PROPAGATION AND ABSORPTION OF ELECTRON CYCLOTRON MASER EMISSION DURING SOLAR FLARES

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ABSTRACT: The propagation and absorption of the maser radiation emitted during solar flares are examined through linear theory and electromagnetic particle simulations. While linear theory predicts complete absorption of the maser radiation at the second harmonic layer (where the local cyclotron frequency is roughly one-half the frequency of the maser radiation), particle simulations indicate that some radiation escapes due to reemission of absorbed energy by the ambient plasma. Strong perpendicular heating of the ambient electrons occurs as well.

1. INTRODUCTION

Microwave spike bursts in solar and stellar flares are attributed to the electron cyclotron maser (ECM) instability (Holman et al. 1980; Melrose and Dulk 1982a, 1984; Sharma et al. 1982; Bastian and Bookbinder 1987), which produces intense, highly circularly polarized radiation at the fundamental and harmonics of the local gyrofrequency Ω_e.

One of the fundamental problems associated with attributing microwave spike bursts to the ECM instability is determining how the maser radiation escapes from the solar corona. Specifically, as the radiation propagates outwards, it encounters a second harmonic absorption layer, where the magnetic field magnitude has about one-half the value it has at the point of emission and where strong, gyroresonant absorption can occur. Calculations of the optical depth in the second harmonic absorption layer for nearly perpendicular propagation have shown that it is several orders of magnitude greater than unity (Melrose and Dulk 1982a, b, 1984), i.e., the radiation cannot get through.

The purpose of this investigation is to explore in detail: i) how and how much the incident maser radiation escapes from the second harmonic layer to produce the observed microwave spike bursts; and ii) how the absorbed radiation heats the plasma. Results of calculations using linear theory indicate that the linear response of the ambient plasma to the incident maser radiation is complete absorption of the radiation under virtually all circumstances. In order to investigate the nonlinear response of the plasma to the radiation, 1-D electromagnetic particle simulations are used. The code employed for these simulations is similar to the code used by Winglee et al. (1988).

2. SIMULATION RESULTS

The simulation model used is illustrated in Fig. 1, along with the magnetic field profile. An energtic population of electrons with an unstable DGH distribution is located between x_3 and x_4 and is responsible for the initial emission of maser radiation. A cool, Maxwellian population of electrons to the left of the energetic population represents the second harmonic ambient plasma. Another population of cool electrons to the right of the enegetic electrons serves to reflect radiation propagating to the right due to the increased magnetic field there. Plasma parameters associated with each electron population are indicated. The density of the electrons is a constant function of x. Ions are treated as

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infinitely massive, fixed particles. The magnetic field lies perpendicular to the dimension of the simulation, so that only radiation propagating at right angles to the magnetic field is investigated. The physical size of the simulation system is several tens of meters for typical solar parameters. The optical depth from linear theory for the second harmonic layer in the simulation is about 4.

Two simulations were performed: an undriven case, in which the initial distribution of energetic electrons was allowed to relax, and a driven case, in which the unstable energetic electron distribution was maintained through a process known as "recycling".

Fig. 2 illustrates the absorption of the largest pulse (labeled "C") emitted by the energetic plasma in the undriven simulation. This figure shows the Poynting flux as a function of position for four different times. Negative values of $S(x)$ indicate radiation propagating to the left; positive values, to the right. Pulse C is emerging from the energetic plasma in (a), and undergoes heavy absorption as it propagates through the the absorbing plasma ((b) and (c)). On the other hand, a trailing pulse (labeled "c") undergoes no absorption, and actually grows in energy as it propagates through the absorbtion layer plasma. ((c) and (d)). This growth is due to reemission of absorbed energy by the plasma heated by pulse C. This reemission may be an example of "triggered" emission, as discussed by Winglee (1985) and references therein. About 20% of the incident energy escapes the second harmonic layer in these simulations due to reemission processes.

In the driven simulation, the second harmonic plasma is constantly bombarded with pulses of maser radiation and undergoes continuous heating due to the absorption of this radiation. The nature and extent of this heating is shown in Fig. 3, which shows 4 snapshots of $x - u_x$ phase space for the driven case, where $u_x = p_x/m_e$ and p_x is a component of the perpendicular momentum. Fig. (a) shows the initial phase space configuration. In (b), a heating edge which marks the right side of the second harmonic layer has developed near $x/\Delta = 1100$. Most of the absorption (and therefore most of the heating) occurs in a small region behind this edge, which corresponds to around 10 m in the solar corona. By the end of the simulation (d), the electrons in the region immediately behind the heating edge have undergone a 200% increase in perpendicular energy. The time scale for this increase is about 1 μsec for an emission frequency of 1 GHz. Thus, absorption of maser radiation can cause significant perpendicular heating of electrons on short time and length scales.

