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There's a lot more water on the Moon – and elsewhere in the Solar System – than most people realise

SNEZHANNA/ISTOCK/GETTY IMAGES

WATER, WATER, *everywhere?*

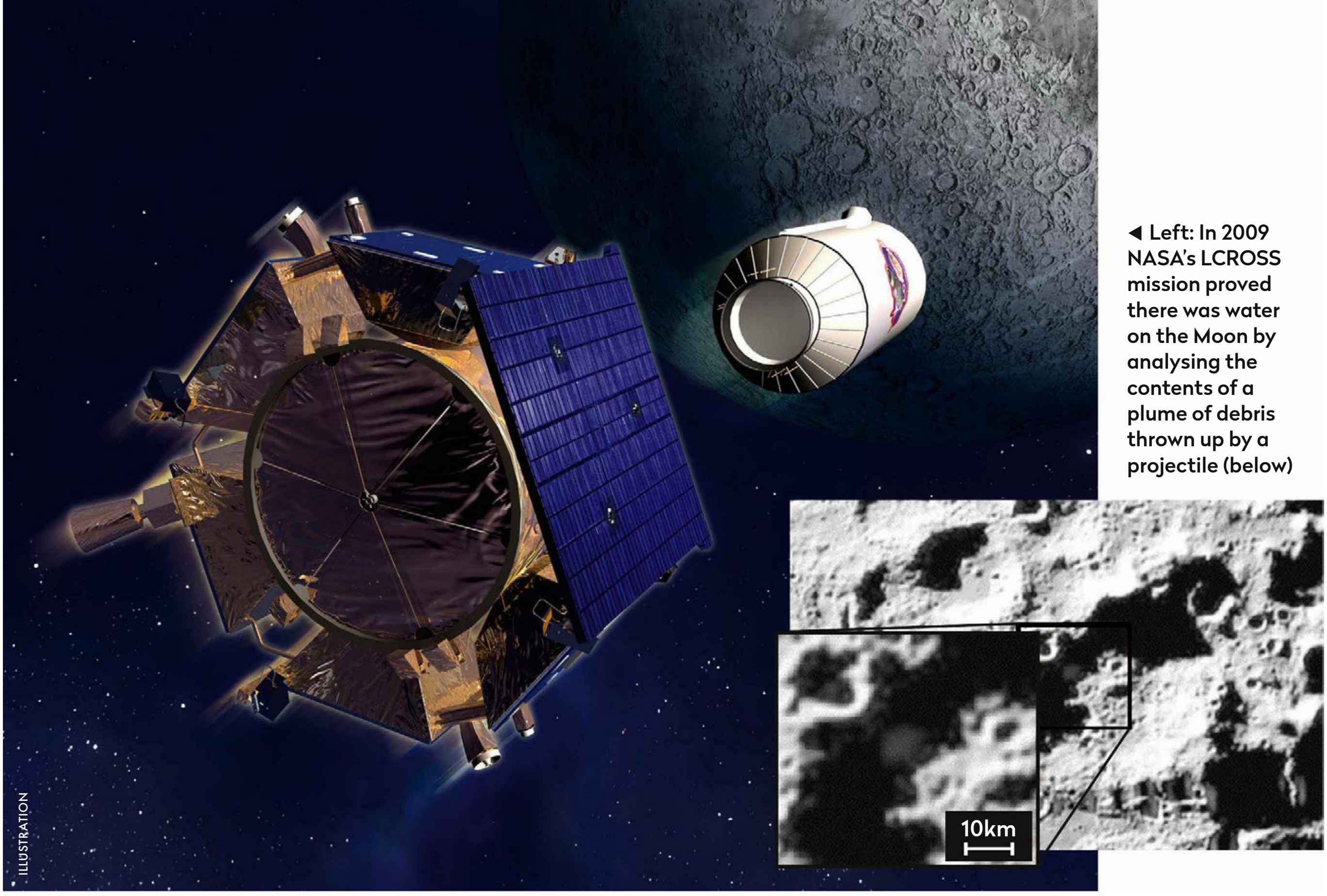
ILLUSTRATION

Penny Wozniakiewicz investigates why astronomers are so concerned with finding water in the Solar System, and why it is vital to our exploration of space

