Large-amplitude coherent structures in plasma near Mars

E. Dubinin[1], *M. Fraenz*[1], *J. Woch*[1], *R. Lundin*[2], and *S. Barabash*[2]

[1] Max-Planck-Institute for Solar System Research, Max-Planck str., 2, 37181 Katlenburg-Lindau, Germany, dubinin@mps.mpg.de

[2] Swedish Institute of Space Physics, Kiruna, Sweden, stas@irf.se, rickard@irf.se

Abstract

Large-amplitude coherent pulses generated in solar wind due to the interaction with extended hydrogen corona produce very structured plasma environment at Mars. The magnetosheath region occurs decomposed into a sequence of periodical compressional waves which impact the ionosphere. An additional wavy dynamics appears due to multi-ion origin of plasma in the transition region. Penetration of these waves into the ionosphere and their damping can be important for ion energization and escape.

1 Introduction

Mars has no a global magnetic field which could protect its atmosphere and ionosphere from solar wind. Moreover due to the extended hydrogen exosphere the interaction starts already at large distances from Mars and some cometary features appear in the interaction pattern. Closer to the planet oxygen ions of the ionospheric origin begin to dominate and multi-ion effects become important. Mars is also a unique object since the Larmour radius of pickup heavy planetary ions (O^+, O_2^+) is much larger than the characteristic size of the obstacle. Besides that the magnetosheath width occurs comparable to the Larmour radius of solar wind protons based on the bulk speed implying the important role of kinetic effects. All these features strongly affect the wave environment at Mars. Here we present the observations of large-amplitude coherent waves at Mars and discuss their role in ion energization and escape.

2 Observations

The Mars Global Surveyor (MGS) and Mars Express (MEX) observations show the existence of large amplitude waves upstream from the bow shock. Low frequency coherent waves at the frequency around the proton cyclotron frequency Ω_p are generated by the exospheric hydrogen ions picked up by solar wind and forming a beam in the plasma frame [1,2]. The waves are characterized by large amplitudes (up to 5 nT peak to peak), high coherency and a bunching to the wave packets [2]. Another type of waves consists of solitary type compressive pulses. Fig. 1 depicts examples of such large-amplitude coherent structures. The panels present the time-energy spectrograms of electron fluxes measured by the ASPERA-3 experiment onboard MEX and the corresponding variations in the electron number density. Amplitude of the oscillations reaches one order of magnitude. For comparison note that similar wave structures with the recurrence time of gyroperiod of water group ions were observed at Giacobinin-Zinner comet [3]. It is also seen that the waves are transported across the bow shock and strongly damped in the dense ionosphere below the boundary of the induced magnetosphere (IMB).

The typical feature of the Martian magnetosheath which probably lacks of space for a wave randomness, is its strong structuring [4]. Fig. 2 shows examples of such a decomposition of the whole magnetosheath into multiple coherent large-amplitude waves. The waves have similar characteristics as the upstream waves and probably were transported through the region of the quasi-parallel bow shock. This can explain their often absence along the orbital segments in the solar wind (see e.g. the orbit on August 9, 2004). However the generation of similar type of solitary structures at the bow shock is also not excluded.

The interesting question is whether such structures affect the ionosphere adjacent to the magnetosheath. Penetration of electromagnetic waves into the upper ionosphere can lead to heating of the ionospheric plasma

978-1-4244-6051-9/11/$26.00 ©2011 IEEE

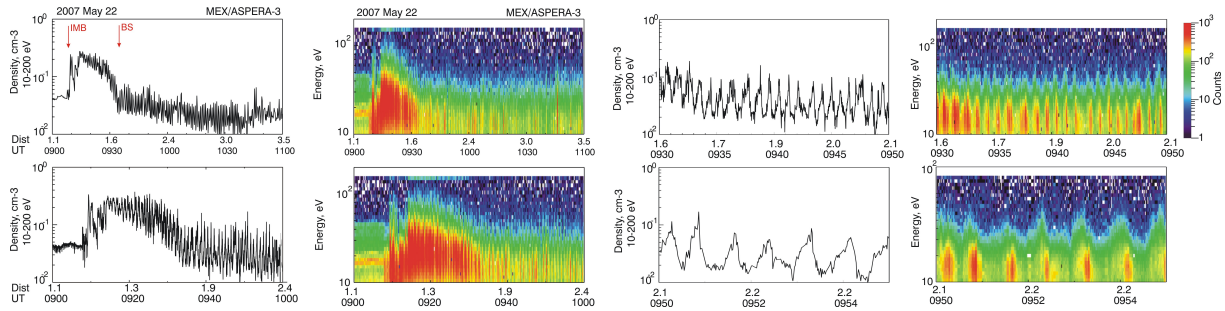

Figure 1: energy-time spectrograms of electron fluxes plotted for different time intervals and corresponding variations in the electron number density. Large-amplitude coherent structures are generated in solar wind and transported across the bow shock.

