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Evidence for Unusually High Densities of Plasma in the Venusian Ionosheath

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Abstract. An unusual occurrence was recorded by Pioneer Venus Orbiter (PVO) in the Venusian ionosheath on November 10-11, 1981 (orbit 1071): more than an order of magnitude higher densities of ions and electrons were observed than have ever been measured by PVO before then or since. This region of enhanced densities covered an extended region in the dayside ionosheath. The purpose of this paper is to briefly present our analysis of these unique observations.

Introduction

Early analyses (Brace et al., 1980; Taylor et al., 1980), of PVO observations at Venus indicated the dynamic behavior of the Venus ionosphere in response to solar wind activity. Dryer et al. (1982) tracked the solar wind plasma from a solar flare to Venus and showed that it caused a compression of the Venus ionosphere. Wolff et al. (1982) presented a simulation of the solar wind compression of the upper dayside ionosphere.

In the present paper we extend these analyses by examining PVO observations from November 10-11, 1981 (orbit 1071) when the PVO spacecraft was in the right place (the subsolar Venusian ionosheath) at the right time (after the passage of a significant interplanetary shock) so that the instruments recorded in the ionosheath a very unusual event: exceptionally high ion and electron densities - the highest observed to date on PVO.

Observations

Figure 1 presents the OETP Langmuir probe observations (Brace et al., 1980) of the electron density for orbit 1071 from 0129 to 0209 UT on November 11, 1981. The high electron densities associated with this orbit are unique and rare in that for a period of more than an hour they are more than an order of magnitude higher than any electron densities observed by the OETP in the ionosheath in the more than ten years of operation of the PVO spacecraft. This region of exceptional enhancement occurred between altitudes of 974 and 4000 km, with solar zenith angles between 19 and 90 deg. The reader can readily compare these elevated densities with those measured under more typical conditions during the next orbit 24 hours later. On orbit 1071 at 0207 UT the spacecraft exits the ionosheath and is in the solar wind where the electron densities are lower but, as shown in the figure, still exceed substantially the more normal electron densities recorded by the OETP in the solar wind. The multiple bow shock crossings that occurred between about 0201 and 0204 UT are also evident.

The observations recorded by the OETP during this unusual event are supported by all the measurements of the "ionospheric" plasma detectors on PVO. This is shown in Figure 2. The top panel (a) reproduces (from Figure 1) the electron number density measured by the OETP; panel (b) shows the simultaneous electron number densities measured by the ORPA, retarding potential analyzer (Knudsen et al., 1980); panel (c) shows the simultaneous ion number densities measured by the OETP; and panel (d) shows the superthermal ion densities measured by the OIMS ion mass spectrometer (Taylor et al., 1980). The data in each of these panels indicate the high particle densities in the ionosheath, the simultaneous abrupt drop in densities at 0207 UT associated with the final bow shock crossing into the solar wind, and the density fluctuations associated with the multiple bow shock crossings (0201-0204 UT). Across the top of Figure 2 we show the ion energy per unit charge (E/Q) spectra obtained by the OPA plasma analyzer which measures the convective plasma in the 0 to 8 kV range (Intriligator et al., 1980). The start time of each spectrum is precisely aligned in time (Intriligator and Scarf, 1982). These spectra, which are consistent with the plasma data in the four panels, are presented in order to indicate that the first two spectra were obtained in the ionosheath, the fourth (the last) spectrum was obtained in the solar wind; and the spectrum immediately before that (the third) is time aliased since it was obtained partially in the ionosheath, partially in the solar wind, and during the multiple bow shock crossing.

