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Stochastic particle acceleration by a random electric field in coronal loops

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RESUMEN
La turbulencia hidromagnética presente en arcos coronales activos especialmente antes de ráfagas, es simulada por un campo eléctrico estocástico que sigue una ley de potencias, con el fin de estudiar numéricamente la aceleración estocástica de una distribución Maxwelliana de partículas. Se supone que estas partículas están atrapadas en el intenso campo magnético de un arco. Se muestra que se crea una cola supratermal en la distribución inicial de velocidades y que la distribución angular de las particulas se vuelve anisotrópica.

PALABRAS CLAVE: aceleración de partículas, regiones activas, ráfagas.

ABSTRACT
The hydromagnetic turbulence present in active loops, especially prior to flares, is simulated by a random electric field with a power law, in order to study numerically the stochastic acceleration of a Maxwellian distribution of particles. These particles are assumed to be trapped in the intense magnetic field of a loop. It is shown that a suprathermal tail is grown in the initial velocity distribution and that the angular distribution of the particles becomes anisotropic.

KEY WORDS: particle acceleration, active regions, flares.

INTRODUCTION

In the last few years it has become evident, thanks mainly to gamma ray observations (see Chupp *et al.*, 1982; Okudeira, 1989), that high energy protons are already present during the impulsive phase of a solar flare. Moreover, Simnett (1985) has proposed that most of the energy of the flare comes from suprathermal ions in the energy range 10^2 - 10^3 kev. On the other hand, there exists some evidence that the energetic particles can be accelerated in an active region prior to flares (Antonucci *et al.*, 1982, 1984; Simnett and Strong, 1984; Veck *et al.*, 1984; Simnett and Ryan, 1985; Smith and Brecht, 1986). In fact, McDonald and van Hollebeke (1985) have shown the existence of precursors in flares approximately 3 hours prior to two large gamma ray flares: that of 21 June 1980 and that of 3 June 1982.

In spite of this evidence, the role that energetic particles play in the development of a flare remains of little importance. Nevertheless, Pérez Enríquez (1985, 1988) has proposed that some of the particles trapped in the intense magnetic field of a coronal loop can be accelerated to generate, after their precipitation into the solar atmosphere, a cromospheric instability capable of producing a flare.

The purpose of this paper is to study numerically the acceleration of protons trapped in the solar corona, in the presence of hydromagnetic turbulence, simulated by a random electric field acting on the particles in a stochastic manner.

DESCRIPTION OF THE MODEL

The appropriate mechanism to study the acceleration of particles in solar active regions before the occurrence of flares is the stochastic acceleration that implies the solution of the Fokker-Planck equations, where the spectrum of the magnetic fluctuations is known exactly. In general, this is not the case, especially for solar coronal loops, mainly because the instruments are still unable to measure the fine structure of the magnetic field. For this reason, studies that involve the spectrum of the magnetic fluctuations are carried out using theoretical models for the turbulence. We consider the existence of hydromagnetic turbulence in the active loop. First we propose that if the particles are trapped in the magnetic field for a time sufficiently long, they are susceptible of being accelerated. This is true when the energy density of the hydromagnetic turbulence is greater than that of the particles so that an interaction between them and the waves leads to an increment of their energy. However, the change in the velocity of the particles is always small as compared to their velocity, in order to maintain the stochastic character of the process.

As the electric field associated with the magnetic field fluctuations is directly involved in the acceleration, we propose a stochastic electric field whose spectrum follows a power law of the form $\delta E^{-\alpha}$, where δE is the intensity of the electric field associated with the magnetic field eddies, and α is the spectral index which can vary between 1 and 2, as responsible of the stochastic acceleration of the particles. We simulate this with the method of Montecarlo (figure 1).

In order to carry out the numerical study of the acceleration of the particles in the active loop in the presence of hydromagnetic turbulence, a computational program is developed which simulates, by the method of Montecarlo, the Maxwellian velocity distribution of the particles, (figure 2) which interact with the random electric field. The interaction takes place while the particles remain trapped in a magnetic "bottle" which simulates a solar active region. The magnetic bottle is described through a sinoidal function whose minimum value corresponds to the magnetic field in the centre (100 gauss) and whose maximum value corresponds to the ends (1000 gauss) (figure 3). The dimensions of the acceleration region are 10^9 cm in length and 10^8 cm in width, which corresponds to those of a large active loop. In order for the particle to remain in the trapping region it must first have a radius of gyration less than the dimensions of the magnetic bottle; close to the magnetic mirror, the pitch angle of the particle must be close to 90° so that it can be reflected; and the particle must be inside the trapping region.

