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A self-consistent three-dimensional aeronomy simulation of highly irradiated WASP-12b

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Abstract

The results of 3D simulations discussing the observed early ingress, absorption in Mg_{II} resonance lines during the transit of WASP-12b are presented. The model is based on the multi-fluid approach which deals with H, He, Mg species and related ions.The model includes the basic hydrogen chemistry and provides the self-consistent description of the nearby planetary environment and a bow-shock creation in front of the highly irradiated exoplanet WASP-12b. It also describes the mass loss process in a self-consistent manner. The dynamics of Mg_{II} ions and transit light curves are estimated. The results with a set of stellar wind parameters and XUV flux values under a realistic Sun-like star condition showed that the planetary atmospheric mass loss rate is proportional to the stellar radiation energy input. The simulated transit light curves demonstrate early ingress as it was observed in the near ultraviolet measurements.

1. Introduction

A remarkable growth in the number of detection of exoplanets has been seen in the last 25 years. In the beginning, most of the planets were discovered with approximately the same mass and radius as Jupiter, but with the orbital periods of $1-10$ days. These sets of highly irradiated exoplanets were categorized as ‘hot-Jupiters’ (HJ), and the importance of atmospheric escape processes was discussed in several papers [1, 2]. The existence of exoplanets with volatile atmospheres at such short orbital periods arises the question of whether the exoplanetary atmospheres are stable or not ([3]). In the case of Hydrogen dominated atmospheres, the high UV fluxes close to the star dissociate the molecular Hydrogen, resulting in the upper regions being dominated by atomic Hydrogen. In these atomic regions heating typically results in gas temperatures of order $5,000-10,000$ K. At such high temperatures, the upper atmospheres of close-in exoplanets are often facilitate the hydrodynamic escape of upper atmosphere.

2. 3D multi-fluid model

Despite of the substantial development in terms of numerical simulations, and new observational results, a self-consistent model which could combine the physics of planetary wind (PW) formation (starting from dense and warm planetary atmosphere) with its global 3D dynamics in the hot stellar wind (SW) plasma environment, encompassing a whole system, is still needed. To understand the mass loss process and other observable phenomena such as early ingress, absorption lines of different species, it is required to meticulously investigate the stellar-planetary winds interactions with a proper emphasis and inclusion of various effects.

2.1. Results

Various simulation runs have been performed with different XUV radiation fluxes and SW conditions. Figure 1 illustrates the spatial structure of the nearby plasma environment around WASP-12b, simulated with $F_{XUV} = 5ergcm^{-2}s^{-1}$ at (1 au), $V_{SC} = 362.8kms^{-1}$, $T_{SC} = 2.5MK$, $Mg/H = 3.75 \times 10^{-5}$, and fig. 2 shows a close comparison between the planet transits obtained from the 3D simulation with the optical and near-ultraviolet (NUV) transmission spectroscopy observations. A statistical and quantitative description of upper atmosphere mass loss dependence on stellar corona conditions and XUV radiation fluxes is presented in table 1.

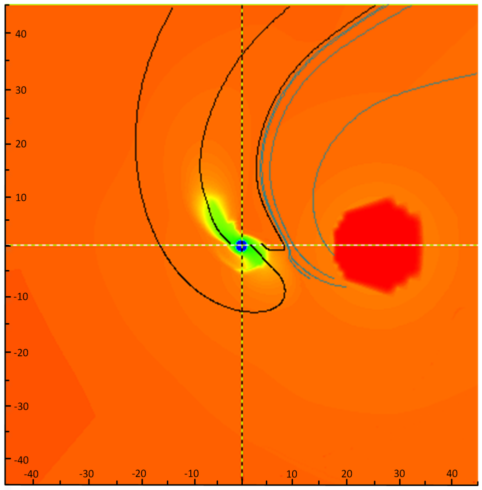

Figure 1: Spatial structures of the nearby plasma environment around WASP-12b.

3. Summary and Conclusions

The simulation results demonstrate that the day-side PW achieve the supersonic velocity and hence a bow-shock is created in front of the planet. We also found that the PW flow is redirected toward the tail and the strongly coupled neutral and ionized components of the expanding PW decouple at the ionopause boundary, where the planetary and stellar protons flows are being stopped by each other. However, the neutrals are accelerated by the pressure gradient and penetrate into the SW. The bulk motion of the escaping planetary material with the velocity of several tens of kms^{-1}, that drags the heavy elements, can sufficiently increase the contribution of resonant thermal line broadening mechanism which will dominate in the absorption of the corresponding stellar lines. We have also estimated the upper atmospheric mass loss in the regimes of PW and SW interaction. The planetary mass loss rates are found to be dependent on XUV flux. The simulated light curves are consistent with the observational results [4, 5] .

Acknowledgements

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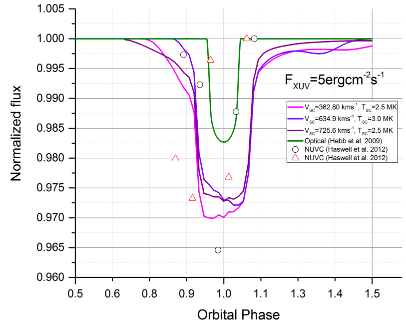

Figure 2: Spatial structures of the nearby plasma environment around WASP-12b.

Table 1: XUV flux, stellar corona parameters and mass loss rate.

F_{XUV} $(ergcm^{-2}s^{-1})$	V_{SC} (kms^{-1})	T_{SC} (MK)	Mass loss rate $(10^{10}gs^{-1})$
05	634.9	3.0	34.06
05	362.8	2.5	36.64
05	725.6	2.5	37.01
10	634.9	3.0	57.15
10	362.8	2.5	60.95
10	725.6	2.5	61.39
20	362.8	2.5	101.07
20	725.6	2.5	101.96

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