# ***AstroTalk: Behind the news headlines of September 2017***

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## ***The hunt is on for chemical analysis of atmospheres outside our solar system***

September was an interesting month for exoplanet watchers. Current instrumentation on the best telescopes on Earth and in space is now used with ever increasing frequency to detect and characterize the atmospheres of alien worlds orbiting distant stars. And it turns out that those alien worlds are sometimes anything but 'normal.'

Astronomers reported this month that the exoplanet WASP-12b reflects almost no light, making it appear essentially pitch black. Using the Space Telescope Imaging Spectrograph (STIS) on the NASA/ESA *Hubble Space Telescope*, an international team of astronomers measured how much light WASP-12b reflects—a quantity known as its 'albedo'—in order to learn more about the composition of the exoplanet's atmosphere.

The results were surprising, explains Taylor Bell from McGill University (Canada):

> "*The measured albedo of WASP-12b is 0.064 at most. This is an extremely low value, making the planet darker than fresh asphalt!*"

Indeed, this makes WASP-12b two times less reflective than our own Moon, which has an albedo of 0.12. Bell adds:

> "*The low albedo shows we still have a lot to learn about WASP-12b and other, similar exoplanets.*"

WASP-12b orbits the Sun-like star WASP-12a, located some 1400 light-years away. With a radius of almost twice that of Jupiter and a year that lasts only just over one Earth day, WASP-12b is categorized as a 'hot Jupiter,' a giant gas planet. Because it is so close to its parent star, the gravitational pull of the star has stretched the exoplanet into an egg shape and raised the surface temperature of its daylight side to 2600 degrees Celsius. This high temperature is also the most likely explanation for WASP-12b's low albedo.

> "*There are other hot Jupiters that have been found to be remarkably black, but they are much cooler than WASP-12b. For those planets, it is suggested that things like clouds and alkali metals are the reason for the absorption of light, but those don't work for WASP-12b because it is so incredibly hot,*" explains Bell.

In fact, the daylight side of WASP-12b is so hot that clouds cannot form and alkali metals are ionized, that is, some of their outermost electrons have been stripped off the atoms because of the intense radiation from the star. It is even hot enough to break up hydrogen molecules into atomic hydrogen, which causes the planet's atmosphere to act more like the atmosphere of a low-mass star than like a planetary atmosphere. This leads to its low albedo.

To measure the albedo of WASP-12b the scientists observed the exoplanet during an eclipse, when the planet was near full phase and passed behind its parent star for a period of time. This is the best method to determine the albedo of an exoplanet, because it allows direct measurements of the amount of light that is reflected. However, this technique requires a precision that is ten times greater than that of traditional transit observations. Using Hubble's Space Telescope Imaging Spectrograph, the scientists were able to measure the albedo of WASP-12b at several different wavelengths. The new data indicate that its atmosphere is composed of atomic hydrogen and helium.

WASP-12b is only the second planet to have spectrally resolved albedo measurements, after HD 189733b, another hot Jupiter. Their data allowed the astronomers to determine whether the planet reflects more light towards the blue or the red end of the spectrum. While HD 189733b is suggested to have a deep blue colour, WASP-12b does not reflect light at any wavelength. It does, however, emit light because of its high temperature, giving it a red hue similar to a hot glowing metal.

> "*The fact that the first two exoplanets with measured spectral albedo exhibit significant differences demonstrates the importance of these types of spectral observations and highlights the great diversity among hot Jupiters*," concludes Bell.

Around the same time, a team of astronomers led by Elyar Sedaghati at the European Southern Observatory (ESO) examined the atmosphere of another exoplanet, WASP-19b. WASP-19b has about the same mass as Jupiter, but—like WASP-12b—it is so close to its parent star that it completes an orbit in just 19 hours and its atmosphere is estimated to have a temperature of about 2000 degrees Celsius.

As WASP-19b passes in front of its parent star, some of the starlight passes through the planet's atmosphere and leaves subtle fingerprints in the light that eventually reaches Earth. By employing the FORS2 instrument on the Very Large Telescope at ESO's Paranal Observatory in Chile, the team was able to carefully analyse this light and deduce that the atmosphere contained small amounts of titanium oxide, water, and traces of sodium, alongside a strongly scattering global haze.

