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Two-dimensional hydrodynamic outflow from exoplanets

Ksenia D. Gorbunova[1]

[1] Institute of Computational Modeling, Siberian Branch of the Russian Academy of Sciences

gksu475@gmail.com

The two-dimensional problem of unsteady outflow of the upper atmosphere of the planet as a result of heating by extreme UV radiation from the Star was considered. In recent years, this task has become especially relevant due to the discovery of a large number of exoplanets in various Star systems and their evolution study. Many authors has intensively solved the problem, with the pressure, density and radial velocity around the planet are assumed to have spherical symmetry. However, in reality, spherical symmetry is broken due to the peculiarity of the propagation and absorption of UV radiation and the presence of a shadow domain. In addition to the radial velocity, there is also a meridional velocity component, which becomes larger with increasing deviation angle from the central axis directed towards the Star. The meridional acceleration of particles is determined by the angular pressure gradient, which grows monotonically with increasing spherical angle at a fixed distance from the planet. At a given spherical angle, this gradient first increases with distance from the planet, reaching a maximum at a distance of about one and a half radii of the planet and then decreases. The meridional velocity seems to behave in a similar way.

Two-dimensional calculations were carried out on a spherical grid using the compact MacCormack-type scheme [1, 2]. To calculate the intensity of radiation propagating in the atmosphere along straight rays, the method of characteristics with interpolation on a spherical grid was applied. The characteristics of the warm sub-Neptune TOI-421c and its host Star given in the article by Carleo et al [3] were used as the calculation data.

Comparison with one-dimensional spherically symmetric models has shown that they significantly overestimate the integral gas flow rate. The two-dimensional model allows us to obtain a more realistic estimate of the atmospheric mass loss, being important for evolutionary problems.

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