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NONTHERMAL RADIATION PROCESSES IN INTERPLANETARY PLASMAS

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RESUMEN. En la interacción de haces de electrones energéticos con plasmas interplanetarios, se excitan ondas intensas de Langmuir debido a inestabilidad del haz de plasma. Las ondas Langmuir a su vez interaccionan con fluctuaciones de densidad de baja frecuencia para producir radiaciones. Si la longitud de las ondas de Langmuir exceden las condiciones del umbral, se puede efectuar la conversión de modo no lineal a ondas electromagnéticas a través de inestabilidades paramétricas. Así se puede excitar en un plasma inestabilidades paramétricas electromagnéticas impulsadas por ondas intensas de Langmuir: (1) inestabilidades de decaimiento/fusión electromagnética impulsadas por una bomba de Langmuir que viaja; (2) inestabilidades dobles electromagnéticas de decaimiento/fusión impulsadas por dos bombas de Langmuir directamente opuestas; y (3) inestabilidades de dos corrientes oscilatorias electromagnéticas impulsadas por dos bombas de Langmuir de corrientes contrarias. Se concluye que las inestabilidades paramétricas electromagnéticas inducidas por las ondas de Langmuir son las fuentes posibles de radiaciones no térmicas en plasmas interplanetarios.

ABSTRACT: Nonthermal radio emissions near the local electron plasma frequency have been detected in various regions of interplanetary plasmas: solar wind, upstream of planetary bow shock, and heliopause. Energetic electron beams accelerated by solar flares, planetary bow shocks, and the terminal shock of heliosphere provide the energy source for these radio emissions. Thus, it is expected that similar nonthermal radiation processes may be responsible for the generation of these radio emissions. As energetic electron beams interact with interplanetary plasmas, intense Langmuir waves are excited due to a beam-plasma instability. The Langmuir waves then interact with low-frequency density fluctuations to produce radiations near the local electron plasma frequency. If Langmuir waves are of sufficiently large amplitude to exceed the threshold conditions, nonlinear mode conversion into electromagnetic waves can be effected through parametric instabilities. A number of electromagnetic parametric instabilities driven by intense Langmuir waves can be excited in a plasma: (1) electromagnetic decay/fusion instabilities driven by a traveling Langmuir pump; (2) double electromagnetic decay/fusion instabilities driven by two oppositely directed Langmuir pumps; and (3) electromagnetic oscillating two-stream instabilities driven by two counterstreaming Langmuir pumps. It is concluded that the electromagnetic parametric instabilities induced by Langmuir waves are likely sources of nonthermal radiations in interplanetary plasmas.

Key words: INTERPLANETARY MEDIUM — PLASMAS

I. INTRODUCTION

Nonthermal radiations in the vicinity of the local fundamental electron plasma frequency fp have been detected in three distinct regions of the interplanetary medium: solar wind, upstream of planetary bow shock, and heliopause. Presumably, these three types of radio emissions arise from the interaction of energetic electron beams with solar wind plasma. Through a beam-plasma instability intense Langmuir waves are excited, which can then be mode-converted into electromagnetic waves. It is likely that the same physical processes are responsible for generating these radio emissions.

In this paper, we discuss the observed properties of these nonthermal radiations in interplanetary plasmas and propose a nonlinear generation mechanism using the concept of wave-wave interactions in plasma.

II. NONLINEAR GENERATION OF THE FUNDAMENTAL RADIATION IN PLASMA

Several coherent (fixed phase) parametric processes can convert intense Langmuir waves into electromagnetic waves near the fundamental electron plasma frequency. The processes $L \rightarrow T \pm S$ involve the decay/fusion of a Langmuir wave (L) into an electromagnetic wave (T) through a parallel/antiparallel propagating ion-acoustic wave (S); these are called electromagnetic decay/fusion instabilities (EDI/EFI), respectively. The processes $L \rightarrow T \pm S^*$ involve the coupling of two oppositely directed Langmuir waves ($L^{\pm}$) with purely growing density perturbations (S^*) to produce two electromagnetic waves ($T_{\pm}$) traveling in opposite directions; these are called electromagnetic oscillating two-stream instabilities (EOTSI). A unified formulation of EOTSI, EDI and EFI, including strongly turbulent regimes in which quasi-reactive modes are excited, has been given by Chian and Alves (1988).

