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LOW ENERGY (E<400 eV) IONS IN THE MAGNETOSPHERE OF MARS AS MEASURED BY THE HARP INSTRUMENT ON PHOBOS 2

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ABSTRACT

Low energy (<400 eV) ion fluxes measured by the hyperbolic retarding potential analyser (HARP), during the first two elliptic orbits of the Phobos 2 spacecraft, are presented. Combining these results with the overlapping higher energy observations of the TAUS instrument, carried on the same spacecraft, we show the presence of flowing and shocked/thermalized solar wind ions inside the magnetosheath and antisunward flowing heavy ion population below the upper boundary of the magnetic barrier. Our results are not consistent with the presence of a dense, stagnated planetary ion population there, in the region explored by Phobos-2. Our results do not indicate the existence of additional sharp plasma boundaries, such as the proposed ion composition (mass loading) boundary. The observed characteristics of the outer regions of the Venus mantle and the combined HARP and TAUS measurements close to and inside of the magnetic barrier at Mars do not indicate the presence of significant differences.

INTRODUCTION

The interaction of the solar wind with the plasma environment of Mars shows many similarities to that of Venus, even though some observations and models indicate the presence of a small intrinsic magnetic dipole field (Axford, 1991; Verigin et al., 1993). At Venus the magnetic barrier forms the obstacle to the solar wind flow, and the shocked solar wind comes into direct contact with planetary ions. It is generally believed that at Mars the situation is similar. However, the interaction of the solar wind with the Martian plasma shows many differences from that at Venus, as it was demonstrated by past space missions to Mars (Verigin et al., 1993, 1996, Kotova et al., 1996). It is very likely that the differences between the plasma environment of Mars and Venus are not the results of coincidence due to the rather limited data base from Mars, but are real differences. On the other hand it is not clear at this time whether it is the differences or the similarities between these planetary environments which are the more important and dominant factors. In order to learn more about these issues, we report, in this brief note, results from the ion measurements made by the differential Hyperbolic Retarding Potential Analyser (HARP), which was carried aboard the Phobos 2 spacecraft. Specifically we present results obtained during two of the elliptical orbits, on February 1 and 5, 1986. We also compare these results with observations of the other ion spectrometers, TAUS and ASPERA, carried by Phobos 2.

OBSERVATIONS

The HARP instrument measured ion spectra in a fan of eight coplanar view directions, symmetrically arranged with respect to the antisolar axis (Shutte et al., 1989). HARP measured also electrons, but those results are discussed elsewhere. The field of view of each angular sector was 10x20 degrees; the sensor head was mounted on the backside of the solar panels. The ion energy range, 0.2-500 eV, was covered in 42 steps, with the integration time of one step being one second. The TAUS instrument (Rosenbauer et al., 1989) measured protons and "heavy" ions ("heavy" denotes all ions besides protons) in the 30 eV to 6 keV range, covering a 40x40 degrees sunward looking field of view, centred on a direction perpendicular to the solar panels. Therefore, TAUS was looking basically sunward, while HARP was observing in the anti-sunward direction. The four upper energy channels of HARP cover the same energy range as the twelve lowest energy ones in the TAUS instrument. The ASPERA spectrometer (Lundin et al., 1991) measured electrons, protons, and "heavy" ions in an energy range of 0.5 eV - 50 keV with a field of view of 5x360 degrees. The 360 degree plane of view of ASPERA was parallel to that of the HARP. Thus the fields of view of these three ion spectrometers overlapped and were complementary to each other. During the first two elliptic orbits the spacecraft was slowly rotating (and slightly nutating) about an axis perpendicular to the solar panels (roughly the X-axis), with an angular velocity of about 1 rotation per 10 min, the angle of nutation time to time was close to 15 degrees. Due to the nutation of the spacecraft the field of view of the spectrometers changed considerably with respect to the solar direction, causing modulations in the observations. The first two orbits were highly elliptical with a periapsis 866 km and 860 km, respectively. For about eight minutes on both sides of the periapsis, the spacecraft remained at altitudes below 1100 km, thus providing an extended opportunity to observe the magnetosheath and the magnetic barrier regions. During the first orbit, on February 1, the spacecraft velocity at the bow shock crossing was about 4 km/s (v_x= -2 km/s), and at the periapsis of the orbit it was 4.3 km/s (v_x= -3.5 km/s).

Figure 1 shows the HARP ion data obtained on February 1, 1989, between 18.31 UT and 19.1 UT; the total magnetic field is also shown for comparison. Only ion fluxes with energies greater than 10 eV are shown; at these higher energies the effects associated with the uncertainty of the spacecraft potential (Pedersen et al., 1991) become small. The trends to be discussed are also present at the lower energies, with some gaps around 2 to 3 eV. During this February 1 orbit the bow shock was crossed at 18.4 UT, at a solar zenith angle of about 5 degrees. The solar zenith angle changed rapidly along the spacecraft trajectory with the terminator being reached at 18.83 UT.

