The Predictive Power of Computational Astrophysics as a Discovery Tool
Proceedings IAU Symposium No. 362, 2023
D. Bisikalo, D. Wiebe & C. Boily, eds.
doi:10.1017/S1743921322001855

Study of the non-thermal atmospheric loss for exoplanet π Men c

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Abstract. We have studied the input of the exothermic photochemistry into the formation of the non-thermal escape flux in the transition $H_2 - H$ region of the extended upper atmosphere of the hot exoplanet - the sub-neptune π Men c. The formation rate and the energy spectrum of hydrogen atoms formed with an excess of kinetic energy due to the exothermic photochemistry forced by the stellar XUV radiation were calculated using a numerical kinetic Monte Carlo model of a hot planetary corona. The escape flux was estimated to be equal to $2.5{\times}10^{12}$ $cm^{-2}s^{-1}$ for the mean level of stellar activity in the XUV radiation flux. This results in the mean estimate of the atmospheric loss rate due to the exothermic photochemistry equal to $6.7{\times}10^8$ $g\ s^{-1}$. The calculated estimate is close to the observational estimates of the possible atmospheric loss rate for the exoplanet π Men c in the range less than $1.0{\times}10^9$ gs^{-1}.

Keywords. exoplanet, numerical model, exoplanets atmosphere, non-thermal escape

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We have studied the input of the exothermic photochemistry into the non-thermal atmospheric loss in the transition $H_2 - H$ region of the extended upper atmosphere of the hot exoplanet - the sub-neptune π Men c. This exoplanet is a typical example of the hot sub-Neptune (super-Earth), and is the first transit planet discovered by the TESS space telescope (Gandolfi *et al.* 2018). The atmosphere of this exoplanet was studied in HST observations - no absorption in $H\ Ly-\alpha$ line was detected (Garcia Munoz *et al.* 2020).

Stellar XUV flux was modeled basing on the solar XUV spectrum scaled to the orbit of π Men c with the semi-major axis ar=0.067 a.u. using the scaling coefficients from (Garcia Munoz *et al.* 2020) for stellar XUV flux. It currently corresponds to the mean level F10.7=100 of solar activity. Impact processes by the suprathermal photoelectrons were taken into account. Precipitation from stellar wind/magnetosphere was not considered. The formation rate and the energy spectrum of hydrogen atoms formed with an excess of kinetic energy due to the exothermic photochemistry forced by the stellar XUV radiation were calculated using a numerical kinetic Monte Carlo model (Avtaeva A. A. & Shematovich V. I. 2021) and are shown in Figures 1 and 2. It is seen, that there are slow and fast fractions of the fresh H atoms. As a result of model realization, we derive the kinetic-energy distribution functions for suprathermal hydrogen atoms in the H−2→H transition region. As an example, the energy spectrum of upward moving H atoms at height of 3.53 R_0 are shown in Figure 3 (R_0 is a photometric planet radius). It is seen that the suprathermal tails are formed in the energy distribution functions atomic

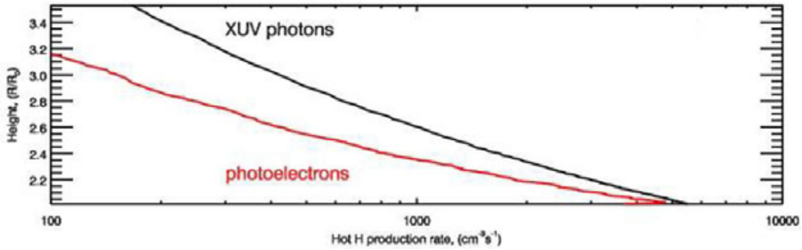

Figure 1. Height profiles of hot H production rates due to the photodissociation and dissociative ionization of molecular hydrogen by the stellar XUV radiation (black line) and by the impact of suprathermal photoelectrons (red line).

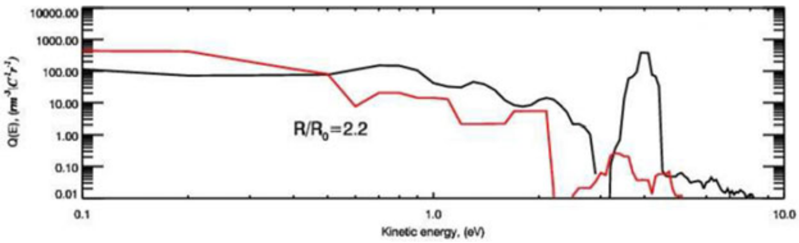

Figure 2. Energy spectra of the source functions for hot H atoms formed due to dissociation by stellar XUV flux (black line) and due to the impact by the suprathermal photoelectrons (red line).

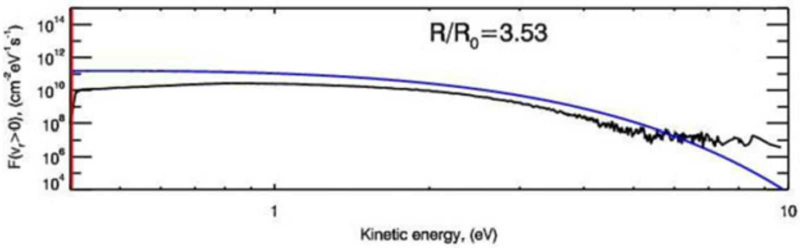

Figure 3. Energy specra of the upward moving H atoms at height of of 3.53 R_0. Blue line shows the energy spectrum of the upward moving thermal flux of H atoms, calculated with Maxwellian distribution for gas temperature taken from aeronomic model Shaikhislamov *et al.* (2020).

hydrogen in the transition region populating the hot fraction of the extended hydrogen corona of the sub-neptune π Men c.

Non-thermal escape flux in the planet-star direction is equal to 2.5×10^{12} $cm^{-2}s^{-1}$ for mean level of stellar activity. It is of the same value as the Jeans escape rate of 1.0×10^{12} $cm^{-2}s^{-1}$ for thermal H atoms. Non-thermal mass loss rate is about 6.7×10^{8} gs^{-1}. The calculations have shown that the non-thermal flux of hydrogen escape from the atmosphere is comparable to the thermal flux and should be taken into account in the current aeronomic models of hot exoplanets.

We acknowledge the support by Russian Science Foundation (Project 22-22-00909).

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