Ion Escape from the Martian Ionosphere

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VENUS PVO ORPA
Knudsen JGR 1992

ION DYNAMICS IN THE VENUS IONOSPHERE 177

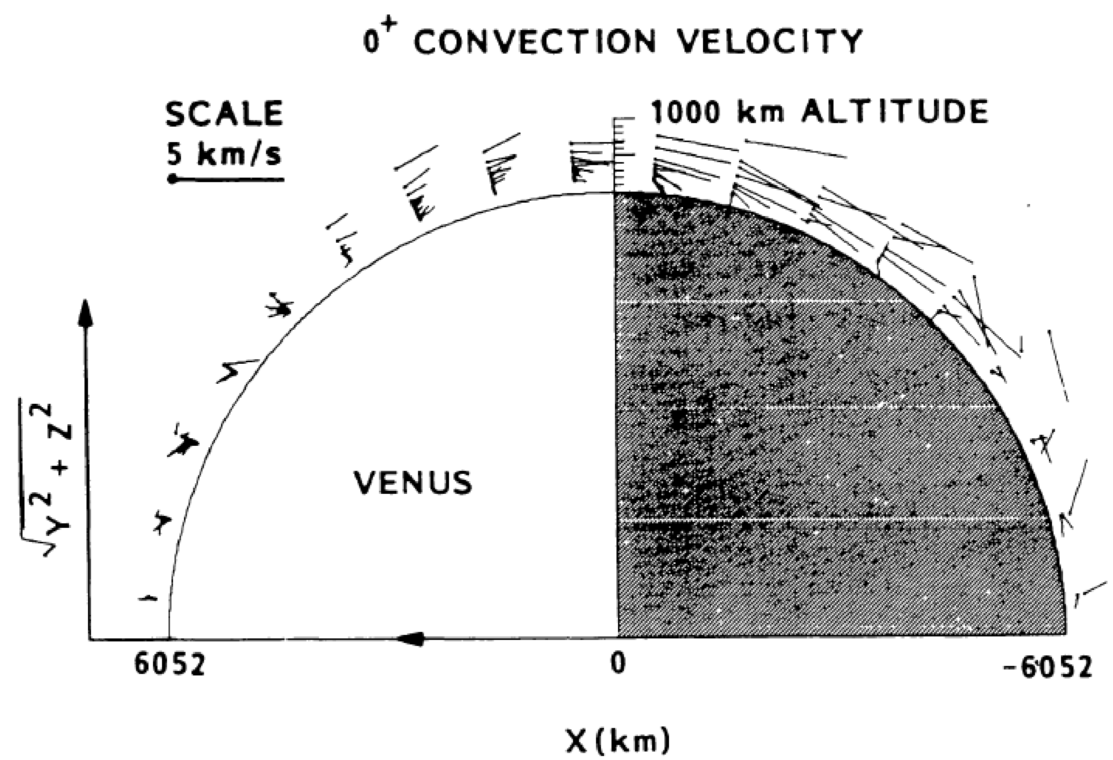
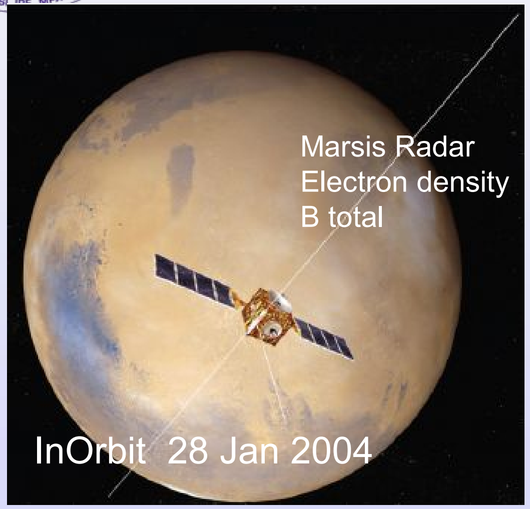
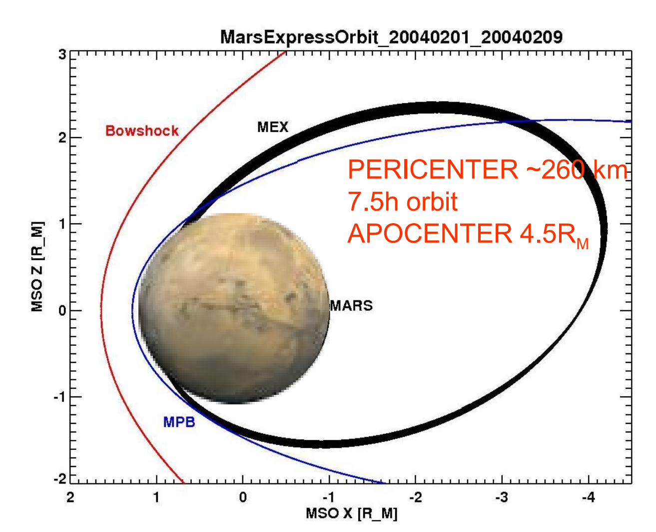
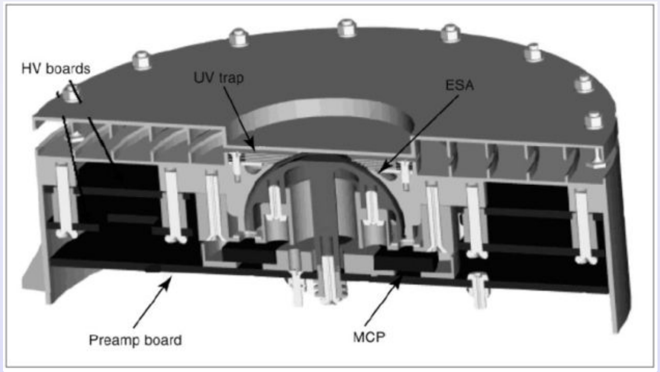


Fig. 5. Average ion velocities measured in the outbound leg of the orbit during the first 3.5 years of the Pioneer Venus mission (after Knudsen *et al.*, 1982a).