> "*Detecting such molecules is, however, no simple feat*," explains Sedaghati. "*Not only do we need data of exceptional quality, but we also need to perform a sophisticated analysis. We used an algorithm that explores many millions of spectra spanning a wide range of chemical compositions, temperatures, and cloud or haze properties in order to draw our conclusions*."

Titanium oxide is rarely seen on Earth. It is known to exist in the atmospheres of cool stars. In the atmospheres of hot planets like WASP-19b, it acts as a heat absorber. If present in large enough quantities, these molecules prevent heat from entering or escaping through the atmosphere, leading to a thermal inversion—the temperature is higher in the upper atmosphere and lower further down, the opposite of the normal situation. Ozone plays a similar role in Earth's atmosphere, where it causes inversion in the stratosphere.

In Earth's atmosphere, the stratosphere sits above the troposphere—the turbulent, active-weather region that reaches from the ground to the altitude where nearly all clouds top out. In the troposphere, the temperature is warmer at the bottom—ground level—and cools down at higher altitudes. On Earth, temperature inversion occurs because ozone in the stratosphere absorbs much of the Sun's ultraviolet radiation, preventing it from reaching the surface, protecting the biosphere, and therefore warming the stratosphere instead.

Similar temperature inversions occur in the stratospheres of other planets in our solar system, such as Jupiter and Saturn. In these cases, the culprit is a different group of molecules called hydrocarbons; methane, for instance, is responsible for heating in the stratospheres of Jupiter and Saturn's moon, Titan, for example. Neither ozone nor hydrocarbons, however, could survive at the high temperatures of most known exoplanets. This leads to a debate as to whether stratospheres would exist on them at all.

> "*The presence of titanium oxide in the atmosphere of WASP-19b can have substantial effects on the atmospheric temperature structure and circulation*," explains Ryan MacDonald at the University of Cambridge (UK). "*To be able to examine exoplanets at this level of detail is promising and very exciting*," adds Nikku Madhusudhan (University of Cambridge), who oversaw the theoretical interpretation of the observations.

The astronomers collected observations of WASP-19b over a period of more than a year. By measuring the relative variations in the planet's radius at different wavelengths of light that passed through its atmosphere and comparing the observations to atmospheric models, they could extrapolate different atmospheric properties, such as its chemical content. This new information about the presence of metal oxides and other substances will allow much better modelling of exoplanet atmospheres.

Looking to the future, once astronomers are able to observe atmospheres of possibly habitable planets, the improved models will give them a much better idea of how to interpret those observations.

> "*This important discovery is the outcome of a refurbishment of the FORS2 instrument that was done exactly for this purpose*," adds ESO team member Henri Boffin, who led the refurbishment project. "*Since then, FORS2 has become the best instrument to perform this kind of study from the ground*."

Meanwhile, in August 2017, another international team of scientists found the strongest evidence to date for a stratosphere on an enormous planet outside our solar system, with an atmosphere hot enough to boil iron. The team made the discovery by observing glowing water molecules in the atmosphere of WASP-121b with the *Hubble Space Telescope*.

Scientists used spectroscopy to analyse how the planet's brightness changed at different wavelengths of light. Water vapour in the planet's atmosphere, for example, behaves in predictable ways in response to different wavelengths of light, depending on its temperature. At cooler temperatures, water vapour in the upper atmosphere blocks light of specific wavelengths radiating from deeper layers towards space. But at higher temperatures, the water molecules in the upper atmosphere glow at these wavelengths instead.

The phenomenon is similar to what happens with fireworks, which get their colours from chemicals emitting light. When metallic substances are heated and vaporized, their electrons move into higher energy states. Depending on the material, these electrons will emit light at specific wavelengths as they lose energy: sodium produces orange-yellow and strontium produces red, for example.

The water molecules in the atmosphere of WASP-121b similarly give off radiation as they lose energy, but it is in the form of infrared light, which the human eye is unable to detect.

> "*Theoretical models have suggested that stratospheres may define a special class of ultra-hot exoplanets, with important implications for the atmospheric physics and chemistry*," said Tom Evans at the University of Exeter (UK). "*When we pointed Hubble at WASP-121b, we saw glowing water molecules, implying that the planet has a strong stratosphere*."

