Simultaneous Photoelecron and Ion Measurements in the Martian Ionosphere

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Abstract:

The Analyzer of Space Plasmas and Energetic Atoms (ASPERA-3) experiment on board the Mars Express spacecraft conducts measurements of electrons by the Electron Spectrometer (ELS), ions by the Ion Mass Analyzer (IMA), and neutral particles by the Neutral Particle Imager (NPI) and the Neutral Particle Detector (NPD). While orbiting Mars, the ELS is able to observe peaks in the photoelectron spectrum due to photoionization of carbon dioxide and atomic oxygen by Solar Helium 30.4 nm photons. The source of these peaks in the photoelectron spectrum is the dayside Martian ionosphere, with the majority of photoelectrons created at the exobase where the density is greatest. A fraction of these photoelectrons is transported to altitudes of the spacecraft. ELS observes photoelectron peaks in the Martian ionosphere on nearly every ionospheric transit. During the times when the Mars Express spacecraft traveled through the ionosphere and ELS observed photoelectron peaks, few ions of any significance were measured. Due to charge neutrality arguments, when the photoelectrons are observed, there must be ions present to balance the electronic charge. The missing observations of significant ions at the times that photoelectrons are measured lent support for adjustments to internal voltage settings within the IMA. These adjustments were carried out by ESA in the spring of 2007 and were intended to increase the sensitivity of IMA in the low-energy ion range. After these adjustments were made, low-energy ions are observed in the ionosphere whenever ELS observes photoelectron peaks.

1.0 Introduction:

Since December 25, 2003, the Mars Express spacecraft has been orbiting Mars. During this period, measurements of the particle environment at Mars have been made by the Analyzer of Space Plasmas and Energetic Atoms (ASPERA-3) Experiment [Barabash et al., 2004], consisting of the Electron Spectrometer (ELS) to measure electrons, the Ion Mass Analyzer (IMA) to measure ions, and two neutral particle imagers, the Neutral Particle Detector (NPD) and Neutral Particle Imager (NPI). The ELS has observed photoelectron peaks in the energy spectrum which are mainly due to interaction between a Solar 30.4 nm photon and carbon dioxide near the Martian exobase [Mantas and Hanson, 1979; Fox and Dalgarno, 1979]. Some portion of electrons in the area of the peaks are generated locally. These are more likely generated by photoelectrons from atomic oxygen (both transported and locally generated). These photoelectron peaks are theoretically located between 21 eV and 24 eV, and at 27 eV.

After the carbon dioxide or atomic oxygen are ionized the charged components are subject to motion dictated by the local magnetic field and are transported accordingly [Mantas and Hanson, 1979]. The ASPERA-3 ELS has commonly observed photoelectron peaks in the Martian ionosphere while orbiting the planet [Frahm et al, 2004]. During the nominal mission of Mars Express, the IMA sensitivity was tuned to measure escaping higher energy ions, and the capability to observe low energy ions was limited. Late in the spring of 2007 the IMA was reprogrammed to increase its sensitivity to lower energy ions.

2.0 Past Observations

An example of an observational pass through the Martian Ionosphere is shown in Figure 1 from 31 March 2007. This plot shows two panels, both of which are energy-time spectrograms in differential energy flux (or energy intensity) as the color-coded value (particle energy is shown on the vertical axis and time shown on the horizontal axis). Overlaid on the spectrogram in the lower panel is the altitude of the Mars Express spacecraft, drawn against the scale on the right axis. The solar zenith angle of the spacecraft is marked at the bottom of the lower spectrogram. In the upper spectrogram, ions from sector 0 of IMA are drawn. The elevation analyzer of IMA is sweeping, creating measurement cycles of about 3 minutes. In the lower spectrogram, electrons from sector 4 are drawn using a saturated color scale to emphasize ionospheric features. ELS sector 4 views the same direction as IMA sector 0.

