NIRISS instrument on Webb maps an ultra-hot Jupiter-like exoplanet's atmosphere

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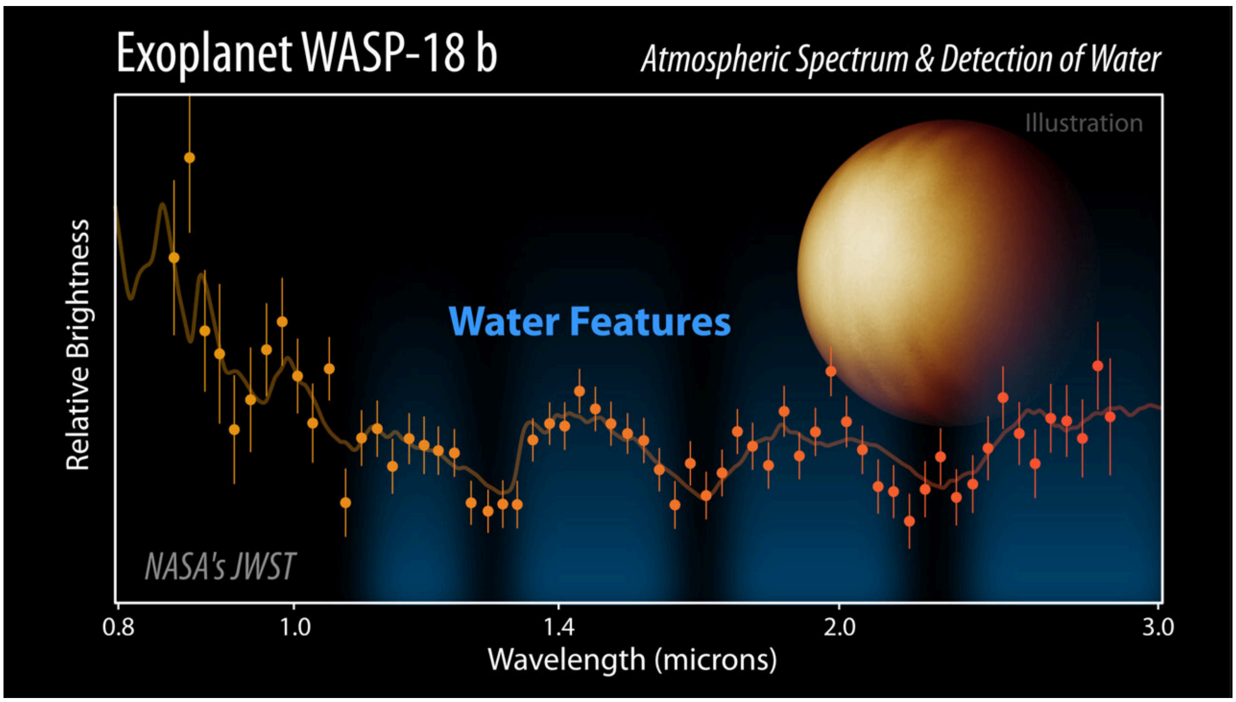


The team obtained the thermal emission spectrum of WASP-18 b by measuring the amount of light it emits over the Webb Telescope's NIRISS SOSS 0.85 - 2.8 micron wavelength range, capturing 65% of the total energy emitted by the planet. WASP-18 b is so hot on the day side of this tidally locked planet that water molecules would be vaporized. Webb directly observed water vapor on the planet in even relatively small amounts, indicating the sensitivity of the observatory. Credit: NASA/JPL-Caltech (R. Hurt/IPAC)

400 light-years out there is something that is so tantalizing that astronomers have been studying it since its discovery in 2009. One orbit for WASP-18 b around its star that is slightly larger than our sun takes just 23 hours. There is nothing like it in our solar system.

