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/S1743921322001533

Thermal atmospheric escape of close-in exoplanets

Eugenia S. Kalinicheva and Valery I. Shematovich

Institute of Astronomy, Russian Academy of Sciences
Pyatnitskaya str., 48, Moscow 119017, Russia
email: kalinicheva@inasan.ru

Abstract. In this work we applied the previously developed self-consistent 1D model of hydrogen-helium atmosphere with suprathermal electrons to close-in hot neptune GJ 436 b. The obtained height profile of density shows the two-scale structure of the planetary atmosphere. The mass-loss rate is found to be about $1.6 \times 10^9 gs^{-1}$.

Keywords. exoplanetary atmosphere, thermal atmospheric loss, numerical model

Many of recently discovered exoplanets with extended hydrogen-helium atmospheres are orbiting their host stars on very close orbits. Extremely high soft X-ray and ultraviolet (XUV) radiation causes the hydrodynamic escape of their gaseous envelopes. Such effects have been already observed for some planetary systems with either giant planets and smaller ones like super-Earths. Hot neptunes are extrasolar planets with masses and radii about the mass and radius of our Neptune in the Solar system, but are orbiting closer to their host stars (closer than 0.1 AU). The thermospheric temperatures of such planets are extremely high, up to thousands Kelvin. Such high temperature is caused by absorption of host-star XUV radiation.

In this work we present the atmosphere model of the well-known hot neptune GJ 436 b. The envelope was obtained using a previously developed self-consistent one-dimensional aeronomic model of the hydrogen-helium atmosphere, which includes the presence of suprathermal electrons (Ionov *et al.* 2017). This object was observed by the Hubble Space Telescope (HST) which showed the clear presence of extended gaseous envelope formation with the size comparable to the host star disk radius. The COS/HST independent transit observations have shown a 50% absorption in the Ly-α line in the Doppler velocity shift range (-120, -40) km/s (Ehrenreich *et al.* 2015, Lavie *et al.* 2017). The data also showed the presence of a dense cloud in front of the planet and its long gaseous tail.

The main advantage of the model used is the including of suprathermal particles contribution which leads to the more accurate calculation of atmospheric heating and, accordingly, clarifying the rate of its outflow Ionov *et al.* (2017), Ionov *et al.* (2018). Close-in exoplanets are exposed to the very high fluxes of XUV star radiation which makes the accurate heating calculations very important. High-energy radiation heats the upper atmosphere, ionizing atomic hydrogen and helium. Part of this radiation energy passes into the kinetic energy of reaction products. Usually, if the fresh photoelectron energy exeeds the thermal energy by several orders of magnitude (suprathermal particle), it can enter into a secondary reaction of ionization or excitation of other atmospheric particles. At the same time, the kinetic energy that the suprathermal electron had initially is expended. Taking into account these processes makes a significant contribution to the

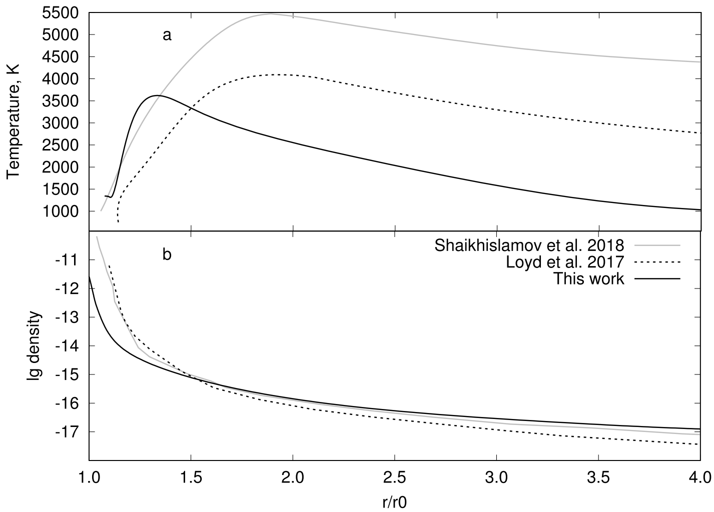

Figure 1. Outflow temperature and density of exoplanet GJ 436b as a function of height. Solid grey line represents Shaikhislamov *et al.* (2018), dotted black line represents Loyd *et al.* (2017), solid black line represents this work.

dynamics and energy of the exoplanetary atmosphere Ionov *et al.* (2017), Ionov *et al.* (2018).

The obtained height profiles of the atmospheric temperature (Figure 1a) and density (Figure 1b) of the simulated exoplanet were calculated, they differ significantly from the results of other authors, as the accounting of photoelectrons leads to a decrease in the rate of atmospheric heating and, accordingly, the rate of mass loss, which affects the evolution of the gaseous envelope of a hot exoplanet at astronomical times. The calculations revealed a two-level structure of the atmosphere under study. The lower part of the atmosphere is more massive and has an exponential density decrease (see distances less then 1.2 r/r_0). The density of the upper atmosphere, the corona, changes much slower (see, distances above 1.2 r/r_0) according to the height scale, which responds to a higher temperature at the peak of the gas heating. The preliminary calculated mass loss rate is found be $\dot{M} = 1.6 \times 10^9 gs^{-1}$. It is lower than Shaikhislamov *et al.* (2018) and Loyd *et al.* (2017) calculations ($\dot{M} = 3.1 \times 10^9 gs^{-1}$) and is close to the upper estimate in the Kulow *et al.* (2014) calculations ($\dot{M} = 3.7 \times 10^6 - 1.1 \times 10^9 gs^{-1}$).

The reported study was funded by RFBR according to the research project № 20-32-90149

References

I. F. Shaikhislamov, M. L. Khodachenko, H. Lammer, A. G. Berezutsky, I. B. Miroshnichenko, M. S. Rumenskikh 2018, *MNRAS* 481, 4, 5315

R. O. P. Loyd, T. T. Koskinen, K. France, C. Schneider, S. Redfield 2017, *ApJ* (Letters) 834, 2, L17

J. R. Kulow, K. France, J. Linsky, R. O. P. Loyd 2014, *ApJ* 786, 2, 132

D. E. Ionov, V. I. Shematovich, Ya. N. Pavlyuchenkov 2017, *Astron. Rep.* 61, 387

D. Ehrenreich, V. Bourrier, P. J. Wheatley, A. Lecavelier des Etangs, G. Hebrard, S. Udry, X. Bonfils, Xavier Delfosse, J.-M. Desert, D. K. Sing, A. Vidal-Madja 2015, *Nature* 522, 7557, 459

B. Lavie, D. Ehrenreich, V. Bourrier, A. Lecavelier des Etangs, A. Vidal-Madjar, X. Delfosse, A. Gracia Berna, K. Heng, N. Thomas, S. Udry, P. J. Wheatley 2017, *A&A* 605, L7

D. E. Ionov, Ya. N. Pavlyuchenkov, V. I. Shematovich 2018, *MNRAS* 476, 4, 5639

https://doi.org/10.1017/S1743921322001533 Published online by Cambridge University Press