# If astronomers see these chemicals in a planet's atmosphere, there's likely an advanced civilization there

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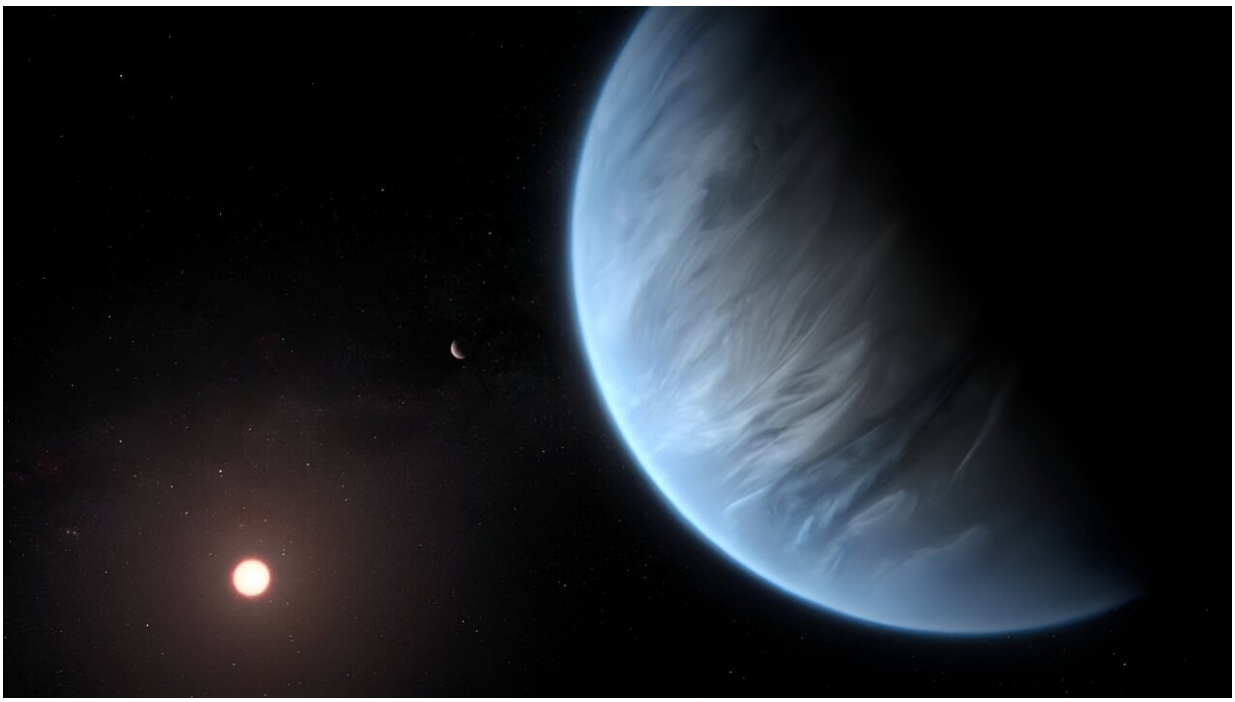

Artist rendition of a potential water-world exoplanet that might support advanced civilizations. Such life could advertise its existence via technosignatures from industrial or other activities. Credit: ESA / Hubble / M. Kornmesser

In an age of ever-growing numbers of exoplanets circling other stars, it's natural that astronomers search for signatures of advanced civilizations.

Such signatures may have biological or technological origins.

What if, instead of looking for radio signals (as SETI and others have done), we look for something a little different? How about evidence of atmospheric pollution produced by technological societies? After all, we're familiar with it here on Earth. That's the thrust of a paper in *Scientific Reports* by MIT's Sara Seager and an international team of scientists.

They suggest that technological civilizations might be uncovered via a hunt for chemicals not created by life. Specifically, the team proposes nitrogen trifluoride ($NF_3$) and sulfur hexafluoride ($SF_6$). They are ideal technosignature gases to find because, as they state in the paper, "Life on Earth is not known to produce any molecules with N–F or S–F bonds, and this includes fully fluorinated N and S compounds."

In fact, the paper states that fluorine is nearly excluded from the chemistry of life on Earth. Other natural processes don't create it in huge amounts, either. That leaves only artificial (read: industrial) pollution. In other words, those gases would be the atmospheric by-products of industrial activity. Here on Earth, their abundance increased rapidly (from nearly non-existent) since the Industrial Revolution began.

Not only are these gases specific to industrial processes (at least here on Earth), but they have very unique spectral features. When found in the atmosphere of a distant planet, their spectral fingerprints would leap out from the background spectra. So, if astronomers see those fingerprints in an alien world's atmosphere, perhaps a reasonably advanced civilization generated them.

