Radiating exoplanet discovered in 'perfect tidal storm'

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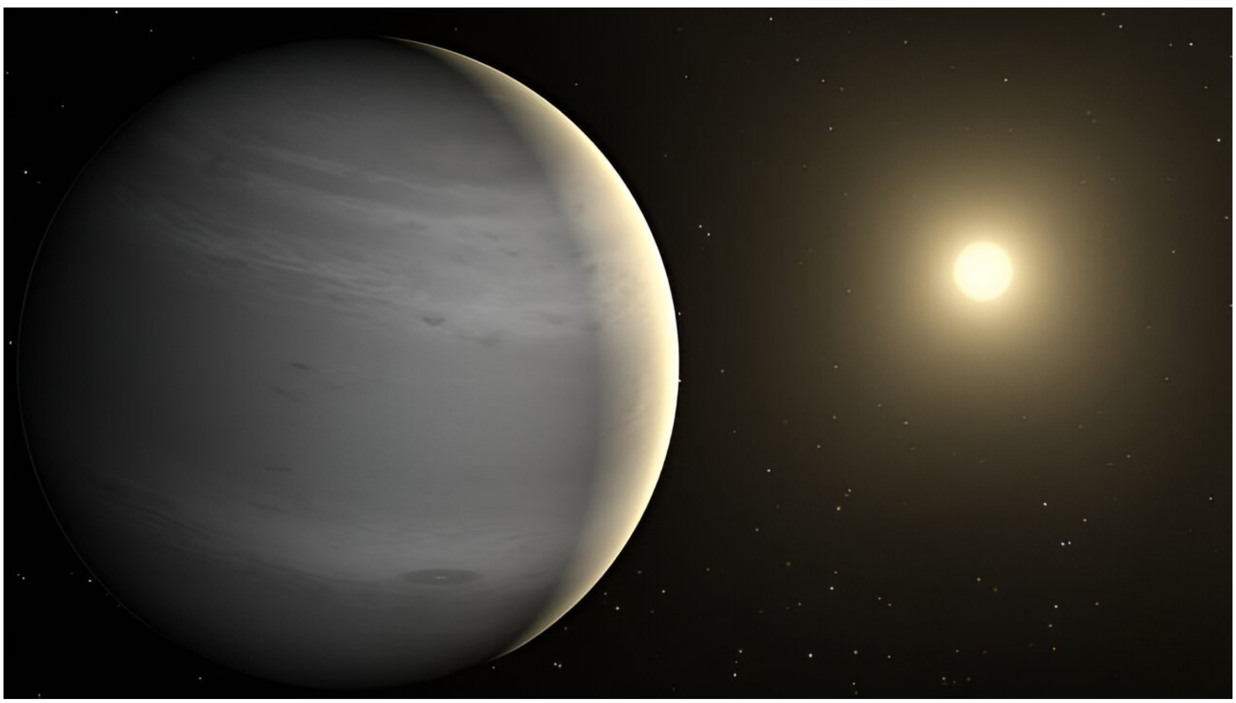

Artist's illustration of HD 104067 b, which is the outermost exoplanet in the HD 104067 system, and responsible for potentially causing massive tidal energy on the innermost exoplanet candidate, TOI-6713.01. Credit: NASA/JPL-Caltech

Can tidal forces cause an exoplanet's surface to radiate heat? This is what a study accepted to the *Astronomical Journal* hopes to address as a team of international researchers used data collected from ground-based instruments to confirm the existence of a second exoplanet residing within the exoplanetary system, HD 104067, along with using NASA's Transiting Exoplanet Survey Satellite (TESS) mission to identify an additional exoplanet candidate. The study is available on the *arXiv* preprint server.

What's unique about this exoplanet candidate, which orbits innermost compared to the other two, is that the tidal forces exhibited from the outer two exoplanets are potentially causing the candidates' surface to radiate with its surface temperature reaching as high as 2,300 degrees Celsius (4,200 degrees Fahrenheit), which the researchers refer to as a "perfect tidal storm."

Universe Today discusses this fantastic research with Dr. Stephen Kane, who is a Professor of Planetary Astrophysics at UC Riverside and lead author of the study, regarding the motivation behind the study, significant results, the significance of the "tidal storm" aspects, follow-up research, and implications for this system on studying other exoplanetary systems. So, what was the motivation behind this study?

"The star (HD 104067) was a star known to harbor a giant planet in a 55-day orbit, and I have a long history of obsessing over known systems," Dr. Kane tells Universe Today. "When TESS detected a possible transiting Earth-size planet in a 2.2-day orbit (TOI-6713.01), I decided to examine the system further. We gathered all RV data and found that there is ANOTHER (Uranus mass) planet in a 13-day orbit. So, it started with the TESS data, then the system just kept getting more interesting the more we studied it."

Dr. Kane's history of exoplanetary research encompasses a myriad of solar system architectures, specifically those containing highly eccentric exoplanets, but also includes follow-up work after exoplanets are confirmed within a system. Most recently, he was the second author on a study discussing a revised system architecture in the HD 134606 system, along with discovering two new Super-Earths within that system, as well.

For this most recent study, Dr. Kane and his colleagues used data from the High Accuracy Radial velocity Planet Searcher (HARPS) and High Resolution Echelle Spectrometer (HIRES) ground-based instruments and the aforementioned TESS mission to ascertain the characteristics and parameters of both the parent star, HD 105067, and the corresponding exoplanets orbiting it. But, aside from discovering additional exoplanets within the system, as Dr. Kane mentions, what are the most significant results from this study?