WASP-121b, located approximately 900 light-years from Earth, is another hot Jupiter, although with a greater mass and radius than Jupiter, making it much puffier. Like WASP-12B and WASP-19b, it orbits its parent star every 1.3 days, and is also around the closest distance it could be before the star's gravity would start ripping it apart. This close proximity also means that the top of the atmosphere is heated to a blazing hot 2500 degrees Celsius—the temperature at which iron exists in gas rather than solid form.

In solar system planets, the change in temperature within a stratosphere is typically less than 100 degrees Celsius. However, on WASP-121b, the temperature in the stratosphere rises by 1000 Celsius.

> "*We've measured a strong rise in the temperature of WASP-121b's atmosphere at higher altitudes, but we don't yet know what's causing this dramatic heating*," says Nikolay Nikolov (University of Exeter). "*We hope to address this mystery with upcoming observations at other wavelengths*."

Vanadium oxide and titanium oxide gases are candidate heat sources, since they strongly absorb starlight at visible wavelengths, similar to ozone absorbing ultraviolet radiation. These compounds are expected to be present in only the hottest of hot Jupiters, since high temperatures are required to keep them in the gaseous state. Indeed, vanadium oxide and titanium oxide are commonly seen in brown dwarfs, 'failed stars' that have some commonalities with exoplanets.

Previous research spanning the past decade has indicated possible evidence for stratospheres on other exoplanets, but this is the first time that glowing water molecules have been detected, the clearest signal yet for an exoplanet stratosphere.

> "*This new research is the smoking gun evidence scientists have been searching for when studying hot exoplanets. We have discovered this hot Jupiter has a stratosphere, a common feature seen in most of our solar system planets*," says David Sing, also at the University of Exeter. "*It's a truly exciting find as we're seeing dramatic differences planet-to-planet which is giving valuable clues in figuring out how planets behave under different conditions, and we're only just scratching the surface of all the new Hubble data*."

An example of the detection of a possible stratosphere elsewhere in the Milky Way galaxy was provided by *Hubble Space Telescope* observations of the massive and blazing-hot exoplanet known as WASP-33b only a few years ago, in 2015.

At the time, this was hailed as an important discovery, because the presence of a stratosphere can provide clues about the composition of a planet and how it formed.

> "*Some of these planets are so hot in their upper atmospheres, they're essentially boiling off into space*," said Avi Mandell, a planetary scientist at NASA's Goddard Space Flight Center in Greenbelt (USA). "*At these temperatures, we don't necessarily expect to find an atmosphere that has molecules that can lead to these multi-layered structures*."

Using Hubble's Wide Field Camera 3, which can capture a spectrum of the near-infrared region where the signature for water appears, the researchers identified a temperature inversion in the atmosphere of the hot Jupiter WASP-33b. Team members also think they know which molecule in WASP-33b's atmosphere caused the inversion—titanium oxide.

> "*These two lines of evidence together make a very convincing case that we have detected a stratosphere on an exoplanet*," said Korey Haynes of George Mason University (USA) at the time.
>
> "*Understanding the links between stratospheres and chemical compositions is critical to studying atmospheric processes in exoplanets*," said Nikku Madhusudhan. "*Our finding marks a key breakthrough in this direction*."

With our increasingly sophisticated equipment and analysis techniques, it is only a matter of time before we will be able to study the atmospheres of potentially habitable planets. Exciting times, indeed!

