On the Causes of Spectral Enhancements in Solar Wind Power Spectra

T. Unti

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91103

C. T. Russell

Institute of Geophysics and Planetary Physics, University of California, Los Angeles, California 90024

Enhancements in power spectra of solar wind ion flux in the frequency neighborhood of 0.5 Hz had been noted by Unti et al. (1973). It was speculated that these were due to convected small-scale density irregularities. In this paper we examine 54 flux spectra, calculated from Ogo 5 data. It is seen that the few prominent spectral peaks which occur were not generated by density irregularities but were due to several different causes, including convected discontinuities and propagating transverse waves. A superposition of many spectra, however, reveals a moderate enhancement at a frequency corresponding to convected features with a correlation length of a proton gyroradius, consistent with the results of Neugebauer (1975).

INTRODUCTION

Measurements of the scintillations of signals from compact radio sources have been interpreted by some radio astronomers as indicating the existence of small-scale electron number density fluctuations or 'blobs' in the interplanetary medium with a scale size of a proton gyroradius. These irregularities, convected in the solar wind, would constitute a separate regime from the low-frequency plasma density variations measured by spacecraft [Hewish, 1972; Matheson and Little, 1971; Rickett, 1973; Houminer, 1973; Coles et al., 1974; Neugebauer, 1975]. However, this interpretation has been called into question [Young, 1971; Cronyn, 1972; Jokipii and Hollweg, 1970], and it has been suggested that the scintillation data could adequately be fit by a power law distribution of irregularity scale size. On the other hand, of 32 power spectra of the solar wind flux obtained by Ogo 5 in the frequency range 0.0048–13.3 Hz by Unti et al. [1973], only about three quarters of the curves could be closely fit by a power law. The remaining curves had small power enhancements in the neighborhood expected for convected proton gyroradius irregularities.

It is the purpose of this paper to examine spectral features of high-frequency solar wind ion flux spectra and compare these ion flux data with the simultaneously measured magnetic field data to determine the nature of the spectral features and thence infer their cause. To do this, we examine spectra and cross spectra of the flux and field data as well as the simultaneous time series. These results show that the spectral features observed by Unti et al. were not generated solely by density irregularities but were due to several causes. Furthermore, all of the well-defined spectral peaks were significantly below the frequency expected for convected proton gyroradius size irregularities. Thus if irregularities with a scale size of a proton gyroradius persist to 1 AU, they represent at best a minor contribution to the measured flux spectrum. The blobs would be more likely to manifest themselves as a modest enhancement in an average of many spectra rather than as gross distortions from power law in individual spectra.

INSTRUMENTATION AND DATA PROCESSING

The solar wind measurements discussed herein were obtained by the Jet Propulsion Laboratory plasma experiment onboard Ogo 5 which had both a Faraday cup detector for the rapid measurement of the positive ion flux and direction and a curved plate analyzer for the slower determination of solar wind velocity, temperature, and composition. These instruments and the data reduction methods employed have been described by Graham and Vescelus [1967] and Neugebauer [1971]. In the data analyzed here, the highest acquisition rate for ion flux measurements was 36 ms. These measurements were averaged to yield an 'equivalent measurement' every 288 ms (the details are given in the appendix of Unti et al. [1973]). The solar wind direction was measured every 1.152 s, and the remaining solar wind parameters were determined every 5.184 s.

The magnetic field measurements were obtained with the University of California at Los Angeles flux gate magnetometer on the same satellite [Snares and Benjamin, 1966]. The field values are quantized to $\pm 0.0025 \gamma$. The absolute accuracy of the readings is limited to roughly $1 \gamma$ by slowly varying spacecraft fields and sensor drifts. In the data discussed here, field readings, obtained every 18 ms, have been corrected by comparison with Explorer 33 and 35 magnetometer data unless otherwise noted. These values were then averaged to one sample every 288 ms for comparison with ion flux data. All field data used in this paper are presented in a coordinate system in which the z axis is parallel to the average field, the y axis is perpendicular to the earth-spacecraft line, and the x axis has a positive component in the direction from the spacecraft toward the earth.

