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PLASMA TURBULENCE IN THE DOWNSTREAM IONOSHEATH OF VENUS

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Abstract. We compare observations made by the Pioneer Venus Orbiter plasma analyzer and the plasma wave instrument in the Venus ionosheath. Large increases in plasma wave turbulence levels appear to be connected with changing plasma distributions and interpenetrating plasma beams. We identify some of these plasma waves as Doppler—shifted ion acoustic waves due to beam/beam interactions, but different forms of instabilities are probably also operative. The changes in the temperature, intensity and energy of the peak in the PVO plasma distributions are similar to those observed by Venera 10 closer to the planet and appear to be evidence for rarefaction and compression in the downstream ionosheath. Some of the changes in the PVO plasma distributions may be related to the presence of a second ion population or the acceleration of protons.

Introduction

In discussing the planned science goals of the Pioneer Venus Orbiter mission, Bauer et al. (1977) noted that many important dynamical questions were related to studies of microscopic processes that could develop downstream from the main solar wind—planet interaction region, in a possible wake cavity, a magnetic tail or a plasma sheet. Several early reports called attention to very significant downstream observations of heavy ion mass addition to the shocked solar wind (Mihalov et al., 1980; Intriligator, 1982) and to measurements of sporadic or sustained plasma wave enhancements in this region (Scarf et al., 1980). Russell et al. (1981) showed that the Venus tail is well developed with its boundary marked by a change in the plasma wave spectrum. In this paper we expand the analysis of the downstream ionosheath region by showing that the variations in plasma wave activity are correlated with the detection of large—scale fluctuations in the plasma parameters. We show that the downstream ionosheath of Venus has regions with intense high frequency turbulence, similar to that observed in the sheath behind Titan (Gurnett et al., 1981, 1982). We note that these high turbulence levels are not customarily found in the magnetosheaths of Earth, Jupiter or Saturn.

Observations

We start our examination of the downstream ionosheath measurements by considering data from orbit 176, May 29, 1979. Figure 1 shows the 5.4 kHz electric field amplitudes (12 seconds peaks and averages) from the plasma wave experiment and the corresponding plasma proton distributions from the plasma analyzer experiment (Intriligator et al., 1980) from 1325 to 1505 UT. The upper and lower time scales are the same since the plasma analyzer scans have increasing plate voltage (E/Q) with increasing time; thus this plot shows the instantaneous variation in flux with time. The trajectory plot for orbit 176 in a rotated coordinate system, where the vertical axis is the distance perpendicular to the sun—Venus line, is also shown.

Comparison of the plasma distributions and the 5.4 kHz signal indicates that enhanced 5.4 kHz signals are present when the plasma distributions are changing and particularly when there is an absence of significant measurable plasma at the higher E/Q values (e.g., >~2kv). Enhanced 5.4 kHz signals are also associated with large—scale changes in the polar (north—south) flow directions of the peak ion flux in the spectra from ~1340 to ~1415 UT and from ~1425 to ~1450 UT as indicated by the changes in the collector number associated with the peak.

Figure 2 shows the plasma proton density and speed and the 5.4 kHz signal in the ionosheath on orbit 176. As already indicated in the spectra in Figure 1, the peak in the distributions from 0730 to 1700 UT occurs at the low energy end and we associate this with protons (H^+). The proton temperatures during this time are on the order of 10^5 °K. The densities and speeds in Figure 2 were evaluated using a comprehensive multicomponent ion species moment calculation developed at CRC. This fitting routine makes the assumption that the plasma distribution is stable over the instrument cycle time. When it is changing there is the possibility of introducing errors here. This calculation has been calibrated (Intriligator, 1982) by comparing parameters for solar wind spectra obtained from the CRC comprehensive multicomponent ion species moment method with the NASA Ames least squares program's calculated parameters for these same spectra. The variability of the density and speed in this part of orbit 176 is evident from Figure 2.

