MARS ION AND SPUTTERING ESCAPE NETWORK (MISEN) R. J. Lillis[1], S. M. Curry[1], D. E. Larson[1], C. T. Russell[2], D. A. Brain[3], D. W. Curtis[1], J. Parker[3], N. Parrish[3], J. Puig-Suari[4] , [1]UC Berkeley Space Sciences Laboratory (rlillis@ssl.berkeley.edu), [2]UCLA Department of Earth and Space sciences, [3]Laboratory for Atmospheric and Space Physics, University of Colorado Boulder, [4]Advanced Space LLC, Boulder, Colorado, [5]Tyvak LLC, Irvine, California

Introduction: Atmospheric escape to space has played a decisive role in the history of Mars' atmosphere and habitability, as a primary driver for its evolution from a planet where liquid water was at least episodically stable to the cold, arid planet we see today. The MAVEN mission [1] was designed to characterize atmospheric escape and its dependence on solar energetic drivers, and hence to enable reliable estimates of atmospheric escape over Martian history. MAVEN measures escape through four primary channels or processes. Two of the escape processes, photochemical escape of O, C and N and Jeans escape of H, are driven mostly by solar EUV flux and Martian season and can be constrained with remote sensing measurements [2]. MAVEN is continuing to characterize these processes and allow their effect on atmospheric loss, now and over time, to be well understood.

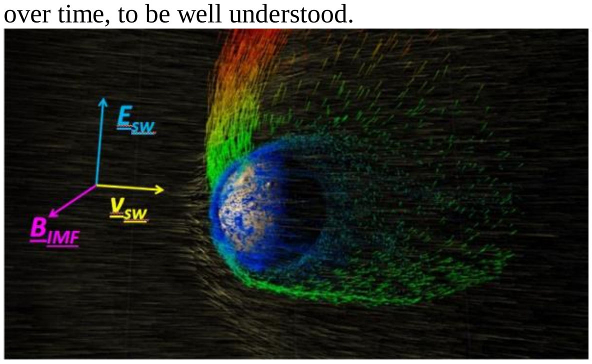

Figure 1: simulation of ion escape from Mars. Yellow, magenta and blue arrows represent solar wind velocity, IMF direction and convection electric field respectively. Colors represent log energy, increasing from blue to red.

In contrast, the other two processes are governed mostly by the motion of ions in near-Mars space, and hence by the global patterns of electric and magnetic fields resulting from the interaction of Mars' upper atmosphere and ionosphere with the highly variable solar wind and interplanetary magnetic field (IMF), as shown in Figure 1. These processes are a) ion escape, where neutrals from the thermosphere or exosphere are ionized, then energized and accelerated away from Mars by these field, and b) sputtering (or sputtered) escape, where neutrals are ionized but then accelerated back into the atmosphere, giving sufficient energy to thermospheric (< 200 km) neutrals to allow them to escape, essentially 'splashing' them out [3]. As the sputtered neutrals cannot be directly detected by any existing instrument, straightforward calculation are used to convert precipitating ion spectra into sputtered escape rates [4]. Both processes have complex global structure, are dependent on EUV, and vary significantly with solar wind density and velocity and the strength and direction of the IMF.

MAVEN is fundamentally limited by its single platform, in three major ways:

a) A single spacecraft can sample only along its orbit track, making it very difficult to determine whether an observed variation in these processes is spatial or temporal and providing only a very small slice of their highly dynamic global patterns. This makes statistical escape maps built up over many months artificially 'lumpy' [5] and missing much, and possibly most, of the true variability.
b) Escape correlations with heliospheric drivers such as solar wind pressure suffer from an inherent time lag: at least an hour separates any measurement of escape from the most recent or the next measurement of the upstream solar wind. In contrast, models show that solar wind disturbances propagate through the Martian magnetosphere in ~1 minute [6]. In addition, MAVEN's orbital precession results in multi-month gaps where upstream conditions are not sampled at all [7].
c) **S**pace weather structures such as coronal mass ejections and corotating interaction regions can cause large increases (the so-called 'tsunami' theory of erosion) in both ion escape and sputtering escape [8,9, 10]. However these events are relatively infrequent and unique; this escape has never been measured except along a single orbit track and so its global pattern and variability is presently unknown.

