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STEADY-STATE PLASMA TRANSITION IN THE VENUS IONOSHEATH

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Abstract The results of an extended analysis of the plasma and electric field data of the Pioneer Venus Orbiter (PVO) are presented. We report the persistent presence of a plasma transition embedded in the flanks of the Venus ionosheath between the bow shock and the ionopause. This transition is identified by the repeated presence of characteristic bursts in the 30 kHz channel of the electric field detector of the PVO. The observed electric field signals coincide with the onset of different plasma conditions in the inner ionosheath where more rarified plasma fluxes are measured. The repeated identification of this intermediate ionosheath transition in the PVO data indicates that it is present as a steady state feature of the Venus plasma environment. The distribution of PVO orbits in which the transition is observed suggests that it is more favourably detected in the vicinity of and downstream from the terminator.

Introduction

The plasma conditions in the Venus near plasma environment were first examined during the Mariner 5 fly-by in 1967 (Bridge et al., 1967; Sheffer et al., 1979). They revealed that in addition to a bow shock crossing, which is characterized by a sudden deceleration of the solar wind and an accompanying increase in the density and temperature of the flow, there is evidence of an intermediate plasma boundary located nearly half way between the bow shock and the planet along the Mariner 5 trajectory. Across the intermediate transition (labeled event B in Figure 1 of the Sheffer et al. report) the flow speed initiates a steeper decrease, and the temperature a further increase, with decreasing distance from the planet. Unlike the case at the bow shock crossing, however, the magnetic field intensity and the plasma density show smaller values downstream. This latter variation was adopted to identify the intermediate transition as a rarefaction wave associated with the entry of the shocked solar wind into the planet's wake.

Measurements conducted with the Venera 9 and 10 orbiters (Vaisberg et al., 1976) also revealed the presence of a region of rarified and slower moving plasma by the flanks of the ionosheath, although its external boundary was usually not well defined (Romanov et al., 1979). Flow modeling calculations (Rizzi, 1972) based on the Mariner 5 data suggested that the rarefaction wave could emerge from the ionopause near the terminator and extend downstream within the ionosheath. The sharp change of plasma properties seen across that transition resulted, in this view, from the downstream distribution of disturbances produced at the ionopause. However, the possibility that the observed plasma behavior resulted, instead, from time dependent variations in the solar wind conditions prevented its identification in terms of a steady state feature in the Venus plasma environment.

This question was left unanswered over the years despite the acquisition of the PVO data. Observations conducted with the retarding potential analyzer (ORPA) stressed the existence of conditions in the inner ionosheath different from those present further outside. From the analysis of some selected orbits it was reported, in particular, that along the flanks of the ionosheath there is a region which is contaminated with electrons of ionospheric origin (Spenner et al., 1980). That region, called the plasma mantle, was identified as having properties different from those of the ionosheath proper, and was assumed to be the downstream extension of the magnetic barrier exterior to the dayside ionosphere.

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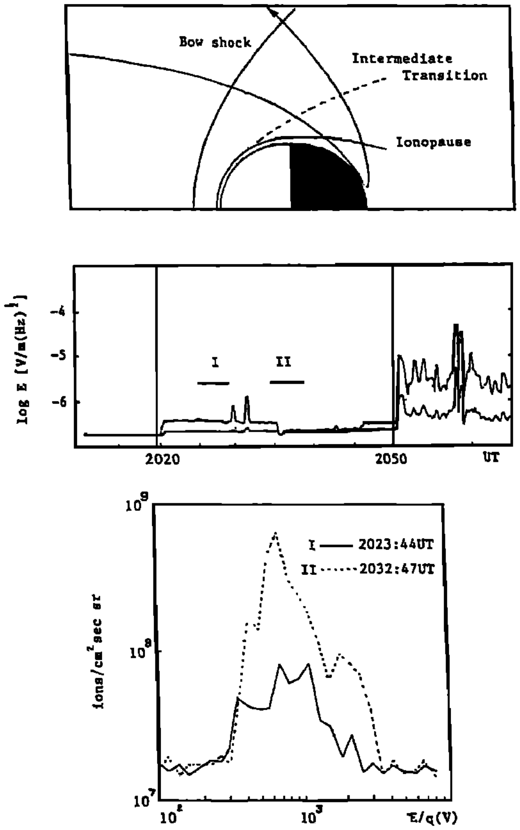
Plasma and Electric Field Measurements