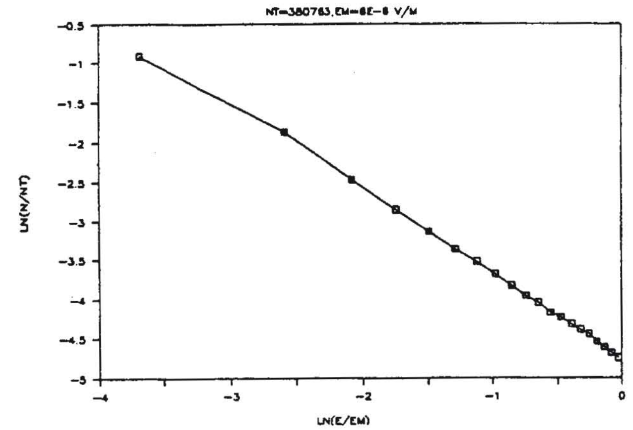

Fig. 1. Energy spectrum of the stochastic electric field generated by the Montecarlo Method. The maximum value of the field is Em = 6 x 10^{-6} v/m.

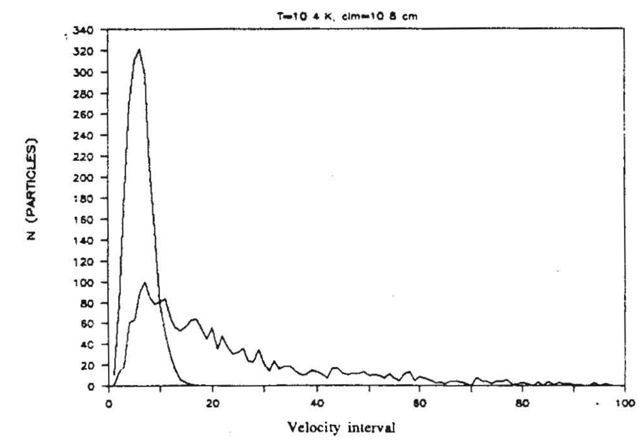

Fig. 2. Initial and final velocity distributions for a temperature of 10^4 K after 500 seg.

RESULTS OF THE NUMERICAL EXPERIMENT

We examine first the case in which the mean free path between the interaction of the particles with the electric fields (mfp) is constant, and next the presumably more realistic case, according to theory (for instance the quasilinear theory, Jokipii, 1971) in which the mfp is a function of the velocity of the particles. The first case is justified because in the interplanetary medium there are some extensive regions where the mfp is constant (Moussas *et al.*, 1982).

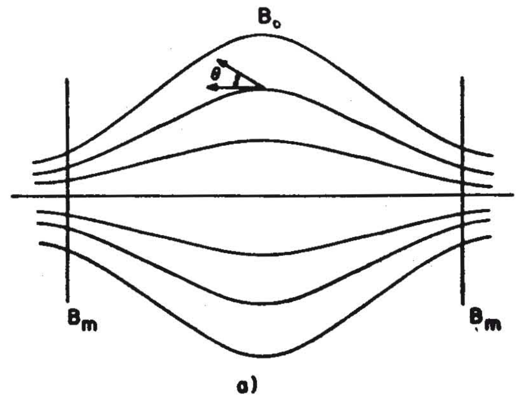

Fig. 3. Simplified configuration of the magnetic field at the centre, is about 100 gauss. Bm, the field at the ends is about 1000 gauss. θ represents the pitch angle of a particle, i.e., the angle between the velocity vector and the field line.

The results of the analysis are the following:

1. In both cases there is a tendency for the total energy of the particles to increase (figure 4 shows an example.) This could emphasize the proposition that some important heatings found prior to flares are the result of an acceleration process independent of the flare process itself.

