A MODEL FOR IMPULSIVE ELECTRON ACCELERATION TO ENERGIES OF TENS OF kT_e

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1. OUTLINE

We describe a model for first stage electron acceleration based on quasi-linear interaction with Langmuir waves. The acceleration takes place in a MHD-unstable plasma region (length L, volume V) that contains many microscopically unstable current layers, which act as (quasi-stationary) sources of Langmuir waves, Figure 1. Our work does not depend on the details of the generation mechanism for Langmuir waves, nor on the details of the MHD instability. For the latter, one could think of multiple tearing instabilities.

An essential feature is that the Langmuir wave energy density w^ℓ is very inhomogeneously distributed in the acceleration region. As a result, during most of the time an electron does not interact with Langmuir waves. We take this into account in the following way. Instead of a Langmuir wave distribution w_κ which is large only in a small (filamentary) fraction εV of the volume V, we work with a diluted distribution εw_κ, spread homogeneously over V. The second feature that we include is escape of electrons from the source. Our model is an extension of earlier work by Benz (1976); it contains two phenomenological parameters, the filling factor ε, and ν (below). A full description is published elsewhere (Hoyng *et al.*, 1979).

2. EQUATION

The following equation for the tail of the electron velocity distribution is obtained:

$$\partial f/\partial t = x^{-2} \frac{\partial}{\partial x} d(x) \frac{\partial}{\partial x} f + b\,x\,(f_M - f) \tag{1}$$

$$d(x) = (\pi\omega_e/2x)\,\varepsilon \int_x^1 \kappa^{-3} w_\kappa \, d\kappa ; \qquad b = \omega_e (\nu L k_e)^{-1}$$

$$\int_0^1 w_\kappa \, d\kappa \equiv w^\ell \quad ; \qquad x = v/v_e \quad ; \qquad \kappa = k/k_e$$

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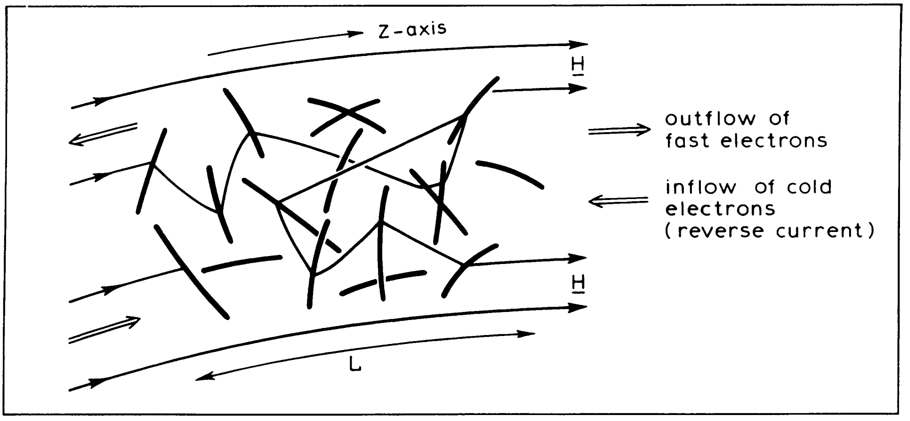

Figure 1. Outline of the acceleration region, containing many unstable current layers radiating Langmuir waves into the adjacent plasma. One 'stochastic' fieldline is sketched, but no attempt is made to draw a realistic field pattern. For application to type III bursts the region must be embedded in an open field.

ω_e, $v_e = (k_b T_e/m_e)^{\frac{1}{2}}$ are the electron plasma frequency and thermal speed; $k_e = \omega_e/v_e$. w^ℓ is the (undiluted) energy density in Langmuir waves relative to the electron thermal energy density. The electron temperature is constant everywhere (corresponding maxwellian f_M). Escape is simulated with $(f_M - f)/\tau$, where $\tau = \nu L/v$ is the lifetime of an electron in the source $(\nu > 1)$. This term expresses the fact that different values of the tail distribution inside and outside the acceleration region equalize by free streaming on a timescale τ. Reverse current effects and Coulomb interactions are ignored. The (stationary) Langmuir wave distribution w_K in (1) is supposed to be known. Strong or weak turbulence shows up only through a possibly different w_K.

