Large exomoons unlikely around Kepler-1625 b and Kepler-1708 b, astronomers say

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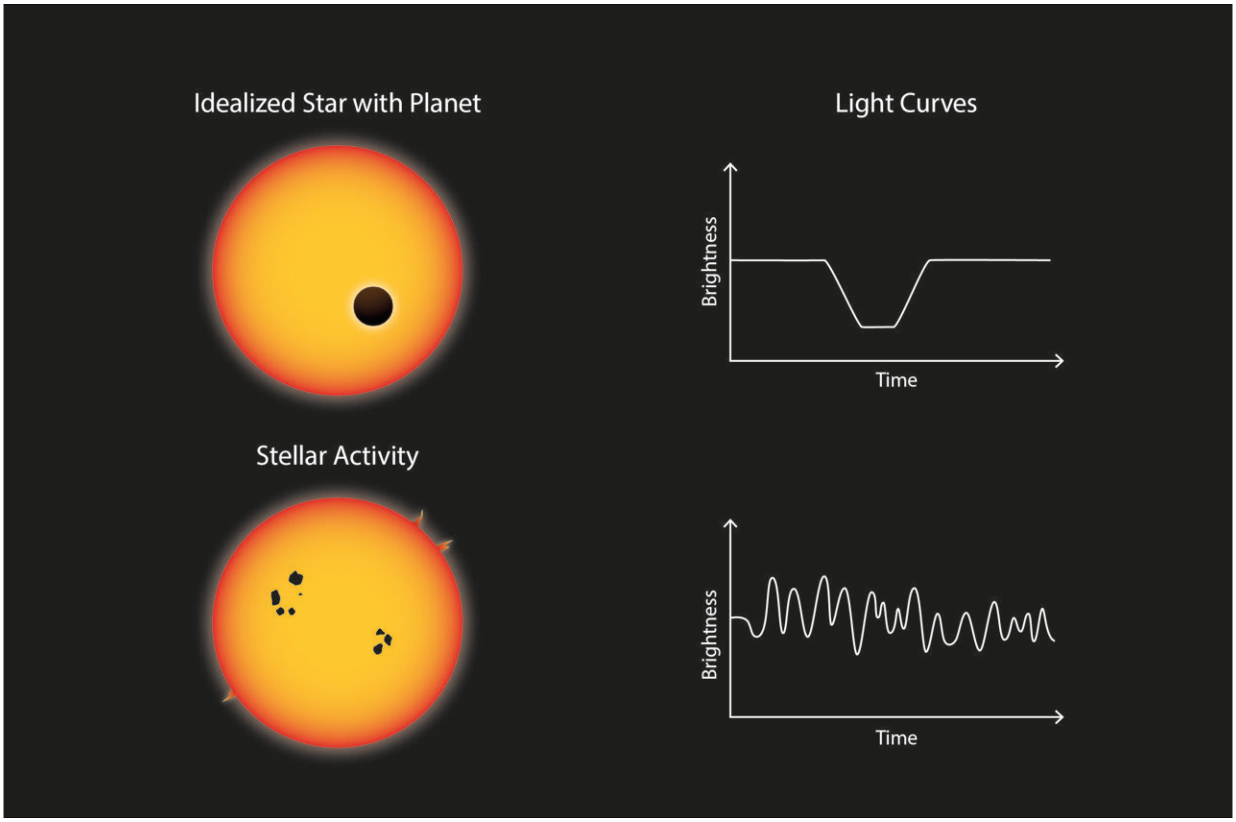

Several influences can create a moon-like signal in a light curve—even without the presence of an actual moon. Credit: MPS/hormesdesign.de

Only two of the more than 5,300 known exoplanets have so far provided evidence of moons in orbit around them. In observations of the planets

Kepler-1625b and Kepler-1708b from the Kepler and Hubble space telescopes, researchers discovered traces of such moons for the first time.

A new study now raises doubts about these previous claims. As scientists from the Max Planck Institute for Solar System Research (MPS) and the Sonnenberg Observatory, both in Germany, report today in the journal *Nature Astronomy*, "planet-only" interpretations of the observations are more conclusive.

For their analysis, the researchers used their newly developed computer algorithm Pandora, which facilitates and accelerates the search for exomoons. They also investigated what kind of exomoons can be found in principle in modern space-based astronomical observations. Their answer is quite shocking.

In our solar system, the fact that a planet is orbited by one or more moons is rather the rule than the exception: apart from Mercury and Venus, all other planets have such companions; in the case of the gas giant Saturn researchers have found 140 natural satellites until today.

Scientists, therefore, consider it likely that planets in distant star systems also harbor moons. So far, however, there has only been evidence of such exomoons in two cases: Kepler-1625b and Kepler-1708b. This low yield is not surprising. After all, distant satellites are naturally much smaller than their home worlds—and therefore much harder to find. It is extremely time-consuming to comb through the observational data of thousands of exoplanets for evidence of moons.

