Neptune-like exoplanets can be cloudy or clear: New findings suggest the reason why

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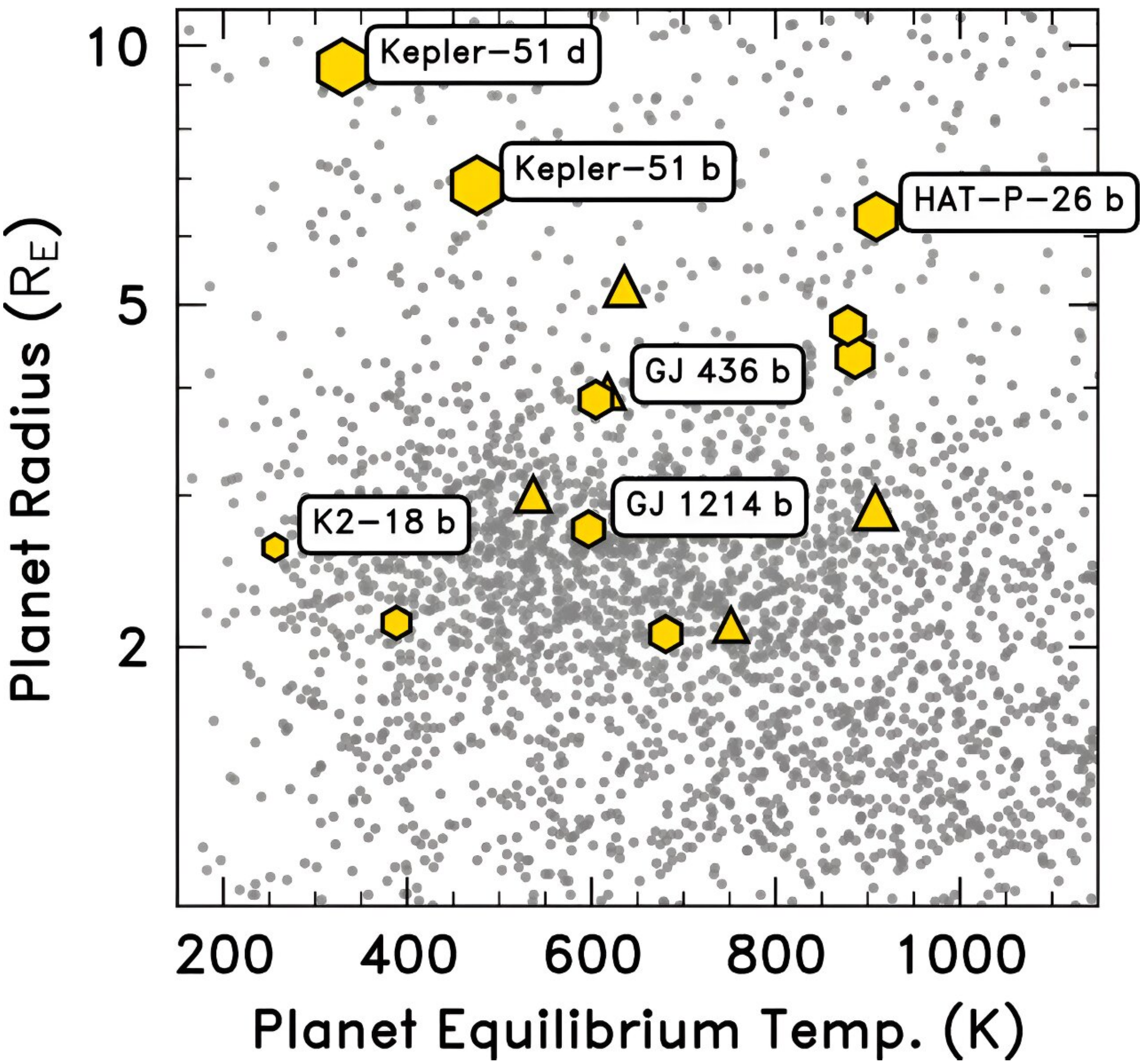

This work's sample overlaid with known transiting planets. Hexagons indicate planets in our sample also being observed by JWST through Cycle 2, while triangles are not yet scheduled or approved for JWST observations. Selected targets have been labeled. Credit: *The Astrophysical Journal Letters* (2024). DOI: 10.3847/2041-8213/ad1b5c

The study of "exoplanets," the sci-fi-sounding name for all planets in the cosmos beyond our own solar system, is a fairly new field. Mainly, exoplanet researchers like those in the ExoLab at the University of Kansas use data from space-borne telescopes such as the Hubble Space Telescope and Webb Space Telescope. Whenever news headlines offer findings of "Earth-like" planets or planets with the potential to support humanity, they're talking about exoplanets within our own Milky Way.

Jonathan Brande, a doctoral candidate in the ExoLab at the University of Kansas, has just published findings in *The Astrophysical Journal Letters* showing new atmospheric detail in a set of 15 exoplanets similar to Neptune. While none could support humanity, a better understanding of their behavior might help us to understand why we don't have a small Neptune, while most solar systems seem to feature a planet of this class.