Dr. Kane tells Universe Today, "The most amazing outcome of our work was that the dynamics of the system causes the 2.2-day period to experience enormous tidal effects, similar to those experienced by Io. In this case though, TOI-6713.01 experiences 10 million times more tidal energy than Io, resulting in a 2,600K [2,300 degrees Celsius (4,200 degrees Fahrenheit)] surface temperature. This means the planet literally glows at optical wavelengths."

Jupiter's moon, Io, is the most volcanically active planetary body in the solar system, which is produced from tidal heating caused by Jupiter's massive gravity throughout Io's slightly eccentric (elongated) orbit lasting 1.77 days. This means that Io gets closer to Jupiter during certain points and farther away from Jupiter at other points causing Io to compress and expand, respectively.

Over millions of years, this constant friction within Io's interior has led to the heating of its core, resulting in the hundreds of volcanoes that comprise Io's surface and no visible impact craters, as well. As Dr. Kane mentions, this new exoplanet candidate "experiences 10 million times more tidal energy than Io," which could raise additional questions regarding its own volcanic activity or other geologic processes. Therefore, what is the significance of the "tidal storm" aspects of TOI-6713.01?

Dr. Kane tells Universe Today, "The reason TOI-6713.01 experiences such strong tidal forces is because of the eccentricity of the outer two giant planets, forcing TOI-6713.01 into an eccentric orbit also. Thus, I referred to the planet as being caught in a perfect tidal storm."

The HD 104067 system with its two outer giant exoplanets forcing the innermost TOI-6713.01 into a "perfect tidal storm" is slightly reminiscent of Jupiter's first three Galilean moons, Io, Europa, and Ganymede, regarding their gravitational effects on each other throughout their orbits.

There are some differences, however, since Jupiter's massive gravity is the primary force driving Io's volcanic activity, and all three moons are in what's known as orbital resonance, which means the orbits are ratioed with each other. For example, for every four orbits of Io there are two orbits of Europa and one orbit of Ganymede, making their orbital resonance 4:2:1, which results in each moon causing regular gravitational influences on each other.

Therefore, with the tidal storm aspect on TOI-6713.01 being caused by the eccentricities of the two outer giants, how does this compare to the relationship between Io, Europa, and Ganymede?

Dr. Kane tells Universe Today, "The Laplace resonance of the Galilean moons creates a particularly powerful configuration, whereby regular alignments of the inner three moons regularly force Io into an eccentric orbit. The HD 104067 system is not in resonance but is still able to produce a power configuration by virtue of the b and c planets being so massive and is therefore more of a 'brute force' effect of forcing the inner transiting planet into an eccentric orbit."

As noted, TOI-6713.01 was discovered using the radial velocity method, also known as Doppler spectroscopy, meaning astronomers measured the miniscule changes in the movement of the parent star as it's slightly tugged by the planet during the latter's orbit.

These slight changes cause the parent star to wobble as the two bodies tug on each other, and astronomers use a spectrograph to detect changes in these wobbles as the star moves "closer" and "farther away" from us to find exoplanets.

This method has proven to be very effective in finding exoplanets, as it accounts for almost 20% of the total confirmed exoplanets to date, and the first exoplanet orbiting a star like our own was discovered using this method. However, despite the effectiveness of radial velocity, the study notes how TOI-6713.01 "has yet to be confirmed," so what additional observations are required to confirm its existence?

Dr. Kanes tells Universe Today, "Because the planet is so small, it's difficult to detect it from the radial velocity data. However, the transits look clean, and we have ruled out stellar contamination. Additional transits will help, but we're quite confident in the existence of the planet at this point."

This study comes as the total number of exoplanetary systems is almost 4,200 with the number of confirmed exoplanets exceeding 5,600 and more than 10,100 exoplanet candidates waiting to hopefully be confirmed. These system architectures have been found to vary widely from our own solar system, which is comprised of the terrestrial (rocky) planets closer to the sun and the gas giants orbiting much farther out.

Examples include hot Jupiters that orbit dangerously close to their parent star, some in only a few days, and other systems boasting seven Earth-sized exoplanets, some of which orbit within the habitable zone. Therefore, what can this unique solar system architecture teach us about exoplanetary systems, overall, and what other exoplanetary systems mirror it?

Dr. Kane tells Universe Today, "This system is a great example of extreme environments that planets can find themselves in. There have been several cases of terrestrial planets that are close to their star and heated by the energy from the star, but very few cases where the tidal energy is melting the planet from within."

The potential discovery of an exoplanet orbiting in a "perfect tidal storm" further demonstrates the myriad of characteristics that exoplanets and exoplanetary systems exhibit while contrasting with both our own solar system and what astronomers have learned about them until now. If confirmed, TOI-6713.01 will continue to mold our understanding regarding the formation and evolution of exoplanets and exoplanetary systems throughout not only our Milky Way galaxy, but throughout the cosmos, as well.

"The universe is an amazing place!" Dr. Kane tells Universe Today. "The fun thing about this particular project is that it all started with 'Hmm … this might be interesting' then turned into something far more fascinating than I could have imagined! Just goes to show, never miss the chance to follow your curiosity."

More information: Stephen R. Kane et al, A Perfect Tidal Storm: HD 104067 Planetary Architecture Creating an Incandescent World, *arXiv* (2024). DOI: 10.48550/arxiv.2403.17062

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