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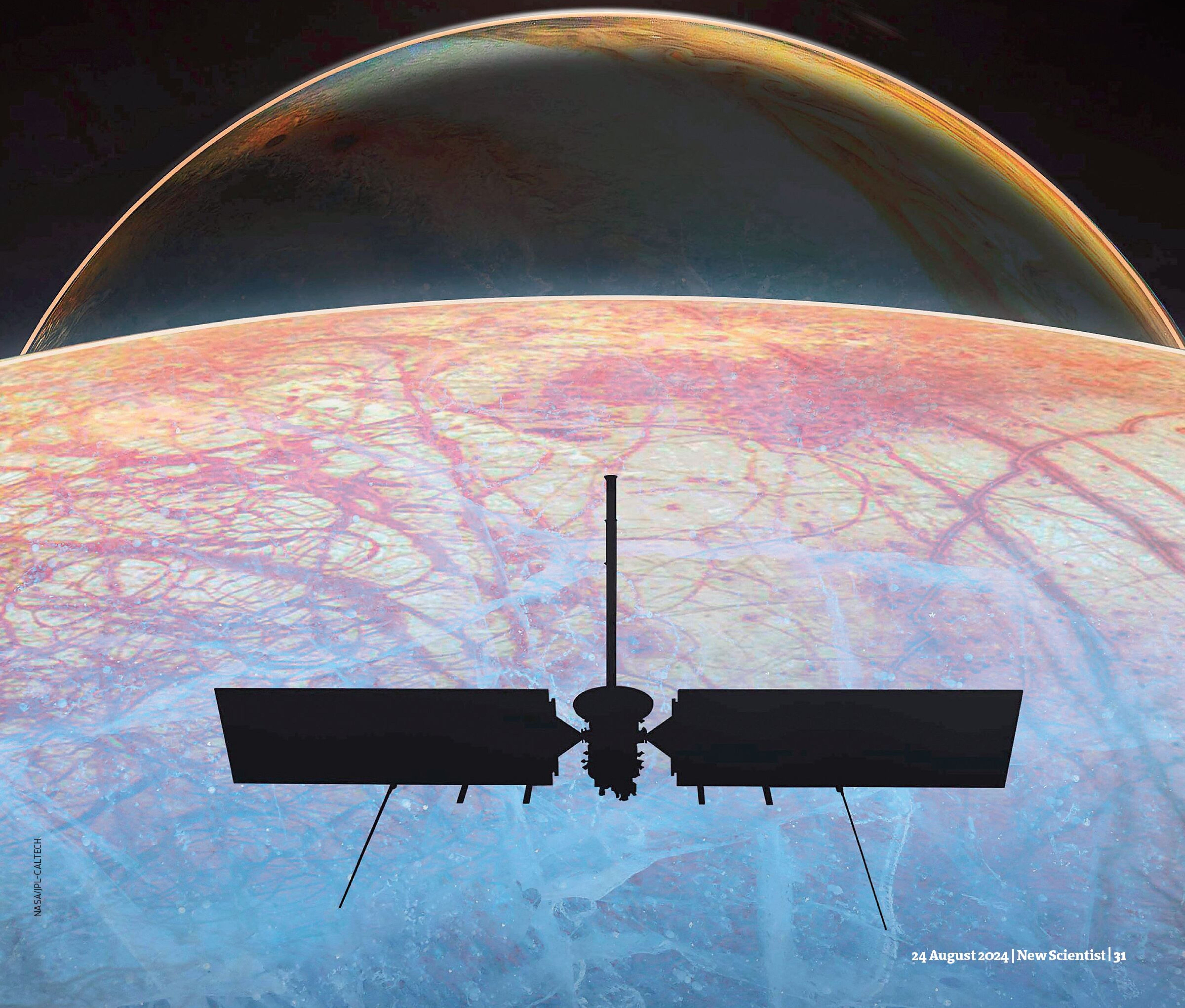
Mission to Europa

A NASA probe is about to set off for one of Jupiter's icy moons to see if it could harbour life. What's so special about Europa and what exactly are we looking for, asks **Abigail Beall**



NASA/JPL-CALTECH

SEEN against the backdrop of Jupiter's dramatic, swirling atmosphere, Europa might at first appear a bit drab. With its greyish-white surface, you might even say it resembles a well-worn cue ball in a run-down pool hall. On closer inspection, however, the Jovian system's fourth-largest moon is shimmering with intrigue from deep within.

