PHOTOCHEMICAL ESCAPE OF THE MARTIAN ATMOSPHERE: LOOKING FORWARD TO MAVEN.

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Introduction: Photochemical escape is broadly defined as a process by which a) an exothermic reaction results in an upward-traveling neutral particle whose velocity exceeds the escape velocity and b) the particle is not prevented from escaping through any subsequent collisions. At Mars, it is expected to be a significant channel for escape, particularly in the early solar system when extreme ultraviolet (EUV) fluxes were much higher [1].

Therefore, to understand the atmospheric and a climate evolution of Mars, it is essential to determine contemporary photochemical escape rates and how they vary with solar and atmospheric conditions.

The photochemical escape of Martian H, O, N and C atoms is the result of photodissociation, photodissociative ionization and electron-impact dissociative ionization of the primary neutral constituents CO_2, CO, N_2, CO and O_2, as well as dissociative recombination (DR) of N_2^+, CO^+, NO^+ and O_2^+[2]. By approximately 2 orders of magnitude the dominant escaping atom is O, mostly the result of DR of O_2^+ (the dominant ion in the Mars ionosphere [3]).

Photochemical escape dependencies. Because this process depends both on 3 different processes: ionization, recombination and atom transport, it is dependent on a number of factors. Firstly, ionization increases with increased EUV flux through photoionization, with increased electron precipitation through electron impact ionization (particularly on the nightside) and infrequent but intense ionization by solar energetic particles. Second, rates of dissociative recombination are inversely dependent on electron temperature as slower electrons recombine more easily. Third, the relative strengths of the different branches of dissociative recombination (producing atoms with energies above and below escape energy) are dependent on the electronic, rotational and vibrational distributions of molecular ions (again, mostly O_2^+). Lastly, photochemical escape rates are inversely dependent on the column mass of thermal neutrals above the altitudes of hot atom production as collisions with such neutrals inhibit escape.

Difficulties, models and uncertainties. Because escaping hot atoms have not been and will not (in the near future) be directly measured, models of production and transport (through the atmosphere) of such atoms must be used to constrain escape rates. These models [2, 4, 5] require altitude profiles of neutral densities and electron and ion densities and temperatures, as well as compositional information. All prior escape rate estimates to this point have been based on the two dayside Viking Lander descent profiles of ions and neutrals [3, 6], despite the electron temperature data being limited to above 200 km [7]. This has led to large uncertainties in photochemical escape rate estimates (varying over almost 2 orders of magnitude 7×10^{24} to 2×10^{26} s^{-1})[8]. It is expected that MAVEN measurements will revolutionize our understanding of photochemical escape from Mars.

MAVEN Strategy for determining photochemical escape.

As mentioned above, even though photochemical escape will not be directly measured by MAVEN, all the relevant quantities upon which it depends will be measured. LPW will measure electron density and temperature, NGIMS will measure neutral and ion density and STATIC will measure ion temperature. For every periapsis pass, we will have an inbound and outbound altitude profile of these quantities. Models of the processes described above must then be applied to this data in order to calculate photochemical escape fluxes. 4 separate calculations must be made for every altitude profile:

1. Profiles of O_2^+ DR rates will be calculated straightforwardly from electron temperature, electron density and O_2^+ density.
2. Profiles of rotational and vibrational distributions of O_2^+ ions will be calculated from profiles of CO_2, O, O_2, O^+, CO_2^+ and CO^+ via a lookup table from an empirical model based on the framework of [2].
3. Profiles of energy distributions of hot O atoms will be calculated from the results of step 2 and from profiles of electron and ion temperatures.
4. Profiles of all neutral densities will be input into models of hot O transport in order to calculate photochemical escape fluxes from DR of O_2^+.

Thus for every orbit we will have 2 calculations of photochemical escape flux: inbound and outbound. As the mission progresses we expect to characterize the photochemical escape as a function of all relevant factors, in particular solar zenith angle and EUV flux. The latter will change with solar activity, solar rotation and Mars heliocentric distance, while MAVEN will sample the former from 0 to 150 degrees as the periapsis location precesses over the primary mission. Figure 1 demonstrates this process for O escape with “mock data” altitude profiles of neutral, ion and electron densities and temperatures, as well as escape probabilities, hot atom energy distributions and production rate of escaping and non-escaping oxygen atoms.

