Tidal heating could make exomoons much more habitable (and detectable)

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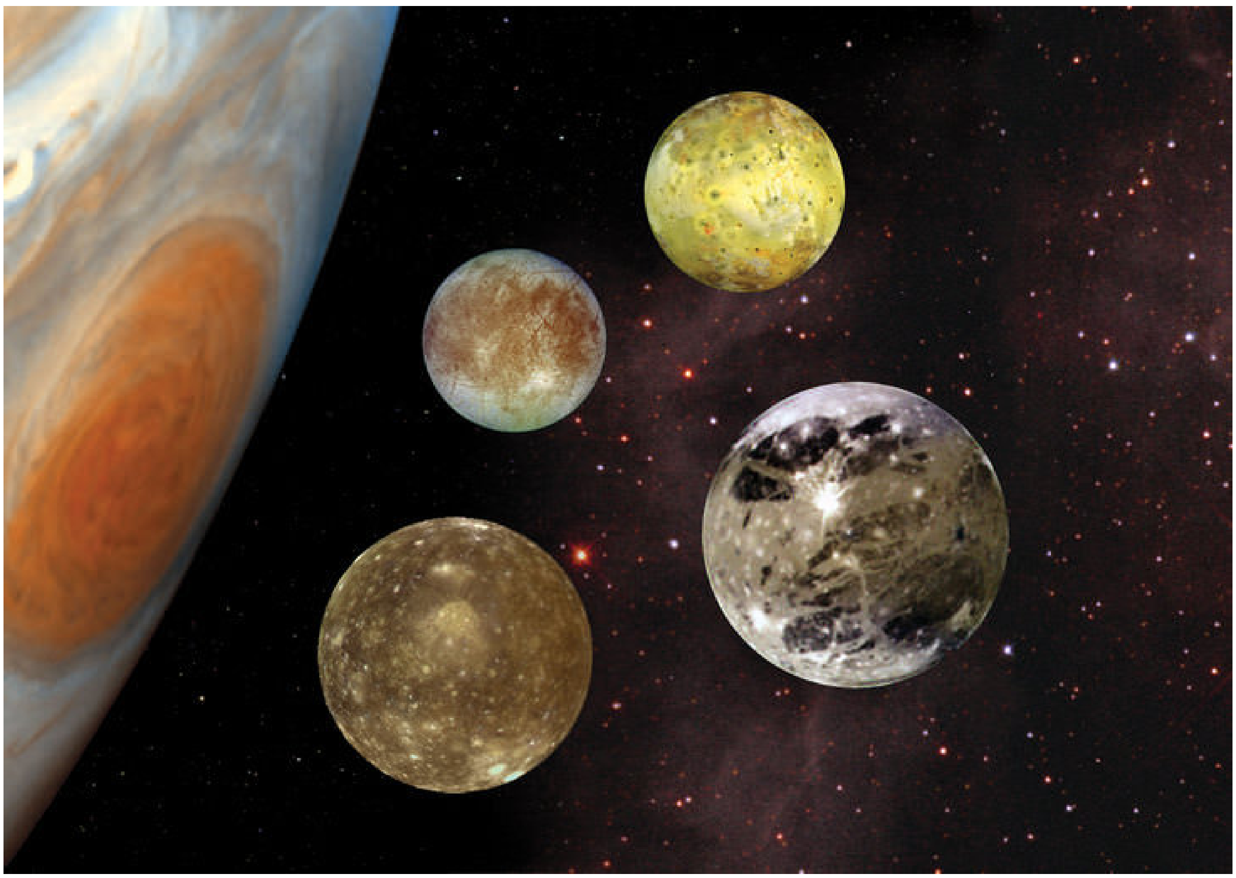


Illustration of Jupiter and the Galilean satellites. Credit: NASA

Within the solar system, most of our astrobiological research is aimed at Mars, which is considered to be the next-most habitable body beyond

Earth. However, future efforts are aimed at exploring icy satellites in the outer solar system that could also be habitable (like Europa, Enceladus, Titan, and more). This dichotomy between terrestrial (rocky) planets that orbit within their a system's habitable zones (HZ) and icy moons that orbit farther from their parent stars is expected to inform future extrasolar planet surveys and astrobiology research.

In fact, some believe that exomoons may play a vital role in the habitability of exoplanets and could also be a good place to look for life beyond the solar system. In a new study, a team of researchers investigated how the orbit of exomoons around their parent bodies could lead to (and place limits on) tidal heating—where gravitational interaction leads to geological activity and heating in the interior. This, in turn, could help exoplanet-hunters and astrobiologists determine which exomoons are more likely to be habitable.