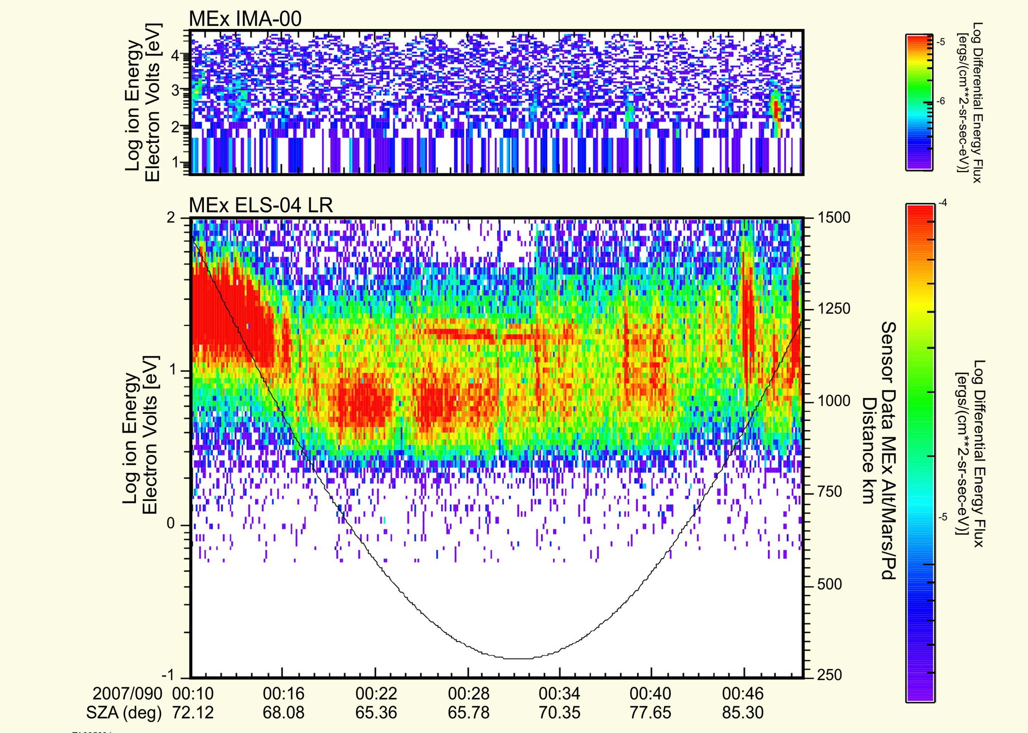

Figure 1. ASPERA-3 Electron and Ion Spectrograms. Shown is data from 31 March 2007 in the ionosphere of Mars. Sensitivity to low-energy ions reflects that during the nominal mission.

The data shows that the magnetosheath occurs at the beginning of the spectrograms. At about 0002 UT, the transition begins from the magnetosheath to the ionosphere. This plasma boundary is called the Inner Magnetospheric Boundary (IMB) [Lundin et al., 2004]. Ionospheric plasma is observed beginning about 0017 UT. At the lowest altitudes, photoelectron peaks are observed at around 20 eV between 0025 UT and 0035 UT as horizontal intense lines in the ionospheric electrons. Beginning at 0042 UT, the spacecraft transitions out of the Martian ionosphere and away from the planet.

The observed photoelectron peaks in the electron energy spectrum are generated when solar 30.4 nm photons photoionize carbon dioxide and/or atomic oxygen in the dayside Martion atmosphere and ionosphere. The liberated electrons are strongly observed by ELS. Since the carbon dioxide and atomic oxygen are ionized, one would expect to observe the ion e.g. CO_2^+ and O^+ product in the low-energy region of the IMA detector, co-located in the region where the photoelectron peaks are observed. Since in the ionosphere, photoelectron peaks are quite isotropic, it is expected that the parent ions should be observed at all IMA elevation angles, or at least, at the IMA elevation where ELS performs its measurement. However, these ions are not observed because the measurement range on the IMA is not tuned to measure ions of low enough energy.

3.0 Present Measurement

Most recently, the IMA been has reconfigured to increase its sensitivity to lower energy ions. This has allowed IMA to measure ions in the ionosphere coincident with observed photoelectron peaks. As example is shown in Figure 2 from 10 July 2007. The format of Figure 2 is the same as Figure 1. With this pass, the spacecraft transitions from the nightside of the planet toward the dayside of the planet. At about 2218 UT, the satellite begins to detect dayside plasma. Photoelectron peaks in the ionosphere show almost immediately, but they are strongest between 2221 UT and 2232 UT. During this time, low energy ions are observed in the ionosphere below the energy of 20 eV (in this particular pass, the ion elevation sweep has been halted so that IMA measures in the same plane as ELS). The spacecraft begins to leave the ionosphere beginning at 2235 UT and has transitioned to measuring the magnetosheath by 2238 UT.

