Correction

INNER WORKINGS

Correction for "Inner Workings: Hunting for microbial life throughout the solar system," by Adam Mann, which was first published November 6, 2018; 10.1073/pnas.1816535115 (*Proc Natl Acad Sci USA* 115:11348–11350).

The editors note that on page 11350, left column, last paragraph, line 6, "being developed by" should instead appear as "being used for astrobiological investigations by;" and in the same paragraph, line 8, "East Boothbay, MA" should instead appear as "East Boothbay, ME." The online version has been corrected.

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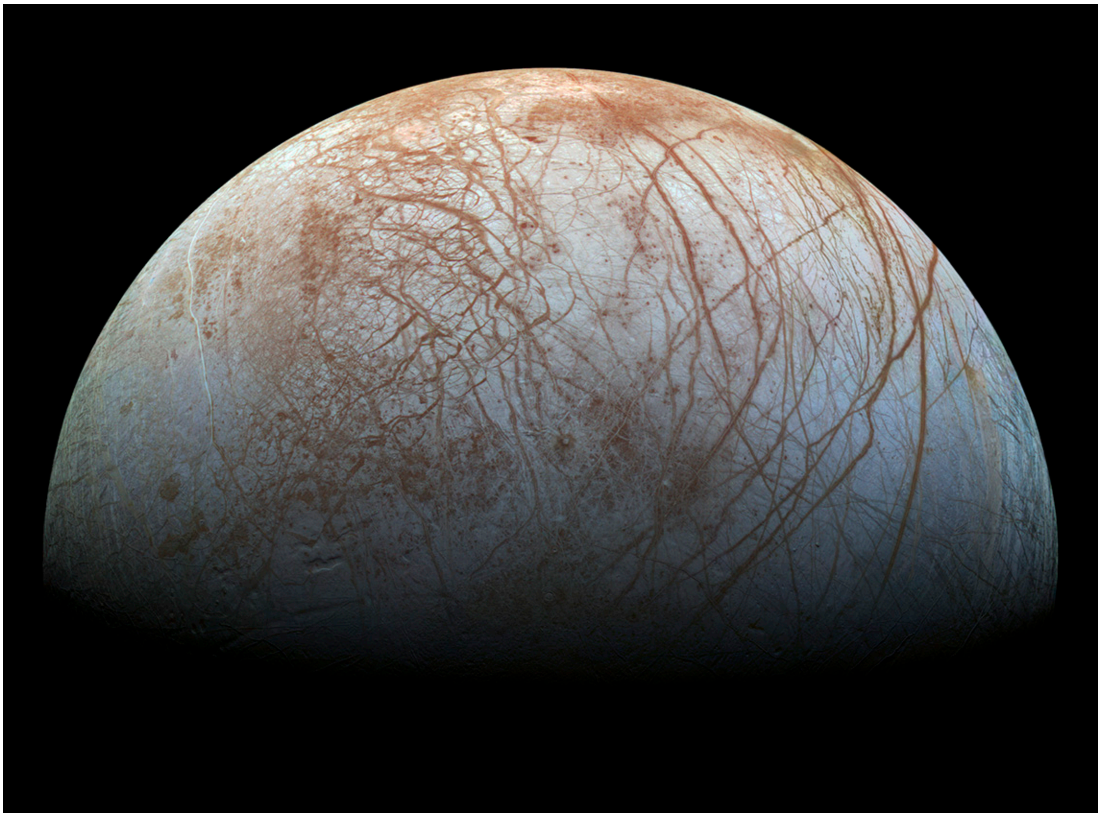
Hunting for microbial life throughout the solar system

