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Magnetic Configuration Dependence of Particle Acceleration Efficiency in Solar Flares

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Abstract

Acceleration of protons and electrons in a neutral current sheet (NCS), which forms as a consequence of filament eruption in the corona, is considered as a possible mechanism of generation of the relativistic particles during the late phase of solar flares. From a set of magnetic field configurations, the particle energization in solar flares has been studied in the flare region using an electromagnetic particle in cell simulation code. In this paper, we study the ability of some of them to accelerate the plasma in the flare region. Three magnetic field configuration models of the literature have been used in to evaluate the protons and electrons behaviour and their acceleration efficiency. Ours results point out that depending on each configuration, the maximum energy and the particles maximum acceleration efficiency is reached at different times and with different values for each model.

1 Introduction

Generation of charged particles with energies exceeding the thermal energy is known to be a widespread phenomenon in cosmic plasmas. This process, thermal particle acceleration, is the subject of a great deal of study. The mechanisms of acceleration, however, still baffle the full theoretical understanding. This is specially true of the particle acceleration in solar flares, because the existing wealth of observations imposes severe restrictions on the models for acceleration. A successful flare model should quantitatively explain the origin and characteristics or energetic particles, both nonrelativistic and relativistic, in solar flares.

The examination of the magnetic field configuration models should be done focussing on the analysis in different characteristics: the energy source, the associated local instability, the magnetic field configuration, etc. The analysis will be developed concentrating on magnetic field because it seems to be the main source of flare energy.

The solar flares are defined as magnetic energy released as a burst due to sudden changes of the currents flowing in the solar corona. The magnetic reconnection is the origin of this phenomenon. When two opposite magnetic fields touch lightly, in the boundary surface the magnetic field neutralizes due to a very intense electric field. This boundary region is commonly named neutral current sheet. The current sheet thickness depends on the ambient plasma conductivity of the solar corona. Ideally magnetic reconnection may be treated as two collisionless plasmas with magnetic field lines merging at the boundary layer. Therefore an electromagnetic energy transferred into kinetic energy takes place as plasma flowing into the reconnection region, being accelerated along the current sheet.

The acceleration efficiency in several models has been studied in this work. With this aim, the simulation particle in cell code has been adapted to evaluate the plasma particles dynamic under different magnetic field configurations.

2 Simulation

The main aim of our work is the analysis of the particle acceleration capability of these models, Table 1, as well as to quantify their acceleration efficiency.

Table 1. *- Configurations of the magnetic fields models of neutral current sheet.*

MODELS	MAGNETIC FIELDS
Priest – Forbes	$B = B_0((y-2)^2-1+z^2, -x, 1)$
Syrovatsii	$B = B_0(-y, -x, 0)$
Smith – Raadu	$B = (B_0, -B_0/L, 0)$

Simulation of plasma dynamics under several theoretical configurations of magnetic reconnection in neutral current sheets has been performed with a particle in cell simulation code. It has been considered a cubic flare region of 10^{27} cm^3, with neutral fully ionized plasma in thermal equilibrium, at 10^7K. The simulation region has been spatially divided into twenty cells along each spatial dimension. At the initial state, the protons and electrons have been distributed homogeneously along the cells. The initial distribution of the particle velocity follows a Gaussian distribution centered to the selected thermal velocity. Space and time have been discretized and the time-step has been fixed to 1.7 ms so that the Courant Condition is fulfilled. The particles, which escape from the simulation flare region, are stored in a file and then, it is our purpose to carry them out across the interplanetary medium until they reach the Earth neighbourhood where they can be detected. The observational characteristics of the emerging flare particles can be obtained with different models, letting a full comparison between them, in order to determine the most suitable one, in comparison with observations.

It is very important to note that processes as collision, radiation ... have not been considered in the particle energy losses. Steady magnetic field configurations have been used for simulation in this work, taking into account electromagnetic fields generated by particle motion. The boundary condition is the storage of particles that leave the acceleration region, replacing stored particles with new particles at the ambient temperature of the plasma.

Table 1 shows the magnetic field configurations used as the set of simulated models. B is the magnetic field intensity with an upper limit of 100G, B_0 is the input magnetic field parameter and $L{\sim}10^9$ cm is the sheet length.

3 Results

Results of the Priest-Forbes, Syrovatskii and Smith-Raadu models have been presented in the following figures, because these models show the highest discrepancies found. The particles motion under these magnetic field models have been simulated during 50 ms. Both, electron and proton populations show a different behaviour in the maximum energy acquired as well as in the acceleration efficiency.

As it can be noticed in figure 2, the Priest-Forbes model generates a faster energy increase for protons than the Syrovatskii and Smith-Raadu models. For these last models the energy increase is only about few MeV. Moreover, in figure 1 we can check that the configuration with the highest proton acceleration efficiency is the Priest-Forbes model. For the Syrovatskii and Smith-Raadu magnetic configurations models the proton acceleration efficiency increases quickly in the first time-steps, afterwards a steeper decrease is observed and finally it increases again reaching values between 0.1 and 1 s^{-1}.

