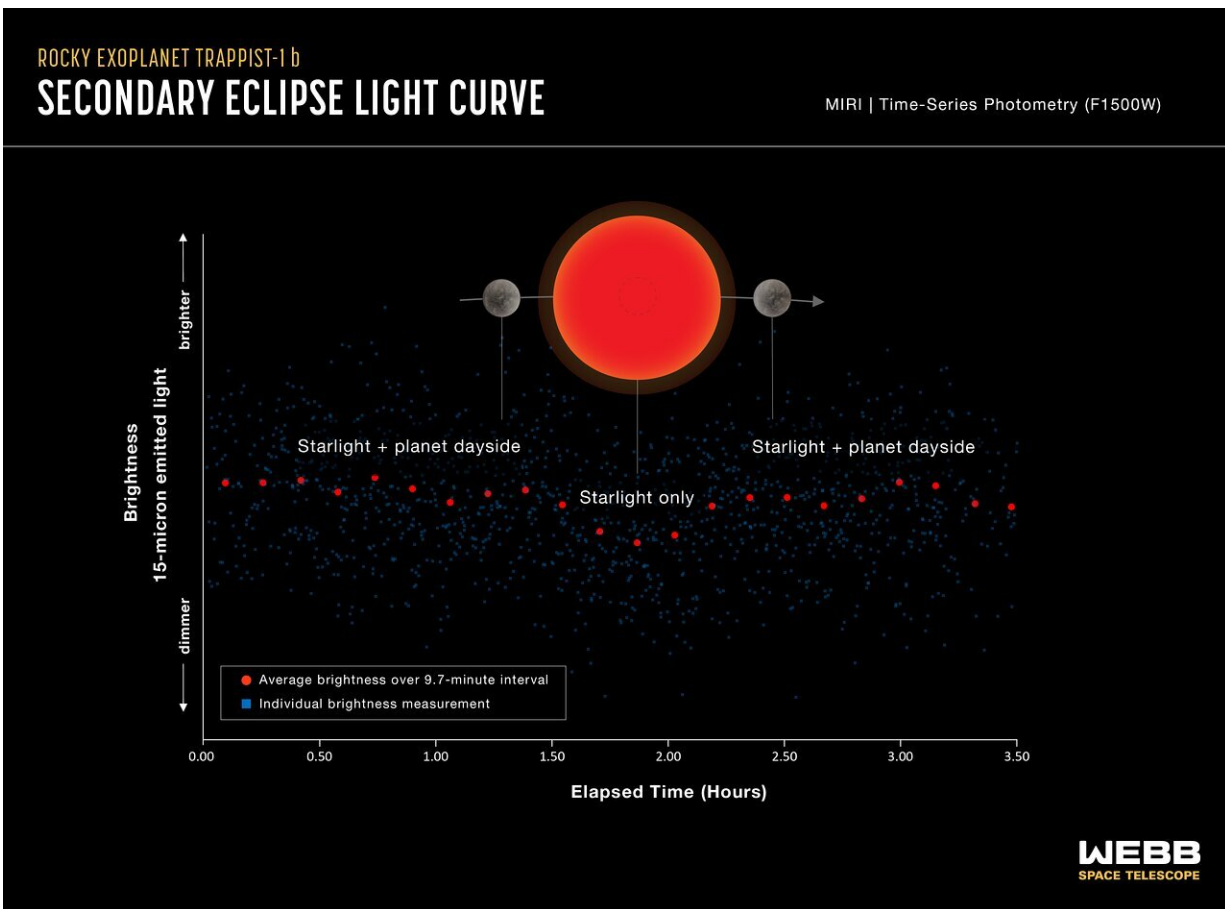


Webb space telescope measures the temperature of a rocky exoplanet

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Light curve showing the change in brightness of the TRAPPIST-1 system as the innermost planet, TRAPPIST-1 b, moves behind the star. This phenomenon is known as a secondary eclipse. Credit: European Space Agency

An international team of researchers has used the NASA/ESA/CSA James Webb Space Telescope to measure the temperature of the rocky exoplanet TRAPPIST-1 b. The measurement is based on the planet's thermal emission: heat energy given off in the form of infrared light detected by Webb's Mid-Infrared Instrument (MIRI).