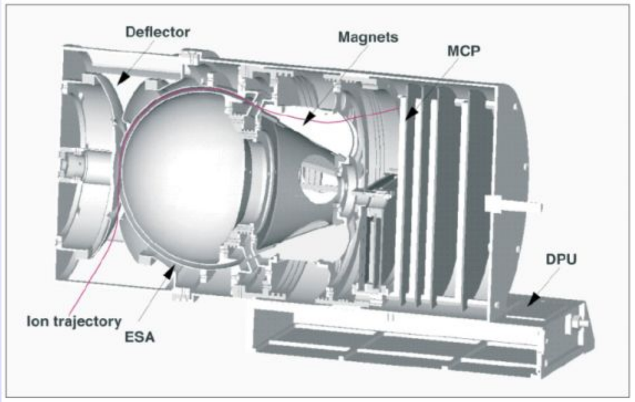
Plasma Instruments on Mars Express





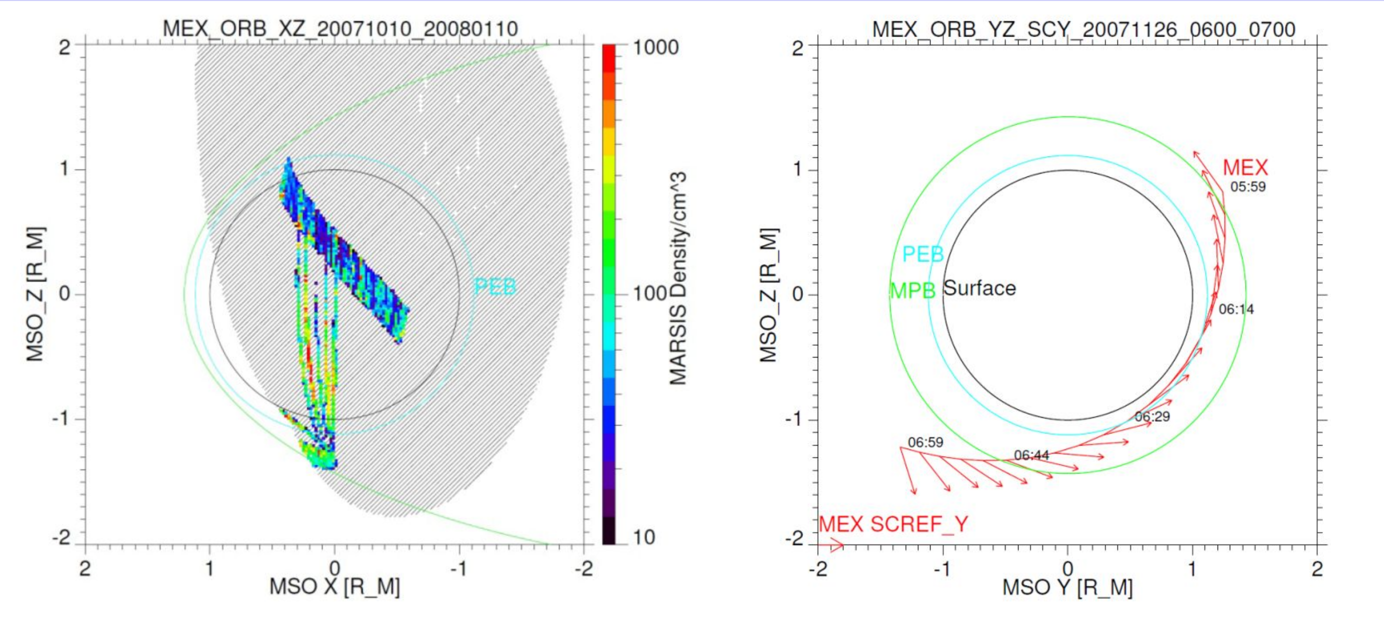


Electron Spectrometer,
2D,16 sectors,1eV-20keV

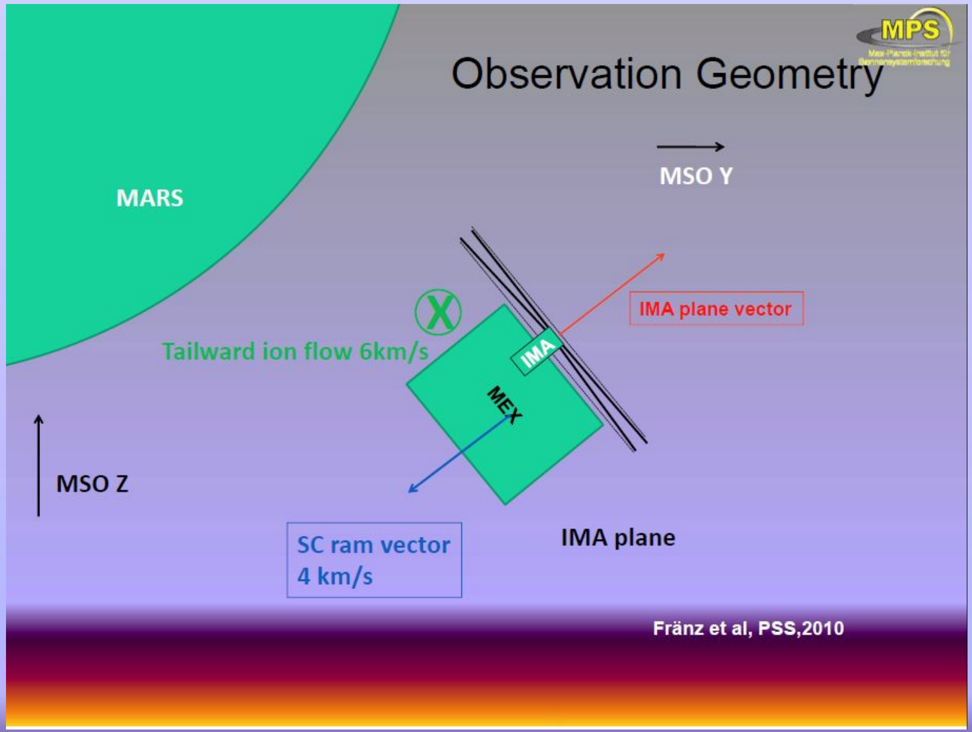


Ion Spectrometer,3D, 16x16 sectors
10eV-40keV, 32 mass rings
Below 50eV electrostatic scanner
is switched off > only 2D measurement!

