Reprinted from Nature, Vol. 295, No. 5844, pp. 46-48, 7 January 1982

Chorus-related electrostatic bursts in the Earth's outer magnetosphere

L. A. Reinleitner, D. A. Gurnett & D. L. Gallagher

Department of Physics and Astronomy, University of Iowa, Iowa City, Iowa 52242, USA

We report here recent studies of wideband plasma wave data from the ISEE 1 and ISEE 2 spacecraft which reveal that whistler-mode chorus emissions in the Earth's outer magnetosphere are often accompanied by high-frequency bursts of electrostatic noise. The chorus features that correlate to the electrostatic bursts have a hook-like frequency–time variation in the frequency range 200–400 Hz, and the associated electrostatic bursts have a frequency range of ~4–8 kHz. In some cases these electrostatic bursts have a harmonic frequency structure with a frequency spacing corresponding to the chorus frequency. This harmonic structure apparently results from the fact that the burst intensity is modulated at the chorus frequency.

Selected wideband spectrograms[1] obtained from ISEE 1 of the chorus-related electrostatic bursts are shown in Figs 1–3. Figure 1 indicates some of the general features of the bursts. In this case, the bursts appear to be strongly correlated to discrete hook-like features in the chorus band[2]. In addition to this example, many cases of the electrostatic bursts are observed in conjunction with intense chorus bands without hooks. In such cases the electrostatic bursts are usually merged together in a nearly continuous band similar to the extended burst in Fig. 1 from about 1738:40 to 1738:50 UT. A comprehensive survey of the locations where the bursts (with or without hooks) are observed has not yet been performed. However, all cases observed have been in the outer magnetosphere near the day-side magnetopause boundary from 7.0 to 17.5 magnetic local time (MLT), about 9–12 R_E and within ~30° of the magnetic equator.

The frequent occurrences of the electrostatic bursts, whether accompanied by hooks in the chorus band or not, as well as the rather limited physical region of occurrence, strongly indicate that the bursts are not caused by instrumental effects. To check that the bursts are not due to some cross-modulation effect in the instrument electronics, wideband data from the IMP 6 spacecraft have been examined. (The plasma wave instrumentation on IMP 6 is detailed in refs 3 and 4.) Although IMP 6 was not in the correct wideband mode to observe both frequencies of interest as often as ISEE 1, intense chorus accompanied by electrostatic bursts have, nevertheless, been found in several passes through the outer magnetosphere on the dayside region.

The electrostatic bursts have several characteristics. The bursts typically occur in a frequency band extending from near the electron plasma frequency f_p as determined by the lower edge of the continuum radiation[4], down to approximately half f_p, as in Fig. 1. In the examples shown, the frequency range of the burst does not extend up into the continuum radiation, although bursts extending up into the plasma frequency have been found. In all cases, the bursts occur at frequencies above the electron gyrofrequency ($f_g \sim 1.2$ kHz in Fig. 1).

The bursts have been described as electrostatic because no wave magnetic field can be detected in association with them. Typically the broadband electric field strength of the bursts are about 50 μV m^{-1}. Because the wave magnetic field remains at the instrument noise level in all cases, a limit can be placed on the electric-to- magnetic field ratio of about $E/cB \gtrsim 0.25$ (which corresponds to an index of refraction $n \lesssim 4$). Because no electromagnetic plasma wave mode is known to exist with $E/cB \gtrsim 0.25$ in the frequency range $f_g < f_{burst} < f_p$, the bursts are almost certainly electrostatic. The typical field strengths of the chorus emissions associated with the electrostatic bursts are about 300 μV m^{-1} and 40×10^{-12} T.

The electrostatic bursts occasionally have narrowband harmonic structure of the type shown in Fig. 2. The harmonic structure should not be confused with the vertical striations due to the rapid time dependence of the bursts. The harmonic structure is only evident when the chorus emission has a narrow bandwidth, such as when the hook-shaped features occur. The frequency spacing of the harmonic structure corresponds exactly with the instantaneous emission frequency of the chorus burst.

When chorus hooks are found to be correlated with the electrostatic bursts, the onset of the electrostatic burst usually coincides with the minimum frequency of the hook. This relationship can be seen most clearly in the first and last hook in the upper panels of Fig. 3. Note that the electrostatic burst usually continues for a time after the hook has disappeared or merged back into the chorus band.

