Books & arts

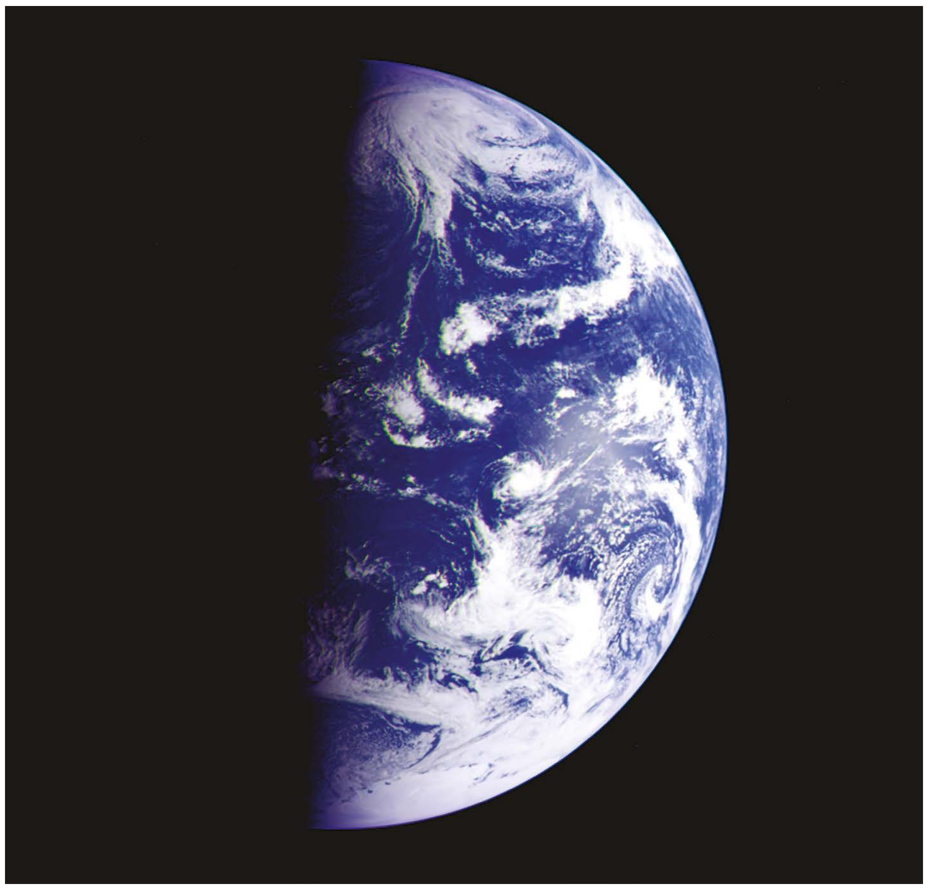
Is there life on … Earth?

Carl Sagan's bold experiment asking what we could tell about our planet from space in still reverberates 30 years on. **By Alexandra Witze**

It began the way many discoveries do — a tickling of curiosity in the back of someone's mind. That someone was astronomer and communicator Carl Sagan. The thing doing the tickling was the trajectory of NASA's Galileo spacecraft, which had launched in October 1989 and was the first to orbit Jupiter. The result was a paper in *Nature* 30 years ago this week that changed how scientists thought about looking for life on other planets.

The opportunity stemmed from a tragic mishap. Almost four years before Galileo's launch, in January 1986, the space shuttle Challenger had exploded shortly after lift-off, taking seven lives with it. NASA cancelled its plans to dispatch Galileo on a speedy path to Jupiter using a liquid-fuelled rocket aboard another space shuttle. Instead, the probe was released more gently from an orbiting shuttle, with mission engineers slingshotting it around Venus and Earth so it could gain the gravitational boosts that would catapult it all the way to Jupiter.

On 8 December 1990, Galileo was due to skim past Earth, just 960 kilometres above the surface. The tickling became an itch that Sagan had to scratch. He talked NASA into pointing the spacecraft's instruments at our planet. The resulting paper was titled 'A search for life on Earth from the Galileo spacecraft'[1].



NASA/JPL

Anything down there? Earth as seen by the Galileo probe in 1990.

The outside view

We are in a unique position of knowing that life exists on Earth. To use our own home to test whether we could discern that remotely was an extraordinary suggestion at the time, when so little was known about the environments in which life might thrive. "It's almost like a science-fiction story wrapped up in a paper," says David Grinspoon, senior scientist for astrobiology strategy at NASA's headquarters in Washington DC. "Let's imagine that we're seeing Earth for the first time."

