A carbon-lite atmosphere could be a sign of water and life on other terrestrial planets, study finds

December 29 2023, by Jennifer Chu

Credit: Pixabay/CC0 Public Domain

Scientists at MIT, the University of Birmingham, and elsewhere say that astronomers' best chance of finding liquid water, and even life on other planets, is to look for the absence, rather than the presence, of a chemical feature in their atmospheres.

The researchers propose that if a terrestrial planet has substantially less carbon dioxide in its atmosphere compared to other planets in the same system, it could be a sign of liquid water—and possibly life—on that planet's surface.

What's more, this new signature is within the sights of NASA's James Webb Space Telescope (JWST). While scientists have proposed other signs of habitability, those features are challenging if not impossible to measure with current technologies. The team says this new signature, of relatively depleted carbon dioxide, is the only sign of habitability that is detectable now.

"The Holy Grail in exoplanet science is to look for habitable worlds, and the presence of life, but all the features that have been talked about so far have been beyond the reach of the newest observatories," says Julien de Wit, assistant professor of planetary sciences at MIT. "Now we have a way to find out if there's liquid water on another planet. And it's something we can get to in the next few years."

The team's findings will appear in *Nature Astronomy*. De Wit co-led the study with Amaury Triaud of the University of Birmingham in the UK. Their MIT co-authors include Benjamin Rackham, Prajwal Niraula, Ana Glidden Oliver Jagoutz, Matej Peč, Janusz Petkowski, and Sara Seager, along with Frieder Klein at the Woods Hole Oceanographic Institution (WHOI), Martin Turbet of Ècole Polytechnique in France, and Franck Selsis of the Laboratoire d'astrophysique de Bordeaux.

Beyond a glimmer

Astronomers have so far detected more than 5,200 worlds beyond our solar system. With current telescopes, astronomers can directly measure a planet's distance to its star and the time it takes it to complete an orbit. Those measurements can help scientists infer whether a planet is within a habitable zone. But there's been no way to directly confirm whether a planet is indeed habitable, meaning that liquid water exists on its surface.

Across our own solar system, scientists can detect the presence of liquid oceans by observing "glints"—flashes of sunlight that reflect off liquid surfaces. These glints, or specular reflections, have been observed, for instance, on Saturn's largest moon, Titan, which helped to confirm the moon's large lakes.

Detecting a similar glimmer in far-off planets, however, is out of reach with current technologies. But de Wit and his colleagues realized there's another habitable feature close to home that could be detectable in distant worlds.

"An idea came to us, by looking at what's going on with the terrestrial planets in our own system," Triaud says.

Venus, Earth, and Mars share similarities, in that all three are rocky and inhabit a relatively temperate region with respect to the sun. Earth is the only planet among the trio that currently hosts liquid water. And the team noted another obvious distinction: Earth has significantly less carbon dioxide in its atmosphere.

"We assume that these planets were created in a similar fashion, and if we see one planet with much less carbon now, it must have gone somewhere," Triaud says. "The only process that could remove that much carbon from an atmosphere is a strong water cycle involving oceans of liquid water."

Indeed, the Earth's oceans have played a major and sustained role in absorbing carbon dioxide. Over hundreds of millions of years, the oceans have taken up a huge amount of carbon dioxide, nearly equal to the amount that persists in Venus' atmosphere today. This planetary-scale effect has left Earth's atmosphere significantly depleted of carbon dioxide compared to its planetary neighbors.

"On Earth, much of the atmospheric carbon dioxide has been sequestered in seawater and solid rock over geological timescales, which has helped to regulate climate and habitability for billions of years," says study co-author Frieder Klein.

The team reasoned that if a similar depletion of carbon dioxide were detected in a far-off planet, relative to its neighbors, this would be a reliable signal of liquid oceans and life on its surface.

"After reviewing extensively the literature of many fields from biology, to chemistry, and even carbon sequestration in the context of climate change, we believe that indeed if we detect carbon depletion, it has a good chance of being a strong sign of liquid water and/or life," de Wit says.

A roadmap to life

In their study, the team lays out a strategy for detecting habitable planets by searching for a signature of depleted carbon dioxide. Such a search would work best for "peas-in-a-pod" systems, in which multiple terrestrial planets, all about the same size, orbit relatively close to each other, similar to our own solar system. The first step the team proposes is to confirm that the planets have atmospheres, by simply looking for the presence of carbon dioxide, which is expected to dominate most planetary atmospheres.

"Carbon dioxide is a very strong absorber in the infrared, and can be easily detected in the atmospheres of exoplanets," de Wit explains. "A signal of carbon dioxide can then reveal the presence of exoplanet atmospheres."

Once astronomers determine that multiple planets in a system host atmospheres, they can move on to measure their carbon dioxide content, to see whether one planet has significantly less than the others. If so, the planet is likely habitable, meaning that it hosts significant bodies of liquid water on its surface.

But habitable conditions doesn't necessarily mean that a planet is inhabited. To see whether life might actually exist, the team proposes that astronomers look for another feature in a planet's atmosphere: ozone.

On Earth, the researchers note that plants and some microbes contribute to drawing carbon dioxide, although not nearly as much as the oceans. Nevertheless, as part of this process, the lifeforms emit oxygen, which reacts with the sun's photons to transform into ozone—a molecule that is far easier to detect than oxygen itself.

The researchers say that if a planet's atmosphere shows signs of both ozone and depleted carbon dioxide, it likely is a habitable, and inhabited world.

"If we see ozone, chances are pretty high that it's connected to carbon dioxide being consumed by life," Triaud says. "And if it's life, it's glorious life. It would not be just a few bacteria. It would be a planetary-scale biomass that's able to process a huge amount of carbon, and interact with it."

The team estimates that NASA's James Webb Space Telescope would be able to measure carbon dioxide, and possibly ozone, in nearby, multiplanet systems such as TRAPPIST-1—a seven-planet system that orbits a bright star, just 40 light years from Earth.

"TRAPPIST-1 is one of only a handful of systems where we could do terrestrial atmospheric studies with JWST," de Wit says. "Now we have a roadmap for finding habitable planets. If we all work together, paradigm-shifting discoveries could be done within the next few years."

More information: Amaury H. M. J. Triaud et al, Atmospheric carbon depletion as a tracer of water oceans and biomass on temperate terrestrial exoplanets, *Nature Astronomy* (2023). DOI: 10.1038/s41550-023-02157-9

Provided by Massachusetts Institute of Technology