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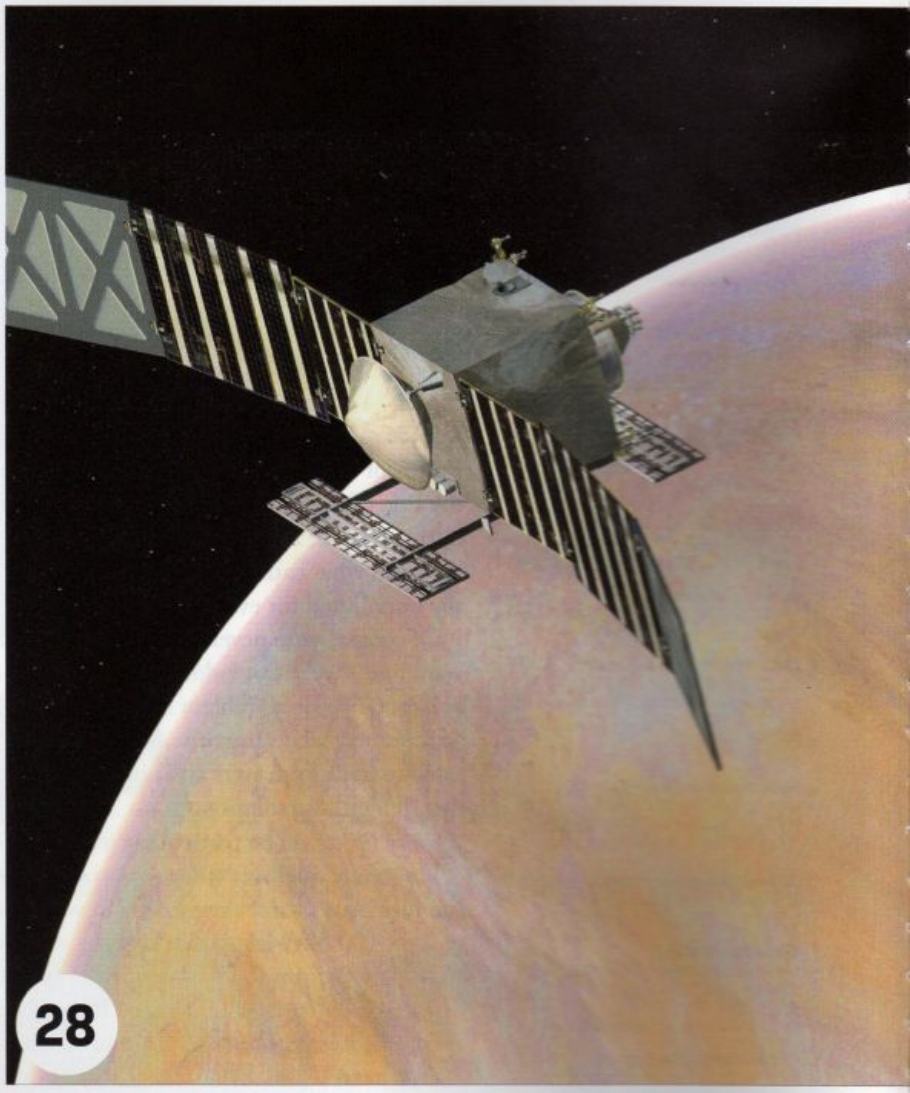
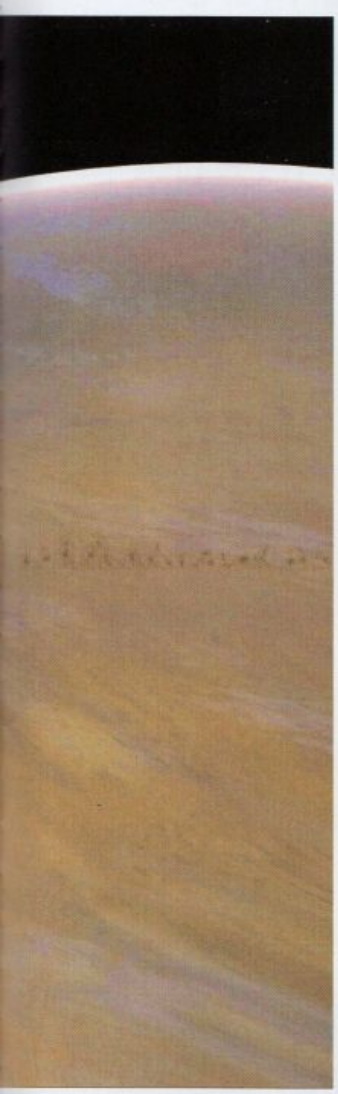
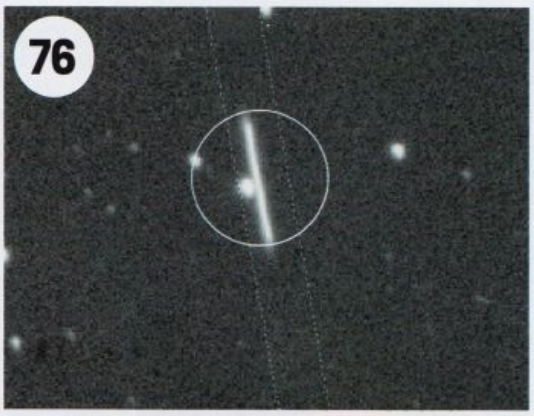
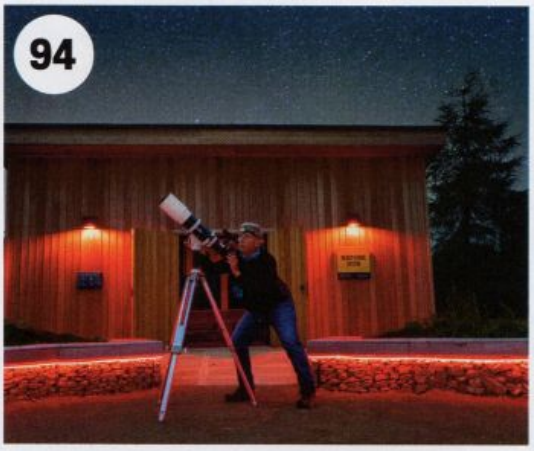