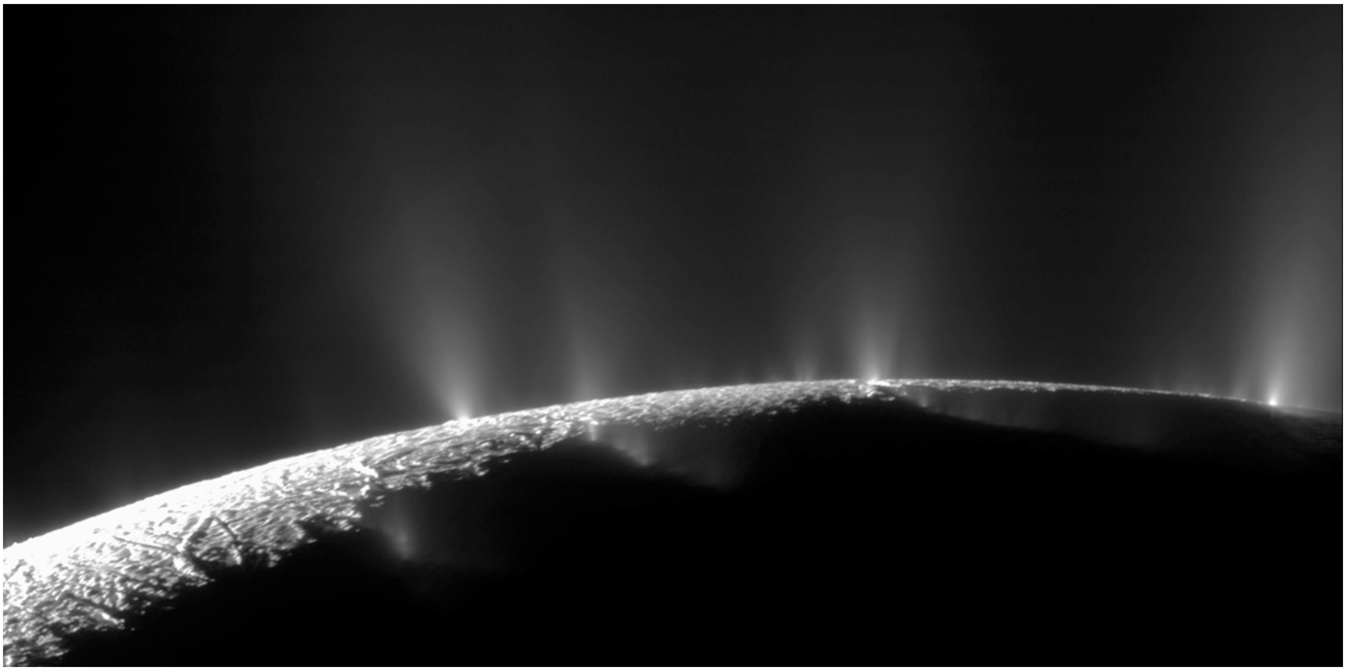
Adam Mann, *Science Writer*

A robotic lander surveys a frosty landscape near the northern pole of Mars sometime in the 2020s. Revving up a powerful 1-meter drill, it bores into the polar subsurface, extracts a sample, and runs it through a battery of cleverly designed instruments. Maybe, just maybe, it uncovers the chemical residues of living organisms.

This is the proposed *Icebreaker Life* mission, a couch-sized lander that would till through the same frozen soil visited by NASA's *Phoenix* spacecraft in 2008 to find evidence of ancient microbes (1). *Icebreaker* is not alone. Within the astrobiological community, there is a growing consensus that it's time to directly hunt for life elsewhere in the solar system. No such experiment has been attempted since the 1976 twin *Viking* landers' life-detection instruments turned up inconclusive results on Mars (2). But this year, NASA put out a call to develop technology to go to another world and look for signatures of microbial life, the first such solicitation in more than 40 years. "We've got places that are so intriguing that it's becoming much more compelling to look for life," says atmospheric scientist Hunter Waite of the Southwest Research Institute in San Antonio, TX. And in October, the National Academies of Sciences, Engineering, and Medicine released a detailed report, titled *An Astrobiology Strategy for the Search for Life in the*



Jupiter's icy moon Europa, seen here in enhanced color based on images from the 1990s *Galileo* mission, is among the candidates for harboring microbial life. Image courtesy of NASA/JPL-Caltech/SETI Institute.



Researchers suspect that the geysers of Saturn's moon Enceladus, pictured here based on images from the 2010 *Cassini-Huygens* mission, could possibly contain microbial life. Image courtesy of NASA/JPL/Space Science Institute.

Universe, urging NASA to make astrobiology an integral part of a broad range of future missions (3).

