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PLASMA AND ELECTRIC FIELD MEASUREMENTS OF THE PVO IN THE VENUS IONOSHEATH

H. Pérez-de-Tejada

Instituto de Geofísica,
Universidad Nacional Autónoma de México, Ensenada, Baja California, México

D. S. Intriligator

Carmel Research Center, PO BOX 1732, Santa Mónica, Ca. 90406

F. L. Scarf

Applied Technology Division, Space and Technology Group, TRW, Redondo Beach Ca., 90278

Abstract. A study of the plasma and electric field measurements of the PVO in the Venus ionosheath near the terminator region is presented. A drastic decrease of the particle flux intensity measured with the plasma instrument is encountered in the inner ionosheath before the inbound crossing of the ionopause. The outer boundary of the region of weak plasma fluxes is consistent with the presence of a rarefaction wave as reported previously from the Mariner 5, Venera and PVO plasma measurements in the Venus wake. Near that boundary there are, in addition, appreciable changes in the electric field signals detected with the PVO electric field detector. These observations suggest the existence of local plasma wave activity associated with turbulent flow conditions in that region.

Introduction

The behavior of the shocked solar wind as it streams around the Venus ionospheric obstacle is currently the subject of intense experimental scrutiny because of the necessity to identify the processes which characterize its interaction with the ionospheric plasma. The near polar trajectory of the PVO has allowed the examination of plasma fluxes streaming in the near vicinity of the terminator and, in particular, downstream from the magnetic polar regions where it is believed that particle fluxes enter more favorably into the wake [Brace et al, 1979; Pérez-de-Tejada, 1980; Zeleny and Vaisberg, 1983].

Indications that the plasma in the Venus inner ionosheath may reflect changes produced by phenomena taking place at and near the ionopause were first provided by the plasma and magnetic measurements conducted during the Mariner 5 fly-by [Bridge et al, 1967]. These observations indicated the detection of a strong rarefaction wave extending downstream from the terminator through the ionosheath [Spreiter et al, 1970; Rizzi 1971]. This wave delimits a region of noticeably decreased density and velocity values (with respect to those seen in the outer ionosheath) and was believed to reflect the expansion of the ionosheath flow into the umbra. Pérez-de-Tejada [1979] noted, in this regard, that the area integrated mass flux present within the Venus wake is comparable to the mass flux deficit exhibited by the ionosheath flow outside. The tacit implication of this result is that the total mass flux of the plasma streaming past the planet is conserved and that the bulk of the fluxes present within the wake are of solar wind origin. Recent experimental support of this result has been obtained in the observation of very low ($\sim 1\%$) concentrations of 0^+ ions (characteristic of the upper Venus ionosphere) with respect to the ambient shocked solar wind proton population in the wake [Mihalov et al, 1980; Intriligator, 1982]. With such low relative concentrations the momentum flux of the planetary ions is only a small fraction of that of the shocked solar wind, and is not sufficient to account for the loss of momentum flux observed within the velocity boundary layer in the ionosheath (see Pérez-de-Tejada [1982]).

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The existence of a region of low plasma density in the inner ionosheath has also been reported by Spenner et al [1980] from the ORPA measurements of the PVO. These authors indicate that in the vicinity of the ionopause near the terminator the electron population is generally more rarified than that seen in the outer ionosheath, and that it appears to contain a low energy component of ionospheric origin. The width of this region (which they call the plasma mantle) is reported to be ~ 1500 km just behind the terminator, and thus of the same order of magnitude of the temperature and velocity boundary layers inferred from the Venera plasma measurements at roughly the same locations (Verigin et al [1978], see Figure 8). This circumstance prompted Pérez-de-Tejada [1980, 1982] to suggest that such a region coincides with that in which there are changes caused by a viscous-like interaction with the ionospheric plasma at the terminator, and that the lower densities result from an expansion associated with a viscously produced heating of the local plasma.

In the present report it is shown that the plasma probe measurements conducted with the PVO are also consistent with the existence of a region of weak particle fluxes above the ionopause near the terminator. The outer boundary of this region appears to be very thin, at least in some orbits, and is characterized consistently by noticeable changes in the electric field signals detected with the PVO electric field detector. This latter property is then used to examine the conditions which may bring about the turbulent character of the flow in the inner ionosheath.