Combined ASPERA3 and MARSIS observations in Mars terminator plane



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).



Mars cross terminator escape flow

Fränz et al, PSS,2010

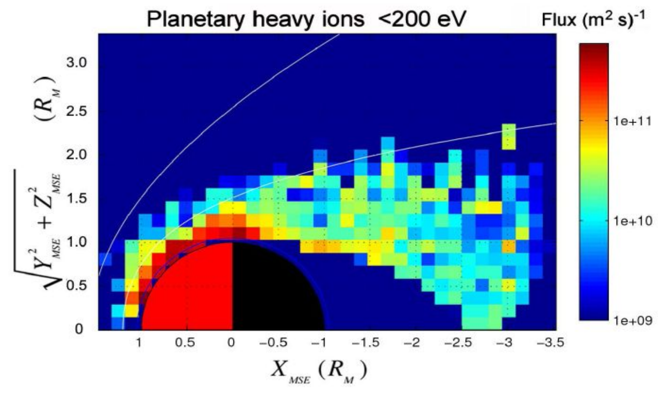


Figure 3. Low-energy (<200 eV) planetary heavy ion (O^+, O_2^+, CO_2^+) fluxes near Mars. Colour scale represents average fluxes in the 500×500 km quadrants.

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

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^{2}s 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?

Ion acceleration by pressure gradient across terminator

Elphic et al., 1984

Momentum Equation

We wish to examine the nightward plasma flow that results from the balance between pressure gradients, neutral drag and ion viscosity. The appropriate form of the equation is

$$\rho\nu_{in}u + \rho u\frac{\partial u}{\partial x} + \frac{\partial}{\partial z}\eta\frac{\partial u}{\partial z} = -\frac{\partial p}{\partial x} + \rho\nu_{in}u_n \qquad (1)$$

where u is the bulk horizontal plasma velocity, ρ is the plasma mass density, p is the total plasma pressure, η is the ion viscosity of the plasma (as opposed to eddy viscosity), ν_{in} is the ion-neutral collision frequency for momentum transfer, and u_n is the neutral wind velocity. The coordinates x and z are horizontal and vertical,

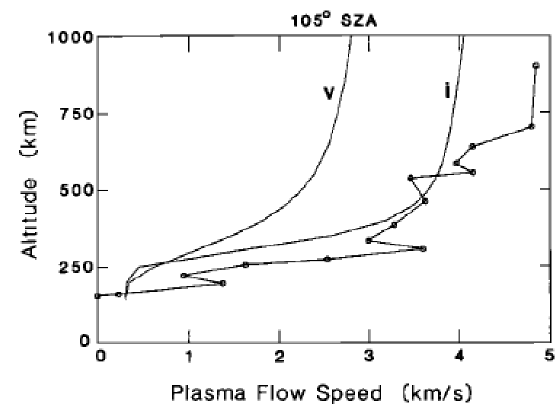
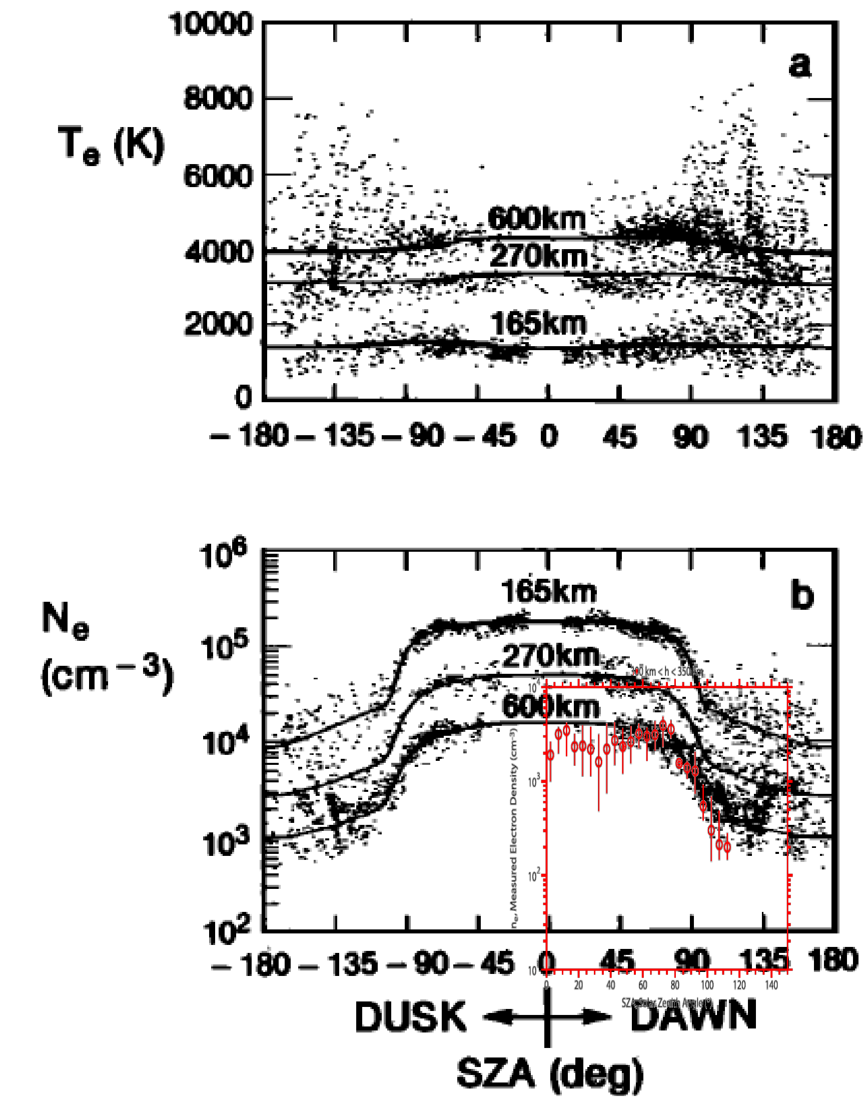


Fig. 2. Flow speed profile for viscid (v) and inviscid (i) solutions at 105° solar zenith angle. Also shown are medians of the measured ion flow corresponding to the 100-110° solar zenith angle bin (circles) from the PVO retarding potential analyzer.