THE NIGHT SKY

◀ On the cover: Spend a week on the Moon this November. Image: Fernando Oliveira de Menezes.





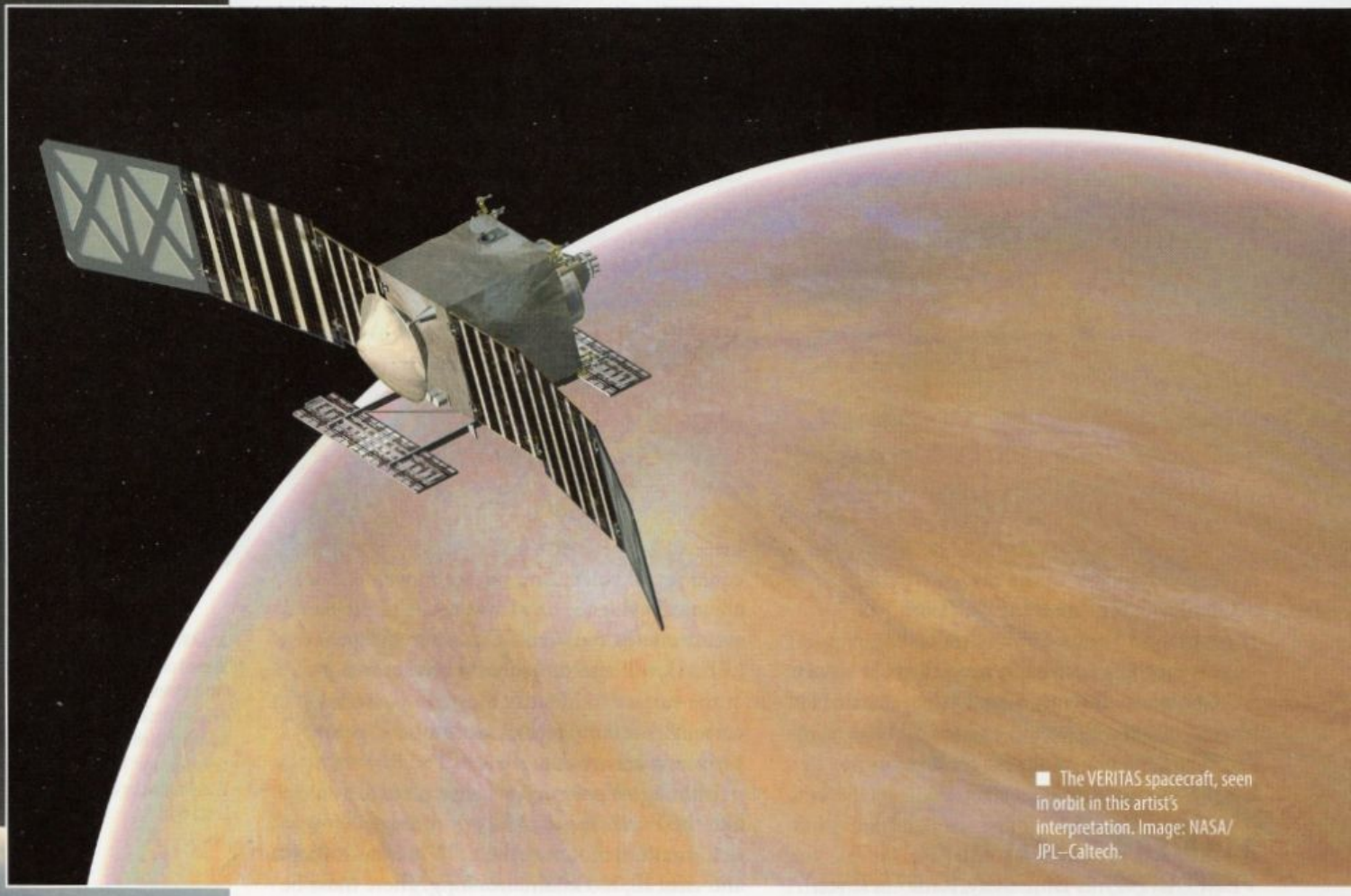


EQUIPMENT

SETTING OUT FOR A SISTER PLANET

THE NEW MISSIONS TO VENUS

A flotilla of five Venus-bound spacecraft will carry new instruments to answer old questions, writes **Steve Murray.**



■ The VERITAS spacecraft, seen in orbit in this artist's interpretation. Image: NASA/JPL–Caltech.

VENUS is a troubled sibling. Formed at around the same time as Earth, and with about the same size, and probably made from similar materials, our histories should have unfolded in parallel. But somehow, Venus took an ominous path. Today, its surface broils at temperatures reaching 470 degrees Celsius, beneath a dense (92 bar) toxic atmosphere blanketed by thick clouds. What happened? Since 1962, twenty-seven spacecraft have searched Venus for answers to that question, but the planet still hides its biggest secrets.

Now, Europe, the United States, India and Russia are each preparing new spacecraft that will journey to Venus later this decade. Equipped with improved instruments, they'll supply fresh data to push back more of the planet's mysteries. Bringing these programmes into existence, however, demanded persistence from the scientists who conceived them. Their eventual reward will be a deeper look at the planet beneath the clouds. Nothing can keep its secrets forever.

GAUGING CURRENT CONDITIONS

The EnVision mission, selected this year by the European Space Agency (ESA), evolved through several selection cycles. Richard Ghail, a geologist at Royal Holloway, University of London and Principal Investigator for EnVision, first submitted the orbiter concept in 2010.

"It was originally part of a Venus balloon mission, but they decided they couldn't afford it," he says. Modified proposals got better reviews, but final approval didn't come until NASA stepped in with additional money to put the project over the top in 2018.

For those who may wonder, EnVision isn't an acronym. "I came up with the name with the idea that we would envision Venus in a whole new way," says Ghail. The mission could launch as early as 2031.

