Wave-Particle Interactions in the Venus Wake and Tail

D. S. Intriligator

Carmel Research Center

F. L. Scarf

TRW Space and Technology Group

We present the first analysis of Pioneer Venus Orbiter plasma, electric field, and magnetic field observations in the Venus tail. We have studied the first season of Pioneer Venus Orbiter tail passage (approximately June 1979) in order to determine the main plasma and field configuration in this region at this time and to ascertain some of the basic physical processes. Our analysis shows that the boundary of the Venusian tail is often characterized by changing plasma distributions and enhanced plasma wave activity. We use summary plasma probe parameters to argue that the waves are Doppler-shifted ion acoustic oscillations. In the magnetotail region there is generally an exclusion of high-density plasma, but when plasma is detected, the distributions often appear to be non-Maxwellian at the highest time resolution, and these distorted distribution functions are generally accompanied by enhanced plasma wave signals and magnetic field reversals indicative of electric currents. On the basis of our analyses of the high-resolution plasma and wave observations for orbit 189, we identify a different time from that previously defined on the basis of the magnetic field data for the spacecraft entrance into the magnetotail. The wave activity in the Venus tail appears similar to the broadband noise identified in the earth's tail, but at Venus the levels are usually higher.

INTRODUCTION

In 1967, close-in observations from Venera 4 and Mariner 5 first demonstrated that Venus has no significant planetary magnetic field, while more distant measurements from Mariner 5 showed that a tail-like magnetic field developed behind the planet (see, for example, Russell [1979] and Bauer et al. [1977]). During its Venus flyby, Mariner 10 also traversed the distant wake region [Bridge et al., 1974; Ness et al., 1974; Lepping and Behannon, 1978]. Subsequently, detailed information on the location of the Venus tail and the characteristics of the plasma and magnetic field out to about 4 \( R_V \) came from analysis of measurements on the Venera 9 and 10 orbiters [Gringauz et al., 1976; Vaisberg et al., 1976; Verigin et al., 1978; Romanov et al., 1979; Breus, 1980; Dolginov et al., 1980; Russell, 1976a, b]. The Pioneer Venus Orbiter (PVO) provided the first opportunity to investigate the tail out to a distance of 12 \( R_V \), and it also provided the first opportunity to study plasma wave phenomena in this region. Mihalov et al. [1980] initially showed that the cavity does extend out well beyond 4 \( R_V \), and they tentatively identified energetic O\(^+\) ions in the distant wake. Russell et al. [1981] then examined the Pioneer Venus magnetic field and plasma wave data; they demonstrated that a well-defined magnetic tail exists and that the tail boundary is often characterized by changes in the plasma wave spectrum.

Intriligator [1982] continued the study of the tail by analyzing the simultaneous heavy ion and proton observations for the June 1979 PVO distant tail crossings. This study provided clear evidence for the intermittent presence of heavy ions near the boundary of the tail and identified O\(^+\) as the prevalent constituent of the heavy ions. The O\(^+\) number densities were found to be of the order of 1\% of those of the protons. The speeds and flow angles (azimuthal and polar) of the heavy ions and the protons were found to be similar. Perez-de-Tejada et al. [1982] examined simultaneous plasma and magnetic field data from PVO in the wake region for the June 1979 tail crossings and found that the accelerated planetary O\(^+\) ions tend to move in the direction of the shocked solar wind flow and not necessarily along the local magnetic field direction as predicted for ion pickup in comets [Alfven, 1981; Brandt, 1976]. Recently, Mihalov and Barnes [1982] examined the plasma observations for the June 1979 crossings of the distant wake and tail, and they provided descriptions of the morphology of O\(^+\) in the wake.