A new study led by Université de Montréal Ph.D. student Louis-Philippe Coulombe about this exoplanet, an ultra-hot gas giant 10 times more massive than Jupiter, based on new data from the Canadian NIRISS instrument on the James Webb Space Telescope (JWST) holds many surprises.

Mapping an exoplanet

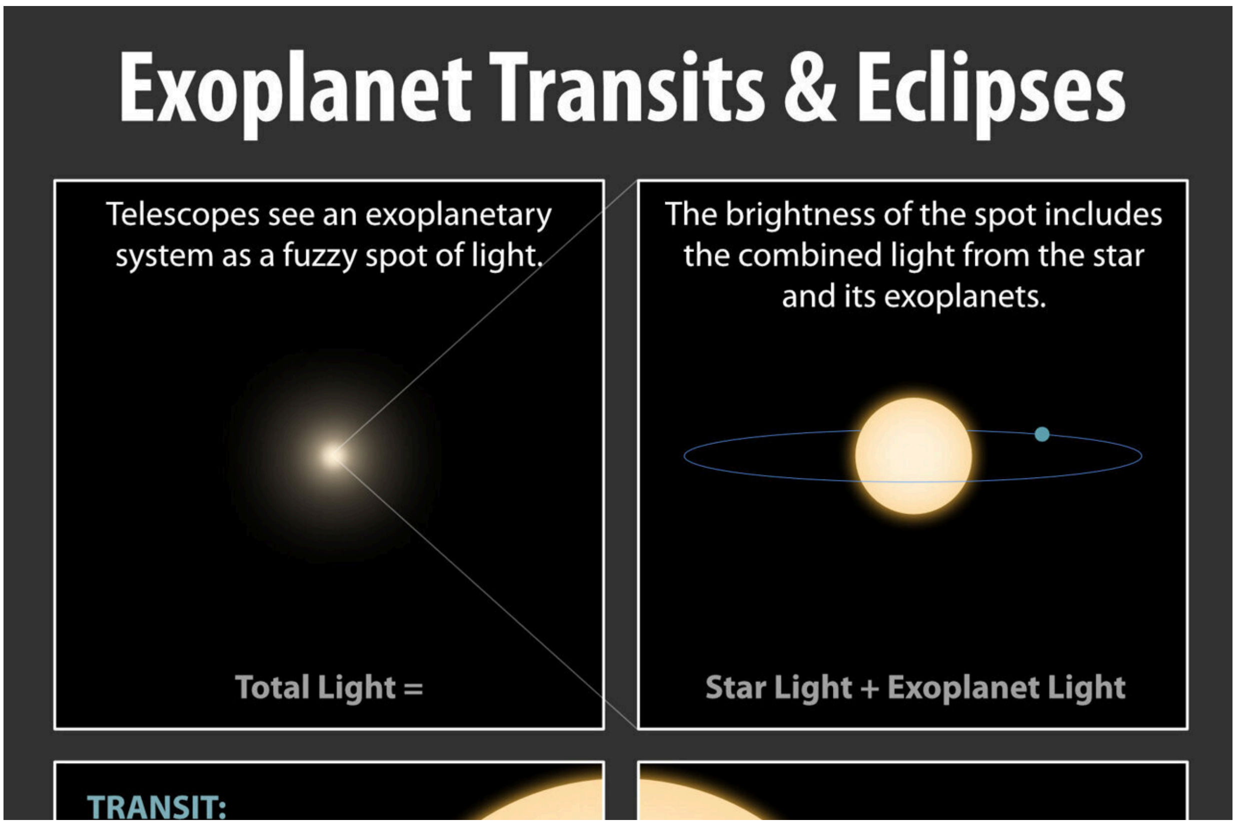
An international team of astronomers have identified water vapor in the atmosphere of the exoplanet WASP-18 b and made a temperature map of the planet as it slipped behind, and reappeared from, its star. This event is known as a secondary eclipse. Scientists can read the combined light from the star and planet, then refine the measurements from just the star as the planet moves behind it.

