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Suprathermal hydrogen in the extended upper atmosphere of HD 209458b

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Abstract

Observations with Hubble Space Telescope (HST) show absorption in the Lyman-α line during transit of a Jupiter-type planet HD 209458b in front of its parent star, revealing the occurrence of high-velocity hydrogen atoms in the extended upper atmosphere of the exoplanet [1]. These observations were currently interpreted as a signature of an extended and evaporating atomic hydrogen exosphere and allowed to constrain the escape rate of the planet atmosphere up to ~ 10^{10} g s^{-1} [1,2]. Further HST observations of absorption in the Balmer continuum [3] indicated the presence of hot (or suprathermal) hydrogen atoms in the upper atmosphere of HD 209458b. The fundamental question of the HD 209458b atmosphere evolution forced by the stellar UV irradiation, plasma inflow of the stellar wind, and tidal forces of the parent star is still intensively investigated [4].

In this report we present the numerical stochastic model, in which the kinetics and dynamics of the suprathermal (hot) atomic hydrogen in the extended upper atmosphere of HD 209458b is considered on the molecular level of description. The following sources of suprathermal atomic hydrogen were taken into account: (i) dissociation and dissociative ionization of the molecular hydrogen by the stellar UV radiation; (ii) photoelectron impact dissociation of H_2. The dissociation processes of H_2 result in the formation of hydrogen atoms with excess kinetic energies up to a few eVs. Thermalization rate of these freshly formed suprathermal hydrogen atoms is mainly determined by the elastic collisions with the thermal atomic hydrogen of the ambient upper atmosphere. Because HD 209458b orbits close in (~ 0.045 a.u.) to the parent star its upper atmosphere is strongly heated by the stellar UV radiation resulting in the high temperatures (up to ~ 10^4 K) [5]. Such elastic collisions at suprathermal energies up to a few eVs are characterized by the scattering angle distributions strongly peaked at small angles, therefore a stable fraction of hot atomic hydrogen can be formed. To calculate the rates and energy spectra of the suprathermal hydrogen atoms formed in the H_2 dissociation processes a Monte Carlo model [6] of electron kinetics and transport in the planetary upper atmosphere was adopted. The kinetics and dynamics of the suprathermal hydrogen atoms in the upper atmosphere of HD 209458b was considered using the numerical stochastic model of the planetary corona [7].

It was found that UV stellar radiation results in the formation of a stable fraction of suprathermal H in the upper atmosphere of HD 209458b due to H_2 dissociation processes and of nonthermal escape rate up to ~ 10^9 g s^{-1} depending on the level of stellar activity. Therefore the nonthermal escape of atomic hydrogen due to the H_2 dissociation processes can be competitive with the earlier proposed thermal hydrodynamic escape [1,2,4] used to explain the HST observation [1]. Moreover, the additional input due to the atmospheric sputtering of the extended hydrogen corona by the plasma of stellar wind can significantly increase the nonthermal escape rate of hot hydrogen.

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