Plasma Measurements in the Ionosheath

Due to the fact that the PVO moves across a significant extension of the ionosheath during the time taken by the plasma instrument to complete a cycle of measurements it is, in general, difficult to determine representative values of the density, temperature, and velocity of the flow in that region. Despite this limitation it is possible to identify, in some orbits, consistent changes in the particle flux intensity which reveal the onset of different conditions in the inner regions of the ionosheath. Examples of such cases are presented in Figures 1 and 2. These show (lower panels) the ion energy spectra [Intriligator et al, 1980] of the plasma in the outer (cycle I) and inner (cycle II) regions of the ionosheath as recorded during the inbound legs of orbits 72 and 80. The upper panels of both figures show the trajectory of the PVO in a two dimensional plane in which the vertical coordinate represents the distance to the Sun-Venus axis. The long (white) boxes indicate, in turn, the position of the PVO at the time of the energy measurements shown in the lower panels. Angular scan measurements at the peak energy of each spectrum were also conducted after each energy scan. The position of the PVO when these observations were made is indicated in Figures 1 and 2 by the short (black) boxes.

Most notable in the data of Figures 1 and 2 is a dramatic drop in the intensity of the dominant particle fluxes, that occurred during the energy scans conducted in the inner ionosheath. In orbit 72 this was observed as a very pronounced post peak decrease of the flux intensity in the spectrum of the cycle of measurements that began at 1950:12 UT. At $\sim$ 1953:30 UT the particle flux intensity measured in the 582.7 eV energy step was almost two orders of magnitude smaller

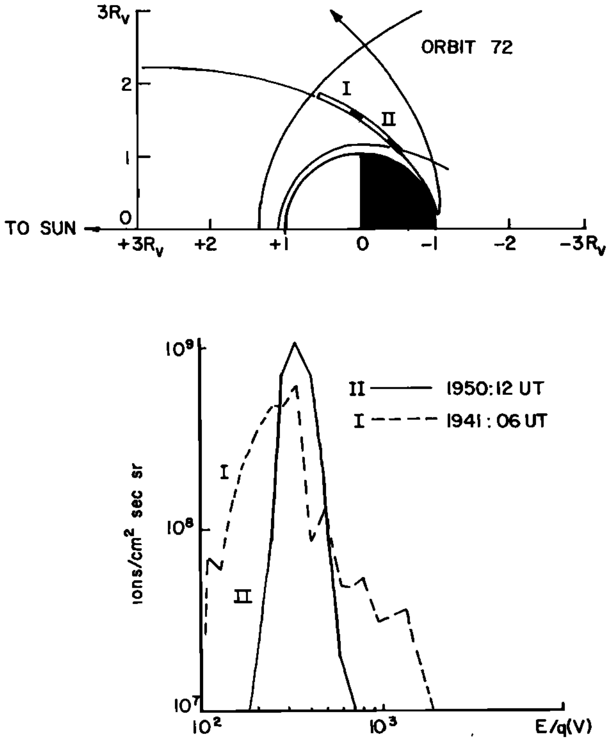

Fig. 1. Upper panel: Approximate position of the PVO in the solar ecliptic (x,r) plane during the two cycles of measurements conducted within the ionosheath on the inbound leg of orbit 72 (x is directed toward the Sun and r is transverse to the Sun-Venus axis). Lower panel: Ion energy spectra measured during the energy scan beginning at 1950:12 UT and 1941:06 UT.

than the (peak) value seen in the 356.6 eV energy step, thus giving the spectrum an apparent thin shape. Low intensity fluxes (showing consistently a similar azimuthal direction) were seen after 1954 UT, but went below the threshold of the instrument before the spacecraft entered the ionosphere at ~ 1957 UT. A similar but better defined transition is present in the data of orbit 80 where a sudden drop of the particle flux intensity was encountered at ~ 1939 UT. In this case the "chopped off" shape of the energy spectrum measured in the second cycle of measurements is evident. The much lower intensities recorded after that time appear to be a drastic departure from what otherwise would have been an energy spectrum similar to that seen in the first cycle of measurements. Thus the high energy tail (due either to a high speed proton component, or to a heavy mass population) of the first spectrum appears to be drastically decreased in the second energy spectrum. Evidence that no particle fluxes with intensities comparable to those shown in Figure 2 were present after 1940 UT in the energy range of the peak of the distribution is also provided by the observations made during the following angular scan (between ~ 1942 UT and ~ 1943 UT). These latter measurements were conducted while the PVO was still in the ionosheath (the ionopause crossing occurred at ~ 1945 UT) and revealed particle fluxes of about two orders of magnitude smaller than those shown in Figure 2. All of these observations thus suggest that a significant decrease of the intensity of the dominant ~ 1 keV particle fluxes observed in both spectra in Figure 2 took place in the inner ionosheath.