The correspondence is quite good between the increased signals in the 5.4 kHz channel and the changes in the plasma distributions. During the intervals with 5.4 kHz peaks, Figure 2 shows that the plasma density was variable, but that it generally fell between 20 and 60 protons/cm³. For this density range the electron plasma frequency, f_p^e ($= 9\sqrt{N}$ kHz) is well above the 30 kHz frequency channel for the plasma wave instrument, while in the rest frame the ion plasma frequency is 0.95 to 1.6 kHz, which falls between the 730 Hz and 5.4 kHz channels. However, when the plasma is streaming, large Doppler shifts are very important for slow, short wavelength plasma oscillations such as ion acoustic waves. The apparent frequency, f′, is related to the rest frame frequency, f, by

$$f' = f + v(\text{stream})/\lambda(\text{wave}) \tag{1}$$

so that the apparent frequency is essentially determined by the Doppler effect. Figure 2 shows a mean speed of about 350 km/sec in regions with 5.4 kHz signals, and hence

$$\lambda \approx \frac{350 \text{ km/sec}}{5.4 \text{ kHz}} \approx 65 \text{ meters} \tag{2}$$

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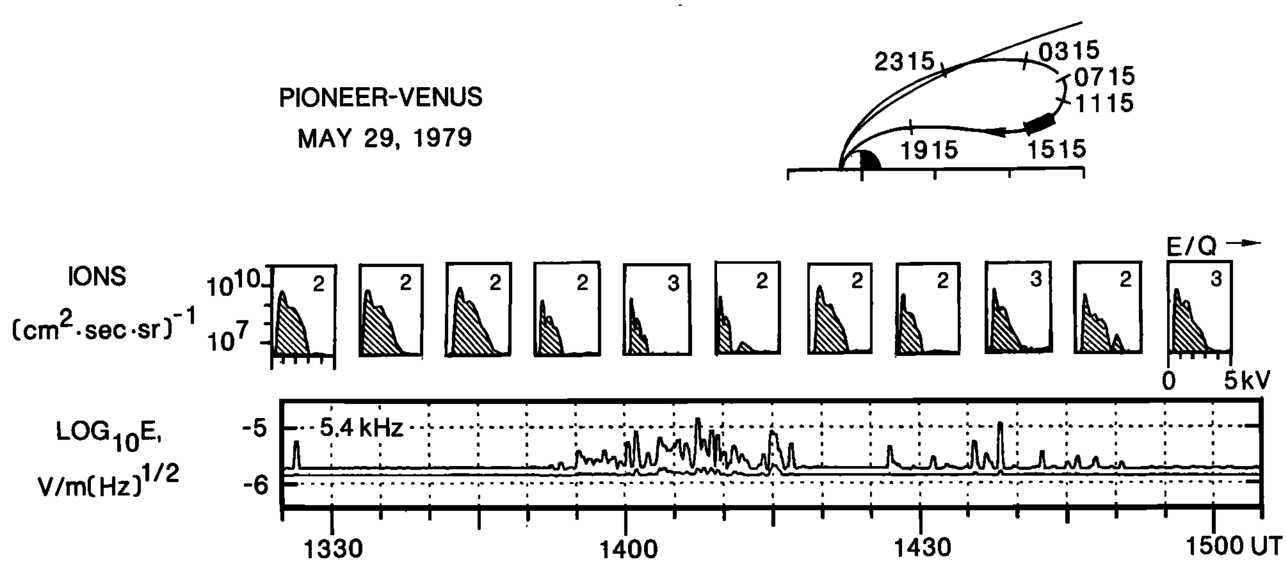

Fig. 1. Simultaneous plasma wave and plasma analyzer measurements in the ionosheath on orbit 176 from 1325 to 1505 UT. The 5.4 kHz wave channel signals and the corresponding plasma distributions in the energy per unit charge (E/Q) range of 0 to 5 kv are presented. The number of the collector (Intriligator et al. 1980) measuring the peak flux in each E/Q spectrum is indicated in each box. The spacecraft trajectory in a rotated coordinate system is shown.

A temperature near 10^5 °K was measured at this time, so that the Debye length, λ_d, was near 3 meters and the minimum electrostatic wavelength for ion waves, $2\pi\lambda_d$, was near 20 meters. This reasoning leads to a conclusion that the wave instrument detected short wavelength ion acoustic waves similar to those found in the solar wind on Helios (Gurnett and Anderson, 1977), Voyager (Kurth et al., 1979), Pioneer Venus (Scarf et al., 1980), and ISEE (Kennel et al., 1982). However, the downstream plasma conditions of Figures 1 and 2 differ greatly from those found in the solar wind; in particular, the large changes in the plasma distributions and polar flow angles shown in Figures 1 and 2 suggest that these ion acoustic waves could be generated by beam/beam instabilities.