## Searching for chemical fingerprints of advanced civilizations

As we've learned recently, astronomers can now search in more detail for gases in exoplanet atmospheres. And, those searches turn up gases that might indicate life. A possible JWST observation shows evidence of a biologically derived gas. The telescope dissected the light from the planet's star as it passed through the world's atmosphere and the fingerprint of that gas showed up in the data.

Spectroscopy via JWST is a powerful tool that astronomers have waited decades to wield. But, not all discoveries have to be of biologically derived gases. The same technique can be used to look for technologically derived ones. That includes those suggested by Seager's team as technosignatures.

To find evidence for them in exoplanet atmospheres, Seager's team created a new tool called a "spectra phalanx plot." Essentially it allows users to create a visual comparison of all the spectral peaks in a gas molecules spectrum. It groups molecules with similar peaks together. This allows further analysis of the spectral clusters. In addition, the team uses its data to simulate model atmospheres. The result is an approximation of atmospheric abundances of the gases the scientists want to detect at a target planet. The team also maintains a "natural products database" of compounds that are generated by natural biochemical processes. This helps them understand the unique qualities of fully fluorinated compounds that likely arise from nonbiological (industrial) processes.

## What about other signatures of life?

Biological and industrial processes aren't the clues to life that astronomers could search out. There are a number of other technosignatures that could show up. They could include artificial lights seen on a world, some kinds of megastructures (either on the planet or surrounding it, such as Dyson spheres), waste heat or other types of

emissions, or some kind of radio signals.

The fields of astronomy and astrophysics are awash in amazing data. It turns out that astronomers are sitting on a gold mine of information that could well include possible technosignatures from other civilizations. The data comes from sky surveys at all wavelengths and streams of data from solar system exploration. Couple such treasuries of information with machine-learning algorithms and the rise of AI, and we have sophisticated tools in the hunt for technosignatures. They can help identify anomalies in survey data that could indicate the presence of life and advanced civilizations.

## Using big data to hunt for advanced civilizations

In 2019, a group of astronomers led by George Djorgovski convened a workshop called "Data-driven Approaches to Searches for the Technosignatures of Advanced Civilizations." It was held by the Keck Institute for Space Studies. The objective was to revisit searches for evidence of alien technologies in light of advances in the hunt for other planets and the growth of data-driven astronomy. Although delayed by the pandemic shutdowns, the final report from this workshop remains extremely interesting reading. It outlines the background and motivation for the workshop and examines methodologies for using the big databases of astronomy data.

In particular, the report focuses on machine learning to spot "outlier data" that might indicate a technosignature. It also talks about what to look for in the large databases (including such things as Dysonian structures). Finally, it outlines other types of signals to look for in the databases and some possible ideas for artifact searches inside the solar system.

Interestingly, the report also suggests that unexpected discoveries in

astronomy and astrophysics will be a result of the search for life elsewhere. It states, "A key outcome of this workshop was that technosignature searches should be conducted in a manner consistent with Freeman Dyson's "First Law of SETI Investigations," namely "every search for alien civilizations should be planned to give interesting results even when no aliens are discovered." This approach to technosignature searches is commensurate with NASA's approach to biosignatures in that no single observation or measurement can be taken as providing full certainty for the detection of life."

## Public acceptance of 'The search'

One of the largest factors in the search for life elsewhere, however, is not scientific. It's social. As both Seager's paper and the Keck report mention, we have to examine our own biases when we do these searches. For a long time, people simply assumed that other civilizations would naturally just beam out a "cosmic hello" to us. Or, they'd come to us in flying saucers. As both papers suggest, the signals from other civilizations may be far more subtle and alien than we expect.

The other part of the "social" equation is that any search for life elsewhere needs substantial public support. The Keck report states: "At the moment, SETI and the search for technosignatures are met with mixed positive and negative reactions. Many past papers and claims were erroneous, and have led to others making outrageous claims that were not scientifically verified. The same situation occurred when the search for exoplanets began. It took many verified detections to mainstream the field of exoplanets. It is important to have financial support (thus public support) to be able to search for technosignatures in earnest."

The Keck report suggests that scientists approach audiences in ways that help explain the science involved and the stakes of discovery. A message for the public is going to be quite different from the messaging intended

to get peer review support inside the community. And, of course, funding agencies need to see funding proposals from legitimate science teams doing what they can to advance the fields of astronomy, astrophysics, and the search for life elsewhere. Such a combined approach to public education is going to be important, particularly as scientists are now able to do detailed studies of exoplanets and their atmospheres in the search for life in the universe.

**More information:** Sara Seager et al, Fully fluorinated non-carbon compounds NF3 and SF6 as ideal technosignature gases, *Scientific Reports* (2023). DOI: 10.1038/s41598-023-39972-z

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