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Multi-fluid modeling of upper atmosphere mass loss and absorption line for WASP-12b

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Abstract

The work presents the multi-fluid numerical modeling to interpret the observed absorption in Mg_{II} resonance lines during the transit of WASP-12b and to quantify the crucial mechanisms responsible for exoplanetary upper atmosphere mass loss. The model simulates the expansion of upper atmosphere due to stellar XUV radiation and includes the hydrogen chemistry and effects of stellar wind. The two case-scenarios of the planetary material escape and interaction with the stellar wind, namely the 'blown by the wind' (without the inclusion of tidal force) and 'captured by the star' (with the tidal force) have been modeled for different stellar XUV radiation fluxes and different stellar wind parameters. In the first case, the planetary mass loss is controlled completely by the stellar radiation energy input. However, in the 'captured by the star' case, the mass loss is mainly due to the gravitational interaction effects. The dynamics of Mg_{II} ions was modeled with three different sets of stellar wind parameters and XUV flux values under a realistic Sun-like star condition. The results appear in good agreement with the observations.

1. Introduction

WASP-12b is one of the recently observed close-orbit, short period hot Jupiters [1, 2]. The Roche lobe size of the planet is a little larger than the planet radius, and therefore the planet mass loss due to tidal force has to be a very common phenomenon for this planet. Fossati et al. [2] and Haswell et al. [3] investigated two transits of the planet and advocated the likelihood of early ingress in the near-UV of the planet compared to its optical light curve which is reminiscent of absorbing material around the planet. Fossati et al. [2] and Nochols et al. [4] have detected an extra absorption in the Mg_{II} resonance line cores at the 2.8σ level.

The main objective of the present work is to analyze the two scenario namely the formation of bow-shock and diffused cloud or torus due to the material escape from the planetary exosphere to understand the observed phenomenon of early ingress, extra absorption in Mg_{II} resonance line and mass loss processes.

2. Multi-fluid Simulation results

A 2D multi-fluid model developed in [5, 6] is adopted for the specific case of WASP-12b. In the 'blown by the wind' case, the stellar wind (SW) total pressure is sufficiently high enough to stop the planetary wind (PW), and to create an ionopause, and a bow shock. However, in the 'captured by the star' case, the PW expands beyond the Roche lobe towards the star being further pulled by the tidal force. Figures 1 and 2, illustrate the density distribution of the main interacting constituents, respectively for the case of 'blown by the wind' and 'captured by the star' regimes. The simulated absorption profiles of Mg_{II} line for the magnesium abundance Mg/H=3.7x10^{-5}are shown in Fig. 3, for the both regimes.

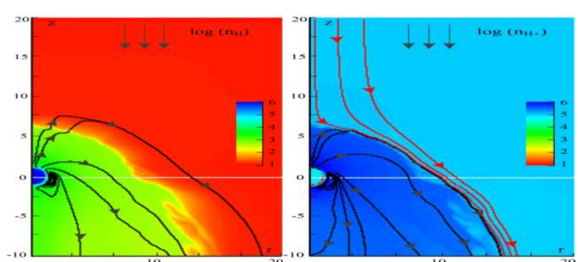

Figure 1. The density distribution of planetary atoms, ions and stellar protons in the case of 'blown by the wind'regime for F_{XUV}=5ergcm^{-2}s^{-1}, n_{SW}=310^{4}cm^{-3}, T_{SW}=1.4MK, and V_{sw}=172kms^{-1}.

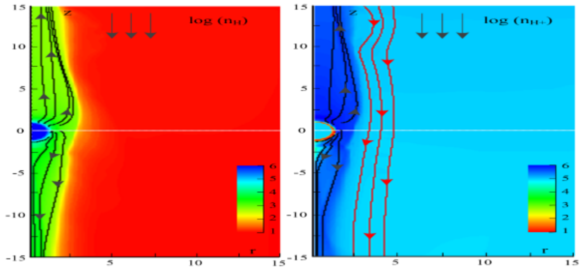

Figure 2. The density distribution of planetary atoms, ions and stellar protons for the case of 'captured by the star by the wind' regime for F_{XUV}=5ergcm^{-2}s^{-1}, n_{SW}=1x10^{4}cm^{-3}, T_{SW}=3.17MK, and V_{sw}=417kms^{-1}.

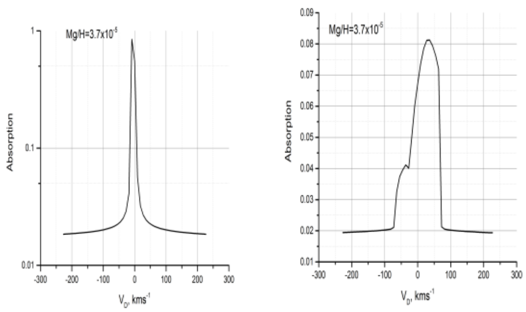

Figure 3. Absorption profile of Mg_{II} line calculated at magnesium abundance of Mg/H=3.7x10^{-5}, for the cases of 'blown by the wind' and 'captured by the star' regimes respectively.

3. Mass loss

The average mass loss rate values for different SW-PW interaction regimes are summarized in Table 1 and Table 2 respectively.

Table 1: 'Blown by the wind' regime

F_{XUV} (ergcm^{-2}s^{-1})	n_{SW} (cm^{-3})	V_{SW} (kms^{-1})	T_{SW} (MK)	Mass loss rate (10^{10}gs^{-1})
5	3x10^{4}	172	1.4	28.81
10	6x10^{4}	172	1.4	49.10
20	6x10^{4}	172	1.4	88.87

Table 2: 'Captured by the wind' regime

F_{XUV} (ergcm^{-2}s^{-1})	n_{SW} (cm^{-3})	V_{SW} (kms^{-1})	T_{SW} (MK)	Mass loss rate (10^{10}gs^{-1})
5	1x10^{4}, 3x10^{4}	417	3.17	145.38, 222.98
10	1.5x10^{4}, 3x10^{5}	417	3.17	169.95, 197.64
20	1.5x10^{4}, 3x10^{5}	417	3.17	186.53, 225.29

4. Summary and Conclusions

The simulation results demonstrate that in the 'blown by the wind' regime when a slow SW condition and no tidal force is considered in the model, we observe a very strong absorption of Mg_{II}. However, in the 'captured by the star' regime, we found that the change in the XUV radiation fluxes does not make a significant change in the absorption profile of Mg_{II} line. However, the SW condition has a major impact on the Mg_{II} absorption line. In the case of 'captured by the star' regime, the calculated absorption shows a good agreement with the observed value of absorption in Mg_{II} line which is 3-4%.

Acknowledgments

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