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DETECTION OF LANGMUIR SOLITONS: IMPLICATIONS FOR TYPE III BURST EMISSION MECHANISMS AT $2\omega_{PE}$

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Abstract. We present the experimental verification of existing theoretical models of emission mechanisms of solar type III bursts at the second harmonic of the plasma frequency, ω_{pe} . This study is based on the detection of Langmuir and envelope solitons by the Ulysses spacecraft inside three type III burst source regions. We show that the oscillating-two-stream instability, coherent radiation by Langmuir solitons and stochastic phase mixing of the Langmuir waves in the strong turbulence regime are the appropriate emission mechanisms at $2\omega_{pe}$.

Key words: Langmuir Solitons – Type III Bursts

1. Introduction

The identification of the mechanisms responsible for: (1) stabilizing the type III electron beams and (2) conversion of Langmuir waves into electromagnetic radiation at the fundamental of the plasma frequency, ω_{pe} , and its second harmonic, $2\omega_{pe}$, is one of the outstanding problems in solar radio astronomy. The Ulysses high time resolution observations of Langmuir waves associated with local type III bursts indicate that the strong turbulence processes, such as the modulational instability, the oscillating two-stream instability, Langmuir soliton formation and Langmuir collapse dominate not only the emission processes at ω_{pe} , but also beam stabilization processes (Thejappa et al., 1993, 1995a and b). The purpose of the present paper is to identify the mechanisms responsible for the type III emission at $2\omega_{pe}$. The observations and theoretical analysis will be presented in sections 2 and 3, respectively, which will be summarized in Table 1.

2. Observations

The Unified Radio and Plasma Wave Experiment (Stone et. al., 1992) on the Ulysses spacecraft has detected three local type III bursts (Reiner et al., 1992, Thejappa et. al., 1993, 1995a, b and c). In Fig. 1a, we present the wave activity associated with one of these events. The top two panels

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show the type III burst electric field at $\simeq 27.5$ and $\simeq 15.5$ kHz respectively. The third panel shows the Langmuir waves at 13.8 kHz with a 16 s resolution. The fourth panel shows the ion-acoustic-like wave activity at 2.3 kHz. The fifth and sixth panels show the peak electric field data at 112 and 2.7 Hz, respectively. Fig. 1b presents the typical high time resolution ($\simeq 1$ ms) observations of Langmuir waves, which occur as broad peaks sometimes superposed with millisecond spikes. The intense Langmuir millisecond spikes

TABLE I
Summary of Observations and Predictions

Date	Dec. 11, 1990	Feb 22, 1991	Mar 7, 1991
Electron Density $n_e(\text{m}^{-3})$	1.7×10^6	1.3×10^6	1.3×10^6
Ele. Plasma Freq., $f_{pe} = \omega_{pe}/2\pi$ (kHz)	11.7	10.2	10.2
Electron Temperature, $T_e(\text{K})$	10^5	7.6×10^4	4.7×10^4
Ion Temperature, T_i (K)	5×10^4	10^4	7×10^3
Electron Thermal Speed, v_{Te} (ms^{-1})	1.2×10^6	1.1×10^6	8.4×10^5
Solar Wind Speed, V_w (kms^{-1})	382	310	401
Debye Length λ_D (m)	17	17	13
Magnetic Field, B (γ)	6	2	2
Beam Speed, v_b (ms^{-1})	3.5×10^7	3.5×10^7	3.5×10^7
Langmuir Wave number, $k_L \text{ m}^{-1}$	2.1×10^{-3}	1.8×10^{-3}	1.8×10^{-3}
Relative Spectral width, $\Delta k_L/k_L$	0.1-0.2	0.1 -0.2	0.1-0.2
$k_0/k_L = \omega_{pe}/65v_{Te}k_L$	0.45	0.5	0.65
Peak Ele. Field of ms spikes, E_0 (Vm^{-1})	9×10^{-3}	—	1.3×10^{-2}
$\frac{W_0}{n_e T_e} = \frac{\epsilon_0 E_0^2}{2n_e T_e}$	1.5×10^{-4}	—	9×10^{-4}
Peak Field of broad peaks, E_L (Vm^{-1})	3.3×10^{-3}	2.3×10^{-3}	4.6×10^{-3}
$\frac{W_L}{n_e T_e} = \frac{\epsilon_0 E_L^2}{2n_e T_e}$	2×10^{-5}	1.7×10^{-5}	1.1×10^{-4}
Spatial Scale of ms peaks Δz (m)	382	310	401
Tra. Spa. Sca. of ms peaks $\rho \simeq v_b/\Omega_e$ (km)	33	99	99
EM Wave Number, $k = 3.6 \times 10^{-8} f_{pe} \text{ m}^{-1}$	4.2×10^{-4}	3.7×10^{-4}	3.7×10^{-4}
Har. Peak Ele. Field, E_t ($\text{Vm}^{-1} \text{Hz}^{1/2}$)	1.6×10^{-8}	8×10^{-9}	9×10^{-9}
$T_B = 2.8 \times 10^{36} E_t^2/f^2$ (K)	10^{12}	4×10^{11}	5×10^{11}
T_B (OTSI) (K)	2.4×10^{13}	1.4×10^{11}	6.1×10^{13}
T_B (Soliton) (K)	1.6×10^{14}	1.7×10^{13}	1.5×10^{14}
T_B (Stochastic) (K)	3.9×10^{13}	1.1×10^{13}	1.3×10^{13}