In this paper we present the first descriptions of combined tail measurements from the Pioneer Venus plasma analyzer, magnetometer, and plasma wave detector. Our study employs the observations from the first season (approximately June 1979) of the PVO tail passage. We have studied in detail the simultaneous plasma and field data from orbits 180–195, but in this paper we concentrate on the analyses for orbits 188, 189, and 191. These orbits are representative of the first tail passage with the exception of the exit from the tail on orbit 191, which is atypical as discussed below in the summary observations and discussion sections. The Orbiter measurements show that the boundary of the magnetotail is often characterized by changing plasma distributions and enhanced plasma wave activity. We use summary plasma analyzer parameters to show that the waves can be identified as Doppler-shifted ion acoustic oscillations. In the magnetotail region there is generally an exclusion of high-density plasma, but when plasma is detected, the distributions usually appear to be non-Maxwellian at the highest time resolution (i.e., one flux reading with its associated polar and azimuthal directions at a given \( E/Q \) step per revolution (see next section for summary of relevant instrument operation)). These distorted distribution functions are generally accompanied by enhanced plasma wave signals and magnetic field reversals indicative of electric currents. On the basis of our analyses of the high-resolution plasma and wave observations for orbit 189, we identify a different time from that previously defined on the basis of the magnetic field data for the spacecraft entrance into the mag-
Fig. 1. Simultaneous 30-kHz, 5.4-kHz, and 730-Hz plasma wave signals, magnetic field measurements [Russell et al., 1981], and the plasma proton density and speed in the vicinity of the tail on orbit 188. The proton parameters were calculated from the plasma analyzer energy and angular scans, using the comprehensive multicomponent ion species moment calculation developed at Carmel Research Center [Intriligator and Scarf, 1982].

netotail. We also demonstrate that the wave activity in the Venus tail appears similar to the broadband noise identified in the earth's tail, but we note that at Venus the levels are usually higher.

SUMMARY OF RELEVANT INSTRUMENT OPERATION AND DATA PROCESSING

Orbiter Electric Field Detector (OEFD)

The OEFD operation is described by Scarf et al. [1980a, b]. The wave instrument signals are processed with a four-channel spectrum analyzer having 30% bandwidth filters with center frequencies at 100 Hz, 730 Hz, 5.4 kHz, and 30 kHz. For the data employed in this study the spacecraft transmitted at 1024 bits/s yielding two plasma wave scans per second.

In Figure 1 and subsequent summary and high-resolution figures, the broad decrease in the amplitude of the 30 kHz, 5.4 kHz, and the 730 Hz signals (e.g., beginning near 1415 UT) is associated with the spacecraft's entrance into optical shadow [Scarf et al., 1980]. At these times the local interference signal from the solar cells decreases as shown in the figure. In Figures 1–3 we have omitted the 100-Hz channel data, since in this region it has large interference from the spacecraft solar panels.

The OEFD peak broadband noise spectra, such as the one shown in Figure 8, cover the frequency range from 100 Hz to 30 kHz. The in-flight threshold levels for this investigation (and for other wave investigations using short electric field antenna systems) are presented by Scarf et al. [1980b].

Orbiter Plasma Analyzer (OPA)

The plasma analyzer operation is described by Intriligator et al. [1980] and Intriligator [1982]. The plasma analyzer is a curved-plate electrostatic analyzer covering the energy per unit charge (E/Q) range from ~0 to 8 kv in 32 steps logarithmically spaced in energy [Intriligator et al., 1980]. The OPA measures the plasma at one E/Q step per spacecraft revolution at all azimuthal angles on all five collectors and transmits the peak flux reading and the associated azimuthal angle and collector number. The collector number is indicative of the polar (north-south) flow [Intriligator et al., 1980]. After each 32-step E/Q scan there are detailed azimuthal and polar scans obtained at the four E/Q steps around the peak.

The plasma parameters shown in Figure 1 and subsequent figures were calculated by using the comprehensive multiple ion species moment calculation [Intriligator and Scarf, 1982] developed at Carmel Research Center. The time shown for each plasma parameter is the time of the end of the complete instrument cycle (i.e., after the E/Q scan and the angular scan) as described above and by Intriligator et al. [1980]. As shown in the high time resolution data discussed below, for the orbits examined in this paper the complete instrument cycle is about 9 min in duration. It is important to note that the calculation of plasma parameters assumes that the plasma distribution is steady during each plasma E/Q spectrum; if this is not the case, then the parameters cannot be interpreted without fur-
higher voltages. Thus it should be noted that while the be-
has more E/Q steps at the lower voltage range than at the
proton distributions) change very rapidly over wide ranges.
Figure 4 and subsequent plots) align in time with the corre-
ginning and end points of each E/Q scan precisely (i.e., for
have increasing plate voltage (E/Q) with time (i.e., they make
plasma wave measurements. Since the plasma analyzer scans
aligned to coincide with the corresponding times of the
chronized [Intriligator and Scarf 1982], since the plasma ana-
alyzer scans have increasing plate voltage (E/Q) with increasing

