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Photoheating efficiency for hydrogen-dominated atmospheres of exoplanets

V. I. Shematovich
Institute of Astronomy RAS, Moscow, Russian Federation (shematov@inasan.ru)

Abstract

Many of the exoplanets are placed in the close-in orbits therefore their atmospheres are exposed to intense radiation field and plasma flow from the host star. Energy absorption by the upper atmospheres of such exoplanets significantly affects their thermal balance and chemistry. The high temperatures of the outermost atmospheric layers may produce mass outflows that are sufficiently high for the subsequent evolution of the planet. Heating of the upper atmosphere due to the absorption of the stellar XUV (soft X rays and extreme ultraviolet) radiation is mostly driven by photoionization and the generation of photoelectrons. Photoelectrons excite, ionize, and dissociate atoms and molecules until they lose enough energy and become thermalized i.e., share their energy with thermal electrons in Coulomb collisions. Thermal electrons share their energy with ions and eventually, the neutral atmosphere. In the current aeronomic models [1-3] the volume heating rate is usually fitted by the external parameter - photoheating efficiency which determines the temperature and velocity profiles in the extrasolar planetary atmospheres. This value is a ratio of absorbed energy accumulated as a gas heat to the deposited energy of the stellar XUV radiation in the planetary atmosphere [4].

To calculate the energy deposition rate and photoheating efficiency in the self-consistent way the Monte Carlo model [5] of the stellar XUV radiation absorption and of the accompanying photoelectron flux kinetics and transport in the upper planetary atmospheres was used. This model was recently developed for the following aeronomic applications in the studies of: (i) $CO_2/CO/N_2/O_2$ atmospheres of terrestrial planets; (ii) $H_2/H/He$ atmospheres of giant planets; (iii) $H_2O/OH/H$ atmospheres of comets, KBOs, and super-Earths. Main inputs into the model are: (i) atomic and molecular data on the photoabsorption and electron impact cross sections; (ii) model of the stellar XUV radiation; ((iii) composition and space distribution of the neutral atmospheres. Outputs of the model are: (i) energy deposition rates and heating efficiencies; (ii) collision-induced optical emissions; (iii) photochemistry and transport of excited and hot species [6]. In the numerical simulations the evolution of the system of modeling particles (representing photoelectrons) due to collisional processes and particle transport is calculated from the initial to the steady state [5] and the space distribution of the energy spectra of photoelectrons are estimated. The relative importance of the collisional processes is governed by their cross sections.

Photo- and photoelectron impact heating of the $H_2/He/H$ atmosphere was calculated for the upper atmosphere model [1] of the planet HD209458b and the XUV stellar spectrum approximated by the quit Sun conditions. It was found that photoheating efficiency is a height dependent and varies in the range 40 ÷ 60%. The relative inputs of the soft X rays and EUV radiation were estimated.

Calculations showed that energy deposition rate of the stellar XUV radiation in the $H_2/He/H$ atmosphere and the photoheating efficiency are strongly dependent on (i) the composition of the neutral atmosphere, and (ii) the energy spectrum of the stellar XUV radiation. Both characteristics are height-dependent ones. The model is critically dependent on the relevant data on the stellar XUV flux and the atomic and molecular data on photo-absorption and electron impact cross sections. Detailed kinetics of the photoelectrons and the calculated height profiles of the photoheating efficiency can be used in the aeronomic models of the hydrogen-dominant atmospheres of the Solar System giant planets and of hot Jupiters and super-Earths.

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