From what we can tell, its icy outer layer conceals a vast global ocean containing twice the volume of water on Earth. This, in addition to hints of geophysical activity – such as the rusty lines that streak its surface – and complex chemistry, is why Europa has long captivated astronomers searching for habitable worlds beyond our pale blue dot. So could Europa have the conditions for life? We're about to find out.

In October, NASA will launch Europa Clipper, a $5 billion probe that will get a closer look at the moon's geology and chemistry – and, with any luck, identify the telltale signatures of habitability. The mission has been decades in the making, building on previous forays that have thrown up tantalising clues as to what lurks inside the moon's frozen shell – and no shortage of questions.

Clipper promises answers. It will study the moon's surface and the ocean hidden beneath in unprecedented detail. It could even sample the water in plumes of vapour if, as we suspect, they are erupting from Europa's surface. And although it isn't designed to find direct evidence of life – a bacterial cell, say – recent developments suggest there is a fleeting chance it could do exactly that. "With Europa Clipper, we're really entering a new phase of astrobiology," says Sam Howell, a project staff scientist on the mission.

We first laid eyes on Europa in 1610, when the astronomer Galileo Galilei spotted four worlds orbiting Jupiter. These days, we know of more than 90 moons in the Jovian system. Europa has held a particular fascination, though, partly because its icy surface is remarkably crater-free – evidence that below the hard exterior is a dynamic world, with geological processes constantly reshaping its surface.

Like all of Jupiter's innermost moons, Europa is stretched and squeezed by the gravity of the giant planet. As its oval-shaped orbit brings it periodically nearer and farther from Jupiter, a gravitational tug of war flexes the moon's interior, creating friction that warms it from the inside in a process called tidal heating. But it wasn't until we got up close, when NASA's Galileo probe visited in the 1990s, that we realised what that meant.

Europa Clipper under construction at NASA's Jet Propulsion Lab in California

Nobody had expected there to be liquid water on Jupiter's icy moons – let alone an enormous ocean. These worlds lie more than 750 million kilometres from the sun, after all, with surface temperatures of around -160°C (-184°F). But Europa defied this assumption when the Galileo mission discovered it had a secondary magnetic field.

The only way this could be so is if Jupiter's own magnetic field interacts with something conductive inside the moon. The most plausible explanation is that Europa hides a salty ocean beneath its icy crust, kept from freezing by the tidal heating. "We really weren't expecting that," says Kathleen Craft at Johns Hopkins University in Maryland, who is part of the Europa Clipper mission.

It gets more intriguing, though, because further investigations revealed that Europa could well have all the ingredients needed for life: not only a liquid ocean but also essential chemicals and energy, in the form of radiation from Jupiter. "The ocean may be an ideal environment to harbour primitive life, having conditions similar to those in Earth's thermal vents in its deep oceans, where life may have arisen on our planet," says Bonnie Buratti, deputy project scientist for the mission.

Planetary scientists would love nothing more than to sample that water directly. That might just be possible because there are reasons to think that Europa may be venting plumes of water vapour into space.