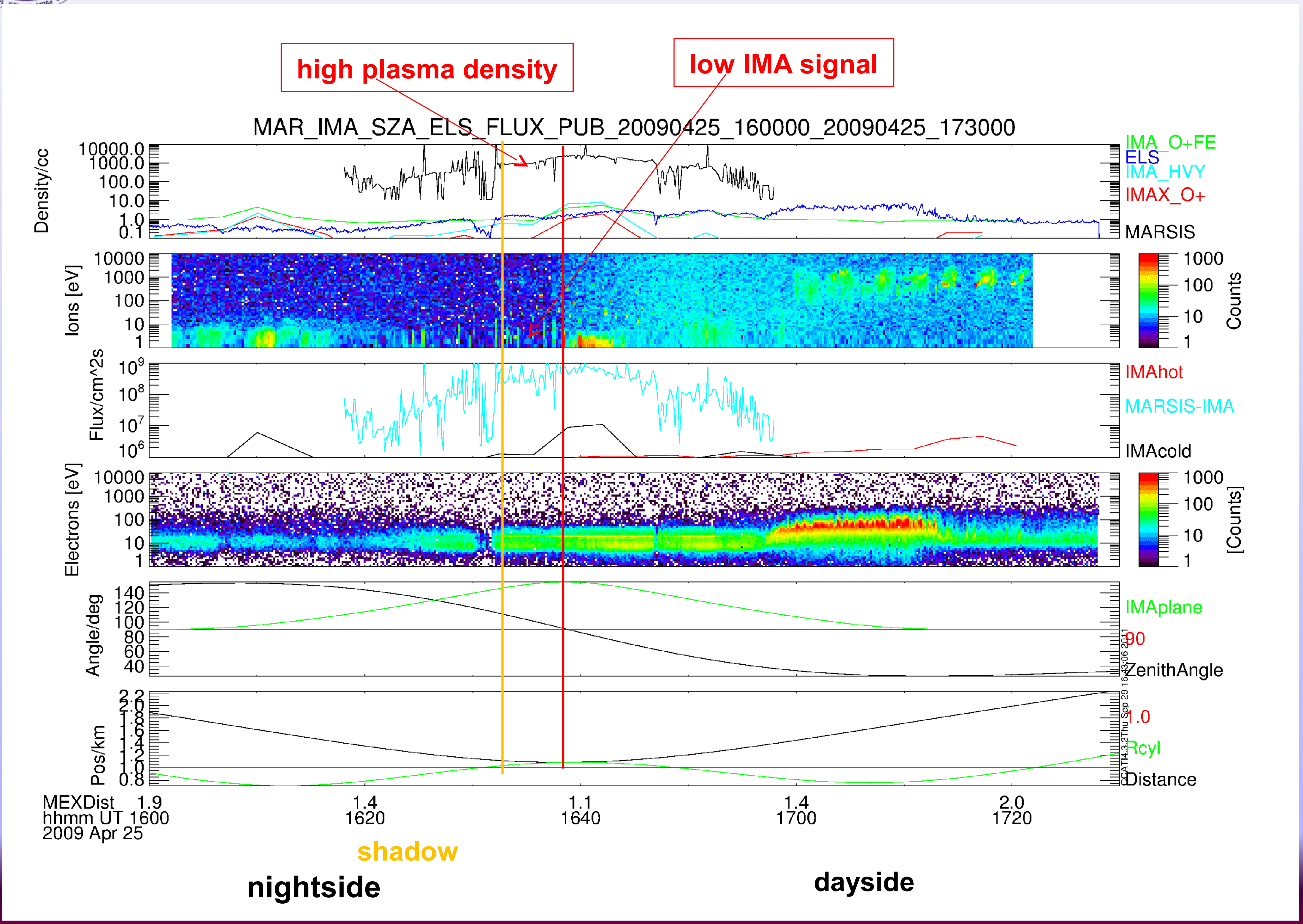


Venus
Theis et al., 1984

Mars 300-350km
Duru 2008

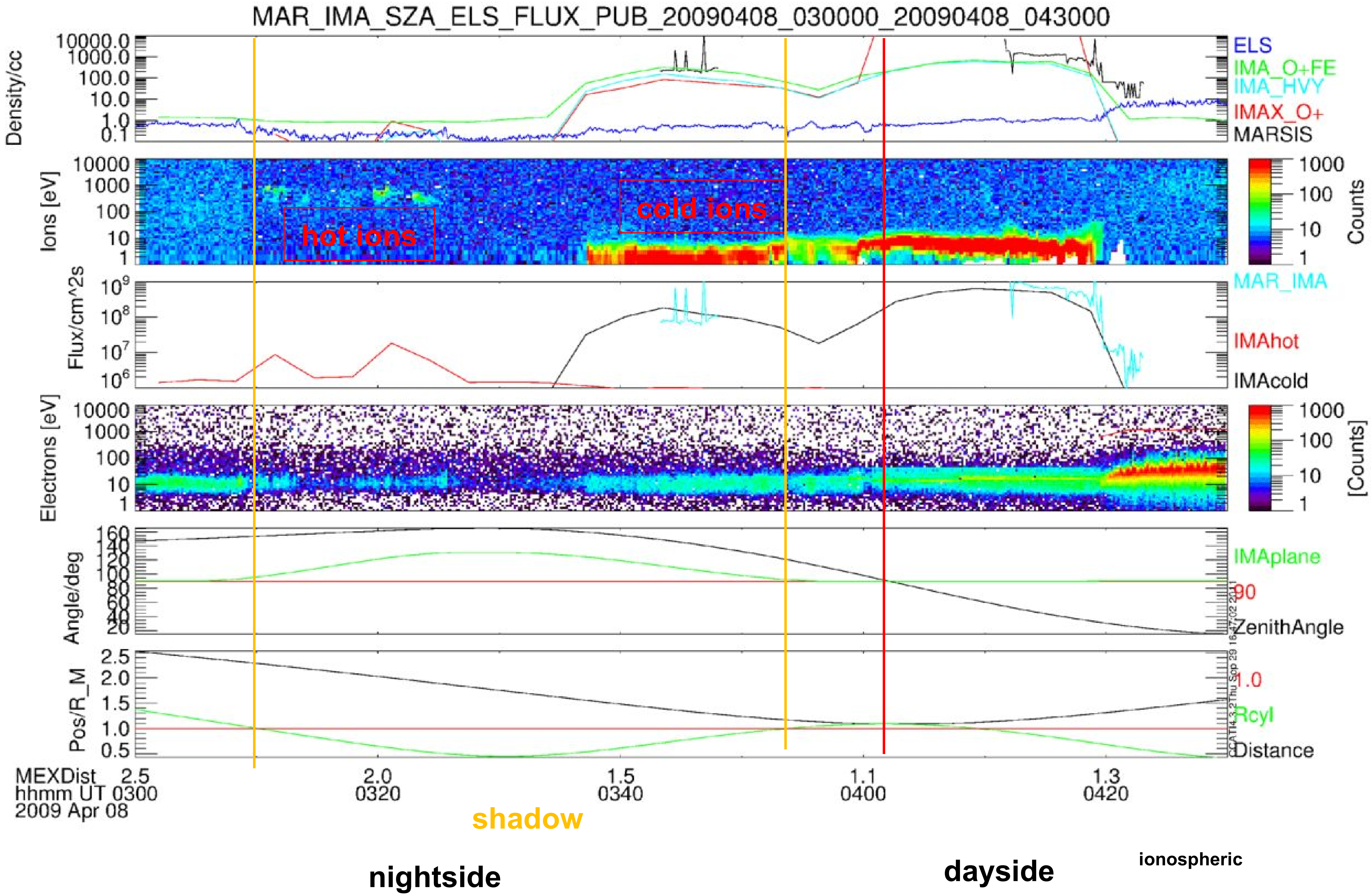
Acceleration of ions across the terminator at Venus can be explained by the day-night pressure gradient in an inviscid collisional plasma.