Figure 3 shows the plama wave observations and plasma distributions from orbit 177. There is enhanced activity in the 730 Hz channel and intermittent enhancements in the 5.4 kHz channel. These are again associated with changes in the plasma distributions. There is a change in the shape of the plasma distribution between 0810 and 0830 UT. In these two spectra the low energy peak (the H^+ peak) occurs at ~1 kv. Both spectra show substantial fluxes above the peak with evidence of a second peak at ~2.5 kv. The second peak could be indicative of the presence of a different ion or of the acceleration of protons. In comparing the relative intensities at various voltages ("energies") to infer relative densities the reader should recall (Intriligator et al., 1980) that the range of energies accepted at a given energy step is a constant percentage of the nominal energy of that step so that the "energy window" is larger at higher energies. Thus a normalizing energy correction factor must be inserted before relative densities can be inferred. We do not make this correction here because if one assumes that the higher energy population is due to heavy ions with different charges travelling at the same speed as the protons, a factor which takes account of charge also must be used to infer the relative densities (strictly speaking the abscissa is energy per unit charge (E/Q). On the other hand, if the higher energy population represents protons accelerated to high speeds, then a factor which takes account of these high speeds must be used (i.e., higher speeds lead to higher fluxes and currents).

The spectra in Figure 3 show the continued presence and evolution of both peaks. The low energy peak is quite intense and broad (hot), and it occurs at an elevated energy at 0820 UT. The 0820 UT spectrum also has an unusually more intense and hotter higher energy population. The increased intensity, energy, and temperature of both the lower energy and higher energy populations in the 0820 UT spectrum could be indicative of compression of the ionosheath (Vaisberg et al., 1976). Similarly, the decreased intensity, energy and temperature of both the lower energy and higher energy populations in the 0810 and 0837 UT spectra could

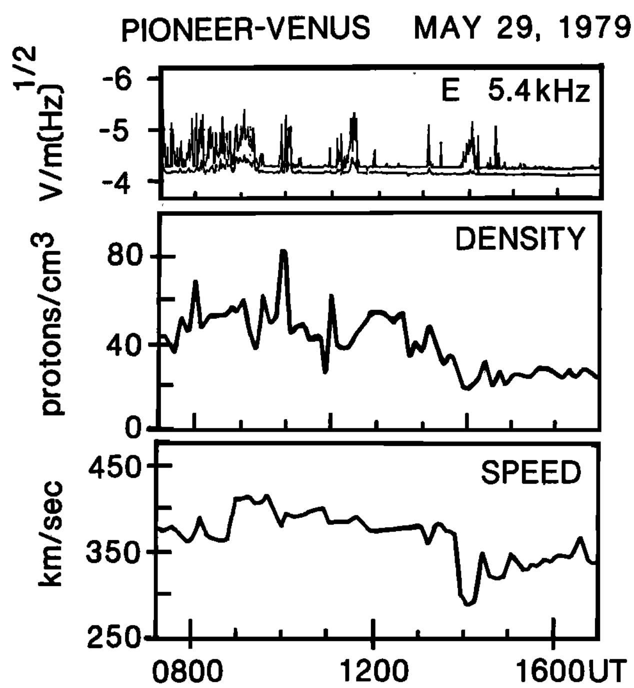

Fig. 2. Proton density and speed and the simultaneous 5.4 kHz signal in the ionosheath on orbit 176. The proton parameters were calculated from the plasma analyzer energy and angular scans using the comprehensive multicomponent ion species moment calculation developed at CRC.