Staring up at the Moon with the naked eye, we can forgive early astronomers for assuming the dark patches spread out over its surface were seas – or 'maria' as they were named, after the Latin word for seas. Informed by centuries of ever-improving observations and over 60 years of space exploration, we now know the maria are not seas but rather vast expanses of volcanic basalt that erupted over the lunar surface several billion years ago.

The Moon is in fact very dry: more so than any desert on Earth. Yet despite that, on 23 August 2023 the Indian Space Research Organisation's Chandrayaan-3 mission successfully deployed its lander and rover near the lunar south pole in search of water.

So why search for water in such a dry location? Although there is no liquid water on the Moon, water is present in the form of ice trapped between grains in the lunar soil and incorporated into minerals and glassy beads produced by impacts. The potential for such hidden water was first suggested by remote observations of the surface, and later confirmed by NASA's LCROSS mission, which in 2009 fired an empty rocket stage into a crater on the lunar surface and identified ice in the plume of material ▶



◀ Left: In 2009 NASA's LCROSS mission proved there was water on the Moon by analysing the contents of a plume of debris thrown up by a projectile (below)

▶ flung up from the crash site. Further observations of the surface by the likes of the NASA and German Aerospace Center's SOFIA telescope have since suggested the south polar region of the Moon in particular may host far more water than we ever imagined. As much as 100–400mg of water (about one raindrop) may be present in each kilo of soil.

While this may seem a small amount, it has prompted several space agencies to propose lunar surface missions and instruments to find and characterise lunar water over the next decade.

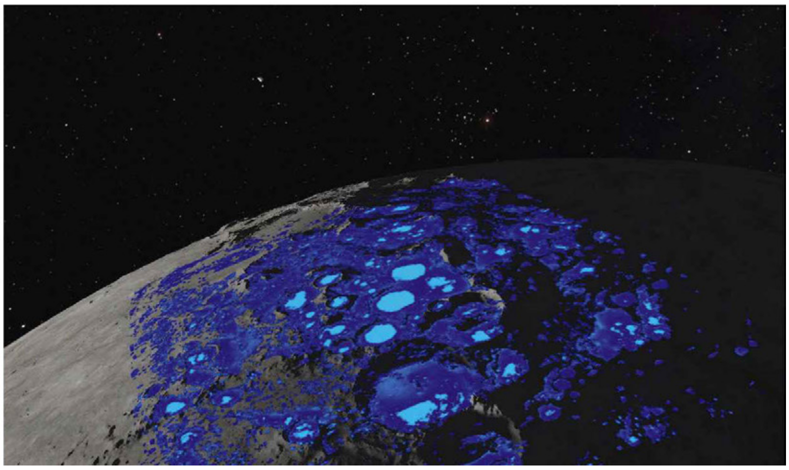
PROSPECTing for water

One such instrument is the European Space Agency's (ESA) PROSPECT payload, destined for the south polar region. This consists of a drill to dig down and obtain samples from the near-surface, together with an onboard laboratory that will subject samples to heat and measure the gases, including any water vapour, that are released.

"Should water really be present in such significant quantities, the potential implications would be enormous, especially for upcoming human exploration programmes," says Dr Dave Heather, PROSPECT project scientist at ESA. "Water is essential for human survival. It can be used for drinking and also be broken down into its constituent components to provide oxygen for breathing."

All life as we know it needs water. We ourselves are made up of 55–60 per cent water and we need a continuous supply to stay alive. Water is also needed for daily hygiene and, if a colony is to be even remotely self-sustaining, for growing crops. Water also has another handy use up its sleeve – if you split it into hydrogen and oxygen, you get the components for rocket fuel.

