Cold Ion Escape from the Martian Ionosphere

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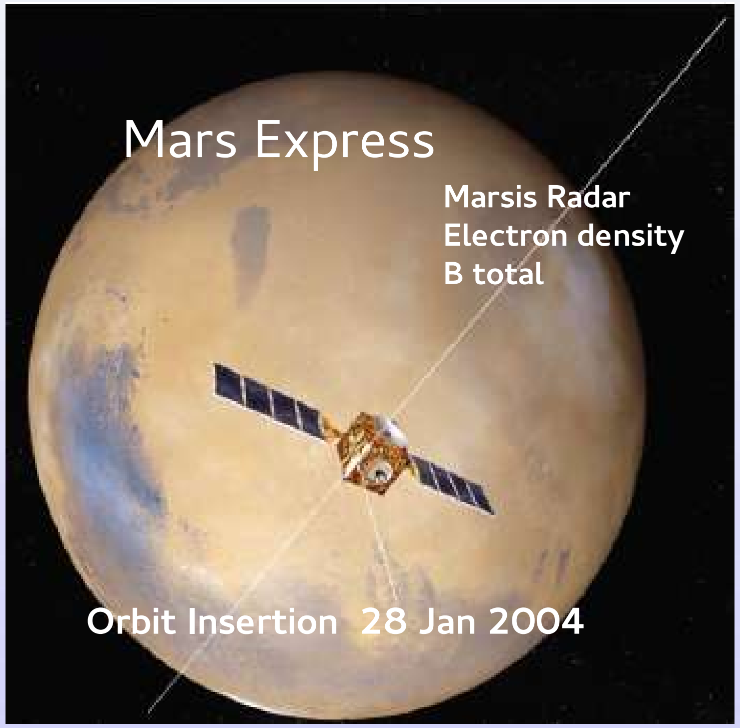
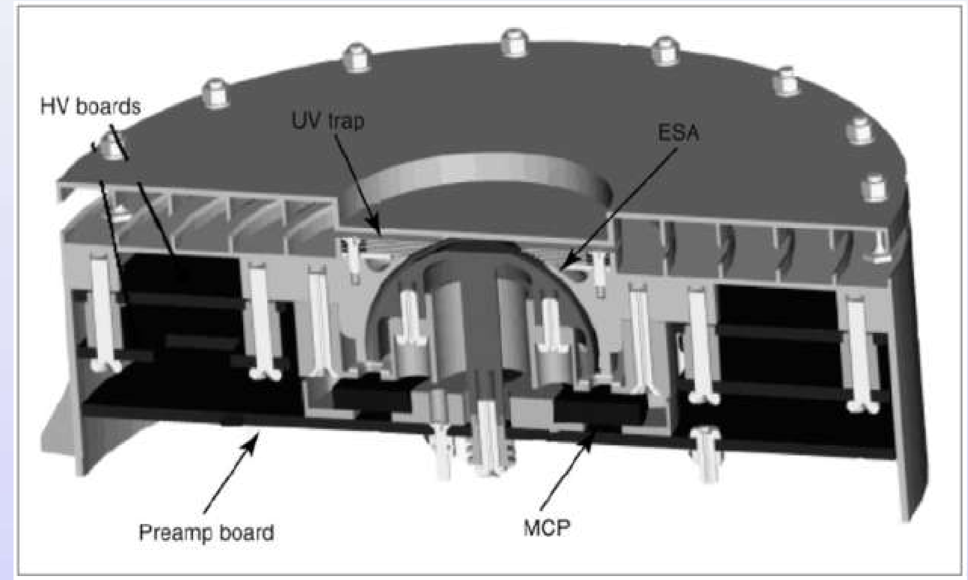
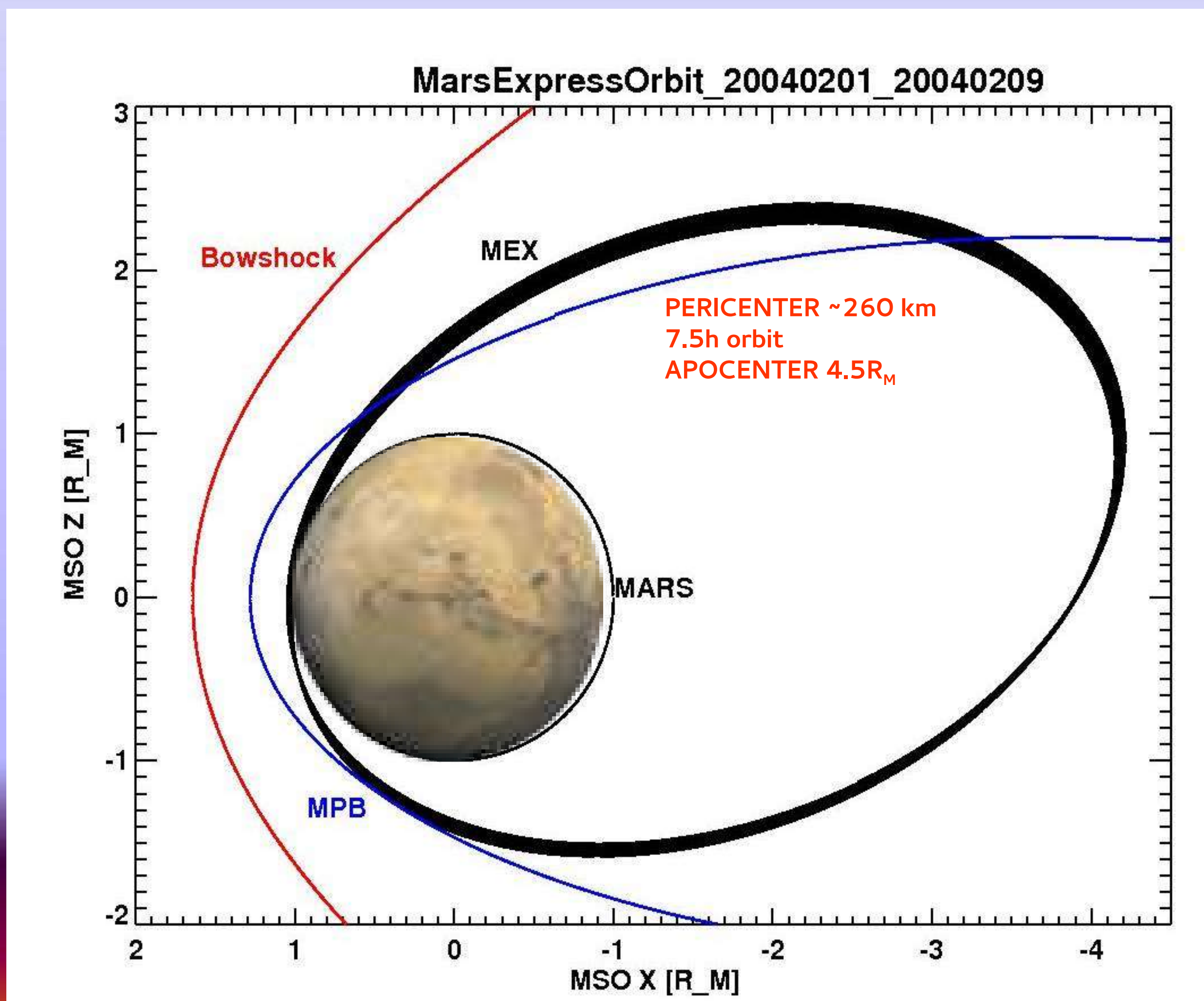
Content

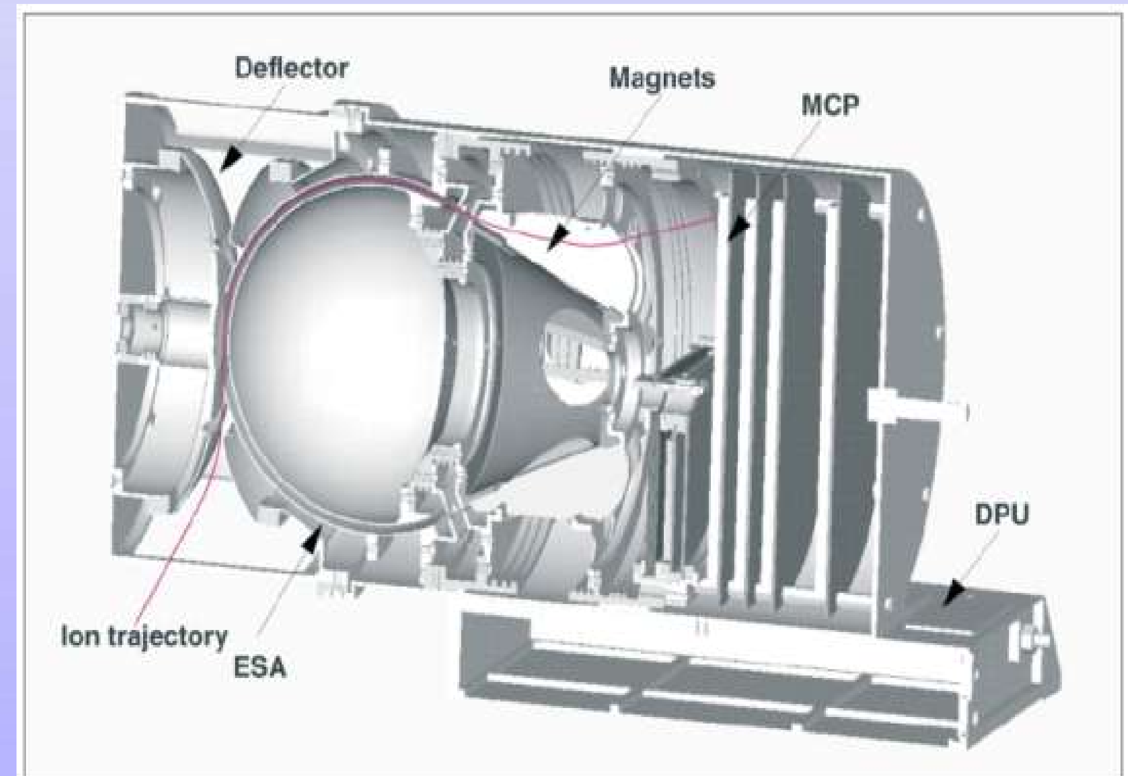
Plasma Instruments on Mars Express





Electron Spectrometer ELS, 2D,16sectors,1eV–20keV





Ion Spectrometer IMA,3D, 16x16 sectors 10eV–40keV, 32 mass rings
MEX: Below 50eV electrostatic scanner is switched off:
only 2D measurement!