An alternative approach to examine the stratification of the Venus ionosheath was devised in terms of the analysis of the electric field signals detected in the 30 kHz channel of the PVO electric field detector (OEFD) (Pérez-de-Tejada et al., 1984). Noise recorded in that channel reflects wave activity associated with plasma oscillations produced when the local density is in the 8–15 cm^{-3} range. A preliminary study of some selected orbits showed that under suitable circumstances this condition can be used to pinpoint changes in the plasma density.

An example which illustrates the technique employed is described in Figure 1 for the outbound pass of orbit 60. The upper panel shows the projection of the PVO trajectory on a plane in which the vertical coordinate is the distance to the Sun–Venus line. The middle panel shows the 12-sec peak and average values of the electric field noise recorded in the 30 kHz channel as the spacecraft moved outbound across the ionopause (at ~2019 UT), through the ionosheath, and into the solar wind across the bow shock (at ~2050 UT). The position of the bow shock and ionopause are indicated by the vertical lines and were obtained, respectively, from the orbiter magnetic field detector (OMAG) (C. T. Russell, private communication, 1985) and from the electron temperature probe (OETP) data (L. H. Brace, private communication, 1985).

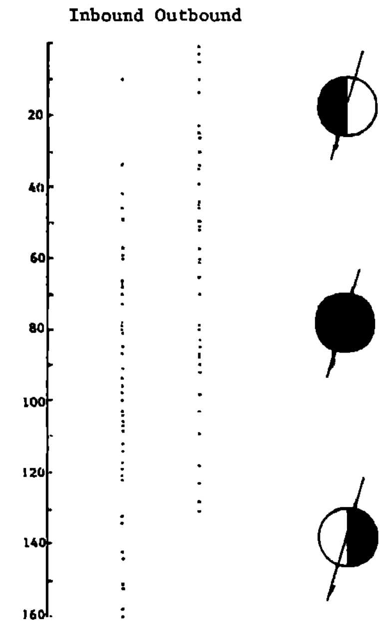
Signals upstream from the bow shock reflect wave activity whose frequency occurs within the response range of the 30 kHz channel. As a result of the compression that the flow experiences across the bow shock the plasma density increases downstream, and the 30 kHz channel is no longer suitable for detecting local wave activity. This change of conditions results in the generally quiet aspect of the 30 kHz channel's signature immediately downstream from the bow shock. In the example shown in Figure 1 there is, however, an additional burst of electric field signals, located at ~2030–32 UT nearly half way between the bow shock and the ionopause, which indicates that the response range of the 30 kHz channel was again suitable for registering local wave activity. The strong signals observed at this time suggest an expansion of the flow in which the plasma density drops from values > 15 cm^{-3} upstream to < 8 cm^{-3} downstream (the 30 kHz signal step at ~2035 UT is not relevant since it results from interference produced by switching modes of other PVO instruments, Strangeway, 1990). As in the analysis conducted on orbits 72 and 80 reported earlier (Pérez-de-Tejada et al, 1984), the



1 – (Upper panel) Trajectory of the PVO during orbit 60 projected on a plane in which the vertical coordinate is the distance to the Venus–sun line. (middle panel) Electric field signals recorded in the 30 kHz channel of the PVO electric field detector during the outbound transit of the Venus ionosheath (the vertical lines at ~ 2019 UT and at ~ 2050 UT indicate, respectively, the ionopause and bow shock crossings). (lower panel) Ion energy per unit charge (E/Q) spectra measured during the energy scans beginning at 2023:44 UT and 2032:43 UT.

