Dual-Spacecraft Observation of Density Features in the Near-Terminator Martian Ionosphere: Mars Express Ionospheric Sounding and MAVEN

D. D. Morgan[1], D. A. Gurnett[1], J. S. Halekas[1], R. A. Frahm[2], P. R. Mahaffy[2], J. E. C. Connerney[2]

[1]*Department of Physics and Astronomy, University of Iowa, Iowa City, Iowa, U. S.*
[2]*Southwest Research Institute, San Antonio, Texas, US*
[3]*NASA Goddard Spaceflight Center, Greenbelt, Maryland, U. S.*
(Contact: david-morgan@uiowa.edu)

Abstract

The Mars Advanced Radar for Subsurface and Ionosphere Sounding (MARSIS), on the Mars Express spacecraft, incorporates the Active Ionospheric Sounding (AIS) mode, which is used to sound the topside of the Martian ionosphere. This instrument has been used over the last ten years to identify and study a wide variety of ionospheric features. The advent of the Mars Atmosphere and Volatile Evolution (MAVEN) spacecraft, inserted into Mars orbit in September 2014, allows us to look at the ionosphere with two spacecraft. In this study, we find density depletiion features, identifiable within an hour and a few ten of degrees in solar zenith angle in the MARSIS AIS and MAVEN Neutral Gas and Ion Mass Spectrometer (NGIMS) data. These depletion features occur during a time of mild disturbance of the ionosphere, marked by intrusion of ionospheric plasma into the ionosphere, truncated local density measurements, and loss of the MARSIS AIS surface reflection. Changes in the solar wind and proximity to a strong crustal field anomaly both appear to be related to the existence of these dropouts.

I. Introduction

For several years prior to the arrival of the Mars Atmosphere Volatiles Evolution (MAVEN) spacecraft into Mars orbit on 21 September 2014, Mars Express (MEX) was the only spacecraft at Mars that had significant resources dedicated to the Martian atmosphere and ionosphere. As an example, no method existed of monitoring the solar wind in situ near Mars while MEX probed the ionosphere. With the arrival of MAVEN at Mars, a wealth of instrumentation targeting the atmosphere and ionosphere is now available to Mars scientists. In this presentation, we shall make a first attempt to utilize the Mars Advanced Radar for Subsurface and Ionosphere Sounding, Active Ionospheric Sounding mode, to probe the ionosphere with the MAVEN spacecraft operating somewhat nearby.

II. MARSIS AIS Data

The Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) on board the Mars Express (MEX) spacecraft incorporates two modes of operation: subsurface and ionospheric. In this presentation we shall make use of data from the ionospheric mode.

The method of sounding consists of the following steps: a sounding pulse at a given frequency is emitted (duration $91.4\ \mu$s*, bandwidth* 10.9 kHz*). After a brief dead time, the preamp is switched to "receive" mode and signal is detected for 80* $91.4\ \mu$s *time intervals. The result of this process is shown in top and bottom panels of Figure 1, for night- and dayside sample ionograms. The periapsis of the Mars Express orbit is* ≈ 325 km*. Because of the sequential-in-frequency sounding and because the main peak of the Martian ionosphere is* ≈ 130 km *at the subsolar point, and higher elsewhere on the dayside, MARSIS AIS is classified as a swept-frequency topside sounder.*

For a given orbit, ionograms can be stacked horizontally in time to give an impression of the data over an orbits pass, typically 45 minutes in duration. Examples of this are given in Figure 2. On the left is Orbit 13903: the strength of the surface reflection indicates that during this period, the ionosphere is relatively undisturbed. On the right, Orbit 13934. Disappearance of the surface reflection shows that there is a relatively high density of electrons during this orbit, indicating disturbance in the ionosphere. The relation of the strength of the surface reflection to electron density is discussed in [4] and more quantitatively in [5]. For discussion of the various MARSIS AIS data objects and processing thereof, see [1].

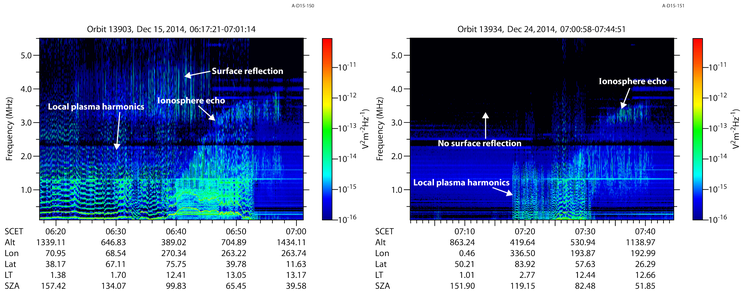

Figure 2: Sample spectrograms.

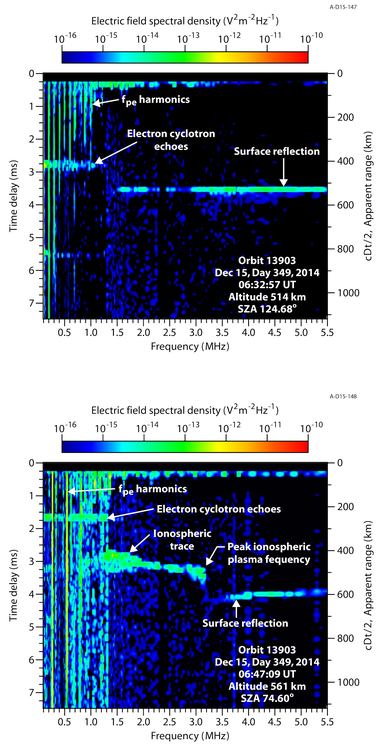

Figure 1: Sample ionogram from night- and dayside segments of MEX orbit 13903.