In Figure 4 and the subsequent high-resolution figures, the
plasma analyzer and plasma wave time scales shown are syn-
chronized [Intriligator and Scarf, 1982], since the plasma ana-
lyzer scans have increasing plate voltage (E/Q) with increasing
these plots show the instantaneous variation in flux
with time. The start and stop times of each of the plasma
analyzer ion energy per unit charge (E/Q) scans (e.g., the
beginning and end of the horizontal axis in each box) have been
aligned to coincide with the corresponding times of the
plasma wave measurements. Since the plasma analyzer scans
have increasing plate voltage (E/Q) with time (i.e., they make
one E/Q step per revolution of the spacecraft), the instrument
has more E/Q steps at the lower voltage range than at the
higher voltages. Thus it should be noted that while the be-
ning and end points of each E/Q scan precisely (i.e., for
Figure 4 and subsequent plots) align in time with the corre-
sponding plasma wave measurements, within the E/Q scan on
this linear plot the times of the measured plasma distribution
may not precisely line up with the corresponding plasma wave
measurements. However, the precise time of each point in the
plasma distribution is known and is utilized where relevant.
The number of the collector measuring the peak flux in each
E/Q spectrum [Intriligator et al., 1980] is indicated in each
box in Figure 4. In all the measurable E/Q spectra in Figure 4
the collector measuring the peak plasma flux is collector 3,
indicating that during this interval the peak proton flux is
consistently flowing near the ecliptic (e.g., ±7.5° of the space-
craft equatorial plane).

SUMMARY OBSERVATIONS

In the vicinity of the tail on orbit 188, Figure 1 shows the
1-min peaks and averages of the 30-kHz, 5.4-kHz, and 730-Hz
electric field from the plasma wave detector [Scarf et al.,
1980a, b], the 1-min average magnetic field in spacecraft coor-
dinates (taken from the work of Russell et al. [1981]; see their
paper for the definition of the coordinate system) and the
equivalent steady state plasma density and speed derived from
the plasma analyzer [Intriligator et al., 1980]. The spacecraft
trajectory for orbit 188 is shown in Figure 4. Enhanced 5.4-
kHz signals are evident just outside the tail, as reported by
Russell et al. [1981]. In the magnetotail the magnetic field is
usually predominately parallel or antiparallel to the X direc-
tion, i.e., either toward or away from the planet [Russell et al.,
1981]. There are frequent reversals of the field within the mag-
etotail. The plasma parameters in Figure 1 indicate that in
the magnetotail there is a general exclusion of high-density
plasma.

Comparison of the 5.4-kHz electric field channel, magnetic
field, and plasma parameters in Figure 1 indicates the excel-
lent agreement between all three parameters as to the space-
craft’s entrance into and exit from the tail (i.e., the region
designated “magnetotail” in Figure 1). The enhanced 5.4-kHz
plasma wave signals on the boundary, and the change in mag-
etic field orientation and the absence of measurable plasma
just before 1200 UT, all provide a clear signature of the space-
craft’s entrance into the tail. The spacecraft’s exit from the
magnetotail just before 1800 UT is indicated by the onset of
the 5.4 kHz-enhancement, the change in the magnetic field
orientation, and the presence of measurable plasma. Within
the tail the intervals when measurable plasma is present (e.g.,
before 1300 UT) appear to be associated with magnetic field
reversals and on some occasions are accompanied by 5.4-kHz
bursts. We will examine the relationship of the higher time
resolution electric field observations to the high time resolu-
tion plasma distributions in this region in the next section.