The power spectra were calculated according to the method of Blackman and Tukey [1959], with coherence and phase of the cross-spectral calculations as explained by Jenkins and Watts [1969]. Many spectra were also calculated by using fast Fourier transform methods. Similar if not identical results were obtained throughout.

POWER SPECTRAL ANALYSIS OF THE ION FLUX DATA

In order to obtain data which covered the frequency range expected for convected gyroradius features we restricted our analysis to data obtained at the highest data rate available on Ogo 5, analyzing every case which was not clearly associated with other shock effects and some cases that were. This resulted in 54 flux spectra, 32 of which are presented in Figures 1 and 2. Of the spectra not shown, three are shown in the article by Unti et al. [1973], and 19 were from intervals in which the
magnetic field exhibited fluctuations characteristic of bow shock associated disturbances [Fairfield, 1969; Russell et al., 1971]. The data acquisition pattern and the division of the spectra into two or three overlapping frequency segments are performed in the same manner as that used by Unitt et al. [1973].

The first 28 spectra are ordered chronologically (from left to right and top to bottom) according to the starting time of their data intervals. In the following discussion they will be designated by their corresponding day-hour-minute (day 1 is January 1); e.g., the first spectrum in Figure 1 will be referenced as 70-07-24. These 28 'short' spectra were computed from ~80-s data intervals; their frequency interval extends from 0.018 to 13.3 Hz. Beyond about 10 Hz the spectra usually have no significance; the tails are 'hooked' due to aliasing, or they may dip into the instrument digital noise level. The upper limit of the noise level is at 11.3 on the ordinate scale; however, the actual digitization noise would generally run 3–5 dB lower.

Occasionally, there were four sequential sets of data which could be combined to yield lower-frequency spectra; the last panel of four spectra in Figure 2 was obtained in this manner. These 'long' spectra were computed from data intervals of about 51 min and have a frequency range from 0.0048 to 13.3 Hz (they will be referenced with an L prefix, e.g., L71-16-29).

The vertical line near the lower left corner of the first spectrum in Figure 1 represents the size of the interval (5 dB) into which 90% of the spectral estimates should fall. The 5-dB vertical line is the 90% confidence interval for every flux and field spectrum shown in this paper. The bandwidths of the individual spectral segments for low, middle, and high frequencies are 0.035, 0.14, and 4.11 Hz, respectively.

It is seen that two of the spectra show strong enhancements in the neighborhood of 10−4 Hz; these are spectra 71-16-43 and 76-19-46. A third strongly enhanced spectrum was exhibited and discussed by Unitt et al. [1973]; it will be analyzed further in the following section. Some of the spectra show mild enhancements or at least flattening in this frequency neighborhood, e.g., 71-10-09 and 76-19-49. Many spectra display excess power just below 10−4 Hz, at the region of overlap of the low- and high-frequency segments, e.g., 70-07-27, 70-08-21, and 71-15-41. Spectra such as 71-16-26 give no indication of enhancement but merely show statistical fluctuations about a base power law line.

Each of the first three panels of Figure 2 consists of a sequence of four spectra computed from consecutive data sets (explained above). Apparently there is no coherent evolution of an enhancement from one data interval to the next; this is particularly evident in the quartet of spectra beginning with 76-19-46. The pronounced hump near 10−4 Hz all but vanishes in the next 80-s interval, and the slight rise in 76-19-48 is not statistically significant. In 76-19-49 the enhancement is again present. Although it is not as prominent as it was before, it spans the same frequency range. In 76-19-50 the enhancement degenerates to strong oscillations. Similarly, clear trends are not discernible in the quartets beginning with 71-16-29 and 71-16-40. An interpretation in terms of variable density blobs would suggest that the blobs tend to be bunched rather than uniformly distributed.