Implications for Martian climate: integrated photochemical loss from the Martian atmosphere. Within the first six months of the maven mission, we will have established the dependence of photochemical escape on solar Zenith angle, solar EUV flux and neutral atmosphere conditions. This, combined with further simulations with progressively higher EUV fluxes, will allow us to make a total integrated loss estimate over the course of Martian history and hence a determination of the impact of this loss process on the evolution of the Martian climate.

References: [1] Zahnle & Walker, 1982, Rev. Geophys, [2] Fox and Hać, 2009, JGR. [3] 7, JGR. [4] Lee et al., 2014, JGR, [5] Rahmati et al., 2014, GRL, [6] Nier and McElroy, 1977, JGR, [7] Hanson and Mantas, 1988, JGR. [8] Brain et al., 2013, Mars book chapter. [9] Lillis et al., 2014, SSR.

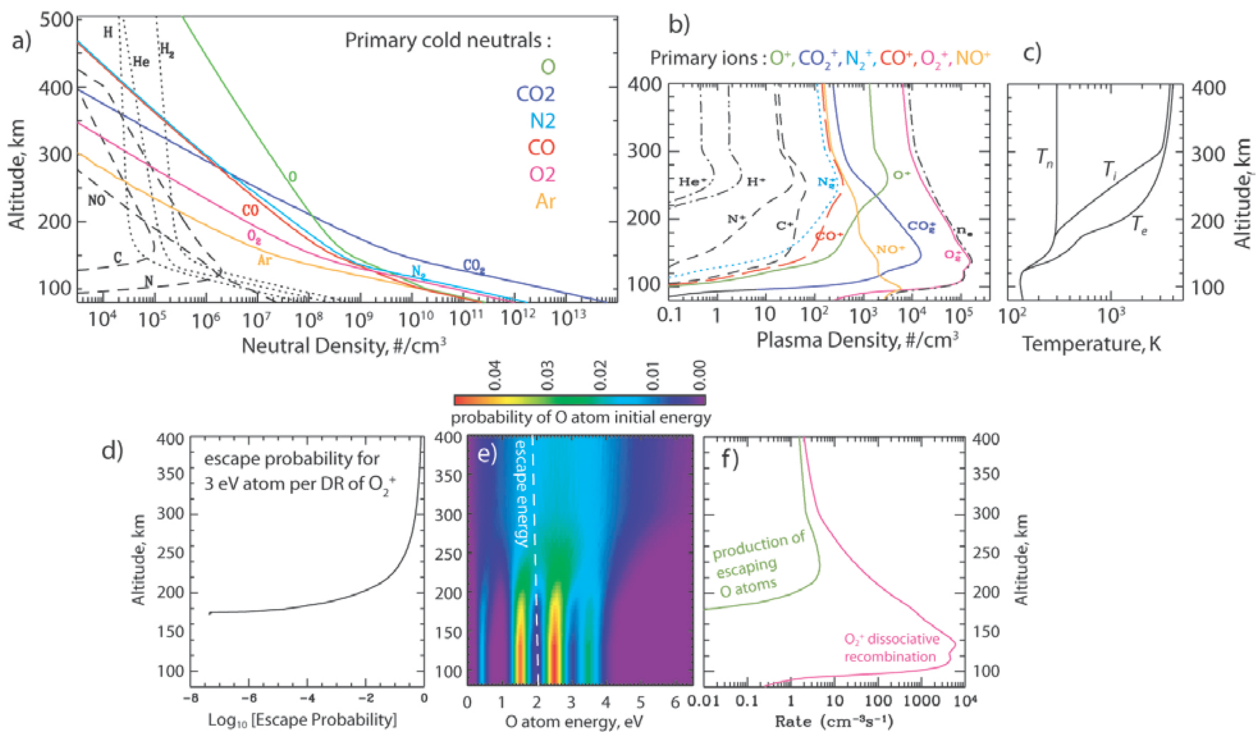

Figure 1: Example of how photochemical escape will be derived from MAVEN data. "Mock data" altitude profiles of quantities from a predicted MAVEN trajectory for November 4, 2014, are shown in the top row and quantities relating to the resulting photochemical escape derived are shown in the bottom row. Panel a) shows cold neutral densities with major species in color, panel b) shows electron and ion densities with major species in color. Panel c) shows neutral, ion and electron temperatures. Panel d) shows the escape probability for a 3eV atom produced as part of isotropic distribution. Panel e) shows the calculated energy distribution of hot O atoms created by DR of O_2^+. Panel f) shows the O_2^+ DR rate and the production rate of atoms which escape. This figure was adapted from Lillis et al., 2014 [9].