EnVision will concentrate on questions about present-day Venus. "In order to understand its past," says Ghail, "we have to understand what it is today." A three-channel spectroscopy system (VenSpec) will characterise the composition of surface rocks and make measurements of the atmosphere, including tests for sulphur components and an unknown ultraviolet absorbing agent in the upper clouds.

The orbiter's instrument suite focuses on geological processes, including their interaction with the atmosphere.

"I've been interested in tectonics since my PhD days," says Ghail. "So I really want to

■ The EnVision spacecraft cruises above Venus in this artist's impression as it seeks to understand Venus' geology and surface interaction with the atmosphere. Image: ESA/VR2Planets/Damia Bouic.

understand how Venus works as a planet geologically." A high-resolution synthetic aperture radar (VenSAR) will image the planet's surface topography in stereo, while interferometry will characterise its current tectonic, sedimentary and volcanic processes. A ground-penetrating subsurface radar sounder (SRS) will map the boundaries of terrain features like impact craters and tectonic properties.

EnVision will also assess the equilibrium between planet and atmosphere. "We know from Venus Express that the atmosphere is more dynamic than we expected," says Ghail. "The clouds are being sustained by processes that put water vapour and sulphur dioxide into them and ultimately remove it. Is there some recycling going on?" In other words, does the planet change over time or does it have processes that maintain stable conditions as in the case of Earth?

Ghail isn't yet sure what EnVision will encounter on Venus, but he thinks that important things are happening there. "I suspect we're going to find lots of activity in unexpected places," he says. "It would be incredibly surprising if a planet almost the size of the Earth was completely inactive."

BUILDING A GLOBAL MAP

VERITAS (Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy) is one of two Venus missions selected this year by NASA. A 2028 launch is currently planned.