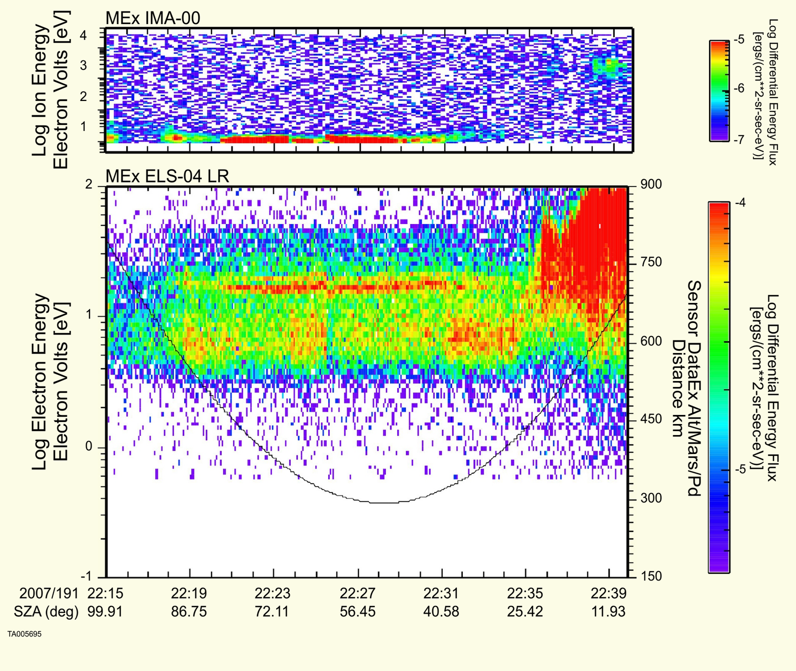

Figure 2. ASPERA-3 Electron and Increased Sensitivity Ion Spectrograms. Shown is data from 10 July 2007 in the Martian ionosphere. Sensitivity to low-energy ions has been increased so that they can be and are observed.

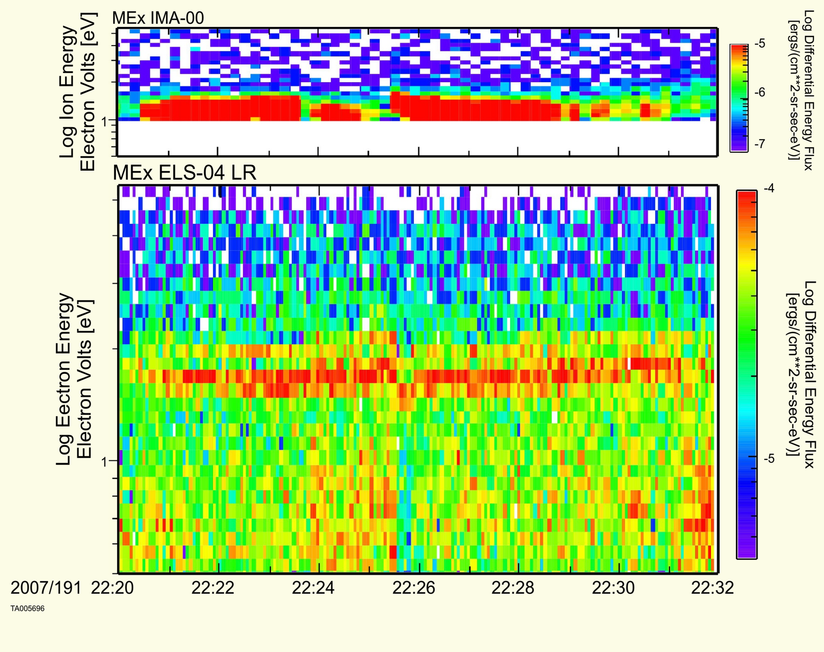

Figure 3. Pixel Resolution of ASPERA-3 Electron and Increased Sensitivity Ion Spectrograms. Shown is data from 10 July 2007 in the Martian ionosphere on an increased time-resolution scale such that each individual measurement can be viewed.