Venus PVO Results
Ion acceleration by pressure gradient across terminator

VENUS PVO ORPA
Knudsen JGR 1992

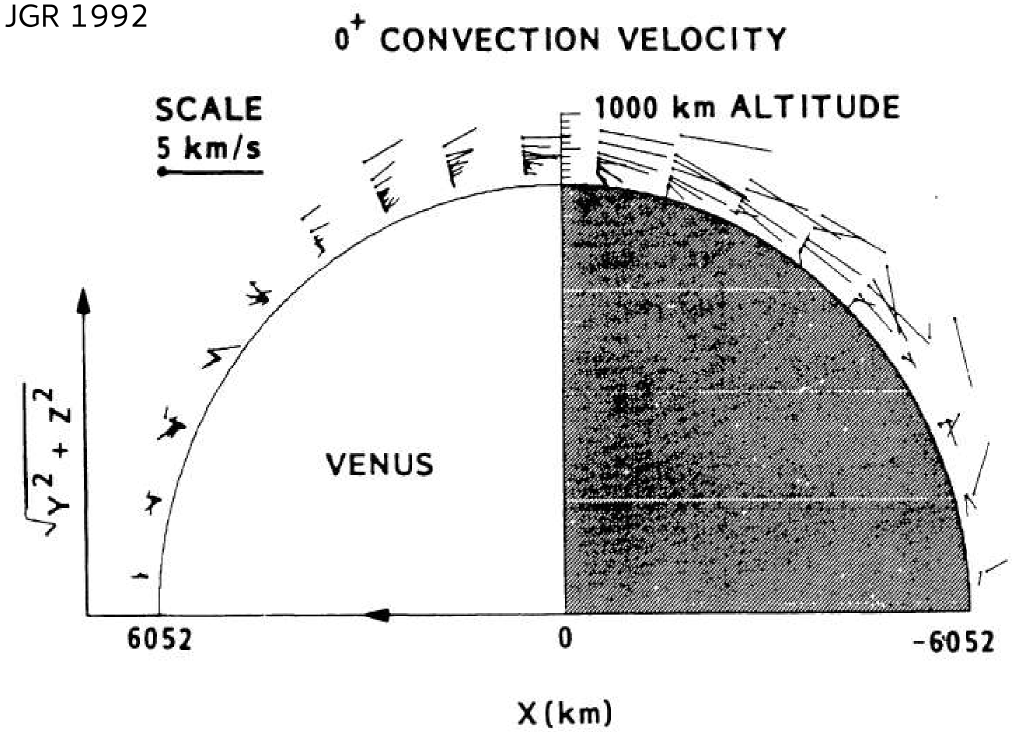
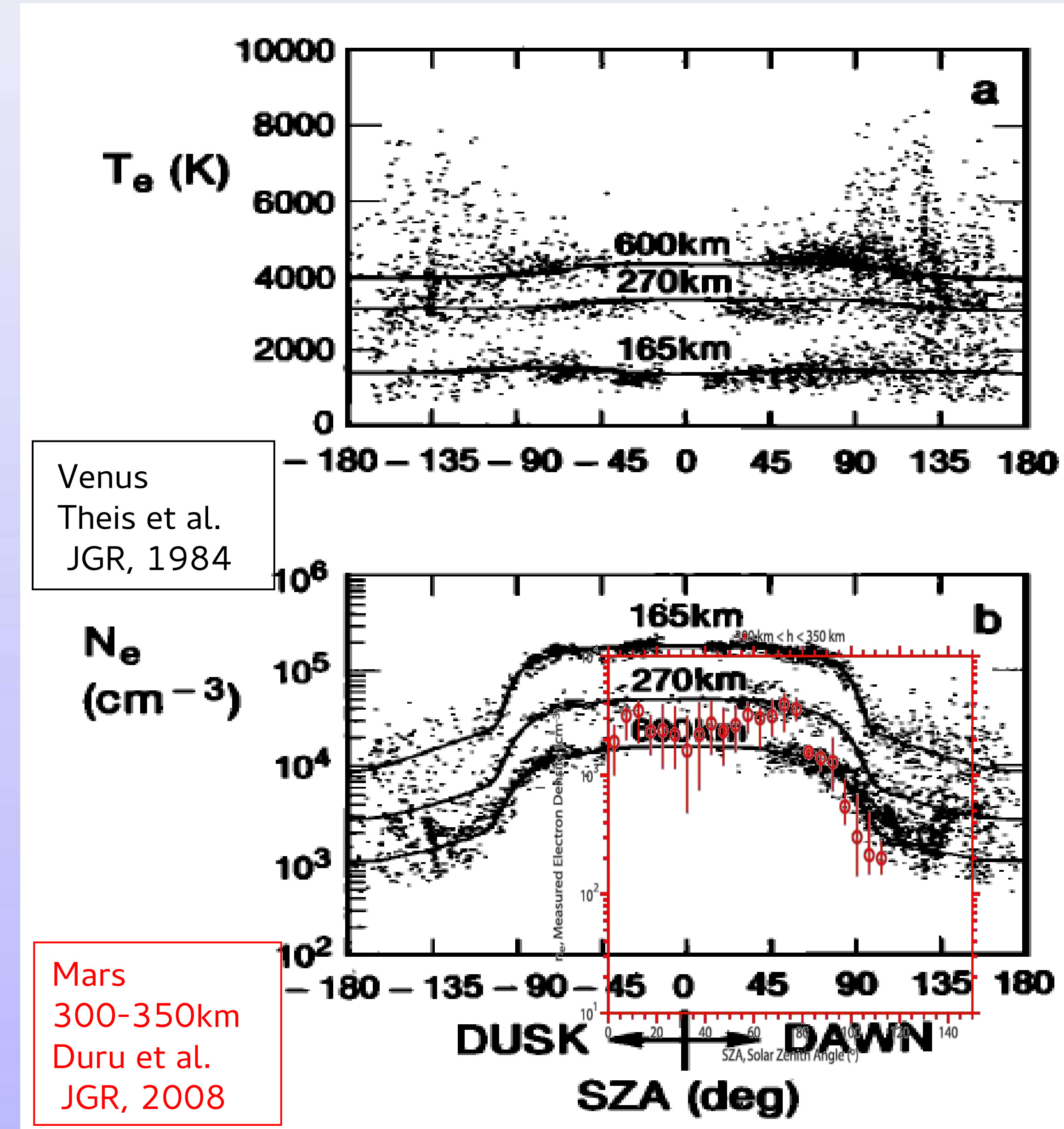


Fig. 5. Average ion velocities measured in the outbound leg of the orbit during the first 3.5 years of the Pioneer Venus mission (after Knudsen *et al.*, 1982a).



Acceleration of ions across the terminator at Venus can be explained by the day-night pressure gradient in an inviscid collisional plasma (Elphic et al.,GRL, 1984).

MARS

Previous ion escape determinations based on ASPERA3 alone

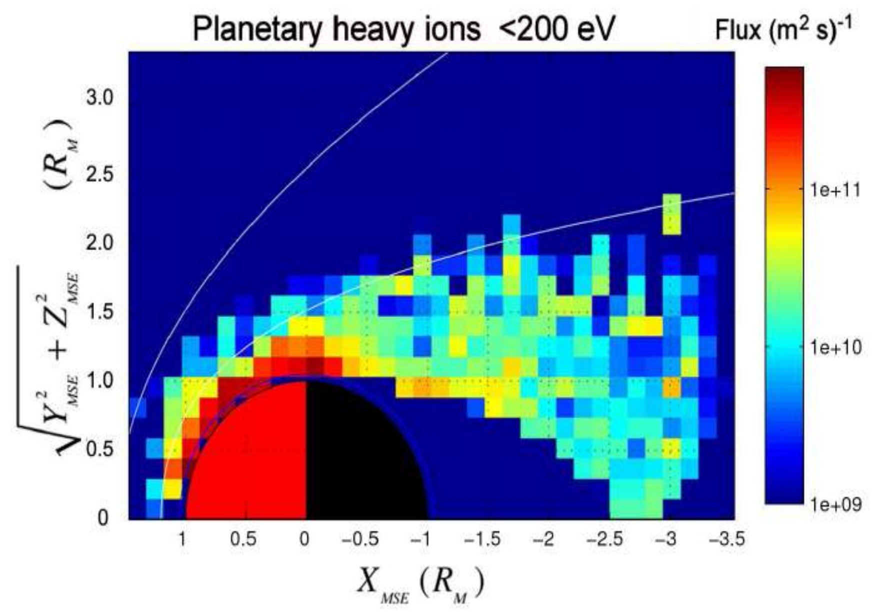
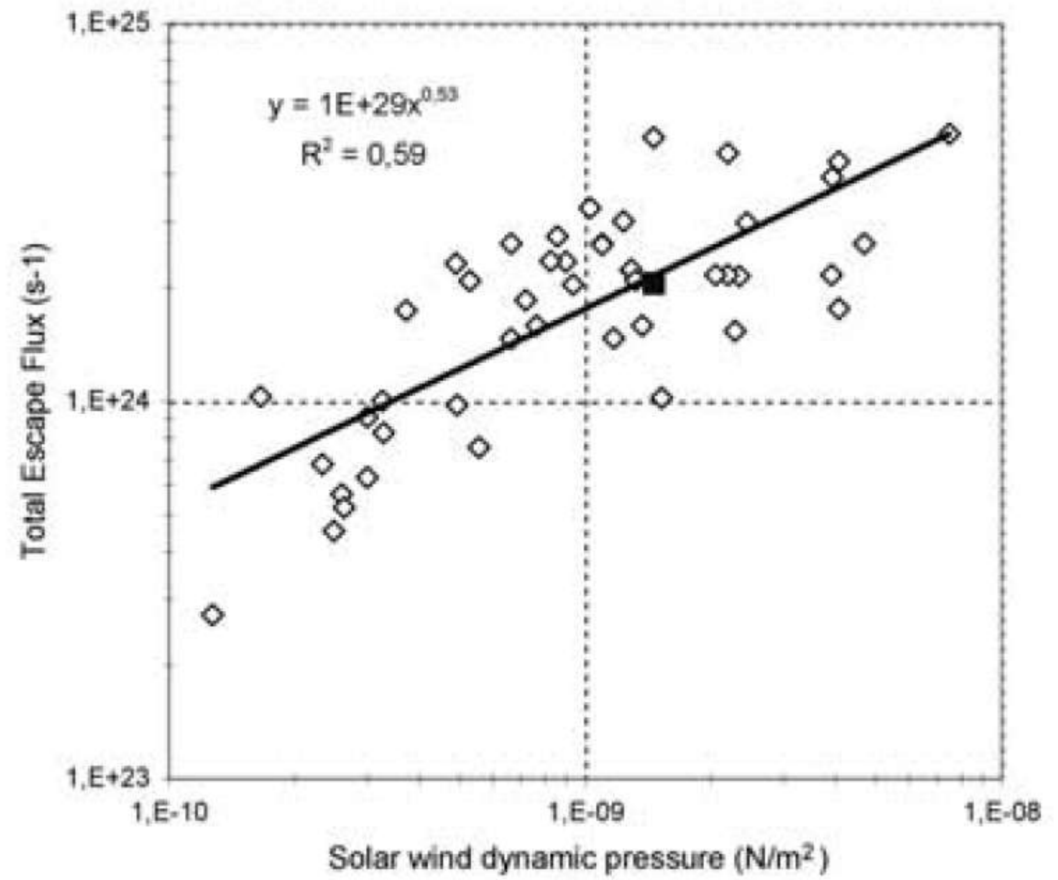