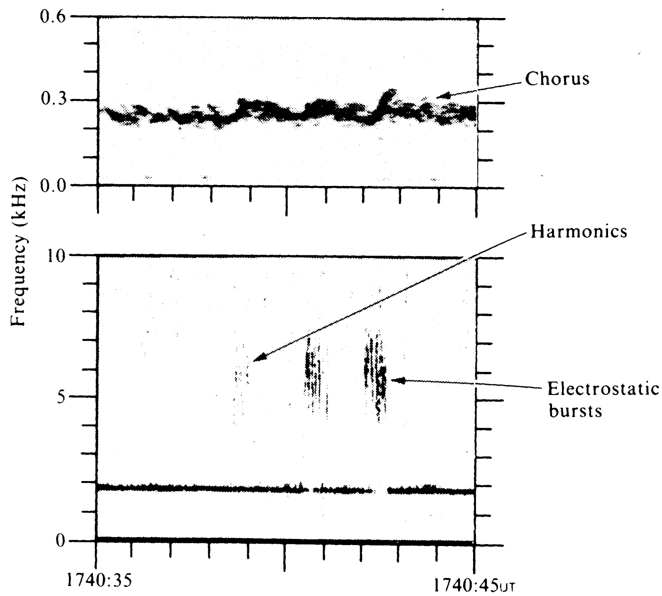

Fig. 2 Wideband plasma wave data showing narrowband harmonic structure for 5 November 1977. $R = 11.01\ R_E$; magnetic lat. = 21.1°; MLT = 11.7 h.

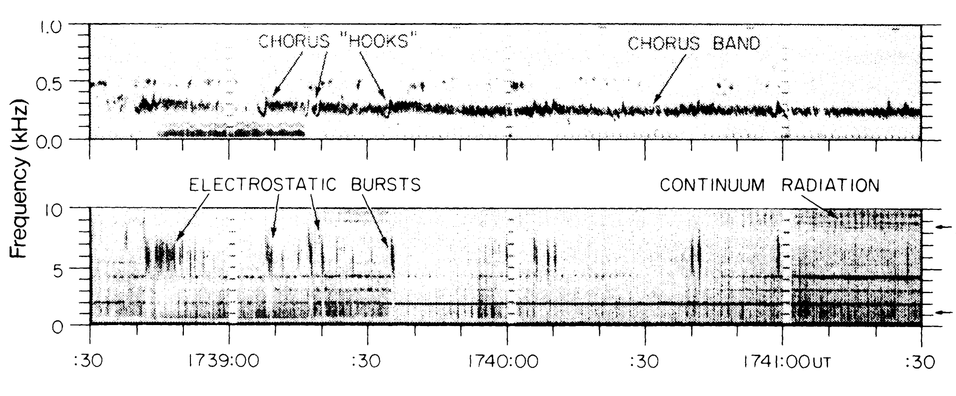

Fig. 1 Frequency versus time wideband plasma wave data for 5 November 1977 showing general features of the chorus related electrostatic bursts. The slight interference from 1738:45 to 1739:17 UT (also in Fig. 3) is from the ISEE electron density experiment. $R = 11.04 R_E$; magnetic lat. = 21.1°; MLT = 11.6 h.