The coupled wave equations (Chian and Alves 1988) that describe the coherent generation of electromagnetic waves by intense Langmuir waves via ponderomotive coupling with ion-acoustic waves are given by

$$\left[\frac{\partial^2}{\partial t^2} - c^2\nabla^2 + \omega_p^2\right] E_T = - \frac{\omega_p^2}{n_o} (nE_L)_T \ , \qquad (1)$$

$$\left[\frac{\partial^2}{\partial t^2} - c_s^2\nabla^2 \right] n = \frac{\omega_p^2 \varepsilon_o}{2m_i\omega_L\omega_T} \nabla^2 \langle E_T . E_T \rangle \ , \qquad (2)$$

where $\omega_p = (n_o e^2/m_e\varepsilon_o)^{1/2}$; $v_{th} = (KT_e/m_e)^{1/2}$; $c_s = (KT_e/m_i)^{1/2}$; $\langle\ \rangle$ denotes the fast time average; the subscripts L and T refer to Langmuir and transverse electromagnetic waves, respectively; $(\ )_T$ refers to the projection in the direction of E_T; and the quasi-neutrality approximation $n_e \simeq n_i \equiv n$ for slow time scale density perturbations was assumed.

Our theoretical results (Chian and Alves 1988) can be summarized as follows: (i) electromagnetic decay/fusion and double electromagnetic decay/fusion instabilities are essentially three-wave processes in which a Langmuir wave excites an electromagnetic wave and a traveling ion-acoustic wave, whereas electromagnetic oscillating two-stream instabilities are four-wave processes in which two Langmuir waves excite two electromagnetic waves by means of forced, localized density perturbations; (ii) electromagnetic decay/fusion and double electromagnetic decay/fusion instabilities are convective, whereas electromagnetic oscillating two-stream instabilties are absolute; (iii) electromagnetic fusion/decay and double electromagnetic fusion/decay instabilities are essentially down-conversion processes ($\omega_T < \omega_L$) except when large frequency mismatch is induced, whereas electromagnetic oscillating two-stream instabilities are necessarily up-conversion processes ($\omega_T > \omega_L$); and (iv) the dissipative threshold for electromagnetic fusion/decay and double electromagnetic fusion/decay instabilities depend on the damping rates of both ion-acoustic and electromagnetic waves, whereas the threshold for electromagnetic oscillating two-stream instabilities is independent of the damping rate of density perturbations.

III. TYPE III SOLAR RADIO BURSTS

Type III radio bursts are a type of solar radio emission produced by energetic electron streams, accelerated either in solar flares or in active storm regions, that penetrate the solar corona and the interplanetary medium, up to distances of 1 AU and even beyond (Lin et al. 1986). As electron streams move away from the Sun, Langmuir waves are excited due to a beam-plasma instability. The Langmuir waves then interact with low-frequency density fluctuations to generate fundamental radiaton with frequencies near the local electron plasma frequency. Alternatively, the Langmuir waves can interact with each other to emit harmonic radiation with frequencies near twice the local electron plasma frequency.

The electromagnetic waves generated by the electromagnetic oscillating two-stream instability, as well as EDI/EFI, may provide a natural source for interplanetary type III radio bursts near the fundamental electron plasma frequency (Chian and Alves, 1988). In a recent paper, Lin et al (1986) presented the interplanetary data from ISEE 3 spacecraft at 1 AU that indicate strong evidence for occurrence of nonlinear wave-wave interactions associated with type III emission. Experimental observations in support of parametric processes are, in brief: (1) close temporal correlation of the low-frequency bursts with the intense Langmuir wave spikes; (2) the electric field of the correlated low-frequency bursts appears to increase linearly with the Langmuir wave amplitude; and (3) the wave numbers of low-frequency modes are comparable to the Langmuir wave numbers. All the above features are intrinsic properties of EOTSI, as well as EDI/EFI, discussed in this paper. Observations 1 and 2 are evident from the nonlinear ion-acoustic wave equation (2), whereas observation 3 is the kinematics condition upon which all three parametric processes are based.