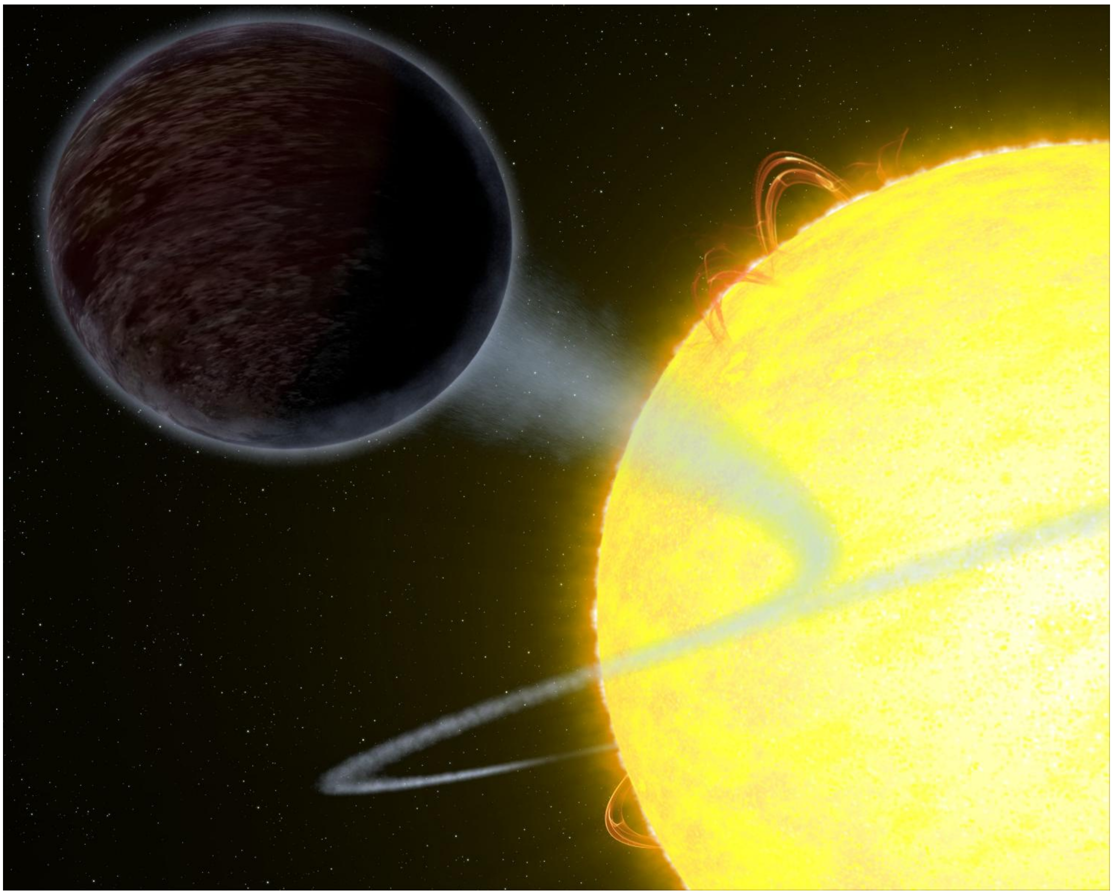

**Figure 1**: This artist's impression shows the exoplanet WASP-12b—an alien world as black as fresh asphalt, orbiting a star like our Sun. Scientists were able to measure its albedo: the amount of light the planet reflects. The results showed that the planet is extremely dark at optical wavelengths. (*Credit: NASA, ESA, and G. Bacon, STScI*)