Contracted Ionosphere Coincident with Weak Event in Solar Wind?

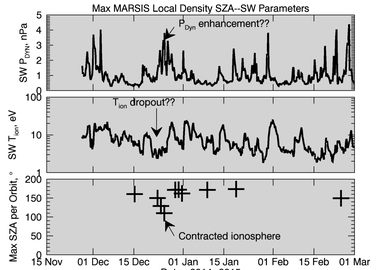

Figure 3: Bottom panel: MARSIS AIS maximum extent of ionosphere by SZA with time. Contracted ionospheres occur for orbits 13930, 13934, and 13938. Middle panel: SWIA solar wind temperature series, averaged by MAVEN orbit. A weak dropout is barely visible simultaneous with the ionospheric contraction. Top panel: SWIA orbit averaged dynamic pressure. A weak enhancement is barely visible simultaneous with the ionospheric contraction.

Using ten examples we have made a plot of the maximum solar zenith angle of the ionopause visible by MARSIS AIS local plasma harmonics, shown in the bottom panel of Figure 3. The center and top panels of this figure show the ion density and the dynamic pressure, averaged by orbit for time outside the bow shock and in the solar wind, from the Solar Wind Ion Analyzer (SWIA) [2] on board the MAVEN spacecraft. A dropout in the former and an enhancement of the latter are barely visible. The high altitude ionosphere is seen to contract successively for three orbits in late December 2014, orbits 13930, 13934, and 13938. The MARSIS AIS spectrograms for these three orbits are devoid of surface reflection and have truncated local plasma frequency,as shown for orbit 13934 in Figure 2(right).

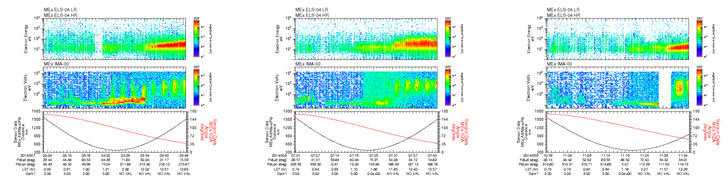

Figure 4: ASPERA-3 ELS (top panels) and IMA (middle panels) data for orbits 13930, 13934, and 13938, corresponding to the disturbance shown above. The bottom panel show spacecraft altitude and solar zenith angle.

Figure 4 shows the electron and ion spectrograms for the three orbits where both the solar wind and ionosphere were seen to be disturbed. Intrusion of solar wind ions is evident in the spectrograms for orbits 13930 and 13934. The spectrogram for orbit 13938 shows the ionospheric ions depleted but the no visible intrusion of solar wind plasma.

III. Dual-Spacecraft Observation of Density Features

Figure 5 shows MARSIS AIS local densities in conjunction with data from the Neutral Gas and Ion Mass Spectrometer on board the MAVEN spacecraft, described by [3]. Several density dropout features in NGIMS and MARSIS AIS appear to be organized by SZA and occur in or around a region of enhanced strong crustal magnetic field.

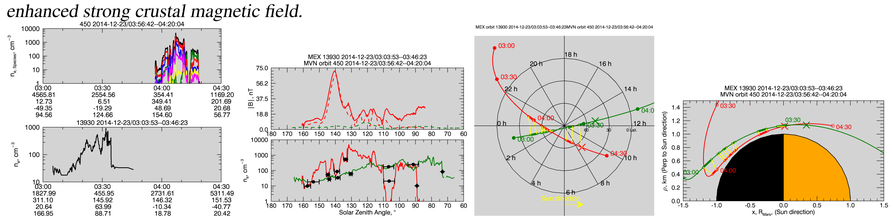

Figure 5: Four parts showing MARSIS AIS local density features corresponding to MAVEN NGIMS features. Leftmost: MARSIS AIS local density (bottom) and NGIMS electron density with five ion species (top) as a function of time. second from left: Second from left: bottom panel, MARSIS AIS local electron density (green) and the NGIMS total electron density (red) plotted as a function of SZA. The black bars indicate density depletion features that appear to be organized by SZA. Third from left: MAVEN (red) and MEX (green) orbits on a Local Time–Latitude map, with possible density depletion features. Rightmost: orbits and features mapped in MSO-x and MSO-ρ.

Tentative conclusion: *Since the three orbits encompassing the density dropout are without visible surface reflection, it is likely that the ionosphere is disturbed at this time. The weak disturbances in the solar wind parameters are probably associated with both the disturbance and the density depletions associated with strong crustal field. The depletions appear to last approximately an hour and to be ten of kilometers deep and hundreds of kilometers across. Examination of a larger data set should give a more conclusive result.*

Acknowledgement *This work was supported at Iowa under JPL subcontract 1224107 with the Jet Propulsion Laboratory and at Southwest Research Institute under NASA contract NASW-00003.*

References

[1] Gurnett, D. A., et al. 2005, Science, 310, 1929 .
[2] Halekas, J. S., et al. 2015, Space Sci. Rev., 195, 125.
[3] Mahaffy, P. R., et al. 2015, Space Sci. Rev., 195, 49.
[4] Morgan, D. D., et al. 2006, Geophys. Res. Lett., 33, L13202.
[5] Withers, P. 2011, Radio Sci., 46.