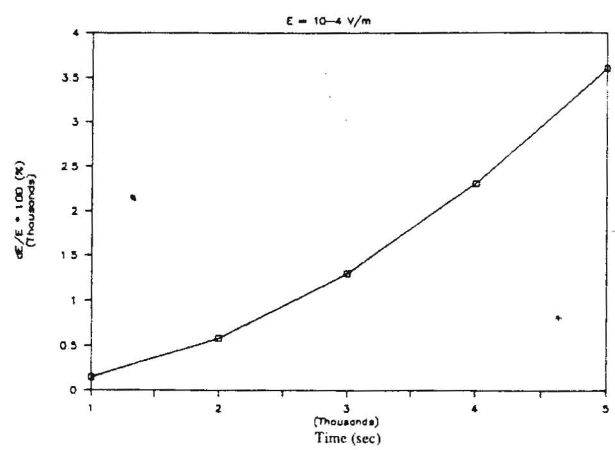

Fig. 4. Total energy gain for a maximum electric field of 10^{-5} v/m for a variable mean free path after 5000 seg.

2. In both cases the velocity distribution of the particles grows a suprathermal tail, that is, the particles in the distribution move from low to high energies, compensating the loss of particles in the course of

the experiment. Figure 2 shows an example. The difference between the two cases is that for the variable mfp; this happens only for an electric field sufficiently intense.

3. The pitch angle distributions for both cases are completely different. For the case of constant mfp, the final distribution is anisotropic with peaks around the loss cone angle (figure 5), as was obtained through numerical simulations in the interplanetary medium (Valdés-Galicia *et al.*, 1988). For the case of variable mfp, the distribution is anisotropic with a peak around 90° (figure 6), as obtained from the analysis of the acceleration of particles in the interplanetary medium, using the quasilinear theory.

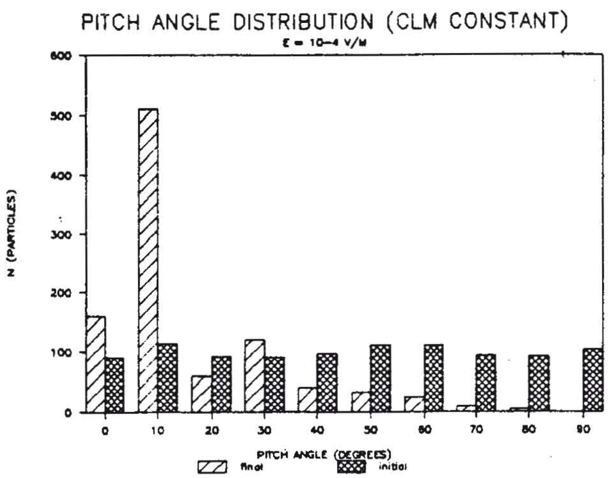

Fig. 5. Initial and final pitch angle distributions for a constant mean free path of 10^8 cm after 5000 seg. and a temperature of 10^5 K.

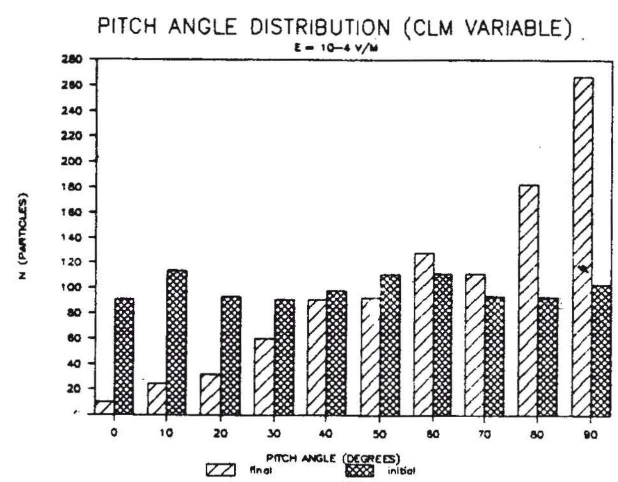

Fig. 6. Initial and final pitch angle distribution for 10^4, 10^{-5} and 10^{-6} v6m maximum electric fields, for a variable mean free path after 5000 seg.

In summary, the presence of hydromagnetic turbulence in an active region, which is observed through the brightenings in soft X rays prior to the occurrence of some flares, might point to the existence of a process of stochastic acceleration whose consequences can only be determined exactly when we know the real power spectrum of the magnetic field in these regions of the Sun.

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