The changes in the particle flux intensity seen in the inner ionosheath in orbits 72 and 80 are consistent with those expected across a rarefaction wave as reported previously from the Mariner 5, from the Venera 9 and 10, and from the PVO plasma measurements [Bridge et al, 1967; Romanov et al, 1979; Intriligator and Scarf, 1982]. As noted earlier, the data obtained in those experiments also indicated an appreciable decrease of particle fluxes in the inner regions of the ionosheath. The changes reported here are more noticeable, however, and seem to involve a larger fraction of the flux intensity present in the outer ionosheath. This difference may be due either to the fact that the PVO measurements were conducted at locations much closer to the planet or, alternatively, to time varying conditions of the ionosheath flow itself. An alternative interpretation of the decrease of particle fluxes across the rarefaction wave, as a result of the replacement of the shocked solar wind plasma by (cool) ionospheric particles through charge exchange collisions and mass loading processes, has also been proposed by Russell and Vaisberg [1983]. Even though it is clear that the local flow will undoubtedly be contaminated with ionospheric and exospheric material [Michel 1971; Cloutier et al, 1974; Gombosi et al, 1981; Slavin et al, 1983] there are consistent experimental indications that the plasma in the region of depressed particle fluxes exhibits temperatures comparable to, or even larger than, those seen in the outer ionosheath [Verigin et al, 1978; Romanov et al, 1979; Pérez-de-Tejada et al, 1983]. Consequently, it is very likely that the dominant population in that region is still formed by particles of solar wind origin, and that the rarefaction wave simply reflects the expansion of the local plasma as a result of its interaction with the ionosphere.

Ionosheath Plasma Wave Observations

The initial report on the PVO plasma wave observations [Scarf et al, 1979] contained a discussion of phenomena associated with the Venus bow shock. It was shown that 30 kHz electron plasma oscillations are detected in the upstream region whenever the solar wind density is in the appropriate range for that frequency (N = 8-15 electrons/cm^3 gives f = 25-35 kHz); that intense levels of low frequency oscillations (electrostatic ion sound waves and electromagnetic whistlers) develop very near the bow shock current layer, and that more moderate turbulence levels are customarily found just downstream from the shock in the outer ionosheath. Later, Taylor et al [1979] focused attention on wave phenomena near the inner boundary of the ionosheath; they noted that just outside of the ionopause only 100 Hz whistler mode signals are detected, and

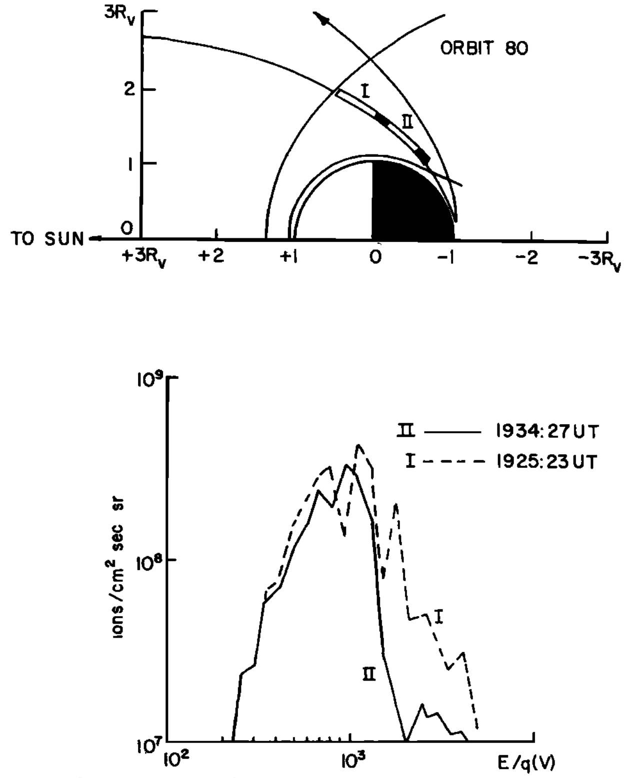

Fig. 2. Same as Figure 1 for the measurements conducted during the inbound leg of orbit 80.

they evaluated the ionospheric heating associated with damping of these waves.