Figure 3. Low-energy (<200 eV) planetary heavy ion (O^+, O_2^+, CO_2^+) fluxes near Mars. Colour scale represents average fluxes in the 500×500 km quadrants.

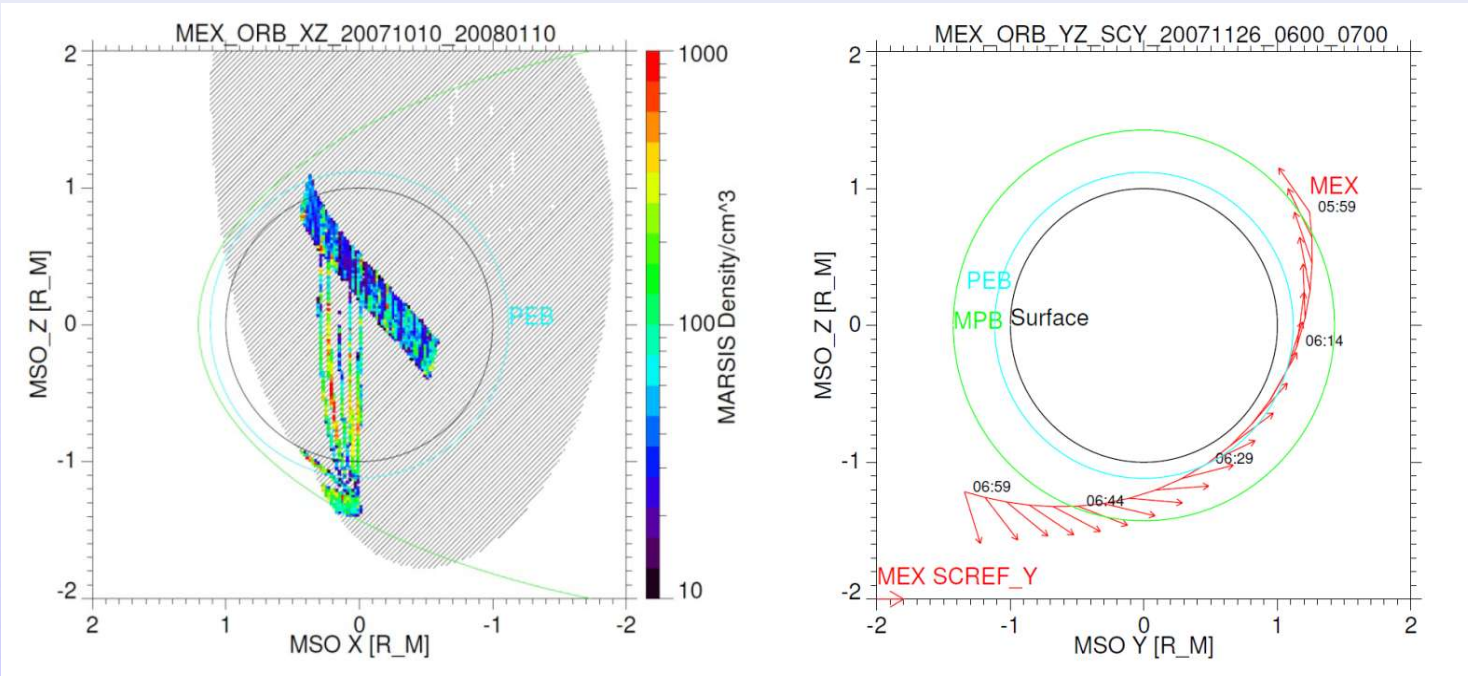


Escape rate 0.15-0.45 RM downstream of terminator: 2.0-3.7 10^{24} ions/s
(Lundin et al. GRL 2008a, Nilsson et al. 2011)

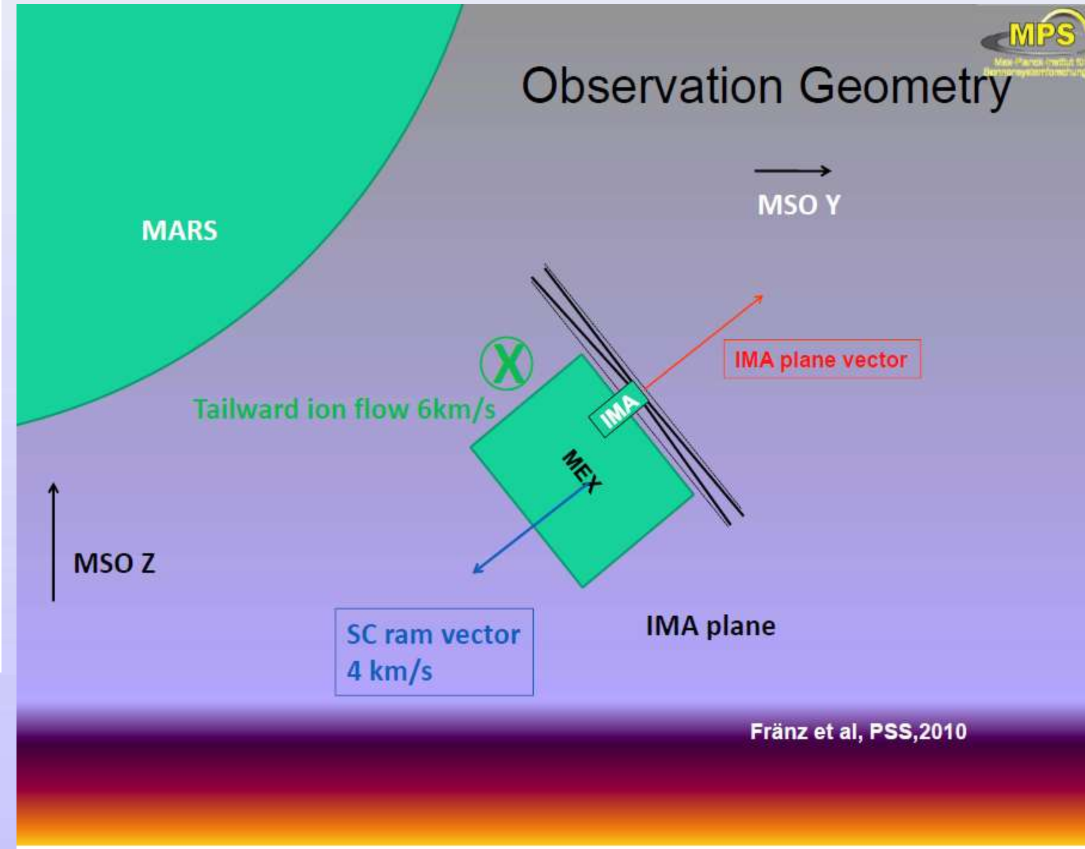
1 order lower than expected from models (Fox et al. 2008) and Phobos observations.

Dependence of escape on solar wind pressure
(Lundin et al. GRL 2008b)

Combined ASPERA3 and MARSIS observations in Mars terminator plane (Fränz et al., PSS, 2010)



Orbits in Martian terminator plane in 2007 where both MARSIS and ASPERA3 data were recorded (left) and orientation of IMA plane during terminator passage for one orbit (right).