To further illustrate the unusual nature of the observations on orbit 1071 we show in Figure 3 the corresponding data for orbit 1077, the next orbit when all the PVO instruments whose data are shown in Figure 2 were in the same data-taking mode as they were in orbit 1071. These data were taken entirely within the ionosheath, as no bow shock was encountered. The data in Figure 3 show that the electron densities measured by the OETP and the ORPA, and the superthermal ion densities measured by the OIMS, were substantially lower on this more typical orbit (orbit 1077) than they were on orbit 1071. Since usually there are no

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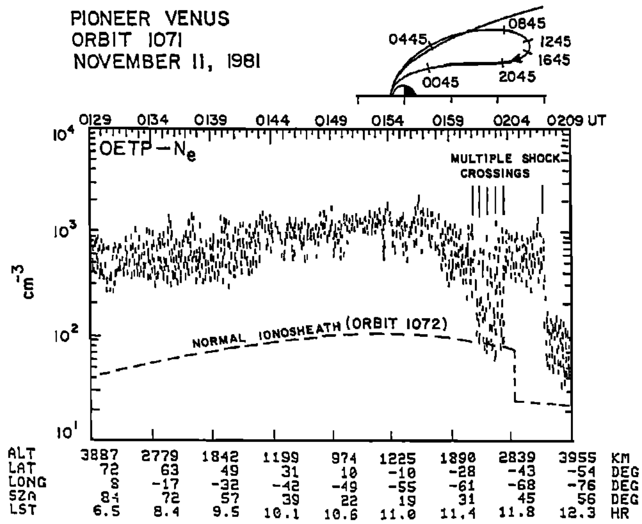

Fig. 1. High resolution electron temperature probe, OETP, electron densities in the vicinity of periapsis on orbit 1071. For comparison the typical level of these densities (from orbit 1072) is also shown.

hot ions in this region, there is no panel in Figure 3 showing the OETP ion density for the more typical conditions of orbit 1077. The difference between the densities on orbits 1071 and 1077 is striking and clearly indicates the unique enhancements of ionosheath electron and ion densities on orbit 1071.

Figure 4 shows the magnetic field magnitude for orbits 1069 through 1073. This comparison of magnetic field profiles emphasizes the difference between orbit 1071 and the other orbits (note that the vertical scales differ considerably extending to 160 gamma for orbits 1070 and 1071 and only to 80 gamma on orbits 1072 and 1073).

Since the spacecraft approached the planet and the subsolar region along essentially the same path as was taken on the other orbits, the increases in magnetic field magnitude on orbit 1071 cannot be attributed solely to changes in the configuration of the ionosheath (and bow shock). These observations imply that during orbit 1071 the magnetic field downstream of the bow shock and/or the (external) solar wind must be radically different from their states on the other orbits shown.

The OPA (solar wind) plasma analyzer and the OEFD electric field observations support the possibility of significant changes in the interplanetary medium during orbit 1071. Figure 5 shows for orbit 1071 the four channels (100 Hz, 730 Hz, 5.4 kHz, and 30 kHz) of the OEFD; the magnetic field intensity (B_T), and the B_x, B_y, and B_z magnetic field components measured by the OMAG; the proton plasma parameters derived from the OPA observations.

OPA proton plasma parameters were obtained (Intriligator and Scarf, 1982, 1984) from the CRC multicomponent (e.g. proton, He^{++}) fit to the plasma distributions (i.e., the ion energy per unit charge spectra). The substantial change in the plasma parameters at 1903 UT (labelled shock 1) is almost certainly indicative of the passage of a travelling interplanetary shock past Venus and past the PVO spacecraft. The corresponding increase in plasma wave activity in the 100 Hz