"This is the third time this was proposed for funding," says Suzanne Smrekar, a geophysicist at the Jet Propulsion Laboratory and Principal Investigator for VERITAS. Originally submitted in 2010, intervening developments in radar technology, new discoveries by Venus Express, and a growing desire to understand exoplanets changed the fortunes of VERITAS. "I was in the right place at the right time to push this forward, although I can't say it was my idea uniquely." Smrekar calls herself a "life-long Venusian."

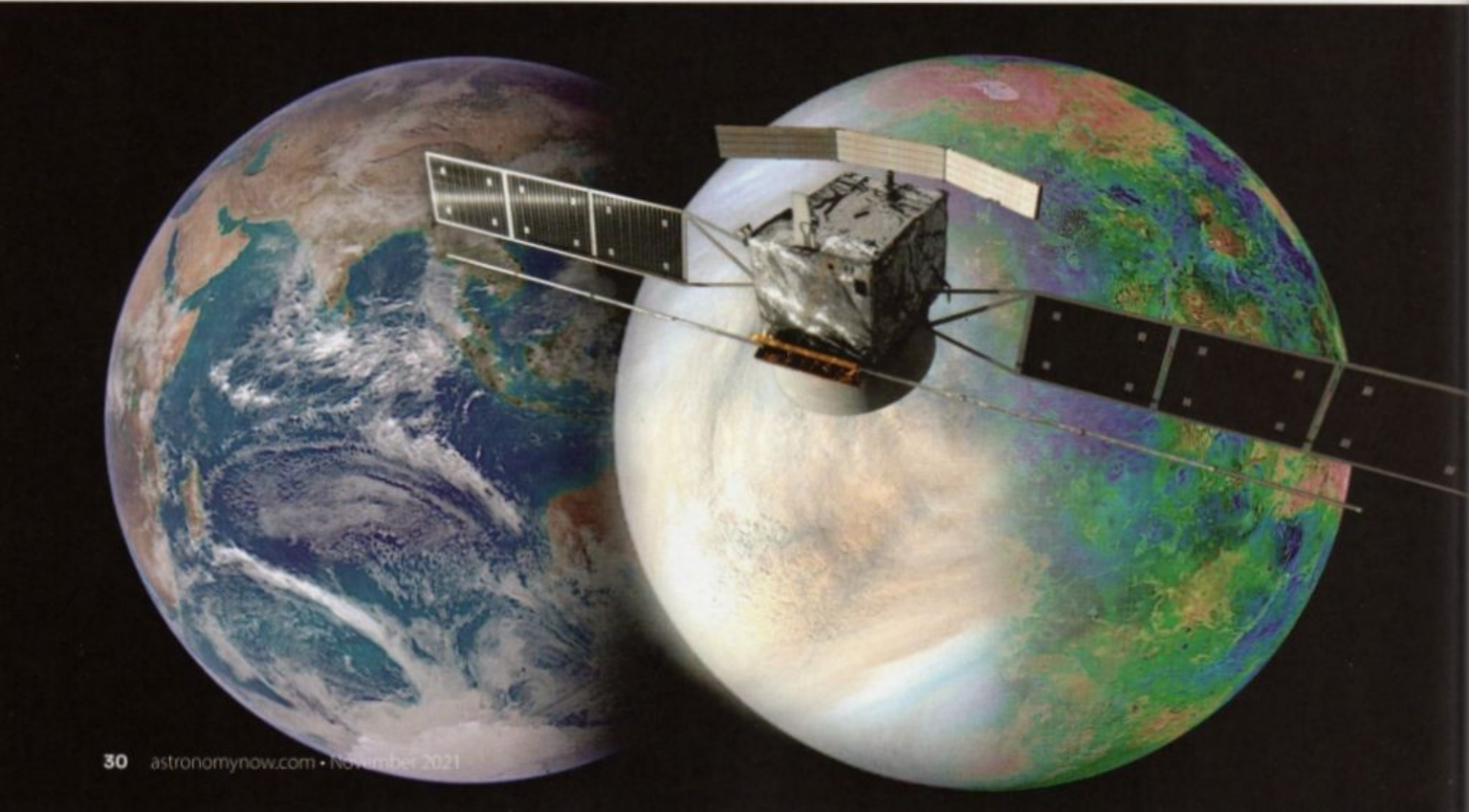
"How does Venus operate?" she asks. "How is the interior coupled to the surface and coupled to the atmosphere? These questions have fascinated me for my entire career."