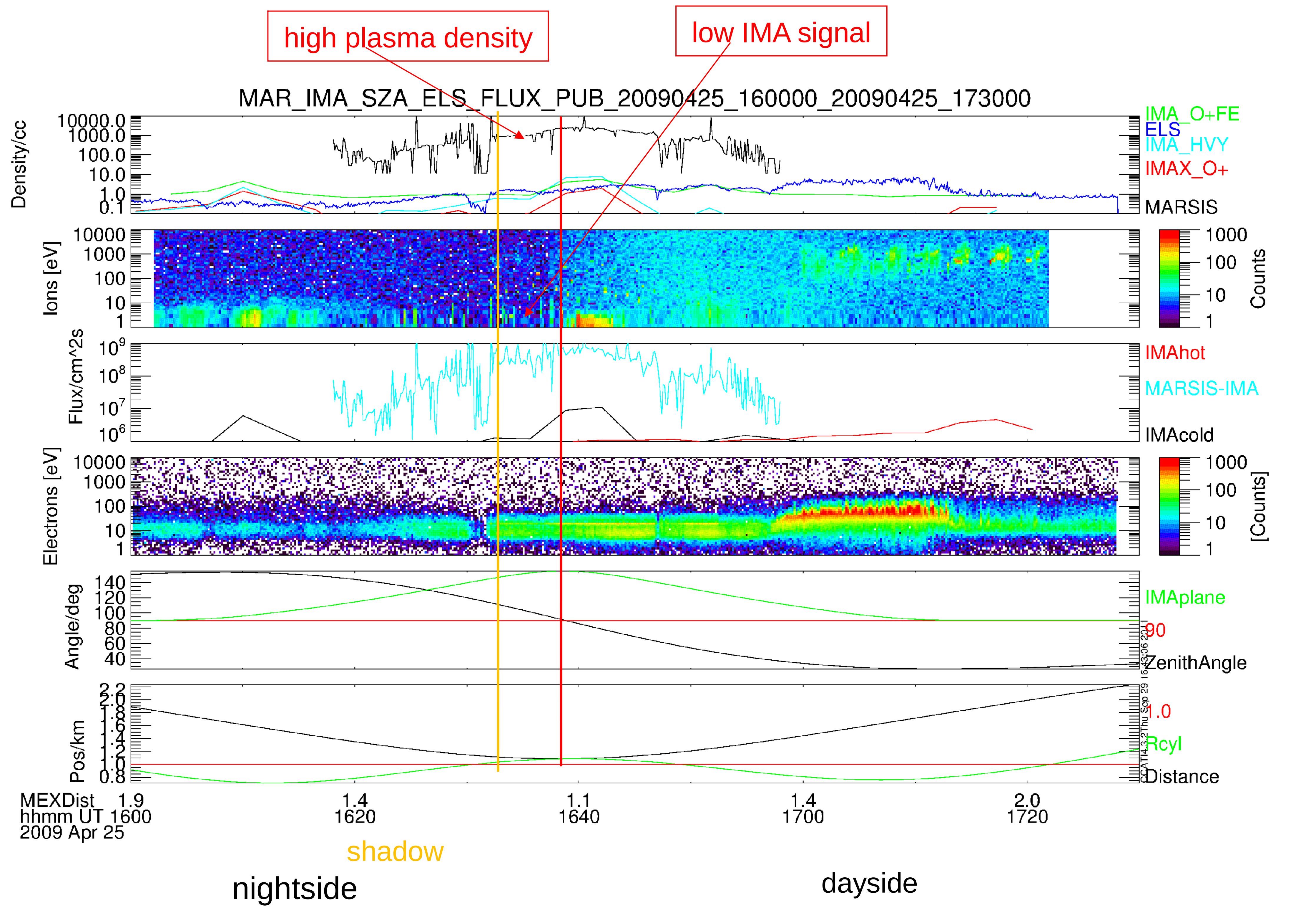
We observe O+ densities of 2000±200/cm^3 and a bulk speed of 6±1km/s corresponding to a flux of 0.9 10^9/cm^2s over the altitude range 290-400km.

If we assume that this flux is constant over a 100km shell around the terminator we get a lower limit for the ionospheric escape flux of 2.5±0.5 10^{25}ions/s.

This agrees well with models of the ionospheric dayside upward ion flow (Fox, 2009) but is 10 times higher than the value reported for the heavy ion flow downstream of the terminator (Lundin et al. 2008, Nilsson et al. 2011).

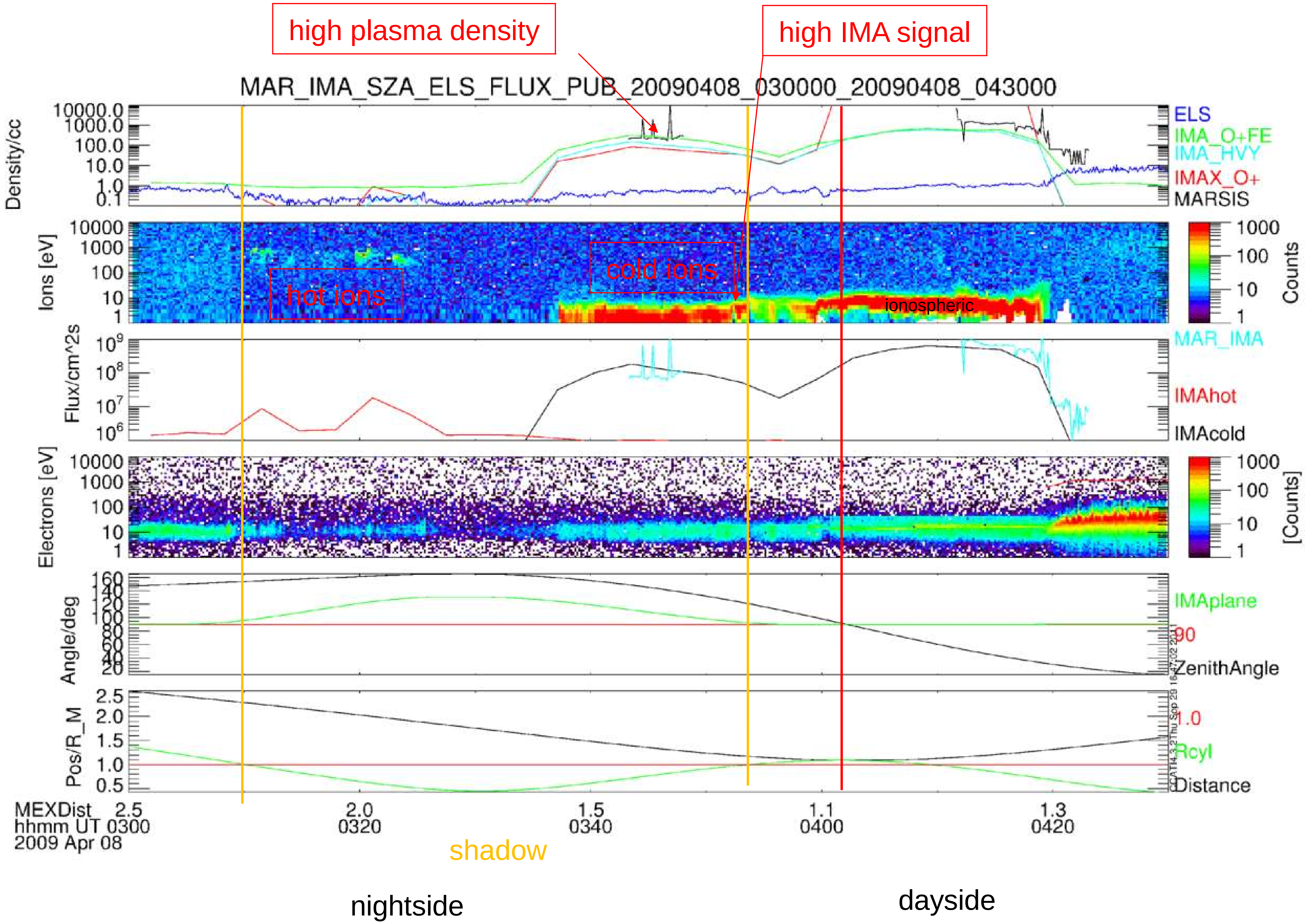
Does the transterminator flow of about 3x10^{25}ions/s escape?

New MARSIS nightside observations in 2007-2014



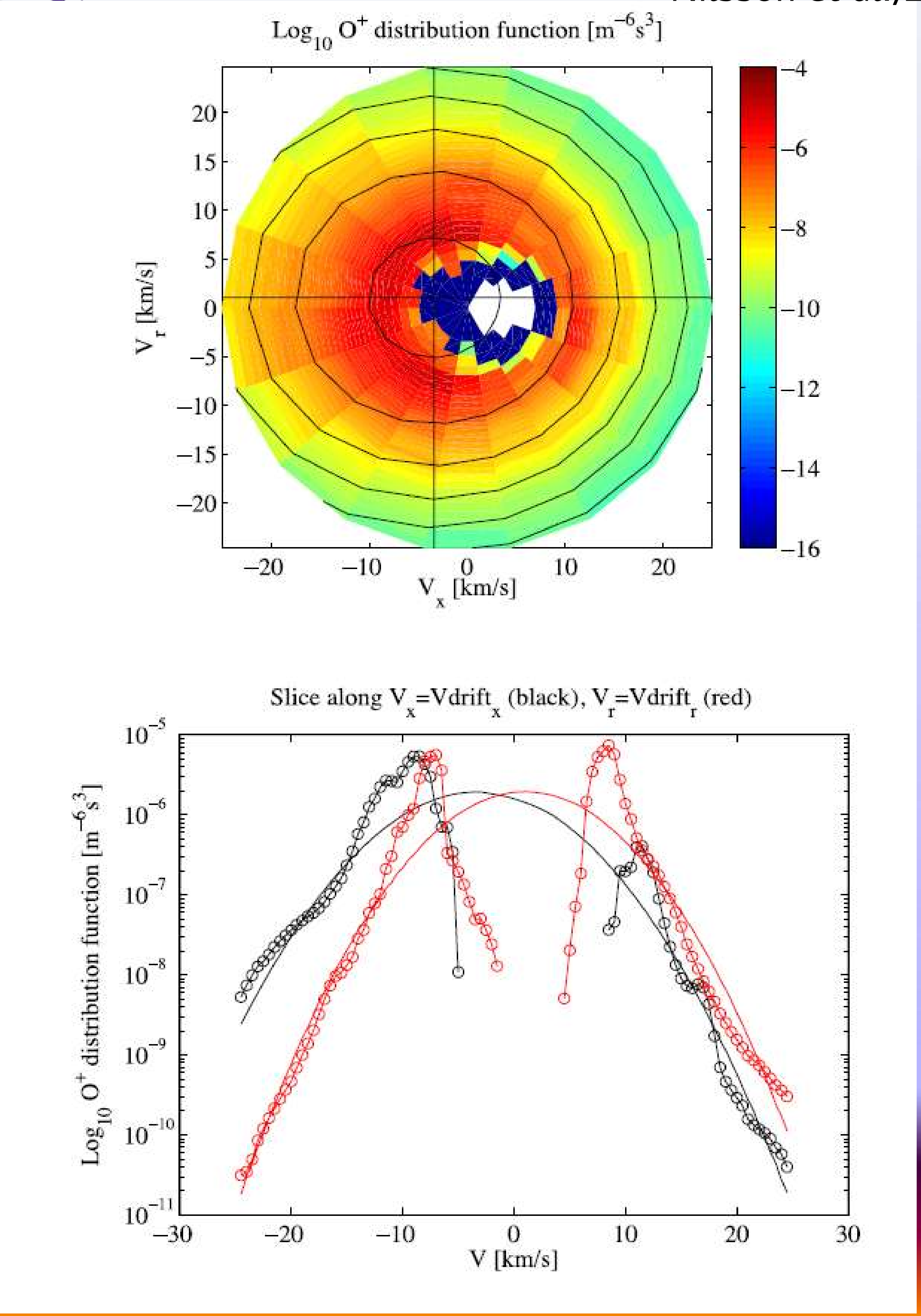
Combined observations of MARSIS, ASPERA-ELS and ASPERA IMA.
Many orbits with nightside plasma density >100/cc but very low IMA density

