is constantly varying, complicating the search for the induction signatures considerably. "The way that I like to describe it, is it's like trying to find lots of needles in a haystack and those needles are changing shape and colour all the time," says Dougherty.

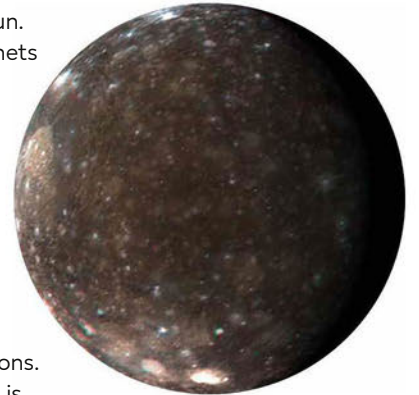
Exploring what lies beneath Ganymede's surface will be key to helping scientists get insights into



worlds far beyond the realm of the Sun. "We're sure there are many other planets and moons out in our Universe which have a similar internal structure to Ganymede, and Ganymede allows us to better understand them and how they might have formed," explains Dougherty.

What lies beneath

It's not just at Ganymede that JUICE will be tackling big unresolved questions. Neighbouring Callisto, it would seem, is the odd one out of Jupiter's icy moons, in that its subsurface structure doesn't appear to be what planetary scientists call differentiated. "There isn't a solid core and there aren't the different layers in the interior that we're almost certain we have at



▲ **Why does Callisto seem so different to the others? JUICE will investigate its surface and interior for clues**

Life on the icy moons

Could habitats capable of supporting life be lurking under the crusts of Jupiter's icy moons?

There are only a few spots in our Solar System where large bodies of liquid water are either present or strongly suspected: Earth itself, and the interiors of some of the icy moons of the gas giants. Where there's liquid water on our own planet we almost always find lifeforms, and so the faraway oceans of the icy moons have become sites of immense interest in the search for life beyond our own world.

Among the forces thought to be heating the insides of Jupiter's largest moons is the gravitational push and pull between themselves, as well as with the giant planet – a process that warms them through friction. In the case of the icy moons, this heating is likely to be what is keeping their interior oceans liquid beneath icy crusts 15–150km thick.

At Saturn, the Cassini mission found evidence of possible hydrothermal vent activity in the subsurface ocean of its icy moon Enceladus. Is a similar thing happening at Ganymede, Callisto or Europa? On Earth such locations are often teeming with life. Could microbes be surviving in the depths of these Jovian moons? Though JUICE may not be able to answer for certain, it provides a great opportunity to begin that process.



▲ **There may be volcano-strewn oceans under the moons' frozen surfaces**

Eyes on Europa

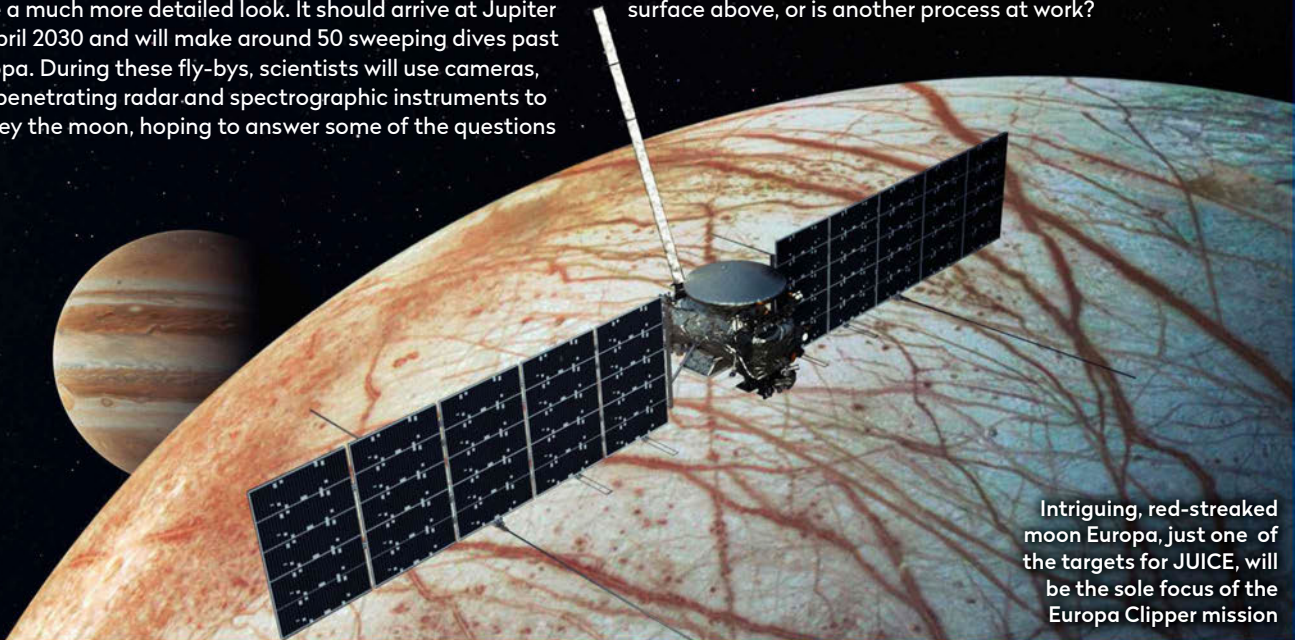
Next year, another mission – Clipper – will be heading towards Jupiter’s icy moon Europa