The same side, known as the dayside, of WASP-18 b always faces its star, just as the same side of the Moon always faces Earth. This is called tidal locking. The temperature, or brightness, map of the exoplanet shows a huge change in temperature—up to 1,000 degrees—from the hottest point facing the star to the terminator, where day and night sides of the tidally-locked planet meet in permanent twilight.

"JWST is giving us the sensitivity to make much more detailed maps of hot giant planets like WASP-18 b than ever before. This is the first time a planet has been mapped with JWST, and it's really exciting to see that some of what our models predicted, such as a sharp drop in temperature away from the point on the planet directly facing the star, is actually seen in the data," said Megan Mansfield, a Sagan Fellow at the University of

Arizona, and one of the authors of the paper describing the results.

The team mapped temperature gradients across the day side of the planet. Given how much cooler the planet is at the terminator, there is likely something hindering winds from efficiently redistributing heat to the night side. But what is affecting the winds is still a mystery.

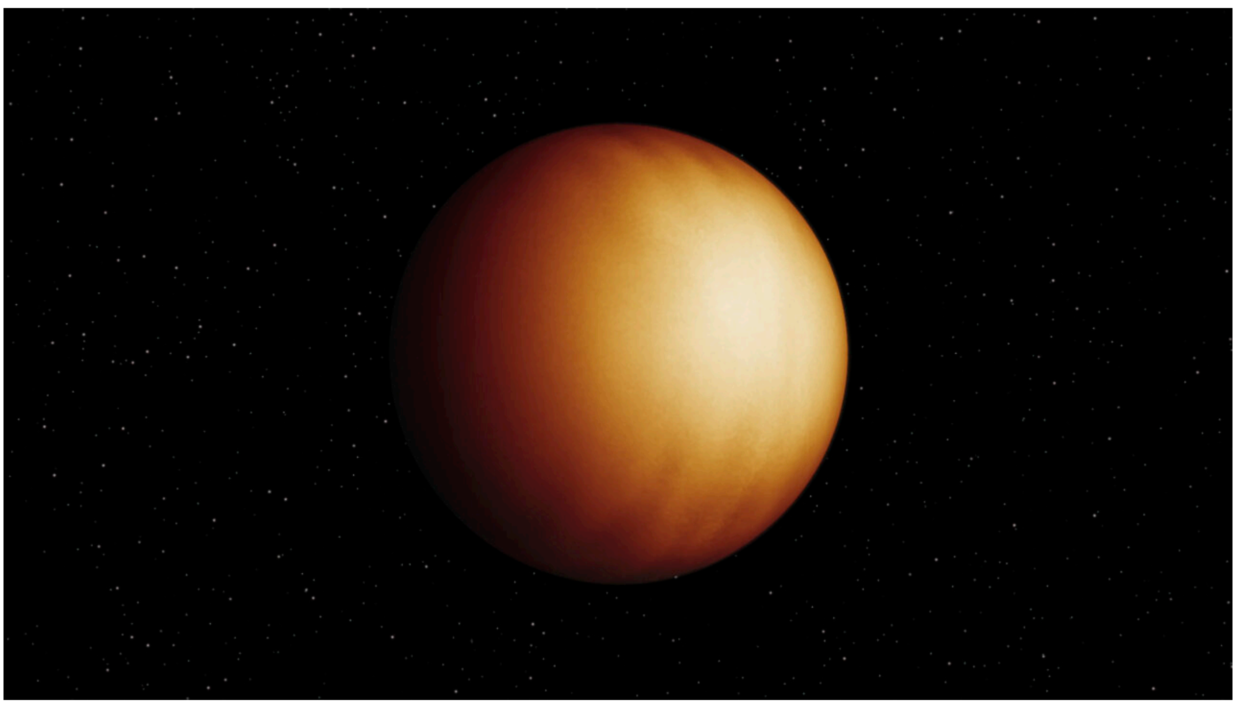


This infographic explains how astronomers use exoplanet transits and eclipses to learn more about these distant worlds. Credit: NASA/JPL-Caltech/R. Hurt

"The brightness map of WASP-18 b shows a lack of east-west winds that is best matched by models with atmospheric drag. One possible explanation is that this planet has a strong magnetic field, which would be an exciting discovery," said co-author Ryan Challener, of the University of Michigan.