It is useful to examine the plasma, wave, and magnetic field
observations for another orbit. Figure 2, which is similar to
Figure 1, shows the 30-kHz, 5.4-kHz, and 730-Hz channel
plasma wave signals, the magnetic field observations [Russell
et al., 1981] and the plasma density and speed for orbit 191.
Russell et al. [1981] noted there were no enhanced 5.4-kHz
plasma wave signals in the vicinity of the exit of the mag-
etotail, and this is evident in Figure 2. We note that the one
prominent density peak in the tail (e.g., between 1230 and
1300 UT) is correlated with a burst of 5.4-kHz noise. This
density peak is also correlated with a rather prolonged re-
versal in the X component of the magnetic field.

In Figure 2 there are a few other examples of measurable
plasma within the magnetotail. For example, after 0900 UT
when the spacecraft made its initial entrance into the mag-
In our study of the plasma and wave observations in the magnetotail near 1900 UT, there is a disturbance recorded in the plasma, magnetic field, and electric field parameters. This discontinuity is particularly intriguing, since it occurs when the spacecraft is in a region that is closer to the planet than the regions sampled earlier. Moreover, in terms of the distance perpendicular to the sun-Venus axis, at 1900 UT the spacecraft is relatively close to the previously observed boundary of the magnetotail as indicated in the trajectory for this orbit shown in Figure 9. However, based on the available information we cannot unambiguously determine whether this discontinuity is associated with the flapping of the boundary of the tail past the spacecraft or with the downstream passage of an interplanetary discontinuity originating upstream in the solar wind.

In our study of the plasma and wave observations in the magnetotail region, we have found a general correlation near the boundary of the tail between changing plasma distributions and enhanced plasma wave signals with the exception of the spacecraft exit from orbit 191 as noted above. On the basis of this correlation we have identified the magnetotail on orbit 189 as illustrated in Figure 3. While we generally agree with the magnetotail identifications by Russell et al. [1981], this identification of the magnetotail on orbit 189 is different from that previously defined on the basis of the magnetometer data. Our identification, however, is consistent with the plasma observations as discussed by Intriligator [1982]. The changes in the magnetic field between ~1200 and 1400 UT in Figure 3 were associated with the magnetotail by Russell et al. While there are some changes in the plasma and wave observations during this time, we associate these phenomena with a boundary layer. We identify 1400 UT as the beginning of the magnetotail on the basis of the general exclusion of measurable plasma and the 5.4-kHz and 730-Hz signals. In the discussion section we will reconsider the correlated plasma distributions and plasma wave enhancements, attributing these measurements to detection of Doppler-shifted ion waves.

**HIGH-RESOLUTION ANALYSIS: A CASE STUDY**

In order to investigate further the relation of the plasma analyzer and plasma wave measurements to Venusian tail associated phenomena, we present here the detailed plasma analyzer and plasma wave observations from 1015 to 1920 UT on orbit 188. Figure 4 shows higher time resolution observations (12-s peaks and averages) of the 5.4-kHz and 730-Hz electric field amplitudes from the plasma wave experiment and the corresponding plasma ion distributions from the plasma analyzer experiment from 1015 to 1215 UT. The trajectory plot for orbit 188 in a rotated coordinate system, where the vertical axis is the distance perpendicular to the sun-Venus line, is also shown.

For the ion E/Q spectra of Figure 4 and subsequent plots the low-energy particle population is identified as shocked solar wind protons [Intriligator, 1982; Intriligator and Scarf, 1982]. The high-energy shoulder adjacent to the proton distribution is associated with shocked solar wind alpha particles. This shoulder also may include a high-energy tail of the solar wind protons [Intriligator, 1982; Intriligator and Scarf, 1982].
hanced 5.4-kHz signal at 1045 UT could be associated with this acceleration process. Similarly, the enhanced 5.4-kHz signals from 1050 to 1132 UT may be associated with the decrease in the speed of the low-energy plasma peak (e.g., the proton peak) in the corresponding plasma distributions in Figure 4. This decrease in speed is particularly evident in the plot of the proton speed in Figure 1.