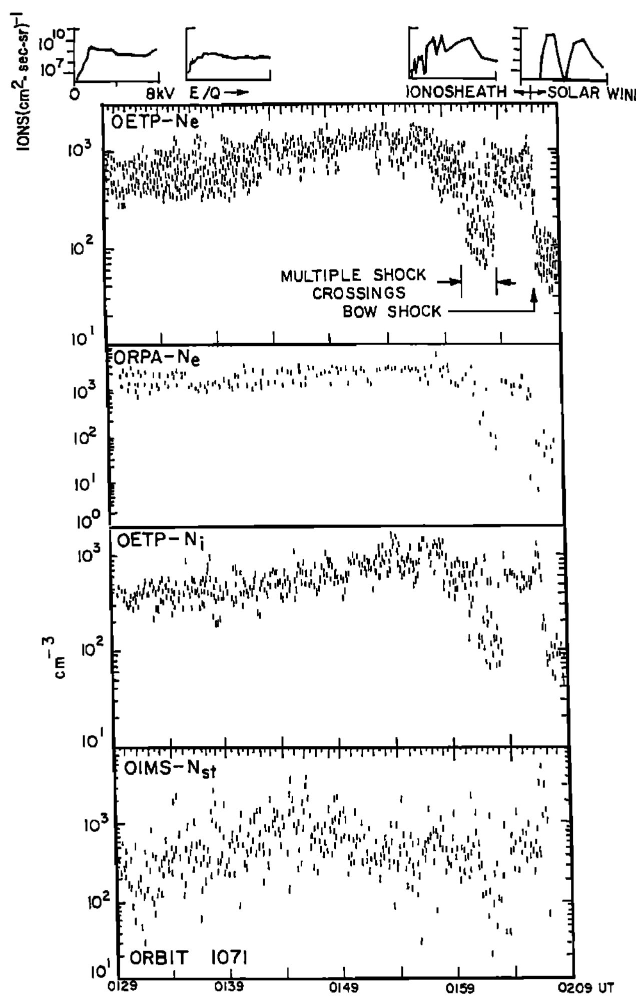

Fig. 2. Summary of PVO plasma observations in the vicinity of periapses on orbit 1071 from all of the plasma detectors. The electron densities, N_e, are the highest obtained to date in the ionosheath. The ion densities, N_i, and the superthermal ion densities, N_{st}, are also unusually high. The OPA plasma ion spectra at the top of the figure indicate that measurable fluxes of convective plasma were observed out to the highest range (8 kV) of the instrument.

channel and the sharp increase in the magnetic field magnitude are consistent with the passage of an interplanetary shock. The B_z and B_y components indicate a rotation in the magnetic field.

A second event occurred at 2342 UT (labelled shock 2?) as indicated in the plasma speed, the magnetic field magnitude, and the 730 Hz, 5.4 kHz, and 30 kHz plasma wave channels. The B_x and B_y components indicate a rotation of the field here as well. It is not as certain that this is associated with the passage of an interplanetary shock. It is possible that this event is associated with the crossing of a boundary internal to the ionosheath (Perez et al., 1985, 1990) rather than an interplanetary shock.

Discussion

The purpose of this paper is to introduce to the scientific community our analysis of some

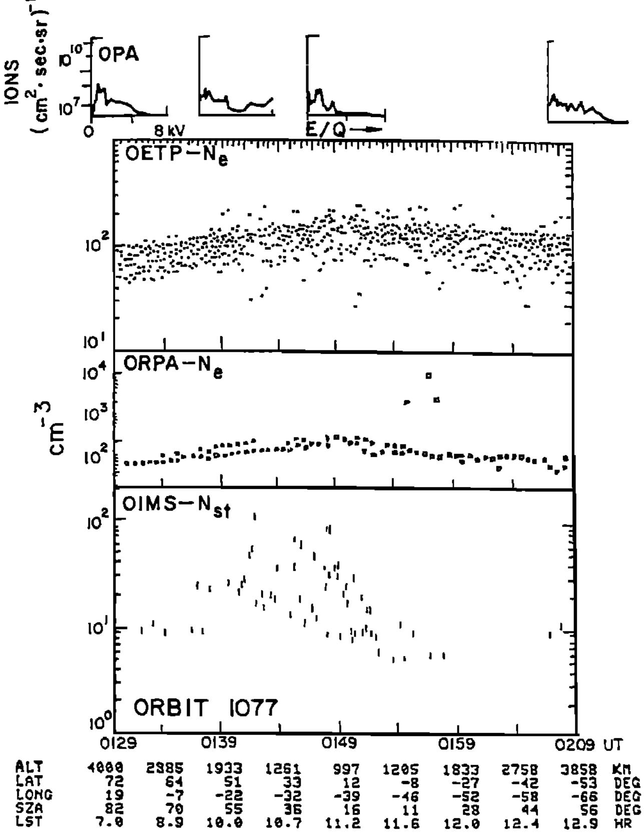

Fig. 3. The same as Fig. 2 for orbit 1077. These values are more typical ionosheath data. This orbit was selected since the plasma instruments were in the same mode on orbit 1077 as they were on orbit 1071.