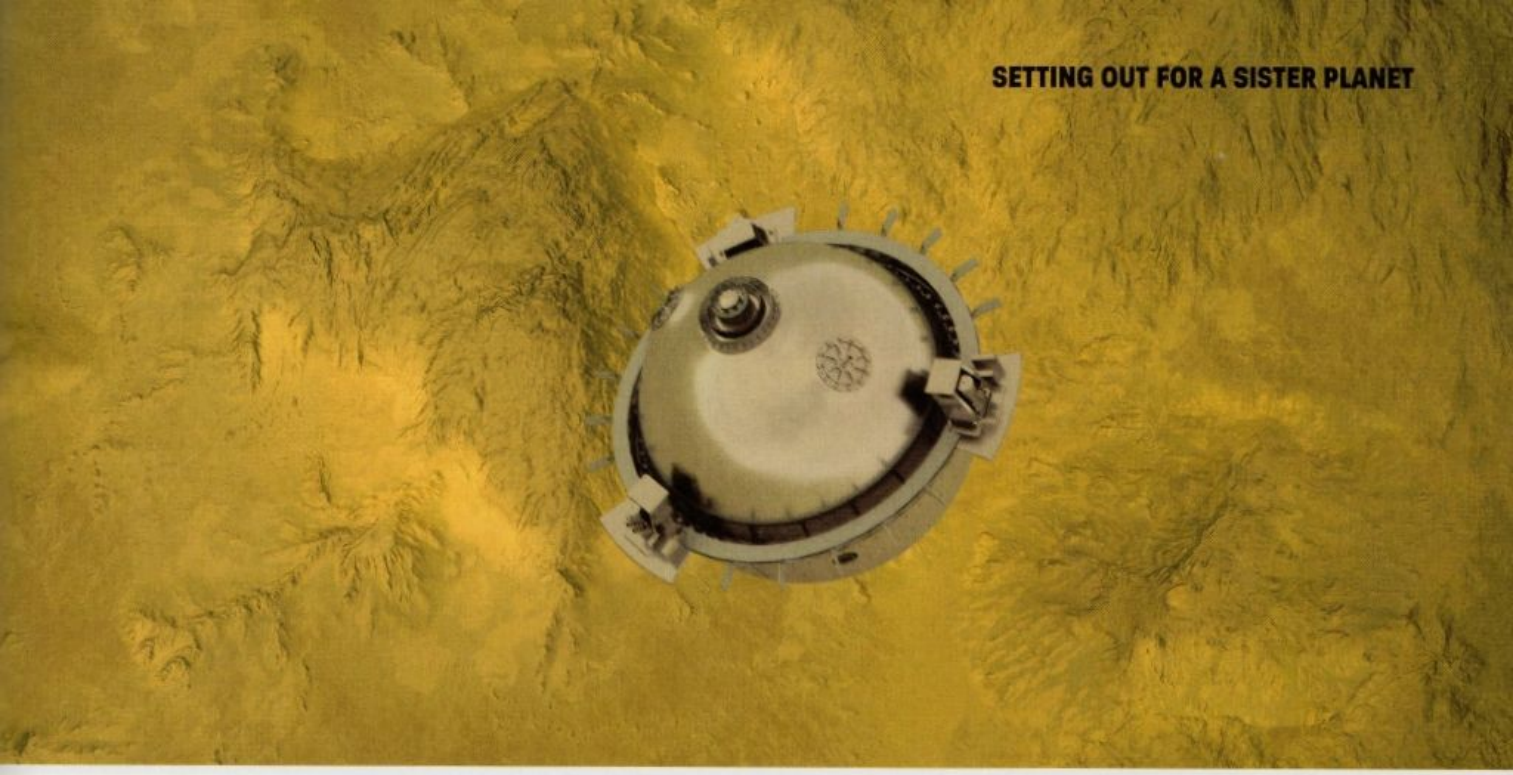
VERITAS' instruments, like those of EnVision, emphasise the study of surface conditions. The Venus Interferometric Synthetic Aperture Radar (VISAR) will scan the entire planet, creating 3D topographic maps of active surface deformations that could reveal volcanism, surface movement or chemical evidence of past water. A multi-band spectrometer, the Venus Emissivity Mapper (VEM), will also measure thermal emissions at the surface to identify rock compositions, current or recent volcanic activity, and near-surface water vapour.

Although Venus doesn't have plate tectonics like the Earth, it has plenty of surface deformation: mountain belts 11 kilometres high and rifts 10,000 kilometres long. There must be active geologic processes going on and Smrekar believes they involve subduction – the process by which parts of the planet's crust sink into the mantle to be recycled.

"Subduction is thought to be the first step in plate tectonics on Earth," she says. "I would love

▲ DAVINCI's roughly spherically shaped probe, seen in this artist's impression in free-fall descent close to the surface having passed through Venus' clouds. Image: NASA GSFC Visualization by CI Labs' Michael Lentz *et al.*





to understand the conditions that allow that and to understand why Venus hasn't evolved plate tectonics."