in the solar wind were identified as collapsing solitons (Kellogg et al., 1992). The millisecond spikes associated with the present local type III events are identified as stable Langmuir solitons, whereas the broad peaks are identified as envelope solitons (Thejappa et al., 1993; 1995a, b and c). The temper-

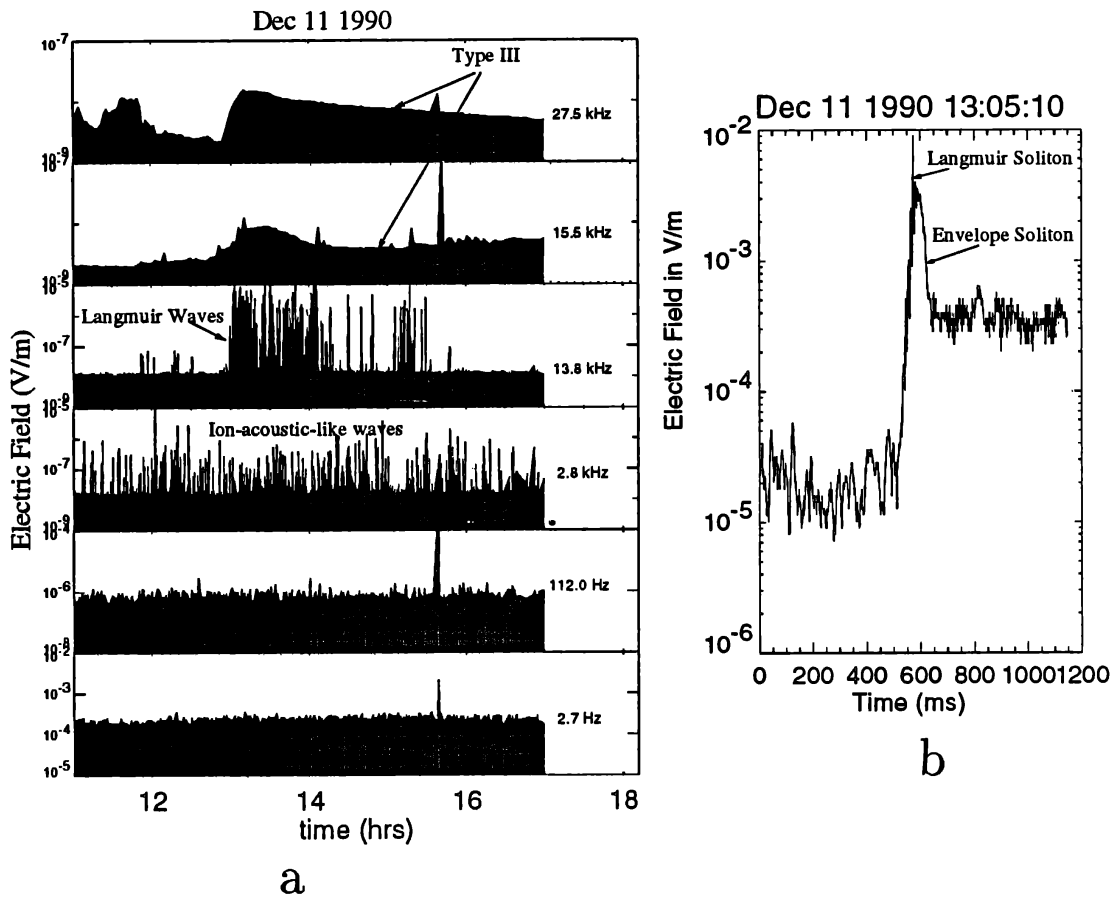


Fig. 1. Radio and in situ plasma wave phenomena

atures and the magnetic field values are taken from Ulysses archive data, made available from the NSSDC.

3. Discussion

The wave-wave process $L + L \pm S \rightarrow T$ is proposed as one of the efficient emission mechanisms for second harmonic radiation (Melrose et al., 1986; Cairns and Melrose, 1985; Cairns 1987; Robinson et al., 1994), where L, S and T are Langmuir, ion-acoustic and electro-magnetic waves, respectively. The conditions for this process to occur are $T_e > 5 \times 10^5$ K for a narrow peaked Langmuir wave distribution (Melrose, 1982) and $\frac{\Delta k_L}{k_L} > \frac{k_0}{k_L}$ (Cairns and Melrose 1985; Cairns 1987; Melrose et al 1986) for a broad Langmuir spectrum with a relative width of $\frac{\Delta k_L}{k_L}$. As seen from Table 1, the observed T_e values are well below 5×10^5 K and the $\frac{\Delta k_L}{k_L}$ values usually range from 0.1 to 0.2 (see also, Lin et. al., 1986) being much below the observed k_0/k_L values, which range from 0.5 to 0.7, indicating that $L + L \pm S \rightarrow T$ is unlikely.

The emission process involving induced scattering is also unlikely since k_L can become much less than k in such a process (Zheleznyakov, 1977).