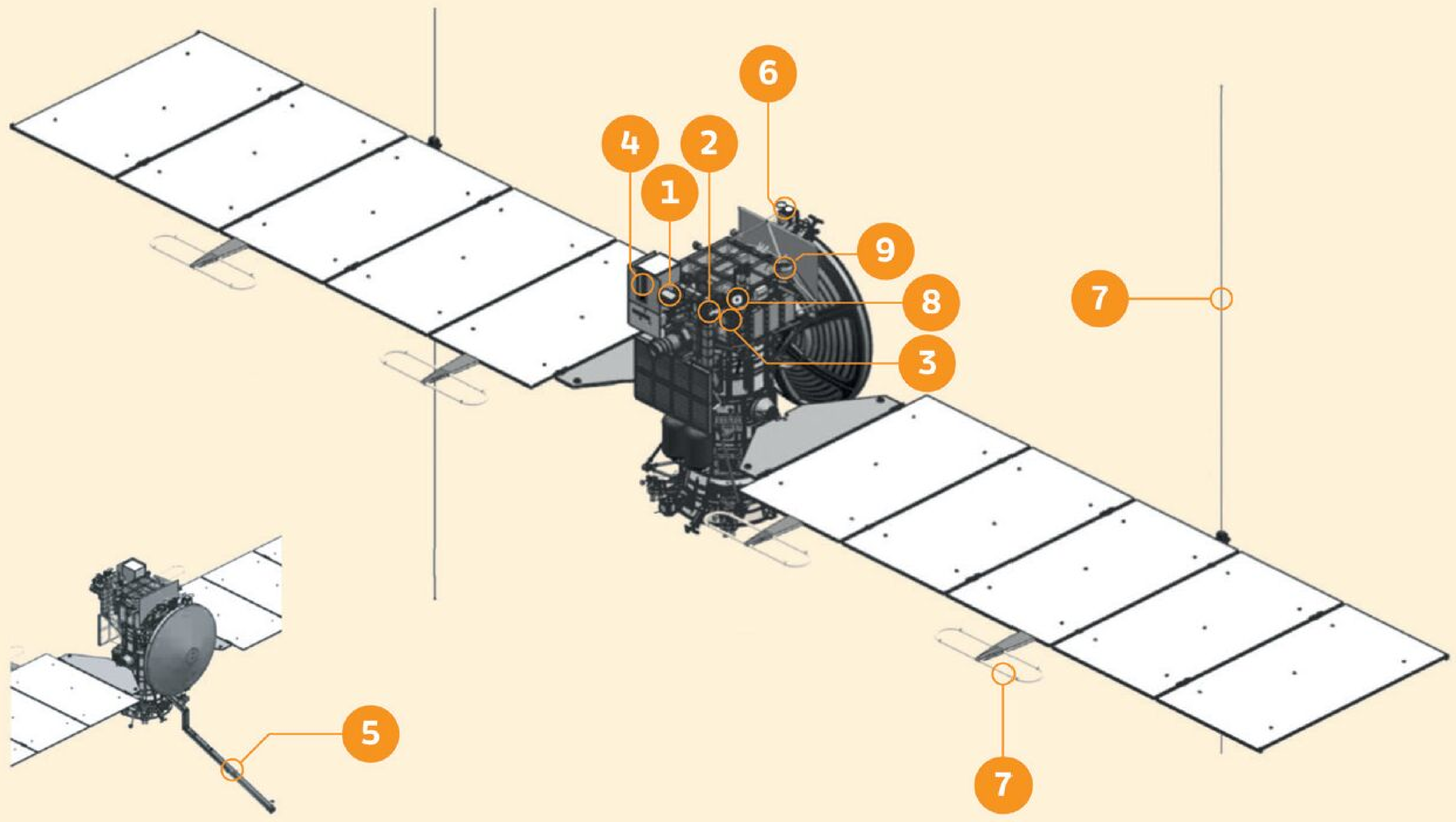
In 2005, the Cassini spacecraft discovered that one of Saturn's moons, Enceladus – which is less than a sixth of Europa's diameter – was shooting plumes out of its south pole. "That was also kind of crazy, because it's this tiny ice ball but it had all this activity," says Craft.