New MARSIS nightside observations in 2007-2011



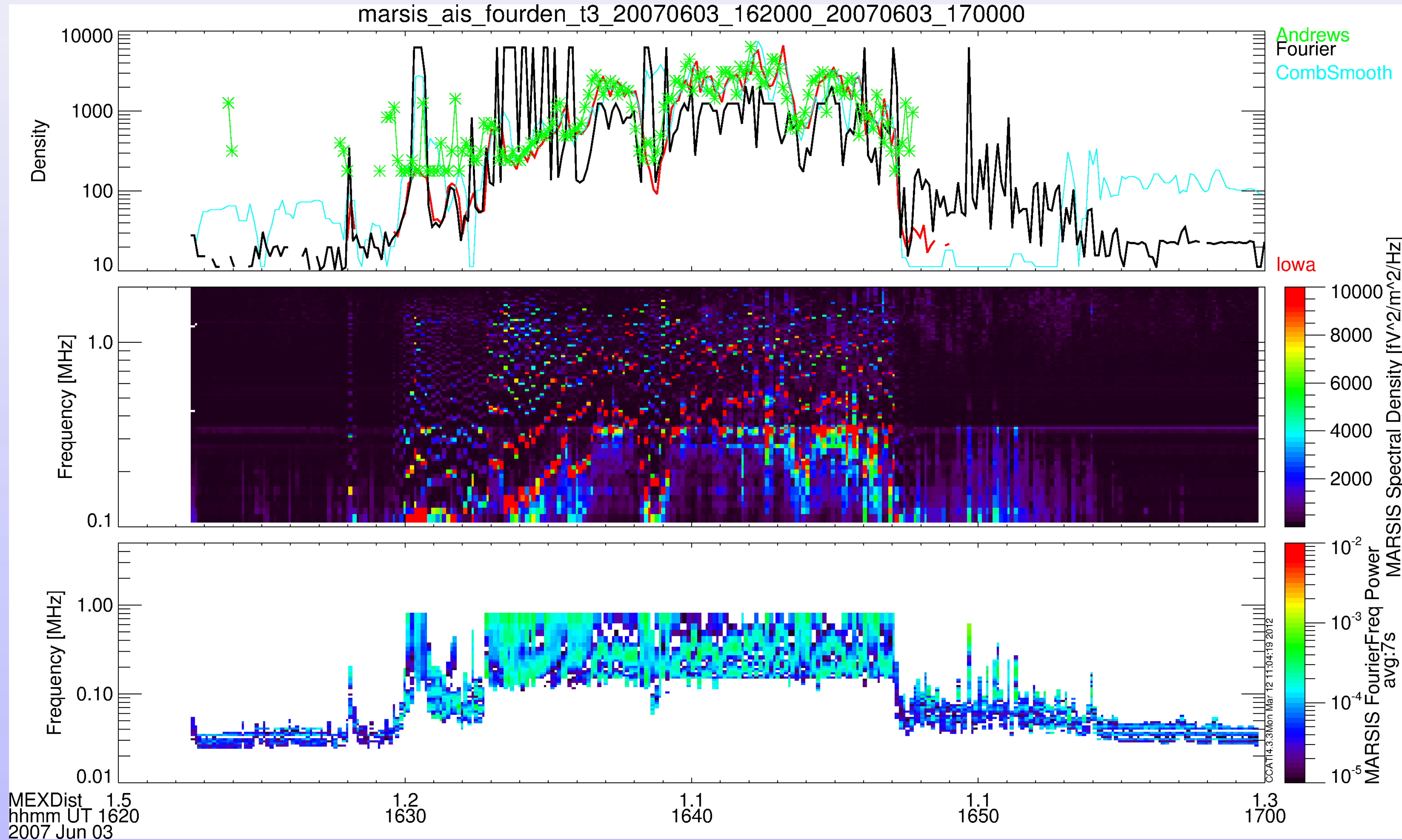
Combined observations of MARSIS, ASPERA-ELS and ASPERA IMA.
Many orbits with nightside plasma density >100/cc but very low IMA density

