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It's raining hot Jupiters: 3D MHD simulations of star-planet-wind interaction

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Abstract

We present 3D MHD simulations of the wind-wind interactions that occur between a solar-type star and a short period hot Jupiter exoplanet. The results are compared to recent observations of the hot Jupiter hosting systems HD 189733 and HD 179949, in which intermittent enhancement of the stellar surface emission is reported. Our results show that atmospheric escape, induced by the host star's incident radiation, accretes onto the stellar surface. Both the location and size of the accretion region vary with time, indicating that the intermittent stellar surface emission is due to the accretion stream either pulsing in size or precessing round the star and consequently out of phase with the planet's orbit or being obscured from the observer.

1. Introduction

Recent observations of the HJ hosting systems HD 189733, conducted with the Cosmic Origins Spectrograph on board the Hubble Space Telescope (COS-HST) [3], and HD 179949, conducted with the Echelle Spectro Polarimetric Device for the Observation of Stars instrument at the Canada-France-Hawaii Telescope (ESPaDOnS-CFHT) [4], indicate that stellar emission is synchronised with the orbit of the HJ and is intermittent in nature. It has been proposed that this is due to an accretion stream, composed of material from the hosted HJs making foot-fall on the stellar surfaces, at $\sim 90^\circ$ ahead of the sub-planetary point in both cases. We present 3D MHD simulations which model a representative HJ hosting system, test this proposition and determine the mechanism for the intermittent emission. The full results of this study are communicated in [1].

2. Modelling

The simulation are based on a thermally expanding solar wind model, which is applied to both the star and the HJ. The techniques used are based on those of [2]. The parameters for our model star and HJ are summarised in Table 1.

Table 1: Stellar and planetary parameters.

Parameter	Star	Planet
Mass	$1\ M_\odot$	$0.5\ M_\mathrm{J}$
Radius	$1\ R_\odot$	$1.5\ R_\mathrm{J}$
Temperature	10^6 K	10^4 K
Magnetic field	2 G	1 G
Semi-major axis	–	0.047 au
Orbital period	–	3.7 days
Rotational period	3.7 days	3.7 days

The equations of MHD were solved on a Cartesian grid using adaptive mesh refinement to capture fine detail, and passive scalars were used to track the motion of HJ material and assess the accretion location and extent.

3. Results and Discussion

Fig. 1 shows a 2D projection of the density profile from the 3D simulation, once steady state had been reached. The star is central to the plot, with the HJ to the right. The accretion stream is clearly seen as an arch of material flowing between HJ and star. The red arrow indicates the region ahead of the planet in which the accretion takes place.

The accretion area and mass-flux rate are shown in Fig. 2. The stellar surface area, where accretion takes place, fluctuates between 0.05% and 0.3%, while the mass-flux through the accretion area remains approximately constant. This tells us that there is a pulsing of the accretion spot density as the same material flux is accreted through a periodically changing accretion area. The latitude of accretion is stable at $\sim 50^\circ$S and the longitude precesses around the star from $\sim 138^\circ$ to $\sim 227^\circ$ ahead of the sub-planetary point.

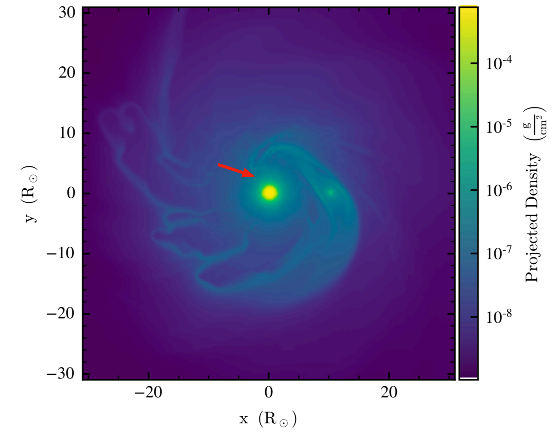

Figure 1: Projected density plot showing the global evolution of the star-planet system and the accretion stream connecting the two, indicated by the red arrow.

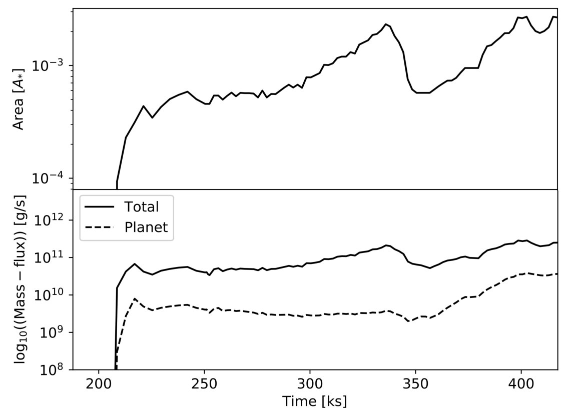

Figure 2: Top: area of stellar surface occupied by accretion spot. Bottom: mass-flux through the accretion area. Both the total mass-flux (average of 1.89×10^{11} g/s), and the mass-flux of planetary material (average of 2.38×10^{10} g/s) are shown.

The nature of the accretion is variable in both location and rate, with the final accretion point occurring at 133 degrees west and 53 degrees south of the sub-planetary point. The size of the accretion spot itself has been found to vary with a period of 67 ks (approximately 1/5 of the orbital period).

This periodicity is congruous with the observed intermittency of emission from the HD 189733 and HD 179949 systems, but the period is not consistent. The changing accretion location, together with the periodicity, however, may explain this difference.

The simulation results are therefore compatible with the proposition that the star-planet interaction via wind-wind interaction and accretion is responsible for the observed enhanced stellar surface emission of HD 189733 and HD 179949.

4. Summary and Conclusions

We have conducted a high resolution 3D MHD simulation which characterises the behavior of interacting stellar and planetary wind material in the context of star-planet-wind interaction for a representative HJ hosting system. Our results show that the nature of the accretion is variable both in location and in rate.

Based on our results for the accretion spot location and the evolution of the spot size, the intermittent nature of observed enhanced stellar surface emission may be attributed to the accretion stream either pulsing in size or precessing around the star, out of phase with the planet's orbit, or being obscured from the observer.

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