Mars is the nearest target. Two discoveries over the summer reinforced its potential for hosting life—a possible reservoir of briny water that lies beneath its ice cap and organic material preserved in 3-billion-year-old mudstones at Gale Crater, where NASA's *Curiosity* rover is exploring (4, 5). Jupiter's icy moon Europa and its enormous subsurface ocean is another perennial favorite. It will be visited by the orbiting *Europa Clipper* mission next decade, and plans are in the works for a lander sometime afterward. Finally, there is Saturn's tiny geyser-spewing moon Enceladus—spacecraft could fly through a spout and investigate a sample from its global ocean in detail (6).

"We know where to look, and we know how to look," Ellen Stofan, director of the Smithsonian National Air and Space Museum in Washington, DC, told legislators during a Senate subcommittee hearing on the search for life in August. "We have the technology to determine if life has evolved elsewhere in this solar system and can easily do so within the next few decades."

Of Mars and Microbes

Efforts to look for life on other worlds got off to a rocky start in the 1970s, when the *Viking 1* and *Viking 2* spacecraft descended to the Martian surface. They each carried three biological experiments. The most intriguing outcome came from the Labeled Release experiment, which added a drop of nutrient-rich water tagged with radioactive carbon-14 to soil samples and then detected the isotope in gases rising from the material, suggesting that microorganisms might have metabolized and excreted the carbon-14. But the other experiments found no evidence of organic compounds on Mars, leaving researchers with a mixed bag of findings. "You had an ambiguous result," says geochemist Ariel Anbar of Arizona State University in Tempe, AZ. "And we ran away from the ambiguity."

Because the experiments looked like a failure to much of the public, Anbar says for decades NASA balked at projects intent on finding microbial life. But the passage of time and new evidence, including the discoveries of hardy microbial organisms on Earth and the prevalence of water on other worlds in the solar system, are renewing interest in life detection, says Anbar.

Mars, in particular, is a favored destination. Because of periodic swings in the tilt of the planet's axis, Mars' northernmost region was much warmer and potentially habitable as recently as 5 million years ago, so there's incentive to revisit the region. To avoid the uncertainty of *Viking*'s findings, astrobiologist Marc Neveu of NASA headquarters in Washington, DC, and his colleagues used findings from the past 20 years of astrobiology research to develop the "Ladder of Life Detection," which they published in June. The ladder has 15 "rungs," each a measurable criterion that gets increasingly suggestive of evidence of life elsewhere—ranging from identifying habitability to detecting biomolecules to spotting metabolizing, evolving organisms—for researchers to use in their investigations (7).

For instance, finding amino acids, the building blocks of proteins, might be an early indication that some particular rock is interesting, especially if the amino acids are in ratios typical of microorganisms on Earth. More complex organic molecules, which seem too intricate to have been generated by abiotic processes, might be the next hint. Evidence of metabolic processes, such as waste heat coming from the sample, would be more revealing. The most convincing would be to study the sample with a microscope and see tiny cells moving around.

Yet, life detection is tricky, and the document details how astrobiologists can be led astray. "It's important to us to explain to the public why it's not a slam dunk thing to do," says Mary Voytek, director of NASA's astrobiology program in Washington, DC. "If we found a planet with cows on it, it would be really easy. But we're looking for microbial life."

One mission that could assist in the search for such microbial life is the *Mars 2020* rover, a follow-up to *Curiosity* (which found complex organic molecules on Mars in June). Although *Mars 2020* won't be detecting signs of life, it will cache 0.5 kilogram of biologically interesting material. In April, NASA and the European Space Agency agreed to work together to bring the samples back to Earth for rigorous analysis. They could launch *Curiosity*'s cache into Martian orbit and use a spacecraft to capture and return the material, possibly by the end of the next decade. "To do this seriously, you need to bring things to Earth," says geochemist and *Mars 2020* project scientist Ken Farley of the California Institute of Technology in Pasadena, CA.

Icebreaker could do lab work on Mars itself, using a suite of complementary instruments, including the Signs Of LIfe Detector (SOLID), a small chip containing hundreds of antibodies that recognize common organics such as amino acids (which make up proteins) and nucleic acids (which make up DNA and RNA), as well as proteins common to extremophile bacteria on Earth. Such molecules could survive for millions of years in ice even if Martian life went extinct long ago.

