Modeling the variability of Martian O+ ions escape due to Solar Wind forcing

Ronan Modolo [1], Francois Leblanc [2], Jean-Yves Chaufray [2], Norberto Romanelli [3,4], Eduard Dubinin [5], Vincent Génot [6], Claire Baskevitch [1], Dave Brain [7], Shannon Curry [8] and Robert Lillis [8]

[1]LATMOS / UVSQ / SU / CNRS, 11 bd d'Alembert, 78280 Guyancourt, France, [2]LATMOS / SU / UVSQ / CNRS, 4 place jussieu, 75252 Paris cedex 05, France, [3] NASA Goddard Space Flight Center, Greenbelt, Maryland, USA, [4] CRESST II, University of Maryland, Baltimore County, USA, [5] Max Planck Institute, MPS, Gottingen, Germany, [6] IRAP / U. Paul Sabatier / CNRS / CDPP, 9 avenue du Colonnel Roche, 31400 Toulouse,France, [7] LASP / Univ. of Colorado, Boulder, Colorado, USA, [8] SSL / Univ. of Berkeley, Berkeley, California, USA

Abstract:

During the last decade, MAVEN space mission have emphasized a widespread spatial distribution of escaping O+ ions [1 - 3]. Statistical studies have demonstrated that such structure is constant and present an asymmetry with respect to the solar wind convective electric field direction. In the Mars Solar Ecliptic coordinate system, continuous large O+ ion fluxes have been observed from the Martian wake to the Northward hemisphere. Global hybrid models have been developed since more than fifteen years [4 - 8] predicting and reproducing successfully the main characteristics of these escaping ion signatures. To further characterize this heavy-ion escape and its variability due to the solar wind forcing, global hybrid simulations have been performed with different set of upstream solar wind parameters. The impact of the solar wind drivers on the dynamics of O+ ion fluxes are reported and compared to the statistical ion fluxes maps derived from MAVEN/STATIC observations [2].

The LatHyS Model

Hybrid formalism :

Ions → **kinetic description** : represented by a population of weighted macro-particles. 6 ion species are included (H+sw, He++, H+pl, O+, O2+, CO2+)

Electrons → **fluid description**, contribute to quasi-neutrality , current and pressure calculation. (2 electron fluids : solar wind and ionospheric electrons)

Coupled to Maxwell's equations

Methodology

- Various LatHyS simulations have been performed for différent solar wind conditions.
- We use AMDA to determine, for each MAVEN orbit, the average solar wind parameters (particularly $\overrightarrow{B_{IMF}}$) to transform MAVEN S/C trajectory from MSO to MSE ($\vec{E} = -\vec{v} \times \vec{B}$ along $+Z_{MSE}$ axis).
- Simulated O+ ion fluxes are computed along MAVEN MSE S/C track for a better comparison with MAVEN data (also in MSE coordinate)
- Similar to MAVEN observations [2] we filter the low energy population (E> 25 eV)
- The comparison is limited to 11/11/2014 to 28/02/2015 , time interval used by [1-3]

Evidence of escaping O+ ions (LatHyS)

- Evidences of escaping planetary plasma [1,2] also emphasized in simulations [4-8] (Figure 1)
- Strong asymmetry between +E and –E hemisphere
  - cold and "dense" tailward ion outflow in the –E hemisphere, confined with the induced Martian magnetosphere
  - energetic O+ ion in the plume, along the $\vec{E} = -\vec{v} \times \vec{B}$ direction

