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ELECTRON PLASMA WAVES IN THE SOLAR WIND: AMPTE/IRM AND UKS OBSERVATIONS

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ABSTRACT

Selected events of plasma wave and electromagnetic emissions in the earth's electron fore-shock region have been studied. Strong emissions are observed in the plasma-wave band when the site of the satellite is magnetically connected to the bow shock. These emissions are generally highly fluctuating. Under certain conditions one observes electromagnetic radiation at the second harmonic produced locally. Electromagnetic emission generated at a position far away from the site of the spacecraft is occasionally detected giving rise to remote sensing of the bow shock. These emissions are related to energetic electron fluxes.

INTRODUCTION

In fall 1984 the Ampte spacecraft offered the chance to detect plasma wave emissions in the region in front of the earth's bow shock wave /1/. Launched in August 1984 into a highly elliptical equatorial orbit, the Ampte spacecraft (apogee at about 18.7 R_e) traversed the bow shock several times and was as well in the upstream solar wind as also in the ion and electron fore-shock regions /2/. It consisted of two spacecraft, IRM and UKS, separated by a few tens of kilometers and equipped with instruments including plasma wave instrumentation as described in /3,4/. We present observations of plasma wave and electromagnetic emissions obtained during two passages of the electron fore-shock region.

OBSERVATIONS

Figure 1 shows one hour spectrograms of the electric plasma wave fields obtained on Nov 15, 1984. The upper two panels show the peak and average values of the wave power spectral density (PSD) (Iowa plasma wave instrument, 31 Hz to 178 kHz). The 16 channels shown are logarithmically spaced in frequency. The averages are taken over one second, while the peak values give the highest power measured during each second. The central panels show the magnetic field in GSE coordinates. The lowest panel is the electric PSD measured by the Aerospace/Univ. Wash. swept frequency receiver (SFR3) in 32 equally spaced frequency channels between 9 and 99 kHz. The spacecraft was in the solar wind just in front of the bow shock. The shock crossing appeared at 1145 UT. A first brief shock encounter took place at 1119 UT.

The electric PSD outside the shock encounters in the solar wind shows the LF electrostatic waves in the solar wind thought to be ion acoustic modes /5/ driven by heat flux instabilities. The frequency of these emissions is restricted to $<$ 3.11 kHz with a flat maximum in the 100-300 Hz interval.

Before the shock encounters intense electrostatic wave at 31 kHz is seen in the peaks and averages in Fig. 1. It disappears at the bow shock passage near 1145 UT. Comparison shows that the emission is highly variable in time. Broadening is observed in connection with intensification in the 31 kHz band and at low frequencies. The SFR3-data show this line emission between 36 and 40 kHz, highly structured in time and frequency, of bandwidth 15 kHz, about 50% of the emitted frequency 1119 UT. After the SFR3 a second weaker band appears between 70-80 kHz at twice the frequency of the lower band. The appearance of the upper band coincides with broadening of the peaks and averages at 31 kHz to 56 kHz. This widening is an indication for the detection of both bands seen in the SFR3 and is thus further evidence for the validity of the SFR3 measurements. The high frequency harmonic emission stays until the spacecraft reaches the bow shock when it disappears.

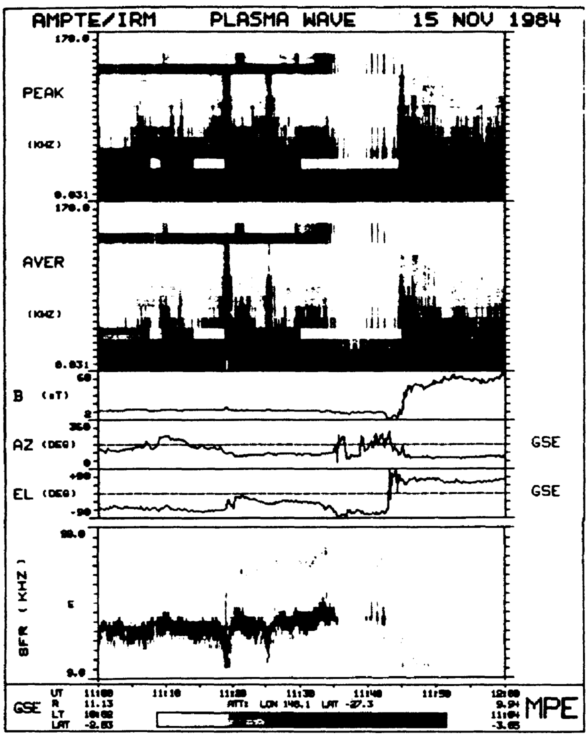

Fig. 1. Spectrograms of plasma waves observed on Nov 15, 1984, by the AMPTE/ITM satellite. For a description see text.