The region of the ionosphere where the photoelectron peaks are observed are shown as a blow-up in Figure 3 to highlight the individual measurements made by the instruments. On this scale, the variability of the intensity and energy of the photoelectron peaks is revealed. Here, the intensity variations are due to (1) fluctuations in the intensity levels of the produced atmospheric electrons (possibly controlled by the local magnetic field), (2) the location difference between the exact instrument response compared to the residual line transition energy, and (3) measurement statistics. Variations in energy are produced from spacecraft charging, which ranges from about -6V to -10V (determined as the difference between the theoretical and measured energy of the photoelectron peaks). A negative spacecraft potential means that electrons will be decelerated and ions will be accelerated when plasma is detected at the spacecraft.

The general charging trend is observed in data from IMA as well; however because of the difference in accumulation time, the time resolution on IMA (11.5 sec spectrum) is not the same as ELS (4 sec spectrum). The spacecraft charging trend is about -7V prior to 2224:50 UT, which establishes the minimum energy observed by accelerating ionospheric ions into IMA. The drop in the ion range between 2224:50 UT and 2225:20 UT is seen as a shift downward in ion energy due to a change in the spacecraft charging to -6V giving less acceleration to the ions. Between 2225:20 UT and 2226 UT, spacecraft charging increases to about -10V and then decreases back to -7V, and the ions reflect this change by showing a slight decrease in their observed energy range. The drop in ion flux just before 2224 UT is most likely due to a change in flux rather than a change in spacecraft charging because there is no significant change in the observed electron data.

3.1 Electron Angular Distribution

The electron angular distribution is shown in Figure 4 as spectrograms covering the blown up ionospheric region as in Figure 3 for each ELS sector (16 total). Data from ELS sector 0 (top) through sector 7 (bottom) are shown at the left and data from ELS sector 8 (top) through sector 15 (bottom) are shown at the right. The electron angular distribution does not appear to be isotropic. The fluxes in ELS sector 0 (top left) and sectors 12-15 (lower right) are contaminated due to spacecraft interference and show less flux than expected.