Spectrum L71-16-29 was computed from the sequence of data intervals 71-16-29 through 71-16-33. The mid-frequency and high-frequency segments are averages of the four consecutive short spectra shown in the first panel of Figure 2. Similarly, L71-16-40 is the composite long spectrum corresponding to the second panel, and L76-19-46 corresponds to the third panel. (The four short spectra corresponding to L73-08-10 were not individually computed.)

Except for three spectra (71-16-43, 76-19-46, and Figure 7 of Unitt et al. [1973]), most of the enhancements are very small, falling within the 90% confidence limits of statistical fluctuations. However, it is statistically unlikely that several successive points should rise above an average base curve. For example, 60% confidence limits would correspond to a vertical
interval half the size of the 90\% limit shown in the first spectrum of Figure 1, or one quarter of a unit interval on the ordinate axis. The probability that k consecutive points would be one eighth of a unit interval above an average curve would be (0.4)^k if the spectral estimates were independent. Since the estimates are not completely independent, the probability lies between (0.4)^{1/4} and (0.4)^{1/2} [Blackmun and Tukey, 1959, p. 147]. Thus even a mild enhancement (one eighth of a unit interval on the vertical axis) consisting of four or more consecutive points has only a small probability of being a statistical fluctuation.

Each 'data point' used in the computation of the low-frequency segments of the short spectra and the mid-frequency segments of the long spectra is the average of three flux measurements spaced 0.036 s apart. To be certain that this averaging had no undesired effect on the spectral curves, 12 of the spectra were recomputed by using each point of the trio of points individually. In every case it was found that averaging the points served only to reduce aliasing at the high-frequency tail of the curve.

In order to investigate the cause of the enhancements we selected 19 of these intervals for cross correlation with the magnetic field. Before discussing those intervals of possible gyroradius irregularities we will examine the effects of bow shock associated waves on the ion flux and the field.

**Bow Shock Associated Disturbances**

Since the Ogo 5 orbit never carries the satellite more than roughly 10 R_s from the bow shock, the question arises whether the humped spectra are associated with effects upstream from the bow shock. Therefore 19 data segments were analyzed which contained strong magnetic fluctuations of the type associated with upstream bow shock effects [Greenstadt, 1968; Fairfield, 1969; Russell et al., 1971; Childers and Russell, 1972]. Also, four segments of data in which waves of this type were apparently present but whose amplitudes were much reduced were included in Figure 1 (top panel).

A typical bow shock disturbed data interval, with spectra and cross spectra, is 70-07-39, shown in Figure 3. The presence of bow shock associated waves is evident in the first half of the data in which the flux and the field are strongly affected. The power spectra have slopes considerably steeper than -2. At low frequencies the cross spectra show high coherence at zero phase between the flux and the field magnitude, as might be expected for a large-amplitude low-frequency compressional wave.

The situation may be quite different for mild contamination. The magnetic field fluctuations during the interval corresponding to the first panel of spectra in Figure 1 gave indications of weak to moderate influence from the bow shock. Further, the field data indicated that Ogo was situated on a field line most probably connected to the bow shock. It is seen that some spectral flattening occurs in the overlap regions of 70-07-24, 70-07-27, and 70-07-28. However, none of these flux spectra nor any of the strongly affected spectra exhibited a clearly defined peak, nor did any of the field spectra. No examples of discrete wave packets [Russell et al., 1971] which lead to peaked spectra at frequencies of about 0.4 Hz were found in these data. Finally, we note that there was no evidence of interpenetrating ion streams [Feldman et al., 1973] in any of the data.

