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Astronomy

JWST ends game of hide and seek with methane

Gloria Guilluy

The space telescope has helped to determine the atmospheric composition of an exoplanet using the light spectrum of its host star. Spectral changes as the planet orbits the star reveal the long-sought presence of exoplanetary methane. **See p.709**

Exoplanetary science is no longer about simply hunting for planets outside the Solar System – it is now in an era of atmospheric characterization. Investigating the atmospheres of distant worlds could help to solve the puzzles of how planets form and migrate, because the path of a planet's evolution shapes its atmospheric composition[1]. These studies typically focus on molecules rich in oxygen and carbon, such as water, carbon dioxide, carbon monoxide and methane. However, space telescopes have not found methane in the atmosphere of an exoplanet orbiting close to its host star. On page 709, Bell *et al.*[2] used the James Webb Space Telescope (JWST) to obtain robust evidence of methane in the atmosphere of a Jupiter-like exoplanet known as WASP-80b. The study ends the search for exoplanetary methane and reaffirms JWST's extraordinary capabilities.

WASP-80b is a gas-giant exoplanet that orbits a small red star about every three days. Although it is about the size of Jupiter, WASP-80b has only about half its mass. And just as the Moon does with Earth, WASP-80b always presents the same face – its dayside – to its companion. With a temperature of 800 kelvin, WASP-80b is hotter than any planet in the Solar System. Yet, it is considered only 'warm' in the context of exoplanets, because extreme conditions can result in much higher temperatures, reaching nearly 5,000 K.

The 2012 discovery of WASP-80b was made possible by the planet's relatively large size compared with its star[3]. This feature also makes WASP-80b a good candidate for atmospheric studies, which scientists have undertaken with both ground- and space-based telescopes. These investigations uncovered a weak signal of water and a potential detection of carbon dioxide, but no methane was detected by space-borne instruments[4,5]. However, ground-based observations[6] detected methane in the atmosphere at WASP-80b's terminator (the boundary line between the dark and illuminated sides of the planet), making new observations essential to confirm its presence in the planet's atmosphere.

The prospect of finding methane in the atmosphere of an exoplanet is intriguing for several reasons, but two factors are key. First, methane has a pivotal role in determining the carbon content of giant planets in the Solar System[7], so accurate measurements of this molecule in exoplanetary atmospheres offer a basis for comparing our giants with planets orbiting other stars – and, in particular, their formation and migration pathways.

Second, much like the presence of water on a planet's surface, methane in the atmosphere can be construed as a potential hint of life. However, the presence of methane alone is insufficient to declare a planet habitable, because non-biological processes can also generate this molecule. But the occurrence of methane mixed with other gases, such as carbon dioxide, might be harder to explain with non-biological processes alone. Methane is especially suggestive in atmospheres with negligible carbon monoxide, which microbial life consumes in vast quantities[8].

Bell and colleagues' detection of methane in WASP-80b's atmosphere, therefore, holds profound significance. The first step in studying an exoplanetary atmosphere is to capture a direct image of it. However, for planets, such as WASP-80b, that orbit close to their host stars, distinguishing the two celestial bodies poses an immense challenge because the star is much brighter than the planet, and therefore hides it. To overcome this problem and explore the composition of WASP-80b's atmosphere, Bell *et al.* used a clever comparative technique.

The authors initially explored the exoplanet's atmosphere at its terminator (Fig. 1). First, JWST was trained only on the star, so that the team could measure the spectrum of light emanating from it. Later, during WASP-80b's transit in front of its star,

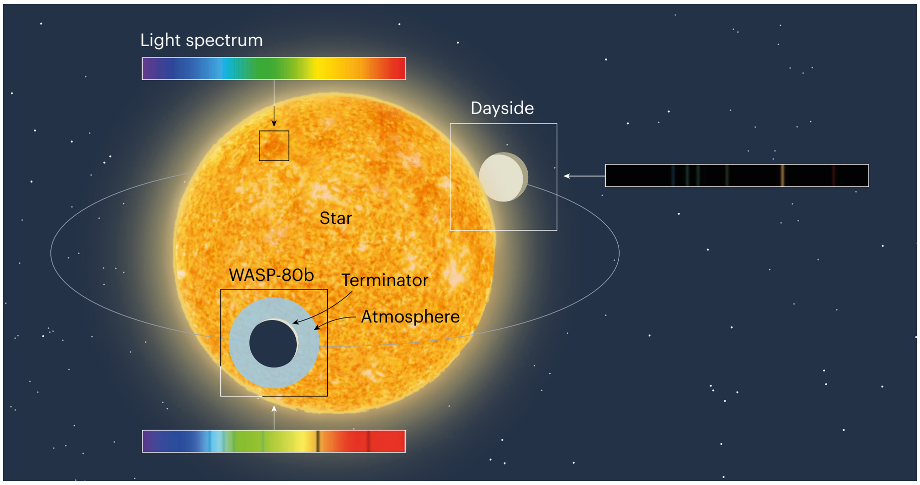

Figure 1 | Detecting methane in the atmosphere of the exoplanet WASP-80b. Bell *et al.*[2] used the James Webb Space Telescope (JWST) to investigate the chemical components in the atmosphere of WASP-80b, with a specific focus on methane. As the planet transited in front of its host star, light from the star passed through the planet's atmosphere at the terminator (the boundary between the dark and illuminated sides of the planet), creating lines in the light spectrum captured by the telescope, corresponding to specific molecules. By comparing this spectrum with that of the star alone, the authors could reveal the atmosphere's composition at the terminator. A similar comparison was made of the composition on the planet's 'dayside' as it moved behind the host star. Using this technique, the authors found a signature consistent with methane in the atmosphere at both the terminator and dayside.

