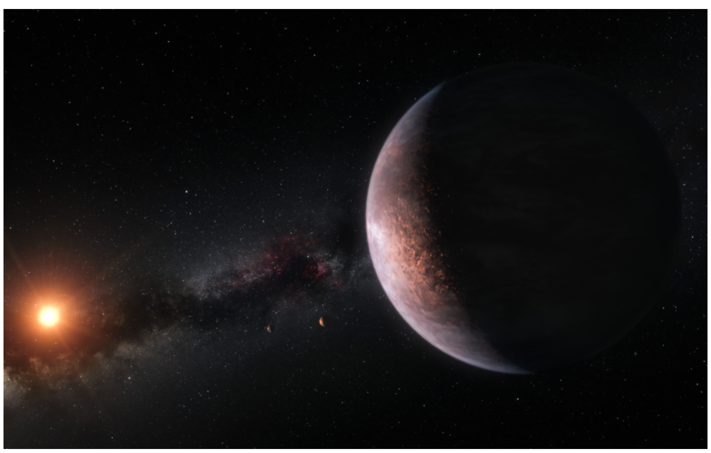
Webb Telescope Searches for Exoplanet Atmospheres

The recent detection of CO_2 around a distant Jupiter-like planet spurs optimism for detecting atmospheric gases around Earth-like planets orbiting faraway stars.

By **Rachel Berkowitz**

In 2017 astronomers observed seven Earth-sized planets orbiting a small, cool star called TRAPPIST-1 in the constellation Aquarius. Three of these exoplanets lie within the star's habitable zone, the distance from the star at which a planet with Earth's atmosphere could host liquid water. But do these planets, and the other exoplanets orbiting distant stars, have the atmospheric conditions necessary for liquid water? Do they have any atmosphere at all? Using the recently launched James Webb Space Telescope (JWST), researchers now hope to answer these questions.

Jacob Lustig-Yaeger, an astronomer at the Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland, coleads a program on the JWST to search for signs of an atmosphere on multiple exoplanets, including one in the TRAPPIST-1 system. His observations involve sifting through the spectrum of light that gets absorbed by the planet's atmosphere as it passes between us and its host star. He is looking for the spectral signature of common molecules—such as water, carbon dioxide (CO_2), and methane—that are found in the atmospheres of Earth and some of its rocky inner planet neighbors. "If we find any one of these molecules in the planet spectra that we get from JWST, then we will have detected the atmosphere," says Lustig-Yaeger. Under the right circumstances, some of these molecules may also represent so-called biosignature gases, defined as those that can be produced by life and can accumulate in an atmosphere to detectable levels.



An artist's impression of the TRAPPIST-1 planetary system shows an ultracool dwarf star and the rocky planets that orbit it.
Credit: ESO/M. Kornmesser

JWST has already shown that it is up to the task of spotting molecules around distant worlds. In August, JWST detected a clear signal of CO_2 in the absorption spectrum of WASP-39b, a Jupiter-like planet 700 light-years away from Earth [**1**]. That observation marked the first direct detection of this important atmospheric gas on an exoplanet. But a key goal for JWST exoplanet observers is to detect CO_2 signatures in the spectra of Earth-like rocky planets. The presence of this greenhouse gas would not only reveal information about these exoplanets, but it might also help piece together the history of Venus and Mars, both of which are rich in CO_2. "If you have CO_2-dominated atmospheres [around exoplanets], then you can extrapolate pathways that led to what we see in our Solar System," says Néstor Espinoza, an astrophysicist at the Space Telescope Science Institute in Maryland.