Figure 2 presents half an hour of observations of wave and plasma data obtained during the time of Fig. 1. The six panels show from top to bottom integrated PSD in the SFR3 (70-80 kHz, 36-40 kHz), peak (31-56 kHz) plasma frequency f_e obtained from the electron density measurement of the plasma instrument the magnetic field, and the densities of the energetic electrons and protons, respectively. The contact with the bow shock is evident from the steep rises in the density (plasma frequency) and magnetic field at 1519 UT.

The second panel shows the high variability in the electron plasma waves. The higher frequency harmonic band also shows high variability but in general very weak emission before 1109 UT. The average plasma frequency was about 21 kHz. The lower band is hence just above the local plasma frequency with the plasma frequency being at its low frequency cut-off.

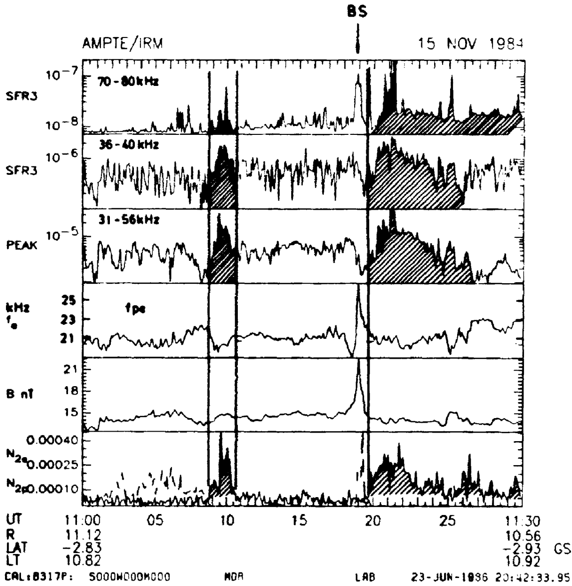

Fig. 2. Variation of wave and plasma parameters on Nov 15, 1984. Shadowing indicates the periods of increased wave intensities and energetic electron densities (N_{2e}). BS indicates the bow shock encounter.

The vertical lines indicate changes in the energetic electron fluxes related to the electron plasma frequency emission. Between 1109 UT and 1111 UT the energetic protons disappear while the energetic electron fluxes increase in intensity by a factor of about ten. The peak and fundamental panels demonstrate highly increased and much less variable emissions. The harmonic emission intensities and becomes less variable. From 1111 UT until 1120 UT the fundamental emission is still strong, and a weak harmonic emission appears. After 1120 UT there are again enhanced energetic electron fluxes accompanied by intense emission at the fundamental and intense radiation at the harmonic.

Another observation of waves related to f_e is shown in Fig. 3 of Nov 29, 1984. This day showed the passage of a discontinuity at 0746 UT, when the plasma frequency dropped from 24 kHz to 22 kHz. Radiation in a narrow band is seen right before this time (top panel) at low PSD at 56 kHz, not related to any local natural frequency. After the discontinuity the band divides itself into one at 56 kHz and a new band at 46 kHz, roughly the local plasma harmonic, separated by a 10 kHz wide gap of emission. The intensities of these two bands are anticorrelated. Though this splitting mechanism might depend on the local conditions and the discontinuity, the generation of the emission itself must occur at a different place. Absence of local plasma frequency waves indicates that locally the plasma is passive. The electron measurements indicate that we are outside the fore-shock. Thus a remote sensing of the fore-shock region is given by the presence of the initial emission line indicating that the source region plasma density must be a factor of about two higher than the local plasma density.

We have observed very strong local plasma frequency emission also on Nov 1, 1984, near the boundary of the electron fore-shock, accompanied by local harmonic radiation.

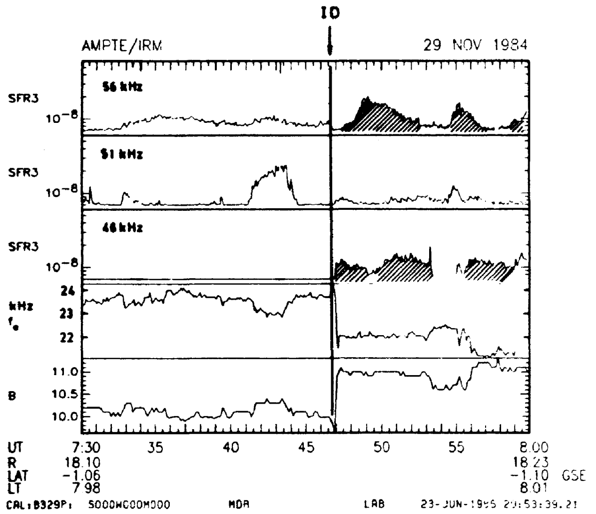

Fig. 3. Wave power spectral density on Nov 29, 1984, outside the electron fore-shock. No local plasma frequency emission is found. The electromagnetic radiation present before encounter of the interplanetary discontinuity (ID) splits into two bands of enhanced power after the passage of the discontinuity.

