

About the Atmospheric Loss of Hot Neptune GJ 436b

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Abstract. We applied the previously developed self-consistent 1D model of hydrogen-helium atmosphere with suprathermal electrons accounted to close-in hot neptune GJ 436 b. The height profiles of the gas temperature, velocity and density are computed. The two-scale structure of the planetary atmosphere was found. The mass-loss rate is found to be about $1.6 \times 10^9 \text{gs}^{-1}$.

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Exoplanets with extended hydrogen-helium atmospheres were discovered in abundance in recent years. Many of them are orbiting very close to their host stars. Extremely high soft X-ray and ultraviolet (XUV) radiation causes the hydrodynamic escape of their planetary atmospheres. Such effects are observed for some near planetary systems with hot jupiters, sub-neptunes and super-earthes. 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 temperature increase is explained by the host star UV flux absorption. Despite the discovery of a large number of extrasolar jupiters and super-earthes in orbits close to their host stars, the number of hot neptunes (0.6-18 masses of Neptune, orbital period less than three days) turned out to be very small. The corresponding area on the mass-period diagram is called the Hot Neptune Desert or short-period Neptune Desert (Mazeh et al. 2016). The generally accepted explanation for this phenomenon is that such planets do not have enough mass to hold their gas envelopes, which outflow under the influence of the high XUV radiation of the host star. It was concluded (Ionov et al. 2018) that the presence of the Neptune Desert could not be explained only by the atmospheric loss due to the photoevaporation by the stellar radiation. In the case of relatively low-mass hot neptunes, the upper limit

estimate of mass loss approaches the estimates by Owen (2019) of atmospheric photoevaporation rate. In the case of more massive hot neptunes, this mechanism does not result in any significant atmospheric loss.

In this paper, the gaseous envelope of the well-known hot neptune GJ 436 b was modeled 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). The Hubble Space Telescope (HST) observations by Kulow et al. (2014) showed the warm Neptune Gliese 436b extended gaseous envelope formation, which is comparable to the host star disk size. Two independent transit observations series using COS/HST 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). Besides the long tail, the hydrogen absorption also shows early ingress, i.e. the presence of a dense cloud extending in front of the planet at a distance comparable to the host star disk size.

The advantage of the model used in comparison with the models made by other authors is a more accurate calculation of atmospheric heating by including the contribution of suprathermal particles, and, accordingly, clarifying the rate of its outflow (Ionov et al. 2017, 2018). This is essential for the simulations of the hot exoplanetary atmospheres, because such exoplanets are exposed to very high flows of XUV star radiation and stellar wind plasma. 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 exceeds 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 dynamics and energy of the exoplanetary atmosphere (Ionov et al. 2017, 2018).

In this paper we present the results of the gaseous envelope modeling and the estimates of atmospheric thermal mass loss rate for the well-studied exoplanet hot neptune GJ 436 b. The height profiles of the atmospheric temperature (Figure 1a), velocity (Figure 1b) and density(Figure 1c) of the simulated exoplanet are 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 1 - 1.2 r/r0 in Figure 1c). The density of the upper atmosphere, the

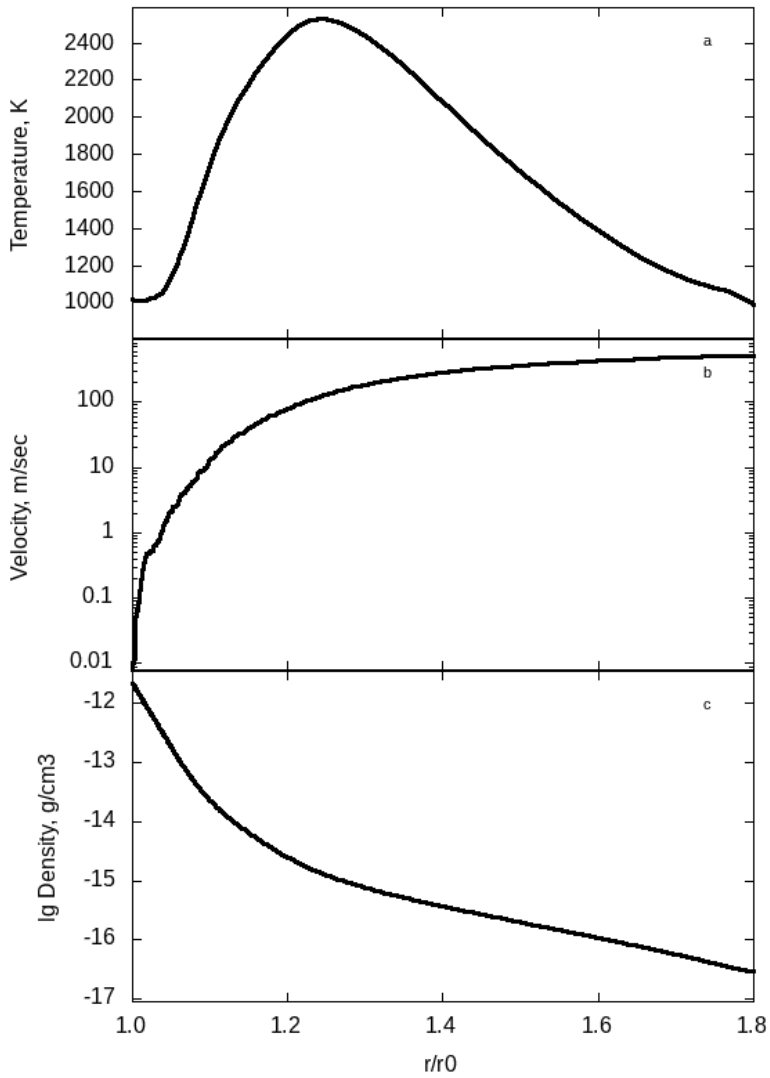


Fig. 1. Outflow temperature, velocity, and density of exoplanet GJ 436b as a function of height.

corona, changes much more slowly (see, distances of 1.2 r/r_0 in Figure.1c) according to the height scale, which responds to a higher temperature at the peak of the gas heating (see Figure 1a). The preliminary calculated mass loss rate is found be $\dot{M} = 1.6 \times 10^9 \text{gs}^{-1}$. It is lower than Shaikhislamov et al. (2018) and Loyd et al. (2017) calculations ($\dot{M} = 3.1 \times 10^9 \text{gs}^{-1}$) and significantly exceeds Kulow et al. (2014) calculations ($\dot{M} = 3.7 \times 10^6 - 1.1 \times 10^9 \text{gs}^{-1}$).

The processes of heating by the host star XUV radiation and the accompanying photoelectrons flux are an important source of thermal energy in the extended upper atmosphere of exoplanet GJ 436b. This leads to the formation of a dense underlying atmosphere and an extended corona. One important consequence of the complex two-scale structure of the hot neptune GJ 436b atmospheric gas distribution formation is the formation of a atmospheric gas thermal outflow from the planet envelope.

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