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A reexamination of "interstellar ion waves" previously identified in Pioneer 10 magnetic field data

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Abstract. Pioneer 10 magnetic field measurements, believed to include waves associated with the pick-up of interstellar hydrogen atoms, have been further analyzed. Power spectra and waveform data reveal that the signals previously interpreted as waves are an artifact. They resulted from a very low telemetry/sampling rate, associated with the large distance of Pioneer 10 from Earth, which caused aliasing of a sinusoidal signal at the spacecraft spin frequency to a low frequency just above the proton gyrofrequency. Thus the Pioneer 10 plasma analyzer evidence for interstellar pickup ions must be considered separately from the magnetometer data: The validity of the plasma measurements is not affected by this data artifact.

Introduction

Intriligator et al., (1996) presented evidence of H^+ ions picked up from the interstellar hydrogen flowing through the heliosphere in the plasma data obtained by Pioneer 10 near 8.5 AU. The example presented was from data collected over a 10 day interval in December 1975. The Pioneer 10 plasma analyzer observations of interstellar pickup ions, combined with more recent observations from Ulysses (Gloeckler et al., 1993), open a much wider window for study of the pick-up process as a function of heliographic position and phase of the solar cycle.

Intriligator et al., (1996) also studied the Pioneer 10 magnetic field data obtained concurrently with the plasma measurements and reported evidence of the detection of waves generated by the pickup ions.

We have reanalyzed the Pioneer magnetic field data to try to confirm the existence of the waves and to compare their properties with the Interstellar Ion Waves (IIW) identified in the Ulysses magnetic field observations near 5 A U (Murphy et al. 1995). The Ulysses results have shown that the waves are difficult to detect because of their low amplitude levels and intermittent character which has rendered the usual power spectral analysis virtually useless and made it necessary to resort to dynamic spectra (frequency vs. time). It was thus interesting that the waves identified in the Pioneer 10 data were seen in power spectra covering an interval of 10 days.

Unfortunately, we find that the "waves" identified in the Pioneer data are an artifact. This article presents the evidence supporting this conclusion. It also provides the means by which such an artifact can be properly identified in these or other data. The low level of the real interstellar ion waves makes it necessary to exert extreme caution to avoid mis-identifying interference signals of various kinds as naturally-occurring phenomena.

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Analysis

In Intriligator et al., the wave identification was based on power spectra, cross spectra and coherency spectra of the two field components, B_N and B_T, reproduced here as Figure 1. Each of the panels shows an enhancement in power around 4.4 x 10^{-3} Hz. The proton gyro frequency, f_P, also shown, is about a factor of two smaller. A high degree of coherency, approaching a value of 1.0, is associated with the peak in power. Although, the relative phase was not shown, it was stated that the signal is circularly polarized with the two components 90° out of phase.

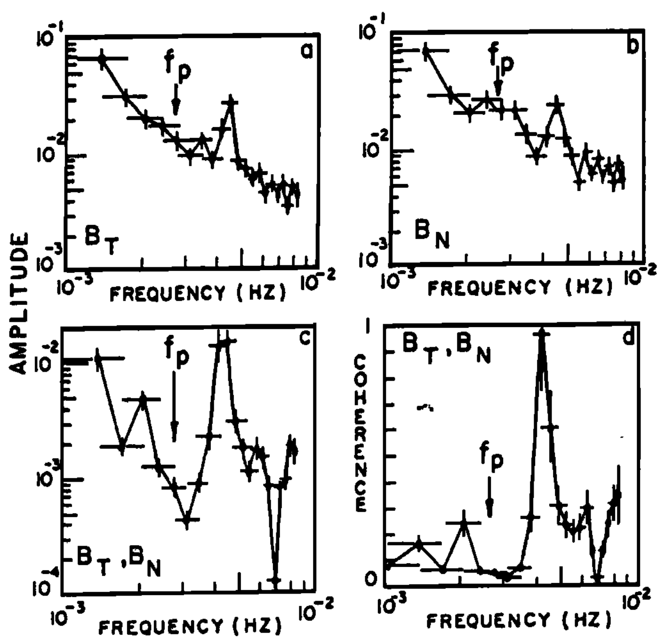

Figure 1. Figure 3 of Intriligator et al. showing the identification of low frequency waves thought to be associated with interstellar pickup ions. Shown are the autospectra for B_T (Fig. 1a) and B_N (Fig. 1b) and the B_T-B_N cross spectrum (Fig. 1c) and coherence (Fig. 1d) for Pioneer 10 magnetometer data collected between 18:00 UT on day of year 278 and 24:00 on day of year 280, 1975. The proton gyrofrequency is marked fp.