It came at a time, too, when the search for life elsewhere in the Solar System was at a low ebb. US and Soviet robotic missions in the 1960s and 1970s had revealed that Venus — once thought to be a haven for exotic organisms — was hellishly hot beneath its dense clouds of carbon dioxide. Mars, crisscrossed by the 'irrigation canals' of astronomers' imagination[2], was a seemingly barren wasteland. In 1990, no one yet knew about the buried oceans that lay on Jupiter's moon Europa — a discovery that Galileo would go on to make[3] — or on Saturn's moon Enceladus, both of which are now seen as potential cradles of extraterrestrial life.

Crucially, Sagan and his collaborators took a deliberately agnostic approach to the detection of life, says astrobiologist Lisa Kaltenegger, who heads the Carl Sagan Institute at Cornell University in Ithaca, New York. "Of course he wants to find life, every scientist does," she says. "But he says, let's take that wish and be even more cautious — because we want to find it." The existence of life was to be, in the words of the paper, the "hypothesis of last resort" for explaining what Galileo observed.

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But even through this veil of scepticism, the spacecraft delivered. High-resolution images of Australia and Antarctica obtained as Galileo flew overhead did not yield signs of civilization. Still, Galileo measured oxygen and methane in Earth's atmosphere, the latter in ratios that suggested a disequilibrium brought about by living organisms. It spotted a steep cliff in the infrared spectrum of sunlight reflecting off the planet, a distinctive 'red edge' that indicates the presence of vegetation. And it picked up radio transmissions coming from the surface that were moderated as if engineered. "A strong case can be made that the signals are generated by an intelligent form of life on Earth," Sagan's team wrote, rather cheekily.

A powerful control

Karl Ziemelis, now chief physical sciences editor at *Nature*, handled the paper as a rookie editor. He says it remains one of his favourites – and one of the hardest to get in. Editorial approval for the paper was far from unanimous, because it was not obviously describing something new. But, according to Ziemelis, that was mostly beside the point. "It was an incredibly powerful control experiment for something that wasn't really on many people's radar at the time," he says.

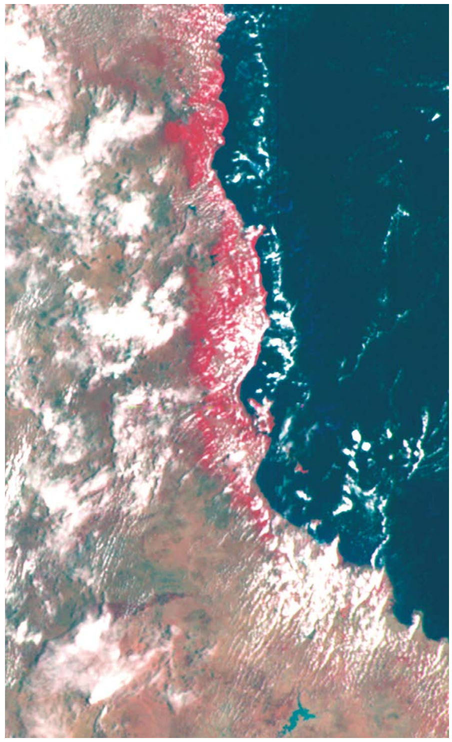
"While the answer was known, it profoundly changed our way of thinking about the answer," says Kaltenegger. Only by stepping back and regarding Earth as a planet like any other – perhaps harbouring life, perhaps not – can researchers begin to get a true perspective on our place in the Universe and the likelihood of life elsewhere, she says.

It takes on a new importance given developments since the Galileo flyby. In 1990, no planets orbiting stars other than the Sun were known. It was another two years before astronomers conclusively reported the first 'exoplanet' orbiting a rotating dead star known as a pulsar[4], and three years more before they found[5] the first around a Sun-like star, 51 Pegasi. Today, scientists know of more than 5,500 exoplanets, few of which look like anything in the Solar System. They range from 'super-Earths' with bizarre geologies and 'mini-Neptunes' with gassy atmospheres to 'hot Jupiters', huge planets whirling close to their blazing stars.

When Sagan and his colleagues pointed Galileo at Earth, they invented a scientific framework for looking for signs of life on these other worlds – one that has permeated every search for such biosignatures since. Kaltenegger still gives Sagan's paper to her students to show them how it is done. Life is the last, not first, inference to draw when seeing something unusual on another planet, she tells them. Extraordinary claims require extraordinary evidence.

