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Ions accelerated by sounder-plasma interaction as observed by Mars Express

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Abstract

Ion sensor of the Analyzer of Space Plasmas and Energetic Atoms (ASPERA-3) experiment detects accelerated ions during pulses of radio emissions from the powerful topside sounder the Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS) experiment onboard Mars Express. Accelerated ions (O_2^+, O^+ and lighter ions) are observed in a range up to $800eV$ when MARSIS transmits at a frequency close to the plasma frequency. The observed ion beams are often accompanied by a small decrease in electron flux observed by the Electron Spectrometer (ELS) of ASPERA-3. Observations indicate that the voltage applied to the antenna causes charging of the spacecraft to several hundreds of volts by the electrons of the ambient plasma. Positively charged ions are accelerated when the spacecraft discharges.

1. Introduction

Operation of active wave devices, such as high-frequency transmitters, in plasma lead to a strong modification of a surrounding environment. An intense radio pulse might results in high potentials in spatial plasma that far exceed the potential equivalent of thermal or flow energies of all the ambient plasma particle species. Prominent example of the related phenomena is charged-particle acceleration by RF fields in the vicinity of an active antenna [1].

The local acceleration of near-satellite plasma ions during the pulses of radio emission of the powerful (up to 400W) topside sounder MARSIS transmitter was detected on board the Mars Express (MEX) spacecraft by the Ion Mass Analyzer (IMA) of ASPERA-3 experiment. The investigation of sounder-accelerated particles observed on MEX can provide a much improved picture of the plasma behaviour in the near field of an active antenna as well as inspire a new plasma diagnostic technique. The ability to detect accelerated ions will allow Mars Express to conduct future active experiments at Mars.

2. Observations

The top panel (a) in Figure 1 shows the IMA O^+ differential number fluxes during 30 minutes around pericenter on orbit 12495 (pericenter reached at 2013- 10-31 05:46:31 UTC). The MEX altitude is superimposed on the same panel and is shown with red line.

Intense periodic disturbances in the ion data are seen when MEX altitude is below 1000 km. In each of the individual events accelerated O^+ ions are observed in 2-4 consecutive energy channels of IMA, that indicates almost monoenergetic ion beams. The beams are observed with energies starting from several 10s eV (typically 40 eV) but never exceed 800 eV. Corresponding differential fluxes are found to be in the range $10^4 - 10^5 particles/eV/s/str/cm^2$.

Detailed timing analysis showed that the appearance of accelerated ions coincides with periods when the MARSIS sounder is transmitting. This can be seen at panel (b) of Figure 1. White boxes shown with dashed lines correspond to the 1.257 s intervals of MARSIS active sounding phase. Intense fluxes of accelerated ions are only detected during these periods. Horizontal solid white lines within white boxes in panel (b) indicate time intervals within the 1.257 s long periods of the MARSIS active sounding phase, when MARSIS transmits in the frequency range from f_{pe} to $2f_{pe}$, where f_{pe} is local plasma frequency (corresponding electron density is shown with a red line in panel (b)). The peak flux of accelerated ions in each of the individual events occurs during these intervals. Analysis of the data collected by ELS indicates the presence of a negative potential around the spacecraft. Panel (c) in Figure 1 shows the electron differential flux measured during the period when the most intense fluxes of accelerated ions were detected. The total flux of electrons with energies up to 110 eV is shown with a

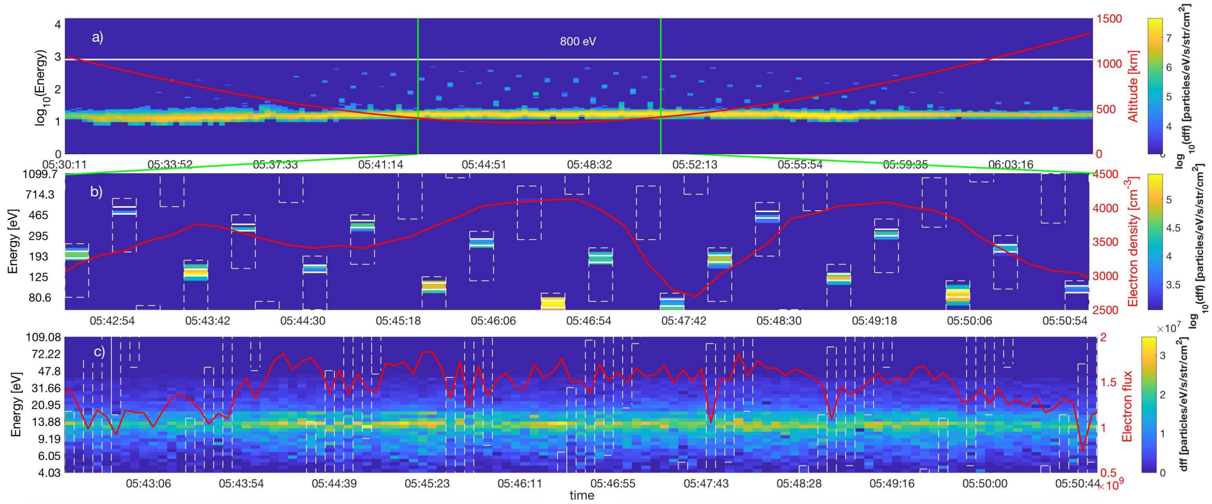

Figure 1: Data obtained by the ASPERA-3 ELS and IMA sensors on 2013-10-31 from 05:30 to 06:04 UTC. From top to bottom: (a) O^+ differential number flux (dff [$particles/eV/s/cm^2/str$]), MEX altitude is superimposed and shown with red colour; (b) zoomed-in time interval of O^+ from $05:42:26$ to $05:50:56$, the $1.257s$ intervals from the MARSIS active sounding phase are shown with white boxes and white lines within the boxes indicate time intervals when MARSIS was operating in the range of frequencies from f_{pe} to $2f_{pe}$, background plasma density measured by MARSIS is shown with red; (c) zoomed-in time interval for electrons overlaid with the total flux of electrons, for energies up to $110eV$ shown with a red line. White boxes show the $1.257s$ intervals of MARSIS active sounding phase.

red line. As before, the white boxes denote time intervals when MARSIS is turned on. One notices that the electron flux measured during these periods is considerably lower in comparison to measurements that were made when MARSIS was idle. The decrease in electron flux is believed to be caused by the negative potential that lasts several ms after the end of a pulse and prevents electrons from entering the ELS sensor.

3. Summary and Conclusions

Data collected by IMA onboard MEX enabled first ever study of the effect of charged particles acceleration in the vicinity of a powerful RF transmitter under plasma conditions other than that of the Earth's ionosphere. Preliminary study showed that the intense fluxes of accelerated ions (up to $10^6 particles/eV/s/str/cm^2$) are frequently observed during periods when MARSIS operates in the range of frequencies from f_{pe} to $2f_{pe}$. Accelerated ions have typical energy ranges up to $550 - 800eV$. Observation of the accelerated ions is often accompanied by a decrease in electron flux detected by ELS. A model for the RF-induced spacecraft potential [2] suggests that ions at the highest energies are collected when MARSIS is transmitting, while lower energy ions are collected during the few millisecond discharge period following the transmission.

The creation of substantial charged particle fluxes by RF transmitters has important implications for active experiments in space physics. Active diagnostic of the plasma composition can serve as one of the examples of such experiments. A combination of the time decreasing electric potential and time-of-flight effect results in acceleration of the lighter particles to higher energy, enabling identification of the ions species that are almost indistinguishable under normal conditions. This could be used to improve upon our knowledge of the ion composition of Martian ionosphere.

References

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