Discovery of planet too big for its sun throws off solar system formation models

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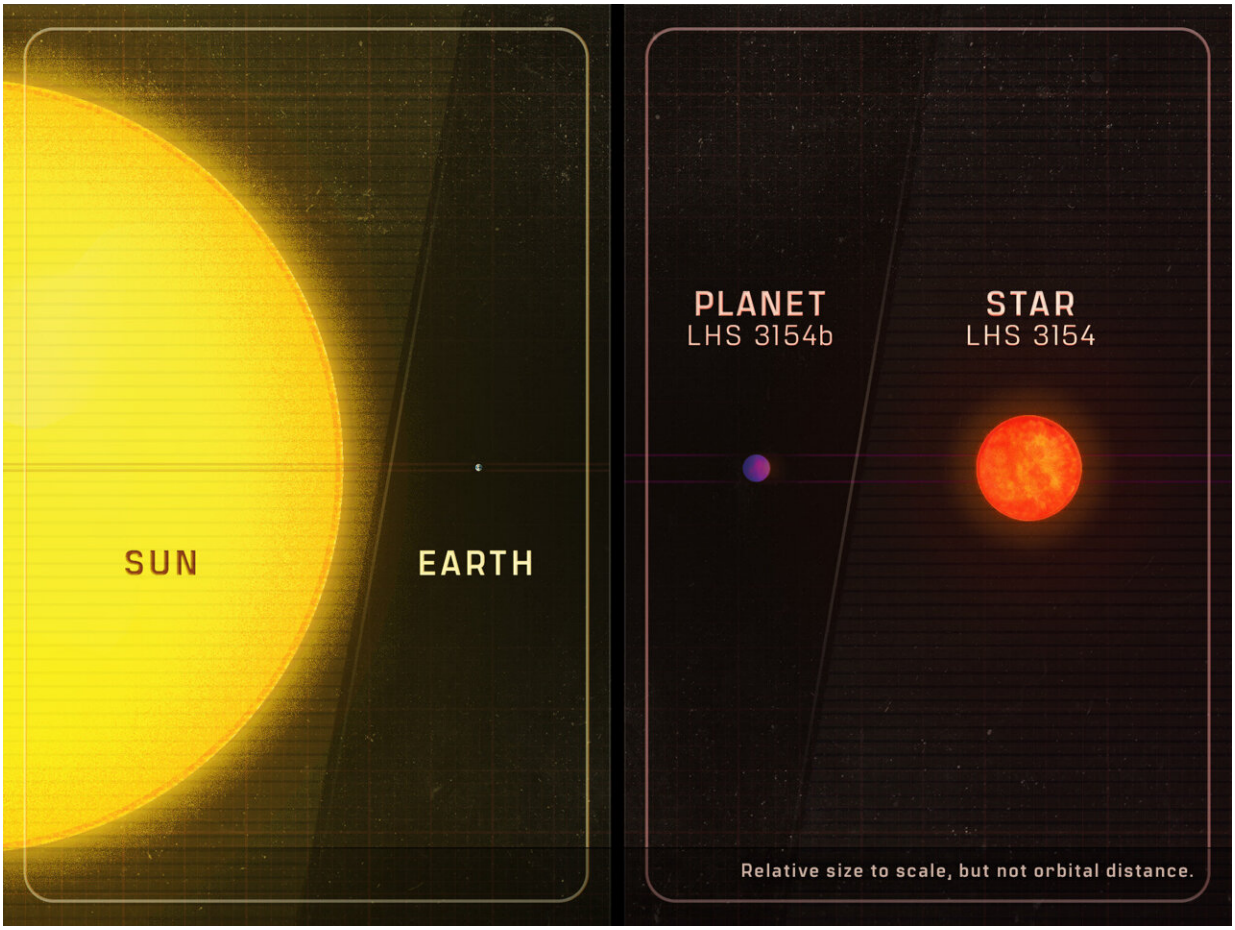


An artistic rendering of the mass comparison of LHS 3154 system and our own Earth and sun. Credit: Penn State University

The discovery of a planet that is far too massive for its sun is calling into question what was previously understood about the formation of planets and their solar systems, according to Penn State researchers.