The result indicates that the planet's dayside has a temperature of about 500 Kelvin (roughly 230°C), and suggests that it has no significant [atmosphere](#). This is the first detection of any form of light emitted by an exoplanet as small and as cool as the rocky [planets](#) in our own solar system. The result marks an important step in determining whether planets orbiting small active stars like TRAPPIST-1 can sustain atmospheres needed to support life. It also bodes well for Webb's ability to characterize temperate, Earth-sized exoplanets using MIRI.

"These observations really take advantage of Webb's mid-infrared capability," said Thomas Greene, an astrophysicist at NASA's Ames Research Center and lead author on the study published today in the journal *Nature*. "No previous telescopes have had the sensitivity to measure such dim mid-infrared light."

Rocky planets orbiting ultra cool red dwarfs

In early 2017, astronomers reported the discovery of seven rocky planets orbiting an ultracool red dwarf star (or M dwarf) 40 light-years from Earth. What is remarkable about the planets is their similarity in size and mass to the inner, rocky planets of our own solar system. Although they all orbit much closer to their star than any of our planets orbit the sun—all could fit comfortably within the orbit of Mercury—they receive comparable amounts of energy from their tiny star.

TRAPPIST-1 b, the innermost planet, has an orbital distance about one hundredth that of Earth's and receives about four times the amount of

energy that Earth gets from the sun. Although it is not within the system's habitable zone, observations of the planet can provide important information about its sibling planets, as well as those of other M-dwarf systems.

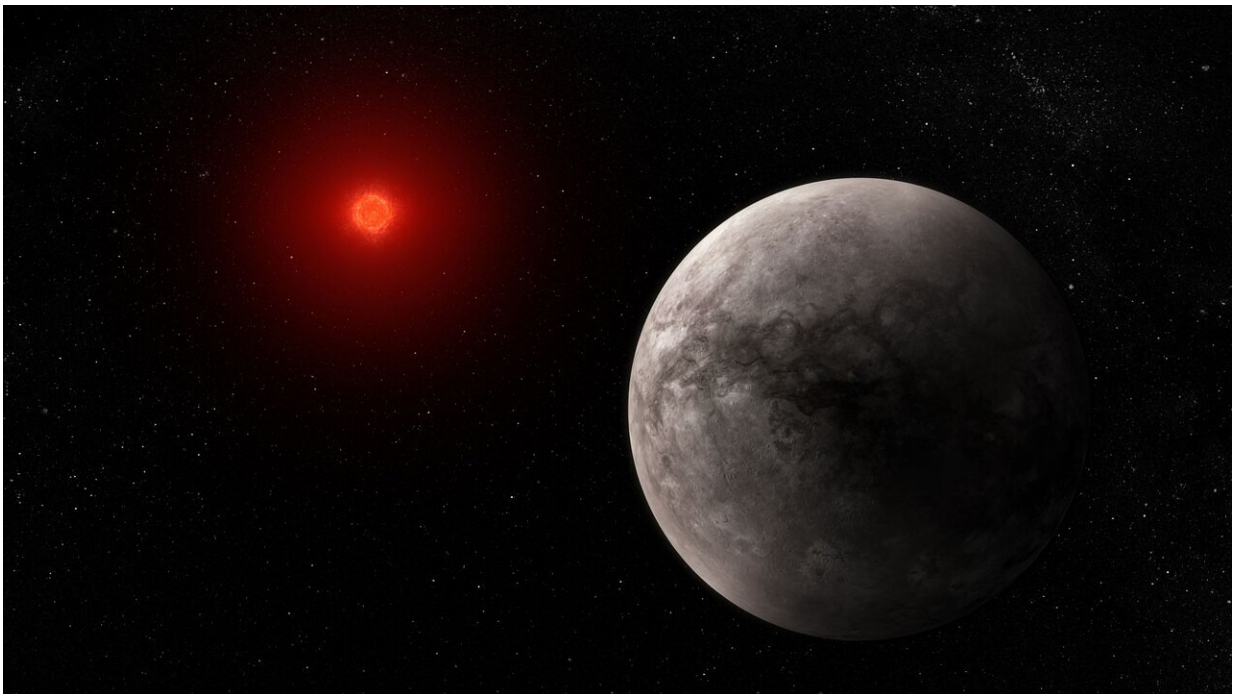


Illustration showing what the hot rocky exoplanet TRAPPIST-1 b could look like. TRAPPIST-1 b, the innermost of seven known planets in the TRAPPIST-1 system, orbits its star at a distance of 0.011 AU, completing one circuit in just 1.51 Earth-days. TRAPPIST-1 b is slightly larger than Earth, but has around the same density, which indicates that it must have a rocky composition. Webb's measurement of mid-infrared light given off by TRAPPIST-1 b suggests that the planet does not have any substantial atmosphere. The star, TRAPPIST-1, is an ultracool red dwarf (M dwarf) with a temperature of only 2566 K and a mass just 0.09 times the mass of the Sun. Credit: European Space Agency

"There are ten times as many of these stars in the Milky Way as there are

stars like the sun, and they are twice as likely to have rocky planets as stars like the sun," explained Greene. "But they are also very active—they are very bright when they're young and they give off flares and X-rays that can wipe out an atmosphere."