The wave measurements near the bow shock and near the ionopause are clearly of importance because the related wave-particle interactions lead to particle heating and energy transfer, and in a subsequent report Scarf et al [1980] analyzed these ionosheath boundary processes in greater detail. However, the plasma probe observations discussed above suggest that it is also very important to search for wave-particle interactions and energy transfer phenomena that could be operative within the ionosheath, especially for those orbits (such as 72 and 80) where there appear to be well defined transitions in the plasma distribution functions.

Figures 3 and 4 show, for orbits 72 and 80 respectively, all of the electric field measurements for a period that started just upstream from the inbound bow shock crossing and ended when the spacecraft entered the shadow of Venus. For both orbits we note that: (1) downstream from the bow shock, strong turbulence was detected in all low-frequency channels and the signal level decreased as the spacecraft moved toward Venus, (2) toward the end of the ionosheath traversal, the only detectable activity appeared in the 100 Hz channel (the regular modulation that is evident in all the background levels is associated with the sun-oriented anisotropy of the plasma sheath surrounding the spacecraft, as discussed by Scarf et al [1979]).

A striking and unusual feature of these observations involves the localized nature of the transition from post-shock turbulence to a preionopause wave spectrum. We note, in particular, that in a one-minute interval centered around 1953 UT in orbit 72 there was a distinct peak in the 100 Hz wave level, followed by a noticeable decrease in this and in the 730 Hz channel. At that time there were also measurable electric bursts in the 30 kHz channel and, as noted at the top of Figure 3, a change in the magnetic field direction (C. T. Russell, private communication). The identification of the 30 kHz electron plasma oscillations generally means that significant fluxes of suprathermal electrons were present, or that an electron beam was passing through the local plasma.

Similar features were also observed in the electric field data of Figure 4 for orbit 80. In this case it is also evident that there is a clear correlation between the detection of the 30 kHz bursts and the decrease of the intensity of the 100 Hz signals at ~ 1939 UT. Also, the 730 Hz signals are seen to fall to background levels at the beginning of the second scan, but the transition is not sharp.

The labels at the top of Figures 3 and 4 relate the variations in the wave activity to the change in the plasma and magnetic field characteristics. The scan start times are the same as those given in Figures 1 and 2, but these start times do not fully identify when the ions were actually detected since the analyzer voltage is continuously varied in a cyclic manner. The cross hatched areas at the top of Figures 3 and 4 do show when the ions associated with the energy and angular scans were measured, and these boxes represent the intervals that should be analyzed in terms of possible local wave-particle interactions.

From the comparison of the plasma and electric field data of both orbits it is clear that a remarkable agreement exists between the observation of the 30 kHz signals and the dominant changes of the particle spectra. Thus, we note that the sudden drop of the particle

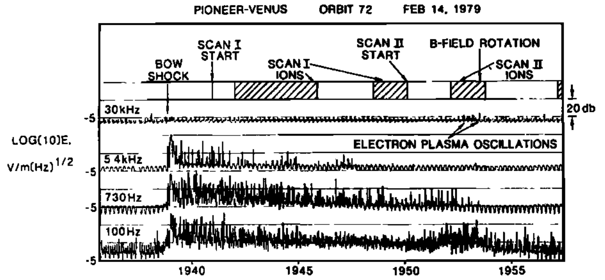

Fig. 3. Electric field signals on the 100 Hz, 730 Hz, 5.4 kHz and 30 kHz channels of the OEFD instrument during the inbound crossing of the Venus ionosheath in orbit 72.

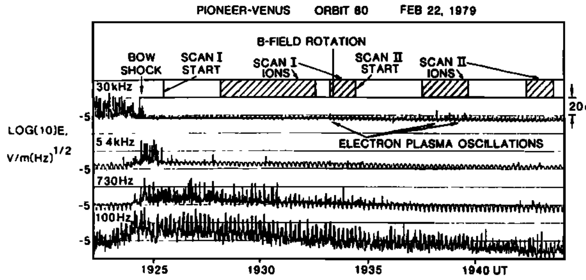

Fig. 4. Same as Figure 3 for the measurements conducted during the inbound leg of orbit 80.

flux intensity seen in the inner ionosheath occurred very nearly at the time when such an electric field activity took place. More specifically, the observation in orbit 80 (Figures 2 and 4) of different particle flux levels before and after ~ 1939 UT is clearly marked by the detection, at that time, of the 30 kHz bursts and the decrease of the 100 Hz signal. Similarly, the severe drop of the particle flux intensity seen near 1953:30 UT in orbit 72 (Figure 1) also coincides very approximately with the detection of the 30 kHz bursts and with the decrease of the intensity of the 730 Hz and 100 Hz signals (Figure 3).