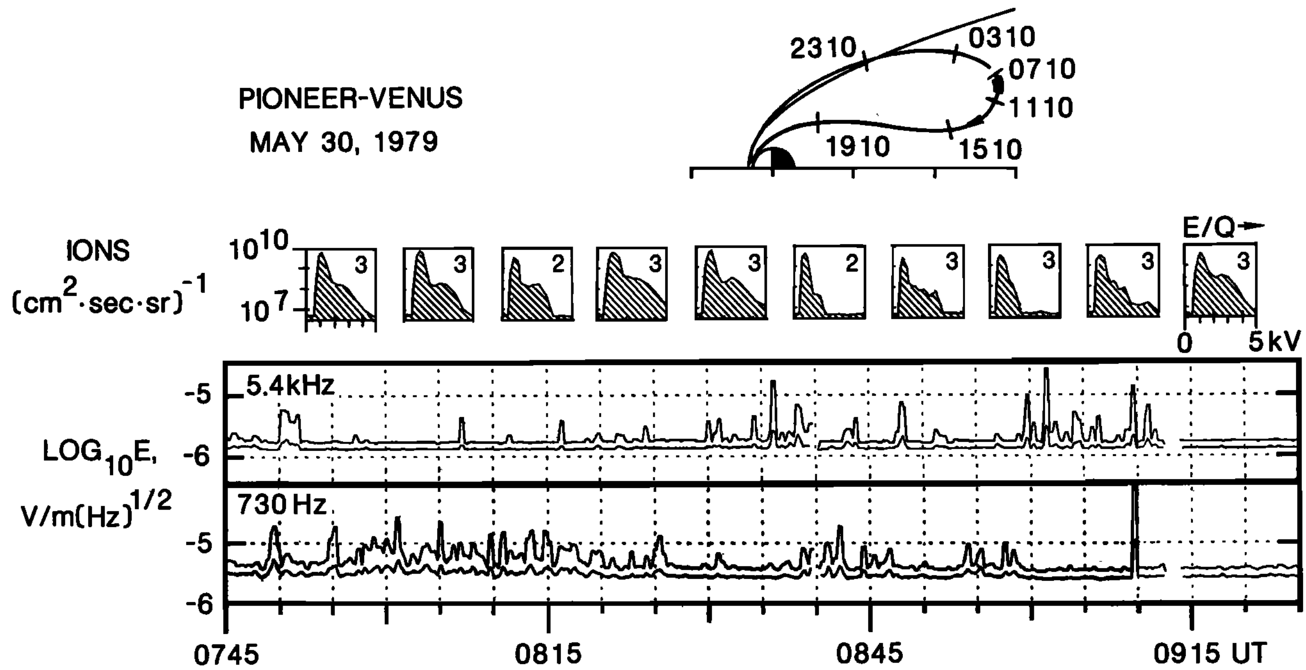

Fig. 3. The same as Figure 1 for orbit 177 from 0745 to 0925 UT. The 730 Hz channel is also shown.

be indicative of rarefaction of the ionosheath (Vaisberg et al., 1976). However, our observations are made considerably farther downstream than the Venera 10 observations.

The 0847 UT spectrum shows further decreases in the values of the parameters associated with the lower energy population but increases (e.g., in intensity and temperature) associated with the higher energy population. In contrast, the 0857 UT spectrum displays an increase in the intensity and temperature of the lower energy population and only a hint of the presence of a higher energy population. The higher energy population is more intense in the 0910 UT spectrum and the 0915 UT spectrum shows increases associated with both populations. In Figure 3 there appears to be a good correlation between the enhancements in the 730 Hz and 5.4 kHz channel and the changes in the plasma distributions.

Figure 4 shows the density and speed obtained during the ionosheath passage on orbit 177 as well as the plasma wave observations. As in the spectra in Figure 1, the peak in each of the ionosheath plasma distributions occurs at the lower energy end of the distribution and the densities and speeds, therefore, are associated with protons (H^+). The proton temperatures during this time are on the order of 10^5 °K. The densities associated with the enhanced higher energy component (e.g., as in the 0827 UT spectrum) are on the order of 1% of the densities associated with the main proton peak.

Discussion

The plasma wave and plasma analyzer observations presented indicate the presence of rapidly changing plasma distributions accompanied by enhanced 5.4 kHz wave activity in the Venusian ionosheath. The 5.4 kHz turbulence is most readily explained in terms of Doppler—shifted ion acoustic waves associated with the changing distributions. Although the long cycle time of the plasma analyzer does not allow us to identify the distribution function changes in an unambiguous way, it seems likely that counterstreaming beam/beam configurations develop, at least for short time periods. In this case, we can speculate that electrostatic instabilities of the type discussed by Stringer (1964), Papadopoulos (1973) and others generate the ion acoustic waves.

The figures emphasize the continuously changing plasma ion distributions and parameters and the corresponding enhanced plasma wave activity throughout the Venusian ionosheath. The associated enhancements in the 5.4 kHz and the 730 Hz channels most likely imply the presence of Doppler—shifted ion acoustic waves generated by plasma instabilities associated with the changing plasma distributions. At times interpenetrating plasma beams are also present as indicated by the variations in the collector number associated with the peak proton flux.