New MARSIS nightside observations in 2007-2014



On some orbits MARSIS and IMA agree when IMA field of view and SC potential fit.

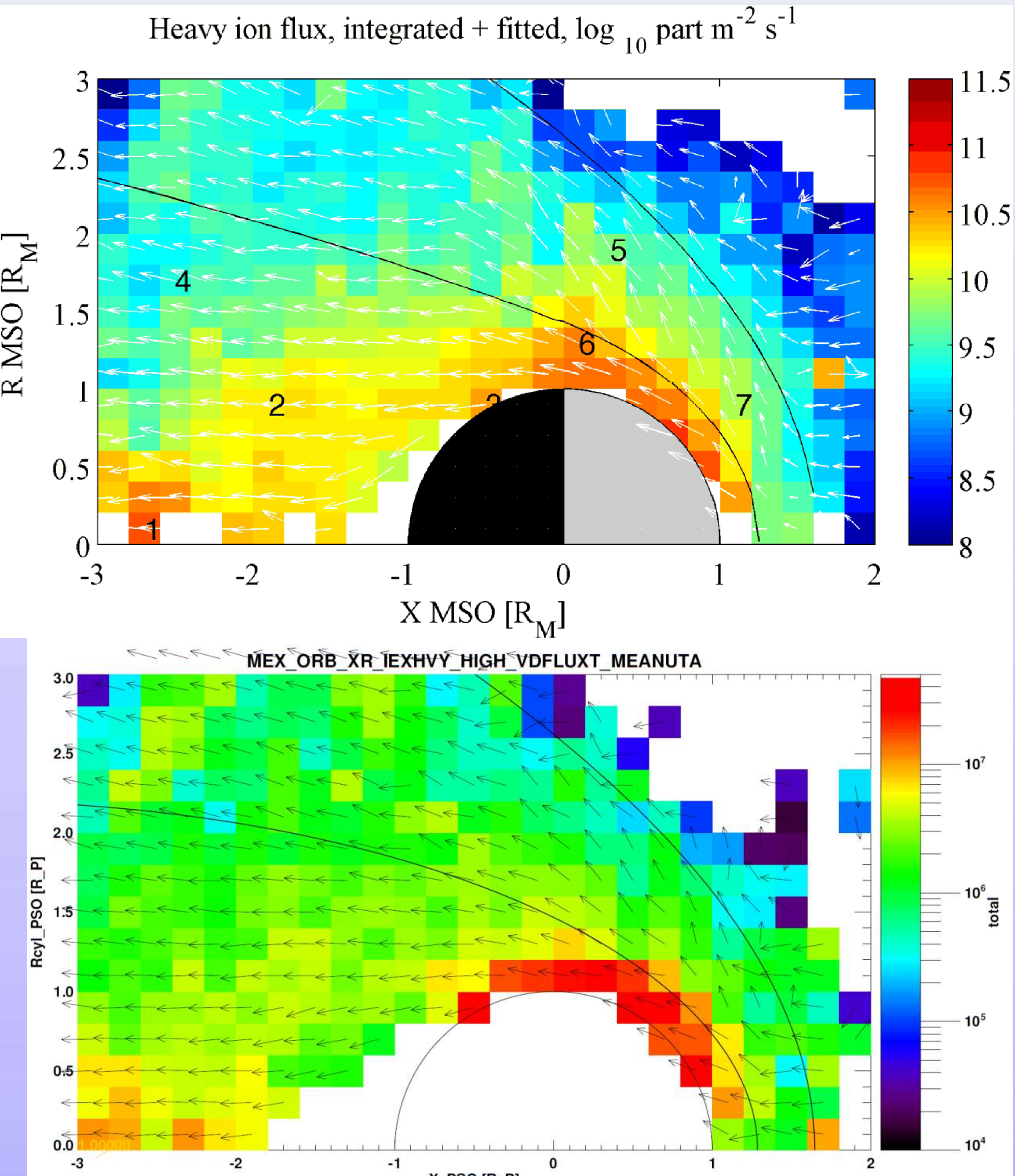
The mean velocity distribution function
Nilsson et al.,EPSL, 2012



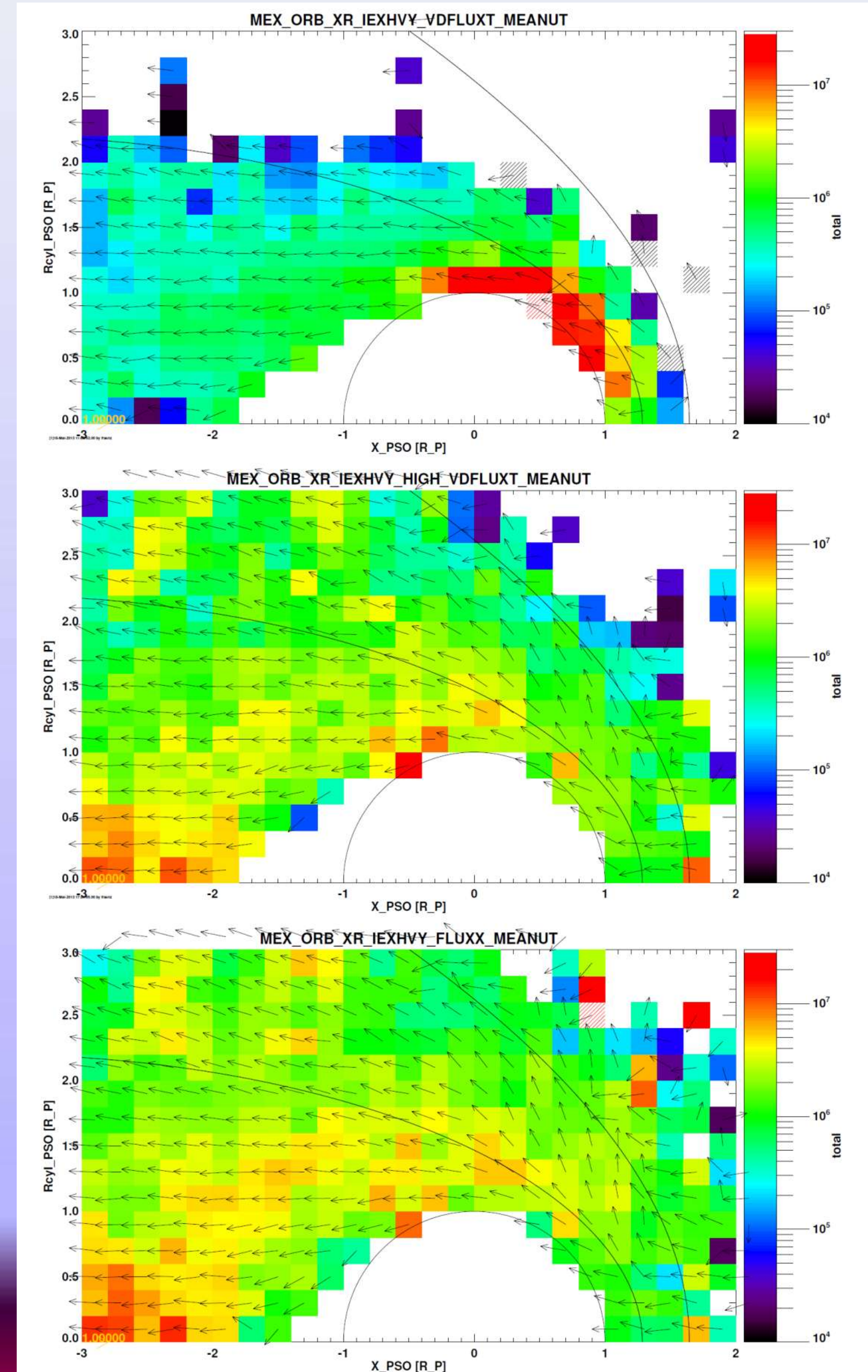
At energies < 50eV ASPERA IMA measures only a in a 2D plane with 4deg polar width. Idea to overcome this: sample a mean velocity distribution (VD) from many orbits.

Problem: the missing observations at E<10eV can not be reconstructed from the mean VD.

Mean Velocity Distribution Functions
Flux Average



Total flux of heavy ions from MEX Aspera IMA observed between 1 May 2007 and 1 March 2011.
Top: from Nilsson et al. (2012), scaled in c/m^2s
bottom from Imaextra Heavy averaged VD adding low (<50eV) and high (>50eV) energy, scaled in c/cm^2s.