Our understanding of plasma motion in the terrestrial magnetosphere previously suffered from many of the same limitations and ambiguities: multi-spacecraft missions such as Cluster II (2000), THEMIS (2006), the Van Allen Probes (2012), and MMS (2015), along with constant monitoring of the upstream solar conditions from missions such as Wind (1994) and ACE (1997), have revolutionized our understanding of of a wide array of magnetospheric and ionospheric phenomena. In a similar fashion at Mars, we will only be able to understand the spatial and temporal variability of ion and neutral escape, the underlying physics of such processes, and ultimately, their importance to climate evolution with multiple spacecraft and a simultaneous solar wind monitor.

MISEN has two primary science objectives, which flow from both 2015 MEPAG Goals (II.A2 and II.C3) and 2014 NASA Science Plan Goals (chapter 4, Goals 1 and 2).

- Characterize the global patterns, variability, and real-time response to changing solar wind conditions, of ion escape at Mars.
- Characterize the global patterns, variability, and real-time response to changing solar wind conditions, of ion precipitation into the atmosphere, and resulting sputtered escape of neutrals.

MISEN mission architecture: MISEN consists of 3 identical spacecraft in complementary elliptical orbits around Mars, each measuring magnetic field and electron and ion energy spectra and angular distributions. Figure 2 shows an example orbital configuration. This will ensure global coverage of both the precipitation and escape of planetary heavy ions from Mars, as well as >95% coverage of upstream solar wind conditions.

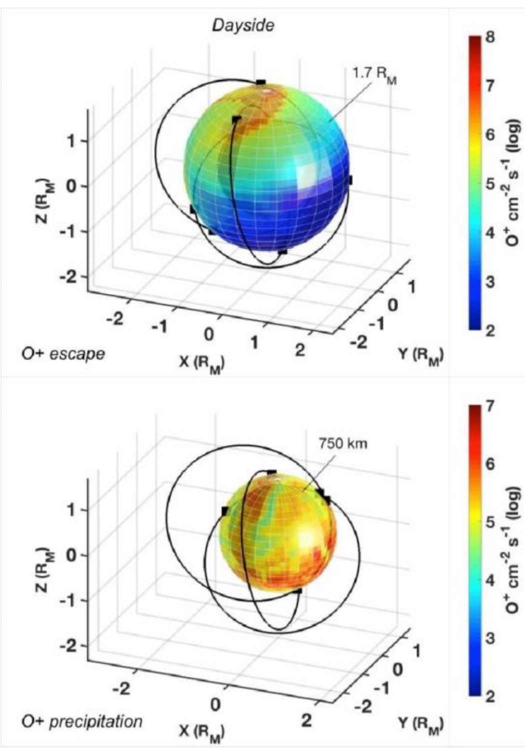

Figure 2: MHD predictions of O+ escape and precipitation with MISEN fly-thrus. Top: a projected map of simulated O+ escape at 1.7 Mars radii. Bottom: a projected map of O+ precipitation at 750 km.

Mission design: The three spacecraft will separate from the ESPA ring after a trans-Mars injection burn and cruise via a constant-thrust trajectory to a Mars rendezvous in under two years.

Payload and Accommodation: The MISEN Science payload consists of:

- Magnetometer, accommodated on a 60 cm folding boom, to characterize magnetic field.
- Ion spectrometer, with mass discrimination, to detect precipitating and escaping Planetary ions
- Electron spectrometer, to determine magnetic topology.

Communications: a foldable antenna and the JPL cubesat IRIS radio will transmit science data directly back from Mars orbit without the need for relay from existing Mars assets.

Mission operations are simple, with the spacecraft spinning in order to collect fully three-dimensional plasma data. No special pointing is required except during downlink.

In summary, MISEN will provide simultaneous multipoint measurements of the plasma environment in near-Mars space (including the solar wind), building on MAVEN's legacy for a fraction of the cost, and revealing for the first time the global patterns of ion and sputtering escape, and how and why they vary.

References: [1] Jakosky et al., *SSR*, 2015, [2] Lillis et al., *SSR*, 2015, [3] Luhmann et al., *JGR*, 1992, [4]Wang et al., *JGR*, 2014, [5] Brain et al., *GRL*, 2015, [6] Ma et al., *JGR* 2014, [7] Halekas et al., *JGR*, 2016, [8] Jakosky et al., *Science*, 2015 , [9] Edberg et al., *GRL*, 2010, [10] Curry et al., *JGR*, 2018.