But space travel is a costly business, and one that gets more expensive and more complex the more you want to take with you and the further you want to go. Minimising mass on board spacecraft is a high priority for space agencies and mission engineers. Since water is vital to any human space mission, it cannot simply be left behind, but perhaps now we can mine it from lunar soils.



▲ The lunar south pole is thought to be the Moon's most water-rich region

Dr Mahesh Anand, a professor of planetary science at the Open University, is exploring ways to do this. "Water is considered a key resource for enabling a more affordable and sustainable exploration of the Moon," he says. "The availability, extraction and utilisation of water in situ on the Moon would therefore lower the cost and risks for future missions."

If the Moon harbours water, where else might we find it, and in what form? Today, Earth is the only planetary body in our Solar System with sustained liquid water present on its surface. This is because water exists as a liquid at a range of pressures and temperatures that are found, thankfully for us, on Earth's surface. However, over the last few decades a plethora of telescopes and spacecraft have shown that water is present throughout our Solar System.

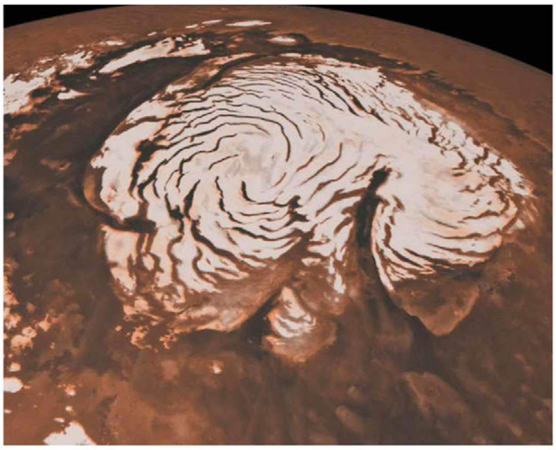
How Earth became blue

Was Earth always so aqueous? A short history of water on our planet

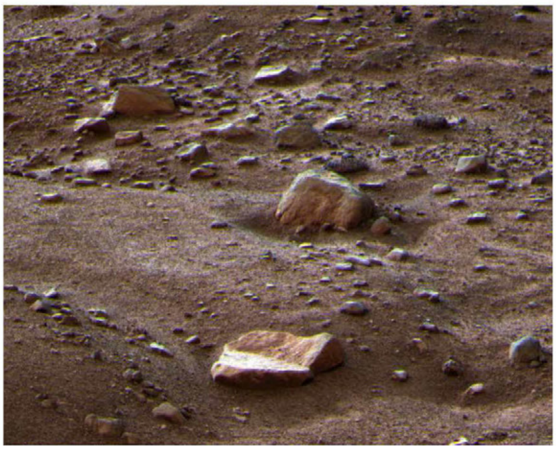
The volume of water on Earth is actually quite small compared to the planet's volume overall. Further out in the Solar System, this is not the case

Today, over 1,000 quintillion litres of water exist on Earth, most of which make up the oceans that cover over 70 per cent of its surface. Our Blue Planet may be blue now, but things may have been quite different when it first formed.

In some formation theories, the early Earth was initially dry, having formed in the inner region of the Solar System inside the so-called 'snow-line', close to the Sun, where temperatures are so high that volatiles like water are in their gaseous form. The snow-line is the distance from a star beyond which temperatures on a planetary body become low enough for water to condense out from gas and form solid icy grains. In this scenario, it is believed that Earth's water was delivered later by impacting comets and asteroids. In contrast, planetary bodies forming beyond the snow-line in the outer Solar System were fed with plenty of icy materials. This is evident when we compare the size of Earth's water reservoir with those estimated for the largest Kuiper Belt objects (such as Pluto and Charon) and the icy satellites of Jupiter, Saturn, Uranus and Neptune.



