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Hα Absorption in Transiting Exoplanet Atmospheres

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Abstract. Recent observations by Jensen *et al.* of Hα absorption by the upper atmosphere of HD189733b have motivated the need for a theoretical understanding of the distribution of $n = 2$ hydrogen within hot Jupiter atmospheres. With this in mind, we model the $n = 2$ state of atomic hydrogen in a hydrostatic atmosphere in thermal and photoionization equilibrium. Both collisional and radiative transitions are included in the calculation of the n = 2 state level population. In our model, the Hα absorption is dominated by a $\tau \sim 1$ shell composed of metastable 2s hydrogen located within the neutral atomic layer, with the contribution coming roughly uniformly throughout the layer instead of from a specific impact parameter. An ionization rate an order of magnitude over the expected value can reproduce the observed transit depth.

Keywords. line: formation – planets and satellites: atmospheres – stars: individual (HD 189733, HD 209458)

1. Introduction

The absorption of starlight during transit is a useful probe to study the structure of exoplanet atmospheres. The detection of absorption of Lyman-α (e.g., Vidal-Madjar *et al.* 2003) provides evidence for ground state hydrogen in the atmospheres of hot Jupiters but provides minimal information about the thermal structure. Hα provides a complementary probe of the neutral hydrogen content, in that it provides information about the thermal structure of the atmosphere. Our goal is to understand and model the formation of $n = 2$ hydrogen within hot Jupiter atmospheres, and to use our models to understand the results of Jensen *et al.* (2012).

2. Method

We model a spherically-symmetric, hydrostatic atmosphere in thermal and photoionization equilibrium. For simplicity, we consider UV photoelectric heating as the primary heating source and Lyman-α cooling as the primary cooling mechanism. The ionization state is found by balancing photoionization and radiative recombination. Since the ionizing flux from HD189733 is a large source of uncertainty in the model, we parameterize the UV flux using the synthetic spectrum downloaded from the X-exoplanets Archive at the CAB (Sanz-Forcada *et al.* 2011) as a baseline. Attenuation of UV is treated in a frequency dependent fashion (Trammell *et al.* 2011).

The abundance of $n = 2$ hydrogen is determined by modeling collisional and radiative excitation and de-excitation, radiative recombination, and photoionization of excited states.

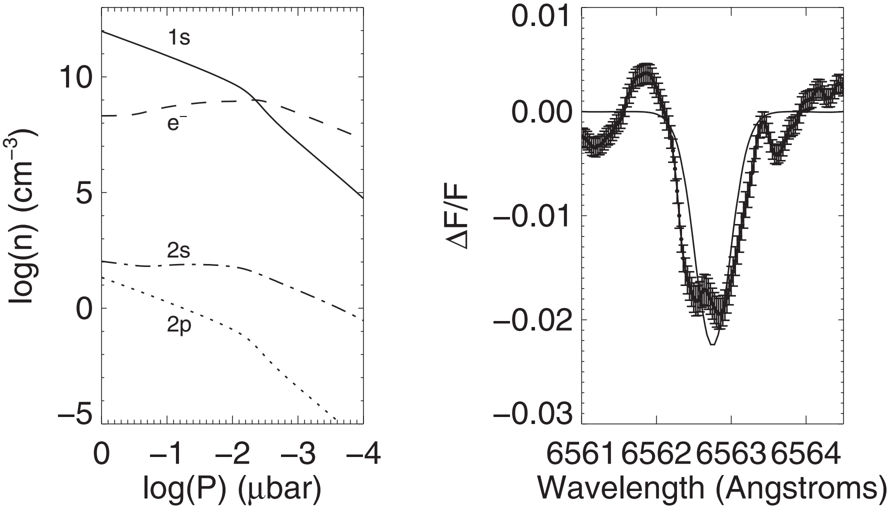

Figure 1. *Left:* Number densities versus pressure. Shown are the densities for 1s (solid line), electrons (dashed line), 2s (dash-dot line), and 2p (dotted line). *Right:* $\Delta F_\lambda / F_\lambda$ for the Hα for HD189733b. The observed data (filled circles) from Jensen *et al.* (2012) are over plotted with error bars.

3. Results

We vary the ionizing flux and find that in order to fit the transit depth quoted by Jensen *et al.* (2012) we require a substellar flux 3.5 times larger than given by the Sanz-Forcada *et al.* (2011) spectrum, if geometric corrections are neglected. Attempts to model the Lyman-α absorption of HD189733b have needed enhanced UV so this is not viewed as cause for concern (Lecavelier Des Etangs *et al.* 2010).

Throughout the model atmosphere, the $n = 2$ hydrogen is predominantly in the 2s state due to the lack of fast radiative transition to the ground state. The primary mechanism for the destruction of 2s then becomes the collisional ℓ-mixing reaction which transitions 2s into 2p hydrogen which can then radiatively de-excite through the Lyman-α transition. Within the ionized upper regions of the atmosphere (i.e., where $n_{\rm e} \geqslant n_{\rm 1s}$) the formation of 2s is due to radiative recombination with collisional excitation from the ground state coming to dominate as the atmosphere becomes predominantly neutral atomic hydrogen. Within the atomic layer, we find that the abundance of 2s hydrogen does not vary significantly relative to the total hydrogen abundance which varies by 3 orders of magnitude (see Figure 1).

References

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