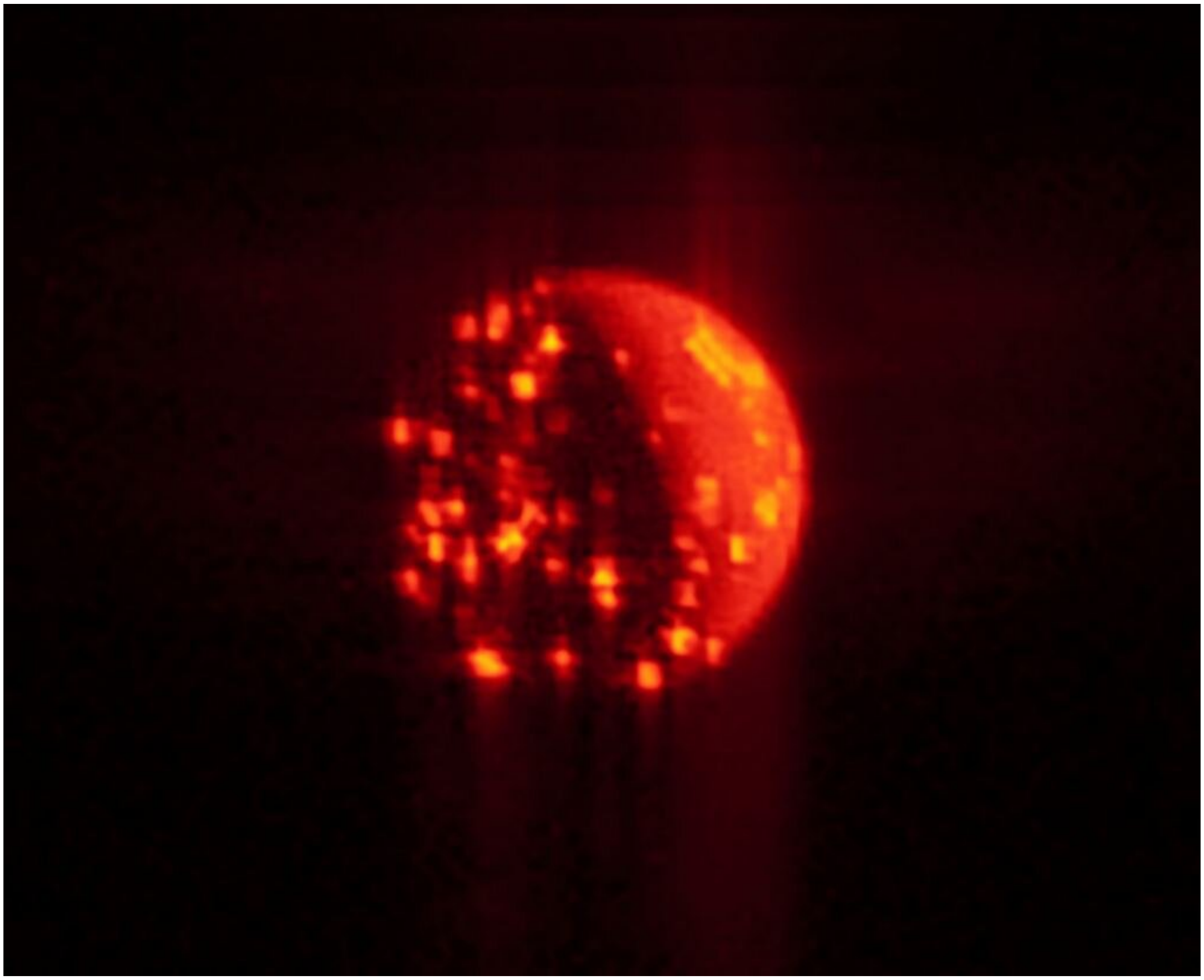
The research was conducted by graduate student Armen Tokadjian and Professor Anthony L. Piro from the University of Southern California (USC) and The Observatories of the Carnegie Institution for Science. The paper that describes their findings ("Tidal Heating of Exomoons in Resonance and Implications for Detection") recently appeared online and has been submitted for publication in the *Astronomical Journal*. Their analysis was inspired largely by the presence of multiplanet moon systems in the solar system, such as those that orbit Jupiter, Saturn, Uranus, and Neptune.