As indicated in Figure 1, ions were detected right after the bow shock was crossed, and were observed until the spacecraft crossed into the magnetic barrier at 18.58 UT. TAUS detected the presence of shocked solar wind protons during this same time interval. On the other hand no significant heavy ion fluxes were seen by TAUS in this time interval. The ions seen by the HARP disappeared as the spacecraft entered the magnetic barrier. At about 18.6 and 18.7 UT, however, small ion fluxes were observed briefly by the HARP. These observations correlate well with the ASPERA cold ion measurements (Lundin et al., 1991). The more intense ion fluxes reappeared in the HARP field of view as the spacecraft moved above the magnetic barrier again, between 18.72 and 18.8 UT. The ions reappeared again later after 18.95 UT. TAUS did not detect "heavy" ions before 18.64 UT; the ions detected after 18.95 UT were seen only at energies above a few hundred eV's. The HARP data do not show significant variations in the four channels corresponding to the different elevation angles.

In Figure 2 the data obtained along the second elliptic orbit are shown. The parameters presented in this figure are the same as those shown in Figure 2. Here again the low energy ion flux appeared in the HARP data as the bow shock was crossed at around midnight. At around 0.2 UT the spacecraft entered the magnetic barrier and the ion flux decreased significantly and did not reappear before 0.4 UT, the limit of the available HARP data. Before 0.32 UT TAUS only detected shocked solar wind protons, but saw no significant ion fluxes. There was a data gap in the TAUS observations between 0.23 and 0.33 UT. After this period TAUS, in contrast of HARP, did observe the presence of ions.

During both of the orbits discussed here, the HARP observed large ion fluxes within the magnetosheath; these ion fluxes dropped significantly in the magnetic barrier region. It needs to be noted again that the HARP looked anti-sunward and measured all ions with approximately equal sensitivity (no ion mass dependence). TAUS looked sunward and measured separately protons and all other heavier ions. These observations are consistent with the expected presence of shocked and highly thermalized solar wind protons in the magnetosheath. The flux measured by the HARP may also include a component due to ions created freshly from the neutral corona. Our observations are consistent with the ASPERA results (Dubinin et al., 1993) measured in the same region.

Inside the magnetic barrier TAUS detected significant ion fluxes in the 100-200 eV range, whereas HARP did not see any significant fluxes. This leads us to conclude that these ions were streaming anti-sunward. The spacecraft itself was moving generally in the anti-sunward direction, therefore ions measured by TAUS must have had a

