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Double tail structure in escaping atmospheres of magnetised close-in planets

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Abstract. High-energy stellar irradiation can photoevaporate planetary atmospheres, which can be observed in spectroscopic transits of hydrogen lines. Here, we investigate the effect of planetary magnetic fields on the observational signatures of atmospheric escape in hot Jupiters.

Keywords. MHD, planets and satellites: atmospheres, magnetic fields, planet-star interactions

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In this work, we use our newly developed 3D self-consistent radiative magnetohydrodynamic (MHD) simulations (Carolan et al. 2021; Hazra et al. 2022) to study the effects of planetary magnetic fields on the dynamics of escaping atmosphere. To investigate the resulting observational signature, we couple the results of our 3D models to Lyman-α transit calculations (Vidotto et al. 2018; Allan & Vidotto 2019). In our models, we account for high energy stellar photons ionising the atmospheric neutral hydrogen atoms, which affects both the heating deposition in the atmosphere of the planet and its ionisation state. In addition to photoionisation, we also include collisional ionisation and recombination and track the proton and neutral components of the flow. Additionally, we also consider Lyman-α cooling and collisional cooling. The reader will be able to find further details of the model and this work in Carolan et al. (2021).

In our model, the stellar wind is injected in the numerical grid through an external boundary (see Figure 1). Using the same stellar wind property, we vary the planet's dipole field strength from 0 to 10 G. In Figure 1, we show a typical structure of the escaping atmosphere in magnetised planets (> 3 G). Escape occurs through polar outflows, as opposed to the predominantly comet-like tail from non-magnetised models (see comparison in Figure 2). We find a small increase in evaporation rate with planetary field, though this should not affect the timescale of atmospheric loss (Figure 3a).

The double-tail structure has some key effects in Lyman-α transit signatures, as summarised in Figure 3b. When considering magnetic fields, we see an increase in line centre absorption due to an increase of the size of dead-zones. Additionally, we also see an increase in redshifted absorption with increase in planetary field. Most of the red shifted material exists around the night-side orbital plane, as some material falls from the comet-like tails back towards the planet. Finally, we also see that with increased magnetic field, there is an initial decrease in blueshifted absorption, as planetary material begins to be

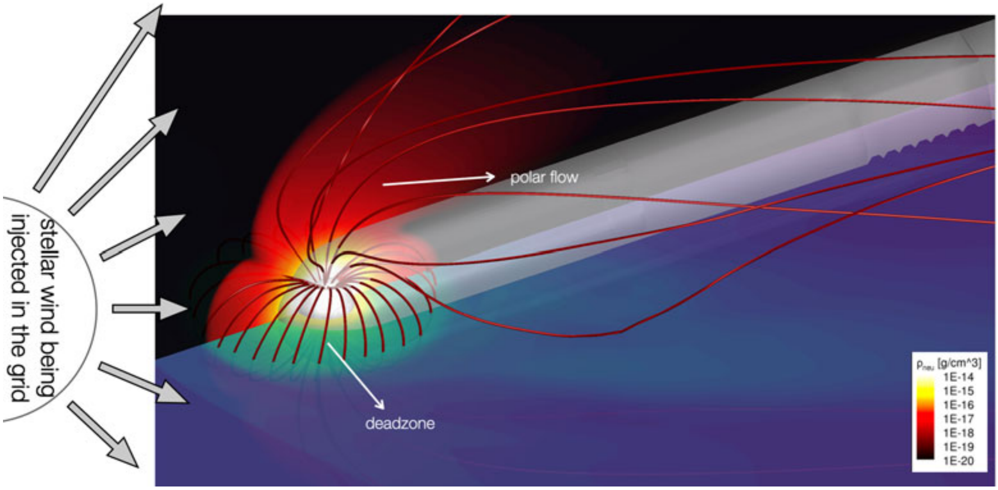

Figure 1. The polar outflows seen in magnetised planets lead to the formation of a double tail structure, above and below the orbital plane, and a dead-zone around the equator.

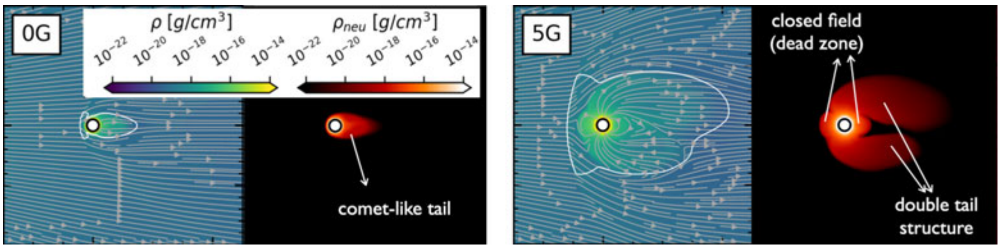

Figure 2. Side view of the planet orbit showing the total (ρ) and neutral Hydrogen ($\rho_{\rm neu}$) density for unmagnetised (left panels) and magnetised (right panels) Hot Jupiters.

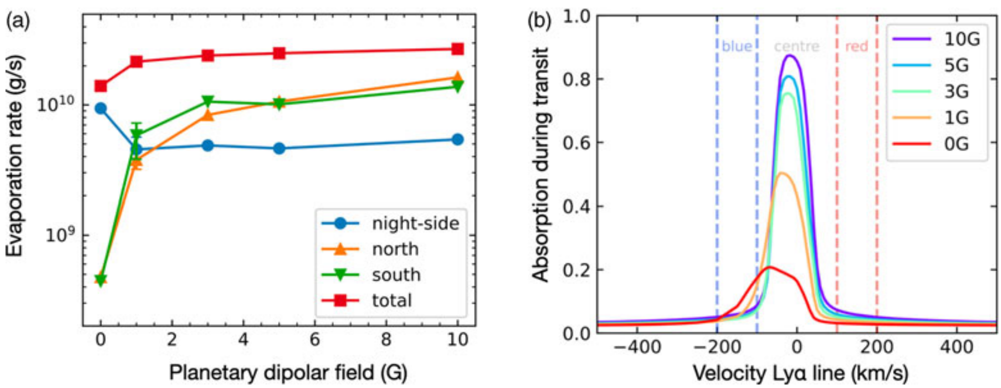

Figure 3. In spite of the small increase in escape rate with planetary field (red line, panel a), we find that Ly-α transit observations are strongly affected by planetary magnetism (panel b).

launched above and below the orbital plane, instead of being fully funnelled on to the orbital plane by the stellar wind, as seen in the 0-G model.

For further details of this work, please see Carolan et al. (2021).

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