Another important focus of VERITAS scientists will be the planet's fractured tessera regions. Tesserae are rough analogues of Earth's continents and they could answer critical questions about the geodynamics of Venus.

"Seven to eight per cent of Venus' surface is covered in tessera plateaus," says Smrekar. "That's a lot. To get that much rock, you need to have processes similar to continent formation on the Earth."

Telemetry signals for VERITAS will also double as gravity probes. The small velocity changes that occur when a satellite orbits over areas of different density on a planet can be detected through Doppler shifts in the satellite's communications signal frequency. These changes from VERITAS will be used to map the mass distribution of Venus' interior. This information can then be used to determine the size and composition of the planet's core and help explain why Venus doesn't have a real magnetosphere (although some magnetic behaviour has been detected by the European Space Agency's Venus Express mission).

Many VERITAS discoveries will almost surely be unexpected. Which among them might most surprise Smrekar? "Evidence of water-driven erosion on the surface," she answers, "left over from a time when Venus had much more water. I'm personally sceptical, but it would be fabulous to be proven wrong."

◀ Earth and Venus – two similarly sized planets with two very different stories. EnVision will probe beneath the clouds to better understand Venus' story. Image: NASA/JAXA/ISAS/DARTS/ Damia Bouic/VR2Planets.

DROPPING THROUGH THE SKY

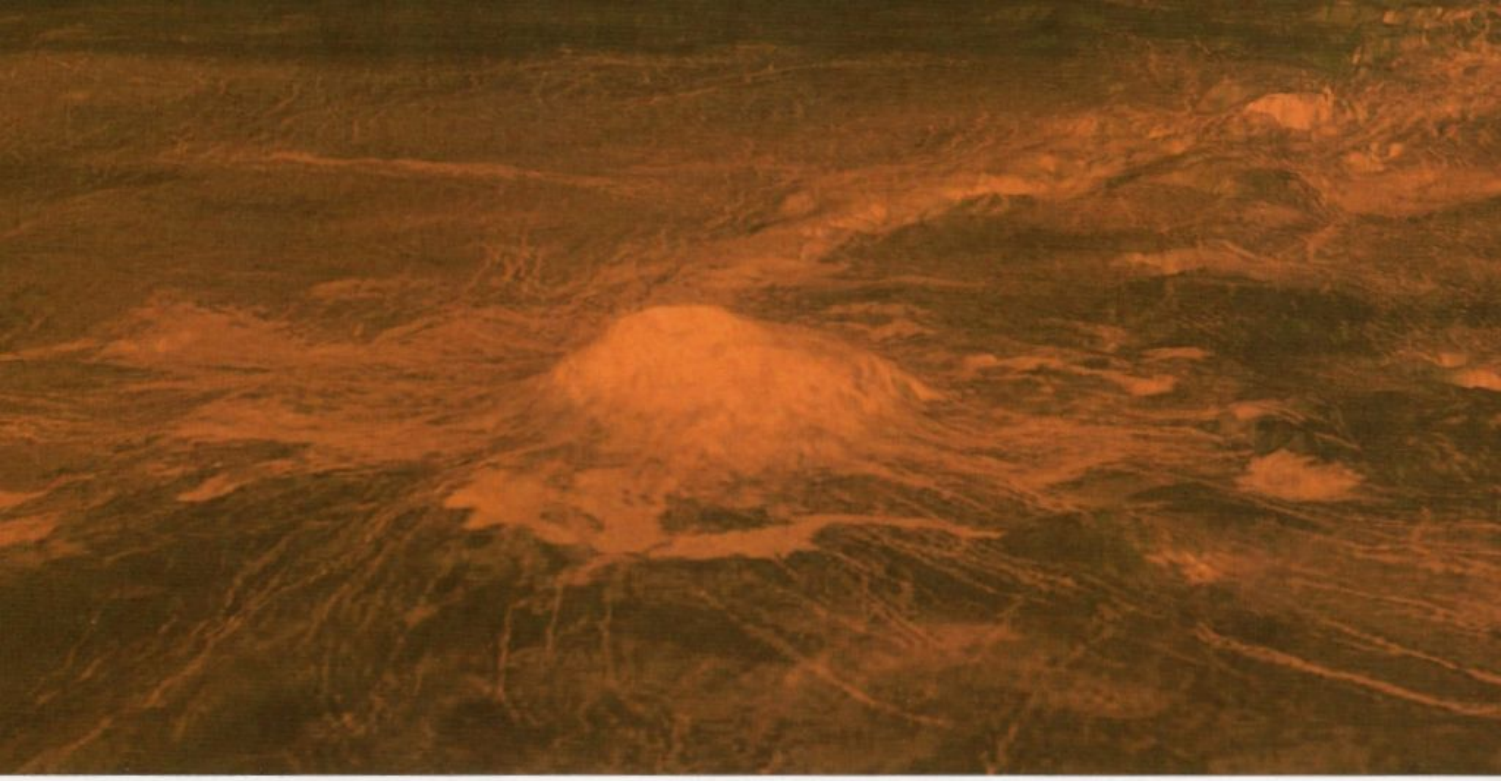
DAVINCI (Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging) could leave for Venus in 2029 or 2030. It's the second Venusian explorer approved by NASA this year. Consisting of both a fly-by spacecraft and a descent probe, DAVINCI will be the first US-led mission into Venus' atmosphere since 1978, and the first to capture photographic images of its surface since the Soviet Venera 13 and 14 landers in 1982. Giada Arney is an astronomer at NASA's Goddard Space Flight Center, and was chosen to be one of two Deputy Principal Investigators for the mission in 2019.