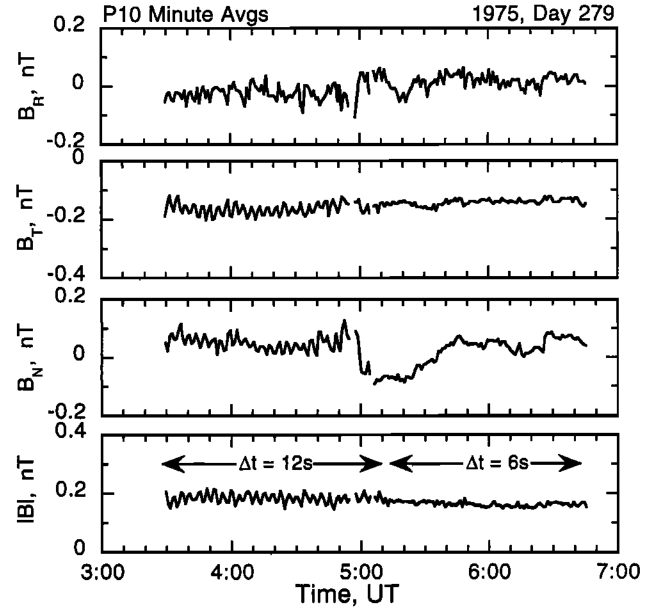

Figure 2. Time series of the wave forms responsible for the peak in the power spectrum shown in figure 1. The top panel shows the radial magnetic field component, the middle two panels show the transverse components, in the RTN coordinate system, while the lower panel shows the magnetic field magnitude.

Certain features of these spectra cause concern. The enhancement being well above f_p is not a characteristic feature of the many examples of waves found in the Ulysses observations where there is a sharp low frequency cutoff just above the gyrofrequency. The enhancement in figure 1 is also symmetric about the peak and appears to occupy a very narrow bandwidth. Power spectra computed at higher frequency resolution, not shown here, confirm the narrow bandwidth of the signal. The Ulysses spectra, on the other hand, show the wave power extending upward to about three times the gyrofrequency with decreasing power. Another concern is that the average field is not radial or nearly radial, a field orientation that has been found in the Ulysses examples to favor the appearance of the waves. Furthermore, for the observed field orientation, some wave power would be expected in the B_R component, but none is seen. Since the Pioneer spin axis, which is also the axis of the telemetry antenna, was nearly radial because of the large distance from Earth, the B_T and B_N components lie in the plane perpendicular to the spin axis. Interference signals lying in this plane would appear to be modulated by the spacecraft spin when the fields are transformed into non-spinning coordinates.

Although spectral analysis is very useful in identifying signals embedded in noise, examination of the time series to identify the corresponding waveforms can be advantageous, especially when the signal is quasi-sinusoidal or narrow band. Figure 2 contains a sample of one minute averages of the three components and the field magnitude over a four hour period during the interval examined by Intriligator et al. The "waves" are clearly evident as the sinusoidal signals in the two middle panels in the left-half figure. By counting cycles, of which there are 16 in about 60 minutes, an average period of 225 sec is obtained which agrees closely with 1/ 4.4 x 10^{-3} Hz =227 sec inferred from the spectra in figure 1.

Fortuitously, the "waves" suddenly disappear, or their amplitude is greatly reduced, near 05:00 hr and throughout the right-hand side of the figure. On further investigation, it was found that this event occurred at a change in the telemetry bit rate. The switch to a significantly higher bit rate was associated with use of a 70m DSN antenna. Further analysis, reported below, shows that this disappearance is attributable to a shift to a higher frequency of the signal, corresponding to