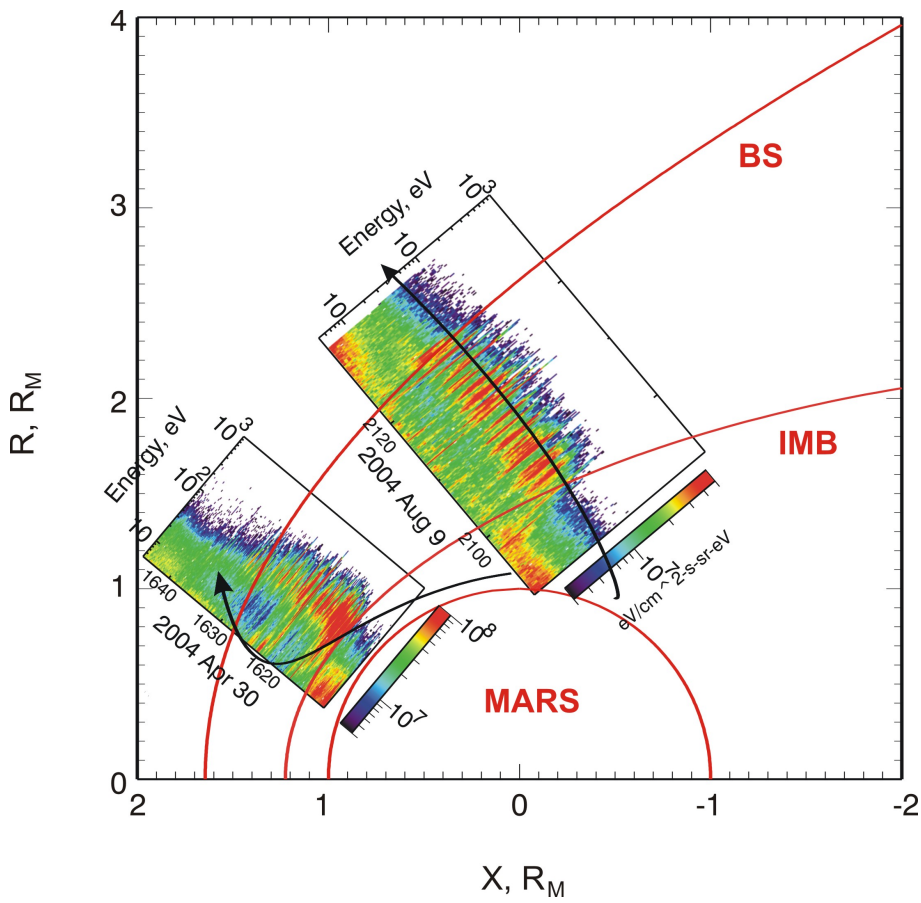

Figure 2: Decomposition of the magnetosheath into a sequence of large amplitude waves.

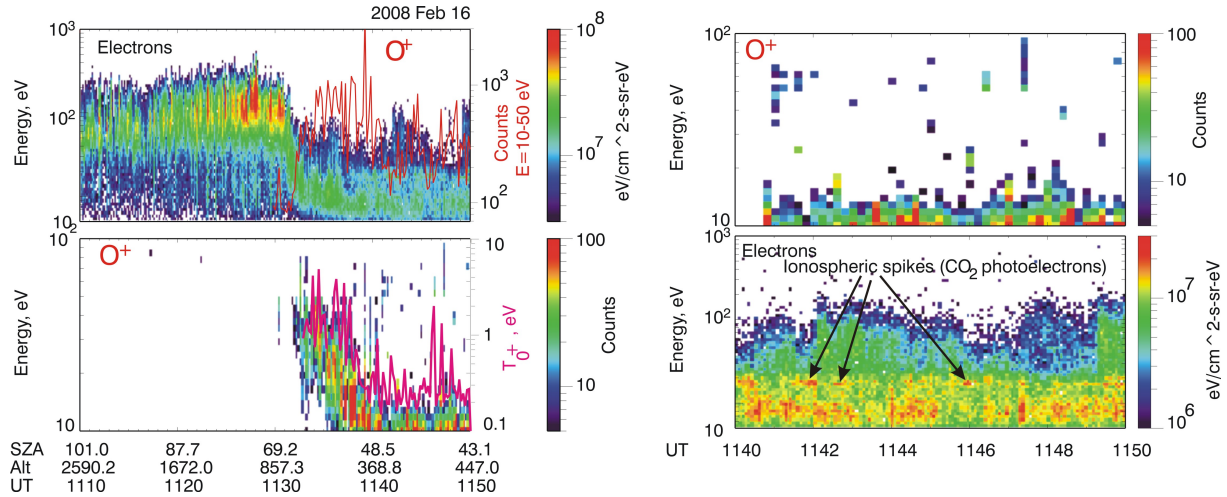

Figure 3: Strong oscillations in fluxes of the low-energy oxygen ions in the ionosphere follow large-amplitude compressional pulses in the magnetosheath. The curves of oxygen fluxes and their temperature are imposed on the spectrograms of electrons and ions, respectively.