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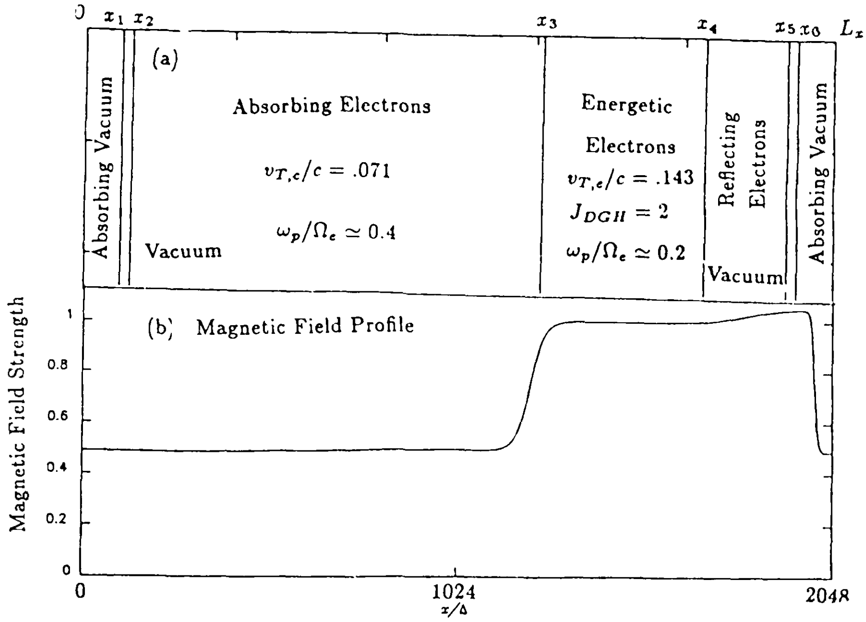

Fig. 1: The simulation model and the magnetic field profile. The magnetic field is perpendicular to the x-axis. The thermal velocity (v_T) and ratio of plasma frequency to gyrofrequency (ω_p/Ω_e) for the energetic and absorbing electron populations are shown.