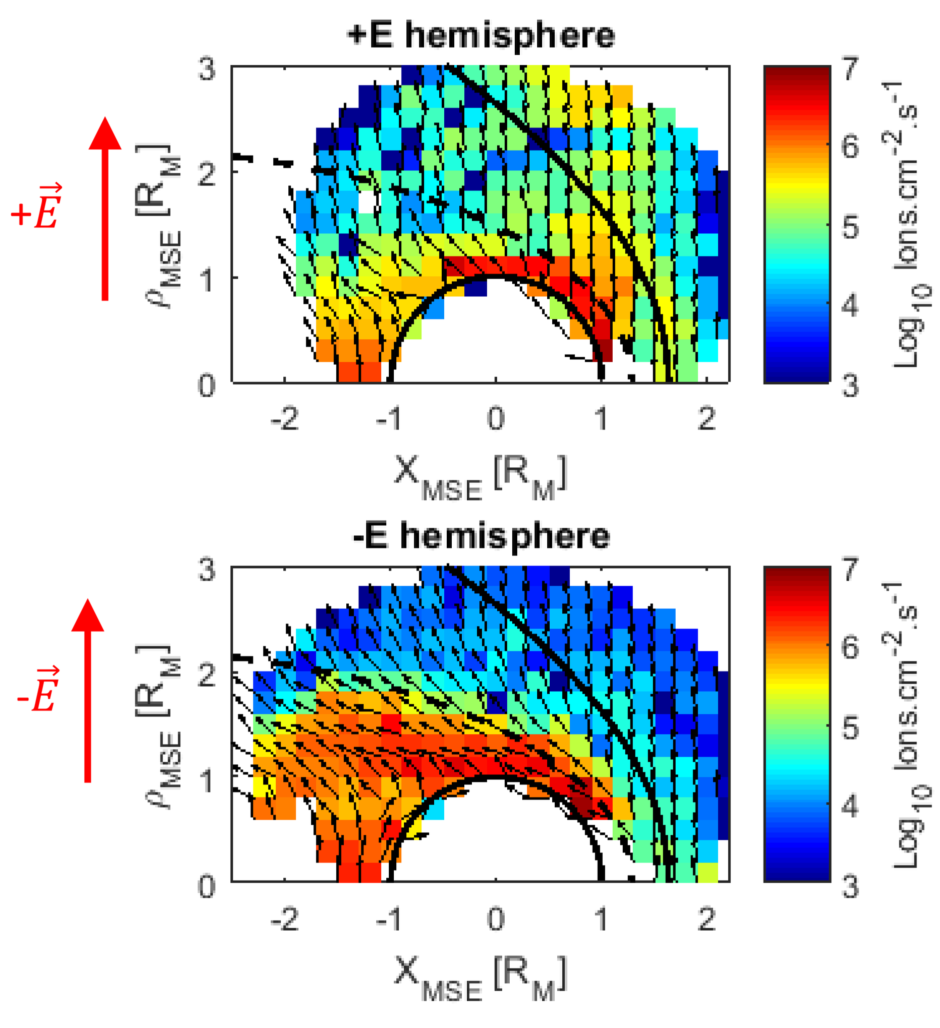

Figure 1 : Simulated O+ ion fluxes along the MAVEN S/C trajectory in a MSE cylindrical coordinate system with a distinction between the +E (top panel) and –E (bottom panel) hemisphere.

MAVEN vs LatHyS O+ ion flux

- A given LatHyS Simulation emphasizes mainly two distinct escape channels (plume and tailward) while MAVEN observations suggest a widespread distribution of O+ ion fluxes [2] from the tail to the plume.
- LatHyS simulation predicts relatively fair estimate of O+ ion escape (Figure 2 and Table 1)

