THE science BREAKER
SCIENCE MEETS SOCIETY

May 24, 2018

Earth & Space

An exoplanet with glowing water reveals its nature

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This Break was edited by Max Caine, *Editor-in-chief* - TheScienceBreaker

Space-based observatories such as the Hubble Space Telescope are providing valuable insights into the atmospheres of planets outside our solar system, known as 'exoplanets'. We have recently used Hubble to uncover the most compelling evidence to date for a stratosphere layer on one such exoplanet, known as WASP-121b.

The term 'stratosphere' refers to a region of atmosphere that is 'stratified', with limited vertical movement of the gas. This will occur if the atmosphere's temperature increases with altitude, because hot gas rises and cool gas sinks. In other words, a stratosphere is caused by upper hotter layers acting as a kind of lid on lower cooler layers of the atmosphere. On Earth, incoming ultraviolet radiation from the Sun is absorbed by ozone molecules from altitudes of about 10km to 50km, heating this upper region of the atmosphere and producing a stratosphere.

Stratospheres are seen in atmospheres throughout the solar system. Jupiter, Saturn, Uranus and Neptune all have stratospheres, driven by the absorption of near-infrared solar radiation by methane gas. Saturn's moon Titan also has a stratosphere, which is thought to be caused by smoggy aerosols in its atmosphere absorbing optical and near-infrared radiation from the Sun.

However, the solar system is just the tip of the galactic iceberg. At last count, over 3,500 exoplanets have been discovered. For a tiny subset of these, we have managed to make precise enough measurements to study their atmospheres by measuring the radiation they emit. The easiest exoplanets to study are the so-called hot Jupiters, which are Jupiter-sized planets orbiting much closer to their host stars than the Sun-Mercury distance. This is because they have thick, extended atmospheres and are heated to high temperatures by their host stars, resulting in strong thermal emission.

Theoretical models of hot Jupiter atmospheres have predicted that two atmosphere classes might exist: those with strong stratospheres (ultrahot Jupiters) and those without strong stratospheres (hot Jupiters). The basic idea is that the ultrahot Jupiters – those with atmospheres' temperatures exceeding about 2'000 degrees Celsius – could have a significant amount of titanium oxide (TiO) and vanadium oxide (VO) gas in their atmospheres. Both these compounds are highly effective at absorbing radiation at optical wavelengths, and as such, they could play a role analogous to that of ozone in the Earth's stratosphere and methane in other solar system atmospheres.

While gases such as TiO and VO will produce a heating effect by absorbing stellar energy at high altitudes, this needs to be balanced by another mechanism that simultaneously cools the atmosphere. Otherwise, the temperature would continue rising indefinitely and the system would be unstable. An efficient way to cool an atmosphere is by hot gas molecules emitting radiation. Different molecules will emit radiation in different ways, giving them unique signatures that we can search for while looking at the planet.

When we pointed Hubble at WASP-121b – a prime example of an ultrahot Jupiter – we detected glowing water gas. That is, we observed the "emitting signature"

characteristic of water molecules. Although there have previously been indications of glowing molecules in other exoplanet atmospheres, this was the first time such a phenomenon had been observed so clearly. The glowing water gas tells us that the uppermost layers of WASP-121b's atmosphere are radiating vast amounts of energy to space in order to balance some other heating process. Although we do not yet know if TiO and VO are indeed causing the heating of WASP-121b's atmosphere, we can observe a strong stratosphere, characterised by a rise in temperature up to as much as 1'000 °C.

It seems plausible that this heating is caused by the absorption of incoming stellar radiation by TiO and VO gases. WASP-121b is a prime candidate for this process, as it has a temperature that is hot enough for these gases to be abundant. To conclusively identify the mystery heat source, however, we must await further observations at higher precisions and covering a greater wavelength range. The upcoming James Webb Space Telescope will achieve both, and is set to greatly advance our knowledge of exoplanet atmospheres.