In 2012, the Hubble Space Telescope spotted hints of something similar on Europa. Spectral imaging revealed a large cloud of hydrogen and oxygen atoms – most likely in the form of water – spewing from the moon's south pole. Then, in 2018, a new analysis of Galileo data collected in 1997 found a sudden shift in

NASA/JPL-CALTECH

Meet the probe

Europa Clipper features nine scientific instruments, each designed to offer insights into the suspected ocean beneath Europa's frozen shell and the prospect of life there



1. **Europa Imaging System (EIS)**
Two 8-megapixel cameras to produce high-resolution pictures

2. **Europa Thermal Emission Imaging System (E-THEMIS)**
To distinguish warmer regions where liquid water may be near or on Europa's surface

3. **Ultraviolet Spectrograph (Europa-UVS)**
To determine the composition of the moon's atmosphere and search for signs of water plumes

4. **Mapping Imaging Spectrometer for Europa (MISE)**
To map the distribution of ice, salts, organic compounds and warm spots

5. **Europa Clipper Magnetometer (ECM)**
To confirm the existence of Europa's subsurface ocean and measure its depth and salinity

6. **Plasma Instrument for Magnetic Sounding (PIMS)**
To further study Europa's ocean

7. **Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON)**
Ice-penetrating radar to study the structure and thickness of Europa's icy shell

8. **Mass Spectrometer for Planetary Exploration/Europa (MASPEX)**
To analyse gases in Europa's faint atmosphere and possible water plumes, plus study ocean chemistry

9. **Surface Dust Analyzer (SUDA)**
To identify the chemistry of any materials being ejected from Europa's surface

Europa's magnetic field that could also indicate a cloud of water coming out from its surface. Any plumes, if they do exist, seem to be weaker than those on Enceladus. "Its plume activity is pretty constant, but what we think for Europa is it might be more periodic," says Craft.

Whether or not there really are plumes on Europa is far from the only mystery. There is much we still don't know, not least the depth and salinity of its putative ocean and what kind of chemistry it might contain. To find out, we need to get a closer look, which is where Clipper comes in.

This is NASA's fourth flagship mission to the outer planets. With a launch window opening in October this year, the spacecraft will reach the Jupiter system in 2030. There, it will orbit Jupiter and perform a series of flybys of Europa, using the nine instruments it carries (see "Meet the probe", above) to figure out whether this moon really does harbour conditions conducive to life.

> "Further investigations revealed that Europa could well have all the ingredients for life"

Clipper's magnetometer will carefully study the strength and direction of Europa's magnetic field, as well as how it varies over time. Combined with measurements of how the high-energy plasma around Europa moves, this will allow us to piece together how much of the magnetic field is generated by electrical currents within Europa's ocean. "By sensing the magnetic field around Jupiter and around Europa, we can tease out properties of that ocean like how salty it is and how deep it is," says Howell (see interview, page 34).

Radar and magnetic field measurements will reveal the thickness of Europa's icy crust to help pinpoint places where the ocean is close to the surface and potentially escaping. Combined with high-resolution photographs, temperature data and analysis of Europa's surface and atmosphere in ultraviolet and infrared, Clipper will also solve ongoing mysteries around what is happening on the surface.

This includes identifying relatively warm spots, which could indicate recent geological activity, and looking for molecules that could have been brought to the surface by sea water, such as carbonates and sulphates. "It's important that we understand the surface landforms and what those tell us about the exchange of material from the surface to the ocean and the ocean to the surface," says Howell.

This exchange of material is fundamental to the kind of chemistry we know underlies life on Earth, and which we believe could be going on inside Europa. It has to do with interactions between reducing agents – molecules with electrons to give away – and oxidising agents, which want more electrons. On Europa, the ›

New Scientist video
Watch the full interview with Sam Howell newscientist.com/video/

reducing chemistry could happen at the sea floor, caused by interactions with the salty ocean, while the oxidising chemistry could happen on the surface, caused by radiation interacting with water or sulphur.

That is why we're so keen to study surface features known as chaos terrain, which look like they are made of ice that has been broken and moved around. "It almost looks like icebergs getting tossed and turned," says Craft. "Those are places where maybe liquid water has come closer to the surface to allow that overturning of the blocks of ice."

