DSMC and MHD simulations of atmospheric escape from a terrestrial planet

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The escape of a planetary atmosphere due to thermal and non-thermal processes is investigated using Direct Simulation Monte Carlo (DSMC)[1] and magneto-hydrodynamic (MHD)[2,3,4] simulations. One of the most challenging problems of thermal escape is to understand slow hydrodynamic escape. Although the two end-member approximations of thermal escape, i.e., hydrodynamic and Jeans escapes, are relatively well understood, the transition between the two, slow hydrodynamic escape, has been poorly understood due to difficulties in its theoretical and numerical treatment. The DSMC method is able to self-consistently solve slow hydrodynamic escape without imposing a priori assumptions on the boundary condition and molecular diffusion. Our DSMC simulations show that the adiabatic cooling associated with the slow hydrodynamic expansion is diminished due to infrequent intermolecular collisions around the exobase, hence higher exobase temperature and escape rates are obtained than previous fluid models. Another challenging problem is to understand the dependences of non-thermal escape on the planetary intrinsic magnetic field and interplanetary magnetic field. Although conventional view is that a planetary intrinsic magnetic field acts as a shield to protect the atmosphere from the solar wind induced non-thermal escape, recent MHD simulations[3] have revealed that a weak intrinsic magnetic field leads to a higher escape rate than that without intrinsic magnetic field. In this presentation, we will show how intrinsic and interplanetary magnetic fields control the ion escape rates and modify escape channels using multi-species MHD simulations.

References

[1] Terada, K., N. Terada, H. Shinagawa, H. Fujiwara, Y. Kasaba, K. Seki, F. Leblanc, J.-Y. Chaufray, and R. Modolo (2016). A full-particle Martian upper thermosphere-exosphere model using the DSMC method. J. Geophys. Res., 121, doi:10.1002/2015JE004961.
[2] Terada, N., Y. N. Kulikov, H. Lammer, H. I. M. Lichtenegger, T. Tanaka, H. Shinagawa, and T. Zhang (2009). Atmosphere and water loss from early Mars under extreme solar wind and EUV conditions. Astrobiology, 9, doi:10.1089/ast.2008.0250.
[3] Sakata, R., K. Seki, S. Sakai, N. Terada, H. Shinagawa, and T. Tanaka (2020). Effects of an intrinsic magnetic field on ion loss from ancient Mars based on multispecies MHD simulations. J. Geophys. Res., 125, doi:10.1029/2019JA026945.
[4] Sakai, S., K. Seki, N. Terada, H. Shinagawa, R. Sakata, T. Tanaka, and Y. Ebihara (2021). Effects of the IMF direction on atmospheric escape from a Mars-like planet under weak intrinsic magnetic field conditions. J. Geophys. Res., 126, doi:10.1029/2020JA028485.

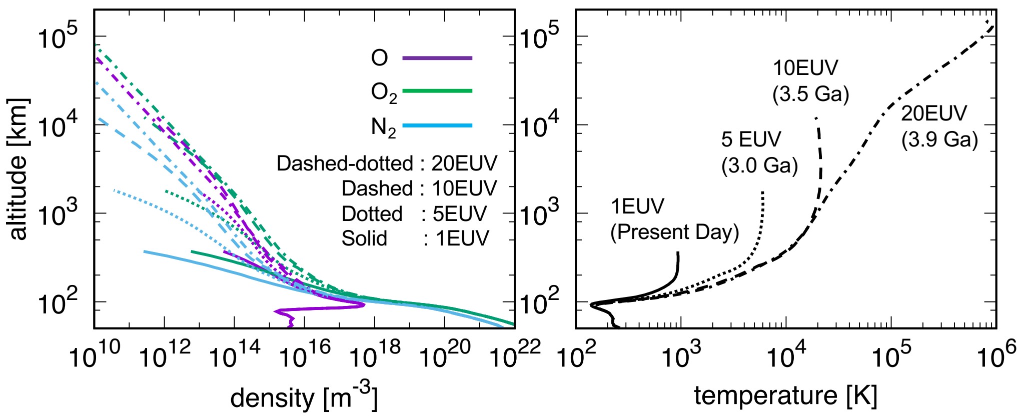

Figure 1. Altitude profiles of number densities and temperatures in the atmosphere of an Earth-like planet obtained from DSMC simulations for different EUV fluxes.