The vertical line to the left of the curve in cross spectrum 70-07-39, F \times B, is equivalent to 1 standard deviation, i.e., the interval into which 68\% of the points should fall statistically. This interval is the same for all the cross spectra between flux and field presented in this paper. The confidence intervals for the phase spectra are harder to obtain, since the interval at any frequency depends upon the magnitude of the coherence at that frequency. (A discussion is given by Jenkins and Watts [1968, p. 380]). On the Figure 3 flux spectrum and those spectra to follow we have indicated with an arrow the frequency corresponding to irregularities with a correlation length of one proton gyroradius convected with the solar wind velocity past the spacecraft [Neugebauer, 1975]. The corresponding frequency is \( \sim 2\pi \) less than that of a periodic disturbance with a wavelength of a proton gyroradius.

**Cross-Correlation Analysis**

In this section we examine the cross correlations between flux and field, beginning with the three cases whose spectra exhibited the most prominent flux power enhancements. These were also the only cases that yielded strong coherences between flux and field.

**Event 76-19-46.** The data, spectra, and cross spectra of flux and field for 76-19-46 are shown in Figure 4. (Note that the ordinate scale of the data varies from one figure to the next.) A strong power enhancement is evident in the flux spectrum. Enhancements are also present in the spectra of field components and field magnitude. The amplitudes of the fluctuations in the B_x and B_y data are considerably greater than those in B_z and B. (Since the coordinate system is oriented such that the average field lies along the z axis, fluctuations in B_x are almost duplicated by fluctuations in the field magnitude B. A strong correlation and coherence at zero phase would then be expected between B_x and B.)

The coherence between the flux and B_x is very high, rising to a peak of 0.95 at 10^{-3} Hz, which indicates that the oscillations centered about a period of \( \sim 3 \) s in flux and field are strongly related. This is corroborated by an inspection of the data. The oscillations are roughly 90° out of phase at this frequency. (The statistical uncertainty in phase increases as the coherence decreases. In the plots examined, random behavior in phase usually begins to occur when the coherence drops below about 0.5.) By contrast, the coherence is very low between flux and B_y. In agreement with this the field spectrum of B_y shows only a hint of an enhancement. The coherence and phase of flux with B_z (almost identical to that of B) are quite high, peaking near 0.9.

In both magnitude and slope the magnetic field spectra of Figure 4 and subsequent figures constitute a credible extension to higher frequencies of the spectra near 1 AU presented by Blake and Belcher [1974].

We now consider the possible causes of these waves. First, the field and flux spectra are not as steep as those associated with bow shock contamination discussed in the previous section, and they contain less power. Second, although the spectral enhancement is near that expected for a discrete wave packet associated with the bow shock, the wave packet seen in the time series of the field data is linearly polarized rather than circularly polarized, as was found for all discrete wave packets analyzed [Russell et al., 1971]. Further, the relative amplitude of low-frequency compressional waves is much less than it is in Figure 3. Finally, extrapolating the field line to the average bow shock, we find that the bow shock is distant, greater than 6 R_s, and is encountered at a grazing angle. The closest approach of the field line to the earth is 17 R_s, slightly behind the earth. In view of the rather large solar wind velocity at this time, 600 km/s, it is quite possible that the field line did not intersect the spacecraft's path.
intersect the bow shock at all. These three points suggest that the cause is not bow shock contamination.

If the observed fluctuations are indeed density irregularities, we might expect either of two modes: entropy fluctuations in which the total pressure is constant but \( n \) and \( B \) vary out of phase (nonpropagating fluctuations carried along by the solar wind; cf. Kontrovitz and Petschek [1966]) or compressional waves in which \( n \) and \( B \) vary in phase. Examination of the