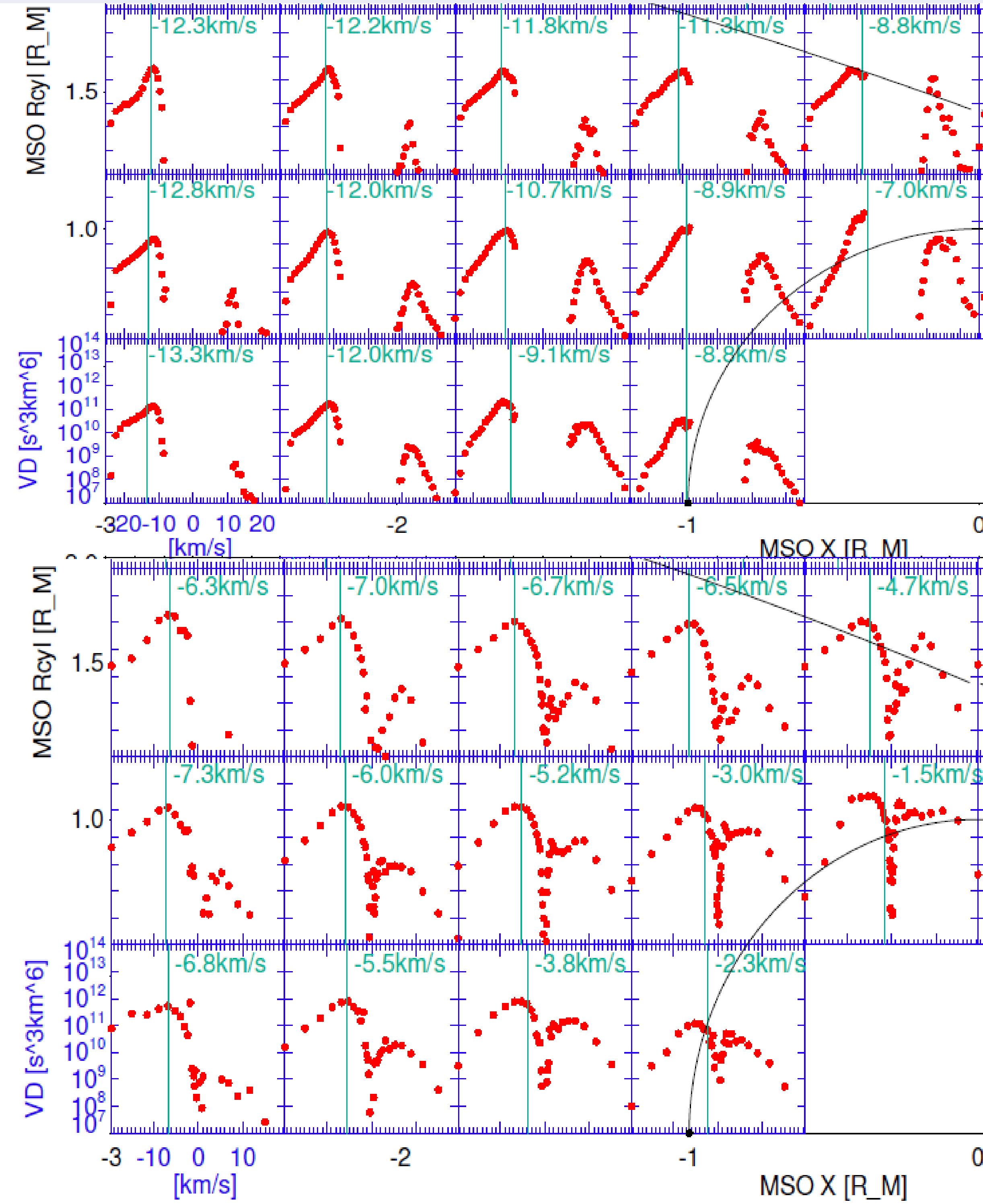
<50eV mean VD method

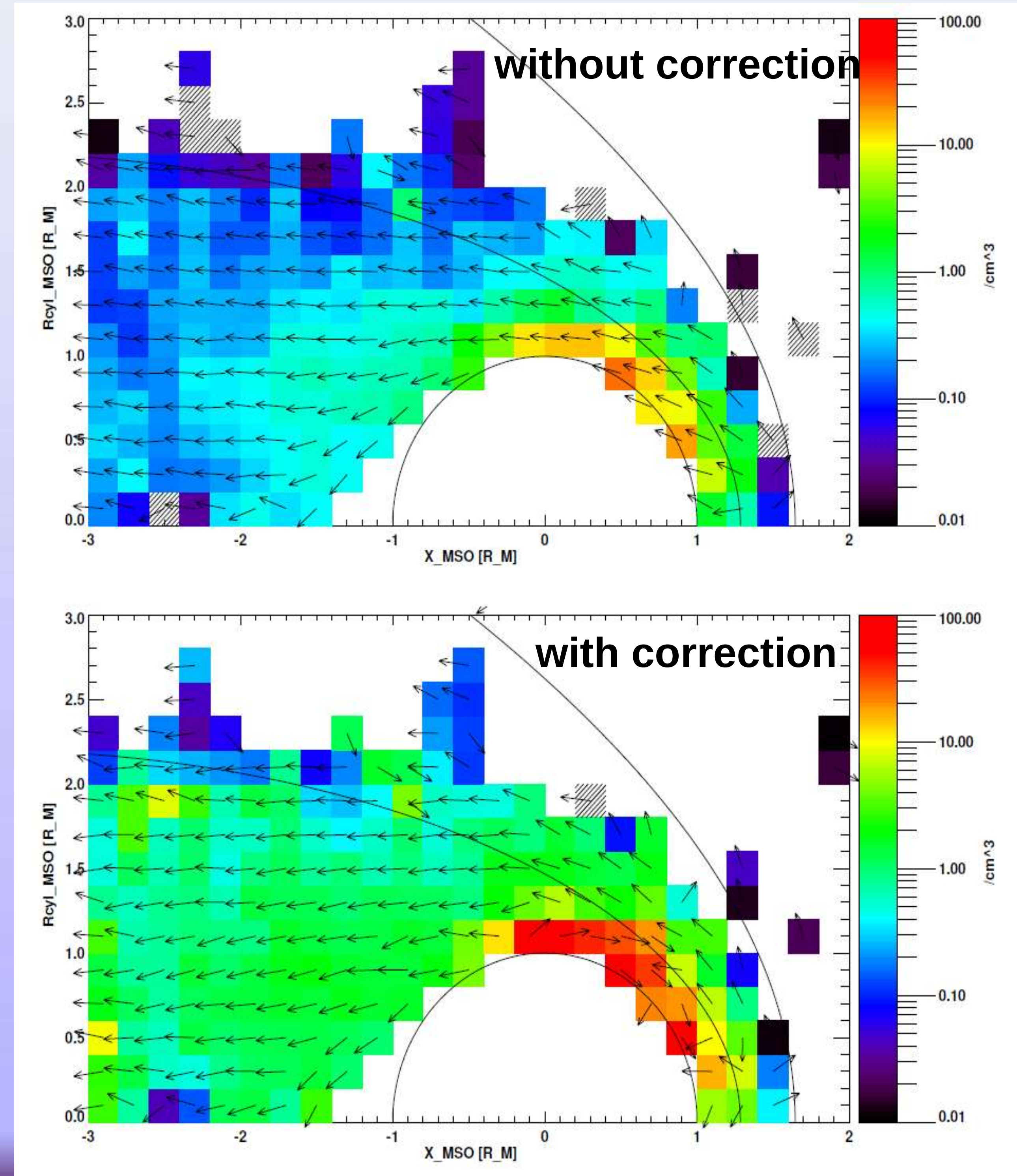
>50eV mean VD method

>50eV record-wise method

SC Potential Correction

Results in higher density but lower velocity



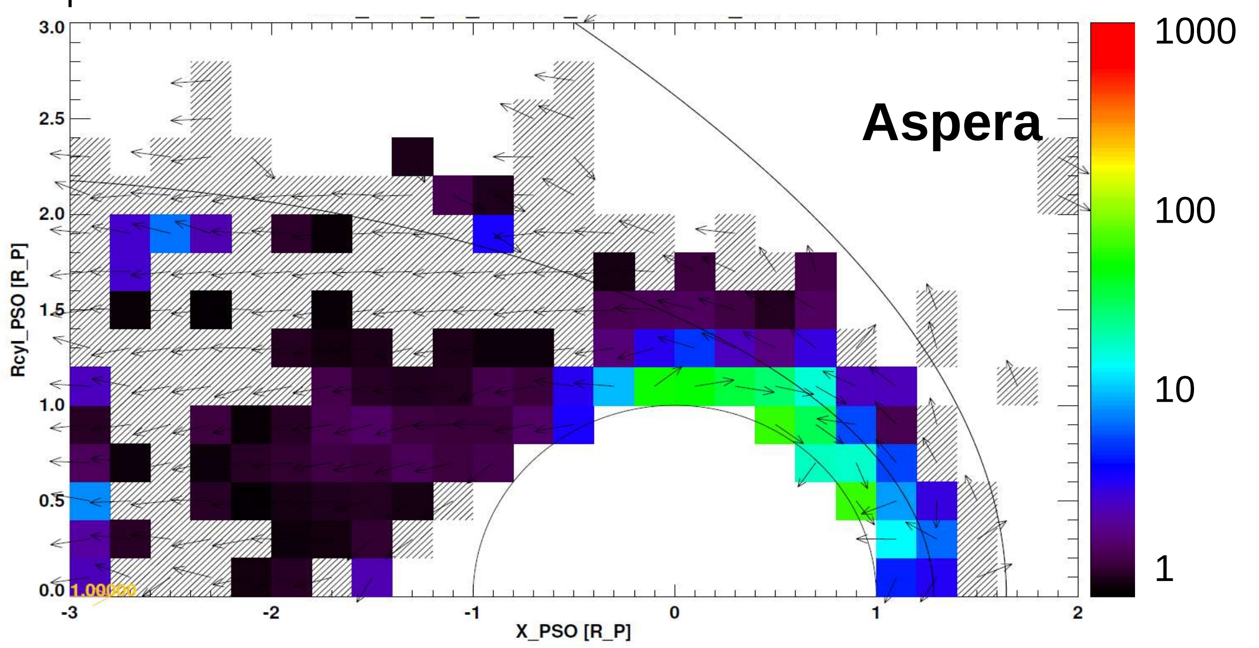


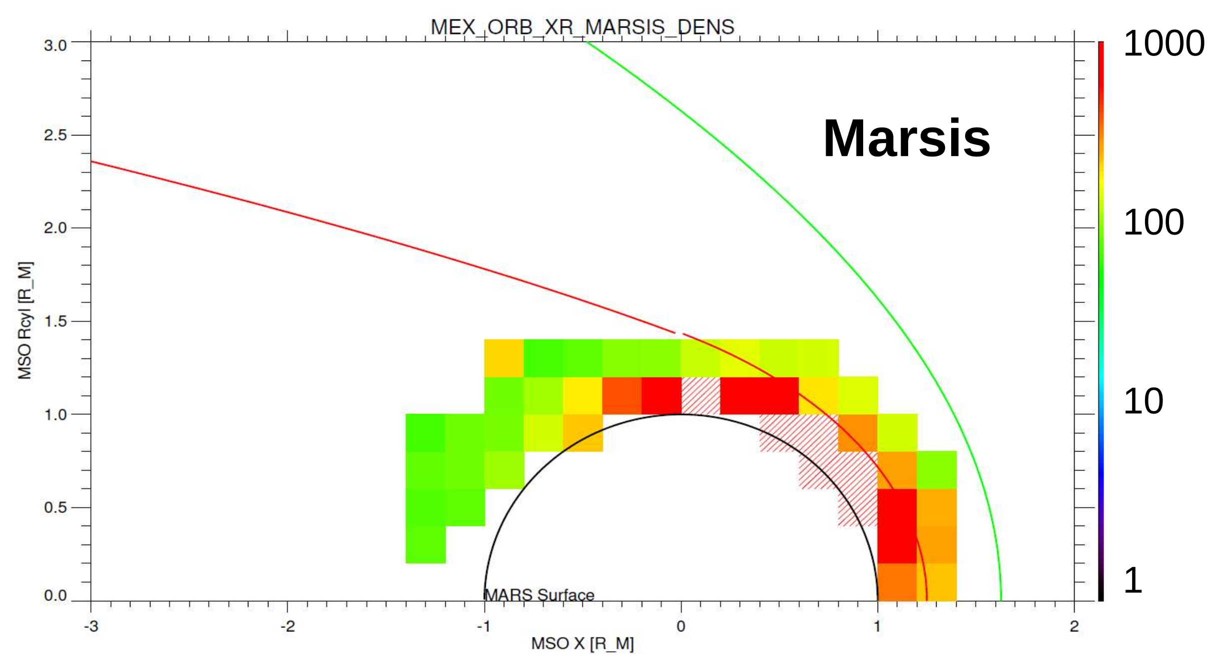
Mean VD function of ions (<50eV) from MEX Aspera IMAEXTRA VD observed between May 2007 and March 2011, n s^3/km^6 vs km/s.
Top without SC velocity and SC potential correction ,
bottom with SC velocity and SC potential correction.