In a paper published in the journal Science, researchers report the discovery of a planet more than 13 times as massive as Earth orbiting the "ultracool" star LHS 3154, which itself is nine times less massive than the sun. The mass ratio of the newly found planet with its host star is more than 100 times higher than that of Earth and the sun.

The finding reveals the most massive known planet in a close orbit around an ultracool dwarf star, the least massive and coldest stars in the universe. The discovery goes against what current theories would predict for planet formation around small stars and marks the first time a planet with such high mass has been spotted orbiting such a low-mass star.

"This discovery really drives home the point of just how little we know about the universe," said Suvrath Mahadevan, the Verne M. Willaman Professor of Astronomy and Astrophysics at Penn State and co-author on the paper. "We wouldn't expect a planet this heavy around such a low-mass star to exist."

He explained that stars are formed from large clouds of gas and dust. After the star is formed, the gas and dust remain as disks of material orbiting the newborn star, which can eventually develop into planets.

"The planet-forming disk around the low-mass star LHS 3154 is not expected to have enough solid mass to make this planet," Mahadevan said. "But it's out there, so now we need to reexamine our understanding of how planets and stars form."

The researchers spotted the oversized planet, named LHS 3154b, using an astronomical spectrograph built at Penn State by a team of scientists

led by Mahadevan. The instrument, called the Habitable Zone Planet Finder or HPF, was designed to detect planets orbiting the coolest stars outside our solar system with the potential for having liquid water—a key ingredient for life—on their surfaces.

While such planets are very difficult to detect around stars like our sun, the low temperature of ultracool stars means that planets capable of having liquid water on their surface are much closer to their star relative to Earth and the sun. This shorter distance between these planets and their stars, combined with the low mass of the ultracool stars, results in a detectable signal announcing the presence of the planet, Mahadevan explained.

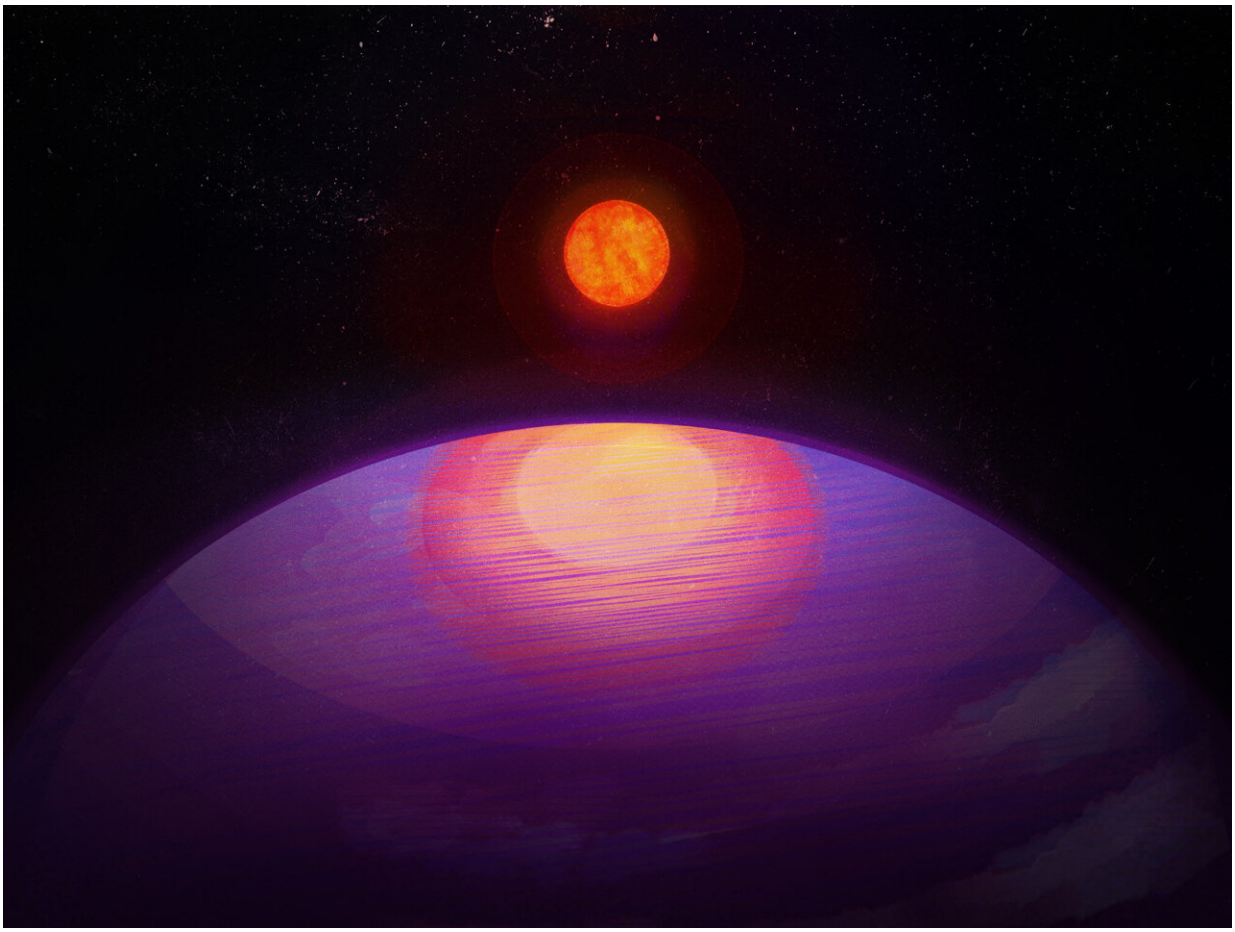
"Think about it like the star is a campfire. The more the fire cools down, the closer you'll need to get to that fire to stay warm," Mahadevan said. "The same is true for planets. If the star is colder, then a planet will need to be closer to that star if it is going to be warm enough to contain liquid water. If a planet has a close enough orbit to its ultracool star, we can detect it by seeing a very subtle change in the color of the star's spectra or light as it is tugged on by an orbiting planet."