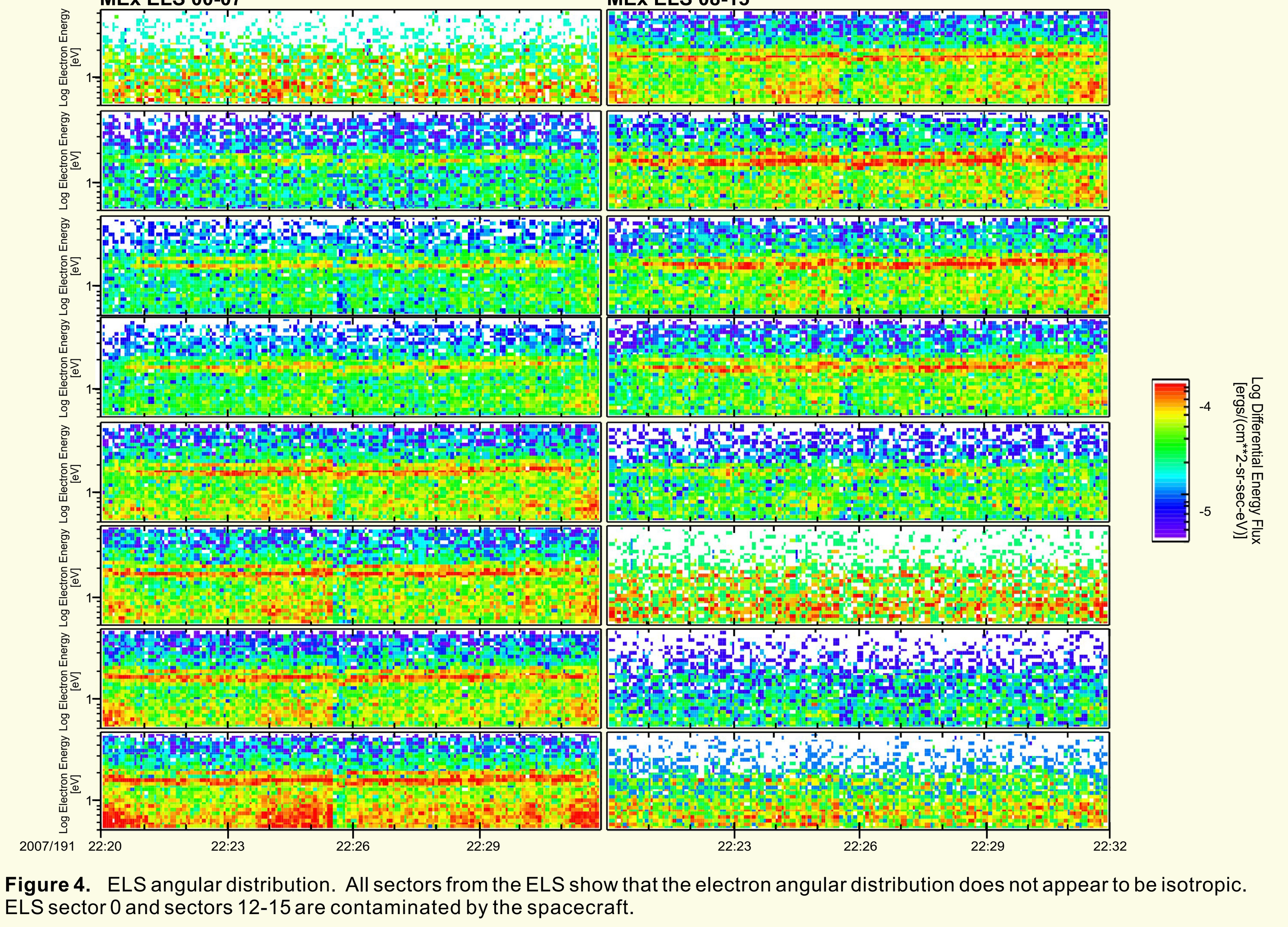

Figure 4. ELS angular distribution. All sectors from the ELS show that the electron angular distribution does not appear to be isotropic. ELS sector 0 and sectors 12-15 are contaminated by the spacecraft.

3.2 Electron Energy Spectra

The electron differential energy flux spectra are shown in Figure 5 for the time region shown in Figure 2. Spectra are from ELS sector 4 cover the energy range between 5 eV and 55 eV. Each spectrum is an average of 35 samples covering about 2.5 minutes. Photoelectron peaks, characteristic of the Martian ionosphere appear at about 15 and 20 eV. These peaks show both consistency throughout the region and that they are a dominant feature in the electron spectrum.

Variations in the flux amplitudes can be due to slight differences in spacecraft charging levels combined with the instrument response function. The differences between the energy of the theoretical peak locations (of 21-24 eV and 27 eV) and their measured locations can also be due to the spacecraft charge. The photoelectron peak at 27 eV is difficult to detect at times because the spacecraft charge shifts the measured energy away from the energy of the instrument response peak for the channel of measurement.