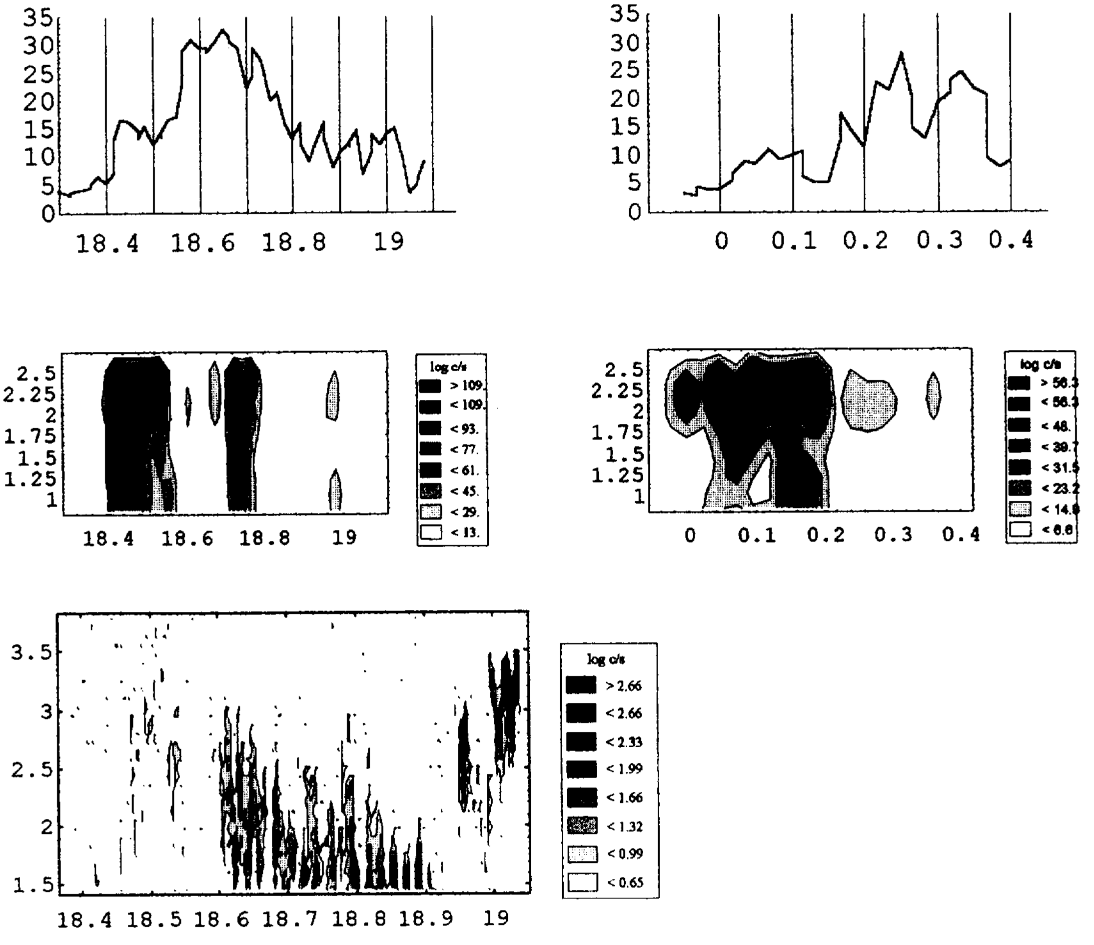

Fig. 1. On the right panels the total magnetic field, HARP and TAUS ion data are shown for the first elliptic orbit; left panels show the total magnetic field, and HARP ion data for the second elliptic orbit. All the horizontal axes show time in UT. <u>Top panels</u>: the total magnetic field in nT. <u>Middle panels</u>: the contour plot of the HARP ion data. The vertical axis shows energy in eV, in log scale. The contour plot displays the logarithm of ion counts per sec. <u>Lower panel:</u> the contour plot of the TAUS heavy ions data. The notation is the same as for the middle panel.

velocity greater than that of the spacecraft, and were energised to the observed values by an unspecified mechanism. This acceleration process cannot be an ExB one, because of the large gyroradius of the ions. It is important to note that HARP, looking anti-sunward, did not observe ion fluxes inside the magnetic barrier. This indicates the lack of a stationary or slow moving ion population in that region. Ions produced by charge exchange or photo/impact ionisation are expected to be relatively stagnant and thus should have been seen by the HARP and thus no significant ion population of planetary origin appears to be present in this region. The combination of these TAUS and HARP measurements indicate the presence of only one "ion boundary", which is located at/near the edge of the magnetic barrier. The existence of a second, sharp ion composition (or mass loading) boundary (Lundin et al., 1991, Dubinin et al., 1995) separating basically stagnating Martian ions from the shocked solar wind, is not seen in the HARP and TAUS data. The outer edge of the anti-sunward streaming heavy ion flow, seen by TAUS, might have appeared as a separate region for ASPERA. This population showed up as a gradually increasing flux in the TAUS instrument, having a large field of view, but may have appeared as a sharper increase in the ASPERA instrument which has a narrow field of view.

SUMMARY AND DISCUSSION

In this paper we presented ion data collected by HARP which was carried on board of the Phobos 2 spacecraft. The data presented came from the first two elliptic orbits, which crossed the dayside magnetosheath and entered the magnetic barrier of Mars. It has been well established that there is a mantle around Venus, which is defined as the region of transition between the shocked solar wind and ionospheric plasma population (Spenner et al., 1980). At Venus the indications are that the mantle is broader in spatial extent than the magnetic barrier and that the magnetic barrier is the effective obstacle to the solar wind flow (Shapiro et al., 1995). There were observations of energetic ions flowing tailward both outside and inside the barrier (Taylor et al., 1981; Grebowsky et al., 1993). The outer boundary of the mantle is a diffuse one, as the decrease in the shocked solar wind and the increase in the planetary ion populations is gradual.

In the magnetosheath of Mars, HARP measured low energy (< 400 eV) ions, whereas inside the magnetic barrier the flow was depleted. These observations, combined with those of TAUS, are consistent with the presence of flowing and shocked/thermalized solar wind ions inside the sheath and an antisunward flowing O^+ ion population inside the magnetic barrier. Our results are not consistent with the presence of a dense, stagnated planetary ion population inside the barrier, in the region explored by Phobos-2. We should repeat that while we did not show the low energy (<10 eV) ions measured by HARP, because of the difficulties associated with their interpretation (e.g. uncertain spacecraft potential) their spatial variations were the same as those of the higher energy ones. The observed characteristics of the outer regions of the Venus mantle and the combined HARP and TAUS measurements at the magnetic barrier region of Mars do not indicate the presence of significant differences.

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