It is also why Europa's putative plumes hold so much intrigue – they could give us a direct look at what kind of chemistry might be going on. And the good news is that if water is bursting out of the subsurface into the atmosphere around it, Clipper's instruments will have the chance to "taste" it.

Signs of life

None of which is to say that anyone is expecting to find evidence of life. "Europa Clipper is not a life-detection mission," says Buratti, echoing what everyone involved is at pains to point out. "It is instead seeking a habitable environment where life might exist." And yet there might well be a chance – albeit a slim one – that it could detect life after all, thanks to the spacecraft's dust detector.

"Europa is shrouded in a very tenuous atmosphere of ice grains from micrometeorites that impact the surface," says Fabian Klenner, who works on the instrument, which is called the Surface Dust Analyzer (SUDA). As Clipper flies past Europa, it will be splattered with dust, ice and gas coming from the moon's surface. "It's a paradise for the SUDA instrument, because it just flies through these grains and analyses them individually."

Using a mass spectrometer, SUDA will reveal the different kinds of ice that Europa's surface is made of. We know it is mostly water ice, but there are other compounds there too. While we have an idea what these might be, SUDA will confirm what kind of salts and organic material, if any, are present. "I'm very curious to understand the organic inventory of the moon," says Klenner, "which is very important to Europa Clipper's mission goal to investigate if Europa is able to support life or not."

The idea that we might do better than that comes from an experiment published in March, in which Klenner and his colleagues set out to test whether, if there were fragments of life floating in the ice grains around Europa, SUDA could find them. To replicate what will

'One day we might look for life directly on Europa'

Sam Howell is a project staff scientist on NASA's Europa Clipper mission and a planetary interior researcher at NASA's Jet Propulsion Laboratory in Pasadena, California. He tells David Stock why the agency is so keen to visit Jupiter's fourth-largest moon and what exactly it is hoping to find there.

David Stock: Why is this probe such a big deal?
Sam Howell: Europa Clipper is in a special class of mission. Historically, NASA has sent three "flagship" missions to the outer solar system. These have fundamentally changed our understanding of the solar system. We had the twin Voyager probes beginning in the 1960s and 1970s, we had the Galileo mission in the late 1990s and early 2000s, and we had the Cassini mission, which recently finished its grand finale at Saturn.

Now, we're going back to Jupiter. The fourth outer solar system flagship mission, Europa Clipper, is going to specifically look at one of the four largest moons of Jupiter, Europa, to find out if it has the conditions necessary for planetary habitability.

Why is this such a promising place to look for signs of the potential for life?
Europa is about the size of our moon and most of it is rock, but the entirety of the world is covered in about 100 kilometres of water. The top maybe 20 km is solid ice and then there is a saltwater ocean, we think, underneath that surface.

We think that life might have originally emerged on Earth in hydrothermal vents on the seafloor [thought to have had the right conditions to generate organic molecules and life-friendly energy]. If you have similar vents on the ocean floor of Europa, that gives you one half of what you need for life, the molecules. The other half, energy, could come from the radiation of Jupiter interacting with Europa's ice.

What are the most interesting parts of Europa to look at in terms of this?
Central to the story of habitability on Europa is our belief that the salty ocean could interact with the seafloor to produce lots of reducing chemistry – that's chemistry in which electrons are given away. And we believe that the radiation at the surface interacting with water, and even with sulphur, could produce strong oxidants – that is, things that want electrons.