One interpretation of the eclipse map is that magnetic effects force the winds to blow from the planet's equator up over the North pole and down over the South pole, instead of East-West, as we would otherwise expect.

Researchers recorded temperature changes at different elevations of the gas giant planet's layers of atmosphere. They saw temperatures increase with elevation, varying by hundreds of degrees.



WASP-18 b, seen in an artistic illustration, is a gas giant exoplanet 10 times more massive than Jupiter that orbits its star in just 23 hours. Researchers used the NIRISS instrument on the James Webb Space Telescope to study the planet as it moved behind its star. Temperatures there reach 2,700 degrees Celsius. Credit: NASA/JPL-Caltech/K. Miller/IPAC

Signs of water vapor

The spectrum of the planet's atmosphere clearly shows multiple small but precisely measured water features, present despite the extreme temperatures of almost 2,700 degrees Celsius. It is so hot that it would tear most water molecules apart, so still seeing its presence speaks to Webb's extraordinary sensitivity to detect remaining water. The amounts recorded in WASP-18 b's atmosphere indicate water vapor is present at various elevations

"It was a great feeling to look at WASP-18 b's JWST spectrum for the first time and see the subtle but precisely measured signature of water," said Louis-Philippe Coulombe, a Ph.D. student at the Université de Montréal, member of the Trottier Institute for Research on Exoplanets (iREx) and lead author of the WASP-18 b paper.

"Using this kind of measurements, we will be able to detect such molecules for a wide range of planets in the years to come," added Björn Benneke, UdeM Professor, iREx member and co-author of this paper. Benneke is Coulombe's Ph.D. advisor as well and has been leading worldwide efforts to study WASP-18 b since 2016.

The work of the NIRISS instrument and early career scientists

The team of astronomers observed WASP-18 b for about six hours using one of Webb's instruments, the Near-Infrared Imager and Slitless Spectrograph (NIRISS), contributed by the Canadian Space Agency and several partners including the Université de Montréal and iREx.

"Because the water features in this spectrum are so subtle, they were difficult to identify in previous observations. That made it really exciting to finally see water features with these JWST observations," said Anjali Piette, a postdoctoral fellow at the Carnegie Institution for Science and one of the authors of the new research.

The WASP-18 b observations were collected as part of the Transiting Exoplanet Community Early Release Science Program led by Natalie Batalha, an astronomer at the University of California, Santa Cruz, who helped coordinate the new research and the more than one hundred researchers in the team. Much of this ground-breaking work is being done by early career scientists like Coulombe, Challener, Piette, and Mansfield.

Proximity, both to its star and to us, helped make WASP-18 b such an intriguing target for these scientists, as did its large mass. WASP-18 b is one of the most massive worlds whose atmospheres we can investigate. Astronomers are striving to understand how such planets form and come to be where they are in their systems. This, too, has some early answers from Webb.

"By analyzing WASP-18 b's spectrum, we not only learn about the various molecules that can be found in its atmosphere but also about the way it formed. We find from our observations that WASP-18 b's composition is very similar to that of its star, meaning it most likely formed from the leftover gas that was present just after the star was born," Coulombe said. "Those results are very valuable to get a clear picture of how strange planets like WASP-18 b, which have no counterpart in our solar system, come to exist."

The paper appears in *Nature*.

More information: Louis-Philippe Coulombe et al, A broadband thermal emission spectrum of the ultra-hot Jupiter WASP-18b, *Nature* (2023). DOI: 10.1038/s41586-023-06230-1

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