▶ Water ice is plentiful at Mars's north pole: the area depicted is around 1,000km across



▶ Images from Martian rovers have revealed frost on the ground in the early mornings

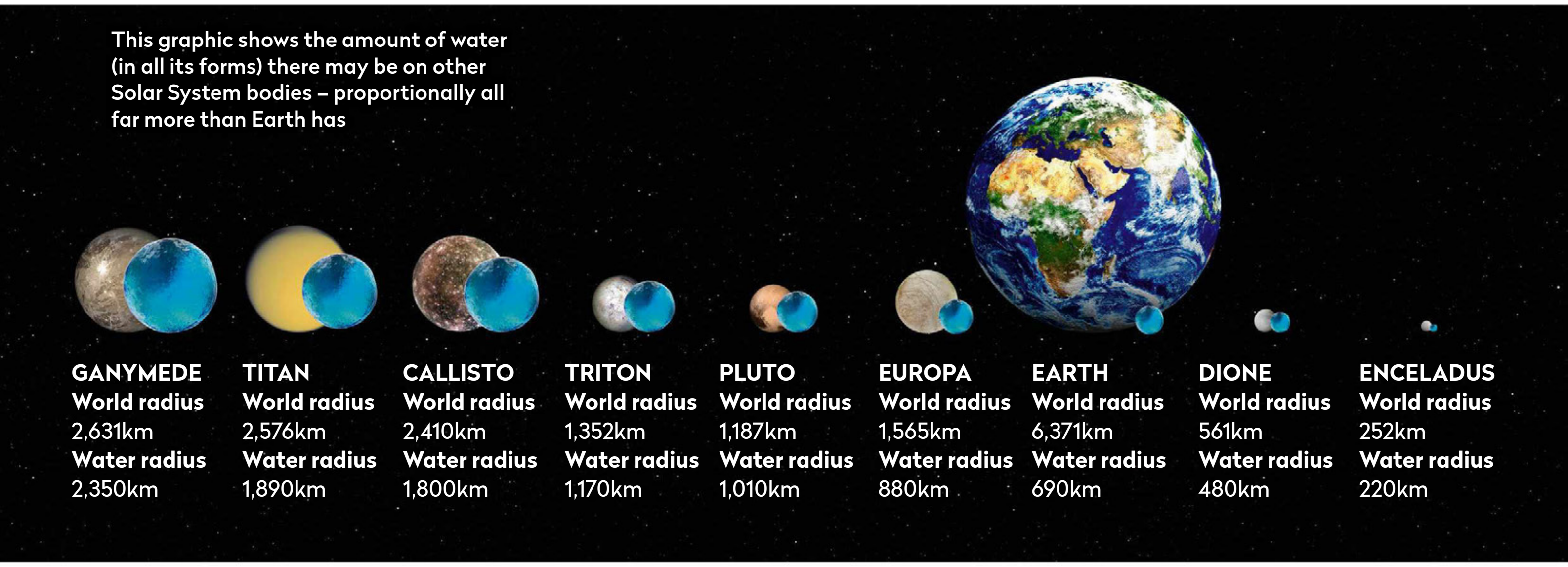
We need only look as far as the other terrestrial planets, Mercury, Venus and Mars to find it. Venus is closer to the Sun than Earth and has an extremely dense, carbon dioxide-rich atmosphere that means its surface is like an oven day and night. You might think such a planet could not possibly host liquid water. Nevertheless, water is present on Venus, albeit only as vapour in its atmosphere.

Mercury sits even closer to the Sun than Venus, but its thin atmosphere means the surface continuously oscillates between hot and cold during the night as the planet rotates. You might expect any water present to have boiled off completely, yet there is evidence that, just like on Earth's Moon, water is present as ice within permanently shadowed regions of craters near Mercury's poles.

Mars and beyond

On Mars, water ice can be found in plain sight in the polar ice caps. Yet there is also evidence of vast quantities of it – perhaps more than five million cubic kilometres – hidden beneath its surface. If all this ice melted, there'd be enough water to create an ocean 35 metres deep over the entire surface of Mars – or fill Loch Ness over 650,000 times!

