Study of Molecular Ion Contribution to the Polar Plume from Mars Based on MAVEN Observations

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Mars once had water on its surface about 4 billion years ago, but there is no liquid water on the surface at present. Escape of the atmosphere to space is considered as the main cause of this climate change. However, the mechanism of the large amount of atmospheric loss is far from understood. Ion escape is one of the important candidates of the loss mechanism. There are three channels of the ion escape, namely, tailward escape, pickup ion, and polar plume. Polar plume ions are accelerated by solar wind electric field and escape to positive E hemisphere of the Mars-Sun-Electric field (MSE) coordinates. It is estimated by Dong et al. [2017] that the escape rate of O^+ plume is 20-30% of the total O^+ escape depending on the solar EUV radiation. The rate is not negligible in order to understand ion escape from Mars. Molecular ions in the polar plume should also be studied since it is shown that main escape species is O_2^+ for tailward escape by Inui et al. [2019]. We recently reported a CO_2^+-rich plume event on August 28, 2015. Peak flux of CO_2^+ was $3.6\text{x}10^6$ $cm^{-2}s^{-1}$, which is about one order of magnitude higher than the average flux of O^+ in the polar plume reported by Dong et al. [2017]. Such high escape flux is unexpected because CO_2^+ is minor component at high-altitude ionosphere due to its small scale height. To fully understand the mechanism of polar plume, it is important to study the composition of the plumes.

In order to investigate relationship between CO_2^+-rich plume event and solar wind conditions, we conducted a statistical study. We analyzed data obtained by STATIC (Supra Thermal and Thermal Ion Composition), MAG (magnetometer) and SWIA (Solar Wind Ion Analyzer) onboard MAVEN (Mars Atmosphere and Volatile EvolutioN) from Dec. 11, 2014 to Feb. 23, 2019. STATIC can measure ion distribution functions with mass discrimination. In order to derive CO_2^+ number density, we use the fitting method invented by Inui et al. [2018]. By fitting a log-normal distribution to O_2^+ count data, we remove O_2^+ contamination in the CO_2^+ mass range. We defined CO_2^+ plume event as the time period when the observed maximum flux of CO_2^+ in an MAVEN orbit is higher than $2.5\text{x}10^5$ $cm^{-2}s^{-1}$. In order to remove false CO_2^+ plume events due to high O_2^+ counts, we set another requirement that CO_2^+ has evident peak which is at least comparable to O_2^+ contamination in the CO_2^+ mass range. The results show that the CO_2^+ plume events tend to be observed under high solar wind dynamic pressure and strong electric field conditions. This result is consistent with hypothesis that CO_2^+ plume is caused by deep penetration of the solar wind electric field due to the high solar wind dynamic pressure. On one hand, detection probability of O_2^+ plume events don't show such dependences on the solar wind parameters. This is probably because O_2^+ is abundant near the ionopause enough to create dense (>$2.5\text{x}10^5$ $cm^{-2}s^{-1}$) O_2^+ plumes regardless of the solar wind conditions. On the other hand, the escape flux of O_2^+ due to the polar plume has weak positive correlation with the solar wind dynamic pressure. This result might reflect high density of O_2^+ near the ionopause under the high solar wind dynamic pressure conditions.

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