Bell and colleagues recorded the spectrum again. Each atmospheric component absorbs stellar light at a distinct frequency, like a unique fingerprint, so by comparing the two spectra acquired and analysing which frequencies were missing during WASP-80b's transit (known as the primary eclipse) the researchers could infer the atmospheric composition at the planet's terminator.

Bell *et al.* also measured the light emitted by the planet's dayside. To achieve this, JWST observed the WASP-80 system during the secondary eclipse, when the planet disappeared behind the star. Through the comparison of the star's spectrum alone (collected during the eclipse) with the combined spectrum of both the star and planet (obtained just before and after the secondary eclipse), the researchers were able to separate the light coming from the planet's dayside and hence determine its atmospheric composition.

The team's measurements show evidence of methane, along with water, in the planet's atmosphere at both the terminator and the dayside. The methane concentration seems to be the same in these two regions, indicating a well-mixed atmosphere. The findings suggest that the composition of WASP-80b's atmosphere differs from that of the Sun in terms of both the carbon-to-oxygen ratio and the concentration of heavy metals. However, the measurements were not precise enough to make definitive speculations about the planet's formation, and this emphasizes the need to access a broader wavelength range than is possible with the particular JWST instrument used by Bell and colleagues.

Nonetheless, the limitations of JWST's predecessors are implicit in the absence of methane in previous studies of transiting planets made with space telescopes. These limitations are attributed to the small wavelength coverage of the instruments, warranting a re-evaluation of planets previously observed with space-based instruments. This is especially pertinent for warm exoplanets, for which chemical models predict methane to be the main carbon-bearing species.

Bell and colleagues found convincing evidence for methane using just one JWST instrument, offering limited wavelength coverage. Their success in this protracted game of hide and seek suggests that using the full spectral capabilities of JWST could offer valuable insights into exoplanet formation, migration and, in turn, comparisons with planets in our Solar System. These efforts might also provide crucial insights into the potential habitability of exoplanets, particularly those that have the perfect combination of characteristics for hosting life — another game worth playing.

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1. Madhusudhan, N. *et al. Space Sci. Rev.* **205**, 285–348 (2016).
2. Bell, T. J. *et al. Nature* **623**, 709–712 (2023).
3. Triaud, A. H. M. J. *et al. Astron. Astrophys.* **551**, A80 (2013).
4. Wong, I. *et al. Astron. J.* **163**, 175 (2022).
5. Tsiaras, A. *et al. Astron. J.* **155**, 156 (2018).
6. Carleo, I. *et al. Astron. J.* **164**, 101 (2022).
7. Guillot, T. *et al.* Preprint at https://arxiv.org/abs/2205.04100 (2022).
8. Thompson, M. A. *et al. Proc. Natl Acad. Sci. USA* **119**, e2117933119 (2022).

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Biophysics

Protein condensation regulates water in cells

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Proteins can condense to form membraneless organelles, which act as vessels for biochemical reactions in cells. An investigation shows that protein condensation is also a cellular mechanism for controlling water availability. **See p.842**

Cells maintain an internal pool of water that is essential for biological processes. Moreover, they need to regulate this water supply quickly in response to environmental challenges that affect water availability — such as high temperatures or imbalances of dissolved molecules — to prevent damage and maintain their normal functions. On page 842, Watson *et al.*[1] show that subcellular-scale phase transitions involving the condensation of proteins and the redistribution of water molecules[2] can enable such rapid responses.

One way in which cells control their internal chemical environment is by allowing the entry or exit of water across the cell membrane through osmosis. Osmosis is the passive transport of water across a semi-permeable membrane, and depends on the relative concentrations of dissolved molecules (solutes). That is, if the solution outside the cell is hypo-osmotic (the solute concentration is lower than that in the cell), then water is driven into the cell. The opposite is true in hyperosmotic conditions (in which the solute concentration is higher outside than in the cell). However, the known cellular regulatory mechanisms that combat osmotic fluctuations operate on timescales of minutes to hours[1,3], and might not be fast enough to protect cells when rapid environmental changes occur.

> **"Biomolecular condensates act as a buffer against environmental changes that could have catastrophic consequences for cells."**

Moreover, molecules in aqueous environments, such as the inside of a cell, are hydrated. In other words, they are surrounded by a layer (or sometimes a few layers) of ordered water molecules around the dissolved molecule. In cells, this 'bound' water is distinct from the disordered, 'free' water that constitutes the rest of the aqueous cytoplasm. Water in cells helps to determine the conformation of macromolecules such as proteins, thereby affecting the functions of these molecules. And because chemical groups exposed on the surface of macromolecules interact with water, those molecules can reciprocally affect the fractions of water that are bound or free[4].

Besides their hydration by intracellular water, proteins and other macromolecules can also associate with each other. These interactions can reorganize the macromolecules in a way that causes them to form distinct phases in cells[5,6], a process known as biomolecular phase separation. The resulting phases are called biomolecular condensates, and can concentrate and segregate macromolecules into membraneless organelles. These organelles thus act as self-assembled containers for biochemical reactions in cells.

Condensates contain water interspersed between neighbouring macromolecules, hydrating the surfaces of those molecules and facilitating their interactions. Some evidence points to a connection between water-mediated interactions and biomolecular phase separation, such that the association of proteins in condensates expels some bound water from protein surfaces[2,7]. This prompted Watson *et al.* to study how biomolecular phase separation affects the equilibrium between bound and free water in cells.

The authors first showed that the chemical responses of cells to changes in environmental