and enhanced escape of oxygen ions to space [5] which may have a significant impact on Mars' atmospheric loss. Since the magnetic field strength inside the induced magnetosphere is about of factor of 10-20 higher than that in the solar wind, the characteristic frequency of large-amplitude structures, which is often close to the proton gyrofrequency $\Omega_{p,sw}$ in solar wind can become close to the oxygen cyclotron frequency Ω_{O^+} in the upper ionosphere causing a strong damping. Figure 3 shows a presence of strong oscillations in the ionospheric plasma at $\sim$ 400 km. Their frequency is close to the characteristic frequency of waves in the sheath. The wavy structures in the low-energy component of oxygen ions are observed not only in the region adjacent to the sheath where planetary plasma gain the momentum from solar wind but also at lower altitudes close to the spacecraft pericenter ($\sim$ 270 km). The ionospheric irregularities are also displayed as spikes of the energy peaks seen in the electron spectrogram. These peaks arising at $E_e \sim 23 - 27$ eV due to CO_2 photoelectrons and shifting to lower energies because of the negative spacecraft potential can be used for tracing of the ionospheric plasma. Heating of the low-energy oxygen component is clearly observed

There is also another efficient mechanism for generation of strongly nonlinear low-frequency structures in a multi-ion plasma [6]. Ion populations moving with different velocities with respect to the net center of charge experience different electric fields. In effect, the different ion fluids intermittently gain or lose energy while exchanging their momentum. As a result plasma in the boundary layer might be striated consisting of alternating bunches of solar wind protons and oxygen ions. Figure 4 shows an example of such a structuring of the Martian boundary layer. It is observed that a periodical acceleration/deceleration of the oxygen ions is accompanied by deceleration/acceleration of solar wind protons. The characteristic frequency of such type of structures is close to the cutoff plasma frequency.

In conclusion, large amplitude low-frequency compressional pulses impacting the Martian ionosphere can contribute to energization and heating of ionospheric ions (see also [7]).

3 Acknowledgments

E. D. and M. F. wish to acknowledge the DLR and DFG for supporting this work by grants FKZ 50 QM 0801, MO539/17-1, SPP 1488 W0910/3-1, respectively.

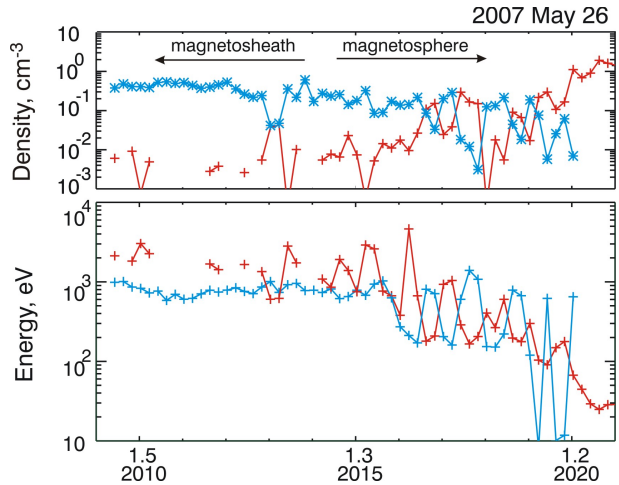

Figure 4: Fine structure of the boundary layer on Mars. Red and blue symbols correspond to O^+ and H^+, respectively. Alternating structures dominated either by solar wind protons or planetary ions characterize plasma dynamics in the transition region.

4 References

1. D. Brain et al.,"Observations of low-frequency electromagnetic plasma waves upstream from the Martian bow shock," *J. Geophys. Res.*, 107, A6 doi10.1029/2000JA000416, 2002.

2. C. Mazelle et al.,"Bow shock and upstream phenomena at Mars," *Space Sci. Rev.*, 111, 2004, pp. 115-181.

3. B. Tsurutani et al.,"Steepened magnetosonic waves at comet Giacobinin-Zinner," *J. Geophys. Res.*, 92, A10, doi:10.1029/JA092iAp11074, 1987.

4. J. D. Winningham et al.,"Electron oscillations in the induced martian magnetosphere," *Icarus*, 182, 2006, pp. 360-370.

5. R. E. Ergun et al.,"Role of plasma waves in Mars' atmospheric loss," *Geophys. Res. Lett.*, 33, L14103, doi: 10.1029/2006GL025785, 2006.

6. E. Dubinin et al.,"Ion energization and escape on Mars and Venus," *Space Sci. Rev.*, submitted 2011.

7. R. Lundin et al.,"Low altitude acceleration of ionospheric ions at Mars," *Geophys. Res. Lett.*, submitted, 2011.