SOLID's focus on proteins found in earthbound microorganisms has been criticized, says instrument designer Victor Parro of the Centro de Astrobiologia in Madrid, but his team thinks it makes sense to search for such compounds because life on Earth and Mars may have evolved similar mechanisms to deal with tough environmental conditions, such as extreme cold, salinity, or dryness. Chris McKay of NASA's Ames Research Center in Mountain View, CA, is readying *Icebreaker* to compete in NASA's next round of *Discovery* funding, and the mission could be selected in the next few years and be ready by 2026.

Beyond the Red Planet

Mars is not the sole focus of attention. The outer solar system contains a cornucopia of icy ocean worlds, such as Jupiter's moon Europa. Last year, NASA published a report on a Europa lander that prioritized life-detection instruments (8). One possibility is a cell-phone–sized DNA sequencer being used for astrobiological investigations by by microbiologist Jackie Goordial of the Bigelow Laboratory for Ocean Sciences in East Boothbay, ME, and her colleagues that could read out any genetic material contained within a sample of melted ice. The sequencer uses a grid of nanopores with an electric current running across them. As a strand of DNA or RNA passes through a pore, it disrupts the current in a characteristic way, potentially allowing researchers to decipher a totally alien code of life. Goordial has detected microbes in Earth's frigid and dry polar regions and says her instrument could be useful for Mars missions as well.

Biophysicist Jay Nadeau of Portland State University in Oregon is setting her sights on a prize more enticing than the DNA of alien microbes: imaging tiny organisms with a portable microscope. Although Mars rovers have carried simple microscopes before, her team's holographic interferometer would be more powerful than anything previously sent to another world. Constructed with no moving parts to help ensure safe landings, the apparatus uses two lasers to capture a 3D image of everything within a 1-cubic-millimeter volume. Researchers can focus on anything of interest and even take short videos. "We need to see something doing the things life does; breathing, moving around, dividing, and eating each other," says Nadeau, who is submitting the design to NASA's Instrument Concepts for Europa Exploration 2 program.

Researchers are also keen to explore Saturn's moon Enceladus and the spectacular jets of water that shoot from below its frozen surface. The *Cassini* spacecraft flew through these spouts, and researchers discovered that the water contained complex organic molecules and telltale chemical signatures, suggesting that hydrothermal vents exist at the bottom of Enceladus' watery ocean. On Earth, such locations host vibrant ecosystems. Two proposals, the Enceladus Life Finder and Enceladus Life Signatures and Habitability missions, each of which would sample the plumes with more sophisticated instruments than *Cassini*, competed for funding last year in NASA's New Frontiers program. Although neither was selected, they each intend to compete in future funding rounds.

The hunt for microbes could expand to other worlds as well, including Saturn's moon Titan and its vast seas of organic hydrocarbons and possibly even the upper cloud layers of Venus, where relatively balmy temperatures reign. Astronomers are hopeful that space-based telescopes looking at the atmospheres of distant exoplanets might detect chemical signatures of living organisms in the next decade.

Detecting any such signature on another world would be a major scientific breakthrough, says Neveu. "It will tell us that biology is not a concept unique to Earth," he adds. "Life is a cosmic phenomenon."

1 McKay CP, et al. (2013) The *Icebreaker Life* mission to Mars: A search for biomolecular evidence for life. *Astrobiology* 13:334–353.

2 Klein HP, et al. (1976) The *Viking* biological investigation: Preliminary results. *Science* 194:99–105.

3 National Academies of Sciences, Engineering, and Medicine (2018) *An Astrobiology Strategy for the Search for Life in the Universe* (National Academies Press, Washington, DC).

4 Orosei R, et al. (2018) Radar evidence of subglacial liquid water on Mars. *Science* 361:490–493.

5 Eigenbrode JL, et al. (2018) Organic matter preserved in 3-billion-year-old mudstones at Gale crater, Mars. *Science* 360:1096–1101.

6 Mann A (2017) Inner Workings: Icy ocean worlds offer chances to find life. *Proc Natl Acad Sci USA* 114:4566–4568.

7 Neveu M, et al. (June 4, 2018) The Ladder of Life Detection. *Astrobiology*, 10.1089/ast.2017.1773.

8 Hand K, et al. (2017) Europa Lander Study 2016 Report (NASA, Washington, DC). Available at solarsystem.nasa.gov/docs/Europa_Lander_SDT_Report_2016.pdf. Accessed September 11, 2018.