"Over the past several years at KU, my focus has been studying the atmospheres of exoplanets through a technique known as transmission spectroscopy," Brande said. "When a planet transits, meaning it moves between our line of sight and the star it orbits, light from the star passes through the planet's atmosphere, getting absorbed by the various gases present. By capturing a spectrum of the star—passing the light through an instrument called a spectrograph, akin to passing it through a prism—we observe a rainbow, measuring the brightness of different constituent colors. Varied areas of brightness or dimness in the spectrum reveal the gases absorbing light in the planet's atmosphere."

With this methodology, several years ago Brande published a paper concerning the "warm Neptune" exoplanet TOI-674 b, where he presented observations indicating the presence of water vapor in its atmosphere. These observations were part of a broader program led by Brande's adviser, Ian Crossfield, associate professor of physics & astronomy at KU, to observe atmospheres of Neptune-sized exoplanets.

"We want to comprehend the behaviors of these planets, given that those slightly larger than Earth and smaller than Neptune are the most common in the galaxy," Brande said.

This recent paper summarizes observations from that program, incorporating data from additional observations to address why some planets appear cloudy while others are clear.

"The goal is to explore the physical explanations behind the distinct appearances of these planets," Brande said.

Brande and his co-authors took special note of regions where exoplanets tend to form clouds or hazes high up in their atmosphere. When such atmospheric aerosols are present, the KU researcher said hazes can block the light filtering through the atmosphere.

"If a planet has a cloud right above the surface with hundreds of kilometers of clear air above it, starlight can easily pass through the clear air and be absorbed only by the specific gases in that part of the atmosphere," Brande said. "However, if the cloud is positioned very high, clouds are generally opaque across the electromagnetic spectrum. While hazes have spectral features, for our work, where we focus on a relatively narrow range with Hubble, they also produce mostly flat spectra."

According to Brande, when these aerosols are present high in the atmosphere, there's no clear path for light to filter through.

"With Hubble, the single gas we're most sensitive to is water vapor," he said. "If we observe water vapor in a planet's atmosphere, that's a good indication that there are no clouds high enough to block its absorption. Conversely, if water vapor is not observed and only a flat spectrum is seen, despite knowing that the planet should have an extended atmosphere, it suggests the likely presence of clouds or hazes at higher altitudes."

Brande led the work of an international team of astronomers on the paper, including Crossfield at KU and collaborators from the Max Planck Institute in Heidelberg, Germany, a cohort led by Laura Kreidberg, and investigators at the University of Texas, Austin, led by Caroline Morley.

Brande and his co-authors approached their analysis differently than previous efforts by focusing on determining the physical parameters of the small-Neptune atmospheres. In contrast, previous analyses often involved fitting a single model spectrum to observations.

"Typically, researchers would take an atmospheric model with pre-computed water content, scale and shift it to match observed planets in their sample," Brande said. "This approach indicates whether the spectrum is clear or cloudy but provides no information about the amount of water vapor or the location of clouds in the atmosphere."

Instead, Brande employed a technique known as "atmospheric retrieval."

"This involved modeling the atmosphere across various planet parameters such as water vapor quantity and cloud location, iterating through hundreds and thousands of simulations to find the best fit configuration," he said.

"Our retrievals gave us a best-fit model spectrum for each planet, from which we calculated how cloudy or clear the planet appeared to be. Then, we compared those measured clarities to a separate suite of models by Caroline Morley, which let us see that our results are in line with expectations for similar planets. In examining cloud and haze behavior, our models indicated that clouds were a better fit than hazes.

"The sedimentation efficiency parameter, reflecting cloud compactness, suggested observed planets had relatively low sedimentation efficiencies, resulting in fluffy clouds. These clouds, made up of particles like water droplets, remained lofted in the atmosphere due to their low settling tendency."

Brande's findings provide insights into the behavior of these planetary atmospheres and caused "substantial interest" when he presented them at a recent meeting of the American Astronomical Society.

Other findings

Moreover, Brande is part of an international observation program, led by Crossfield, that just announced findings of water vapor on GJ 9827d—a planet as hot as Venus 97 light-years from Earth in the constellation Pisces.

The observations, made with the Hubble Space Telescope, show the planet may be just one example of water-rich planets in the Milky Way. They were announced by a team led by Pierre-Alexis Roy of the Trottier Institute for Research on Exoplanets at Université de Montréal.

"We were searching for water vapor on the atmospheres of sub-Neptune-type planets," Brande said. "Pierre-Alexis's paper is the latest from that main effort because it took approximately 10 or 11 orbits or transits of the planet to make the water-vapor detection. Pierre-Alexis's spectrum made it into our paper as one of our trend-data points, and we included all the planets from their proposal and others studied in the literature, making our results stronger. We were in close communication with them during the process of both papers to ensure we were using the proper updated results and accurately reflecting their findings."

More information: Jonathan Brande et al, Clouds and Clarity: Revisiting Atmospheric Feature Trends in Neptune-size Exoplanets, *The Astrophysical Journal Letters* (2024). DOI: 10.3847/2041-8213/ad1b5c

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