To make the search easier and faster, the authors of the new study rely on a search algorithm they developed and optimized themselves for the search for exomoons. They published their method last year, and the algorithm is available to all researchers as open source code. When applied to the observational data from Kepler-1625b and Kepler-1708b, the results were astonishing.

"We would have liked to confirm the discovery of exomoons around Kepler-1625b and Kepler-1708b," says the first author of the new study, MPS scientist Dr. René Heller. "But unfortunately, our analyses show otherwise," he adds.

Hide and seek of an exomoon

The Jupiter-like planet Kepler-1625b made headlines five years ago. Researchers at Columbia University in New York reported strong evidence of a giant moon in its orbit that would dwarf all the moons in the solar system. The scientists analyzed data from NASA's Kepler space telescope, which observed more than 100,000 stars during its first mission from 2009 to 2013 and discovered over 2000 exoplanets.

However, in the years that followed the 2018 discovery claim, the exomoon candidate forced astronomers to play a cosmic version of hide-and-seek. First, it disappeared after the Kepler data had been cleaned from systematic noise. Yet clues were found again in further observations with the Hubble Space Telescope.

And then last year, this extraordinary exomoon candidate got company: according to the New York researchers, another giant moon much larger than Earth orbits the Jupiter-sized planet Kepler-1708b.

The right match

"Exomoons are so far away that we cannot see them directly, even with the most powerful modern telescopes," explains Dr. René Heller. Instead, telescopes record the fluctuations in brightness of distant stars, the time series of which is called a light curve. Researchers then look for signs of moons in these light curves. If an exoplanet passes in front of its star, as seen from Earth, it dims the star by a tiny fraction.

This event is called a transit, and it re-occurs regularly with the orbital period of the planet around the star. An exomoon accompanying the planet would have a similar dimming effect. Its trace in the light curve, however, would not only be significantly weaker.

Due to the movement of the moon and planet around their mutual center of gravity, this additional dimming in the light curve would follow a rather complicated pattern. And there are other effects to be considered, such as planet-moon eclipses, natural brightness variations of the star and other sources of noise generated during telescopic measurements.

To detect the moons, nevertheless, the New York researchers and their German colleagues first calculate millions of "artificial" light curves for all conceivable sizes, mutual distances and orbital orientations of possible planets and moons. An algorithm then compares these simulated light curves with the observed light curve and looks for the best match. The researchers from Göttingen and Sonneberg used their open-source algorithm Pandora, which is optimized for the search for exomoons and can solve this task several orders of magnitude faster than previous algorithms.

No trace of moons

In the case of the planet Kepler-1708b, the German duo now found that scenarios without a moon can explain the observational data just as accurately as those with a moon. "The probability of a moon orbiting Kepler-1708b is clearly lower than previously reported," says Michael Hippke from the Sonneberg Observatory and co-author of the new study. "The data do not suggest the existence of an exomoon around

Kepler-1708b," Hippke continues.

There is much to suggest that Kepler-1625b is also devoid of a giant companion. Transits of this planet in front of its star have previously been observed with the Kepler and the Hubble telescopes.

The German researchers now argue that the instantaneous brightness variation of the star across its disk, an effect known as stellar limb darkening, has a crucial impact on the proposed exomoon signal. The limb of the solar disk, for example, appears darker than the center. However, depending on whether you look at the home star of Kepler-1625b through the Kepler or the Hubble telescope, this limb-darkening effect looks different.

This is because Kepler and Hubble are sensitive to different wavelengths of the light that they receive. The researchers from Göttingen and Sonneberg now argue that their modeling of this effect explains the data more conclusively than a giant exomoon.

Their new, extensive analyses also show that exomoon search algorithms often produce false-positive results. Time and again, they "discover" a moon when there really is just a planet transiting its host star. In the case of a light curve like that of Kepler-1625b, the rate of "false hits" is likely to be around 11 percent.

"The earlier exomoon claim by our colleagues from New York was the result of a search for moons around dozens of exoplanets," says Heller. "According to our estimates, a false-positive finding is not at all surprising, but almost to be expected," he adds.

Strange satellites

The researchers also used their algorithm to predict the types of actual exomoons that could be clearly detectable in light curves space missions like Kepler. According to their analysis, only particularly large moons orbiting their planet in a wide orbit are detectable using current technology.

Compared to the familiar moons of our solar system, they would all be oddballs: at least twice the size of Ganymede, the largest moon in the solar system and therefore almost as big as Earth. "The first exomoons that will be discovered in future observations, such as from the PLATO mission, will certainly be very unusual and therefore exciting to explore," says Heller.

More information: René Heller et al, Large exomoons unlikely around Kepler-1625 b and Kepler-1708 b, *Nature Astronomy* (2023). DOI: 10.1038/s41550-023-02148-w

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