James Webb Space Telescope's first spectrum of a TRAPPIST-1 planet

September 25 2023, by Morgan Sherburne

This artistic representation of the TRAPPIST-1 red dwarf star showcases its very active nature. The star appears to have many stellar spots (colder regions of its surface, similar to sunspots) and flares. The exoplanet TRAPPIST-1 b, the closest planet to the system's central star, can be seen in the foreground with no apparent atmosphere. The exoplanet TRAPPIST-1 g, one of the planets in the system's habitable zone, can be seen in the background to the right of the star. The TRAPPIST-1 system contains seven Earth-sized exoplanets. Credit: Benoît Gougeon, Université de Montréal

In a solar system called TRAPPIST-1, 40 light years from the sun, seven Earth-sized planets revolve around a cold star.

Astronomers obtained new data from the James Webb Space Telescope (JWST) on TRAPPIST-1 b, the planet in the TRAPPIST-1 solar system closest to its star. These new observations offer insights into how its star can affect observations of exoplanets in the habitable zone of cool stars. In the habitable zone, liquid water can still exist on the orbiting planet's surface.

The team, which included University of Michigan astronomer and NASA Sagan Fellow Ryan MacDonald, published its study in the journal *The Astrophysical Journal Letters*.

"Our observations did not see signs of an atmosphere around TRAPPIST-1 b. This tells us the planet could be a bare rock, have clouds high in the atmosphere or have a very heavy molecule like carbon dioxide that makes the atmosphere too small to detect," MacDonald said. "But what we do see is that the star is absolutely the biggest effect dominating our observations, and this will do the exact same thing to other planets in the system."

The majority of the team's investigation was focused on how much they could learn about the impact of the star on observations of the TRAPPIST-1 system planets.

"If we don't figure out how to deal with the star now, it's going to make it much, much harder when we look at the planets in the habitable zone—TRAPPIST-1 d, e and f—to see any atmospheric signals," MacDonald said.

A promising exoplanetary system

TRAPPIST-1, a star much smaller and cooler than our sun located approximately 40 light-years away from Earth, has captured the attention of scientists and space enthusiasts alike since the discovery of its seven Earth-sized exoplanets in 2017. These worlds, tightly packed around their star with three of them within its habitable zone, have fueled hopes of finding potentially habitable environments beyond our solar system.

The study, led by Olivia Lim of the Trottier Institute for Research on Exoplanets at the University of Montreal, used a technique called transmission spectroscopy to gain important insights into the properties of TRAPPIST-1 b. By analyzing the central star's light after it has passed through the exoplanet's atmosphere during a transit, astronomers can see the unique fingerprint left behind by the molecules and atoms found within that atmosphere.

"These observations were made with the NIRISS instrument on JWST, built by an international collaboration led by René Doyon at the University of Montreal, under the auspices of the Canadian Space Agency over a period of nearly 20 years," said Michael Meyer, U-M professor of astronomy. "It was an honor to be part of this collaboration and tremendously exciting to see results like this characterizing diverse worlds around nearby stars coming from this unique capability of NIRISS."

Know thy star, know thy planet

The key finding of the study was the significant impact of stellar activity and contamination when trying to determine the nature of an exoplanet. Stellar contamination refers to the influence of the star's own features, such as dark regions called spots and bright regions called faculae, on the measurements of the exoplanet's atmosphere.

The team found compelling evidence that stellar contamination plays a crucial role in shaping the transmission spectra of TRAPPIST-1 b and, likely, the other planets in the system. The central star's activity can create "ghost signals" that may fool the observer into thinking they have detected a particular molecule in the exoplanet's atmosphere.

This result underscores the importance of considering stellar contamination when planning future observations of all exoplanetary systems. This is especially true for systems like TRAPPIST-1, since it is centered around a red dwarf star that can be particularly active with starspots and frequent flare events.

"In addition to the contamination from stellar spots and faculae, we saw a stellar flare, an unpredictable event during which the star looks brighter for several minutes to hours," Lim said. "This flare affected our measurement of the amount of light blocked by the planet. Such signatures of stellar activity are difficult to model but we need to account for them to ensure that we interpret the data correctly."

MacDonald played a key role in modeling the impact of the star and searching for an atmosphere in the team's observations, running a series of millions of models to explore the full range of properties of cool starspots, hot star active regions and planetary atmospheres that could explain the JWST observations the astronomers were seeing.

No significant atmosphere on TRAPPIST-1 b

While all seven of the TRAPPIST-1 planets have been tantalizing candidates in the search for Earth-sized exoplanets with an atmosphere, TRAPPIST-1 b's proximity to its star means it finds itself in harsher conditions than its siblings. It receives four times more radiation than the Earth does from the sun and has a surface temperature between 120 and 220 degrees Celsius.

However, if TRAPPIST-1 b were to have an atmosphere, it would be the easiest to detect and describe of all the targets in the system. Since TRAPPIST-1 b is the closest planet to its star and thus the hottest planet in the system, its transit creates a stronger signal. All these factors make TRAPPIST-1 b a crucial, yet challenging target of observation.

To account for the impact of stellar contamination, the team conducted two independent atmospheric retrievals, a technique to determine the kind of atmosphere present on TRAPPIST-1 b, based on observations. In the first approach, stellar contamination was removed from the data before they were analyzed. In the second approach, conducted by MacDonald, stellar contamination and the planetary atmosphere were modeled and fit simultaneously.

In both cases, the results indicated that TRAPPIST-1 b's spectra could be well matched by the modeled stellar contamination alone. This suggests no evidence of a significant atmosphere on the planet. Such a result remains very valuable, as it tells astronomers which types of atmospheres are incompatible with the observed data.

Based on their collected JWST observations, Lim and her team explored a range of atmospheric models for TRAPPIST-1 b, examining various possible compositions and scenarios. They found that cloud-free, hydrogen-rich atmospheres were ruled out with high confidence. This means that there appears to be no clear, extended atmosphere around TRAPPIST-1 b.

However, the data could not confidently exclude thinner atmospheres, such as those composed of pure water, carbon dioxide or methane, nor an atmosphere similar to that of Titan, a moon of Saturn and the only moon in the solar system with a significant atmosphere. These results, the first spectrum of a TRAPPIST-1 planet, are generally consistent with previous JWST observations of TRAPPIST-1 b's dayside seen in a single color with the MIRI instrument.

As astronomers continue to explore other rocky planets in the vastness of space, these findings will inform future observing programs on the JWST and other telescopes, contributing to a broader understanding of exoplanetary atmospheres and their potential habitability.

More information: Olivia Lim et al, Atmospheric Reconnaissance of TRAPPIST-1 b with JWST/NIRISS: Evidence for Strong Stellar Contamination in the Transmission Spectra, *The Astrophysical Journal Letters* (2023). DOI: 10.3847/2041-8213/acf7c4

Provided by University of Michigan