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Gaseous heavy metals in the atmosphere of an ultra-hot exoplanet

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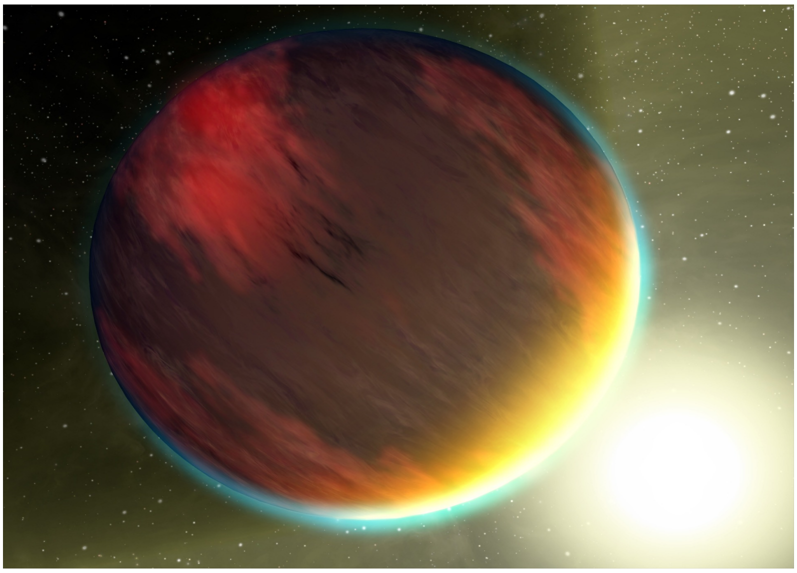
ABSTRACT

Sensitive, high-resolution spectroscopy reveals the presence of heavy metals in the gaseous atmosphere of the ultra-hot Jupiter KELT-9 b. The spectroscopic signatures of these metals provide astronomers with tools to analyse the atmosphere and trace the evolution history of the planet.



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KELT-9 is a hot blue star in the constellation Cygnus. It has a temperature of over 10,000 K and a mass that is over twice larger than the Sun. It is very luminous (though not visible with the naked eye) and as such belongs to a fairly rare class of stars in the galaxy, as the majority of the stars are lighter and cooler than the Sun. It would not have been a particularly special star however, were it not for the fact that it is orbited by a massive gas planet in a very tight orbit, that transits in front of the star as seen from Earth. This planet is named KELT-9 b, and orbits KELT-9 at a distance of 0.0365 AU, which is only 1.6 times the diameter of the star itself. At this distance, one full orbit takes approximately 1.5 days, and because the host star is so hot, the planet is heated to soaring temperatures of over 4,000 K on the illuminated side. This makes KELT-9 b the hottest exoplanet that has ever been discovered around an ordinary star.

The fact that this planet passes in front of its star every 1.5 days allows us to study its atmosphere. During the transit some starlight passes through the upper layers of the atmosphere where it is partially absorbed before moving on towards Earth. Specific wavelengths of light may be absorbed more than others depending on the chemical composition of the gas. So when we obtain a spectrum of the starlight while the planet is transiting, we have the ability to measure the presence of atoms and molecules in the atmosphere of a planet many light years away.

The atmosphere of KELT-9 b is unlike any planet in our solar system. At 4,000 K, it is more reminiscent of the outer layers of a cool star rather than the atmospheres of the solar system planets. At such temperatures, molecules have fallen apart into their atomic constituents due to collisions with other particles. Some atoms have even been stripped of an electron, meaning that the atmosphere partially ionised. The absence of molecules is a big advantage for the study of the atmosphere of KELT-9 b. The chemistry of molecules is complex. There are thousands of possible species that react with each other and may form a large variety of complexes, aerosols and dust- grains. Aerosols and dust-grains are opaque to radiation over a wide range of wavelengths, meaning that they are hard to distinguish in the spectrum of the planet, and may hide the sharper absorption lines of atoms that are also present in the gas. This molecular chemistry is hard to model a priori, and laboratory measurements under conditions that resemble the atmosphere of an extremely hot and irradiated exoplanet are difficult and expensive.

Due to its high temperature, the chemistry in the atmosphere of KELT-9 b may therefore be much easier to understand than the atmospheres of exoplanets that are somewhat cooler. In the spring of 2018, we published a paper pointing this out, and we predicted that the signatures of gaseous iron should be visible in its spectrum. We had also observed a transit of this planet with a highly stabilised and precise spectrograph designed for finding exoplanets (HARPS-North), located on the 3.58 m Italian national telescope (TNG) on the Spanish Canary island of La Palma. With these observations, we were able to test our prediction and managed to find not only the signatures of iron, but even more strongly its ionised variant (which is missing one electron) and ionised titanium in the spectrum of the atmosphere of KELT-9 b.

We proceeded to obtain another transit observation and to search for a wide range of other metals that could also be visible in the spectrum of the planet. In doing so, we discovered the unmistakable signatures of ionized scandium, chromium and yttrium. This is the first time that heavy elements have ever been observed in the atmosphere of an exoplanet, and they could give us clues about how metal-rich this planet is (meaning, which fraction is composed of hydrogen/helium and which is composed of heavier metals). The fact that these metals are mostly in ionised form confirms that the atmosphere must be very hot indeed, perhaps even significantly hotter than 4,000 K. As such, the absorption lines of metals in the spectrum of the of KELT-9 b and other hot gas giants like it, provide ideal tools with which to characterise the chemical composition of the atmospheres far away exoplanets in precise detail. These provide clues about the formation and evolution histories of these planets, and excitingly, the very same techniques will be used in the not so distant future to study cooler, rocky exoplanets, and to search them for the presence of molecules that could indicate the presence of extra-terrestrial life on the surface.