22nd International Cosmic Ray Conference

Volume 3

CONTRIBUTED PAPERS

SH Sessions and Author Index

1991
The Dublin Institute for Advanced Studies
Dublin, Ireland

EFFICIENCY OF PARTICLE ACCELERATION BY MAGNETOSONIC WAVES

A. GALLEGOS-CRUZ
INAOE, A.P. 51 & 216, Puebla, 72000-Pue., MEXICO

Jorge PEREZ-PERAZA & M. ALVAREZ-MADRIGAL
Instituto de Geofisica, UNAM, 04510-C.U., Mexico D.F., MEXICO

ABSTRACT. We show that resonant damping of the slow magnetosonic wave mode in non-collisional regimes may drive efficient particle acceleration, even beginning at thermal energies, when energy dissipation takes place in small localized regions, in the scale of some wavelengths. In the case of the outer corona, it is found that electrons may reach energies of some hundreds of KeV, and that the conformation of energy spectra at $E \leqslant 200$ KeV is determined by the slow mode, over the contribution of the fast mode.

INTRODUCTION. It is very well known that magnetosonic waves in collisional plasmas are strongly damped through a wide variety of non-resonant processes: viscosity, heat conduction, radiation, resistivity, interaction with ions and atoms (e.g. Braginskii, 1965;Eilek, 1979), whereas in non-collisional regimes dissipation is through resonant processes, as Landau damping or Transit-Time-damping (e.g. Barnes, 1966;Hung and Barnes, 1973a,b;Barnes & Scargle, 1973). In particular, the fast magnetosonic wave mode has been widely studied within the context of particle acceleration (e.g. Fisk, 1976;Melrose, 1980;Eilek, 1982) as well as a plausible process of energy transport for coronal heating (e.g. Schwartz & Leroy, 1982). In spite that both modes can coexist simultaneously, the slow mode has been disregarded in most works as a heating process, since this wave mode is rapidly damped in his interaction with the traversed medium by non-resonant processes (collisional regimes) and so, it is only able to propagate through some wavelengths and with angles which lay very close to the magnetic field direction (e.g. Barnes, 1966). In fact, in a comparative analysis of non-resonant damping of both modes, Gallegos & Pérez-Peraza, 1991, found that at the level of the low quiet corona ($T<10^{6}$K, $n>10^{10}$ cm^{-3}, B>10 gauss) the damping of the slow mode is effectively much more important than the damping of the fast mode; however, it is also found that as one climbs toward the high corona (non-collisional regime) the non-resonant damping of both modes has a tendency to take a similar magnitud. Hung & Barnes, 1973a, have shown that damping of the fast mode in collisional regimes becomes a Landau damping in non-collisional regimes ($T=2\times10^{6}$K, $n\leqslant 5\times10^{8}$ cm^{-3}, B<10 gauss). On those basis, one should expect in similar form, that a part of the non-resonant damping of the slow mode has an equivalent resonant damping. If so, such a resonant damping of the slow mode could be associated to some extent with particle acceleration in very localized regions of the corona, in the scale of some few wavelengths (10^{7}- 10^{8})cm, (probably in the close vicinity of the instability sources), which may corresponds to subregions of typical coronal flare regions (10^{9})cm. By assuming the presence of a resonant damping process of the slow mode in non-collisional plasmas, we study here the efficiency of both modes in the acceleration of the electrons of the thermal background matter at several coronal heights, and the contribution of these two modes in the conformation of an acceleration spectrum.

ENERGY SPECTRUM FROM MAGNETOSONIC WAVE ACCELERATION.

Let us assume an homogeneous plasma and isotropy of waves and particles. In this case the momentum diffusion coefficient is $D_{pp\pm} = \alpha_\pm p^2/\beta$ (e.g. Kulsrud & Ferrara, 1971; Achterberg, 1981), where p is the particle momentum, β is the velocity of particles v in terms of the light velocity and $\alpha_\pm$ are the coefficients of the acceleration efficiency, given as

$$\alpha_\pm = \frac{2\pi V_\pm^2(\theta)}{B^2 v} \int_{K_T}^{K_{max}} K W(K) dK \quad . \quad . \quad . \quad . \quad . \quad .(1)$$

