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Plasma wave turbulence at Jupiter's bow shock

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The first measurements of the wave–particle interactions of Jupiter's bow shock are reported, and some of the wave phenomena detected during the inbound passage are discussed.

THE characteristics of a planetary bow shock are important because the plasma that impacts the magnetosphere of a planet represents solar wind that has been drastically modified by the shock process. Plasma instabilities that develop at a shock front are associated with significant acceleration processes that yield non-maxwellian distributions in the downstream magnetosheath as well as significant fluxes of suprathermal ions and electrons in the upstream region. The Voyager 1 plasma wave investigation has provided the first opportunity to study directly the wave–particle interactions of an outer planet bow shock. Here we discuss in detail some of the wave phenomena detected during the inbound passage.

Measurements

The initial report on the Voyager wave data[1] contains a brief summary of the inbound shock measurements with a display of the 16-channel spectrum analyser data from the first bow shock crossing (detected at 14.34 spacecraft time, 28 February 1979, when the spacecraft was at a range of 85 R_J). Figure 1 shows a corresponding plot of the 16-channel wave data for the third shock crossing of 12.27 UT on 1 March, detected when Voyager 1 was at a range of 72 R_J. We focus attention here on this third inbound crossing for which we have the most comprehensive data records.

Before 12.27, Fig. 1 shows that electrons produced steady oscillations in the 5.62 kHz channel, corresponding to an upstream density of ~0.4 electrons cm^{-3}. The high frequency upstream wave amplitudes were almost an order of magnitude higher than those detected in the corresponding region the day before, but in the low-frequency channels where ion acoustic waves and whistlers are generally detected, the 1 March bow shock exhibited a noteworthy absence of precursor wave activity. (The sporadic signals in the 100-Hz channel are interference tones from the stepper motor of the low energy charged particle instrument.) This third shock crossing was characterised by the detection of intense broadbanded noise enhancements in a well defined time interval with duration of the order of 1 min. Analyses of collisionless shock structures[2] suggest that the minimum shock thickness for a laminar structure should be of the order of $\delta_i = c/(2\pi f_p^i)$ where c is the speed of light, f_p^e is the electron plasma frequency ($f_p^e = 9\sqrt{N_e}$ kHz where N_e is the electron density in cm^{-3}) and $f_p^i = f_p^e/43$ (for protons). For our case we know that $f_p^e = 5.6$ kHz, and hence δ_e ($=\delta_i/43$) should be ~8.5 km while δ_i ~365 km. At this time the Voyager radial speed with respect to the planet centre was ~12.7 km s^{-1}, and hence the spacecraft would have traversed a stationary minimum shock with thickness of 8.5 km in ~2 s. The observed duration of about 20–60 s seems to imply that the thickness corresponded to an ion inertial length.

At the time of this shock crossing we were fortunate to have high rate waveform data available that provided complete spectral information over the range 50 to 12 kHz. Figure 2 shows the frequency–time plot made up using the high rate data from 1226.12 to 1227.48 spacecraft time. (A Voyager-to-Earth data transmission of just over 11 Mbits was used to provide the plasma wave information in Fig. 2.) The thick structured 'line' with $f \approx 6$ kHz (before 12.26.45) represents the upstream electron plasma oscillation emission, and we identify the low frequency wave turbulence after 12.26.42 as ion acoustic waves. The upstream electron emission just before this shock has a distinct and unusual structure that may be related to a nonlinear effect operative very near to the shock. Figure 3 shows a