Fig. 3. Data, spectra, and cross spectra of bow shock contaminated data. The crosses denote the phase relationship between flux and field. The proton gyrofrequency is marked by an arrow.
Fig. 4. Data, spectra, and cross spectra for event 76-19-46, 1968. Enhancements are evident in both flux and field spectra near $10^{-4}$ Hz, well below the gyrofrequency.
cross spectra shows that the flux and field strength are out of phase at the coherence peak by close to 180°, in accord with the suggestion that these are constant pressure fluctuations. Further, since $\delta$ is low, $\sim 0.5$ (using the measured ion temperature $8.6 \times 10^6 \, ^\circ K$ and assuming a $1.50 \times 10^9 \, ^\circ K$ electron temperature), it would take a 12% change in flux to balance the roughly 3% changes in field strength observed. On the other hand, there is much more power in the transverse than in the compressional component, and these fluctuations are coherent with the compressional component. Thus it would appear that a likely explanation of the flux fluctuations is that they are associated with a propagating wave rather than with an entropy fluctuation. (There are three propagating MHD wave modes in the solar wind: the slow, fast, and intermediate modes. The latter is often referred to as the Alfvén, the former two as the magnetosonic modes [cf. Thompson, 1964].)

There are two possible ways in which flux variations could occur in the absence of real density changes. First, the radial component of velocity could vary, and second, directional fluctuations could couple with the angular response of the Faraday cup. This could be affected by any of the three MHD wave modes. We defer discussion of this point until the section on event 71-16-43, where several additional examples are investigated.

Finally, we note that the frequency expected from the convection of proton gyroradius scale size features past the observer, indicated by the arrow in the flux spectrum, is almost an order of magnitude higher in frequency than the observed peak. Even if we assume that the density irregularities are perpendicular to the field direction and take account of the orientation of the field relative to the flow, the expected frequency is decreased by only 30%. Hence it seems unlikely that the prominent enhancement in flux spectrum 76-19-46 is due to convected high density blobs.

**Event 78-07-02.** The second data interval which yielded high correlations between flux and field, 78-07-02, is given in Figure 5. This is one of the intervals whose flux spectrum was previously shown by Unr et al. [1973]. A considerable amount of quasi-periodic activity appears, with periods ranging from about 2 to 6 s. As in the previous case, fluctuations perpendicular to the average field appear to dominate. A broad enhancement is seen in a frequency region centered at about $10^{-6} \, \text{Hz}$. The spectra of the field components $B_1$ and $B_2$ give evidence of mild enhancements in the frequency region of interest, although the rise is much less prominent than that of the flux spectrum. The coherence between flux and $B_1$ is surprisingly high, being greater than 0.8 over a fairly broad frequency band extending from about $10^{-7}$ to $10^{-1} \, \text{Hz}$. The coherence between flux and $B_2$ is greater than 0.7 over a narrower range, while $\text{coh}(F \times B_1)$ and $\text{coh}(F \times B)$ are somewhat lower.

The extrapolated field line through Ogo 5 again makes a grazing encounter with the bow shock several earth radii downstream from the satellite. However, as in the previous example, we have several indications that these waves are not associated with so-called upstream phenomena. First, the power levels in the field and flux are much less than is normally observed in bow shock associated events as illustrated in Figure 3. Second, the spectra are less steep than those shown in Figure 3. Third, there is little power in compressional oscillations. We note also that as in the previous example, the solar wind velocity was unusually high, 588 km/s, so that the magnetopause and shock front were probably inward of their usual positions.

In this example there is low coherence between field magnitude and flux variations, ruling out the possible interpretation of the solar wind flux variation as density variations associated with either entropy fluctuations or magnetosonic waves. We would expect in either case the field magnitude fluctuations relative to the average field strength to be at least half of the relative flux variations, since the solar wind $\delta$ was 1.3 at this time, using the observed ion temperature of $1.08 \times 10^9 \, ^\circ K$ and assuming an electron temperature of $1.5 \times 10^8 \, ^\circ K$.

As in the previous example, the coherence of the flux is strongest with the transverse field fluctuations. Thus these fluctuations are most probably due to propagating waves which are causing velocity perturbations either along the radial direction from the sun, and therefore along the axis of the Faraday cup, or transverse to the radial direction. In either case, these again do not represent density irregularities. Again, we note that the expected frequency for a convected irregularity lies well above the observed peak.

