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The near-infrared helium triplet: A tracer of extended atmospheres

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Abstract

Since the early age of exoplanetology, the near infrared helium triplet was seen as one of the most promising tracer of exoplanet atmosphere. However it is only very recently, with the help of high-resolution spectrographs, that it was detected and shows already its full potential. During this talk, I will present an overview of the recent detections and non-detections of helium around a diversity of exoplanets and the first contours that can be drawn from them. I will also shed more light into two detections obtained at high-resolution around a warm-Neptune and a warm-Saturn planets that indicate the power of the helium triplet to probe the atmospheric expansion and dynamics.

1. Introduction

Spectral features of helium are difficult to detect due to their weak intensity and also because transitions to the ground states are in the extreme ultraviolet regime. To detect the presence of helium astronomers have focused their interest into the near infrared helium triplet, which is a tracer of metastable helium atoms. This metastable helium triplet is produced by transitions from the 2^3S state (metastable state) to the 2^3P.

2. Theoretical predictions and low resolutions results

Stellar irradiation causes the atmospheres of close-in exoplanets to expand, which can be probed by atomic species such as the helium triplet at NIR wavelength or the sodium doublet at visible wavelengths [7]. While sodium was rapidly detected at low and high resolution, only one attempt at detecting helium has been reported [4] until 2018. In that year, a low-resolution detection around the warm Saturn, WASP-107b, was obtained for the first time by [8] with the *Hubble Space Telescope*.

3. The impact of high-resolution spectrographs on the search of helium

The pixel size of the *Hubble Space Telescope* is around 25 Å and is thus larger than the width of the helium lines (around 3 Å). Therefore, the triplet is unresolved and diluted, limiting its detectability at low resolution and knowledge about the physical process shaping the atmosphere. Ground-based high-resolution near infrared spectrographs such as CARMENES, SpiRou or GIANO, are then state-of-the-art instruments to detect the helium triplet and give constraints into the extended atmospheric structure and dynamics. During the last year, several detections and non-detections of helium around hot-Jupiters and warm-Neptunes with CARMENES have been reported. These results start to show that there is not a specific type of exoplanets more amenable to detect helium. Hot Jupiters (HD 189733b, Kelt-9b, HD 209458b), warm Saturns (WASP-107b, WASP-69b) and warm Neptunes (HAT-P-11b, GJ436b) seem to be equally split between detections and non-detections. However, all detections have been obtained for planets in mild conditions of irradiation around K-type stars. [6] have shown that the stellar environment of K-type stars, in particular the extreme-ultraviolet and mid-ultraviolet flux, is more favourable to respectively ionise the helium ground state and the helium metastable state, and thus to make the extended exoplanet atmosphere more amenable to characterisation.

4. The helium triplet as a tracer of the structure and dynamics of extended atmospheres

Not only high-resolution spectrographs allow us to retrieve a resolved non-diluted helium signature but also allow us to constrain the atmospheric structure and dynamics probed by this tracer through the helium line profile. Two good examples are HAT-P-11b [1] and WASP-107b [2] for which helium signatures have been obtained at more than 20 σ allowing us to do in-depth characterisation of their atmospheres. The helium profile of HAT-P-11b is clearly symmetric but slightly blueshifted while the helium profile of WASP-107b is asymmetric with a clear excess absorption in its blue wing (Fig. 1). We model these helium profiles with a 3D code simulating simultaneously the thermosphere and the exosphere (the EVE code described in [3, 1], Fig. 2). The HAT-P-11b outcomes show that metastable helium is present in its thermosphere, is negligible in its exosphere and emphasised the presence of zonal wind from the day to the night side. On the contrary, the model outcomes for WASP-107b show that metastable helium fill the thermosphere which extend up to half of the Roche lobe, but the majority of it is present in the exosphere in the form of a cometary-like tail.

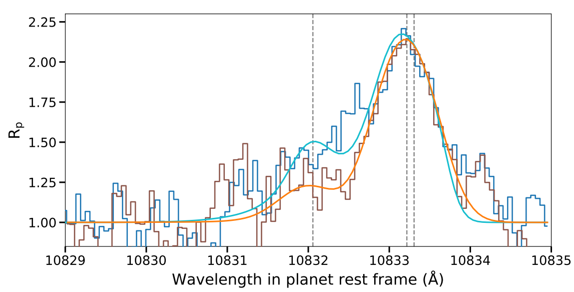

Figure 1: Transmission spectra around the helium triplet for HAT-P-11b (brown histogram) and WASP-107b (blue histogram) expressed in planetary radius. The best fit models obtained with the EVE code are in orange and in cyan.

5. Conclusions

The near infrared helium triplet is thus one of the best tracer of extended atmospheres, including the thermosphere and the exosphere. It is the first atmospheric tracer linking these two parts of exoplanet at-

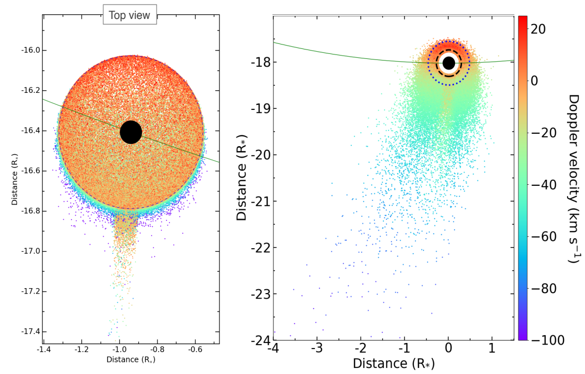

Figure 2: Exospheric contribution to the helium signature modelled by the EVE code. Left panel corresponds to HAT-P-11b [1] and the right panel to WASP-107b [2].

mospheres. Until now, the thermosphere was mainly probed by the sodium doublet while the exosphere was only probed by neutral hydrogen at UV wavelengths. Opposite to these two tracers, the helium triplet is less impacted by telluric contamination, interstellar medium absorption and is in a brighter spectral region. Therefore, this tracer will help us understand the formation and evolution of the hot Neptune desert by studying planets from Jupiters to mini-Neptunes in different conditions of irradiation and stellar environments. Furthermore, spectral identification of helium will greatly enhance atmospheric studies of low-mass exoplanets from Neptunes to Super-Earths, and probe their evolution.

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