Water is also present on Mars, in small quantities, as tenuous clouds high in the atmosphere. Near the poles, visiting Mars landers have observed water freezing out of the atmosphere at night, forming a frost on the ground. ▶



This graphic shows the amount of water (in all its forms) there may be on other Solar System bodies – proportionally all far more than Earth has

▶ Moving beyond Mars we reach the asteroids, which also contain water: potentially hundreds of billions of litres of the stuff. On many asteroids this water has become incorporated into minerals, but on some, like Ceres, water is still present as ice. Indeed, Ceres's low density suggests that as much as 25 per cent of the dwarf planet could be water ice.

At the giant planets, Saturn and Jupiter both have water vapour in their atmospheres, while Uranus and Neptune are thought to have a water ice mantle lurking beneath theirs. Water ice also dominates the spectacular rings around Saturn, accounting for around 99 per cent of the 15 billion billion kilos of material. That's over half the amount of ice currently in the Antarctic ice sheet, but spread out over a much larger area. Perhaps more excitingly, it seems water is also present as ice on many of the moons of the giant planets, and it may even be liquid on some.

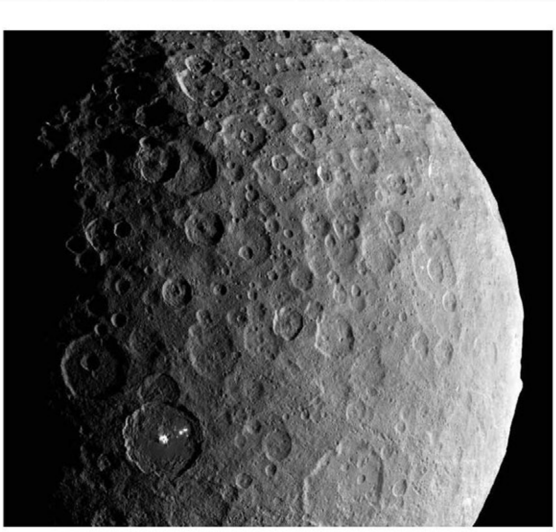
Below the surface

As far as we know, the only surface oceans in our Solar System are found on Earth. However, there is evidence for subsurface oceans on at least the Jovian moons Ganymede, Callisto and Europa, and the Saturnian moons Enceladus, Dione and Titan. Indeed, the total water content (liquid and ice) of these bodies is around 80 times that of Earth.

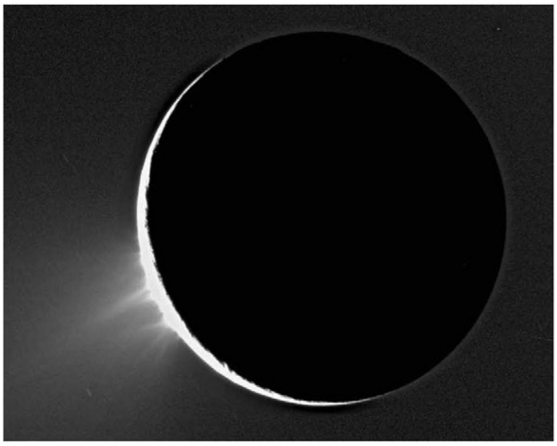
While heating by the Sun at these distances is minimal, the presence of liquid subsurface oceans on these icy worlds is thought possible due to tidal heating, whereby heat is generated as the moons are squashed and squeezed by the gravitational pull of their parent planet fighting against that of their sibling satellites.

During its visit to the Saturnian system, the Cassini spacecraft beamed back remarkable images showing plumes of water vapour and ice grains shooting out from Enceladus's surface. Using the Cosmic Dust Analyser (CDA) on board, Cassini was able to sample and study these plumes. "We found salt- and carbon-rich water ice grains originating from a large reservoir of liquid water below the icy crust of Enceladus," says Dr Ralf Srama, astronomy professor at University of Stuttgart and lead scientist for the CDA.