The right mix for life

This lesson could not be more important today, as scientists stand on the verge of potentially revolutionary, and perhaps monumentally confusing, discoveries by the powerful James Webb Space Telescope (JWST). The telescope is just beginning its remote exploration of the atmospheres of dozens of exoplanets, hunting for the same sort of chemical disequilibrium that Galileo spotted in Earth's atmosphere. It is already turning up early hints of biosignatures that might lead scientists and the public astray.



NASA/JPL

No sign of civilization in Australia.

> **"While the answer was known, it profoundly changed our way of thinking about the answer."**

For instance, JWST has sniffed out methane in the atmosphere of at least one planet. That gas is a powerful signature of life on Earth, but it can also come from volcanoes, no life required. Oxygen captures scientists' attention because much of it is generated by life on Earth, but it can also be formed by light splitting apart molecules of water or carbon dioxide. Finding the right combination of methane and oxygen could indicate the presence of life on another planet – but that world needs to be located in a temperate zone, not too hot nor too cold. Getting the right mix of life-sustaining ingredients in a life-friendly environment is challenging, Kaltenegger says.

The same is true for other intriguing mixes of atmospheric gases. Just last month, astronomers sifting through JWST data reported finding methane and carbon dioxide in the atmosphere of a large exoplanet called K2-18 b. They suggested that the planet might have water oceans covering its surface, and hinted at tantalizing detections of dimethyl sulfide, a compound that, on Earth, comes from phytoplankton and other living organisms[6].

Headlines ran wild, with news stories reporting possible signs of life on K2-18 b. Never mind that the presence of dimethyl sulfide was reported with low confidence and needed further validation. Nor that no water had actually been detected on the planet. And, even if water were present, it might be in an ocean so deep as to choke off all geological activity that could maintain a temperate atmosphere.

Building evidence

Challenges such as these led Jim Green, a former chief scientist at NASA, to propose a framework in 2021 for how to report evidence for life beyond Earth[7]. A progressive scale, from one to seven, for example, could help to convey the level of evidence for life in a particular discovery, he argues. Maybe you've got a signal that could result from biological activity – that would just be a one on the scale. You'd need to work through many more steps, such as ruling out contamination and acquiring independent evidence of the strength of that signal before you could get to level 7 and demonstrate a true discovery of life beyond Earth.

It could take a long time. A telescope might sniff out an intriguing molecule, and scientists would argue about it. Another telescope might be built to work out the context of the observation. Each brick of evidence must be placed on top of another, each layer of mortar mixed through the arguments, scepticism and agnosticism of many, many scientists. And that's assuming that life on another world resembles that on Earth – an assumption underlying the conclusions drawn from Galileo's observations. "The uncertainty may last years or decades," Grinspoon says. Sagan, who died in 1996, would have loved it.

The same year that Galileo observed Earth, Sagan convinced NASA to point another spacecraft in a direction the agency had not been planning. As Voyager 1 raced past Neptune on its way out of the Solar System, it turned its cameras back towards Earth and photographed a tiny speck, gleaming in a sunbeam (see go.nature.com/3q4a9ce). This was the iconic Pale Blue Dot image that inspired Sagan to ruminate in his 1994 book *Pale Blue Dot*: "That's here. That's home. That's us."

That fragile gleaming pixel reshaped how humanity visualizes its place in the Cosmos. So, too, did using Galileo to look for life on Earth, says Kaltenegger: "This is how we can use our pale blue dot to provide a template for the search for life on other planets."

Alexandra Witze writes for *Nature* from Boulder, Colorado.

1. Sagan, C., Thompson, W. R., Carlson, R., Gurnett, D. & Hord, C. *Nature* **365**, 715–721 (1993).
2. Sagan, C. & Pollack, J. B. *Nature* **212**, 117–121 (1966).
3. Kivelson, M. G. *et al. Science* **289**, 1340–1343 (2000).
4. Wolszczan, A. & Frail, D. A. *Nature* **355**, 145–147 (1992).
5. Mayor, M. & Queloz, D. *Nature* **378**, 355–359 (1995).
6. Madhusudhan, N. *et al*. Preprint at https://arxiv.org/abs/2309.05566 (2023).
7. Green, J. *et al. Nature* **598**, 575–579 (2021).