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EXTRASOLAR PLANETS

A whiff of methane

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Investigations of planets outside our Solar System are becoming ever more sophisticated. The latest development is the discovery of a carbon-containing molecule in the atmosphere of one such extrasolar body.

Methane is a constituent of many of the atmospheres in our Solar System: those of Earth, Mars, Titan and the gas giants, Jupiter, Saturn, Uranus and Neptune, all contain traces of it. Despite its low abundance, the methane provides telling clues about planetary formation, evolution, weather, photochemistry and — in the case of Earth — life. We have discovered more than 270 planets outside our Solar System, but for most of them we know nothing more than their mass and orbital properties. Owing to their immense distances from us, and their feeble brightness relative to the incandescence of the stars they orbit, observationally inferring anything about their composition is extremely difficult.

That, however, is just what Swain *et al.*[1] have achieved. On page 329 of this issue, they present the first detection of methane, CH_4, on an extrasolar planet. They also confirm a previous detection[2] of water vapour in the atmosphere of this planet, called HD 189733b, and provide a more robust estimate of its abundance. The planet is a 'hot Jupiter' that orbits only 0.03 Earth–Sun distances from its star. Blasted by starlight, the planet's atmospheric temperatures reach a searing 1,000 K.

Swain and colleagues' finding is the first detection of any carbon-bearing molecule on a planet outside our Solar System. It was made possible by the fact that HD 189733b is a transiting planet — one whose orbit is fortuitously aligned such that the planet periodically passes in front of its star as viewed from Earth. Such transits are relatively easy to detect, even using small telescopes on Earth[3]. In the case of HD 189733b, the planetary transit blocks more than 2% of the starlight, allowing a direct estimate of the planet's radius. Much harder to detect are the subtle variations of this absorption with wavelength that yield clues to atmospheric composition. At wavelengths at which the atmosphere is transparent, starlight passes through the atmosphere unimpeded. At wavelengths that are more opaque, the atmosphere blocks the starlight and the total absorption seen from Earth is greater (Fig. 1). In this way, Swain *et al.*[1] used observations from the NICMOS camera on the Hubble Space Telescope to construct an infrared spectrum of the planet as seen in transmitted starlight; that spectrum shows the tell-tale absorption features of methane and water vapour in the planet's atmosphere.

So what does the measurement tell us about planetary behaviour? The methane abundances on Jupiter, Saturn and both Uranus and Neptune correspond to respective carbon/hydrogen ratios of 3, 7 and ~30–40 times the C/H ratio in the Sun's atmosphere (where carbon resides entirely in atomic form). This provides important clues about planetary formation, because it suggests that these planets not only received carbon from the gas of the solar nebula (which presumably had nearly the solar C/H ratio), but that they also absorbed huge quantities of carbonaceous rocky and icy material as they were forming. For extrasolar planets, one thus expects the C/H ratio (as well as the ratio of other heavy elements to hydrogen) to provide a crucial probe of how much solid material accreted with the gas.

But the story is more complicated for HD 189733b. The observationally inferred methane abundance[1] corresponds to a mole fraction (that is, a ratio of methane to background hydrogen-rich gas) of only 5×10^{-5} or less, which corresponds to only 10% or less of the C/H ratio of the parent star. So where is all the carbon? Methane becomes thermodynamically disfavoured as the temperature rises above 1,000 K; under such conditions, carbon prefers to combine with oxygen to form carbon monoxide (CO) instead. Because the temperature of HD 189733b lies near this transition point, early predictions[4] suggested that the dominant carbon carrier would be CO but that detectable quantities of methane would also exist. The discovery of methane at abundances much less than solar thus makes sense theoretically. Consistent with these ideas, models[5] of an infrared emission spectrum of HD 189733b, recently produced with data gathered by the Spitzer Space Telescope[6], suggest the indirect signature of CO.

Interestingly, Swain *et al.*[1] and Tinetti *et al.*[2] infer a water-vapour mole fraction of 5×10^{-4} for HD 189733b. This value has important implications for the planet's O/H and C/H ratios and hence provides constraints on planetary formation and evolution. How so? For solar elemental ratios — thought to be similar to abundances in the planet's host star — about one oxygen atom is available per 10^3 hydrogen molecules. Likewise, about half a carbon atom is available per 10^3 hydrogen molecules. If carbon resides primarily in CO, as expected for HD 189733b, then the CO locks up half the oxygen atoms, leaving the other half to form water and implying a water mole fraction of about 5×10^{-4}. According to this chain of logic, the inferred water abundance on HD 189733b implies C/H and O/H ratios that are consistent with the values in our Sun and, potentially, in the planet's star. Although lack of knowledge of the C/O ratio on HD 189733b prevents a definitive assessment, these constraints hint that — unlike the giant planets in our Solar System — HD 189733b is not substantially enriched in heavy elements (such as carbon and oxygen) relative to its parent star.

The methane abundance could also hold clues to the exotic weather on this hot Jupiter. If the atmospheric composition is in chemical equilibrium, the carbon on the hot dayside should reside almost entirely in CO, whereas methane would be important on the colder night side. A day–night map of temperatures on this planet[7] suggests the existence of fast winds that can rapidly homogenize the temperature. Because of the finite time needed to interconvert between methane and CO, the methane and CO abundances (and their spatial variation) surely contain information about the atmospheric temperatures and transport timescales[8]. Additional observations and models will be needed to extract this information.

These are exciting times for studies of extrasolar planets. The past few years have seen an avalanche of unprecedented observations constraining the physical properties of HD 189733b and other transiting hot Jupiters. Thirteen years after the discovery of the first extrasolar planet around a Sun-like star, we are finally moving beyond simply discovering such planets to truly characterizing them as worlds. Although the big guns in these discoveries — the Hubble and Spitzer space telescopes — are nearing old age, next-generation platforms such as NASA's James Webb Space Telescope are under development. We are thus now seeing but the opening salvo in a revolution that will extend humankind's view of planetary worlds far beyond the provincial boundaries of our Solar System. ■

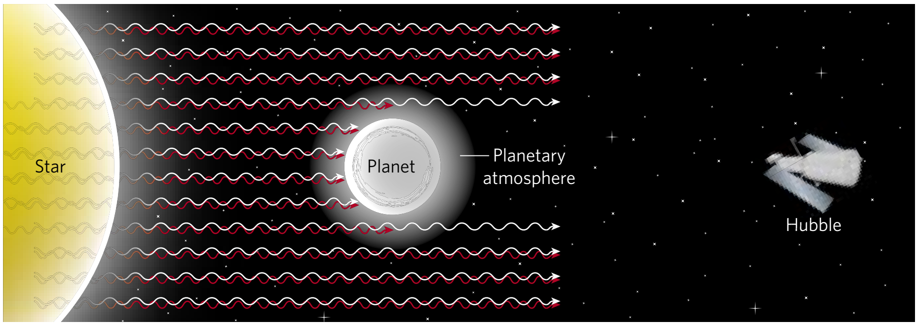

Figure 1 | Methane detection. When a planet passes in front of its star as viewed from Earth, the planetary atmosphere preferentially blocks more of the starlight at wavelengths where the atmosphere is opaque (red) and less at wavelengths where the atmosphere is transparent (white). In this way, Swain *et al.*[1] used the Hubble Space Telescope to obtain a transmission spectrum of the hot Jupiter HD 189733b, which reveals the presence of methane in the planet's atmosphere and confirms the presence of water vapour.

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