Atmospheric Variation and Distribution of Martian Meteoric Mg^+ from MAVEN/IUVS

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Introduction:

Since the discovery of atmospheric Mg^+ at Mars in 2015 by the Mars Atmosphere and Volatile Evolution (MAVEN) mission, there have been almost continuous observations of this meteoric ion layer in a variety of seasons, local times, and latitudes. Here we present the most comprehensive set of observations of the persistent metal ion layer at Mars, constructing the first grand composite maps of a metallic ion species. These maps demonstrate that Mg^+ appears in almost all conditions when illuminated, with peak values varying between 100 and 500 cm^{-3}, dependent on season and local time. There exists significant latitudinal variation within a given season, indicating that Mg^+ is not simply an inert tracer, but instead may be influenced by the meteoric input distribution and/or atmospheric dynamics and chemistry. Geographic maps of latitude and longitude indicate that Mg^+ may be influenced by atmospheric tides, and there is no apparent correlation with remnant crustal magnetic fields. This work also presents counter-intuitive results, such as a reduction of Mg^+ ions in the northern hemisphere during Northern Winter in an apparent correlation with dust aerosols.

Observations and Data Analysis:

The MAVEN spacecraft has a uniquely elliptical orbit that benefits from atmospheric drag and subsequent fuel burns to change the location of periapse in latitude and local time. Over the course of more than seven Earth years, MAVEN has been able to observe a variety of Martian seasons, geographic latitude and longitudes, as well as local times. During the orbital periapse segment the spacecraft descends through the upper atmosphere (down to 140-160 km) so that in-situ measurements of atmospheric atoms and ions, as well as ambient E and B-fields can be measured throughout. This spacecraft orbital geometry provides coverage of local times, solar zenith angles and full longitude coverage over about 4-5 orbits (each orbit is ~5 hours). IUVS is able to create vertical profiles during its periapse orbital segment, when the instrument is oriented orthogonally to the motion of the spacecraft. Using the Mid-UltraViolet (MUV) resonant fluorescent scattering of MgII at 285 nm, IUVS investigates the abundance and structure of this meteoric ion above 60 km, where scattered solar light serves to limit the lowest altitudes from observation. In this work we present the first global results of near continuous monitoring of Mg^+ at Mars with implications for the formation of mesospheric cloud nuclei [1,2] and to provide the first constraints on a seasonally varying meteor input function (MIF) [3,4]. As has been successfully accomplished at Earth [5,6], this global view on meteoric ions also permits a direct investigation of the upper atmosphere, where the dynamics and chemistry can be constrained with a novel set of observations.

Results:

Prior to the Martian insertion of the MAVEN spacecraft in 2014, ionospheric observations of a transient M_3 or M_m layer of electrons near 90 km, coincident with modeled ablation heights [7,8], were presented as evidence of intermittent meteoric ablation. However, after the meteor shower of comet Siding Spring [9,10] and discovery of a persistent layer of meteoric ions [11] provided the first observations of atomic and ionic metal species it was possible to determine that the origin of these radio occultation observations was not meteoric [12]. Initial monitoring of the Mg^+ layer due to sporadic meteors indicated that it was a persistent layer with a fixed altitude and abundance [11]. However, such an early and simplified view has been supplanted by the wealth of data accumulated since 2015.

The Mg^+ layer seems to be dynamic, with peak ablation altitudes shifting, abundances fluctuating, and variations in the top and bottom-sides of the Mg^+ layer, all likely directly related to the underlying atmospheric structure and meteoric chemistry. At the equator, a multi-year analysis shows an enhancement of Mg^+ at morning local times whose layer topside increases throughout the day. Separating these observations by season, the peak altitude Mg^+ appears to respond to the background atmosphere, as the former shifts up and down in altitude. Using zonal medians to compare across latitude, the Mg^+ layer peak altitude can dip as low as 80 km near the south pole and as high as 105 km at equatorial/mid-latitudes. Overall abundances also vary dramatically, in excess of the average 250 ions cm^{-3} reported in [11] to averages of 300-500 ions cm^{-3} in some cases, but also the reduction of Mg^+ in specific seasons warrants further investigation. Finally, in two seasons the geographic distribution may be linked to tidal variations in the background atmosphere.

This dataset represents nearly continuous monitoring of the Mg^+ layer in a variety of geophysical conditions, and the results found herein will provide important constraints for the next generation of meteoric ion chemistry and atmospheric circulation modeling at Mars. Model-observation comparisons should provide insights into mesospheric transport, chemistry and interplanetary dust particle sources. Previous discrepancies between model predictions and metal ion observations led to the development of a novel nucleation scheme for mesospheric clouds[2], and we expect this dataset to provide the impetus to future advances in atmospheric chemistry. Overall, this represents the broadest investigation of meteoric metal ions, summarizes their first-order behavior, and outlines new model challenges for the future.

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