**Event 71-16-43.** The final data interval to yield high coherences is shown in Figure 6. The highest coherence is between the flux and $B$, and is evidently due to the short wavelet occurring near the middle of the data interval. The spectra of both the flux and $B$ are enhanced at a frequency of about $10^{-6} \, \text{Hz}$, which corresponds to a period of about 4 s. We note in this interval and two subsequent intervals on day 71 that the magnetometer records contain an unknown offset, because of a powering down of the sensors when no correlative data were available. Although the offset does not affect the amplitude of the fluctuations, the coordinate system used may not be precisely aligned with the true field-aligned system.

Again this linearly polarized wave packet has none of the features expected for an upstream wave packet, and no compressional component is observed. Thus either radial velocity or transverse velocity fluctuations must be responsible for the observed flux variations. This is the same conclusion as that arrived at in the previous two examples.

We can test this hypothesis by calculating the flux variations expected due to a transverse wave. Any of the three wave modes could cause variations of the observed magnitude, but since there is little or no compressional component in these waves, let us assume that they are Alfvén waves for simplicity of computation. In this case

\begin{equation}
\frac{b}{B} = \pm v/V_A
\end{equation}

where $b$ is the wave perturbation magnetic field, $v$ is the wave perturbation velocity vector, $B$ is the magnetic field strength, and $V_A$ is the Alfvén velocity. At this time the calculated Alfvén velocity was 64 km/s and $b/B$ (peak to peak amplitude) was $15\%$. Thus the expected velocity fluctuation associated with the wave is 10 km/s. Since the measured solar wind velocity at this time was 383 km/s, the expected flux change for a radial velocity perturbation would be roughly $0.9 \times 10^7 \, \text{cm}^- \text{s}^-1$ compared to the $1.5 \times 10^7 \, \text{cm}^- \text{s}^-1$ observed.

Fluctuations transverse to the radial direction also give rise to flux fluctuations due to the angular response of the Faraday cup, which varies as

\begin{equation}
F(\theta) = (1 - 0.0216\theta - 0.000151\theta^2)
\end{equation}

where $\theta$ is measured in degrees from the center of the cup. A $10\, \text{km/s}$ perturbation perpendicular to the cup axis would change $\theta$ by $1.5\, \text{°}$, adding to the measured $4.7\, \text{°}$ angle of the average unperturbed flow, which in turn would change the flux by $1.5 \times 10^7 \, \text{cm}^- \text{s}^-1$.

In practice, both effects calculated above are present in the data, since the $B_1$ direction has components both along the
Fig. 5. Data, spectra, and cross spectra for event 78-07-02, 1968. A broad enhancement is centered at \(10^{-3}\) Hz in the flux spectrum.

Similar calculations have been made for the fluctuations observed in Figures 4 and 5 with similar agreement. Thus we conclude that the velocity perturbations associated with the hydromagnetic waves are largely responsible for the strongly peaked flux spectra with correlated field oscillations.

Other events. Aside from the preceding three cases there...
were very few data segments which resulted in reasonable and significant coherences. Except for a few cases involving discontinuities, the remaining cross-correlation computations showed low coherences, seldom achieving statistical significance. Several of the data segments yielded predictable results, in that the spectra and coherences were enhanced in the expected frequency range, the amplitudes of the coherences, however, were disappointingly low. This is demonstrated in the following example, which is perhaps typical of a majority of the data.

The data and spectra of 70-08-21 are shown in Figure 7. A low-frequency sinusoid of a period of ~70 s distorts the flux data; the field data are relatively smooth. The flux spectrum begins with a slope steeper than -2, reflecting the low-frequency wave form, and then flattens dramatically around $10^{-4}$ Hz. As can be seen in Figure 1, the high-frequency portion of the spectrum is also raised, this enhancement suggesting added power just below $10^{-4}$ Hz.