It is difficult to establish cause-and-effect relations using only data from a 4-channel plasma wave instrument that has limited sensitivity, together with observations from a plasma probe that scans very slowly in comparison to the spacecraft travel time through the ionosheath. We note, however, that the joint set of measurements described above is consistent with the concept that the PVO crossed at ~ 1953:30 UT in orbit 72, and at ~ 1939 UT in orbit 80, a region where the ionosheath plasma became rarified. Thus, a possible interpretation is that the local particle density dropped across values for which the electron plasma frequency fell within the response range of the 30 kHz channel (from $N > 15\ cm^{-3}$ in the outer ionosheath to $N < 8\ cm^{-3}$ in the inner ionosheath). This interpretation is also consistent with the decrease of intensity of the 730 Hz and 100 Hz electron signals at ~ 1953:30 UT in orbit 72, and of the 100 Hz signals at ~ 1939 UT in orbit 80. In fact, given the lower density of the plasma in the inner ionosheath, we would expect that the intensity of the wave activity associated with it also would be decreased with respect to the levels seen in the outer ionosheath.

Discussion

The correlated observation of noticeable variations in the electric field levels in the ionosheath, and drastic changes in the shape of the local plasma spectra, may have important physical implications in regard to the dynamics of the particles that stream around the Venus ionosphere. Collective oscillations and their associated wave-wave and wave-particle interactions may give rise to a continuous exchange of energy between the fluctuating components of the velocity and the electric and magnetic fields. This exchange of energy could, in turn, result in an anomalous transfer of statistical properties within the sheath as required, for example, in the viscous flow interpretation of the interaction of the shocked solar wind with the ionosphere.

This argument can be further explored by noting that the maximum energy flux available in the 100 Hz electric field signals present in the inner ionosheath is of the order of $\sim 10^{-2}$ ergs/cm^2 sec [Scarf et al, 1979]. This energy flux is comparable to the increase of enthalpy flux of the ionosheath flow produced by its interaction with the ionosphere near the terminator [see Perez-de-Tejada, 1982]. Such an agreement does not indicate, however, that the energy budget involved in the turbulent oscillations of the plasma is necessarily derived from the energy stored in the electric field fluctuations. Instead, we can only suggest that the energy flux present in the measured turbulent electric field is of comparable magnitude to the free energy of the plasma, and that most likely both quantities obtain their energy source from the kinetic energy of the shocked solar wind. The energy input to the fluctuating fields should involve the onset of unstable modes in the velocity profile of the shear layer at and above the ionopause. It is well known, for example, that a flow field with a transverse velocity gradient can be subject to Kelvin-Helmholtz instabilities, and develop regions of enhanced vorticity [Michalke, 1964]. The resulting motion should give rise to a cascade of modes into the small scale wavelength of the spectrum, and provide the energy required to maintain the dissipative oscillations. The observation of large amplitude low frequency magnetic field waves in the Venus wake during the Mariner 10 fly-by may be related to such processes. Lepping and Behannon (1978, see Fig. 9) reported, in this regard, magnetic oscillations in the 0.007 Hz - 0.42 Hz frequency range with a power spectral density of up to 100 times larger than that seen in the interplanetary medium. With such large densities it is entirely possible that a sufficient amount of energy be available to generate higher frequency modes. It is also significant to note, in this regard, that the energy flux available in the observed 30 kHz waves (calculated by assuming a phase speed comparable to the thermal speed of the sheath electrons) is, at the most, of the order of 10^{-8} ergs/cm^{-2} sec and thus several orders of magnitude smaller than that present in the 100 Hz noise. This result is consistent with the suggestion that the high frequency oscillations are decay products of stronger wave activity at lower frequencies, and that only small amounts of energy may actually be transferred to high frequencies. The continued analysis of the fluctuating components of the electric, magnetic, and velocity fields in the PVO data should contribute to our understanding of the detailed mechanisms responsible for the distribution of energy among them.

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