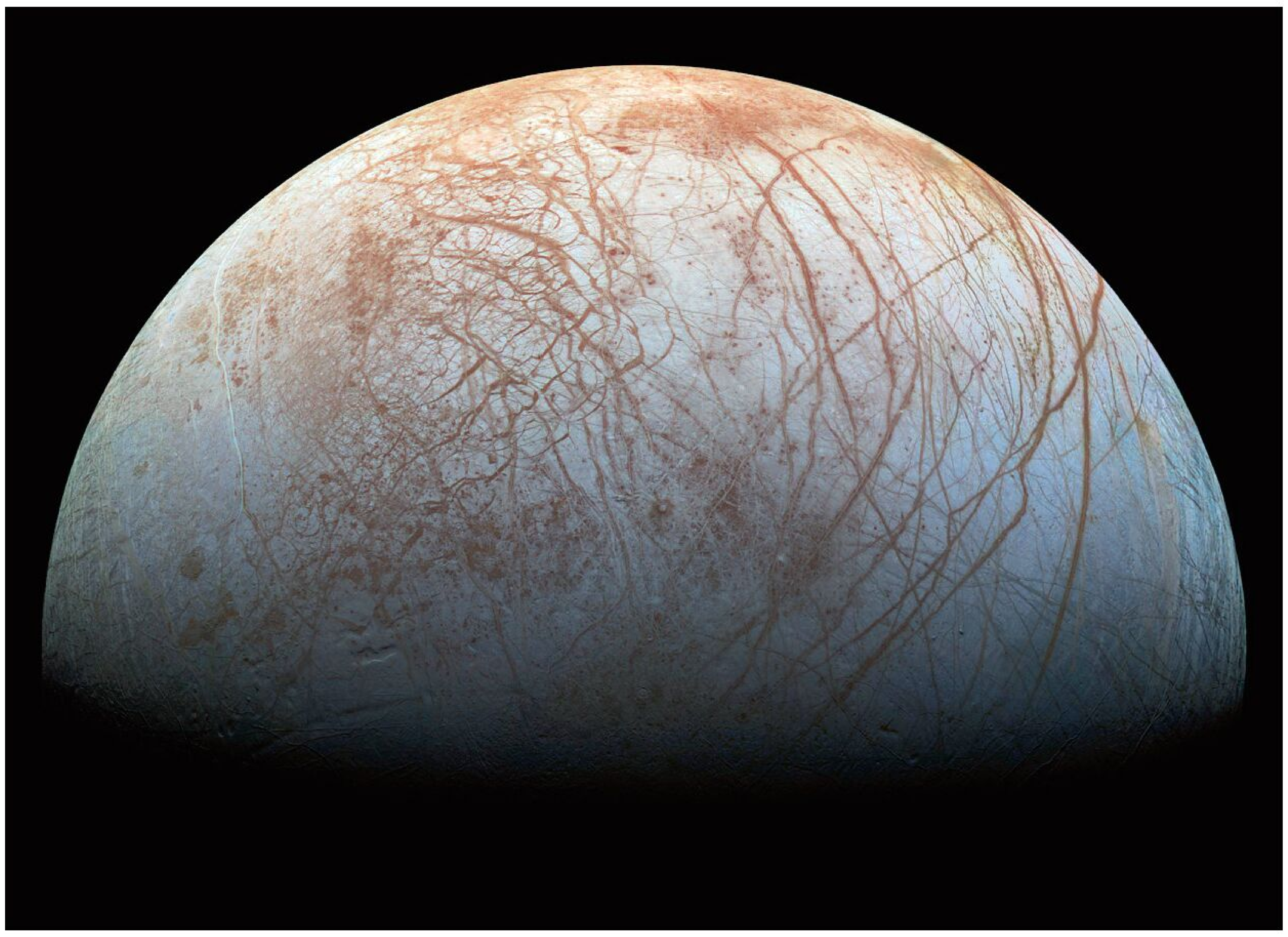
All the life that we know of here on Earth uses the transfer of an electron as its most basic energy source. So what we're really interested in is the place where these oxidants and reductants come together.

How exactly is the probe designed to study the ocean and the surface?
On board the spacecraft we have nine instruments (see "Meet the probe", page 33) and one experiment. Together, they will observe Europa not only in visible light, but in infrared and thermal infrared and in UV, and even with an ice-penetrating radar. We will have in situ instruments that can measure the environment directly.

There is also a dust analyser that can pick up material that has been sputtered off the surface by micrometeorite impacts and "taste" solid material ejected from Europa directly. We will also have a mass spectrometer capable of understanding the atmosphere of Europa and a magnetometer that can infer the size and salinity of Europa's ocean by its interaction with Jupiter's magnetic field.