suggested drop of the local density is supported by the observation of dramatically different plasma ion distributions detected before and after the brief 30 kHz burst in the middle ionosheath. The bottom panel in Figure 1 shows these plasma ion distributions for the measurement cycles initiated at 2023:44 UT and at 2032:47 UT. The time period across which measurable fluxes were recorded in the E/Q scans in each cycle is indicated by the horizontal bars (labeled I and II) in the middle panel. The peak flux intensity measured in cycle II is nearly one order of magnitude larger than that of cycle I and thus substantiates the density change inferred from the observation of the brief 30 kHz signals at ~ 2030–32 UT.

Conditions like those sampled on orbit 60 have now been investigated using a data base of 160 orbits. This set includes 255 ionosheath passes with useful data, and is sufficiently large to almost cover a whole Venus day. Throughout this orbit range the PVO trajectory sweeps regions of the ionosheath which extend from the early afternoon hours, include the nightside hemisphere, and reach the late morning hours. However, because of the ~ 15° tilt of its near circumpolar trajectory (Colin, 1980), PVO traverses different time zones of the ionosheath during its inbound and outbound passes. This peculiarity is particularly important in the duskside orbits (1 through 40), in which the (northern hemisphere) inbound passes of the trajectory occur mostly in the dayside and the (southern hemisphere) outbound passes occur mostly in the nightside. The opposite is true of the dawnside orbits (120 through 160) in which periapsis gradually shifts from the nightside to the dayside across the dawn terminator. A schematic of the north–south projection of the PVO trajectory on the planet, suitable to the duskside, nightside, and dawnside orbits is indicated by the top-to-bottom diagrams on the right in Figure 2.



2 – Distribution of PVO orbits (listed from top to bottom) in which strong ionosheath bursts in the 30 kHz channel of the OEFD instrument are detected. A PVO trajectory, representative of duskside (orbits 1–40), nightside (orbits 41–121) and dawnside (orbits 121–160) ionosheath passes projected on the plane perpendicular to the ecliptic, is indicated by the straight line on the top-to-bottom diagrams on the right (the trajectory shifts gradually from right to left with orbit number in each case).

The coverage of the near-planet ionosheath across the entire nightside hemisphere, together with the probing of the morning and afternoon sectors in orbits 1–160 allows a thorough review of the incidence of conditions similar to those described in Figure 1. The first important result that has now emerged from the examination of the whole data set is the identification of a large (80) number of passes in which there is clear evidence of strong mid-ionosheath 30 kHz electric field bursts with properties similar to those of the burst detected on orbit 60. The abundance of cases in which there is evidence for the flow behavior described before clearly supports the view that the phenomenon responsible for the generation of such bursts is not the result of time dependent changes in the solar wind but a permanent feature associated with the solar wind–Venus interaction process. In addition to the set of passes with strong electric field enhancements similar to that shown in Figure 1 there is another large (52) set of cases in which there are weak electric field signals which may also be related to the flow expansion addressed before. However, since the latter set may also include other noise sources we have restricted our selection of passes with a positive identification of the mid-ionosheath transition to those in which the enhancement is strong and reaches peak values well above the local background level.

Even more revealing than the repeated identification of strong electric field signals in the 30 kHz electric field signature of the ionosheath is the peculiar distribution of the orbits in which they are observed. This is described by the dots marked in Figure 2 (listed with the orbit number from top to bottom) and shows a notable asymmetry between the inbound and outbound passes. In the duskside orbits (1 through 40) there is a ~ 80% preference for the 30 kHz bursts to occur in the outbound passes, while in the dawnside orbits (120 through 160) a similar (77 %) preference is for the inbound passes. The importance of this asymmetry can be better appreciated by recalling that in the first set the outbound traversal of the ionosheath occurs preferently in the nightside, and that the same is true of the inbound traversal in the latter orbit set. What this means is that the brief 30 kHz bursts that identify the mid-ionosheath transition appear to be present preferently in the nightside passes. Very few dayside passes show evidence of the phenomenon, and these are restricted to the near terminator region.

