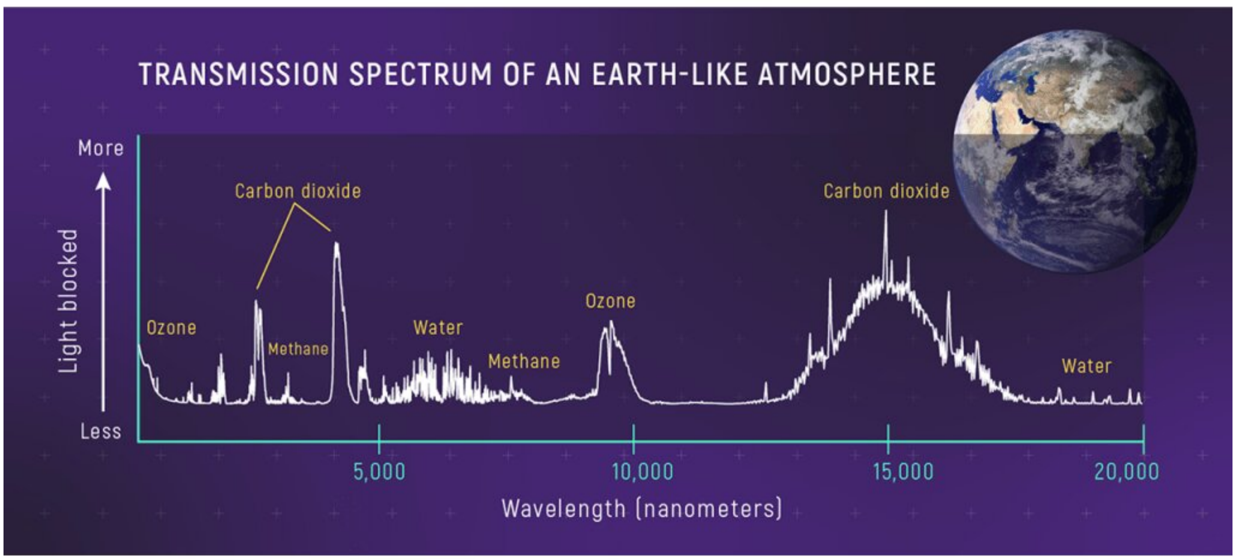
Could next-generation telescopes see that Earth has life?

January 19 2023, by Evan Gough



This image shows the transmission spectrum of an Earth-like atmosphere. It shows wavelengths of sunlight that molecules like ozone (O_3), water (H_2O), carbon dioxide (CO_2), and methane (CH_4) absorb. Detecting all four of these might be a slam dunk that life is there. Credit: NASA, ESA, Leah Hustak (STScI)

While the Earth absorbs a lot of energy from the sun, a lot of it is reflected back into space. The sunlight reflected from Earth is called

Earthshine. We can see it on the dark portion of the moon during a crescent moon. The Farmer's Almanac said it used to be called "the new moon in the old moon's arms."

Earthshine is one instance of planetshine, and when we look at the light from distant exoplanets, we're looking directly at their planetshine without it bouncing off another object.

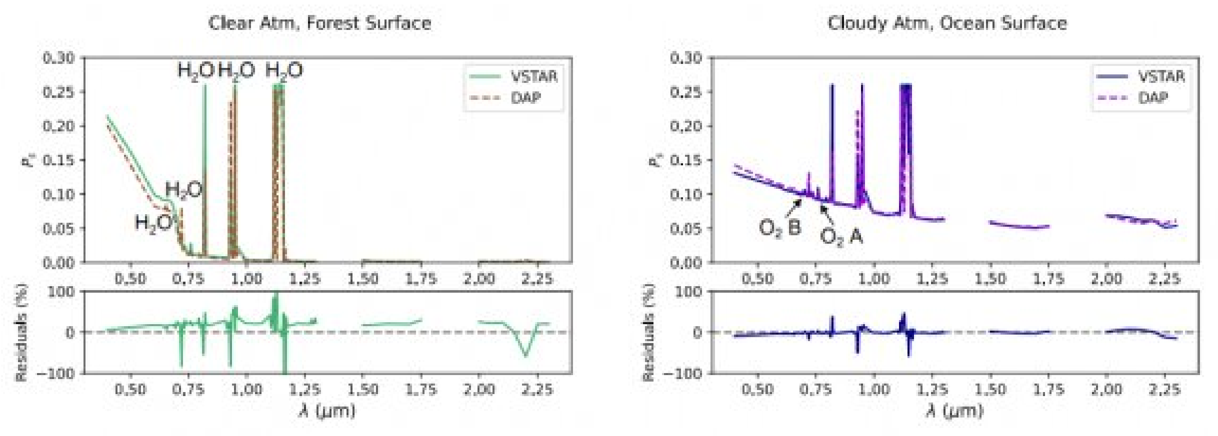
If distant astronomers were looking at Earthshine the way we look at exoplanet shine, would the light tell them our planet is rippling with life?

In the next few years, a number of advanced telescopes will come online. Together with the JWST, they'll give us the types of images scientists have been eagerly anticipating for decades. Thanks to the ground-based European Extremely Large Telescope and Giant Magellan Telescope, and the upcoming LUVOIR space telescope, we'll enter an age of directly-imaged exoplanets. Scientists need to prepare for all those observations and data so they'll be prepared to interpret them.