DISCUSSION AND CONCLUSIONS

Intense and highly time variable plasma waves are found and harmonic radiation in the fore-shock region. Though no magnetic wave components have been measured by the instruments which were all the time in the electric wave mode, it can be concluded that the emission at the fundamental is probably electron plasma waves excited by the energetic electrons in the fore-shock and in its edge. This boundary is represented in the LF-waves by a high PSD. The coincidence of the LF-waves near the ion acoustic frequencies and the high frequency plasma waves then gives rise to wave coupling, responsible for the harmonic radiation.

For the LF-waves below 300 Hz we find an rms wave field amplitude of $E_{LF} \approx 10^{-2}$ V/m, while the wave amplitude of the electron plasma frequency is $E_{pf} \approx 4\times10^{-3}$ V/m, and of the harmonic is $E_H \approx 7\times10^{-4}$ V/m. The ratio of harmonic to plasma frequency amplitude is $10^{-2} \leqslant E_H/E_{pf} \leqslant 0.5$. We do not observe a decay process but instead wave-wave coupling between two Langmuir waves. The normalized to the thermal plasma energy wave energy is found as $W = (\epsilon_0/2)(E_F^2/nT_e) \approx 10^{-5}$ which is a high value much higher than the thermal fluctuation level which is about 10^{-9}, possibly indicating nonlinear behaviour.

We can use the dispersion relation of Langmuir waves, $f^2 = f_e^2(1+3k^2\lambda_e^2)$, to determine the width of the k-spectrum. We find for the wave-number $0 \le k\lambda_e \le 0.94$ with maximum at $(k\lambda_e)_{max} = 0.63$. Assuming that the waves are resonantly excited $(\omega/k = v_b)$, we find for the resonant electron beam velocity $2.03 \le v_b/v_e \le 2.34$, where v_e is the thermal velocity of the electrons. So the beam has velocity spread $\Delta v_b/v_e = 0.63$ and characteristic speed of $v_b = 2.34\ v_e$. This yields a linear growth rate $\gamma/\omega_e = 10(n_b/n) = 13$ Hz. Assuming that the beam stabilizes quasilinearly /6/ we find a saturation level $W = 1.13(n_b/n) \approx 10^{-5}$ or a beam density $n_b/n \approx 10^{-5}$ in rough agreement with the ratio of energetic to plasma electron densities reported above. The estimate for k and W indicates that $3\ k^2\ \lambda_e^2 \gg W/4$ in most of the observed spectrum so that modulational instability seems improbable for this fairly short wave-length spectrum. Thus wave-wave interaction may be the dominant process to generate the observed harmonic emission.

The correlation of the strong plasma waves and LF-waves points on a relation between these. If the LF-waves are connected with a modified two-stream instability in the edge of the electron fore-shock, the electron beam required to excite the intense plasma waves can be generated by nonlinear acceleration of electrons /7/. Enhanced plasma wave and electromagnetic emission should take place and enhanced fluxes of energetic electrons should be found, as has been observed.

The intensities measured on Nov 29, 1984, were $E \approx 10^{-5}$ V/m, and the ratio of wave to thermal energy in this case amounts to about 1.1×10^{-11}, 10^4 times less than reported above. This might be related to a distance effect. Assuming either fundamental or harmonic emission, the density in the radiation source is then found to be 40 cm^{-3} or 10 cm^{-3}, respectively, placing the source either at the bow shock or in the fore-shock region. The former discussion suggests that harmonic radiation is more probable; we therefore expect the radiation source to be in the fore-shock or its edge.

In summary, we have observed highly time variable and broad-band local plasma wave emission above the local plasma frequency of short wave length, correlated with intensification in the LF-wave spectrum and high-energy electrons and related to the edge of the electron fore-shock. Wave intensities and measured electron densities are in good agreement with quasi-linear theory. Harmonic radiation observed at the same time is locally excited by wave-wave interaction between Langmuir waves, though we cannot exclude that modulational instability takes place for the longer wave-lengths of the spectrum. The short beam relaxation length requires local electron acceleration. These questions will be investigated in greater depth in a more elaborated publication.

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