The approximate position of the PVO at the time when the 30 kHz bursts were detected in 67 ionosheath passes is presented in Figure 3 in the same plane of Figure 1. The representative points are coded according to the same (duskside , mid-nightside and dawnside) orbit groups of Figure 2, and include only cases in which the displacement of PVO during the 30 kHz event can be pinpointed or is not very large. It is to be noted that the mid-nightside orbit group (dots and circles) shows the least dispersion (particularly in the inbound passes), and that the corresponding points appear to congregate preferently around fairly well localized regions of the ionosheath.

The geometry of the intermediate transition that the distribution of representative points of Figure 3 suggests is depicted schematically by the dashed line between the bow shock and the ionopause in the upper panel in Figure 1. The trace differs from the shape of the outer boundary of the plasma mantle inferred from the ORPA measurements (Spenner et al., 1980) and agrees with the position of the rarefaction wave reported by Bridge et al. (1967) from the analysis of the Mariner 5 measurements. An important result that supports the geometry indicated in Figure 1 is the peculiarity that the duskside and dawnside cases occur significantly closer to the ionopause than the mid-nightside cases. The fact that there are noticeable 30 kHz bursts present in only a few dayside ionosheath passes in the data set examined, and that these occur near the ionopause by the terminator (despite the fact that the sampling within the ionosheath extends well upstream from that region), is consistent with the view that the intermediate transition may not extend much farther upstream into the dayside ionosheath.

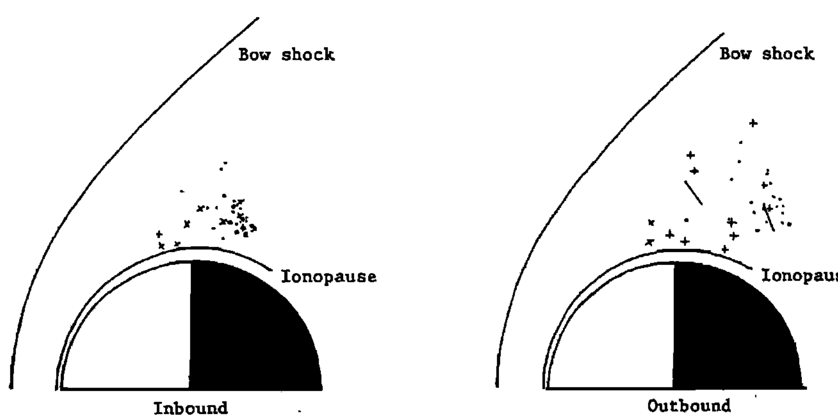
Discussion

While it is difficult at the present time to conduct a general comparison of the geometry of the boundary of the plasma mantle with that of the intermediate transition reported here it should be noted that the conditions observed downstream from the latter do not seem to support the interpretation of the region between that transition and the ionopause as the downstream extension of the magnetic barrier of the dayside ionosheath. For example, as was the case in the Mariner 5 measurements, there are many instances in the PVO orbits with strong mid-ionosheath 30 kHz bursts in which the magnetic field does not increase downstream from the intermediate transition but, in fact, relaxes to much lower values. This variation is different from that seen at the magnetic barrier of the dayside ionosheath, and thus suggests that the plasma conditions in the region between the intermediate transition and the ionopause may be quite different from those within the magnetic pile-up region.

Further analyses are required to examine the dependence of the detection of the mid-ionosheath 30 kHz bursts on the solar wind conditions, as well as their association with related observations. A particularly useful study is the examination of the position of the intermediate transition with respect to that of the ionospheric clouds which are occasionally detected outside the Venus ionosphere in the nightside passes (Brace et al., 1982). A preliminary check of a number of orbits in which the intermediate transition is observed indicates that this feature is not marked by the presence of ionospheric clouds and that, generally, the latter occur in the region between the intermediate transition and the ionopause.