These future telescopes will allow astronomers to characterize more and more Earth-like exoplanets, we hope. But the only way our characterizations of these planets can be accurate is if our models are accurate. Since Earth is the only planet we know of that hosts life and the only habitable planet with known properties, it's our only test case and the only resource astronomers have to validate their models.

That's where Earthshine comes in.

In a new paper, a team of researchers examined how Earthshine can be used to build accurate models of planetshine. The paper is "Polarized Signatures of a Habitable World: Comparing Models of an Exoplanet Earth with Visible and Near-infrared Earthshine Spectra." The lead author is Kenneth Gordon, a graduate student at the Planetary Sciences Group at the University of Central Florida. The paper's been accepted into *The Astrophysical Journal*.



This figure from the study helps explain some of the team's work and results. Both panels contain simulated polarimetric data from two exoplanet Earths. The panel on the left is for an exo-Earth with no clouds and a forest surface. The panel on the right is an ocean planet with one layer of water cloud. The left panel compares how the two models detect H2O, and the right panel compares how they detect O2. As the images show, both models agree with each other broadly. Credit: Gordon et al. 2023

We're discovering a growing number of rocky planets in potentially habitable zones around exoplanets. But to get closer to understanding if they're habitable, we need to characterize their surfaces. Astronomers have limited tools to do that, mostly by studying the light from the planets as they transit in front of their star or detecting the flux directly from the planet.

Those methods work for large, gaseous planets. But they're difficult for rocky planets, and rocky planets are what we're interested in. Large gaseous planets have puffy atmospheres that make spectroscopic study easier. And they emit or reflect more light due to their size, giving them a higher flux in direct imaging. But rocky planets have much smaller atmospheres that are more challenging to study spectroscopically. Because they're smaller, their flux is also lower, making them difficult to image directly.

As our telescopes become more powerful, they'll overcome some of these obstacles to characterizing rocky exoplanets. This new paper is part of how the astronomy community is preparing.

In their paper, the authors point out how even the powerful JWST is hampered in its efforts to fully characterize Earth-like exoplanets. Characterizing the atmospheres of these planets around cool dwarf stars requires long periods of observation. In a previous paper, a separate team of researchers showed that the JWST would need to observe more than 60 transits of one of the well-known TRAPPIST-1 rocky exoplanets to detect Earth-like levels of ozone.

"Using JWST's Near-InfraRed Spectrograph (NIRSpec) and Mid-InfraRed Instrument (MIRI), they found that >60 transits for 1b and >30 transits for 1c and 1d would be required to detect present-day Earth levels of ozone (O_3) on these planets," the authors write. That's a significant expenditure of observing time.

The JWST will also struggle with what astronomers call degeneracies. "… a number of degeneracies will still exist in the characterizations of habitable worlds by JWST, such as differentiating between the optical thicknesses and particle-size distributions of clouds," they write.

The researchers focus on polarimetry in their work. In a nutshell, polarimetry is the measurement of polarized light that's been affected somehow by material that it passes through, reflects off, or is refracted or diffracted by. Polarimetry is also the interpretation of the measurements.

Polarimetry could be key to breaking the deadlock between our advanced telescopes and the small, rocky planets we want to study. It could reduce the needed observation time, too. "Polarimetry is a powerful technique that has the ability to break these degeneracies as it assesses physical aspects of light not measured in non-polarimetric photometry or spectroscopy."

Polarimetry is powerful because it's very sensitive to the properties of exoplanet atmospheres. It's proven its effectiveness in studying our own solar system, including shrouded-by-clouds Venus. "Polarimetry has helped to characterize bodies in the solar system, including the clouds of Venus and the gas giants, as well as the differing icy conditions of the Galilean moons," the authors explain. Polarimetry has been so effective in studying Venus that some want to build a polarimetric radar to study the planet more fully.

The problem is astronomers don't have fine-tuned polarimetric models of exoplanets to help them understand what they're seeing when they study polarimetric planetshine. Models exist, but they need to be tested and validated against real planets, and that's where Earth comes in. "To date, the Earth is the only known and observed habitable "Earth-like' planet, thus serving as a benchmark to infer the biosignatures of life as we know it today," the authors state.

Earthshine is key to this, according to the researchers. "Studies of the optical and near-infrared (NIR) earthshine flux spectra reveal diagnostic biosignatures of the Earth, including the vegetation red edge (VRE), the ocean glint, and spectral features of atmospheric O_2 and H_2O." Other studies have also shown what an effective contribution polarimetry can make in these observations.

The light that reflects off the Earth is polarized, but after bouncing off the moon, it's depolarized. The authors corrected that in their work. They considered five different types of planetary surfaces under both a cloudless and a cloudy sky. They also considered different types of clouds with different particle sizes.

The main point of the study was to compare two different existing models that astronomers can use to interpret polarimetry and gauge their accuracy. One's called DAP, and the other's called VSTAR. The team used both to interpret their polarimetric data and then compared them.

This kind of research illustrates how much work goes into scientific endeavors. While astronomy headlines might make things sound simple, it's complicated. There's a lot more to it than just pointing powerful telescopes at distant objects and then looking at the pictures. It takes a dedicated effort from thousands of people over decades to make astronomy work. There's a lot at stake, and if someday a team of astronomers gets to say, "We did it! We discovered a planet with life!" it'll be because of detailed, intricate work like this that doesn't generate many headlines.

More information: Kenneth E. Gordon et al, Polarized Signatures of a Habitable World: Comparing Models of an Exoplanet Earth with Visible and Near-infrared Earthshine Spectra, *arXiv* (2023). DOI: 10.48550/arxiv.2301.05734

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