Co-author Elsa Ducrot from CEA in France, who was on the team that conducted the initial studies of the TRAPPIST-1 system, added, "It's easier to characterize [terrestrial planets](#) around smaller, cooler stars. If we want to understand habitability around M stars, the TRAPPIST-1 system is a great laboratory. These are the best targets we have for looking at the atmospheres of [rocky planets](#)."

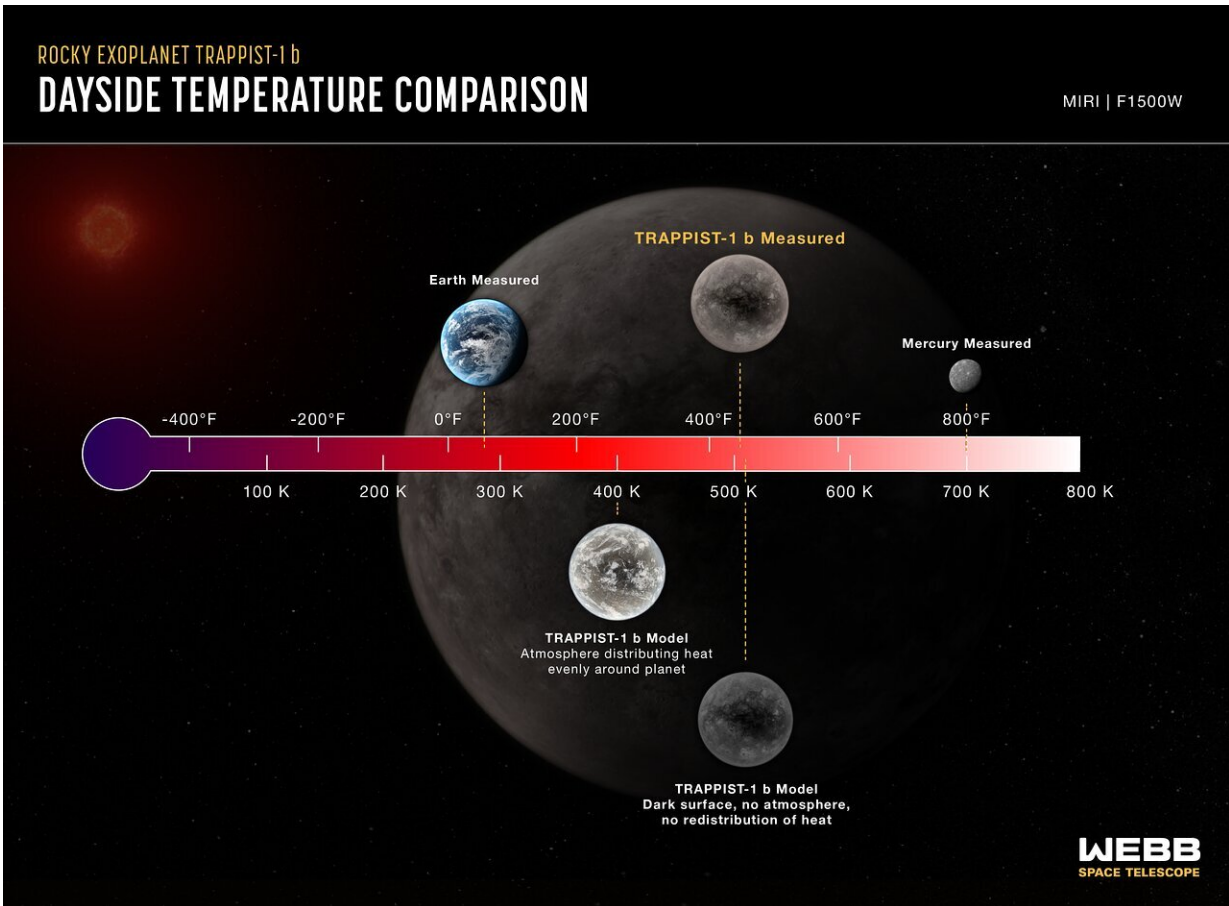
Detecting an atmosphere (or not)

Previous observations of TRAPPIST-1 b with the NASA/ESA Hubble Space Telescope, as well as NASA's Spitzer Space Telescope, found no evidence for a puffy atmosphere, but were not able to rule out a dense one.