In Figure 4 in all the spectra the peak proton flux is measured on collector 3. In these spectra the peak heavy ion flux is also measured on collector 3. This similarity in the polar (north-south) flow directions for the protons and the oxygen ions in this region is consistent with the results of Intriligator [1982]. In the $E/Q$ scan beginning near 1135 UT, the $E/Q$ location of the second peak is not high enough for us to identify it as being associated with oxygen ions unless these $O^+$ ions have not yet been accelerated up to speeds comparable to those of the protons. If this peak were associated with oxygen ions their speed would be less than 150 km/s, which is considerably less than the proton speed (e.g., 210 km/s) at this time. The peak flux of this second peak in this $E/Q$ scan is not measured on collector 3 (the central collector). It is measured on collector 2 [Intriligator et al., 1980]. With regard to the azimuthal (east-west) flow directions, the directions associated with the peak proton and $O^+$ fluxes in Figure 4 are similar to those reported by Intriligator [1982].

Comparison of the plasma distributions and the plasma wave signals indicates that the spacecraft entrance into the magnetotail at 1145 UT is accompanied by the absence of measurable plasma and the absence of enhanced signals in the plasma wave channels; the boundary of the tail (e.g., 1045-1145 UT) is associated with changing plasma distributions and enhanced signals in the 5.4-kHz channel.

Figure 5 shows the plasma distributions and the higher time resolution 5.4-kHz and 730-Hz signals from 1215 to 1415 UT on orbit 188 when the spacecraft is in the magnetotail. The appearances after 1232 UT of measurable plasma fluxes are accompanied by enhanced signals in the 730-Hz channel. The shape and location in $E/Q$ of the plasma distributions in Figure 5 are varying. Generally, however, the high-energy distributions do not appear to be Maxwellian. The collectors associated with the peak fluxes are also varying (e.g., collector 2 at ~1302 UT and collector 3 at ~1310 UT).

There is a low-energy (proton) peak present in the first two spectra showing measurable plasma fluxes. The proton parameters corresponding to these two low-energy peaks are shown in Figure 1. The plasma parameters in Figure 1 for these two cycles are based on the energy scan measurements only, since in this region the intervals of measurable plasma are so intermittent that for the angular scan of the spectrum near 1230 UT there was no measurable plasma at the energies sampled. For the angular scan of the next spectrum measurable plasma was only partially present. Similarly, the other plasma parameters shown in Figure 1 associated with the higher time resolution data in Figure 5 (e.g., the spectrum beginning near 1300 UT) are based on the energy scan observations only, since no measurable plasma was observed during the angular scan. These parameters have been derived by assuming that these peaks are associated with protons. For the 1300 UT spectrum, for example, the speed shown in Figure 1 is a little more than 600 km/s; however, if this spectrum were associated with $O^+$ ions rather than protons, then the speed would be of the order of 150 km/s. While there are measurable plasma distributions observed in the energy scans beginning near 1250, 1310, 1320, 1335, and 1345 UT as shown in Figure 5, these lead to proton densities less than approximately 1 cm$^{-3}$, so that they have not been included in Figure 1.

We note that while there are some enhancements in the 5.4-kHz channel in Figure 4 as discussed above, there are very few enhancements in the 730 Hz channel during the time period covered in Figure 4. In contrast, during the 1215-1415 UT interval shown in Figure 5 there are numerous enhancements in the 730-Hz channel and very few enhancements in the 5.4-kHz channel. In the work of Intriligator and Scarf [1982], we commented on the apparent correlation between the enhancements in these plasma wave channels and the presence of the higher energy component of the plasma distribution. During the 1215-1415 UT time interval the plasma distributions are generally more energetic than the distributions during the 1015-1215 UT interval, with the exception of the three spectra that also indicate the presence of $O^+$ ions.

Figure 6 shows the plasma distributions and plasma wave signals from 1415 to 1615 UT. The decrease in plasma wave amplitudes is associated with the spacecraft entry into the optical shadow [Russell et al., 1981]. The 5.4-kHz peak near 1500 UT is due to the exit of the spacecraft from the optical shadow. The changing plasma distributions and the changing
collectors associated with the peak flux are evident in Figure 6. As in Figure 5, the intermittent presence of measurable plasma is also evident.