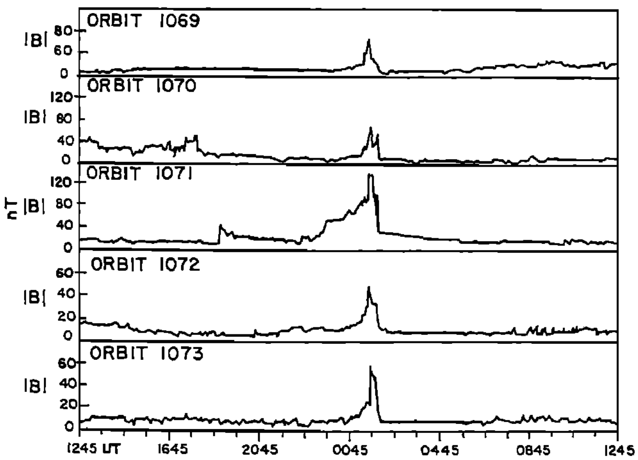

Fig. 4. Magnetic field magnitude for orbits 1069 through 1073. The vertical scales differ considerably for the magnetic field magnitude on these orbits. This comparison of magnetic field profiles emphasizes the differences between orbit 1071 and the neighboring orbits.

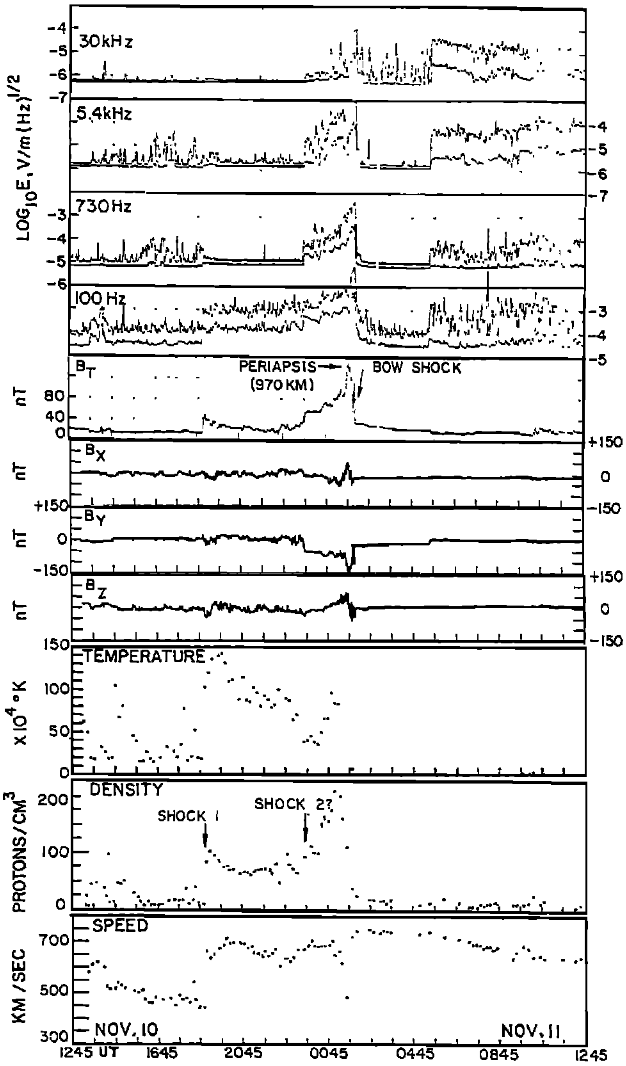

Fig. 5. Simultaneous 30 kHz, 5.4 kHz, 730 Hz, and 100 Hz plasma wave signals, magnetic field measurements, and the plasma proton temperature, density, and speed on orbit 1071, November 11-12, 1981. In the four top panels the two minute peaks (upper lines) and the two minute averages (lower lines) are shown. The proton parameters were estimated from the plasma analyzer energy scans, using the multicomponent ion species moment calculation developed at Carmel Research Center (Intriligator and Scarf, 1982, 1984). The passage of two events is evident. The first occurred near 1903 UT and the second near 2342 UT.

important Pioneer Venus observations. Our analysis of this unique set of observations indicates that there was an unusually large amount of plasma in the dayside ionosheath of Venus on orbit 1071. It is important to be aware of the correlation between the observations from six PVO instruments for this event. While both the solar wind and the Venusian ionosphere are possible sources of this plasma, future analyses and/or simulations by the scientific community will be necessary in order to ascertain the source of this tremendous amount of plasma.

Figures 1 through 3 show that the plasma observations on orbit 1071 were unique. They indicate that at that time in the Venus ionosheath there were enhancements of more than an order of magnitude in the densities of plasma ions and electrons. The observations in Figures 1 and 2 indicate that these ion and electron density enhancements occurred over a wide range of altitude (from 974 to 3955 km), latitude (-54° to +72°), longitude (-76° to +8°), and solar zenith angle (19° to 84°).

The magnetic field profiles in Figure 4 also indicate the unusual nature of the observations on orbit 1071. The plasma, plasma wave, and magnetic field observations shown in Figure 5 indicate that prior to the density enhancements an interplanetary shock past Venus at 1903 UT. At 2342 UT the spacecraft was overtaken by a second event which was either a second interplanetary shock or a boundary associated with the solar wind interaction at Venus (Perez-de-Tejada et al,, 1985, 1990).