In many cases, these icy moons are believed to have interior oceans resulting from tidal heating, where gravitational interaction with a larger planet leads to geological action in the interior. This, in turn, allows for liquid oceans to exist due to the presence of hydrothermal vents at at the core-mantle boundary. The heat and chemicals these vents release into the oceans could make these "Ocean Worlds" potentially habitable—something scientists have been hoping to investigate for decades. As Tokadjian explained to Universe Today via email:

"In terms of astrobiology, tidal heating may boost the surface temperature of a moon to a range where liquid water can exist. Thus even systems outside the habitable zone may warrant further astrobiological studies. For example, Europa hosts a liquid ocean due to tidal interactions with Jupiter, although it lies outside the solar system's ice line."

Considering how plentiful "Ocean Worlds" are in the solar system, it is likely that similar planets and multi-moon systems can be found throughout our galaxy. As Piro explained to Universe Today via email, the presence of exomoons has a lot of important implications for life, including:

- Large moons like our own can stabilize the planet's axial tilt, so the planet has regular seasons
- Tidal interactions can prevent planets from tidally locking with their host star, impacting the climate
- Moons can tidally heat a planet, helping it maintain a molten core, which has many geological implications
- When a gaseous planet is in the habitable zone of a star, the moon itself can host life (think of Endor or Pandora)



An amazingly active Io, Jupiter's "pizza moon," shows multiple volcanoes and hot spots in this photo taken with Juno's infrared camera. Credit: NASA/JPL-Caltech /SwRI/ASI/INAF/JIRAM/Roman Tkachenko

In recent decades, geologists and astrobiologists have theorized that the formation of the moon (ca. 4.5 billion years ago) played a major role in the emergence of life. Our planetary magnetic field is the result of its molten outer core rotating around a solid inner core and in the opposite direction of the planet's own rotation. The presence of this magnetic field shields Earth from harmful radiation and is what allowed our atmosphere to remain stable over time—and not slowly stripped away by solar wind (which was the case with Mars).

In short, the interactions between a planet and its satellites can affect the habitability of both. As Tokadjian and Piro showed in a previous paper using two candidate exoplanets as an example (Kepler-1708 b-i and Kepler-1625 b-i), the presence of exomoons can even be used to explore the interior of exoplanets. In the case of multi-moon systems, said Tokadjian and Piro, the amount of tidal heating depends on several factors. As Piro illustrated:

"As a planet raises tides on a moon, some of the energy stored by the deformation is transferred into heating the moon. This process is dependent on many factors, including the interior structure and size of the moon, the mass of the planet, planet-moon separation, and the moon's orbital eccentricity. In a multi-moon system, the eccentricity can be excited to relatively high values if the moons are in resonance, leading to significant tidal heating."

"In Armen's work, he nicely shows, in analogy to the tidal heating we see for Io around Jupiter, that resonant interactions between multiple moons can efficiently heat exomoons. By 'resonant,' we mean the case where the periods of moons obey some integer multiple (like 2 to 1 or 3 to 2) so that their orbits gravitationally 'kick' each other regularly."

In their paper, Tokadjian and Piro considered moons in a 2:1 orbital resonance around planets of varying size and type (i.e., smaller rocky planets to Neptune-like gas giants and Super-Jupiters). According to their results, the largest tidal heating will occur in moons that orbit rocky Earth-like planets with an orbital period of two to four days. In this case, the tidal luminosity was over 1000 times that of Io, and the tidal temperature reached 480 K (~207 °C; 404 °F).

These findings could have drastic implications for future exoplanet and astrobiology surveys, which are expanding to include the search for exomoons. While missions like Kepler have detected many exomoon candidates, none have been confirmed since exomoons are incredibly difficult to detect using conventional methods and current instruments. As Tokadjian explained, tidal heating could offer new methods for exomoon detection:

"First, we have the secondary eclipse method, which is when a planet and its moon move behind a star resulting in a dip in stellar flux observed. If the moon is significantly heated, this secondary dip will be deeper than what is expected from the planet alone. Second, a heated moon will likely expel volatiles like sodium and potassium through volcanism much like the case of Io. Detecting sodium and potassium signatures in the atmospheres of exoplanets can be a clue for exomoon origin."

In the coming years, next-generation telescopes like the James Webb (which will be releasing its first images on July 12th) will rely on their combination of advanced optics, IR imaging, and spectrometers to detect chemical signatures from exoplanet atmospheres. Other instruments like the ESO's Extremely Large Telescope (ELT) will rely on adaptive optics that will allow for Direct Imaging of exoplanets. The ability to detect chemical signatures of exomoons will greatly increase their ability to find potential signs of life.

More information: Armen Tokadjian, Anthony L. Piro, Tidal Heating of Exomoons in Resonance and Implications for Detection. arXiv:2206.11368v1 [astro-ph.EP], arxiv.org/abs/2206.11368

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