"DAVINCI has been proposed through Goddard in several different incarnations over the years," she says. "It's been a long road to finally get selected, but now we can put some real work into it."

Arney's scientific interests lean towards astrobiology. "I want to know if Venus was ever habitable," she says. "We think of Earth as the planet in our Solar System with oceans. Maybe Venus was like that, too. It's tough to make that call now, though, because our current data is consistent with Venus [both] once being habitable and never being habitable!"

DAVINCI science is focused on Venus' atmosphere, in particular how it formed and how it evolved, and on whether the planet once had an ocean. The spacecraft will image Venus in ultraviolet and near-infrared using a wide-field camera and, after two fly-bys, it will deploy a titanium sphere on a one-hour trip to the surface.

The probe will start collecting data when it reaches an altitude of 67 kilometres. At about 39 kilometres above the surface, it will jettison its braking parachute, relying on Venus' thick atmosphere to slow it for the rest of its journey. Two spectrometers will measure noble gases and



▲ The volcanic mountain of Idunn Mons on Venus. This false-colour image has been generated from radar and topographic data from NASA's Magellan spacecraft in the 1990s. Image: NASA/JPL–Caltech/ESA.

other trace molecules during its fall, while another instrument will study the atmosphere's dynamics.

"Noble gases don't react chemically with other things," says Arney, "so the only way to change them is by physical processes. Helium-4, for example, could be outgassed from volcanoes and quickly lost from the top of the atmosphere because it's so light. If we see it, though, it could tell us that there's recent volcanism on Venus."

As the probe nears the surface, an imaging camera will capture the rough terrain of its final resting site, Alpha Regio. "Some folks have suggested that the heat emitted from Alpha Regio could indicate granite-type rocks," says Arney. On Earth, granitic rocks are formed from continent-building processes that require plate tectonics – and water. Such a discovery would strengthen the tesserae data from VERITAS.

DAVINCI data could also find value far beyond Venus. "If Venus was habitable in the past," says Arney, "then habitability could pop up in challenging places where we might not have thought to look. Maybe some 'exo-Venuses' in other systems could be habitable, too."

COMPLETING THE QUINTET

Two other nations, India and Russia, will augment the NASA and European Space Agency missions with their own spacecraft headed to Venus with additional instruments.

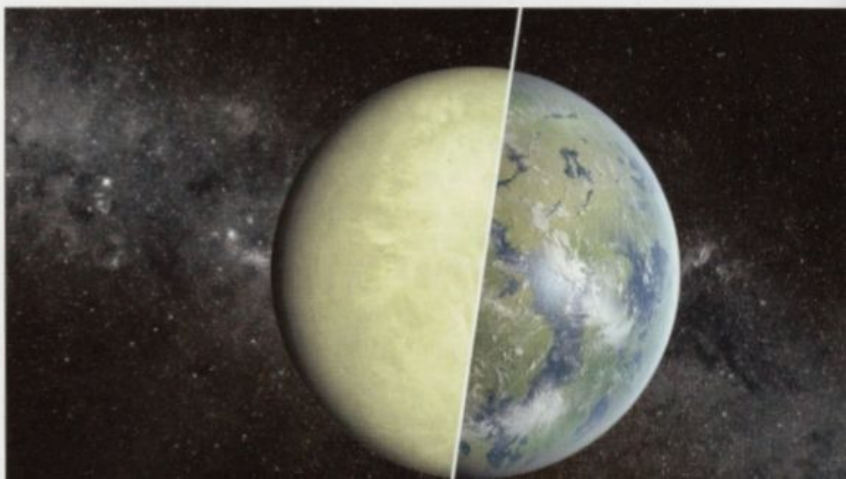
Shukrayaan-1 ('Venus Craft') will be India's first Venus-bound spacecraft. With a launch date as early as 2024, it may lead the way for all the other spacecraft. The Indian Space Research Organisation (ISRO) already has Venus science experience through cooperative work with the Japanese Akatsuki programme, and versions of several of Shukrayaan's instruments have already been tested aboard Chandrayaan ('Moon Craft') lunar probes.