There are three known strong turbulence emission mechanisms, which are not restricted by any kinematic constraints: (1) oscillating-two-stream instability (Papadopoulos et al., 1974), which produces two oppositely propagating symmetric Langmuir wave distributions, (2) coherent emission by Langmuir solitons (Papadopoulos and Freund 1978) and (3) stochastic phase mixing of Langmuir waves at long wavelengths (Kruchina et. al., 1980). The emissivity J in these cases is $30\pi^3(\frac{v_{Te}}{c})^5(\frac{W_L}{n_e T_e})^2 n_e T_e \omega_{pe}$; $\frac{3\sqrt{3}}{8}(\frac{v_{Te}}{c})^4 \frac{cW_0}{\Delta z} \times \frac{1}{k^2 \rho^2}$ and $\frac{3}{32} W_L \omega_{pe} (\frac{3T_e}{m_e c^2})^{5/2}$, respectively. The brightness temperature, T_B is related to J as $\kappa T_B \simeq \frac{(2\pi)^3}{k^2} \frac{J}{(2\pi \Delta f)} L \simeq 9 \times 10^{44} J / f_{pe}^2$, where κ is the Boltzmann constant, $L \simeq 3 \times 10^8$ m is the source size and $\Delta f \simeq 750$ Hz is the bandwidth of the radio receiver. The predicted T_B values by each of these mechanisms for the observed Langmuir wave energy densities agree very well with the actual T_B values for a filling factor of $\simeq 0.1 - 0.01$ (see, Table 1). Since no millisecond spikes have been observed during Feb. 22 event, in some cases we have used W_L values instead W_0 values. Thus the present observations strongly support the strong turbulence processes as the appropriate emission mechanisms at $2\omega_{pe}$.

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