DSMC simulation of slow hydrodynamic escape from terrestrial planets

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Slow hydrodynamic escapes of atmospheric components from terrestrial planets subject to intense EUV radiation are investigated by DSMC simulations to understand the long-term evolution of planetary atmospheric composition.

Sun-like stars in earlier stages of their evolution emit intense EUV radiation. For example, the young sun of 4.5 billion years ago may have emitted 100 times stronger EUV radiation than today. After the formation of planets in a protoplanetary disk, planets get their atmospheres from the remnants of the disk gas and the outgassing due to impacts. The atmospheres were subject to the intense EUV radiation from a young central star, which caused significant heating and massive escape of planetary atmospheres.

The energy-limited escape rate is an upper limit of an atmospheric escape rate. The energy-limited escape is a category of the hydrodynamic escape. After an EUV radiation from a central star became weak, a planetary atmosphere was in hydrostatic equilibrium, and an escape rate became equal to the Jeans escape rate. While hydrodynamic escape and Jeans escape are understood well, there is an incomplete understanding of transition from hydrodynamic to Jeans escapes.

The thermal escape processes such as hydrodynamic escape and Jean escape depend on atmospheric composition. A previous study showed that the exobase temperature of Earth exceeded 10000 K and the atmosphere was well within the hydrodynamic regime when exposed to 20 times stronger EUV levels than present-day Earth. The exobase temperature of a CO2 dominated atmosphere like Mars was not heated as much as Earth's exobase because of efficient CO2 IR cooling. Nonetheless a previous simulation study using a fluid model showed that the exobase temperature reached about 2500 K and the Martian atmosphere was not in the hydrostatic equilibrium when exposed to 20 times stronger EUV levels.

In this study, escape rates from Earth-like and Mars-like planets for different EUV radiation intensities are estimated by DSMC simulations. Our full-particle upper thermosphere simulation model can solve the escape rates self-consistently. We show the escape rates of each species including the transition from hydrodynamic through slow hydrodynamic to Jeans escapes to understand the long-term evolution of planetary atmospheric composition.

Keywords: Atmospheric escape, Terrestrial planets, DSMC simulation