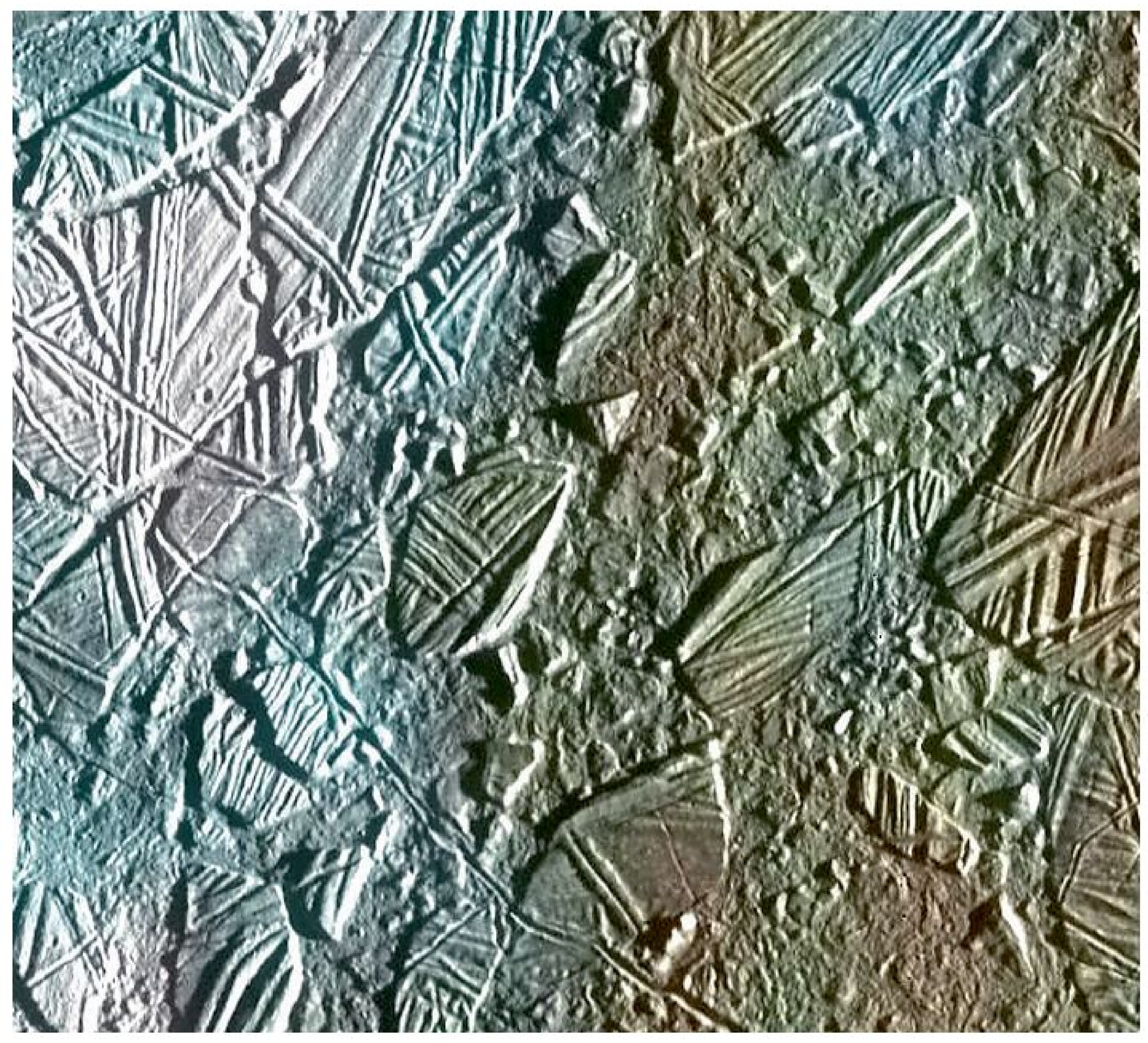
What will those instruments tell us?
We're going to be exploring what processes we think are active in the ice shell today. So we are looking for recent and current activity – everything from where there might be active tectonic faults to where there might be eruptions of water vapour from water trapped within the ice shelf. We are also going to probe the interior.