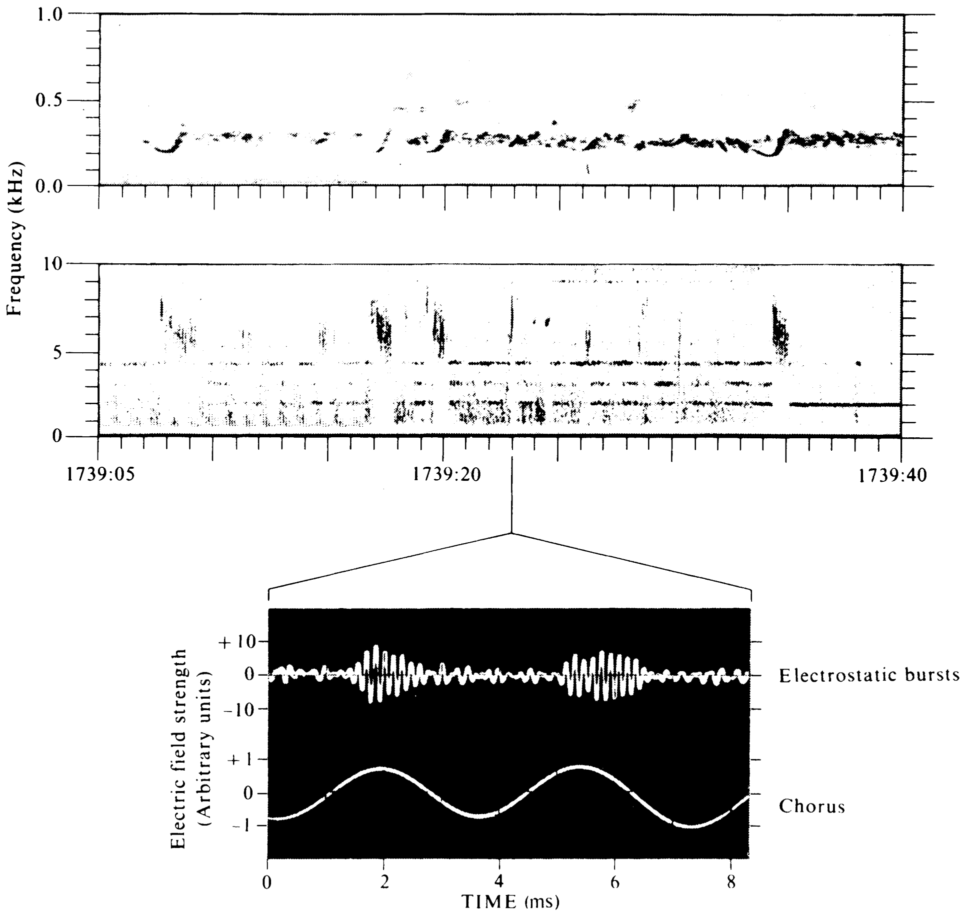

Fig. 3 The lower panel shows the oscilloscope waveform pattern taken from the very short burst indicated in the upper panels of wideband data for 5 November 1977. The low frequency signal in the bottom of the lower panel is the chorus waveform, while the high frequency signal bursts at the top of the lower panel are the electrostatic bursts. The phase of the chorus waveform may differ from that shown by a constant (instrumental) phase factor. $R = 11.04\ R_E$; magnetic lat. $= 21.1°$; MLT $= 11.6$ h.

Comparative studies using both ISEE 1 and ISEE 2, were possible because both spacecraft were in nearly identical orbits with a separation of only hundreds of kilometres. Although virtually identical chorus hooks were found in the electric field wideband data, the electrostatic bursts, while correlated, were not identical at the two spacecraft which indicates that the structure of the electrostatic bursts varies significantly on spatial scales of only hundreds of kilometres. To estimate the wavelength of the electrostatic noise, the electric field strength has been compared on ISEE 1 and 2, which have electric antenna lengths of 215 m and 30 m tip-to-tip. For bursts which had similar characteristics at the two spacecraft, the electric field strengths were in good agreement, thereby indicating that the wavelength of the bursts must be longer than both of the antennas, implying a wavelength for the electrostatic bursts of $\lambda_{\text{burst}} > 215$ m.

Comparisons of the waveforms of the chorus and the electrostatic bursts reveal several interesting features. The lower panel of Fig. 3 shows the electric field versus time for both the chorus and the electrostatic burst. The lower signal is that of the chorus while the upper high frequency signal is the associated electrostatic burst. Both signals have been run through bandpass filters to eliminate signals not in the frequency band of interest. Note that the time duration of these waveform data is only 8 ms. The waveform therefore comprises only a small portion of the electrostatic burst from which it was taken. As can be seen, the electrostatic noise is actually composed of many shorter bursts of a high frequency signal which is modulated at the chorus frequency. Thus, the harmonics evident in Fig. 2 are a modulation effect caused by the periodic pulsing of the electrostatic noise at the frequency of the chorus emission. In the cases where the harmonics do not occur, the chorus does not occur as a single frequency but rather as a band of frequencies, which tends to blend harmonics into a broad continuous spectrum.

The correlation between the envelope of the bursts and the chorus waveform is often not as good as the example shown; however, the basic modulation effect in which the intensity of the high frequency emission maximizes at a given phase of the chorus waveform is usually evident. Also, despite the apparently abrupt initial turn-on of the bursts in the usual wideband data, waveform data show a gradual increase in the amplitude of the high frequency bursts, as well as a gradual decrease toward the end of each burst. For the case shown in the lower panel of Fig. 3, the frequency of the electrostatic emission is 6.7 kHz (±0.5 kHz) which is near but below the plasma frequency of 8.5 kHz (±0.5 kHz) as determined by the lower cutoff of the continuum radiation.

The strong correlation between the envelope of the electrostatic bursts and the chorus waveform suggests some strong physical interaction between these two wave modes. We currently believe that the chorus is phase bunching electrons at the phase velocity of the whistler mode and that these resonant electrons are triggering an electrostatic instability through a two-stream (or bump-on-tail) type mechanism[5]. We are not certain of the exact identification of the electrostatic mode involved but the best candiate seems to be a Langmuir wave or related beam mode, because the emission occurs very close to the local electron plasma frequency. The shift in the frequency of the electrostatic emission below the plasma frequency could be due to either a Doppler shift or an intrinsic effect related to the two-stream interaction.

We also believe that the correlated whistler and electron plasma oscillation bursts detected in the solar wind by Kennel *et al.*,[6] are probably essentially identical to the chorus related electrostatic bursts described here. Most differences are attributable to differing plasma parameters in the two different regions of interest. The hypothesized interaction between these two wave modes is seen as a better alternative than the secondary impulsive electron heating mechanism proposed by Kennel *et al.*[6].

We thank Dr Alain Roux for valuable suggestions on theory, and Dr Roger R. Anderson for help with analysis of the data. This research was supported by NASA through grant NGL-16-001-043 from NASA Headquarters and contract NAS5-20093 with Goddard Space Flight Center, and the Office of Naval Research.

Received 3 July; accepted 16 October 1981.

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