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Statistical study of ion escape from Mars during CIR events based on MAVEN observations

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Mars, lacking a global intrinsic magnetic field, is directly exposed to the solar wind, making its atmosphere vulnerable to escape. This study investigates ion escape driven by solar activity events such as Interplanetary Coronal Mass Ejections (ICMEs) and Corotating Interaction Regions (CIRs), to better understand atmospheric evolution. Both ICMEs and CIRs often facilitate high solar wind dynamic pressure condition and disturb the Martian induced magnetosphere and influence atmospheric escape. MAVEN observations and their comparison with global MHD simulation results show that atmospheric escape rates increased significantly during an ICME event in March 2015[1]. On the other hand, other results of statistical analysis show that the ion escape rate from Mars does not have clear dependence on the solar wind dynamic pressure[2]. These contradictory observations indicate the need for careful investigation of effects of ICMEs and CIRs on the ion loss from Mars. Observationally there are two major escape channels for ions from Mars: polar plumes accelerated by the convective electric field of the solar wind and the tailward escape, a bulk ion outflow through Martian magnetotail[2]. Statistical studies of the polar plumes[3] and tailward escape[4] both indicate that the spatial distributions of the ion escape flux are highly localized in terms of the MSE coordinates determined by the direction of the solar wind electric field. In this study, we aim to evaluate the impact of solar wind on the ion escape from Mars especially during CIRs by carefully investigating the localization effects of both ion escape channels.

Utilizing observations by SWIA and MAG onboard MAVEN from 2015 to 2023, we identified CIRs. The solar wind data satisfying the following criteria were selected: (1) the difference in velocity over two days was greater than 100 km/s. (2) Among the selected data, events where velocity increased following a density rise were classified as CIRs. As a result, we found 131 CIRs over the nine-year period. Because the apoapsis of MAVEN's orbit during the early period (2015 – 2019) was higher than during the later period (2020 – 2023), the frequency of the solar wind observations and thus the number of events were decreased during the later period. The "before" and "CIR" periods relative to CIR arrivals were defined as follows: for each event, a quiet period was visually identified, and the "after" period was defined as 48 hours from the time when the solar wind density first exceeded 1.5 times the average value during that quiet period. We also used median values of all data when upstream solar wind observations were available from 2015 to 2021 as the "normal" dataset to compare with "CIR". Utilizing data from STATIC onboard MAVEN, distributions of heavy ion fluxes are separately examined both in the Mars-Solar-Orbital (MSO) coordinates and the Mars-Solar-Electric field (MSE) coordinates to differentiate the effects of the crustal magnetic field and acceleration by solar wind electric field. We then calculated the differences between the medians of heavy fluxes during "normal" and "CIR" datasets, and ratio of the differences normalized by the median of the "normal". The results show that in the -Z_{MSE} hemisphere, the escaping flux in the optical wake region increased by approximately 50%. The structure of the polar plume tends to shift toward the nightside. Based on these statistical results, we will discuss the effects of CIRs on the spatial distributions of the ion loss from Mars.

References
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