A PERSISTENT METEORIC METAL LAYER IN MARS' ATMOSPHERE

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Introduction: We report on the discovery of a globally persistent meteoric metal layer in Mars' ionosphere, providing the first measurements of meteoric fluence at a planet other than the Earth. Interplanetary dust particles sporadically enter planetary atmospheres at orbital velocities and ablate as collisions occur with ambient gases. Ablation should be ubiquitous at all planets with sufficiently dense atmospheres; therefore each of these planets should contain a layer of metallic species in the atmospheric aerobraking region (90-140 km) that would otherwise be absent. This has implications for a varied range of fields, potentially affecting the formation of clouds, ionospheric layers and chemistry at high altitudes. This discovery indicates that previous observations of transient ionospheric layers at Mars may not be the result of meteoric ablation, and require another unknown generation mechanism (Pätzold et al. 2005). While the presence of this layer validates some aspects of ablation chemistry and meteor dynamics, we find significant differences from Earth's meteoric layer. While concentrations of the dominant ion, Mg^+, are consistent with predicted abundances, its neutral coutnerpart is not observed, indicative of hitherto undetermined atmospheric and ablation physics.

The Mars Atmosphere and Volatile EvolutioN mission (MAVEN) orbits Mars in an elliptical orbit with a close approach to the planet's surface of 150 km at periapse (Jakosky et al., 2015). MAVEN carries a slew of instruments designed to study the Martian atmosphere and ionosphere, as well as the drivers that control its behavior. MAVEN's primary remote sensing instrument for studying the Martian upper atmosphere is the Imaging Ultraviolet Spectrograph (IUVS) (McClintock et al. 2015). The instrument observes in the far and middle UV (110-190 and 190-340) in separate channels, and measures atmospheric emissions from CO_2 and its dissociation and ionization products as well as atomic and molecular species such as N_2 and O (Jain et al., 2015, Evans et al., 2015). The instrument uses a scan mirror to construct vertical profiles of the atmosphere, creating two-dimensional images in each scan. Observations discussed herein are from the periapse segment of its orbit, where we produce 12 limbs scans per orbit in a ~30 minute observation window.

Modeling and Data Processing: Spectra were corrected for detector dark current and scaled to physical units, then individual emissions were obtained from the spectra and these were then binned in altitude. Vertical profiles of this emission were obtained from spectra by fitting multiple linear regressions of individual spectral components, such as molecular bands, atomic lines and reflected solar spectrum background, convolved with the instruments resolution and internal offsets (Stevens et al., 2015). Column abundances of Mg^+ indicate the emission at 280 nm is optically thin, and we use an Abel transform to determine the concentration at the tangent point (Chamberlain and Hunten 1987). The calibration of the instrument is directly related to the retrieved concentrations of Mg^+, and uncertainty in the absolute calibration of the instrument is carried in the systematic uncertainties (30% in the MUV channel). These uncertainties do not affect variability with geography, vertical distribution or temporal variability.

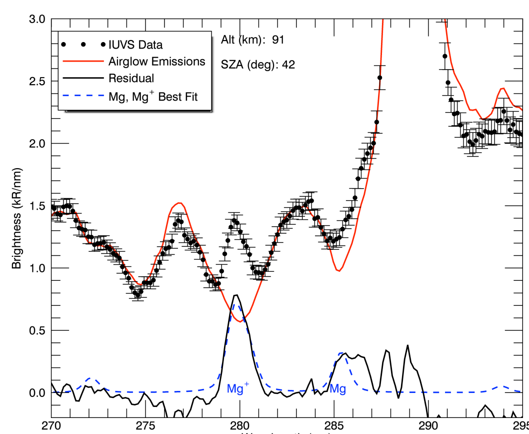

Figure 1: The spectrum from an integration of 4.4 seconds in the MUV channel of IUVS (orbit 3040). The data is shown in black, with known airglow emissions (such as the CO_2^+ UVD, N_2-VK and solar scattered sunlight) fit in red. The residual is shown as the solid black line, with an emission near 280 nm consistent with the Mg^+ doublet. The quality of the Mg fit is suspect due to the emissions' correlation with the airglow peak (120-130 km) and the emissions' proximity to the CO_2^+ UVD near 290 nm.

The Leeds Chemical Ablation Model (CABMOD 1D), verified by terrestrial studies and adapted for the Martian atmosphere, predicts the concentration of metals that would be delivered by interplanetary chondritic meteoritic dust (Vondrak et al. 2008, Whalley and Plane 2010). This model includes heating and melting of the dust particles from collisions with the ambient gases, evaporation of atoms from the molten particle surface and charge exchange with ambient ions. The injected metallic species are the input to a 1D atmospheric model that uses detailed chemistry of Mg, Fe, etc., based on laboratory studies of pertinent reaction rates, and includes turbulent diffusion up to the Mars homopause (~135 km) and ambipolar diffusion above.

This atmospheric model follows the chemical evolution of meteoric metals and their reaction with ambient gases. In the model, Mg^+ recombines by forming clusters with CO_2 that then undergo dissociative recombination with electrons. Because of this recombination, the model predicts the concentration of Mg^+ at 100 km to be equal to its neutral counterpart (see Figure 2). Moreover, since the scattering efficiency of neutral Mg (285 nm) is more than 2 times greater than Mg^+ (280 nm), one expects the emission of Mg to be brighter than Mg^+ at 100 km, which is not seen in any observation (see Figure 1).