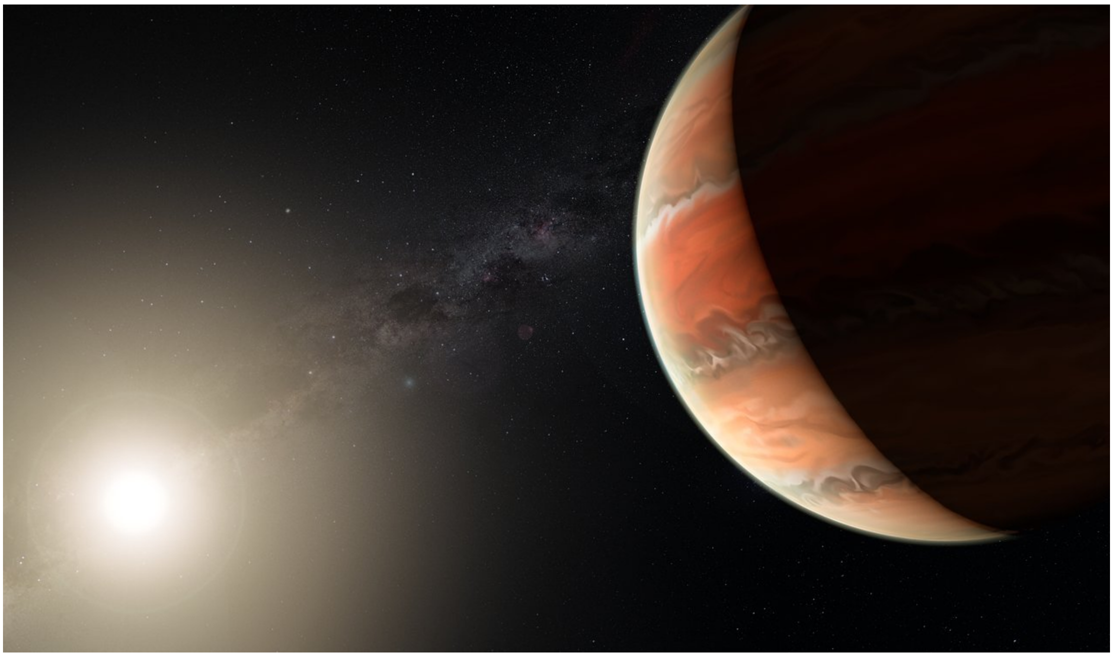

**Figure 2**: An artist's impression showing the exoplanet WASP-19b, in whose atmosphere astronomers detected titanium oxide for the first time. In large enough quantities, titanium oxide can prevent heat from entering or escaping an atmosphere, leading to a thermal inversion—the temperature is higher in the upper atmosphere and lower further down, the opposite of the normal situation. (*Credit: ESO/M. Kornmesser*)

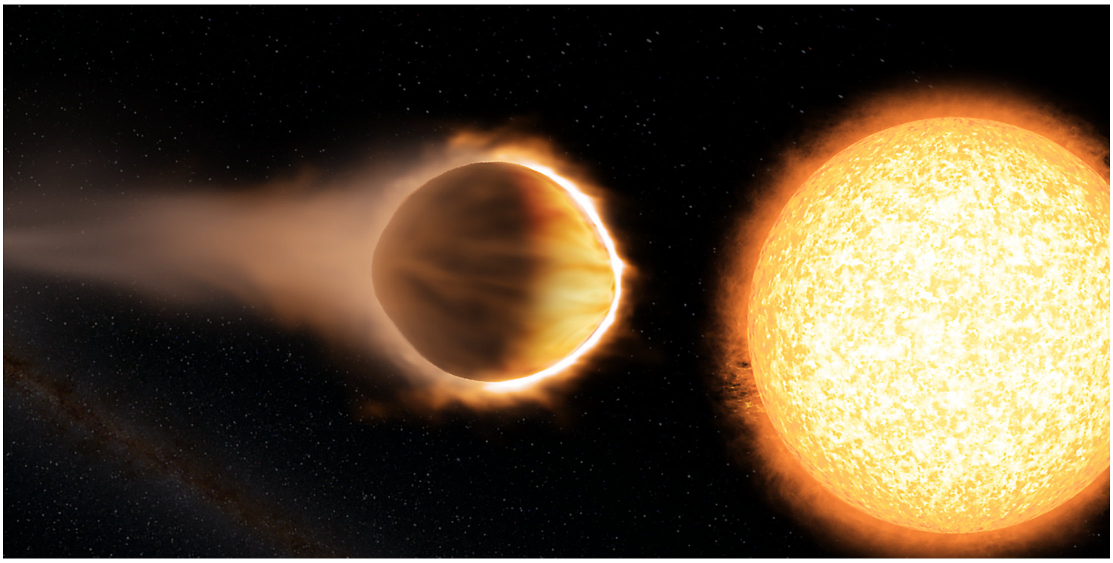

**Figure 3**: Artist's impression of WASP-121b. (*Credit: Engine House VFX, At-Bristol Science Centre, University of Exeter*)