The lack of activity at low frequencies in the field data is seen in the corresponding spectra as mild slopes and depressed
low-frequency spectral estimates. Among the field components, only the spectrum of $B_z$ offers no suggestion of an enhancement just below $10^4$ Hz. The remaining curves show a rise from below $10^8$ Hz to their terminal points.

In the cross-spectral plots, small peaks occur at the appropriate places; at a frequency of about $10^4$ Hz the coherences rise beyond 0.6 in $F \times B$, $F \times B$, and $F \times B$. Although these coherences are not high and they occur over a narrow frequency band, it is seen that peaks do occur where they are expected.

A few of the spectra which appeared to be humped or flattened were found to originate from data that contained square waves, strong discontinuities, or other irregularities. A sudden increase or decrease in a data component should not give rise to a spectral enhancement at a particular frequency but would be expected to contribute toward a spectral slope of $f^{-3}$. This is shown in the following example.

Figure 8 presents the spectra of the flux and field data of 71-10-12. There is a sharp discontinuity at $t = 43$ (0.288 s) in the flux and two field components. Although the discontinuity...
Fig. 8. Data, spectra, and cross spectra for event 71-10-12, 1968. A discontinuity occurs at $t = 43$. A small fluctuation in $B_z$ and $B$ is the largest fluctuation along either the $B_y$ or $B$ data curve. Flatting is seen at about $10^{-4}$ Hz in the flux spectrum and in the spectra of $B_y$ and $B$. The spectrum is steeper than the slopes of $B_y$ and $B$. This tends to confirm the observation that oscillation at low frequencies effectively 'lifts' the low-frequency branch and washes out detail along the spectral curve. It is seen that the slopes of the amplitude of the remaining fluctuations which determines the slope of the spectrum.

The coherences are dominated by the discontinuity which contributes heavily to the power at low frequencies. The peak
in \( \text{coh}(F \times B) \) corresponds to a period of \( \sim 20 \) s, which is roughly the extent of the 'boxcar' oscillations in the \( B_y \) data. The negative swing in \( B_y \) is matched by a positive swing in flux and vice versa. The flattening at \( \sim 10^{-7} \) Hz in the spectra of the flux, \( B_x \), and \( B_y \) does not give rise to clear peaks in coherence at this frequency, although again the discontinuity may be responsible for loss of detail.

In a few cases the power spectra of both the flux and the magnetic field showed prominent humps at nearly the same frequency, yet cross-correlation analysis did not yield high coherences. An example of this enigmatic result is given in Figure 9. In each of the spectra an enhancement peaks at about \( 10^{-6} \) Hz. Despite expectations the coherences between flux and field are low. This negative result appears more reasonable upon close inspection of the field and flux data. Although there is a considerable spread in the (Doppler shifted) periods of the oscillations, the dominant period appears to be \( 11.52 \) s. Fluctuations within this period are...
particularly evident in the first half of the $B_z$ data. However, if
vertical lines are extended through the peaks of these oscil-
lations, it is seen that strong coherences do not exist. Some
correlations are evident, e.g., between $B_x$ and flux in the first
half of the data, with a phase difference of about 180°, but this
relationship is not continued into the last half of the data
segment, where the oscillations in flux slip in and out of phase
with the field oscillations. We interpret this to mean that the
direction of propagation of the waves in the first half and in
the last half of the record is not the same.

The situation is similar in 70-07-27 (Figure 10), although the
enhancements are not as pronounced. In three or four exam-
pies in the analyses, the spectrum of a single field component
bore a strong resemblance to the flux spectrum, displaying a
similar enhancement over the same rather broad frequency
range, yet the expected strong coherence was nonexistent. As
can be seen in Figures 1 and 10, the flux spectrum of 70 07 27
is flat over the frequency range from about 10$^{-3}$ to about 10$^6$
Hz. A similar enhancement appears in $B_z$. The coherence be-
tween flux and $B_z$, however, does not rise above 0.5 at any
frequency. Again, it appears that waves with several source locations are present.