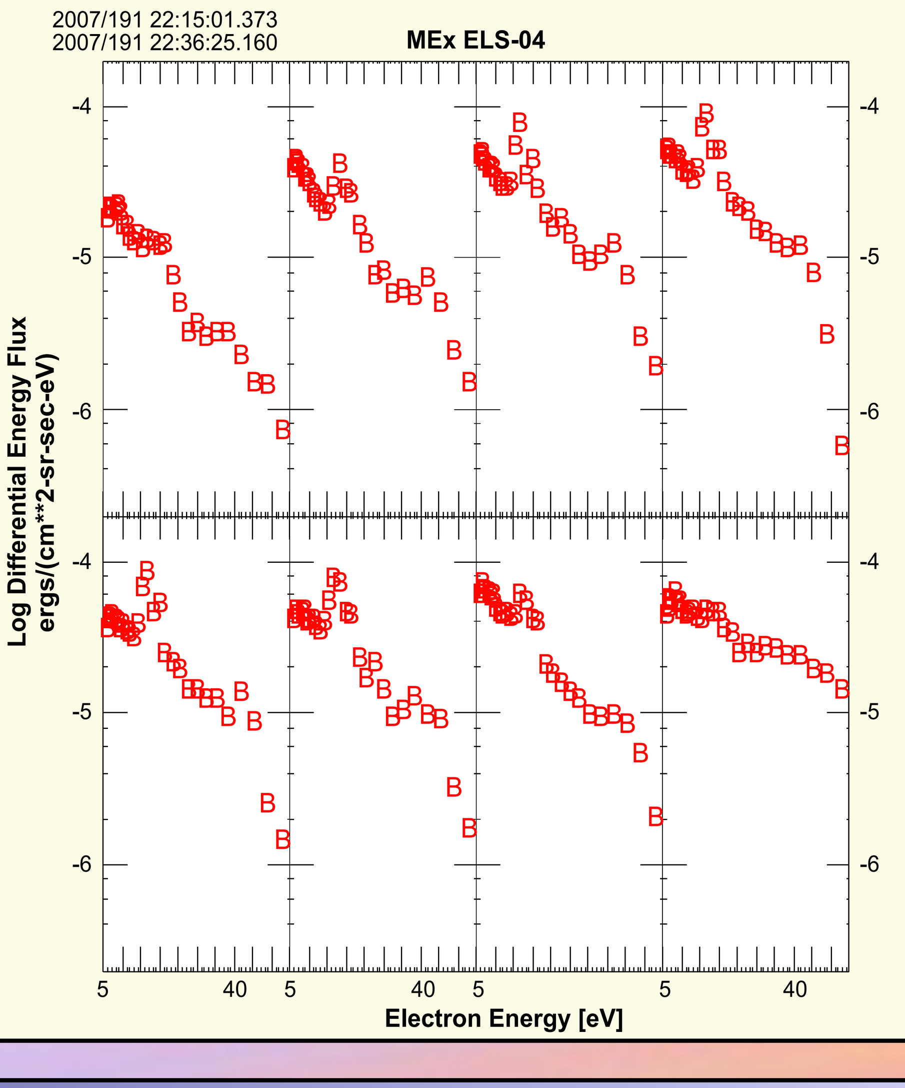

Figure 5. Electron Ionospheric Spectra. The ionosphere of Mars shows photoelectron peaks are both a consistent and dominate feature.

3.3 Ion Angular Distribution

The ion angular distribution is shown in Figure 6 as spectra below 100 eV from 2221:51 UT through 2223:51 UT for each IMA sector (16 total). This figure is typical of the ion spectra within the Martian ionosphere during the time of the data shown in Figure 3. The ion angular distribution is not isotropic, but exhibits an ion flow which is strongest along sector 0. This direction is detecting flow towards dawn with respect to the planet, so the ion plasma is flowing away from the subsolar point.

