# Weather in the solar system can teach us about weather on exoplanets

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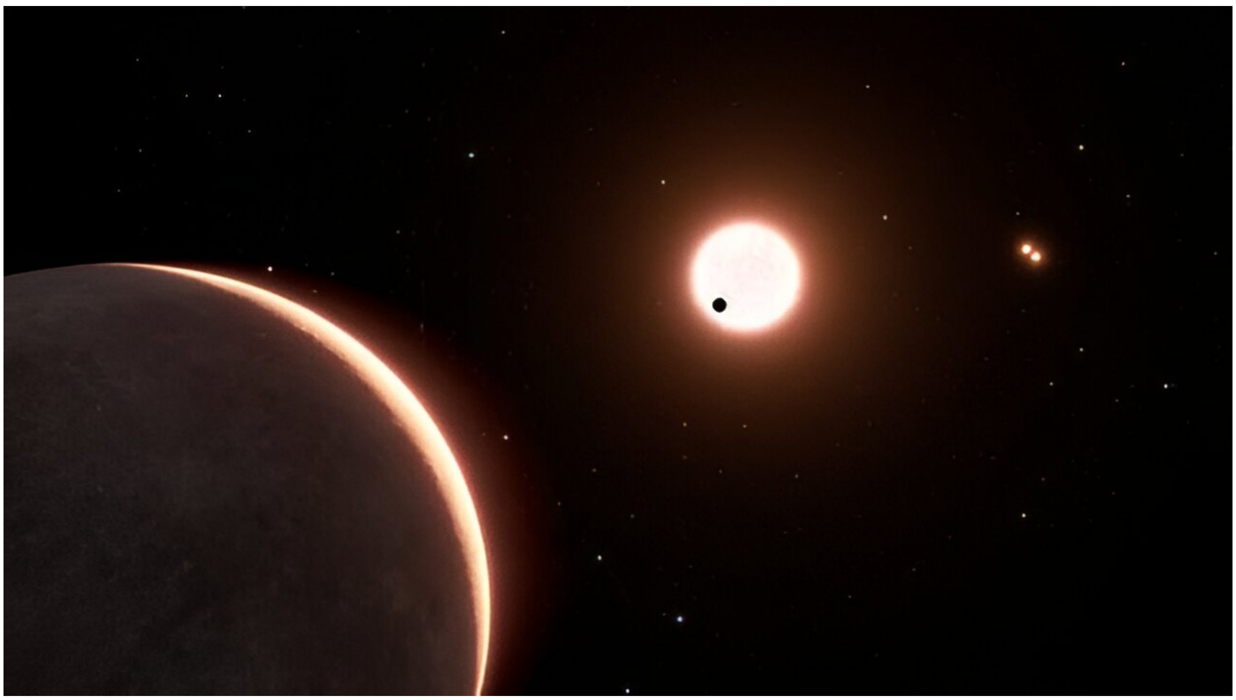

This is an artist's concept of the nearby exoplanet, LTT 1445Ac, which is a nearby Earth-size world. The planet orbits a red dwarf star. The star is in a triple system, with two closely orbiting red dwarfs seen at upper right. The black dot in front of the foreground star is planet LTT 1445Ab, transiting the face of the star. Credit: NASA, ESA, L. Hustak (STScI)

The way astronomers study planets in our own solar system is surprisingly similar to the way they study exoplanets, despite the latter being orders of magnitude more distant. The key is spectroscopy—examining the wavelengths of light that reach a telescope from a planet's atmosphere. Different molecules allow different wavelengths to pass through, creating unique patterns in the spectrum and giving scientists clues about the composition of an atmosphere.

Of course, for planets nearby, we can get more details by visiting them—but this is expensive and difficult—we haven't visited Uranus since Voyager 2 in 1986, for example, so for all intents and purposes, studying Uranus today is done the same way as studying an exoplanet: with a telescope.

A recent review of planetary atmospheres, in our solar system and elsewhere, reveals the incredible complexity and diversity of weather in our solar system, and what we might expect to find around other stars—but also what we don't yet understand about our near neighbors: there's plenty of unknowns. The review was published in *The Astronomy and Astrophysics Review*.

So let's take a weather-watcher's tour of the solar system:

We're skipping Mercury—there's not much of an atmosphere to speak of when you're that close to the sun.

But Venus has an atmosphere, and it is no slouch. Venus' crushing soup of greenhouse gases appears to have variable levels of sulfur dioxide. Planetary scientists theorize, but can't yet prove, that this is the result of active volcanism on the surface.