It is tempting to speculate on the origins of the enhanced densities of ions and electrons. Both the Venusian ionosphere and the solar wind are possible sources of these particles. These particles could have originated in the ionosphere due to the motion of the ionopause and the bow shock as these structures contracted due to the increase in the solar wind pressure associated with the passage of "shock 1" and then expanded due to the subsequent decrease in the solar wind pressure. During this process some ionospheric particles could have been introduced into the ionosheath as the reexpanding field lines transported them out toward the bow shock. Wolff et al. (1982) investigated the effects on the ionosphere above 200 km of a sudden five-fold increase in solar wind pressure. In this "squashed-grape model" of the ionosphere, the sudden increase in solar-wind pressure forces the thermal ionosphere both radially downward and "horizontally" toward the nightside of the planet so that the ionosphere is "squirted" out towards the nightside. We believe that the ionopause was crushed down by the passage of "shock 1." At this time much of the ionosphere may have "squirted" out of the sides and was convected downstream of Venus by the solar wind. Later when the bow shock relaxed some of the ionospheric particles that originally remained in the ionosphere were on field lines that were tied to the bow shock and they were taken into the ionosheath. Eventually, either with the passage of the second interplanetary shock ("shock 2?") or with other solar wind compression of the ionosheath they were heated again. The solar wind density at the time of PVO emergence (0207 UT) was only 20 cm^{-3}. This is far too low to produce the densities of 10^3 cm^{-3} observed only a few minutes earlier in the subsolar ionosheath. Thus it is tempting to speculate that the source of these enhanced densities was the underlying ionosphere where the densities are of the order of 10^4 - $10^5 cm^{-3}$. While it is possible that the solar wind is a source of the enhanced densities in the ionosheath, it seems less likely since it appears more difficult to slow the shocked solar wind so much that there would be a ten-fold pileup of relatively low energy particles. Further analysis of this event, and analyses and simulations of other events may provide additional insight into the origin of the unique and rare observations in the subsolar ionosheath on orbit 1071.

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