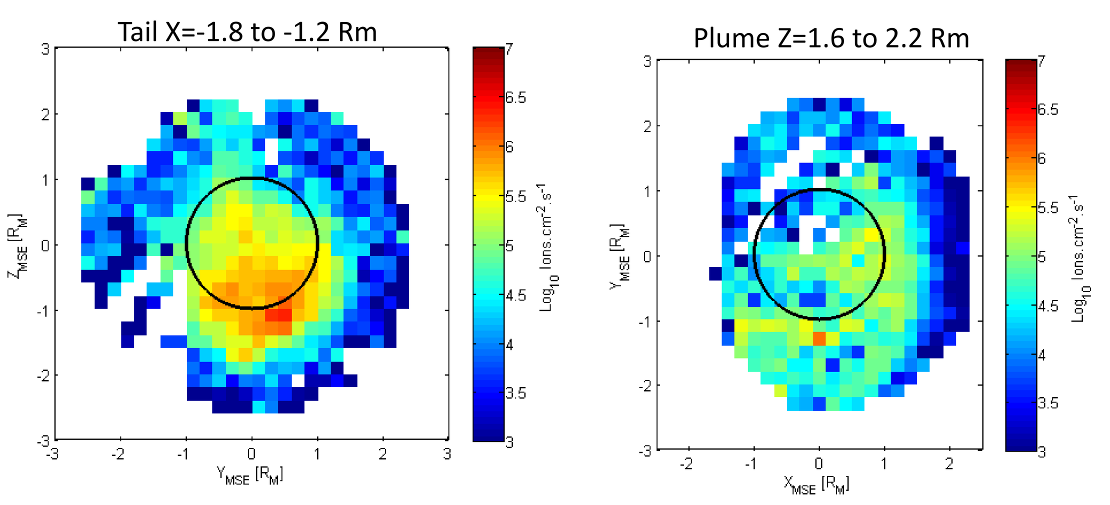

Figure 2 : Net simulated O+ fluxes through cross sections of the tail region (left) and plume region (right) projected in YZ and XY MSE planes.

Table 1 : Tailward / Plume net escape

	Tail		Plume	
Simulation	~0,8x10^{24} ions/s	68%	~3,8x10^{23} ions/s	32%
MAVEN observations [2]	1,3-1,8x10^{24} ions/s	77%	4-5,4x10^{23} ions/s	23%

- We investigate the influence of the solar wind forcing on the O+ escape

Variability of upstream conditions and their influence on O+ ions fluxes

- Simulation results are valid for a given stationnary condition (upstream SW, local time, …) while MAVEN observations reflect a large dispersion of solar wind parameters (Figure 3)

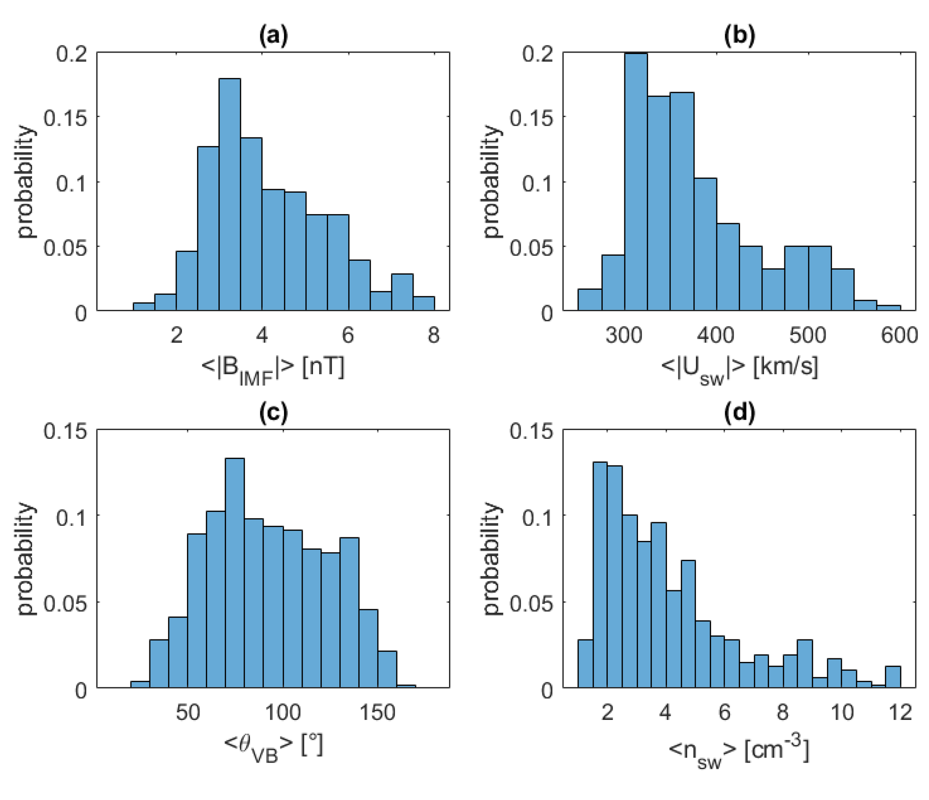

Figure 3 : Distribution of the mean values of solar wind parameters computed from each time interval when MAVEN spacecraft is in the solar wind region: a- the magnitude of the interplanetary magnetic field, b- the bulk velocity of the solar wind, c- the V B angle, d- the solar wind proton density.