New MARSIS nightside observations in 2007-2011



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

Determining local electron density from MARSIS



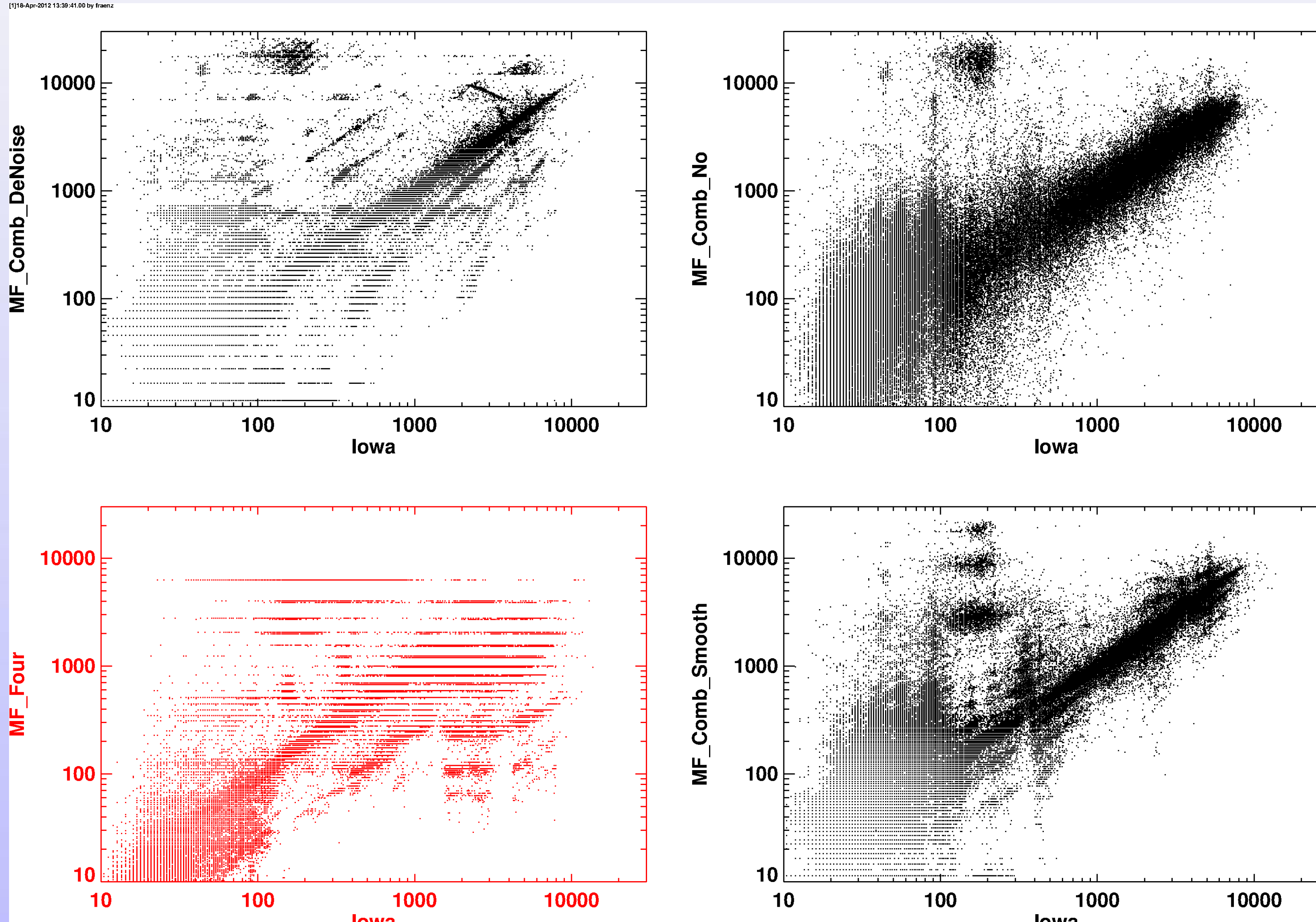
MARSIS observations for one pericenter path on Jun 3 2007, from top to bottom:

A)local electron density from: Iowa group by eye (red), Uppsala group Fourier (green), MPS fitting a delta function comb (cyan), MPS Fourier transform (black)

B) Marsis integrated spectral density spectrum

C) Frequency range and spectral power selected for MPS Fourier method.