3. RESULTS

Based on numerical simulations (Van Grunsven *et al.*, 1979) we choose for w_K a singly peaked distribution (peak position $\bar{\kappa}$). We find that such w_K allow a model d(x) given by $d(x) \propto (\varepsilon w^\ell/\bar{\kappa}^2)(x\bar{\kappa})^\lambda$, $|\lambda| \leqslant 1$, $x\bar{\kappa} \geqslant 1$. For this model d(x) we determine the stationary solution of (1) for $x \geqslant x_o$, requiring $f(x_o) = f_M(x_o)$. x_o is selected such that the power generated in Langmuir waves equals the power lost to escape of fast electrons (usually $x_o \sim 1/\bar{\kappa}$). There is little difference between solutions for different λ, cf. Figure 2; they are characterized by a maximum velocity x_i and a time t_i required to reach stationarity:

$$x_i \simeq \left\{\frac{25\pi}{16}\,\frac{\varepsilon w^\ell}{\bar{\kappa}^2}\,\nu L k_e\right\}^{1/5} \;;\; t_i \simeq (\nu L k_e)^{4/5}\,(\bar{\kappa}^2/\varepsilon w^\ell)^{1/5}\,\omega_e^{-1} \qquad (2)$$

For $x > x_i$ all solutions of (1) decay exponentially. Note that only the combination εw^ℓ matters and that our results depend weakly on ε and ν.

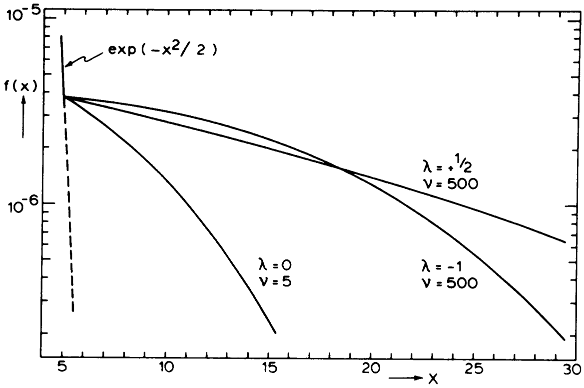

Figure 2. Stationary solutions of Eq. (1) for the model parameters (3). The discontinuity in $\partial f/\partial x$ at the boundary $x_o = 5$ is not realistic.

As an example, we introduce the following model:

$$w^{\ell} = 5 \times 10^{-3} \; ; \; \bar{\kappa} = 0.2 \; ; \; \varepsilon = 10^{-4} \; ; \; \nu = 5 \text{ or } 500$$
$$n = 10^{10} \text{ cm}^{-3} \; ; \; L = 10^{8} \text{ cm} \; ; \; T_e = 10^{7} \text{ K} \tag{3}$$

It has a turbulent volume $\varepsilon V \sim \varepsilon L^3 = 10^{20}$ cm^3 and from (2) we find for $\nu = 5$: $x_i = 10.7$ ($\rightarrow E_{max} \simeq 60 k_b T_e \sim 50$ keV) and $t_i \simeq 0.05$ s. The flux of escaping electrons is $\simeq 10^{32}$ s^{-1} (scaling: x_i^4/ν). The very short switch-on times ($\sim 10^{-6}$ s) usually quoted for turbulent acceleration are inapplicable now.

Our model could be relevant for acceleration of type III burst stream electrons. The quasi-periodic nature of this phenomenon, in our view, would be determined by the time evolution of the MHD instability. We have also applied our model to a single, large area shock as is involved in a type II burst (Hoyng *et al.*, 1979). The model does not include heating of the acceleration region and therefore we do not apply it to solar X-ray bursts.

REFERENCES

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DISCUSSION

Moore: What fraction of the ambient electrons in the Langmuir wave region are accelerated to ~50 KeV energies?

Hoyng: For the source parameters (3) with $\nu = 5$, the relative density of fast electrons ($x > x_o$) in the source region is about 10^{-3}.

Benz: Why do you have a maximum velocity of acceleration? What determines its value, and what is the value?

Hoyng: Using $\kappa^{-1} \leq x$ under the integral defining $d(x)$ one finds $d(x) \leq$ const. x^2, <u>for any</u> w_κ. It follows that the acceleration term in equation (1) is at most of order x^{-2}, while the escape term is of order x. Apparently, the nature of the wave particle interaction is such that at low velocities acceleration dominates, while beyond a well-defined velocity given by x_i, (2), escape always dominates.

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