- We limit the study to the effect of the upstream conditions on the Martian environment to the following parameters :
  - The Crustal Field location. MEX-ASPERA-3 suggest that CF retain strong fluxes in the Southern hemisphere [9]
  - The SW density (affects the plasma β) } Change Pdyn
  - The SW bulk velocity
  - The IMF magnitude } Change $\vec{E} = -\vec{v} \times \vec{B}$
  - The cone angle
- Other parameters that might contribute to change the SW – Mars interaction and are kept constant in the simulations are :
  - The seasonal variability (atmosphere and EUV flux)
  - The planet obliquity that change the MSO latitude of the CF
- Simulation of reference (Ref) :

$n_{sw} = 2{,}3$ cm-3, $V_{SW} = 450$km/s, $B_{IMF} = 3nT$ (θ_{VB}=57° ,Parker spirale), CF SSL = 180°

Results and discussion

- Table 2 summarizes the main effect of each upstream parameters on the O+ ion flux maps and net escape.

Table 2 : Synthesis of upstream parameters on O+ escape

Run 1	Ref	Run 2	Effect
SSL=0	ref	SSL=90 (SSL=270)	No major influence
n=1 cm-3	ref	n=5cm-3	No major change
V=350km/s	ref	V=600km/s	V↘ ⇒ lower ion escape flux
B=2nT	ref	B=6 nT	B↗ ⇒ plume tilted tailward and less fluxes in the plume for low B
θ_{VB}=20°	ref	θ_{VB}=90°	Low θ_{VB} ⇒ almost no plume

- Non-weighted average of different simulated O+ ion flux gives a smoother a more spread distribution (Figure 4)

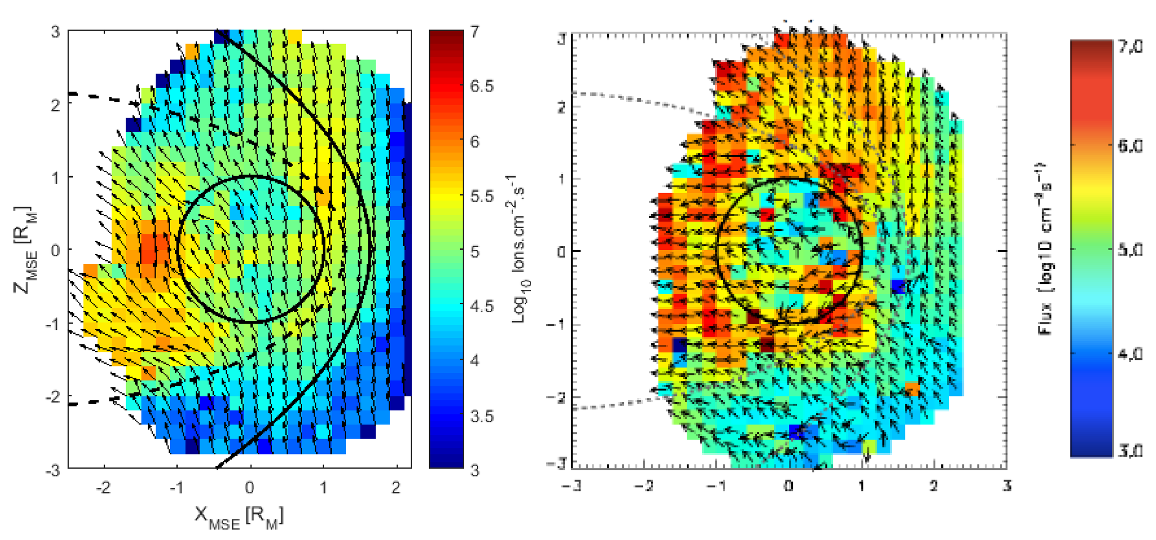

Figure 4 : Simulated (left) and observed (right) O+ ion fluxes along the MAVEN S/C trajectory in MSE coordinate system [2].

- Short term temporal variability of the SW might contribute to artifically spread the ion escape
- Is the LatHys code underestimate the ambipolar electric field ?

References :

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