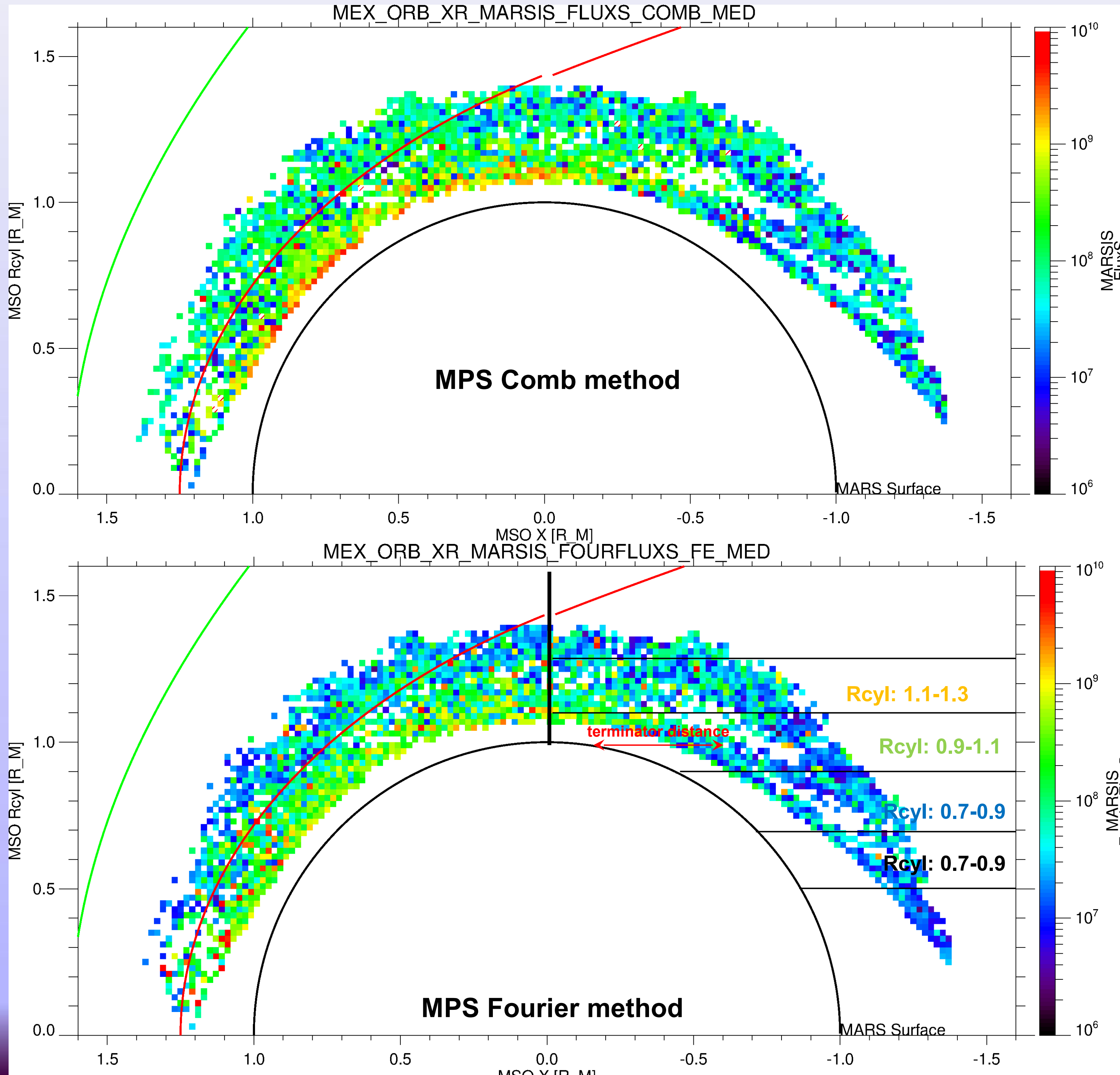
Determining local electron density from MARSIS



Comparison of density determination relative to Iowa method: A)Comb with wavelet denoise,B) Comb with no corrections, C) MPS Fourier (red), D) Comb with subseqent timeseries smooth

Median cold heavy ion flux

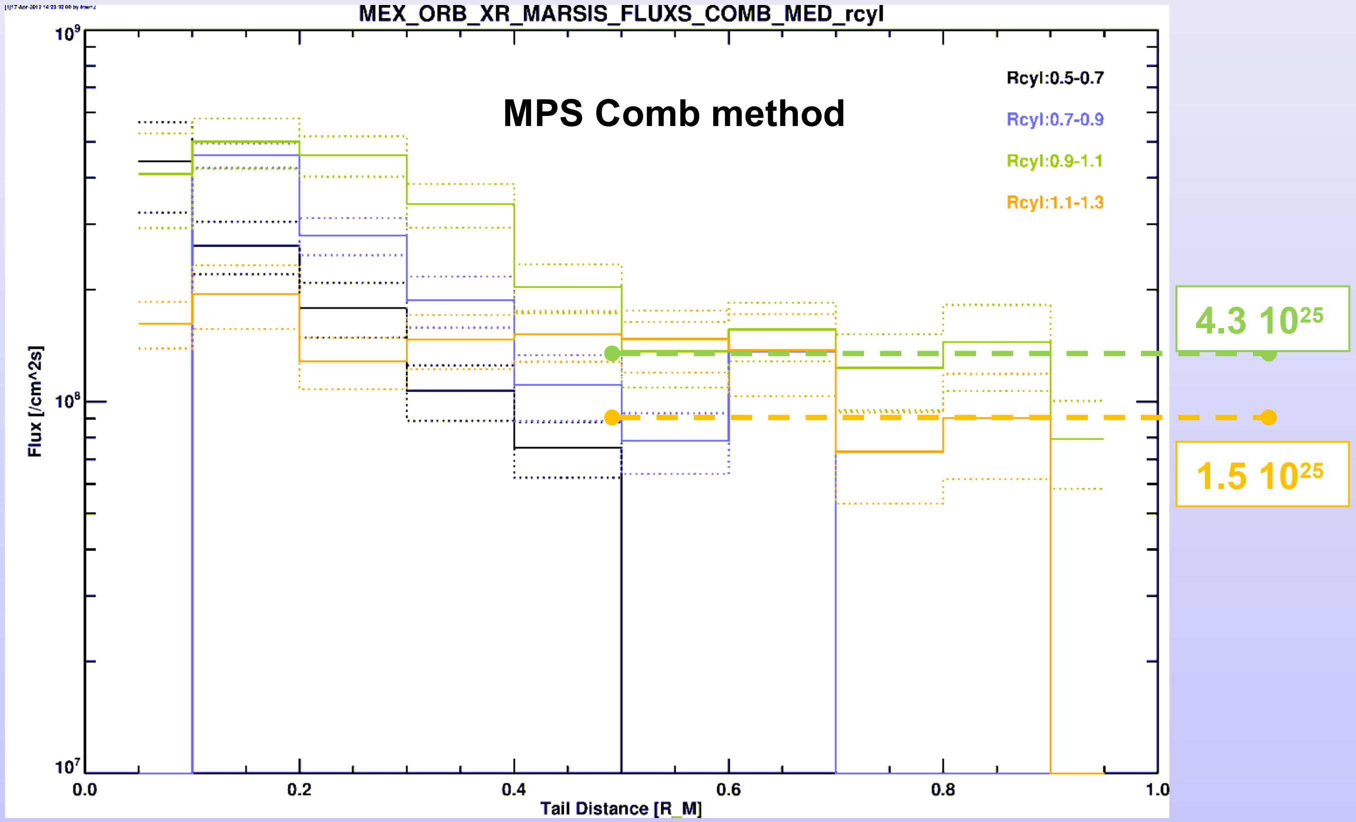
from all orbits in between 05/2007 and 07/2011
where both IMA and MARSIS data are available