As in the case of some of the spectra in Figure 5, the observations of measurable plasma in Figure 6 are so intermittent that no significant plasma fluxes were measured during the angular scans. Thus the plasma parameters included in Figure 1 for the time period corresponding to the higher time resolution observations in Figure 6 are based only on the measurements obtained during the energy scans. As in the previous cases discussed above, only those plasma parameters associated with a density of greater than approximately 1 proton cm$^{-3}$ have been included in Figure 1.

There are no large real enhancements in the 5.4-kHz channel in Figure 6 (i.e., we exclude the peak associated with the reemergence of the spacecraft into sunlight). This is consistent with the 5.4-kHz observations shown in Figure 5 and with the 5.4-kHz observations in Figure 4 subsequent to the entrance into the magnetotail (i.e., after 1145 UT). Thus there is a striking absence of enhancements in the 5.4-kHz channel in the magnetotail on orbit 188. We will show additional 5.4-kHz observations in the magnetotail on this orbit in the next figure. With regard to the enhancements in the 730-Hz channel, Figure 6 indicates that the plasma wave activity in this frequency range also is quite low during this interval (again we are excluding the signals recorded in association with the spacecraft's traversal of the optical shadow region) in contrast to the 730 Hz observations during the period shown in the previous figure. These quiet levels continue in the magnetotail for almost another 1.5 hours, as shown in Figure 7.

Figure 7 presents the plasma distributions and plasma wave signals from 1615 to 1920 UT. A few enhanced plasma wave signals are observed between 1615 and 1705 UT. These are associated with changing plasma distributions and changing angles of polar flow (as indicated by the changing collector numbers). The exit of the spacecraft from the magnetotail at 1750 UT is associated with the persistent appearance of measurable plasma distributions and enhanced 5.4-kHz and 730-Hz signals.
730-Hz plasma wave signals. Particularly large increases in the 5.4 kHz signals appear to occur between 1750 and 1755 UT and between 1840 and 1850 UT when the polar flow angles of the peak plasma fluxes are varying.

In Figures 4-7 it is tempting to associate the intermittent appearances of measurable plasma fluxes and enhanced plasma wave signals with currents flowing in the magnetotail. To investigate this possibility further, we can compare the higher time resolution plasma and wave measurements with the 1-min average magnetic field measurements in Figure 1. From this comparison of our higher time resolution measurements in Figures 4-7 with the magnetic field observations in Figure 1, we can ascertain that in the magnetotail the intermittent plasma fluxes and the enhancements in the plasma wave channels are associated with changing magnetic fields, particularly in the BX component. These field reversals are indicative of electric currents. Orbit 188 passes close to the expected center of the aberrated magnetotail and the spacecraft trajectory through the tail was nearly parallel to the expected current sheet position. Thus the drifts could be associated with field-aligned currents or with currents not aligned with the field.

**Broadband Noise Within the Magnetotail**

Figure 8 compares the characteristic peak broadband noise spectrum in the Venusian tail measured by the PVO plasma wave experiment with the comparable high intensity noise spectrum measured in the earth's tail from IMP 8 [Gurnett et al., 1976]. It is evident from Figure 8 that the broadband noise level in the Venusian tail is considerably higher than that observed in the earth's tail. In the earth's magnetotail regions of increased broadband noise are observed in conjunction with gradients in the magnetic field and plasma parameters. The generally enhanced levels in the Venus magnetotail are also associated with boundaries, suggesting that similar wave-particle interactions develop on the flanks of the tail at earth and Venus.