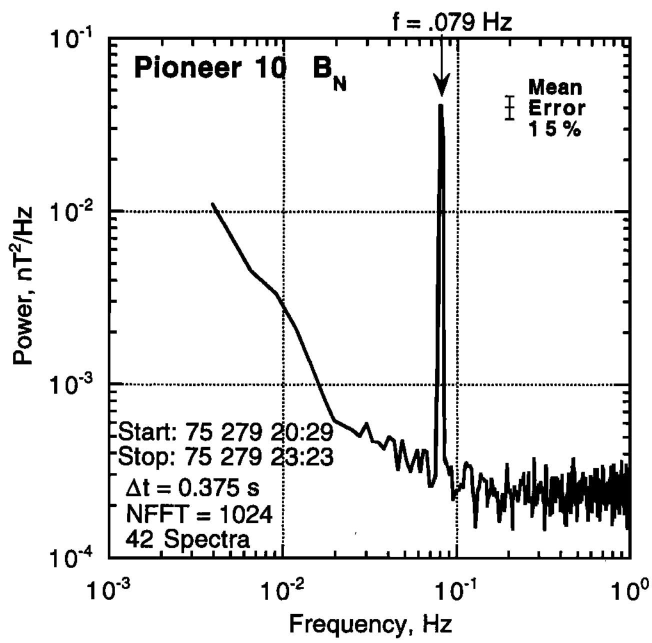

Figure 3. Power spectrum of B_N from 20:29 to 23:23 on day-of-year 279 1975, showing the presence of a strong, narrow signal at the spacecraft spin frequency.

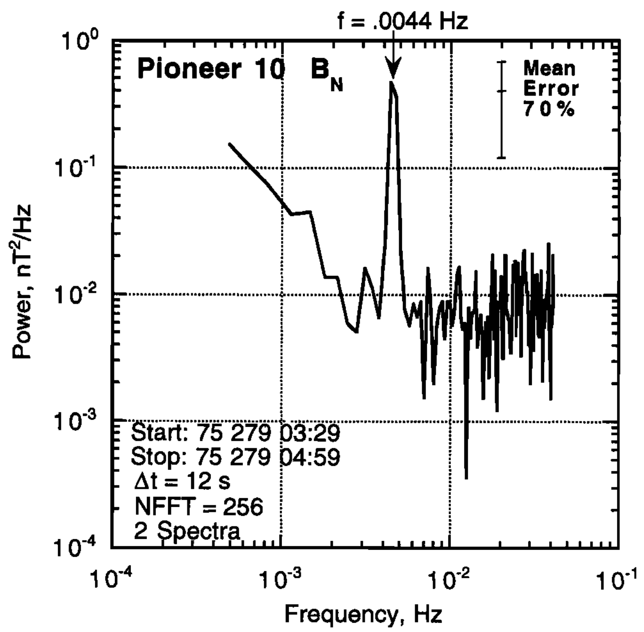

Figure 4. Power spectrum of B_N during the period when low frequency waves were reported by Intriligator et al.. A peak is seen at the frequency expected from aliasing of the spacecraft spin tone because of the low data sampling rate during this interval

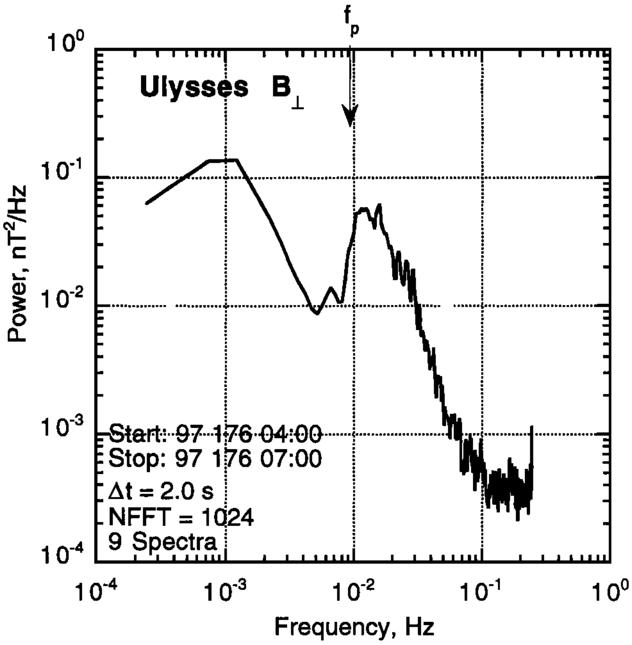

Figure 5. Power spectrum of $B_\perp$, the transverse component of the magnetic field, during an interstellar ion wave event detected by the Ulysses spacecraft. The local proton gyrofrequency is marked as f_p. Prior to the computation of the autospectrum the data are transformed into a coordinate system aligned with the mean magnetic field

a period much shorter than the one minute averaging interval of the data.

