A new crop of landers and rovers seeks to answer key questions about Venus–and, by extension, Earth

Sid Perkins, *Science Writer*

Earth benefitted from a dose of cosmic good luck. While it became balmy and habitable, next-door neighbor Venus ended up hellish and inhospitable. And yet, in terms of size, composition, and approximate distance from our host star, Venus could be Earth's twin—as Earth-like as any extrasolar planet observed so far. So why did Venus suffer its fate? Searching for answers, researchers are seeking to send a new crop of landers to our cloud-shrouded neighbor.

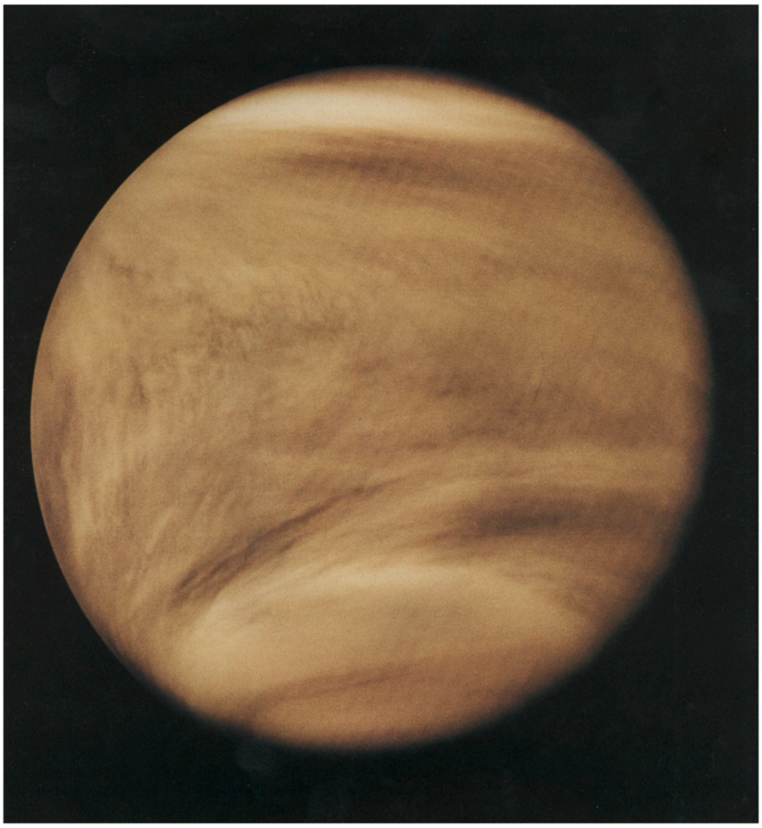
Such missions will not only let researchers understand Venus better but should tell them more about Earth. "Fundamentally, we can't understand why Earth is Earth without understanding why Venus is Venus," says David Grinspoon, a Planetary Science Institute astrobiologist based in Washington, DC.

The only operational spacecraft currently orbiting Venus—Japan's Akatsuki probe, launched in 2010—can study the planet's atmosphere and climate only from above. Landers can directly measure conditions on the ground as well as during their descent to the planet's surface. And although orbiters can get an overall sense of Venusian terrain and mineralogy, landers can do a much better job of gleaning fine-scale geological data.

Landing on Venus, though, is not trivial. Its surface temperature is a scorching 872 °F (467 °C), enough to melt lead; the planet's atmospheric pressure is more than 90 times that of Earth's at sea level; and the thick air, mainly heat-trapping carbon dioxide, also contains trace amounts of acid-forming sulfur dioxide. As a result, previous probes that reached the surface intact didn't fare so well—the record-holder is Venera 13, a Soviet probe that landed on Venus in 1982. It lasted a mere 127 minutes.

So it's not surprising that although planetary researchers have sent numerous landers and rovers to Mars in recent decades, and even landed the Huygens probe on Titan, no landers have travelled to Venus in more than three decades. "Venus has been relegated to the point where it's an underexplored place," says Grinspoon.

That attitude is beginning to change. Some planned missions to Venus will use existing technology—which, like prior landers, will operate only for hundreds of minutes, albeit with vastly superior data-



Future missions should facilitate leaps in our understanding of Venus's chemistry and geology, moving far beyond the findings of the few Venus missions to date. Such missions include the Pioneer Venus Orbiter, which captured this ultraviolet image of Venus's clouds in 1979. Image courtesy of NASA and the NASA Space Science Data Coordinated Archive.

gathering equipment. But a few teams are working to develop devices that could enable missions lasting hundreds of hours, long enough to ask and answer a whole new set of questions.

Open Questions

One question is whether volcanoes are still active on Venus. "If we could confirm that, it would be fantastic," said Stephen Kane, a planetary astrophysicist at the University of California, Riverside, speaking at the American Geophysical Union's fall meeting in December

(1). Ongoing volcanic activity could help researchers figure out how quickly the planet is naturally "resurfaced" by lava. Such data could also help researchers assess the routes that gases and other volatile compounds take in escaping the Venusian interior, as well as the rates, past and present, at which they've done so.

Another question relates to the abundance of elements in Venus' atmosphere and in its rocks, data that would give researchers clues about the planet's internal composition. This, in turn, could shed more light on the disparity between Earth and Venus, given that both formed at about the same time in the same region of the solar system. "The presumption is that they started out with the same stuff," says Grinspoon. "That's plausible, but we don't actually know that."

Other tantalizing clues await. In principle, new data could also offer insights into the fate that awaits Earth. "Venus may be Earth's future, or indeed the end state of all habitable planets," says Kane. Nevertheless, the details of planetary processes and how quickly they unfold are not fully understood. "We can model Venus, but we can't model the transition from Earth to Venus," he says.