It will really provide us with new insight into the sorts of environments on Europa where we think life might emerge, if someday we want to explore them. There are already numerous technologies and mission concepts being developed that might one day look for life directly.



NASA/JPL-CALTECH/SETI INSTITUTE

Reddish streaks (left) and "chaos terrain" (below) on Europa suggest geological activity



NASA/JPL/UNIVERSITY OF ARIZONA

happen during the flybys, where ice particles will collide at high speeds with the instrument and become ionised, they fired a water jet at the same speeds Clipper will be travelling – around 4 to 6 kilometres per second – onto a replica of SUDA. They used a laser to ionise the molecules, breaking them up into their constituent parts.

Surprisingly, they found that if there were any extant cellular life within the ice particles, SUDA would be able to spot it. It is a huge if, to be clear. First, you would need to have life in the ocean. Then, plumes or other mechanisms would have to waft that life up from the depths to the moon's surface. Finally, you'd have to be lucky enough to catch it.

"Imagine you have a very interesting sample, let's say it's a bacterial cell," says Klenner. It might be that only a few out of every 1000 ice grains contain such a cell. Over the course of one flyby, SUDA will analyse a few thousand ice grains individually. "If you find, with a bit of luck, one of the ice grains with a bacterial cell in it, then SUDA can tell you that this single grain had the bacterial cell in it."

The speed also matters. Too slow and you don't have enough energy to ionise the compounds, too fast and you shatter the molecules. "It's really cool that the Goldilocks zone for retention of interesting compounds is 4 to 6 kilometres per second," says Klenner. "This is exactly what Europa Clipper will do."

The most likely scenario is that SUDA and the other instruments on Clipper won't find evidence of life directly, but they will instead point us to zones where we might be able to find it, perhaps places where the ice sheet is thin or water is escaping. This too is vital because it could lead to a series of future missions to land on the moon and ultimately drill into the icy crust and even right into the hidden ocean below.

"Most likely, we'll have a lander first," says Craft. This could be a robot that can get under the surface of the moon, perhaps several metres. It might not get into the water itself, but it could still have a chance at identifying molecules from the ocean. "There is the potential that slow convection brings ocean material up towards the surface," says Craft, "just like our mantle and crust overturns on longer timescales." Europa Clipper will thus be looking for places where this is evidence of seawater recently coming to the surface, should they exist.

Next, the plan would be to send a submersible robot, known as a cryobot, through the ice into the water. NASA hasn't yet firmly decided to support any lander or drilling missions to Europa, but Craft and others are already sketching out how the concept might work. The cryobot would drill into the ice, powered by nuclear fission, melting its way down and taking samples as it goes. "Life as we know it loves interfaces," says Craft, so the most exciting place to study would be the boundary between the ice and the water.

> "Europa Clipper could ultimately lead to a series of missions to land on this moon and drill into its icy crust"

Again, Europa Clipper will pave the way for such a mission by mapping where the ice is thinnest, providing the best chance of getting to the water. If it confirms the ice to be as thick as we expect – that is, a few kilometres to a few tens of kilometres – drilling could take between three and six years. It will be slower than on Earth, owing to gravity being far weaker on Europa.

The final step in exploring the moon would be to find and investigate any hydrothermal vents at the bottom of its ocean. "Europa's ocean is very deep, but if we could ever get to the seafloor, that would be an extremely interesting place," says Craft.

We have only just started to scratch the surface of our own oceans – life around hydrothermal vents was discovered in the 1970s. So the challenge of finding our way around a 100-km-deep ocean, billions of kilometres away, is a daunting one. With Clipper's launch, however, we are at least dipping our toes in the waters of a distant ocean world. ▮

Abigail Beall is a features editor at *New Scientist*