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What would it take to see exoplanet volcanoes?

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Image of a volcano erupting on Jupiter's moon Io—taken from the Galileo spacecraft. Credit: NASA, NASA-JPL, DLR

Even with the clearest image from the best telescope in the world, astronomers still won't know what they're looking at. It takes a fundamental understanding of physics, particularly how light works, to glean scientific data from the images that telescopes like the James Webb Space Telescope (JWST) capture.

To help with that understanding, a whole group of physics modelers specialize in trying to understand what different scenarios would look like with different telescope technologies. A new paper posted to the *arXiv* preprint server fits neatly into this mold, where researchers from UC Riverside, NASA Goddard, American University, and the University of Maryland decided to model what they think volcanic activity would look like on an exoplanet around a sun-like star.

So why is volcanic activity so important? Simply put, it's an indirect way to peer inside the exoplanet to see what geology may be lying underneath the surface. At their core, volcanoes spew whatever is inside the planet onto the outside, especially into the atmosphere. Any telescope that could capture a picture of a volcanic exoplanet's atmosphere would, therefore, have the ability to see what its interior is made up of.

Currently, only a few telescopes are strong enough to even detect exoplanet atmospheres—the JWST is one of them. However, it is only capable of detecting them around red dwarfs. Stars similar in brightness to our own sun would wash out the telescope's sensors, making their data useless.

But that might not be the case for future generations of telescopes. In particular, one is called the LUVOIR telescope, which is still only in the concept stage. LUVOIR could potentially, at least at its current specifications, directly image the atmospheres of Earth-sized exoplanets orbiting a sun-like star at around 1 AU distance.

What does that actually mean, though? Images taken of such distant objects require a special understanding to decipher. It's not as simple as visually seeing the Eiffel Tower in the background of a picture. It's more about interpreting data in a way that can translate into a scientific understanding of what the telescope can capture. One of the best ways to come up with a cipher is to test out the capabilities of the telescopes on objects we already know.

One of the best-studied objects in the universe is Earth itself. We understand the spectra of our atmosphere down to some pretty minute details. We can also model how we think it would appear to telescopes like LUVOIR. While the potential to find another Earth is both compelling and, quite frankly, an actual possibility, this paper takes a more nuanced look at the "exoEarth" model—what changes would there be in the signal based on the presence of different volcanic eruptions?

As mentioned above, volcanoes are one of the best ways to remotely see into a planet's core, so planetary scientists want to get as much data as they can. And, once again, our best data is collected here on Earth. We understand what chemicals come from volcanoes here, which might be picked up in the spectroscopic signature of an exoEarth's atmosphere.

LUVOIR has three main spectrographs that focus on different wavelengths of light—ultraviolet, visible light, and near-infrared. In models of a non-volcanized exoEarth, the UV wavelength showed high sensitivity to ozone, whereas regular oxygen and water vapor were more noticeable in visible light. Water alone was the most visible element in the near-infrared band as well.

What does all this have to do with volcanoes? Aerosols that volcanoes spew into the air as part of their eruption cause havoc on the spectral readings of at least some of these elements—particularly water. According to the paper, "H_2O absorption features were almost entirely concealed by volcanic aerosols while eruptions were ongoing." That seems a pretty clear indicator that if LUVOIR sees a planet with a solid spectral band in the visible and NIR spectra, and those values change dramatically during the observation period, it's probably caused by some form of volcanism.

Another indicator is the presence of sulfur dioxide (acid rain) in an exoplanet's atmosphere. This gas has a relatively short lifetime but is constantly spewed by erupting volcanoes. Unfortunately, its spectral absorption line that LUVOIR would be able to pick up is almost entirely concealed by a similar one for ozone, making it hard to isolate the presence of SO_2 in the data.

Overall, the spectral signature of ongoing volcanism seems to be most in line with variance in the UV (i.e., ozone) and visible light (i.e., O_2 and water) spectra. In particular, a high spike around the ozone spectral line could indicate the presence of an ongoing active eruption. But what's the likelihood we would find a planet like that with LUVOIR?

About 90%, according to the model discussed in the paper. At least if we observe 47 Earth-like planets around sun-like stars, the probability does reach that high. Considering there are already 5,000+ confirmed exoplanets, the chances of LUVOIR finding 47 Earth-like exoplanets are pretty high.

It will be a while until we know for sure, though. LUVOIR is currently estimated to launch in 2039, putting any data we could collect to see any exoplanet atmosphere well into the 2040s. That might seem like a long time from now, but at least it gives theorists more time to develop models of what we might expect to see. Hopefully, there will be plenty of new things to analyze, not just volcanoes.

More information: Colby M. Ostberg et al, The Prospect of Detecting

Volcanic Signatures on an ExoEarth Using Direct Imaging, *arXiv* (2023). DOI: 10.48550/arxiv.2309.15972

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