Finally, there were some flux spectra that showed flattening near the frequency expected for convected proton gyroradius sized structures; however, the corresponding field spectra exhibited little or no enhancement.

**Summary and Discussion**

We have examined a total of 54 flux spectra computed from the highest-resolution Ogo 5 ion plasma data. Of these, 19 occurred during disturbances associated with the near presence of the bow shock. Of the remaining 35 spectra, only three had pronounced enhancements above 0.1 Hz, although many appeared to flatten just below 1 Hz. For 19 of these intervals, cross correlations between flux and field were computed. Coherences greater than 0.8 were found only for the three cases with prominent enhancements. Each of these three events had strong transverse magnetic fluctuations and almost no compressional component. It is most likely that velocity fluctuations associated with the magnetic fluctuation were responsible for the coherent flux variations.

The cause of the other enhancements varied from convected discontinuities to wave events with broad spectra and varying phases. Some events appeared to be quite dissimilar in flux and field.

In all cases where there was an obvious spectral peak, it occurred well below the expected frequency due to convected structures with a correlation length of a proton gyroradius. (We recall that this frequency is a factor of 2π less than that expected from a periodic structure with a wavelength of a proton gyroradius.) As can be seen in Figures 3–10, the gyroradius is situated at the overlap of the two frequency segments, where aliasing of the low-frequency segment and trends in the high-frequency segment may disguise the presence of convected blobs. For this reason we reproduce the analysis of Neugebauer [1975], in which each power spectrum frequency is shifted by dividing by its gyroradius. Magnetic field data were available for 18 of the short spectra shown in Figures 1 and 2. These spectra were normalized, frequency-shifted, and averaged geometrically. The interesting result is shown in Figure 11. In the low-frequency segment a suggestive hump appears directly over the gyroradius, which is located at 10^6 Hz on the frequency-shifted abscissa. The enhancement is not seen in the high-frequency segment. However, the frequency range of the hump is about 10^{-9}–10^{-8} Hz. In this partition fall 134 points (spectral estimates) for the low-frequency segment, while for the high-frequency segment, only 12 points determine the curve in the neighborhood of the gyroradius.

Work is currently in progress to investigate (1) spectra and cross spectra of the frequency-shifted field components and (2) very low frequency (Mariner 5 data) and very high frequency (Ogo 5 data) field-aligned cross spectra.

It may be appropriate to comment here on the lack of correlation between the ion flux and field fluctuations in the predominantly power law background spectrum. Although definite conclusions cannot be established from a lack of correlation, some constraints can be inferred. If, for example, the spectra were simply the sum of two wave processes, one transverse and one compressive, then one would expect to see correlation between both the x, y components and the z components of flux and field. The implication is that when fluctuations in the data yield negligible correlations, the process must be modeled by the sum of many incoherent contributions. (The correlation is also weakened by the fact that the ion flux measurement is influenced by changes in velocity both parallel to and transverse to the flow, while such velocity fluctuations are not necessarily accompanied by field compressions.)

In conclusion, we have shown that sharp spectral peaks of the type discussed by Uniti et al. [1973] do not correspond to variable density blobs. However, at higher frequencies, corresponding to convected features with a correlation length equal to a proton gyroradius, the data are consistent with the existence of density blobs as reported by Neugebauer [1975]. We note that the enhancement at this frequency is a rather subtle effect, clearly evident only upon the superposition of many spectra. Finally, we recall that the Ogo 5 spacecraft is an earth orbiter, and there always exists the possibility that some of the phenomena studied in this paper are bow shock associated despite our attempts to avoid such effects. Thus we recommend that such high-resolution field-plasma correlations be undertaken by interplanetary vehicles.

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