Shukrayaan-1 will map the surface and subsurface of Venus, and study its atmospheric chemistry. Instruments include several spectrometers and radar systems, as well as equipment to investigate how the atmosphere interacts with the solar wind. Richard Ghail has provided technical advice to the programme and sees its potential for some solid contributions.

"[The scientists running the mission] are very capable, as they proved at Mars," he says, referring to India's 2014's Mangalyaan – 'Mars Craft' – mission. "They are focusing on things that they can do that complement everyone else."

Russia is preparing Venera-D (for *Dolgozhivushaya*, or 'long-duration') – an extremely ambitious mission and its first Venusian mission in the post-Soviet era. Their stated goal is to understand Venus from the top of its atmosphere to its deep interior.

The Venera-D Joint Science Definition Team, which includes both US and Russian agency members, presented a mission architecture in their 2019 Phase II report. Core elements include an orbiter and a VEGA-type lander



▼ Venus was a volcanic world in the past, with lava flows creating many of the surface features seen on the planet, but how active is Venus today? Image: NASA/JPL–Caltech/Peter Rubin.

▲ Venus, as imaged by the Mariner 10 spacecraft in 1974. The image has recently been reprocessed. Image: NASA/JPL–Caltech/Kevin M. Gill.

built to survive two to three hours on the surface. A NASA-developed system, the Long-Lived In-Situ Solar System Explorer (LLISSE), could also be attached to the lander to collect data for at least 60 days. Optional additions being considered for the mission include a controlled-altitude balloon system to study clouds, and one or more sub-satellites parked at Lagrange points to study the solar wind.

Current talk suggests a Venera-D launch between 2026 and 2031. If successful, it could mark the beginning of a longer programme, with possible follow-on probes sent in 2031 and 2032.

WEAVING A BIGGER PICTURE

Multiple missions will give us multiple perspectives on Venus, and that's a big win for science. Ghail likens the new spacecraft collective to past Mars missions. "Think of VERITAS as Mars Global Surveyor, DAVINCI as a kind of Pathfinder (without the rover), and EnVision as a Mars Reconnaissance Orbiter. Each of those missions is really important and each answers specific questions."

Smrekar emphasises the relation between the different missions, pointing out that each spacecraft has something to offer the others. DAVINCI, for example, can provide visual imagery to compare against VERITAS' radar images for better interpretability, while VERITAS' global mapping provides a broader context for more site-specific DAVINCI images. And EnVision radar should complement VERITAS' radar.

"EnVision is looking for light materials at the surface, like impact ejecta or erosion processes," says Smrekar. "It's a different type of radar information that will help us interpret our own results. In turn, VERITAS' imaging and topography will help to target EnVision data."

Ultimately, new data will refine our ideas about all the terrestrial planets. According to Smrekar, most Earth-sized exoplanets orbit in the 'Venus region' of their habitable zones, so Venus insights could better focus our search for life processes in other planetary systems.

Closer to home, understanding how Venus could have transformed so profoundly might tell us something about our fortunes here on Earth. "There's every reason to think that Venus was a temperate place initially," says Smrekar. "It had the same faint young Sun and there's evidence that it used to have more water. We just don't yet have the data to really say when things went south."

With mission selection behind them, project teams will now be getting busy. "It's only been a couple of months, of course," notes Arney, "but we've got a big decade in front of us."

Steve Murray is an award-winning science and tech writer in the United States. His website is stevemurrayink.com.

THE PRIVATE MISSION IN SEARCH OF LIFE

It's not just space agencies that are heading for Venus – there's a private space mission vying to reach the second planet from the Sun before any others.

Peter Beck, who is founder and CEO of Rocket Lab in New Zealand, has been planning a mission to Venus in the wake of the controversial claim of phosphine in Venus' atmosphere, which it is purported could have a biological origin (see *Is there life on Venus?, AN*, November 2020). The plan is to house scientific instruments capable of detecting phosphine and/or life in one of Rocket Lab's off-the-shelf Photon spacecraft, and blast it to Venus on one of their Electron rockets in 2023.

▼ An artist's impression of a Rocket Lab Photon spacecraft. Image: Rocket Lab.