One way to reduce the uncertainty is to measure the planet's temperature. "This planet is tidally locked, with one side facing the star at all times and the other in permanent darkness," said Pierre-Olivier Lagage from CEA, a co-author on the paper. "If it has an atmosphere to circulate and redistribute the heat, the dayside will be cooler than if there is no atmosphere."

The team used a technique called secondary eclipse photometry, in which MIRI measured the change in brightness from the system as the planet moved behind the star. Although TRAPPIST-1 b is not hot enough to give off its own visible light, it does have an infrared glow. By subtracting the brightness of the star on its own (during the secondary eclipse) from the brightness of the star and planet combined, they were able to successfully calculate how much infrared light is being given off

by the planet.



Comparison of the dayside temperature of TRAPPIST-1 b as measured using Webb’s Mid-Infrared Instrument (MIRI) to computer models showing what the temperature would be under various conditions. The models take into account the known properties of the system, including the planet’s size and density, the temperature of the star, and the planet’s orbital distance. The temperature of the dayside of Mercury is also shown for reference. The dayside brightness of TRAPPIST-1 b at 15 microns corresponds to a temperature of about 500 K (roughly 230°C). This is consistent with the temperature assuming the planet is tidally locked (one side facing the star at all times), with a dark-colored surface, no atmosphere, and no redistribution of heat from the dayside to the nightside. If the heat energy from the star were distributed evenly around the planet (for example, by a circulating carbon dioxide-free atmosphere), the temperature at 15

microns would be 400 K (125°C). If the atmosphere had a substantial amount of carbon dioxide, it would emit even less 15-micron light and would appear to be even cooler. Although TRAPPIST-1 b is hot by Earth standards, it is cooler than the dayside of Mercury, which consists of bare rock and no significant atmosphere. Mercury receives about 1.6 times more energy from the Sun than TRAPPIST-1 b does from its star. Credit: European Space Agency

Measuring minuscule changes in brightness

Webb's detection of a secondary eclipse is itself a major milestone. With the star more than 1,000 times brighter than the planet, the change in brightness is less than 0.1%.

"There was also some fear that we'd miss the eclipse. The planets all tug on each other, so the orbits are not perfect," said Taylor Bell, the post-doctoral researcher at the Bay Area Environmental Research Institute who analyzed the data. "But it was just amazing: The time of the eclipse that we saw in the data matched the predicted time within a couple of minutes."

Analysis of data from five separate secondary eclipse observations indicates that TRAPPIST-1 b has a dayside temperature of about 500 Kelvin, or roughly 230°C. The team thinks the most likely interpretation is that the planet does not have an atmosphere.

"We compared the results to computer models showing what the temperature should be in different scenarios," explained Ducrot. "The results are almost perfectly consistent with a blackbody made of bare rock and no atmosphere to circulate the heat. We also didn't see any signs of light being absorbed by carbon dioxide, which would be apparent in these measurements."

This research was conducted as part of Guaranteed Time Observation (GTO) program 1177, which is one of eight approved GTO and General Observer (GO) programs designed to help fully characterize the TRAPPIST-1 system. Additional secondary eclipse observations of TRAPPIST-1 b are currently in progress, and now that they know how good the data can be, the team hopes to eventually capture a full phase curve showing the change in brightness over the entire orbit. This will allow them to see how the temperature changes from the day to the night side and confirm if the planet has an atmosphere or not.

"There was one target that I dreamed of having," said Lagage, who worked on the development of the MIRI instrument for more than two decades. "And it was this one. This is the first time we can detect the emission from a rocky, temperate planet. It's a really important step in the story of discovering exoplanets."

More information: Thomas Greene, Thermal Emission from the Earth-sized Exoplanet TRAPPIST-1 b using JWST, *Nature* (2023). [DOI: 10.1038/s41586-023-05951-7](https://doi.org/10.1038/s41586-023-05951-7).
www.nature.com/articles/s41586-023-05951-7

Provided by European Space Agency

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