Figure 3 shows a power spectrum of B_N taken over the interval from 20:29 to 23:23 hr, somewhat later than the data shown in figure 2. There is a strong signal with peak power at 0.0790 Hz. This measured frequency and period (12.66 sec) are close to the spacecraft spin period and spin frequency, f_S, and we can confidently assert that the signal is a residual spin tone in the data. Furthermore, the time interval between triaxial data samples at the prevailing telemetry rate of 1024 bps is 0.375 sec, so that the Nyquist frequency is 1.333 Hz, well above the observed frequency of the peak. With the one minute averages used in the analysis of Intriligator et al., this signal would be filtered out of the data effectively.

Figure 4 contains the spectrum of B_N over the interval from 03:29 to 04:59 hr in figure 2, the period before the low frequency waves disappear. The figure shows that the peak frequency occurs at 0.0044 Hz as described above. At this time, the spacecraft telemetry rate was reduced drastically, by a factor of 32, to only 32 bps. At this telemetry rate, the sampling interval of the magnetometer data has dropped to 12.0 sec leading to a Nyquist frequency, f_N, of 0.04167 Hz. For signals with frequencies less than twice the Nyquist frequency, data aliasing occurs according to the following formula:

$$f_A = 2\, f_N - f_S$$

The tone at the spin period has thus been aliased to the observed frequency, f_A, as follows:

$$f_A = 2\ (\ 0.04167) - 0.0790 = 0.00434 \text{ Hz.}$$

which is consistent with the observed low frequency waves.

Discussion

We have shown that the signals previously identified in Pioneer 10 data as Interstellar Ion Waves are an artifact. The cause is a slight change in the magnetometer offset or zero level (equivalent to the instrument output in the absence of an ambient magnetic field) which developed during the last month of operation when the instrument performance was gradually degrading. The resulting small steady/dc signal in the sensor output appears as a field rotating in the spacecraft spin plane when the measurements are transformed into non-rotating or inertial coordinates. It then appears to be a circularly polarized sinusoidal signal at the spin frequency. It would have been readily identified as such if the telemetry rate had not been so low that it caused aliasing of the spin frequency to a low frequency near the proton gyrofrequency.

Of course, this result does not affect the analysis of the Pioneer plasma measurements: The identification of pickup ions in the plasma data is still valid. It simply means that the presence of the ions is not confirmed by the simultaneous observation of the waves as had been supposed.

This result does not imply that IIW are not present in the Pioneer 10 or 11 data, although attempts to find them have proven unsuccessful: Originally, Pioneer 11 data near 9.6 AU were examined using conventional power spectral analysis with a negative result (Smith, 1989). The Vector Helium Magnetometer flown on Ulysses is an order of magnitude more sensitive (the field- equivalent noise power is ten times smaller) than the Pioneer instrument and when the spacecraft approached 5AU quasi- sinusoidal signals were evident in the data. Subsequent analysis showed that the signals were typically weak and intermittent rendering power spectra computed over more than a few hours useless, because the waves disappear into the much larger background fluctuations that are persistent. A few particularly large wave events were found initially, but the intermittent nature of the waves made a large scale survey difficult. An autospectrum of the transverse magnetic field fluctuations for one such large wave event is shown in figure 5, for comparison with the data shown in figure 1. As can be seen from this figure, there is an enhancement in power over a broad range of frequencies, with a low frequency cutoff at the proton gyrofrequency (marked as f_p). It is a feature of all the wave events seen that they have broadband enhancement in wave power with an abrupt cutoff close the hydrogen gyrofrequency. The spectrum in figure 5 was computed from data collected over three hours on day 176, 1997 with a time resolution of 2 seconds.

The use of dynamic (frequency vs. time) auto and cross spectra has proven much more successful in identifying wave events and has permitted the identification of numerous legitimate examples of IIW in the Ulysses data. In the course of the analysis, we have also instituted a series of precautions to screen out possible low level interference generated by the spacecraft or other experiments. In the future, these techniques can be applied to high resolution Pioneer 10, 11 magnetic field data in an attempt to extend observations of IIW to other distances, physical conditions and phases of the solar cycle.

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