Integrated density from mean VD function of ions (<50eV) from MEX Aspera IMAEXTRA observed between 2007 and 2011, in c/cm^3.
Top without SC velocity and SC potential correction ,
bottom with SC velocity and SC potential correction.

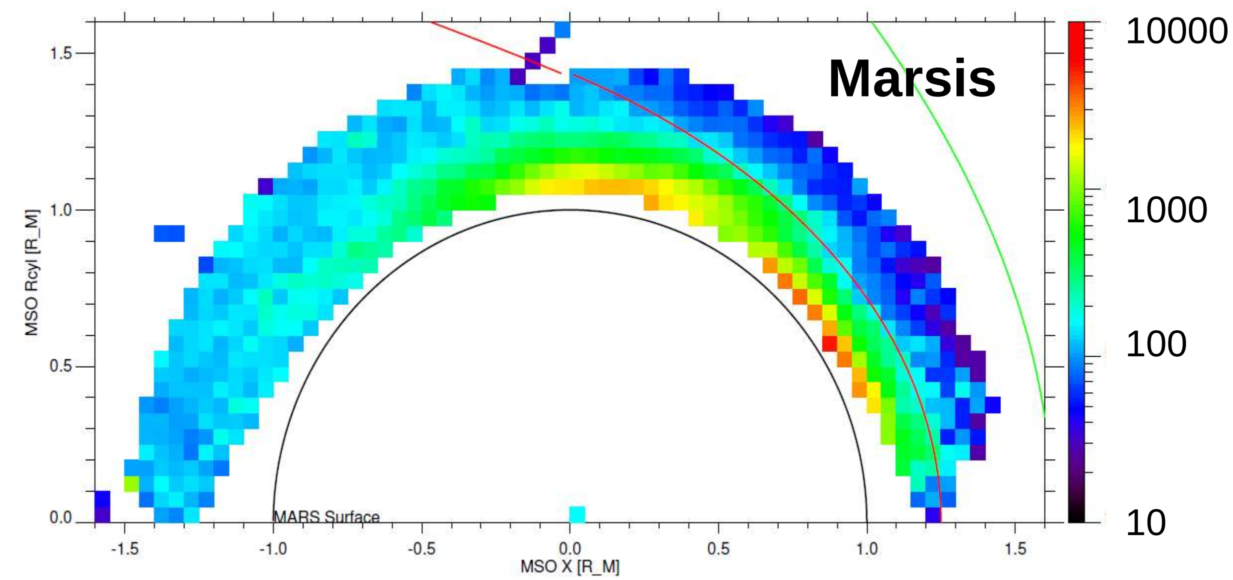
Comparing ASPERA and MARSIS densities (ions/cc)

Integrated density of heavy ions (<50eV) from MEX Aspera IMAEXTRA VD observed between 2007 and 2011, scaled in /cm3s with SC velocity and SC potential correction





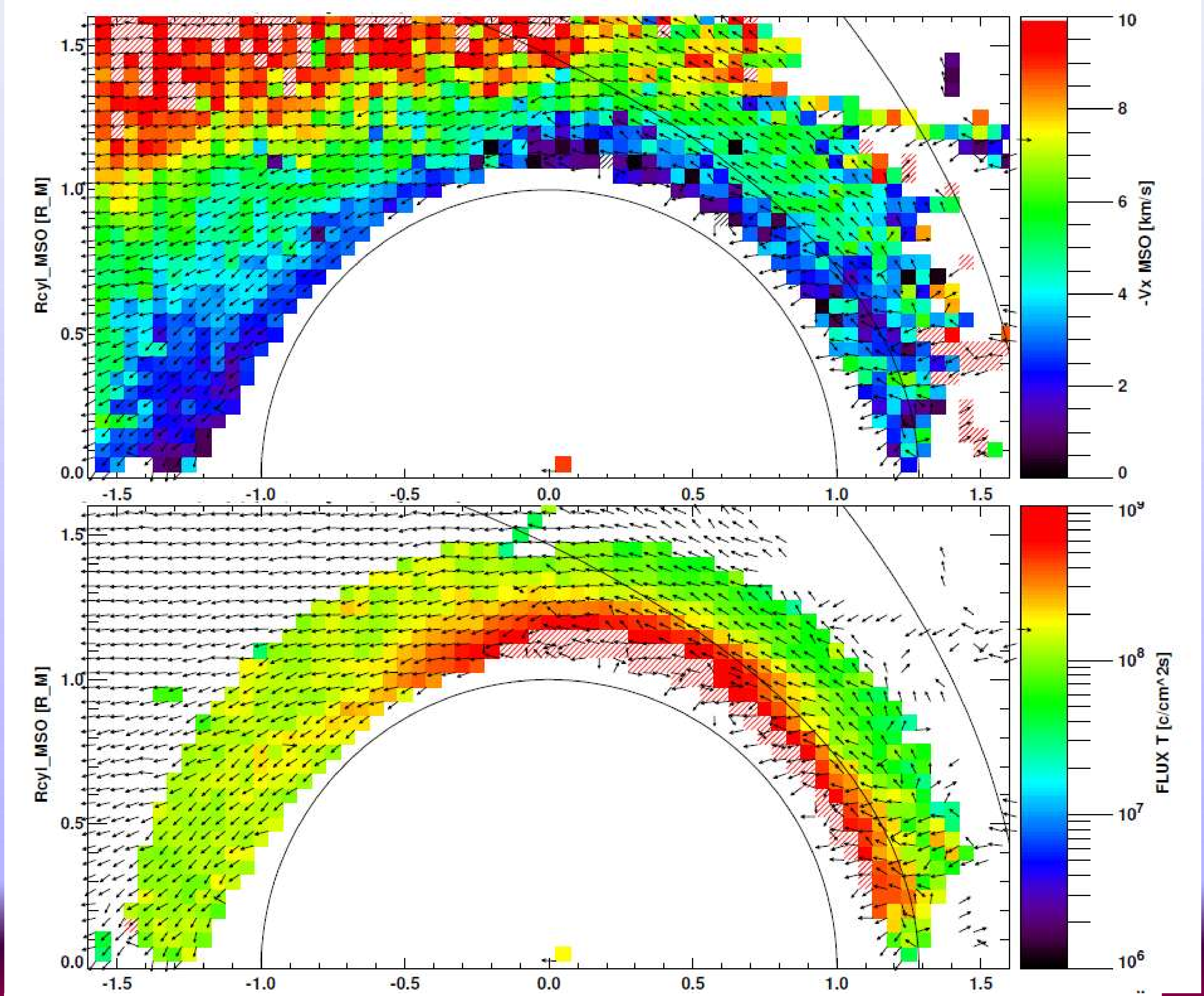
Mean total electron density observed by MARSIS plasma frequency observations (same scale and time range).