IUVS has the spectral resolution and sensitivity to detect the 285 nm atomic Mg emission, but the lack of a clear detection forces us to use Mg^+ to determine an upper limit. We find that IUVS should be sensitive to atomic Mg at 20 atoms/cc, scaling the concentrations of Mg^+ by the ratio of their scattering efficiencies at our most marginal detection of Mg^+. The lack of Mg compared to Mg^+ indicates hitherto unexplained atmospheric chemistry that preferentially neutralizes Mg^+ without producing atomic Mg.

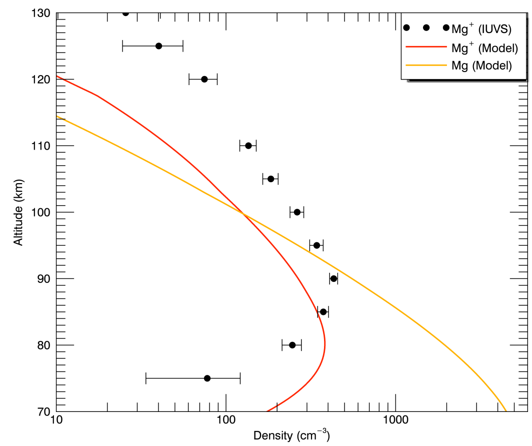

Figure 2: IUVS data from a single orbit (3040) compared with a predicted model (Whalley and Plane 2010). Note the equal predicted concentrations of Mg and Mg^+ at 100 km, yet Mg is not detected in the spectrum in Figure 1. The difference in peak ablation heights is likely due to variability in the Martian atmosphere itself, as demonstrated by the varying homopause altitude with season, local time, etc (Jakosky et al. 2016). Subsequent work will attempt to characterize the variability in peak altitude and concentration.

Mars likely encounters regular meteor showers, analogous to Earth, however we report here that we have been unable to detect any showers other than comet Siding Spring's (Schneider et al. 2015). While there are 25 predicted Mars meteor showers, IUVS was

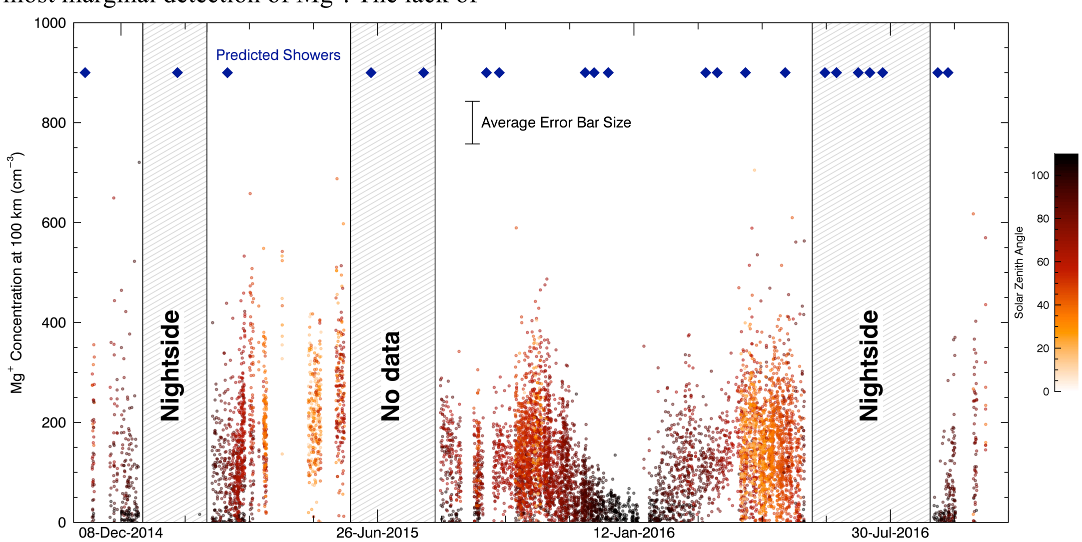

Figure 3: Mg^+ concentrations at 100 km over the course of two Earth years (~ one Mars year). The dominant variability shown here is due to solar zenith angle/local time. As this emission is optically thin, this is indicative that Mg^+ is decreased on the nightside, and global means should be considered near local times of noon. Observations of the persistent layer have sufficient temporal coverage that any transient ionospheric concentration events should be readily identifiable in this data if their source were meteoric ablation. If the transient layers were due to ablation, they would require Mg^+ at a level of 10^4/cc in this graphic.

only able to observe 10 of these events, and none appear to have fluences that would contribute Mg^+ above the normal variability. We can place this constraint in context by comparing this fluence of comet Siding Spring with terrestrial meteor showers. Mg^+ observations cannot directly constrain the particle size distribution, and therefore do not inform us about the abundance of particles >1 mm which create most visible meteors. However, we can estimate their abundance assuming a dust size distribution with a power law of -2.6 (Moorhead et al. 2014) and find the fluence of particles larger than 1 mm is 5×10^6 m^{-2}. This can be interpreted as a zenith hourly rate (ZHR) of 2000, which is 10 times larger than "good" Earth showers; therefore we do not expect to regularly observe typical fluence showers without significant reduction in the variability in the persistent layer.

Results:

1. We will demonstrate that previous observations of transient ionospheric layers at Mars cannot be attributed to meteoric ablation.
2. We will constrain the global fluence at Mars from IDPs, and are the first with the ability to do so.
3. The lack of Mg compared to Mg^+ indicates hitherto unexplained atmospheric chemistry that preferentially neutralizes Mg^+ without producing atomic Mg.
4. Mars likely encounters regular meteor showers, analogous to Earth, however we report here that we have been unable to detect any showers other than comet Siding Spring's.

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