With regard to the possible rarefaction and compression of the ionosheath, the variability of the plasma distributions shown in Figures 1 and 3, are comparable to those shown in Vaisberg et al. (1976). Many of their Venera 10 spectra (shown in their Figures 5 and 6) are similar to the PVO spectra shown above. The plasma distributions in Figures 1 and 3 above that show decreased speeds, temperatures, and intensities are consistent with rarefaction in the ionosheath. The spectra obtained on orbit 177 at 0810 and 0837 UT are examples of rarefaction. The plasma distributions that show increased speeds, temperatures, and intensities are consistent with compression in the ionosheath. The spectra obtained at 0820 UT and 0915 UT are examples of compression. Thus, it appears that there is evidence in the PVO plasma analyzer observations for rarefaction and compression of the Venusian ionosheath and that this evidence is consistent with the Venera 10 observations (Vaisberg et al., 1976; Perez-de-Tejada et al., 1977) although their measurements were obtained much closer to the planet. The plasma wave enhancements may be related to interpenetrating ion beams; such beams are consistent with the conservation of mass flux associated with rarefaction and compression (Perez-de-Tejada, 1977).

The plasma distributions presented in Figures 1 and 3 also provide evidence for the presence and variability of a higher energy (>2kv) plasma population with a density at times on the order of 1% of the proton density. It is tempting to associate this higher energy population in the distributions, for example, on orbit 177 at 0802, 0810, 0819, and 0829 UT, with a second Maxwellian rather than with the high energy

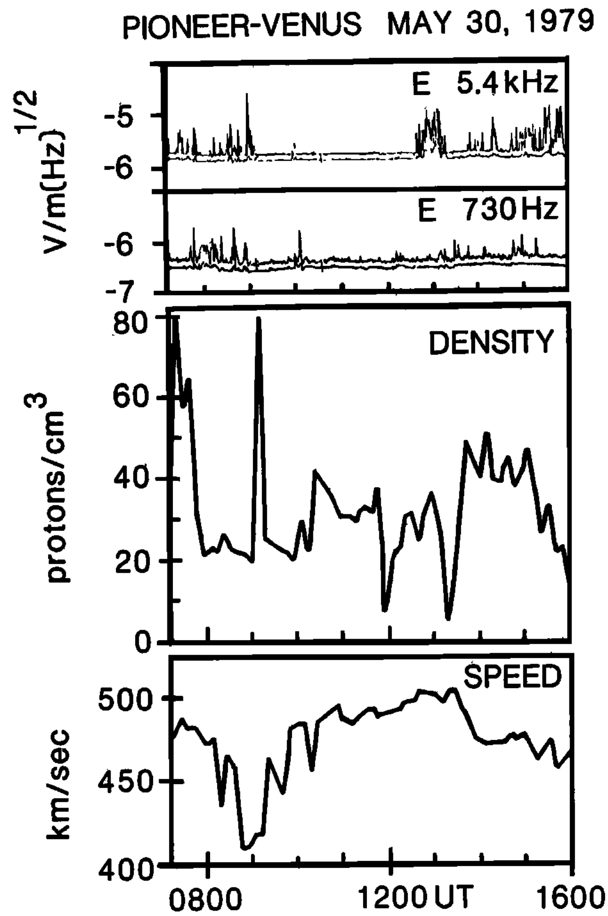

Fig. 4. The same as Figure 2 for orbit 177 with the 730 Hz channel added.

tail of the Maxwellian associated with the protons. This second Maxwellian could be associated with a different ion (e.g., He^+, He^{++}, O^+, O^{++}, etc.) or with accelerated protons. Often the location of the peak of this second distribution does not coincide with the predicted location for He^+ ions travelling at the same speed as protons. If this second population is due to O^+ ions then these ions, which are travelling at considerably lower speeds than the protons, have not yet been accelerated to the shocked solar wind speeds at which they are observed on subsequent orbits (Intriligator, 1982). In any event, it is clear that even far behind Venus we have evidence of large—scale low frequency disorder in the plasma itself, and we have simultaneous observations of intense plasma wave turbulence. In terms of the plasma wave enhancements, the results at Venus and at Titan (Gurnett et al., 1981, 1982) suggest that the interaction of a non—magnetized object with a streaming plasma may produce high turbulence levels in agreement with the recent laboratory results of Intriligator and Steele (1982). It is noteworthy that at Jupiter and at Saturn (Scarf et al., 1979; Gurnett et al., 1981), the noise levels were much lower than the already fairly low levels usually encountered downstream from Earth.

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