

#竹本 泰志¹⁾, 坂田 遼弥²⁾, 関 華奈子^{1,2)}, 堺 正太郎³⁾, 寺田 直樹⁴⁾, 品川 裕之^{5,6)}

(¹⁾ 東京大学理学系研究科地球惑星科学専攻, (²⁾ 東京大学先端科学技術センター, (³⁾ 慶應義塾大学環境情報学部, (⁴⁾ 東北大学理学研究科地球物理学専攻, (⁵⁾ 九州大学国際宇宙惑星環境研究センター, (⁶⁾ 情報通信研究機構

Study of Ion Escape from Mars through Polar Plumes based on Global Multi-Fluid MHD Simulations

#Takemoto Taishi¹⁾, Sakata Ryoya²⁾, Seki Kanako^{1,2)}, Sakai Shotaro³⁾, Terada Naoki⁴⁾, Shinagawa Hiroyuki^{5,6)}

(¹)Department of Earth and Planetary Science, Graduate School of Science, The University of Tokyo, (²)Research Center for Advanced Science and Technology, The University of Tokyo, (³)Faculty of Environment and Information Studies, Keio University, (⁴)Department of Geophysics, Graduate School of Science, Tohoku University, (⁵)International Research Center for Space and Planetary Environmental Science, Kyushu University, (⁶)National Institute of Information and Communications Technology

The atmospheric escape to space is considered to be a major cause of ancient climate change on Mars. One of the ion escape pathways, the polar plume, is a phenomenon in which ions accelerated by the solar wind convection electric field escape from Mars, and its importance has been pointed out in previous studies [e.g., Dong et al., 2017; Sakakura et al., 2022]. Observations by the MAVEN spacecraft suggest that, in addition to O^+ , which has been considered the primary escape species, molecular ions such as O_2^+ and CO_2^+ are also escaping through the polar plumes. In some cases, although CO_2^+ is a minor component in the high-altitude ionosphere, CO_2^+ flux is higher than those of O^+ and O_2^+ in some localized regions [Sakakura et al., 2022]. One of difficulties to simulate the polar plumes is its kinetic nature, since the pick-up ions with a ring distribution function can contribute to the polar plumes. The global MHD simulations have been used as a powerful tool to simulate the ion escape from Mars [e.g., Ma et al., 2014; Sakata et al., 2024]. It is known that the multi-fluid MHD simulations result in asymmetric ion escape between +Z (+E) and -Z (-E) hemispheres in the MSE coordinates [e.g., Sakata et al., 2024], which has the same tendency as the polar plumes. However, the polar plume description capability of the multi-fluid MHD code is far from understood. If this capability can be understood, it will become easier to understand planetary atmospheric escape in a wider parameter space, including exoplanets. The objective of this study is to determine how well plume events can be described by the global multi-fluid MHD simulations.

In this study, we applied the global multi-fluid MHD model, MAESTRO, to the CO_2^+ -rich polar plume event observed by MAVEN on August 27 and 28, 2015, which was reported in details by Sakakura et al. [2022]. MAESTRO takes into account the production and loss processes due to chemical reactions, and can reproduce interaction between the solar wind and Martian atmosphere/crustal magnetic fields, including plasma boundaries, ionospheric profiles, and ion escape. MAESTRO separately solves ion and electron pressures, and photoelectron heating is also considered with a heating effect of 5 eV per photoelectron. In the simulation settings of this study, the solar wind conditions used in Sakakura et al. [2022] for the CO_2^+ -rich polar plume event were used as inputs to MAESTRO: the solar wind density, velocity, and interplanetary magnetic field (IMF) were set to 10 cm^{-3} , 350 km/s, and $5.0 \times (\cos 55^\circ, \sin 55^\circ, 0)$, respectively. We conducted multi-species (MS) and multi-fluid (MF) MHD simulations with MAESTRO for comparison. The MS results were similar to those shown in Sakakura et al. 2022, while MF results show clear asymmetry between +E and -E hemispheres as expected. Comparison between MS and MF results show that characteristic structures such as current sheet and magnetic pile-up boundaries tend to be more smoothed in MF than in MS. The dayside boundary of the molecular ion polar plumes region in MF, the smallest SZA (solar zenith angle) in the density and flux enhancements of CO_2^+ and O_2^+ , was similar to the observation by MAVEN, while the nightside structure was different with more continuous enhancements of the molecular ion densities in the simulations than the observation. We also report on the comparison of the MF results with the plume distributions obtained from statistical trajectory tracings of molecular ions in the electromagnetic fields obtained from the MHD simulations.

References:

- Dong, Y., et al. (2015), J. Geophys. Res., 122, 4009 – 4022, doi:10.1002/2016JA023517.
 Sakakura, K., et al. (2022), J. Geophys. Res., 127, e2021JA029750, doi:10.1029/2021JA029750.
 Ma, Y., et al. (2014), Geophys. Res. Lett., 41, 6563 – 6569, doi:10.1002/2014GL060785.
 Sakata, R., et al. (2024), J. Geophys. Res., 129, e2023JA032320, doi:10.1029/2023JA032320.