SCIENTIFIC HIGHLIGHTS FROM THE MAVEN MISSION TO MARS
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Introduction: The Mars Atmosphere and Volatile Evolution (MAVEN) spacecraft has been orbiting Mars since 21 September 2014 and collecting data in science mode since 16 November 2014. The science objectives of the MAVEN mission are to characterize the upper atmosphere and ionospheric structure and composition, the interactions of the sun and the solar wind with the planet, and the processes driving loss of gas from the atmosphere to space. Our goal is to understand the chain of processes leading to escape today, learn how to extrapolate back in time, and determine the integrated escape of atmosphere over Martian history [1,2].

Mission description: The MAVEN spacecraft is in an elliptical orbit whose altitude ranges from approximately 150 km to 6200 km above the surface. This orbit allows the spacecraft to pass through the upper atmosphere on each orbit to allow in situ observations, and also to make global-scale remote-sensing observations near apoapsis. In addition, we have performed four deep dip campaigns where the periastris reached down to ~125 km, enabling observations of the transition between the lower and upper atmospheres. Thus, we sample the entire upper-atmospheric column, all the way out to altitudes at which the solar wind interacts with the planet and its magnetosphere [1].

Science instruments: MAVEN has nine instrument sensors, which can be divided into groups primarily measuring different aspects of the Mars environment relevant to the goals of MAVEN. The first group of instruments measures the properties of the solar wind and of the sun that drive processes in the upper atmosphere:

- Solar Wind Ion Analyzer, SWIA [3]
- Extreme Ultraviolet Monitor, EUV [5]
- Solar Energetic Particle detector, SEP [6]

The second group measures the structure and composition of the upper atmosphere and of the ions in the ionosphere, and also measures isotope ratios that can tell us about the integrated escape to space. In this group, NGIMS measures properties in situ at the location of the spacecraft, and IUVS measures them remotely, providing a powerful combination of local and global measurements:

- Imaging Ultraviolet Spectrograph, IUVS [7]
- Neutral Gas and Ion Mass Spectrometer, NGIMS [8]

The third group measures the properties of the ionosphere that both drive escape and determine the composition and properties of the escaping ions:

- Magnetometer, MAG [9]
- Langmuir Probe and Waves, LPW [10]
- Suprathermal and Thermal Ion Composition, STATIC [11]

With this combination of measurements, we are able to observe the entire chain from solar energy input that drives the processes controlling the upper atmosphere and ionosphere, to the upper-atmosphere response, to the loss of neutrals and ions to space.

Atmospheric escape: can be divided up broadly into 4 major channels which MAVEN can investigate. Over the course of MAVEN’s primary mission, we have made the observations necessary to estimate the escape rates via these 4 channels during half of a Martian year and under current moderate solar activity conditions.

Ion escape: atmosphere can escape from Mars in ionized form via at least three different processes: 1) bulk ion escape, where large ‘clouds’ of ionosphere are magnetically removed from the planet, 2) ion outflow, where wave-particle interactions or electric potentials can drive ions out of the ionosphere and 3) pick up ion escape, where neutral oxygen atoms in Mars’ exosphere are ionized and then picked up by the solar wind flow. The STATIC instrument has sampled the rate of hydrogen and oxygen ion escape from Mars under a range of solar wind and interplanetary magnetic field conditions. Figure 2 shows net ion escape fluxes measured on a spherical shell of 1.3 Mars radii [12].
Figure 2: maps of ion escape from the dayside and nightside of Mars.

Photochemical escape is broadly defined as a process by which a) an exothermic reaction in the atmosphere results in an upward-traveling neutral particle whose velocity exceeds planetary escape velocity and b) the particle is not prevented from escaping through subsequent collisions. Photochemical escape of oxygen is expected to be a significant channel for atmospheric escape, particularly in the early solar system when extreme ultraviolet (EUV) fluxes were much higher [13]. Figure 3 shows the calculated photochemical escape fluxes as a function of solar zenith angle (abscissa) and heliocentric distance (color). We see that, ~50 days after perihelion, periapsis moves from dusk to subsolar point and escape fluxes range 10^7 to 10^8 cm^-2 s^-1 (mean of 5.9 x 10^7 cm^-2 s^-1 ). Moving away from the subsolar point, escape fluxes are lower (mean of 2.9 x 10^7 cm^-2 s^-1 ) as Mars approaches equinox. We then see extremely low fluxes in darkness. As we move back into the dayside southern hemisphere, approaching aphelion, we see fluxes between SZAs of 60° to 90° that are, expectedly, much lower than equatorial values. However, puzzlingly, aphelion fluxes at equator appear almost as high as perihelion.

Figure 3: total derived photochemical O escape fluxes are shown as a function of solar zenith angle and heliocentric distance.

Sputtering escape is a process whereby neutral particles can be given escape velocity through interactions with precipitating heavy ions. We have estimated sputtering escape to be a negligible contributor under current solar conditions [14] although feedbacks may cause it to increase exponentially under more extreme conditions [15].

Thermal escape of hydrogen is a key driver in the ocean. IUVS observations have shown a hydrogen exosphere with unexpected complexity, indicating a possible hot component caused by heretofore poorly understood atmospheric chemistry and prompting a critical re-examination of historical models of hydrogen loss [16].

Total atmospheric loss estimates over solar system history is a key part of understanding the evolution of Mars’ atmosphere and habitability. We will provide an update on progress toward this important goal.

Other scientific highlights: MAVEN has made several discoveries concerning the Mars upper atmosphere and near space environment, including but not limited to:

- Diffuse aurora caused by energetic electrons [17]
- Interstellar dust in the near-Mars environment [18]
- Metallic layers in the Mars ionosphere observed after the passage of Comet Siding Spring [19, 20]
- Penetrating solar wind protons and negative H ions in the Mars thermosphere [21]
- First in situ measurements of electron densities and temperatures in the Martian nightside [22]
- Neutral atmosphere heating by solar flares [23]
- Thermal tides propagating from the lower atmosphere into the thermosphere [24, 25]
- Shadowing of solar energetic ions by Mars [26]
- Ambipolar electric fields in the ionosphere [27]
- Current sheet flapping in the magnetotail [28]
- A plume of accelerated ions aligned with the solar wind convection electric field [29]
- First mapping of Mars’ oxygen corona [30]
- First study of water and protonated species in the Mars thermosphere [31].