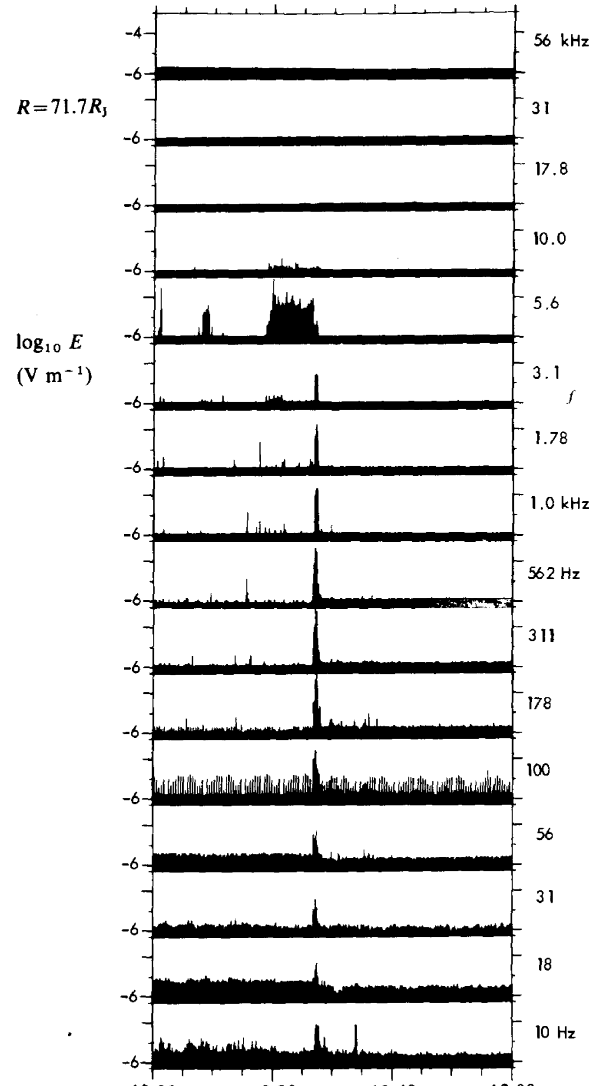

Fig. 1 Measurements of wave amplitudes at the third bow shock crossing. Interference appears in the 100 Hz channel, and the upstream enhancements at 5.6 kHz represents detection of electron plasma oscillations. Note the very low noise levels in the magnetosheath after 12.27.

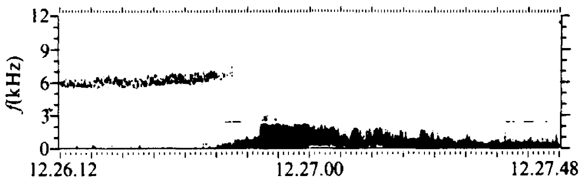

Fig. 2 Frequency–time diagram of bow shock number three made up using the Voyager 1 high rate data link. The upstream electron plasma oscillation line is highly structured just before the shock encounter.

frequency–time plot made up just a few minutes earlier with very narrow and unstructured electron plasma oscillation lines, and it is possible that the structure shown in Fig. 2 is related to the coupling of large amplitude electron plasma oscillations and ion acoustic waves[3]. Similar phenomena have occasionally been detected in the region immediately upstream from the Earth's bow shock[4]. However, as Fig. 2 does not show enhanced ion sound wave levels just before 12.26.42, other explanations for the high frequency wave structure may have to be considered. On the other hand, the broadband channel uses an automatic gain control amplifier that responds primarily to the most intense waves, and the bandpass channel data (Fig. 1) show that

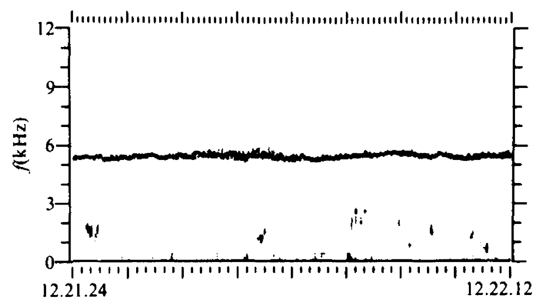

Fig. 3 Frequency–time diagram of regular upstream electron plasma oscillations detected a few minutes before the shock.

the upstream ion waves in the Fig. 2 time interval were at least as intense as the ones shown in Fig. 3.

Figure 2 shows several other features of interest. First we note that the plasma wave activity was very low by the end of the record. This result is also indicated in Fig. 1, which shows that the jovian magnetosheath is characterised by a virtual absence of detectable plasma wave turbulence after passage through the shock. (Scarf *et al.*[1] noted that this is true for the entire sheath traversal into the magnetosphere boundary.) Figure 2 also shows a number of impulsive wave structures within the shock with durations as small as 1, 2 or 3 s (see especially the period after 12.27.06) and it is possible that these structures represent regions with scale sizes comparable to $\delta_e = c/(2\pi f_p^e)$.

Clearly the high frequency and time resolution available from the broadband data link will allow us to carry out detailed studies of the thermalisation and acceleration processes that develop at the very strong jovian bow shocks, and future studies will focus attention on the shock structure and on correlations with data from other Voyager instruments. Recent detailed calculations of shock structure based on the use of marginal stability criteria[5] will be applied here when the complete plasma and magnetic field profiles are available. However, it is already apparent that Jupiter's bow shock region provides material for novel and significant plasma physics studies and future research will also be aimed at understanding the absence of magnetosheath noise, as well as the structured electron plasma emissions detected just upstream from the shock.

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