For the electron population, as it was found for the proton population, the highest efficiency is reached for the Priest-Forbes configuration, figure.3, just after the beginning of the simulation. Afterwards a decrease in the efficiency has been observed. For the Syrovatskii configuration the acceleration efficiency increases 15 ms after the simulation had started. In figure 4, the electron kinetic energy vs. acceleration time has been plotted and it can be observed that for the Priest-Forbes configuration the electron energy increases until almost 1 MeV. For the Syrovatskii configuration the electron energy begins to increase 30 ms after the beginning, but it is able to accelerate electrons to tens of keV. The Smith-Raadu configuration does not reach enough energy for accelerating the electrons, hence the results obtained with this configuration model has not been plotted in figure 3 and 4.

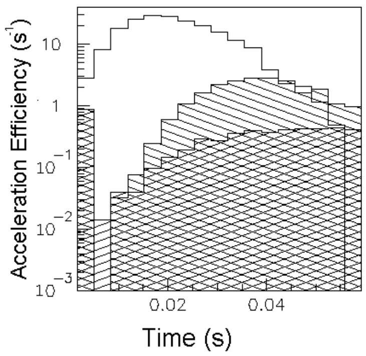

Fig. 1.- *Proton Acceleration Efficiency for the three models*

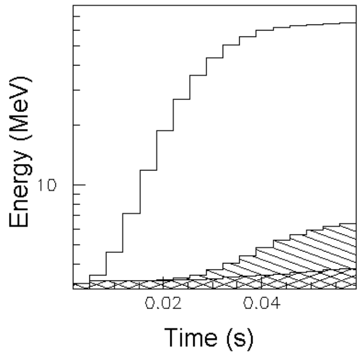

Fig.2.- *Temporal proton energy behaviour for the three models.*

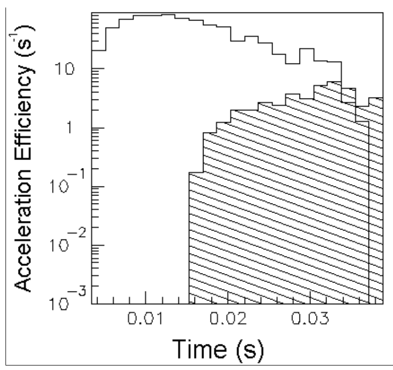

Fig.3.- *Electrons Acceleration Efficiency for three models.*

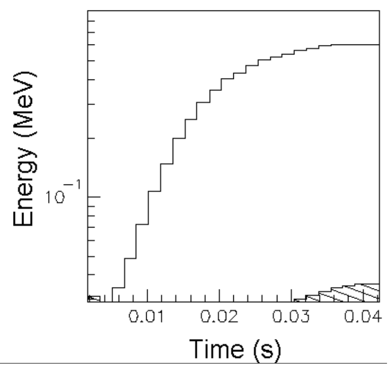

Fig.4.- *Temporal Electrons Energy behaviour for three models .*

PRIEST-FORBES SYROVATSKY SMITH-RAADU

Table 2 and 3 present a summary about our simulation analysis. Table 2 shows the protons and electrons energy as function of the acceleration time for the solar flare models analyzed. With magnetic field intensities of 100 G, the highest proton energy reached has been of 65.3 MeV for the Priest-Forbes configuration model, as well as 0.6 MeV for the most energetic electrons, again for the Priest-Forbes model.

Table 2. *-Acceleration time for which the maximum particle energy is reached. (*)Electron acceleration efficiency is negligible.*

	PROTONS		ELECTRONS	
MODELS	TIME	ENERGY	TIME	ENERGY
PRIEST-FORBES	58 ms	65.3 MeV	42 ms	0.6 MeV
SYROVATSKY	58 ms	6.4 MeV	42 ms	36 keV
SMITH-RAADU	58 ms	3.8 MeV	(*)	(*)

Table 3 shows the acceleration efficiency for protons and electrons. For both, the maximum efficiency is reached for the Priest-Forbes configuration model.

Table 3. *- Time during the acceleration maximum efficiency is reached for protons and electrons for the three magnetic field configurations. (*) Electron acceleration efficiency is negligible.*

	PROTONS		ELECTRONS	
MODELS	TIME MX	MAX. EFF.	TIME MX	MAX. EFF.
PRIEST-FORBES	17 ms	29.3 s^{-1}	12 ms	82.6 s^{-1}
SYROVATSKY	37 ms	2.9 s^{-1}	33 ms	6.2 s^{-1}
SMITH-RAADU	3.4 ms	0.9 s^{-1}	(*)	(*)

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4 Conclusions

Finally, we can state that the Priest-Forbes magnetic field configuration model should produce most efficient proton and electron acceleration reaching efficiencies as high as 29.3 and 82.6 s^{-1} respectively. This acceleration efficiency has been obtained with a main component of the magnetic field near the current sheet of 100 G that corresponds to the characteristic value of the coronal magnetic field. Such magnetic field produce a direct electric field inside the NCS of 10V/cm, compatible with the observation in solar active regions, in particular, in erupting prominences (Foukal and Hinata, 1991).

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