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Non-Detection of a Helium Exosphere for the Hot Jupiter WASP-12b

Laura Kreidberg[1,2] and Antonija Oklopčić[1]

[1] Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138
[2] Harvard Society of Fellows, 78 Mount Auburn Street, Cambridge, MA 02138

INTRODUCTION

A helium exosphere was recently detected around the exoplanet WASP-107b, a low-density, warm Neptune (Spake et al. 2018), based on absorption features from metastable helium at 10833 Å (predicted by Seager & Sasselov 2000; Oklopčić & Hirata 2018). The helium feature provides a new probe of atmospheric escape that is advantageous in several ways: (1) it is observable with near-infrared facilities (in contrast to most other signposts of atmospheric escape that appear in the ultraviolet) and (2) it is minimally affected by interstellar absorption, thereby opening the door to studying atmospheric escape in a greater number of systems.

Inspired by the WASP-107b detection, we searched archival HST observations of another evaporating exoplanet, WASP-12b, for signs of a helium exosphere. WASP-12b is a promising candidate for this search because it is one of the hottest known hot Jupiters ($T_{\rm eq} = 2500$ K; Hebb et al. 2009). At this level of intense irradiation, theory predicts a high rate of escaping atoms and molecules from the planet's atmosphere, and indeed, transit observations in the ultraviolet have revealed a patchy cloud of escaping material (Nichols et al. 2015; Salz et al. 2016).

OBSERVATIONS AND DATA REDUCTION

For this Note, we reanalyzed three transits of WASP-12b observed with the Hubble Space Telescope/Wide Field Camera 3 G102 grism (originally published in Kreidberg et al. 2015). In our analysis, we used the same methodology as Kreidberg et al. (2015), except with different spectral binning to include a narrow band (70 Å, the spectrograph's native resolution) centered on the helium feature, with two wider bands at adjacent wavelengths. The transmission spectrum (shown in Figure 1) is consistent with that reported in Kreidberg et al. (2015) and shows no evidence for variability between epochs. Surprisingly, there is no significant increase in transit depth at 10833 Å. The transit depth for the helium feature is just 59 ± 143 ppm larger than the weighted mean depth in the adjacent wavelength bins, in contrast to past observations of the exosphere in the NUV, which show an increase of $\sim 1\%$ relative to the optical transit depth (Nichols et al. 2015).

MODEL PREDICTIONS

To estimate the expected helium absorption signal of WASP-12b, we used the theoretical model described in Oklopčić & Hirata (2018). In this 1D model, we assumed the thermosphere of the planet is composed of atomic hydrogen and helium in 9:1 number ratio. For the thermospheric density and velocity profiles we adopted the isothermal Parker wind model, assuming the gas temperature of $T = 10^4$ K and the total atmospheric mass loss rate of 4×10^{11} g s^{-1} (based on the results of hydrodynamic simulations of atmospheric escape in WASP-12b by Salz et al. 2016). We used the solar irradiance spectrum as the input spectrum. We considered two density profiles of metastable helium: one calculated for the gas at the substellar point (as in Oklopčić & Hirata 2018), and the other for the gas at the terminator, which is likely a better approximation of the average 3D distribution of the metastable helium. We label these scenarios Model A and B, respectively. For each profile, we predict the expected absorption signal taking into account: 1) gas within the Roche radius of the planet, where the assumptions of our 1D model are more likely to be valid, and 2) all the gas out to 20 planetary radii. As illustrated in Figure 1, the predicted helium feature amplitudes are generally small and agree well with the observations (with the exception of the least physically plausible scenario, Model A with all gas, which is inconsistent with the observed spectrum at $5.2\,\sigma$ confidence).

DISCUSSION

This non-detection raises the question of why the helium feature is larger in WASP-107b than WASP-12b, which also has an exosphere. Even though WASP-12b experiences $20\times$ higher bolometric flux, there are several factors that

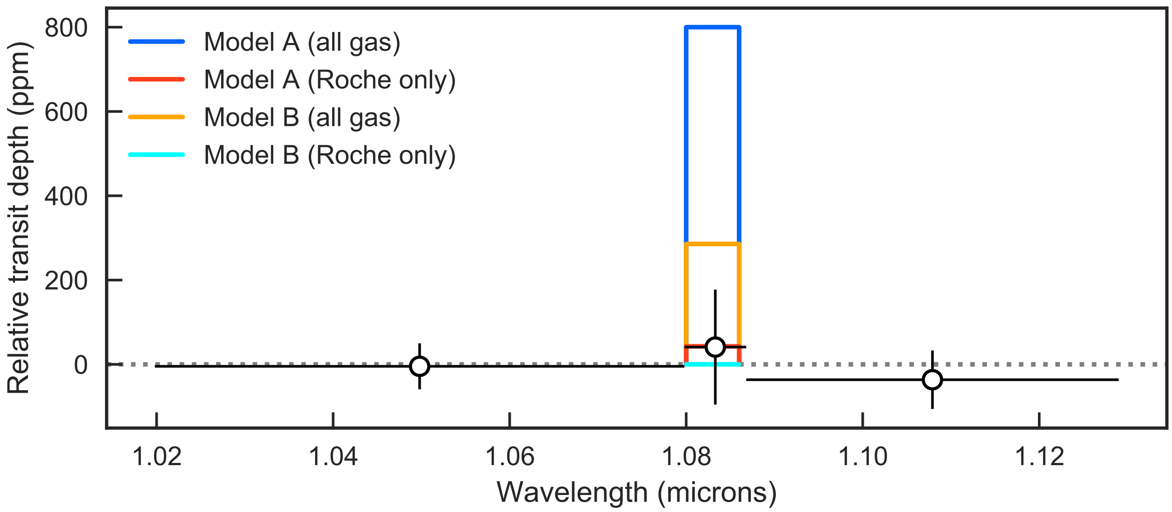

Figure 1. Transmission spectrum of WASP-12b, compared to model predictions for the strength of the 10833Å helium feature.

may contribute to a larger signal for WASP-107b. First, the Roche radius of WASP-107b relative to its host star is 2× larger than for WASP-12b. In addition, the incident stellar spectrum for WASP-107b is more favorable for producing metastable helium. WASP-107 is an active star and expected to be bright in the extreme ultraviolet (EUV), which is responsible for populating the excited metastable state. By contrast, common indicators of stellar activity suggest that WASP-12 is an unusually inactive star, and hence it might be even fainter in the EUV than a typical Sun-like star. In addition, the later spectral type of WASP-107 (K6 versus G0) results in a lower flux of hydrogen-ionizing radiation, which reduces the density of free electrons (collisions with electrons are the main de-populating mechanism of the metastable state). Finally, the escape rate of material from WASP-12b is so high that it may produce a torus of material around the star (Haswell 2017; Debrecht et al. 2018). If the metastable helium is distributed uniformly around the star, the helium absorption feature would exist at all orbital phases, not just during the planet's transit.

In conclusion, metastable helium remains a promising probe of atmospheric escape, but the amplitude of the signal is highly sensitive to the input stellar spectrum and the geometry of the evaporating gas cloud. These considerations should be taken into account in the design of future searches for helium exospheres.

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