Venus also tantalized the astronomical community recently with the prospect of the life-indicating molecule phosphine—a result now in doubt, but still unsettled. More broadly, astronomers have learned that the planet's atmosphere isn't uniform. It has unique layers at different altitudes, some of thick clouds, others hazier and more variable. In one of the denser layers, there is a puzzling feature that absorbs UV-blue light, causing extreme heating.

Astronomers would love to get a close-up look at whatever is causing that absorption: for the moment, it's a mystery.

Moving outwards, we come to Mars which, besides Earth, has the most well-understood weather patterns in the solar system. Its atmosphere is a thin carbon dioxide veil that occasionally produces wispy water-based clouds.

Fog can sometimes form during Martian winter, or at dawn and dusk, and even settle as Earth-like frost. But Mars is not always calm. It regularly features dramatic, planet-wide dust storms, like the one that killed NASA's Opportunity rover in 2018. There also appear to be seasonal variations in hydrogen peroxide and methane in the atmosphere, hinting at the possibility of microscopic life.

Jupiter is next, and its colorful bands reveal the tumultuous nature of its atmosphere. The light-colored stripes occur where gas is rising from below, while the darker areas show sinking air. Giant storms like the great red spot stir up vast regions, and elsewhere ammonia haze condenses into slush and hail, sucking that molecule deep into the atmosphere's interior.

Saturn has giant storms too (called great white spots), though they seem to only form in the northern hemisphere. Astronomers wonder if, in the long term, they might also form in the south. The bland, uniform color of Saturn (compared to Jupiter) is largely because Saturn's atmosphere is 'taller' and less compact, creating a hazy layer over the whole, and hiding the complexity within.

We need to pause at Saturn's moon Titan, too, whose nitrogen-rich atmosphere mimics Earth. Clouds of condensed methane form here, raining back to the surface and pooling in shallow lakes. Astronomers would love to learn more about Titan's weather cycles, including the very real possibility of thunderstorms.

Lastly, Uranus and Neptune both have atmospheres of hydrogen and helium, but they are not identical. Neptune radiates heat, while Uranus is in equilibrium: it seems to have exhausted any internal energy and has little-to-no convective activity. Both, however, feature seasonal changes, and long-term studies will help understand these variations.

So what does this have to do with exoplanets?

Our hard-earned knowledge of solar system planets allows us to accurately model weather patterns and fluid dynamics—and, importantly, see where our models are inadequate. Jupiter, for example, has more complex features than weather models initially predicted. The models didn't take into account the intermixing of chemical components—an important lesson to learn before applying simple weather models to more distant worlds.

Exo-gas giants should behave like Jupiter and Saturn, with plenty of hydrogen and helium, but also heavy metals within. But there are additional considerations for so-called 'Hot Jupiters,' orbiting closer to their stars, and thus behaving differently with respect to their thermal conditions. Luckily, Hot Jupiters are among the easiest exoplanets to get good data for, and when combined with what we know about our own Jupiter, they have already become reasonably well understood.

Of growing interest now is the behavior of 'super-Earths' and 'mini-Neptunes,' a type of mid-sized planet not seen in our solar system. Do these planets have atmospheres? If so, will we be able to learn their composition?

Part of the challenge in understanding planets this size is the possible presence of aerosols, which create hazy layers, not unlike those on Venus, that obscure chemical composition data. Aerosols make spectroscopy difficult, so characterization of the weather patterns on these planets might be a challenge. This is why understanding Venus is so important, and space agencies have made visiting it a priority in the years to come.

Our solar system's ice giants are the glaring omission in our ability to study planets close up, at least since the 1980s. We therefore know very little about the outer planets, relatively speaking, and the authors of the recent review argue that missions to the outer planets ought to be made a priority in the years ahead—not just to understand Uranus and Neptune, but so we can understand their exoplanet counterparts too.

One final conclusion of the review concerns the changing relationship between planetary scientists and exoplanet specialists. For now, studying the solar system informs our expectations of exoplanets.

But as we gather more exoplanet data, the flow of knowledge is likely to reverse. A larger population of exoplanets to study will tell us more about the place of our solar system's planets within a broader galactic population.

As a result, the collaboration between solar system and exoplanet researchers is about to get a whole lot more interesting.

**More information:** Agustín Sánchez-Lavega et al, Dynamics and clouds in planetary atmospheres from telescopic observations, *The Astronomy and Astrophysics Review* (2023). DOI: 10.1007/s00159-023-00150-9

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