**Wave-Particle Interactions Within the Magnetotail**

While Figures 4-7 show some evidence of wave-particle interactions within the magnetotail, a more striking example occurred on orbit 191. Figure 9 presents the relevant plasma
distributions and the plasma wave signals in the 30-kHz, 5.4-kHz, 730-Hz, and 100-Hz channels from 1030 to 1230 UT. The format of this figure is similar to that in Figures 4–7, but at the top of the figure we have included an enlarged version of the plasma distribution measured near 1115 UT, which we discuss in detail below. Figure 9 shows the generally quiet nature of the plasma signals in the 30-kHz, 5.4-kHz, and 730 Hz channels and the general lack of measurable plasma during this time. The noticeable presence of measurable plasma near 1115 UT appears to be correlated with an enhanced signal in these three plasma wave channels. The 100-Hz channel is noticeably noisy throughout the entire time interval shown in Figure 9, indicating the presence of solar array noise and low-frequency waves. Thus we have in Figure 9 a dramatic example of the sudden appearance of measurable plasma and the apparently correlated enhancements in all four plasma wave channels.

An examination of the plasma distribution near 1115 UT indicates the presence of a low-energy peak and then two additional peaks at higher energies that are more intense. A fourth peak is also evident at even higher energies. The lowest energy peaks in the plasma distribution near 1115 UT can be associated with protons having a bulk speed of about 290 km/s with a density less than 1 cm\(^{-3}\). It is tempting to identify the two more intense peaks at higher energies as higher energy protons (the most intense peak) and alpha particles (the next peak). With this identification these higher energy protons have a bulk speed of about 490 km/s and a density slightly larger than 1 cm\(^{-3}\). If we identify the fourth peak as oxygen ions, their speed is in the range of about 270 km/s. This speed for the oxygen ions is similar to the speed associated with the lowest energy proton peak (i.e., 290 km/s). Both of these speeds are considerably less than the speed associated with the intense higher energy proton peak (i.e., about 490 km/s).

Thus it is possible that at this time we are observing both (1) an ambient tail spectrum with its less intense and less energetic proton and oxygen peaks and (2) a more intense and more energetic plasma blob that may be from the ionosheath. The proton and \(^{16}\text{O}\) speeds of 290 and 270 km/s, respectively, in the less intense portions of the plasma distribution are consistent with the results of the detailed analysis of proton and \(^{16}\text{O}\) speeds during the June 1979 tail crossings presented by Intriligator [1982]. While it is possible that the more intense and more energetic portion of the plasma distribution is evidence of local particle acceleration in the tail, it appears more likely that it is associated with an ionosheath spectrum such as those analyzed by Intriligator and Scarf [1982] and that this blob of ionosheath plasma was sampled by the instruments due to some local fluctuations of the ionosheath boundary. Therefore we could be observing interpenetrating ion beams. Intriligator and Scarf [1982] discussed interpenetrating ion beams in the ionosheath. In the present case, we may have interpenetrating ion beams where one beam is an ambient tail plasma beam and the other beam is an ionosheath plasma beam.

**Discussion**

The observations presented above provide many examples of correspondence between enhanced plasma wave levels and changes in the measured plasma distributions. On orbits 188 and 189 the enhanced 5.4-kHz and 730-Hz plasma wave signals in the vicinity of the exit from the magnetotail correspond with the onset of measurable plasma and the evolution of the plasma distributions. These correlated detections are observed in the same spatial region on both orbits.

As discussed by Intriligator and Scarf [1982], enhanced plasma waves are likely to be ion acoustic oscillations. Doppler shifts are important when slow, short wavelength waves (such as ion acoustic waves) develop in plasmas that flow rapidly past the spacecraft. For orbit 188, for example, the plasma speed in the region of interest is about 250 km/s, so that the 5.4-kHz signals imply ion acoustic wavelengths of 46 m (see equations (1), (2) in the work of Intriligator and Scarf [1982]). The relatively low plasma speeds observed on orbits 188 and 189 imply that the Doppler shifts are somewhat smaller than the ones that are appropriate for the ionosheath (e.g., orbits 176 and 177 studied previously); however, the correlated detections near the exit of the magnetotail on orbits 188 and 189 again appear to be consistent with an ion acoustic wave identification.