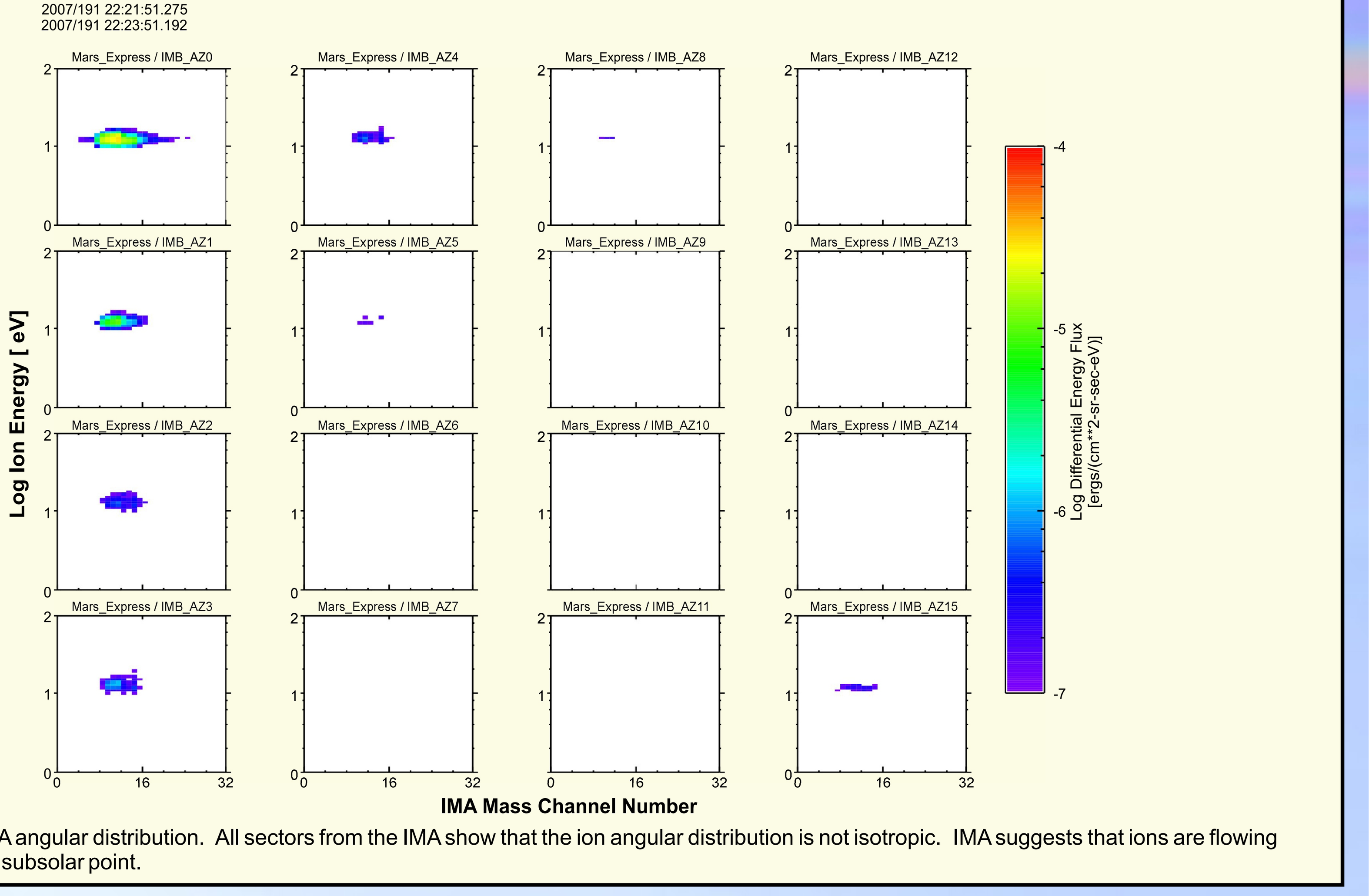

Figure 6. IMA angular distribution. All sectors from the IMA show that the ion angular distribution is not isotropic. IMA suggests that ions are flowing away from the subsolar point.

3.4 Ion Spectra

The IMA mass spectrum for sector 0 is presented in differential energy flux below 100 eV in Figure 7. The spectral data is drawn versus Mass Channel Number. The positions of C^+, O^+, CO^+, O_2^+, and CO_2^+ are estimated for the particular IMA settings of these data and marked on Figure 7. These estimated curves show that the ions measured are products of CO_2^+ (e.g., O_2^+, CO^+, O^+, and C^+). The energy spectrum shows that there is an increase in the energy flux at the location where the CO_2^+ and its dissociative products (C^+, O^+,CO^+, and O_2^+) are expected to appear. The increase in ion fluxes at these masses suggests that the ions creating the photoelectron peaks are measured here.

