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Stellar wind interaction with the expanding atmosphere of Gliese 436b

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Abstract

We study an exosphere of a Neptune-size exoplanet Gliese 436b, orbiting the red dwarf at an extremely close distance (0.028 au), taking into account its interaction with the stellar wind plasma flow. It was shown that Gliese 436 b has a bowshock region between planetary and stellar wind which localized on the distance of ~33 R_p, where density of planetary atoms slightly dominates over the protons.

1. Introduction

The modelled planet Gliese 436b has a mass $M_p=0.07M_J$, radius $R=0.38R_J$ and an estimated surface temperature 700 K. To describe the physical processes in the planetary upper atmosphere and beyond, we use a 2D self-consistent multi-fluid hydrodynamic 2D aeronomy model. In our simulations we investigated basic properties of exosphere during interaction with stellar plasma.

2. Model

To describe the expanding atmosphere of Gliese 436b and its interaction with the stellar wind plasma, we use a 2D axisymmetric multi-fluid hydrodynamic model [1, 2]. Each fluid describes the hydrogen and helium components of the planetary origin (H, H^+, H_2, H_2^+, H_3^+, He, He^+) and the stellar wind protons. The planetary plasma is regarded as a quasineutral fluid with thermal equilibrium: $T_i = T_e$. The model takes into account the basic photo-chemical processes in the hydrogen-dominated atmosphere, allowing to describe in a self-consistent way its heating and ionization due to absorption of the stellar XUV radiation. An approximated spectrum of Gliese 436 in the range of 10-912 Å is used in the simulations. The tidal forces acting on the streams of the escaping planetary upper atmospheric material are also taken into account.

3. Results

At the initial state of the simulations, the atmosphere of Gliese 436b is assumed to consist of the molecular hydrogen and helium atoms at a ratio N_{He} / N_{H2} = 1/5 with the temperature 750 K. We consider the case of a weak stellar wind (SW) with n_{sw}=100 cm^{-3}, T_{sw}=1 MK, V_{sw}=70 km/s, which is much less intense than the solar wind. Because of this fact, , we did not consider generation of Energetic Neutral Atoms (ENAs). The planetary wind (PW) streams, moving towards and away from the star, are formed, driven by the stellar XUV energy input and the stellar gravity. They propagate within the SW plasma, separated from it by a kind of ionopause. In our simulations we took the stellar XUV flux F_{XUV}= 0.8 erg $cm^{-2}s^{-1}$at a distance of 1 a.u.

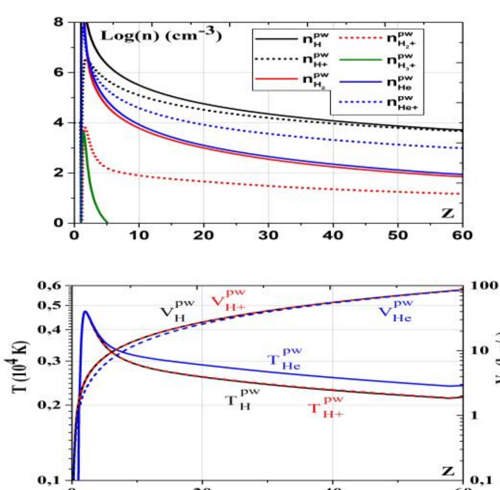
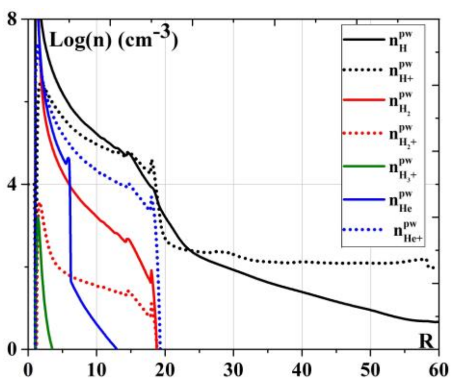


Fig.1 Distribution of density, temperature and velocity of the species in the PW along the planet-star line.

The structure of the expanding PW of Gliese 436 b is shown in Figure 1, which gives the profiles of density, velocity, and temperature for hydrogen atoms, protons and helium atoms along the planet-star line. A strong coupling between atoms and protons in the PW region is indicated by the velocity and temperature profiles, which are rather close to each other. The velocity rapidly increases and at the distance of 50-60 R_p from the planet it reaches ~90 km/s, while the temperature after having a maximum of about 5000 K decreases smoothly down to ~ 2200 K.

The distributions of density and velocity of the species in the PW cross the planet-star line is shown in Figure 2, which reveals three regions: 1) the region of the PW material; 2) an outside area of the SW; and 3) a bowshock between the PW and SW where density and the temperature of the planetary atoms and protons increase. The density of planetary atoms slightly dominates over the protons in the region of the bowshock. Planetary atoms, overcoming the shock, also penetrate into the SW, where they are accelerated up to speeds of ~ 30 km/s, at the distance of ~60Rp, while the planetary protons are stopped by the thermal pressure of the stellar wind protons. PW atoms which penetrate into SW undergo the charge exchange with stellar protons forming ENAs.



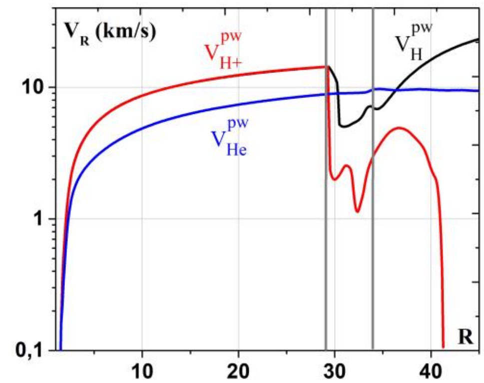


Fig.2 Profiles of density and velocity of the species in the PW across the planet-star line.

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