Even though the onset of measurable plasma distributions near the exit of the magnetotail on orbit 191 was associated with detection of a few brief enhancements in the 5.4-kHz channel, generally the plasma wave activity was very low in this region on this orbit. The plasma temperatures in the tail boundary regions for orbits 188, 189, and 191 were of the order of 10\(^5\) \({}^\circ\text{K}\). The magnetic field magnitudes (10 \(\mu\)T) and the plasma densities (\(\sim 10\) protons/cm\(^3\)) were similar on orbits 188 and 191. Although the plasma speed was somewhat higher on orbit 191 than on orbit 188 (\(\sim 260-300\) km/s versus 240–270 km/s), it does not appear that this could sufficiently shift the frequencies of the ion acoustic waves so that they did not fall within the observable channels. Rather, the observations imply the absence of wave sources in this region at this time.

Within the magnetotail region on orbits 188 and 191, there appears to be a clear correspondence between enhanced plasma wave levels and the presence of measurable plasma and changing plasma distributions. These changes are often correlated with reversals in the \(B_x\) component of the magnetic field, and this implies the presence of currents flowing in this region. Therefore it is reasonable to associate the enhanced wave activity with a current-driven plasma instability.

It should be noted that "clouds" observed at lower altitudes near the ionopause [Brace et al., 1982] have thermal (ionospheric) plasma enhancements and electric field emissions during \(B_x\) reversals.

The 5.4-kHz enhancements on orbits 188 and 191 detected prior to entering the tail also correspond to changing plasma distributions, including those associated with oxygen ions [Intriligator, 1982]. The multiple peaks in the plasma distributions that were observed on orbit 188 just outside the tail and again within the tail (see Figures 4 and 5) correlate with enhanced plasma wave activity. These may be similar to the beam/beam interactions we observed in the ionosheath [Intriligator and Scarf, 1982].

On orbits 188, 189, and 189 the change in the speed of the ions and the correlated enhancements in the 5.4-kHz and 730-Hz channels may be associated with differential streaming due to decreasing speeds. Intriligator [1982] reported the decrease in speeds of oxygen ions and protons in this region on orbit 189 and suggested that this may be indicative of a shear layer. These changes in the plasma speed (and often the density also) do correlate with enhanced plasma wave levels, thereby indicating that there are specific spatial regions in the vicinity of the tail that are associated with large-scale turbulence and that these regions are present on several orbits.
This result is also consistent with the recent laboratory results of Intriligator and Steele [1982] that indicate that stable spatial regions of enhanced turbulence are formed near the boundary of the obstacle shadow downstream from an unmagnetized obstacle in the solar wind flow.

Since some plasma pressure is necessary to inflate the tail, the intervals associated with an absence of measurable plasma most likely imply the presence of a hot isotropic plasma that is not observable with the PVO plasma analyzer. Thus the correlated plasma and wave detections in the tail are associated with the presence of directed low-energy plasma populations.

The enhanced broadband noise level in the Venusian tail is considerably higher than that observed in the earth's tail and provides another indication of the generally higher levels of turbulence downstream from Venus. These increased turbulence levels could be associated with local particle acceleration.

Cause and effect relationships are never easy to discern, even at earth where we have accumulated much data in the magnetotail and magnetosheath. At Venus we have only begun to study some of the tail-associated phenomena and the data set is quite limited. Eventually, it should be possible to answer such questions as, Do the tail current sheets form from ionospheric or ionosheath plasma? Do the currents cause a plasma instability that creates the waves? Do accelerated heavy ions from the ionosphere interact with the ionosheath plasma to create the waves? Future studies should help us clarify the relation between the various tail-associated phenomena, and they should enable us to learn more about the significance of the wave-particle interactions.

Acknowledgments. This paper represents one aspect of research carried out for NASA Ames Research Center by Carmel Research Center under contract NAS2-10926 and by TRW under contract NAS2-9842. C. T. Russell provided the magnetometer data employed in this study. The authors thank one of the referees for helpful comments. The Editor thanks J. Luhmann and two other referees for their assistance in evaluating this paper.

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D. S. Intriligator, Carmel Research Center, P.O. Box 1732, Santa Monica, CA 90406.

F. L. Scarf, TRW Space and Technology Group, Bldg. R-1, Rm. 1176, One Space Park, Redondo Beach, CA 90278.