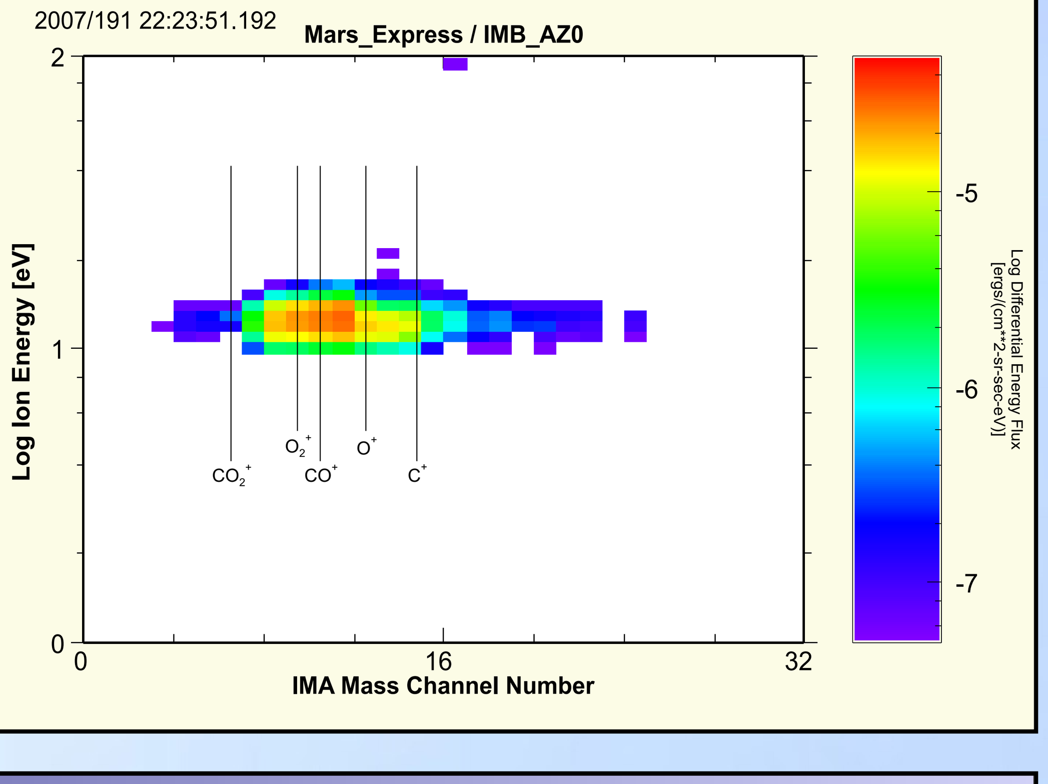

Figure 7. Ion Spectra. For the particular settings on IMA, estimated positions of C^+, O^+, CO^+, O_2^+, and CO_2^+ are shown.

4.0 Summary

Electron spectra exhibiting photoelectron peaks due to ionization of carbon dioxide and atomic oxygen by the Solar 30.4 nm line are observed frequently in the Martian ionosphere by the ASPERA-3 ELS on the Mars Express spacecraft. For its nominal mission, the ASPERA-3 IMA was not tuned to be sensitive to low-energy ions involved in the photoionization process. Recently, the IMA sensitivity to low-energy ions was increased, and now, ions involved in the photoionization process are frequently observed.

For the 10 July 2007 pass presented in this poster:

- photoelectron peaks are observed in the ionosphere,
- photoelectron peaks are modulated in energy by spacecraft charging,
- this photoelectron flux is not isotropic,
- ion components are observed as dissociated components of CO_2^+,
- ion flux is not isotropic,
- ion energy is modulated by spacecraft charging, consistent with the electron behavior.

ASPERA-3 has observed low-energy ions flowing in the Martian ionosphere. These ions are comprised of carbon dioxide and its dissociated products, including atomic oxygen. For the investigated case of the transit of the Mars Express spacecraft through the ionosphere on 10 July 2007, fluctuations in the spacecraft charging level suggest that both the photoelectron and ion energies as well as the ion flux is related to the charge on the spacecraft.Thus, ASPERA-3 can detect both the photoelectron peaks and the dissociated ion components which are generated in the same photoionization process.

5.0 References

Barabash, S., et al., "ASPERA-3: Analyser of Space Plasmas and Energetic Ions for the Mars Express," in Mars Express: The Scientific Payload, eds. A. Wilson and A. Chicarro, European Space Agency special report SP-1240, European Space Agency Research and Scientific Support, European Space Research and Technology Centre, Noordwijk, The Netherlands, 121-139, August 2004.

Fox, J. L., and A. Dalgarno, "Ionization, Luminosity, and Heating of the Upper Atmosphere of Mars," Journal of Geophysical Research, 84, 7315-7333, 1979.

Frahm, R. A., et al., "Carbon dioxide photoelectron energy peaks at Mars," Icarus, 182, 371-382, 2006a.

Lundin, R., et al., Solar Wind-Induced Atmospheric Erosion at Mars: First Results from ASPERA-3 on Mars Express," Science, 305, 1933-1936, 2004.

Mantas, G. P., and W. B. Hanson, "Photoelectron Fluxes in the Martian Ionosphere," Journal of Geophysical Research, 84, 369-385, 1979.