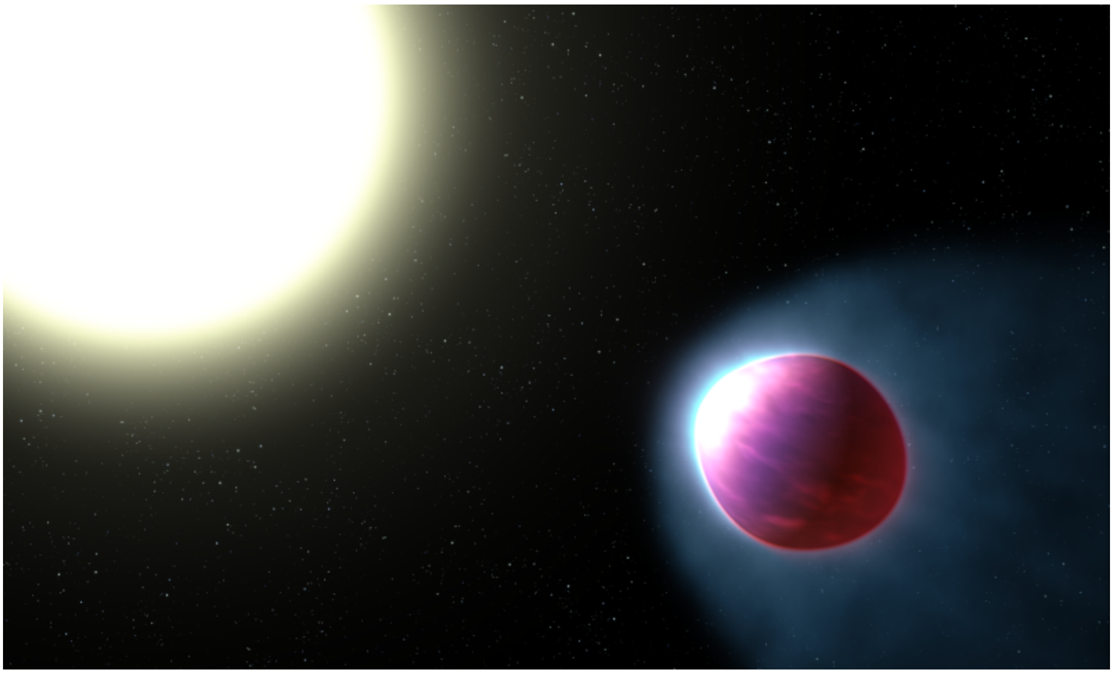

**Figure 4**: Artist's impression of WASP-121b (*Credit: NASA, ESA, and G. Bacon, STScI*)

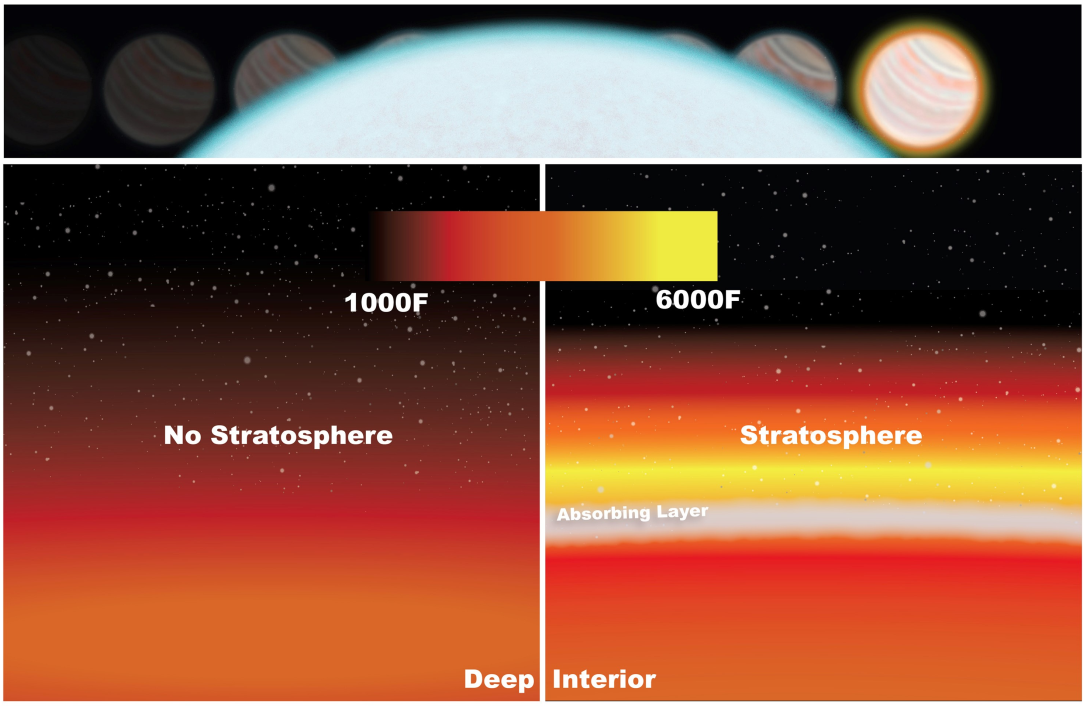


**Figure 5**: WASP-33b's stratosphere was detected by measuring the drop in light as the planet passed behind its parent star (top). Temperatures in the low stratosphere rise because of molecules absorbing radiation from the star (right). Without a stratosphere, temperatures would cool down at higher altitudes (left). (*Credit: NASA/Goddard*)