Jupiter’s fourth-largest moon, Europa, has long been the subject of discussion when it comes to environments that could be hospitable to life within our planetary neighbourhood. The roots of this interest lie predominantly in the data from the Galileo mission, which photographed the moon’s enigmatically furrowed surface and uncovered evidence of a deep, liquid water ocean under its icy crust.

While JUICE will examine Europa, it will be NASA’s Europa Clipper mission, set to launch in October 2024, that will take a much more detailed look. It should arrive at Jupiter in April 2030 and will make around 50 sweeping dives past Europa. During these fly-bys, scientists will use cameras, ice-penetrating radar and spectrographic instruments to survey the moon, hoping to answer some of the questions

left by the Galileo mission, such as how thick Europa’s crust is. Studies suggest it could be between a few kilometres and several tens of kilometres deep. Europa Clipper will also try to piece together the complex history of the relatively young European surface, which in some places appears to have cracked or melted and then re-frozen. The mission may even be able to reveal more about plumes of water vapour that have been detected by the Hubble Space Telescope – could the watery depths of Europa’s ocean be connected to the surface above, or is another process at work?

SIMULATION



Intriguing, red-streaked moon Europa, just one of the targets for JUICE, will be the sole focus of the Europa Clipper mission

Europa and at Ganymede, and the question is why?” says Dougherty. “All of those moons formed at the same time. Why is the internal structure of Callisto so different?” JUICE will look for answers as it flies by.

While JUICE’s focus will be on the icy worlds around Jupiter, it will also be examining the gas giant itself. Professor Leigh Fletcher, a planetary scientist based at the University of Leicester, will be coordinating JUICE’s observations of Jupiter and says there is scientific instrumentation on board that “turns the dial to 11” compared to the capabilities of previous spacecraft. These include the Sub-millimetre Wave Instrument which is capable of observing the planet at sub-millimetre wavelengths of light.

“That’s tremendously exciting for an atmospheric scientist,” says Fletcher, “as it allows us to directly measure the winds and circulation high in the stratosphere, a feat that no previous mission has ever accomplished.”

JUICE’s orbit around the planet will also help it get detailed observations of the giant world of seething clouds and swirling storms. “There are long periods where we can monitor the atmosphere and magnetosphere to see how the Jupiter system changes and shifts over time,” says Fletcher.

“Snapshots are not enough to understand this complex system; we need to see how it changes.”

Built to last

To survive this incredible years-long adventure, JUICE has had to be designed to withstand the radiation environment found at Jupiter. “We have also designed an orbit that will keep us away from the worst of Jupiter’s radiation belts – which is why we only venture in as close as Europa twice, and why we’ll only be able to view Io from a distance,” explains Fletcher.

But, he says, it’s on our own planet where the mission has faced its biggest challenge, in the form of the global COVID pandemic. “Instrumentation developed in labs, institutions and industrial sites across the world had to be brought together by land, air and sea at a time when international travel and collaborative in-person working was facing a challenge like no other,” says Fletcher. “When JUICE sits atop that Ariane 5, waiting to start the next phase of its journey, it will be testament to the sustained effort of thousands here on Earth, under challenges that no one foresaw when we were first dreaming of Europe’s mission to Jupiter.”



Will Gater is an astronomy journalist, author and presenter