The existence of subsurface oceans is exciting because of the potential significance to the question of whether suitable conditions for life might be found beyond Earth. Scientists like Dr Frank Postberg, professor of planetary science at the Freie Universität Berlin, have been working with plume data from CDA to study conditions below Enceladus's icy crust. He says, "We found a variety of salts that tell

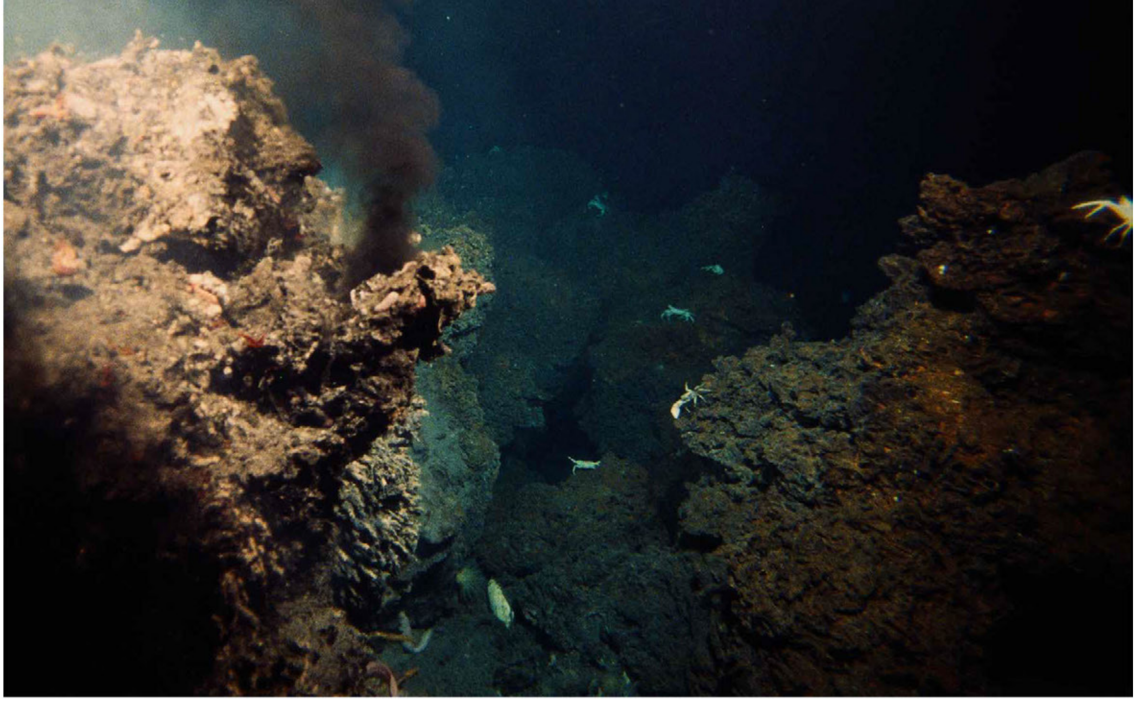


◀ Located in the asteroid belt, dwarf planet Ceres may consist of up to 25 per cent water ice



◀ Massive jets of water erupt from the surface of Saturn's moon Enceladus in this Cassini image captured in 2017

WATER IN SOLAR SYSTEM ILLUSTRATION: SOURCE - STEVE VANCE/NASA/JPL-CALTECH, NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA, NASA/JPL/SPACE SCIENCE INSTITUTE, MARK GARLICK/SCIENCE PHOTO LIBRARY/ALAMY



▶ Hydrothermal vents like those in Earth's oceans could potentially enable life to survive in subsurface oceans on other worlds

us Enceladus's subsurface ocean is a little less salty than Earth's ocean, and is a 'soda ocean' with lots of dissolved carbonates and carbon dioxide, which also provide more alkaline waters than on Earth."