Lin et al (1986) used two sets of interplanetary parameters to show that the threshold for EDI (same as EFI) is about $W_o \approx 10^{-11}$ which is clearly exceeded by the observed Langmuir wave levels, $W_{max} \approx 10^{-6}$ and 10^{-8}, respectively. Since the threshold for EOTSI is within a factor ω_I/Γ_I, of the order of the threshold for EDI and $\omega_I/\Gamma_I \approx 10$ for the interplanetary plasma, we conclude that the observed Langmuir wave amplitudes associated with type III emission certainly exceed the threshold for EOTSI.

IV. RADIO BURSTS UPSTREAM OF PLANETARY BOW SHOCK

Narrow band radio emissions, at the fundamental (fp) and harmonic (2 fp) of the local plasma frequency, have been detected upstream of the Earth's bow shock by OGO-5, IMP-6, IMP-8 and ISEE-3 spacecrafts. Direction-finding measurements located the source region of these radio emissions to be the foreshock region where intense electron plasma oscillations excited by energetic electrons backstreaming into the solar wind from the bow shock have been observed (Gurnett and Frank 1975). Electrostatic waves near the electron plasma frequency are observed when the spacecraft is located on a line of force of the interplanetary magnetic field connected to the bow shock surface (Anderson et al. 1981; Lacombe et al. 1985). A statistical study of the main characteristics of the electron burst noise showed that the electron plasma waves are composed of two distinct parts: narrow band and broad band (Lacombe et al. 1985) The narrow band component has been interpreted as Langmuir waves emitted by a beam-plasma instability. Low-frequency electrostatic ion waves have also been observed in the upstream region of the Earth's bow shock (Anderson et al 1981). Recent studies presented strong evidence that the short wavelength ion waves observed in the Earth's foreshock are Doppler-shifted ion-acoustic waves (Fuselier and Gurnett 1984).

From the observed properties we expect that the emission mechanism of radio bursts upstream of the Earth's bow shock should be similar to type III solar radio bursts.

V. RADIO BURSTS FROM HELIOPAUSE

A radio source in the outer heliosphere has been detected by Voyager 1 and 2 spacecrafts (Kurth et al., 1984). The radio bursts are observed in the frequency range 2-3 kHz, and is above the local solar wind electron plasma frequency. A possible source of this radio emission is the heliopause. At the hiliopause it is expected that there is a terminal shock formed by the interaction of the interstellar wind with the heliophere. If, indeed, the heliopause is the source region of these radio bursts then the emission mechanism should be similar to the cases of radio bursts upstream of the Earth's bow shock and type III solar radio bursts.

REFERENCES

Chian, A.C.-L., and Alves, M.V. 1988, Astrophys. J., **330**, L77.

Lin, R.P., Levedahl, W.K., Lotko, W., Gurnett, D.A., and Scarf, F.L. 1986, Astrophys. J., **308**, 954.
Gurnett, D.A., and Frank, L.A. 1975, Solar Phys. **45**, 477.
Anderson, R.R., Parkes, G.K. Eastman, T.W., Gurnett, D.A., and Frank, L.A. 1981, J. Geophys. Res., **86**, 4.
Lacombe, C., Mangeney, A. , Harvey, C.C., and Scudder, J.D. 1985, J. Geophys. Res., **90**, 73.
Fuselier, S.A., and Gurnett, D.A. 1984, J. Geophys. Res., **89**, 91.
Kurth, W.S., Gurnett, D.A., Scarf, F.L., and Poynter, R.L. 1984, Nature, **312**, 27.

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