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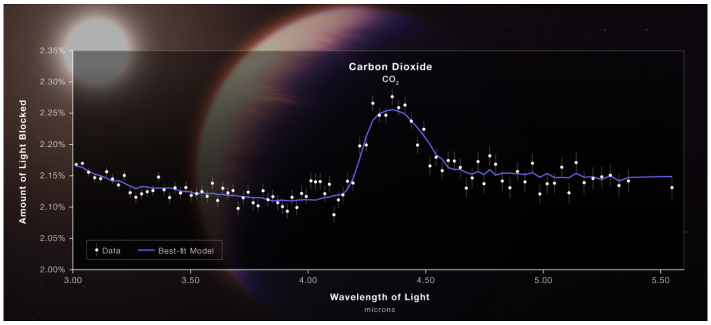

A transmission spectrum of the hot gas giant exoplanet WASP-39b captured by JWST's Near-Infrared Spectrograph on July 10, 2022. The bump reveals the first clear evidence for CO_2 in a planet outside the solar system.
Credit: NASA; ESA; CSA; L. Hustak/STScI; JWST Transiting Exoplanet Community Early Release Science Team

JWST isn't the first space telescope to seek infrared signals from exoplanet atmospheres. Its predecessor, the Hubble Space Telescope, looked for water vapor in a limited range of wavelength measurements between 1.1 to 1.7 μm. "Hubble struggled for many years to find a little bump of water in exoplanet spectra," says Everett Schlawin, of the University of Arizona, a member of the JWST Near Infrared Camera team. It wasn't until 2013 that **Hubble detected a water-vapor signature** in the atmosphere of an exoplanet. In contrast, JWST can look for a multitude of molecules, including CO_2 and other carbon-bearing species, using spectrometers that cover the wavelength range from 0.6 to 12 μm. The telescope also benefits from high spectral resolution that enables relatively faint molecular features to be detected. "Now we're searching for bumps from other molecules, and maybe cloud particles or haze that could be in atmospheres," says Schlawin.

The telescope can study exoplanets in other ways. Using JWST's 6.5-m-wide primary mirror, researchers will be able to collect infrared light coming directly from an exoplanet's surface. These measurements can be made at different points in the planet's orbit, providing clues about the temperature and pressure conditions in different regions on the planet's surface. The result will be maps of exoplanets that show seasonal variations, atmospheric composition, presence or absence of clouds, details of the planetary heat distribution, and more. JWST's detailed observations will allow for improved theories about planetary evolution and habitability. "Before JWST, these higher-dimensional models were very difficult to test," says Espinoza.

However, JWST does not need to detect atmospheric signatures to prove its worth. For small M-dwarf stars, such as TRAPPIST-1, astronomers are uncertain whether the conditions are right for planetary atmospheres to develop. Therefore, finding a planet without an atmosphere is equally as important as finding one with a rich atmosphere, says Megan Mansfield, an exoplanet spectroscopist at the University of Arizona. She will use JWST to observe exoplanet Gl 486b orbiting an M-dwarf star in the constellation Virgo. "If the planet doesn't have an atmosphere, we're still going to be able to get a spectrum of light from the planet, but it will be coming directly from the surface of the planet," she says, providing a chance to learn about surface features and how the rocks formed.

With a surface temperature of 700 K, planets like GI 486b are too hot to be habitable. And high-energy flares from their host stars may strip atmospheres off the small rocky planets early in their lifetime. Studying these hot exoplanets can provide a better understanding of the conditions needed for a planet to retain an atmosphere. "Mercury, for instance, had its atmosphere blown away because it's so close to the Sun," Espinoza says. "The lack of atmosphere tells you a lot about the planet's formation history."

The JWST researchers have no doubt that upcoming observations will reveal surprises that lead to new questions and ultimately significant new insights into planetary atmospheres. The first JWST spectra from WASP-39b and other hot Jupiters agree with both Hubble observations and theoretical predictions. "But [those spectra] also contain intriguing hints of the unexpected. That's pretty much a best-case scenario for science," says Lustig-Yaeger.

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REFERENCES

1. JWST Transiting Exoplanet Community Early Release Science Team, "Identification of carbon dioxide in an exoplanet atmosphere," **Nature (2022).**