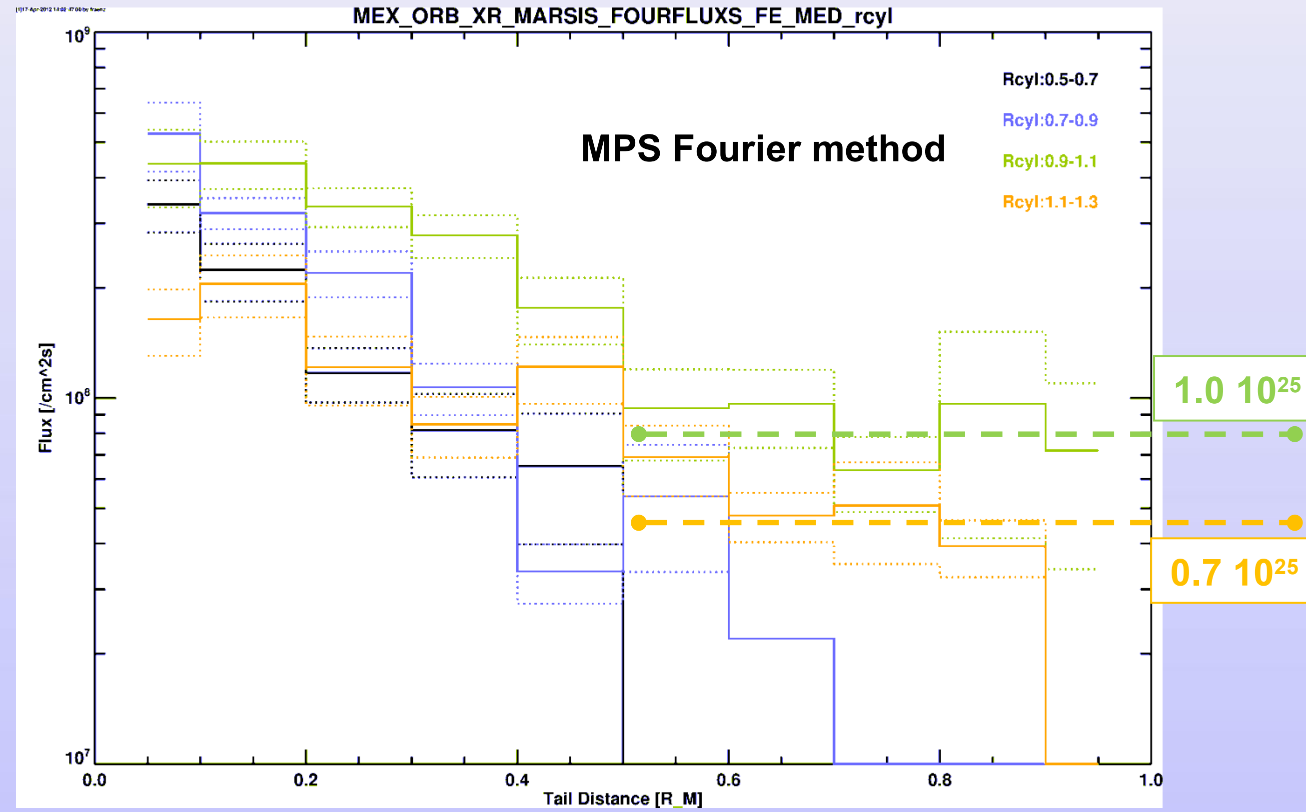


Median heavy ion flux (/cm²s) by multiplication of MARSIS density and IMA velocity (corrected for spacecraft velocity and potential).

Median cold heavy ion flux

from all orbits in between 05/2007 and 07/2011
where both IMA and MARSIS data are available





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

Both methods show that tailward flux becomes constant beyond 0.5 R_M tailward distance and that main flux is between 0.9 and 1.3 R_M cylindrical distance from tail axis.

For the comb method the resulting tailward escape rate is 5.8 10^{25}/s, for the Fourier method only 1.7 10^{25}/s.

Since the Fourier method is better for the low densities observed on the nightside of Mars we adopt the latter value as median escape rate.

Median cold heavy ion flux

Our results for the mean escape of oxygen ions at solar minimum are 10 times higher than by previous studies by Lundin et al. 2008 and Nilsson et al. 2011.
We think that the reasons for this difference are that in previous studies:

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.

Nevertheless in the present study there are significant sources of error:

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.

Ion Escape from the Martian Ionosphere
Conclusions

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 2007-2011 data that at least half 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.

References:
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