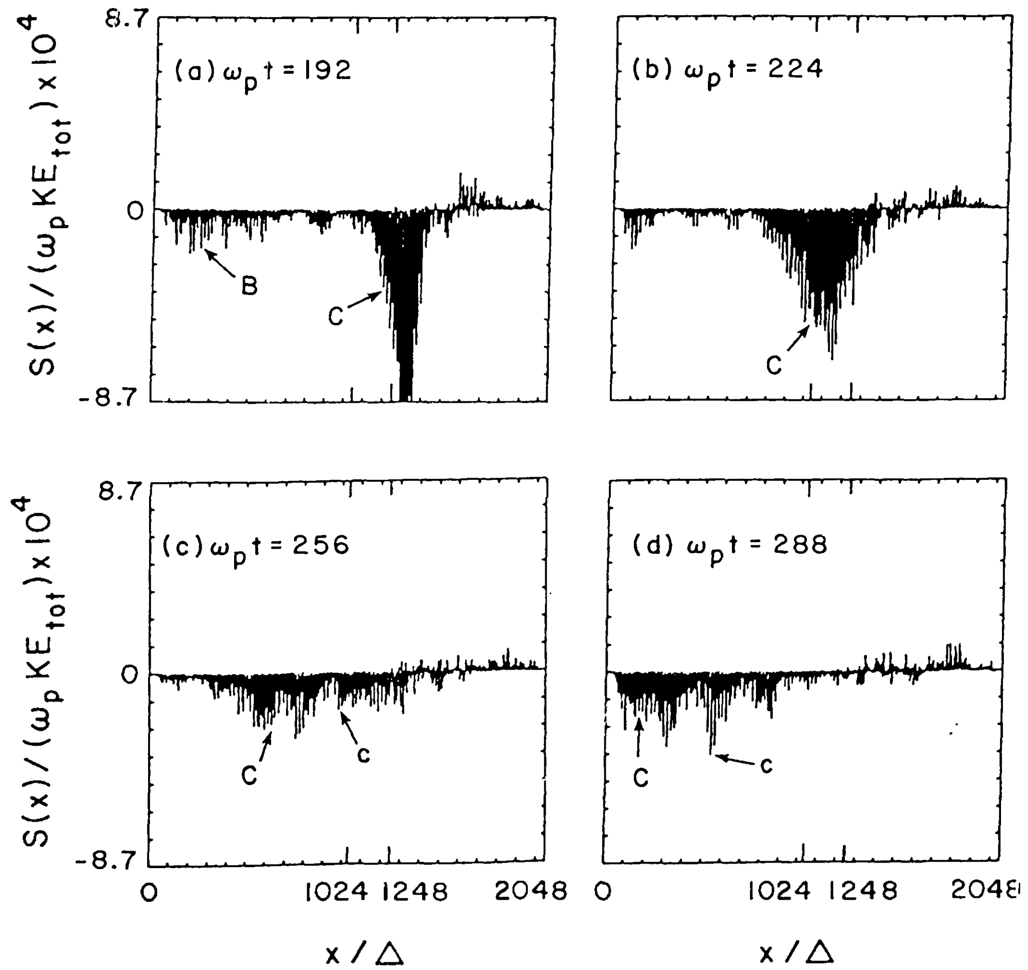

Fig. 2: Snapshots of the Poynting flux $S(x)$ at four different times depicting the absorption of pulse C and a reemission event (pulse c). The absorbing plasma lies to the right of $x/\Delta = 1248$.

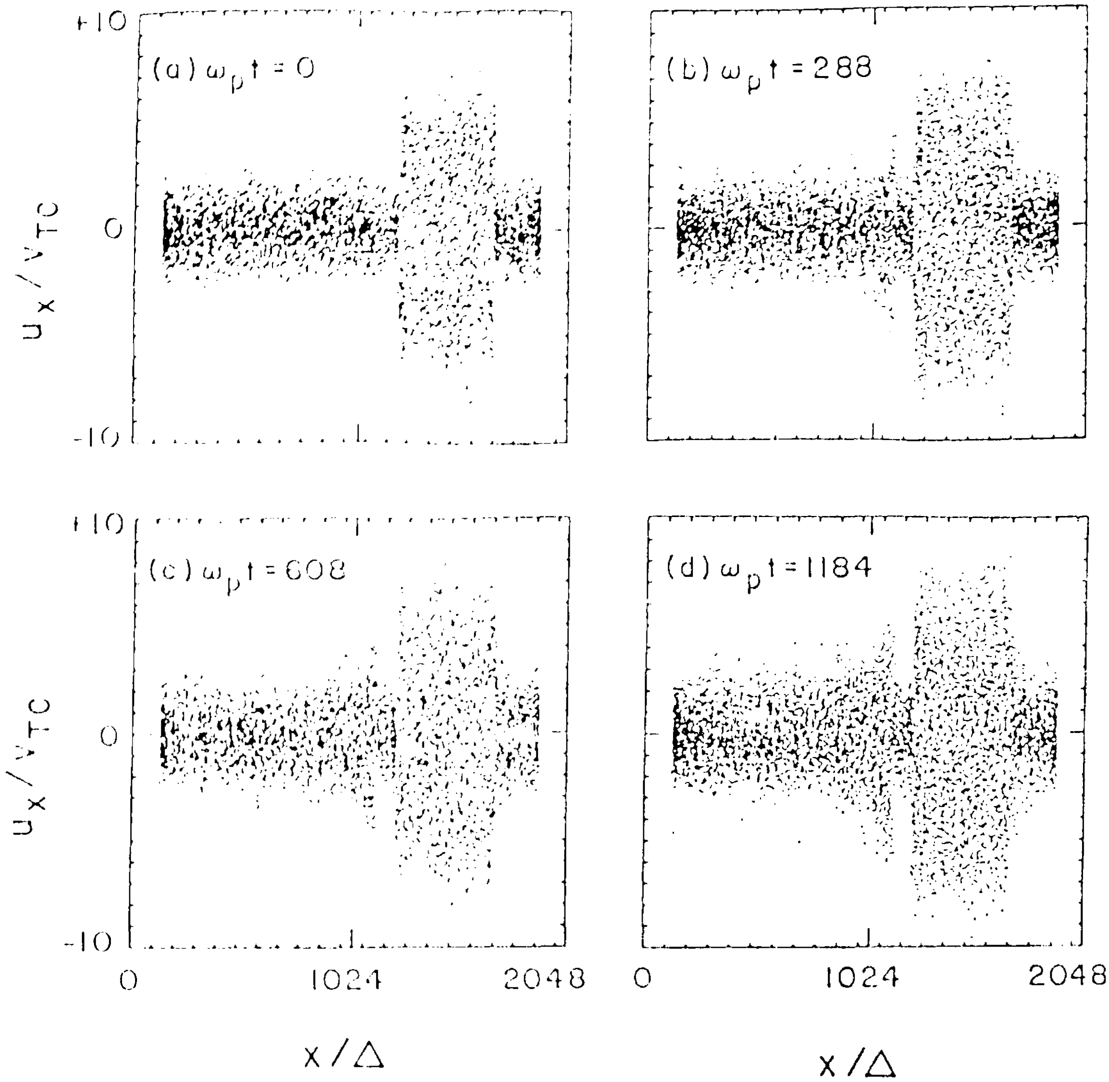

Fig. 3: The heating of the absorbing plasma by maser radiation is depicted for the driven case in these snapshots of $x - u_x$ phase space.

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