Atmospheric Escape at Mars

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Introduction: Several mechanisms have been identified to result in escape of the Martian atmosphere. These mechanisms can be divided in two groups [1]:

- Thermal escape or Jeans escape, which corresponds to the loss of atoms in the high energy tail of the energy distribution at the exobase. This mechanism is important only for the light species such as hydrogen or deuterium.
- Non-thermal escape, which includes the escape of hot neutral species produced by
    1. Chemical reactions, such as dissociative recombination of ions (e.g. $O_2^+ + e^- \rightarrow O + O + \Delta E$), producing the escape of neutral atoms as O, C, N
    2. Ionospheric escape, that is the escape of heavy ions produced above the photochemical equilibrium region and below the ionopause and diffusing to high altitudes where they can be picked up by the solar wind (O_2^+, CO_2^+, O^+)
    3. Exospheric ions escape, that is the escape of exospheric ions produced by ionization (UV, charge exchange or electron impact) of the neutral exosphere and picked up by the solar wind (O^+, H^+)
    4. Energetic Neutral Atoms (ENA) escape, that is the escape of the hot neutral atoms produced by charge exchange between pick up or solar wind ions and the neutral exosphere (O ; H)
    5. Sputtering escape: One part of the pick up ions can reimpact the planet and transfer their energy to the neutral species present at the exobase, leading to additional neutral escape (C, N, O, Ar)

Observations of atmospheric escape by Mars Express: Recent observations from Mars Express have confirmed the presence of escape particles in the environment of Mars. The instrument ASPERA-3 on Mars Express [2] has measured the escape flux of ions in excess of about 30 eV at ~ 3.2×10^{23} s^{-1} (O_2^+ ~ 1.5×10^{23} s^{-1}, O^+ ~ 1.6×10^{23} s^{-1}, and CO_2^+ ~ 8 $\times10^{22}$ s^{-1}) which is one order of magnitude lower than the ion escape measured previously by the Phobos mission [3, 4]. This instrument has also detected for the first time the presence of hydrogen ENA in the environment of Mars validating a non-thermal escape of hydrogen [5]. The instrument SPICAM derived the thermal escape of hydrogen from the Lyman-α emission at ~ 2.2 ±1 $\times10^{26}$ s^{-1} implying a disappearance of the total water content of the atmosphere in 13,000 years if not replenished from polar caps [6]. This value is in good agreement with the previous measurements done by the Mariner missions [7], and is ten times higher than the non-thermal hydrogen escape estimated from theoretical studies and fifty times the escape of H_2 estimated from the observations of the H_2 lines [8, 9]. Unfortunately no other observations of escape flux have been obtained yet and the major part of current escape studies is based on theoretical models and still speculative.

Modeling of the escape mechanisms: Recently, we have [10], for the first time, coupled a 3D model of the Martian exosphere and a 3D model of the Martian magnetosphere formed by Mars' interaction with the solar wind [11] to describe consistently the interaction of the solar wind with the Martian extended corona (Fig. 1).

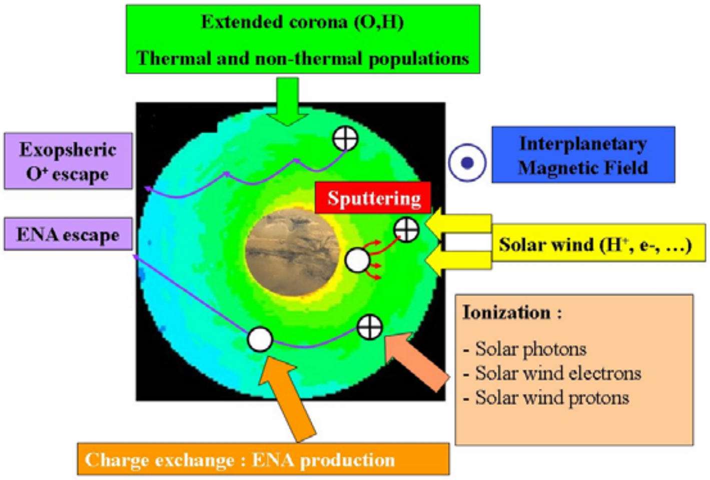

Fig.1 Processes involved in the interaction of the solar wind with the Martian exosphere

This work allows us to estimate the escape of atomic oxygen from several non-thermal processes (mechanisms 1, 3, 4, and 5 listed above) at low and high solar activity (Table 1).

The coupling of the exosphere and the magnetosphere is the first step of a global model needed to describe consistently the escape processes. The coupling of these models with a model of the lower atmosphere and ionosphere is needed to study the ionospheric escape, and temporal variations of the escape rates throughout the Martian year and past conditions.

	LowSolarActivity	High Solar Activity
Dissociative Recombination	$1x10^{25}$	$4x10^{25}$
Exospheric ions escape	$2x10^{23}$	$3x10^{24}$
ENA escape	$4x10^{22}$	$4x10^{23}$
Sputtering	$2x10^{23}$	$7x10^{23}$

Table 1. Oxygen escape flux in s^{-1} at low and high solar activities from[10]

Conclusion:

Estimation of global escape throughout Martian history is still uncertain. Understanding atmospheric escape is one of the major objectives of the future NASA Mars Scout mission. Until now the only neutral specie for which the escape flux has been measured is hydrogen. Other neutral species and particularly neutral oxygen escape have never been measured. The ion escape has been measured by two missions with values differing by one order of magnitude. New measurements are undoubtedly needed to understand the current escape mechanisms and their variations with solar activity. Moreover, accurately modeling atmospheric escape for past conditions by consistently including models of lower atmosphere, ionosphere, exosphere and solar wind interaction is also necessary to understand the evolution of the Martian atmosphere.

References:

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