Promisingly, they also identified organics (which are needed for and can be created by life), phosphorus (which is essential for life as we know it) and minerals that indicate hydrothermal activity – a proposed mechanism for providing materials for chemical reactions and heat in the dark, subsurface world.

Although few spacecraft have ventured beyond Saturn, those that have revealed evidence of water ice on the moons of Uranus and Neptune, and on Kuiper Belt objects such as Pluto, which is thought to be composed of up to 30 per cent water ice. Comets, which we observe from Earth as they traverse the inner Solar System, can originate from the Kuiper Belt or the more distant Oort Cloud and are also laden with water ice. Hundreds of thousands of such icy bodies may occupy the Kuiper Belt, while there may be hundreds of billions or even trillions of them in the Oort Cloud.

Water in various forms is abundant in our Solar System. Observations of other nascent and established systems suggest that they, too, contain water. If space exploration requires water to be present in the locations we wish to visit, it seems our possible destinations are endless.

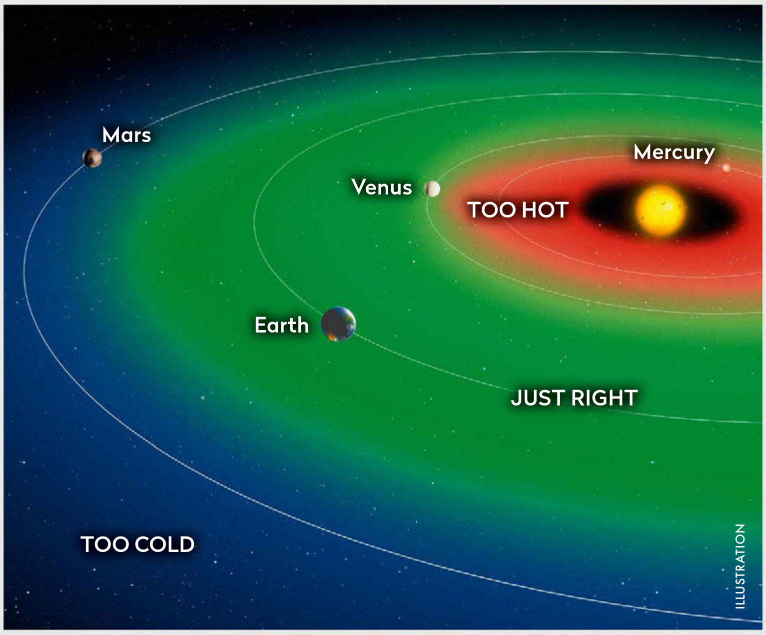
Penny Wozniakiewicz is a senior lecturer in space science at the University of Kent

Where there's liquid, there's life

Follow the water, says NASA, and you just might find signs of sentience beyond Earth

Liquid water is an essential requirement for life as we know it. It acts as a solvent, breaking down and dissolving substances into a form that can be used by life, also providing a liquid medium in which they can then move, interact with other substances and take part in the key chemical reactions that define life. The presence of liquid water is therefore considered a key requirement for any potentially habitable location beyond Earth, with NASA adopting the mantra 'follow the water' in its search for evidence of past and present life on Mars, and the study of its potential habitability.

Indeed, the presence of water is used to define the 'habitable zones' around stars – these are the range of distances from a star at which an orbiting planet may be heated enough by the star's radiation to have liquid water on its surface. But with the discovery of subsurface oceans way beyond the outer limits of the Sun's habitable zone, our own Solar System has shown us that the situation is not so simple, and that niche or local habitable zones made possible by processes such as tidal heating may also exist – and potentially enable life.



▲ The habitable zone, also known as the Goldilocks zone, is the area around a star where liquid water can exist on the surface of orbiting planets. Outside this region, there can still be water in the form of ice or vapour