Located at the Hobby-Eberly Telescope at the McDonald Observatory in Texas, the HPF provides some of the highest precision measurements to date of such infrared signals from nearby stars.

"Making the discovery with HPF was extra special, as it is a new instrument that we designed, developed and built from the ground-up for the purpose of looking at the uncharted planet population around the lowest mass stars," said Guðmundur Stefánsson, NASA Sagan Fellow in Astrophysics at Princeton University and lead author on the paper, who helped develop HPF and worked on the study as a graduate student at Penn State.

"Now we are reaping the rewards, learning new and unexpected aspects of this exciting population of planets orbiting some of the most nearby stars."

The instrument has already yielded critical information in the discovery and confirmation of new planets, Stefánsson explained, but the discovery of the planet LHS 3154b exceeded all expectations.



Artistic rendering of the possible view from LHS 3154b towards its low mass host star. Given its large mass, LHS 3154b probably has a Neptune-like composition. Credit: Penn State

"Based on current survey work with the HPF and other instruments, an object like the one we discovered is likely extremely rare, so detecting it has been really exciting," said Megan Delamer, astronomy graduate student at Penn State and co-author on the paper. "Our current theories of planet formation have trouble accounting for what we're seeing."

In the case of the massive planet discovered orbiting the star LHS 3154, the heavy planetary core inferred by the team's measurements would require a larger amount of solid material in the planet-forming disk than current models would predict, Delamer explained.

The finding also raises questions about prior understandings of the formation of stars, as the dust-mass and dust-to-gas ratio of the disk surrounding stars like LHS 3154—when they were young and newly formed—would need to be 10 times higher than what was observed in order to form a planet as massive as the one the team discovered.

"What we have discovered provides an extreme test case for all existing planet formation theories," Mahadevan said. "This is exactly what we built HPF to do, to discover how the most common stars in our galaxy form planets—and to find those planets."

More information: Guðmundur Stefánsson et al, A Neptune-mass exoplanet in close orbit around a very low mass star challenges formation models, *Science* (2023). DOI: 10.1126/science.abo0233. www.science.org/doi/10.1126/science.abo0233

Frédéric Masset, A low-mass star with a large-mass planet, *Science* (2023). DOI: 10.1126/science.adl3365 , www.science.org/doi/10.1126/science.adl3365

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