(e.g. Eilek, 1984), where $V_\pm(\theta)$ are the corresponding phase velocities of the fast mode (+) and the slow mode (-), θ is the propagation wave angle, K_{max} and K_T are the propagation vectors at the extreme of the magnetosonic turbulence distribution, W(K) and B is the magnetic field strength. To derive the acceleration spectrum we have solved a Fokker-Planck type equation in the energy phase space, assuming that no particles are externally injected, but only local thermal particles participate into the acceleration process

$$\frac{\partial N(E,t)}{\partial t} = \sum_{n=1}^{2} (-1)^n \frac{\partial^n}{\partial E^n}\left[\left\langle \frac{dE^n}{dt} \right\rangle N(E,t)\right] - \frac{N(E,t)}{\tau} \quad . \quad . \quad .(2)$$

where E is the particle total energy and τ is the mean confinement time within the process. The solution of these kind of equations has been widely described in previous works (e.g. Pérez-Peraza & Gallegos, 1991). The energy change rates appearing in (2) has been determined from the diffusion coefficients according to the method of Tystovich, 1977. To solve (2) we employed a technique described by Gallegos & Pérez-Peraza, 1990, on basis to a combination of the WKBJ method and the Laplace Transforms. In the evaluation of the $\alpha_\pm$ we employed a characteristic value of K for this kind of wave modes, $\langle K \rangle \simeq 5\times10^{-8}$ cm^{-1} Since $1/B^2 \int W(K)dk \simeq \langle \delta B^2 \rangle / B^2$ (where $\langle \delta B^2 \rangle$ is the quadratic mean of the magnetic field fluctuations) we have been able to evaluate the rates $\langle dE^n/dt \rangle$ in (2). Finally, neglecting the particular solution of (2) relative to the contribution of thermal particles to the final spectrum (i.e., considering only those that acquire suprathermal energies) the obtained solution is

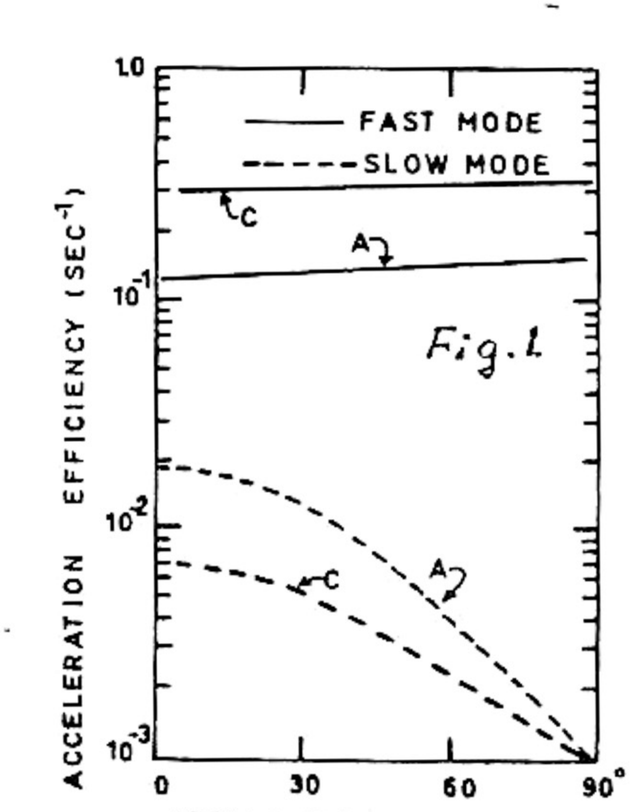
$$N(E,t) = \frac{9\times10^5 N_o E^{\frac{3}{4}} e^{-t/\tau}}{\alpha T^{3/2} (E^2 - m^2c^4)^{\frac{1}{8}}} \int_0^t \frac{t'^{-\frac{3}{2}} dt'}{(t-t')^{\frac{1}{2}}} \int_{E_o}^{E} \frac{(E'-mc^2)^{\frac{1}{2}} e^{-\frac{E'-mc^2}{kT} - \frac{[\ln(E/E')]^2}{2\alpha t'}}}{E'^{\frac{1}{4}} (E'^2 - m^2c^4)^{\frac{1}{8}} [\ln(E/E')]^{-1}} dE' \ldots (3)$$

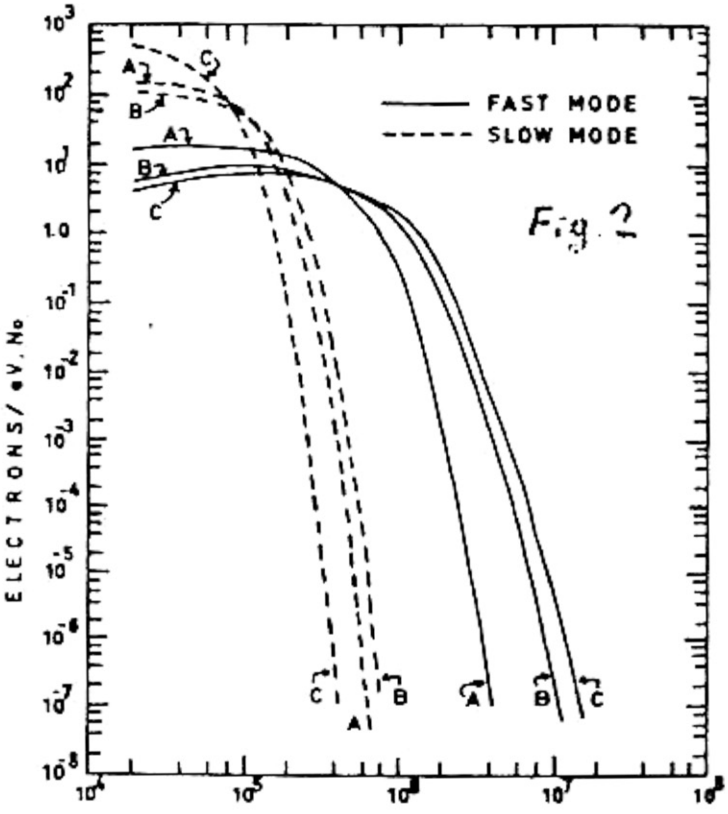
where t is the acceleration time and No is the number of particles per energy interval.