The sudden change of plasma properties seen across the intermediate transition is not contradictory to the overall flow geometry expected from the solar wind flow around Venus. This was first argued in the early interpretation of the Mariner 5 measurements in which a standard (Prandtl-Meyer) expansion of the plasma behind the planet was put forward to account for the lower densities and flow speeds measured downstream (Bridge et al., 1967). However, the observation of enhanced plasma temperatures accompanying these changes, as was reported in later publications (Sheffer et al., 1979; Pérez-de-Tejada et al., 1985), indicates that the expansion process is dissipative, and that the entry of the plasma into the wake cannot simply result from the transit of the solar wind past the planet, but requires the development of phenomena that increase locally the gas temperature.

The observed behavior is more in accord with friction-like processes between the solar wind and the planet's ionosphere. In this view the intermediate transition represents the outer boundary of a viscous layer that develops at the ionopause near the terminator and extends downstream along the sides of the planet's plasma tail (Pérez-de-Tejada et al., 1984). The lower flow speeds seen within the viscous layer reflect



3 - PVO position (projected on the same plane as in Figure 1) at the time when strong electric field 30 kHz bursts were detected in 67 passes through the Venus ionosheath. The representative points are coded as follows: crosses (+) refer to duskside (orbits 1-40) ionosheath passes; exes (x) refer to dawnside (orbits 121-160) ionosheath passes; dots and open circles refer to mid-nightside (orbits 41-120) ionosheath passes (the dots representing cases in which the signals are the strongest). The two straight lines in the outbound passes identify cases in which the (multiple) 30 kHz signals extend across the indicated section of the PVO trajectory. The bow shock and ionopause curves are assumed shapes for their average location.

the effects of a certain transfer of momentum of the shocked solar wind to the ionosphere, and the enhanced temperatures and lower densities, the heat released through viscous dissipation and the ensuing expansion of the gas to match the external (inviscid) pressure. The probable origin of the process responsible for the transfer of momentum has been recently traced to momentum scattering interactions produced under strong plasma turbulent conditions (Wu et al., 1986). The latter have been observed both, in the Venus plasma environment, and in the vicinity of comets Halley and Giacobini-Zinner where, remarkably, there is evidence of a plasma feature with properties similar to those of the intermediate transition of the Venus ionosheath (Pérez-de-Tejada, 1989). The repeated observation of this transition in the PVO data is not inconsistent with earlier claims (Pérez-de-Tejada et al., 1985) that friction phenomena participate continuously in the process of interaction of the solar wind with a planetary ionosphere.

While the presence of a strong contaminant planetary particle population in the solar wind is, in principle, responsible for the onset of the turbulence-generated momentum scattering interactions, the processes that produce that contamination, e.g. mass loading (Intriligator, 1982) and charge exchange collisions, do not seem sufficient to account for the observations. It is not evident, for example, that either mechanism can result in the formation of the sharp transition across which the flow exhibits a sudden deceleration. Both processes are expected to gradually remove momentum from the solar wind, and there is no apparent reason why there should be a sudden increase of their effects across a well-defined transition. Most likely, the contamination of the solar wind produced by mass loading and charge exchange collisions serves mostly to trigger the strong plasma turbulence that is ultimately responsible for an effective transport of statistical properties among the different particle populations. The continued study of the mechanisms that produce that effect should provide a better basis to understand the origin of the intermediate transition.

Conclusions

The results of the plasma and electric field PVO data analysis reported here indicate that in addition to the bow shock and ionopause there is a third (intermediate) steady state transition in the Venus plasma environment. The location and properties of this transition are consistent with those of the rarefaction wave first suggested from the Mariner 5 fly-by observations (Bridge et al., 1967), and provide important new clues to the character of the solar wind-Venus interaction process. The suggested stratification of the Venus ionosheath may be a property shared with the Mars magnetosheath where evidence of an intrinsic layering of that region has recently been reported from the Phobos plasma data analysis (Lundin et al., 1990).

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