Detailed analyses of the Venusian atmosphere, including measuring the proportions of the isotopes of various atmospheric elements, could help researchers better understand such transitions, says Lori Glaze, a planetary scientist at NASA's Goddard Space Flight Center in Greenbelt, MD. For example, precise measurements of the ratio of hydrogen to its heavier isotope, deuterium, could help researchers figure out what happened to Venus' water. Similarly, measurements of the various isotopes of argon, neon, and xenon—the "noble" gases that don't react with other elements and thus don't get chemically locked away in minerals over time—could help scientists estimate the rates at which gases dissolved within Venus' molten materials escaped from the crust of the planet over geologic time. Such data could lead to better models of planetary evolution.

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Examining the minerals on Venus' surface and studying how they've interacted with the planet's atmosphere could elucidate both current and past climates, says Glaze. And that could also help us figure out if Venus ever had an ocean, and, if so, how long it lasted.

"There's every reason to believe that Venus was once more Earth-like," says Grinspoon. Current models of stellar evolution suggest that in the early days of our solar system, the sun may have put out as much as 30% less radiation than it does today. Under a fainter sun (and with a thinner atmosphere of a possibly different composition, and thus a smaller greenhouse effect), Venus might have been habitable—at least for a while, until both the sun and the planet's atmosphere evolved toward today's conditions.

Gearing Up

The proposed Venus In situ Composition Investigations (VICI) mission could help address many of these questions, according to Glaze, the mission's principal investigator. Glaze told the audience at December's American Geophysical Union meeting that the mission as currently envisioned—and subject to NASA's approval—will send two landers on the same craft to our nearest neighbor (2). The landers will amass atmospheric data during their 45-minute drop to the surface and then glean detailed geological information once they touch down.

Crucially, the landers will be deployed during separate flybys of Venus, about 15 months apart, allowing the probes to land at separate locations on the planet. The time gap is also long enough to revise plans for the second landing based on any "lessons learned," whether from a successful first landing or an unexpected but preventable failure, said Glaze.

Much of the equipment for the landers, including cameras and other sensors, will be based on technology developed for Mars rovers but suitably toughened for Venus, Glaze notes. So, even though the cooling systems for the landers will barely last a couple of hours on Venus, the probes will gather higher-quality data than did Venera 13 and within the same time interval.

The key to pulling off even longer-lived missions to Venus is heat-tolerant equipment, such as the electronics being built and tested at NASA's Glenn Research Center in Cleveland. Rather than use silicon-based microcircuits, electronics engineer Philip Neudeck and his colleagues are making bespoke chips out of silicon carbide. In 2016, the team reported successfully testing circuits with 24 transistors under Venus-like temperatures, sans cooling systems or any special protection, for more than 21 days (3). Those tests were terminated at that time only because they lost access to the test facility, which had been reserved for use by another team. Since then, the researchers have tested a 175-transistor circuit under the same conditions for a more impressive 60 days.

All this equipment will need power. But unlike on Mars, the cloudy skies on Venus make solar panels a bad option. Space exploration engineer Michael Paul, of the Johns Hopkins University Applied Physics Laboratory in Laurel, MD, and his colleagues are developing a lithium-based power system that could power a Venus lander or rover. The system's "fuel tank" would hold about 200 kilograms of the super-light metal, which would be molten at Venus' surface. Because lithium readily reacts with carbon dioxide, the system could use the Venusian atmosphere as an oxidizer, says Paul. Also, because the byproducts of the reaction are solids that are denser than lithium, they will simply sink to the bottom of the fuel tank, preventing contamination and interference with sensors or other data-gathering equipment. Such a system could provide 200 watts of electrical power for as much as 5 days (4).

And although not specifically developed with Venus in mind, a heat-tolerant pump made of ceramic materials—the work of mechanical engineer Asegun Henry and his colleagues at Georgia Tech in Atlanta—has shown promise (5). In lab tests, the device, intended to demonstrate such technological capabilities, pumped molten tin at an average temperature of 1,200 °C (far above Venus' surface temperature) for 72 hours. The pump's graphite seals would likely need to be modified so that they don't oxidize or corrode on Venus, says Henry. The solution could be as simple as mixing the graphite with a silicone-like material. Besides pumps, ceramics could be used to make the actuators that push and pull robotic arms bearing lasers, drills or sensors.

By cobbling together a host of such rugged components, engineers hope to make a rewarding return to Venus—to help researchers better understand not only Venus and our own planet, but the multitude of Venus-like exoplanets that astronomers are discovering around distant stars.

"We need to send another lander to Venus," Kane says. "Our solar system is the only place where scientists can get in situ information, and we need to milk that for all it's worth."

1 Kane S, Kopparapu R, Domagal-Goldman SD (2017) The American Geophysical Union Fall Meeting, December 11–15, 2017, New Orleans, LA, P52A-01 (abstr).

2 Glaze LS, Garvin JB, VICI Science Team (2017) The American Geophysical Union Fall Meeting, December 11–15, 2017, New Orleans, LA, P52A-06 (abstr).

3 Neudeck PG, et al. (2016) Prolonged silicon carbide integrated circuit operation in Venus surface atmospheric conditions. *AIP Adv* 6:1–7.

4 Miller TF, Paul MV, Oleson SR (2016) Combustion-based power source for Venus surface missions. *Acta Astronaut* 127:197–208.

5 Amy C, et al. (2017) Pumping liquid metal at high temperatures up to 1,673 kelvin. *Nature* 550:199–203.