RESULTS. For evaluations we have selected three different coronal regions, denoted as points A,B,C in table I., where we have tabulated the corresponding values of $\alpha_\pm$. In Fig. 1. we examined the behavior of the acceleration efficiency as a function of the wave propagation angle: it can be appreciated that for the fast wave mode the efficiency is insensible to Θ , but for the slow mode it decreases rapidly from a maximum at $\Theta = 0°$ to $\alpha_- = 0$ at $\Theta = \pi/2$. However, as an important fraction of wave propagation in the high corona is in the radial direction, we have chosen $\langle\Theta\rangle = 15°$ for further calculations. For evaluations of the spectrum at those three points typical coronal values for $\langle\delta B^2\rangle/B^2 = 0.1$ and $\tau \geq t = 1$ s, were considered. The analysis of fig. 2. shows that at the level of the low corona (point C) the fast mode is highly efficient in the conformation of the acceleration spectrum, and able to accelerate electrons for above of 10 MeV, while with the slow mode electrons are only able to reach some hundreds of KeV. However, at the level of the high corona (point A), the slow mode increases in efficiency, while it decreases with the fast mode at E > 0.5 MeV. It should be noted that for E $\lesssim$ 200 KeV the conformation of the spectrum is dominated by the slow wave mode.

Table1. Source parameters and acceleration efficiencies

Point	T(°K)	n(part/cm^3)	B(gauss)	$\alpha_+(s^{-1})$	$\alpha_-(s^{-1})$
A	2×10^6	10^9	5	0.125	1.49×10^{-2}
B	2×10^6	5×10^8	5	0.248	1.60×10^{-2}
C	8×10^5	10^{10}	25	0.309	6.44×10^{-3}





CONCLUSIONS. From this study it can be inferred that in regions of the high corona (non-collisional regime) where the energetic processes involving magnetosonic waves are mainly of resonant nature, damping of the slow mode may become important in the conformation of the electron acceleration spectrum, mainly in the low energy region. So, this slow mode may give a substantial contribution of the global energy spectrum in solar electron events taking place at high coronal level, in which case we would expect events constrained to $E < 0.5$ MeV, as is the most frequent case in the sun.

REFERENCES.

Achterberg, A., Astron. Astrophys. 97, 259, 1981.

Barnes, A., Phys. Fluids 9, 1483, 1966.

Barnes, A. & Scargle, D.J., Astrophys. J. 184, 251, 1973.

Braginskii, S.I., Rev. Plasma Phys. 1, 205, 1965.

Eilek, J.A., Astrophys. J. 230, 373, 1979.

Eilek, J.A., Astrophys. J. 254, 472, 1982.

Eilek, J.A. and Herriksen, R.N. Astrophys.J. 277, 820, 1984.

Fisk, L.A., J. Geophys. Res. 81, 4633, 1976.

Gallegos, A. & Perez-Peraza, J., Proc. 1st Mexican Nuclear Soc. Conf. 1, 294, 1990.

Gallegos, A. & Perez-Peraza, J., (1991) (in preparation).

Hung, R.J. & Barnes, A., Astrophys. J. 180, 271, 1973a.

Hung, R.J. & Barnes, A., Astrophys. J. 181, 183, 1973b.

Kulsrud, R.M. & Ferrari, A., Ap. Space Sci. 12, 302, 1971.

Melrose, D.B. Plasma Astrphysics Vol 2, Chap. 9, Gordon & Breach, 1980.

Perez-Peraza, J. & Gallegos, A., (1991) submitted to Fundaments Of Cosmic Physics.

Schwartz, S. I. & Leroy, J.L., Astron. Astrophys. 112, 93, 1982.

Tsytovich, V.N., Theory of Turbulent Plasmas, Plenum Press, 1977.