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Calculation of the contrast between the emission of a hot Jupiter and its parent star in H Lyman α

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Abstract

To date, no detection of the Lyman α emission from the atmosphere of a hot Jupiter has been achieved, and no calculation of this emission is available in literature. In the absence of any precise computation, it is agreed that the contrast with the parent star emission is not favorable to this detection. If detected, this line would provide crucial information on the environment of the planet. A preliminary calculation of the emission of a hot Jupiter was presented in [1], but since then the model has been improved, in particular by the inclusion of the thermal emission and by the use of new atmospheric models, and thus contrasts observable from Earth have been evaluated for HD 209458b and HD 189733b. Besides, the Lyman α cooling rates involved in the thermal balance of the atmosphere have been calculated and are shown to be one order of magnitude smaller than those who were used in previous studies.

1. Introduction

We estimate the flux contrast at Lyman α wavelengths for the hot Jupiters HD 209458b and 189733b. Thermal and non-thermal processes are taken into account to estimate the emission of the planets.

2. Case of HD 209458b

A one-dimensional outflow model by Koskinen and Harris (2010, unpublished) was used to calculate the density and temperature profiles in the upper atmosphere of HD209458b.

2.1. Photon emission rate

The excitation of H(2p) due to the stellar radiation is calculated using a kinetic code which describes the photoabsorption and models the transport of photoelectrons [2].

Observations of the upper atmosphere indicate that the temperature exceeds 10,000 K so that thermal collisions can populate H(n=2) significantly. Nevertheless the collision frequency is low enough, so that the atmosphere is not at local thermal equilibrium and the population of the levels of hydrogen atoms is dominated by radiative processes. We have developed a model to calculate the excitation of the H(2p) state in the upper atmosphere of a hot Jupiter. The model takes into account the collisional and radiative processes involved in the population of the n=2 level of H. The collisional part describes the collisions undergone by H and H_2 with H, H^+ and electrons.

Since the atmosphere is optically thick at Ly-α, the excitation rates are included in radiative transfer calculations. By also taking into account the scattering of stellar Ly-α photons, we calculate the intensity and the profile of the Ly-α line that emerges of the atmosphere of the planet. Details on the radiative transfer procedure can be found in [3, 4, 5].

2.2. Impact on the atmosphere model

By doing the calculation on the points of a spatial grid covering all the atmosphere, we calculate the total number of Lyα photons escaping the atmosphere. This gives an estimation of the Lyα cooling rate to be included in the outflow model. The Lyman α cooling play a non-negligible role in the energy balance of the atmosphere. So we get a new atmosphere model for HD 209458b, with temperatures reduced compared to the initial model.

The cooling rates calculated by this method are one order of magnitude smaller than those calculated with a formula proposed by [6], which is adapted to describe an optically thin medium, but has yet been used in studies of the energy balance of hot Jupiters [7]. This indicates how important accurate radiative transfer calculations are in constraining the temperature and escape rates of the upper atmosphere.

2.3. Contrast

The Lyα dayglow corresponding to this new atmosphere model is calculated following the method described in 2.1. The auroral emission is evaluated with the same kinetic transport code, by using scaling laws based on the terrestrial case to estimate the plasma fluxes at the origin of the aurorae. Under this assumption, the auroral emission is shown to be negligible compared to the dayglow. In order to get the wavelength-integrated flux contrast observable from Earth, the absorption of both the stellar and planetary emissions by the interstellar medium is taken into account, using parameters measured by [8]. The flux contrast evaluated at quadrature phase angle reaches $\sim 10^{-2}$, but the weakness of the fluxes makes the detection not feasible with Hubble Space Telescope (HST).

3. Case of HD 189733b

Similar calculations have been carried our for HD 189733b. The flux contrast between the stellar and planetary emission at quadrature is comparable to that obtained for HD 209458b, but in the case of the HD 189733 system, the fluxes are higher, which seems to bring the detection of the planetary line within reach of the STIS instrument of HST.

4. Conclusions

The detection of the Lyα line of a hot Jupiter might be possible with current facilities. Is is now important to use the tools presented here to investigate for systems with the best conditions to detect these emissions, in order to characterize the exospheres. Characterizing the exospheres by models and observations is particularly important because it is related to the escape rates from close-in exoplanets, one of the big issues of exoplanetary science.

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