Mean total electron density observed by MARSIS plasma frequency. Observations 2007-2014 allow higher spatial resolution.

Median cold heavy ion flux

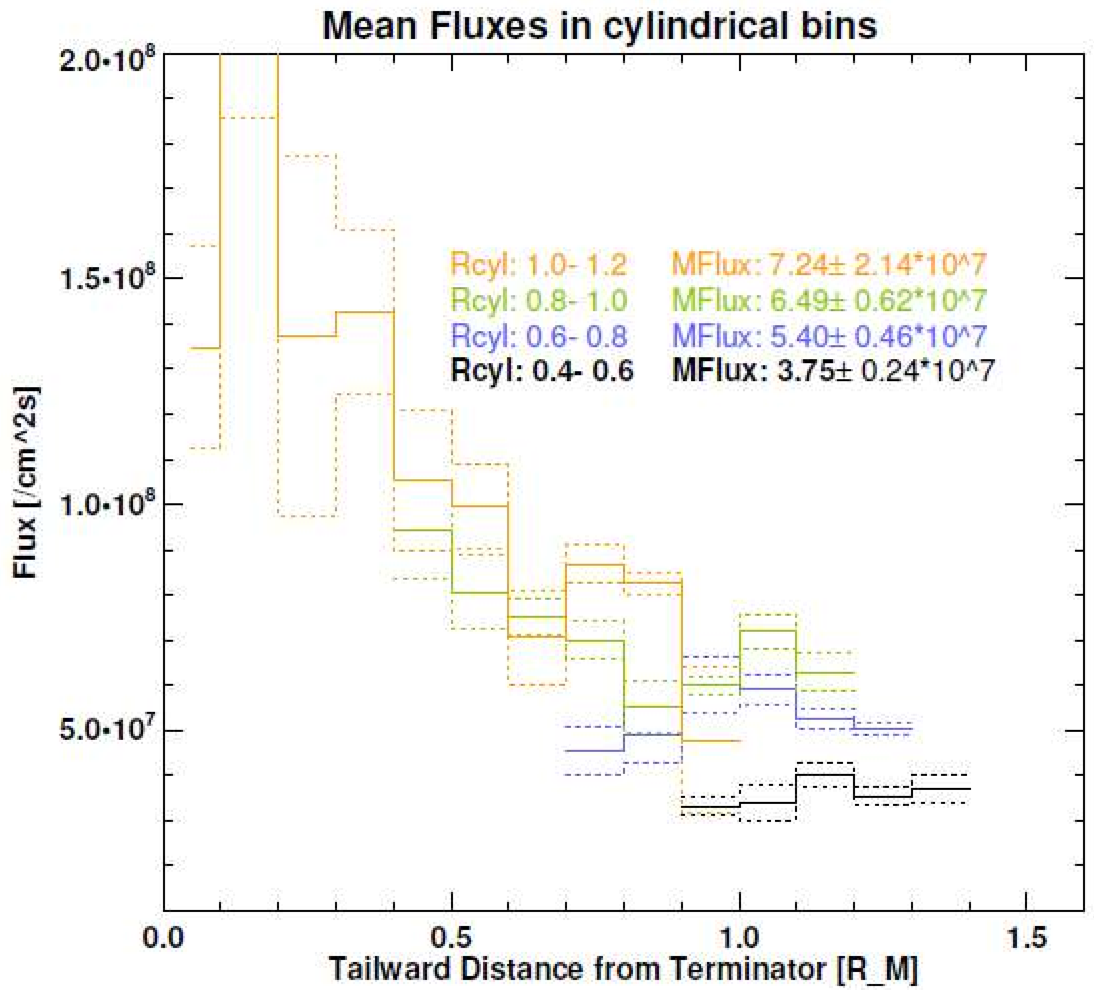
from all orbits in between 05/2007 and 07/2014
where both IMA and MARSIS data are available



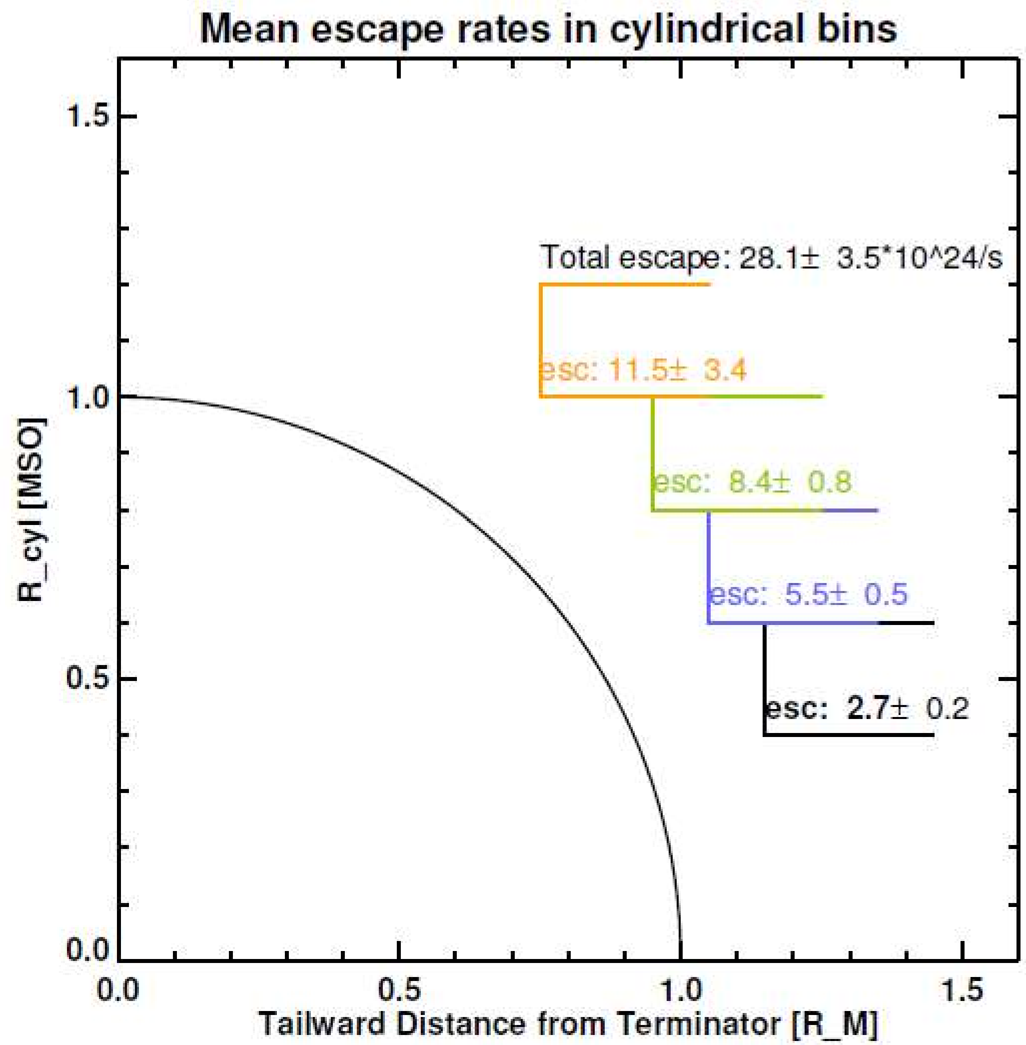
Mean heavy ion tailward velocity (km/s,top) and total flux (/cm^{2}s, bottom) by multiplication of MARSIS density and IMA VD Velocity (corrected for spacecraft velocity and potential).

Median cold heavy ion flux

from all orbits in between 05/2007 and 07/2014
where both IMA and MARSIS data are available



Median heavy ion flux (/cm²s) by multiplication of MARSIS density and IMA Velocity (corrected for spacecraft velocity and potential).
Here the minimum of a set of different velocity measures is taken.



Total cold ion flux (IMA velocity X MARSIS density) as function of tailward distance from terminator for different cylindrical rings around tailaxis.

Tailward flux becomes constant beyond 0.5 R_M tailward distance and main flux is between 0.9 and 1.3 R_M cylindrical distance from tail axis resulting in a median escape rate of 2.8×10^{25}/s.

Cold Ion Escape from the Martian Ionosphere Conclusions

Max-Planck-Institut für Sonnensystemforschung

Mean escape of oxygen ions at solar minimum are 10 times higher than in previous studies by Lundin et al. 2008 and Nilsson et al. 2011 for following reasons:

1. Shift of energy table by varying spacecraft potential was not taken into account
2. the extrapolation from a 2D measurement to 3D distribution function neglected angular offset from bulk flow direction.
3. distribution function was assumed to be static in time (Nilsson et al. 2011)
4. Obscuration by spacecraft was not taken into account properly.
5. No absolute reference for plasma density was used.

Significant sources of error in this study:

1. Spatial coverage of MARSIS observations is limited to 1600km altitude
2. Plasma density can only be measured when > 10/cc
3. Plasma density determination methods disagree below 100/cc
4. Spacecraft potential often ill defined by ELS observations.
5. Mean velocity often ill defined when IMA obscured by spacecraft.

Combination of Aspera-3 and MARSIS:

•Allows for the first time to explain the partial plasma density observed by particle sensors by an angular offset of a Maxwellian plasma distribution

•It confirms that in the terminator region the upper ionosphere is moving at super-sonic speed causing an oxygen ion passage of >2 10^{25}ions/s across the terminator

•We can now confirm using 2007-2014 data that the larger part of this cold ion flow escapes. This means total mean escape flux is 10x higher than previously reported by MEX Aspera because effect of 2D measurement has not been considered in previous studies.

•Acceleration of ions can be explained by transterminator pressure gradient as for Venus but the speed exceeds escape velocity only at Mars.

•Energetic flux observed in central plasma tail has much lower density and does only contribute less than 10% of total ion outflow.

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