24th International

COSMIC RAY CONFERENCE

VOLUME 4

CONTRIBUTED PAPERS

SH SESSIONS

XXIV ICRC
ROME 1995

AUGUST 28 – SEPTEMBER 8, 1995

On Formation of Relativistic Particle Beams in Extended Magnetic Structures: II. Two Source Model for Solar Cosmic Rays

L.I. Miroshnichenko[a,1], J. Pérez-Peraza[a], E.V. Vashenyuk[b], M.D. Rodríguez-Frías[a,2], L. del Peral[a,2] and A. Gallegos-Cruz[c],

[a] *Instituto de Geofísica, U.N.A.M., 04510 - C. U., México D. F., MEXICO*
[b] *Polar Geophysical Institute of RAN, Apatity, 184200, RUSSIA*
[c] *Ciencias Básicas, UPIICSA, IPN, Té 950, Iztacalco 08400, México D. F., MEXICO*

Abstract

In a previous paper we gave evidences of the existence of two separate relativistic components (prompt and delayed ones, PC and DC) in certain solar proton events (SPE). Here we attempt to substantiate a two source scenario for PC and DC generation by reproducing the energy spectra of some characteristic events which present both components. The spectrum of the PC was calculated earlier with regular acceleration in the current sheet. It is shown that the energy spectrum of the DC is well reproduced with stochastic acceleration by magnetosonic wave turbulence.

1 Introduction

As it was noted in the previous paper [1] the first mention of possible existence of two separate components of relativistic SCR was delivered in [2]. Independently, the authors [3] investigating the relevant amounts of all SCR generated by the flare of June 3, 1982 also approached to a concept of two components: the first population is accelerated during the flash phase of the flare, the particles being trapped into closed magnetic structures deeply into the solar atmosphere; the second component with the very hard spectrum is generated high in the corona at a second phase of acceleration, by a coronal shock wave from the same flare.

Certain evidences of two ejections of relativistic protons were found [4] for the Ground Level Event (GLE) of September 29, 1989. Some peculiarities of this GLE may be explained by the model of two separate sources of acceleration [5]. To substantiate such a model in [7] energy spectra of the PC were calculated. Here we will proceed to reproduce energy spectra of the DC for two SPEs.

2 Particle Spectrum of the Prompt Component

Let us assume a rather conventional scenario of flare development at heights $\simeq (0.07 - 0.14)\, R_\odot$. When expanding, the flare-generated magnetic bottle gets in touch with the neighbouring magnetic arcade at heights $\simeq (0.5 - 1.0)\, R_\odot$ where a neutral current sheet (NCS) may be formed due to the process of magnetic reconnection between lines of opposite polarity. Local particles in the non-adiabatic region of the NCS

[1] Permanent address: IZMIRAN, Troitsk, Moscow Region, 142092, RUSSIA
[2] Permanent address: Depto. de Física, Universidad de Alcalá, 28871 Alcalá de Henares, Madrid, SPAIN

may be accelerated by the intense impulsive electric fields produced by the magnetic merging process. According to [7] the energy spectrum of the accelerated particles in a NCS topology is:

$$N(E_k) = 1.47 \cdot 10^7 \left(\frac{nL^2}{BE_{k*}}\right) \left(\frac{E_k}{E_{k*}}\right)^{-1/4} \exp\left[-1.12 \left(\frac{E_k}{E_{k*}}\right)^{3/4}\right] \quad proton/MeV \quad (1)$$

where $E_{k*} = 8.23 \cdot 10^{-3} B^2 (nL)^{2/3}$ MeV, n - plasma density and L - NCS length. In [6] it was shown that the source spectrum of the PC of three events, 23.2.1956, 7.12.1982 and 16.2.1984 may be adequately fitted with this equation to the observational spectra provided the source parameters for the three events are: $B = 30$, 20 and 20 G, $n = 2 \cdot 10^7$, $2 \cdot 10^6$ and $5 \cdot 10^6$ cm^{-3}, $L = 10^{10}$, $2 \cdot 10^9$ and $2 \cdot 10^{10}$ cm, respectively. These values correspond to generation altitudes $\geq 0.5 R_\odot$ in the corona, and the accelerating electric field is in the range $\mathcal{E} = (U/c)B \sim 10^{-2} - 10^{-1}$ $V \cdot cm^{-1}$, where $U = V_A/18$, and V_A = Alfvén velocity. The accelerated particles leaving the source undergo focusing in the diverging magnetic field of the corona and the interplanetary magnetic field producing a major collimated component, though some fraction undergoes simultaneous azimutal drift ($\sim 0.7\, v_\perp$), which could be associated to the delayed arrival of particles generated in well connected events ($\sim 60^\circ$ W) as reported in [8].

3 Particle Spectrum of the Delayed Component

According to the proposed scenario, the bulk of particles are generated in the flare volume or its vicinity and are ejected at the opening of a surrounding closed magnetic structure ("the magnetic bottle"). The acceleration of this component is carried out by the dissipation of local turbulence to a select number of particles able to undergo resonant interaction with the turbulence wave modes. In order to fulfill the resonant requirements [9] particles must have a relatively high initial energy, which is also necessary in order to overcome the Coulomb barrier during their "flight time" in the closed magnetic region. This entails the requirement of an injection mechanism to supply such kind of particles into the resonant stochastic process. Following [10] we assume acceleration by magnetosonic turbulence and monoenergetic injection, where all particles that are susceptible of paticipating to the resonant process have an initial energy around E_0. In this case according to [10] the source energy spectrum, for a steady state situation is:

$$N(E_k) = \frac{q_0}{2} \left(\frac{a_f \alpha}{3}\right)^{-\frac{1}{2}} \left(\beta_0^{3/2} E_0\right)^{-1} \left(\frac{\beta_0}{\beta}\right)^{\frac{1}{4}} \left(\frac{E}{E_0}\right)^{\frac{1}{2}} \exp\left[-\left(\frac{3a_f}{\alpha}\right)^{\frac{1}{2}} J_f\right] \qquad (2)$$

where q_0 $(proton/MeV)$ is the injected flux, $\alpha(s^{-1})$ is the acceleration efficiency, E_0 is the injection energy, E_k = kinetic energy, $a_f = (\alpha/3)(\bar{F} + 3/\alpha\tau)$, τ is the mean confinement time of particles in the acceleration region, β is the particle velocity in terms of the light velocity, β_0 is the velocity corresponding to E_0 and $\bar{F} = 0.5\left[\beta^{-1} + 3\beta - 2\beta^3 + \beta_0^{-1} + 3\beta_0 - 2\beta_0^3\right]$, and $J_f = \tan^{-1}\beta^{1/2} - \tan^{-1}\beta_0^{1/2} + 0.5\ln\left[(1+\beta^{1/2})(1-\beta_0^{1/2})/(1-\beta^{1/2})(1+\beta_0^{1/2})\right]$.

Calculated spectra with later equation for the DC and observational spectra [11,12] for the 29.9.89 and 22.10.89 events are shown on figs 1.a and 1.b, respectively. The best fittings assuming monoenergetic injection at $E_0 = 1\ MeV$ and $\tau \simeq 1\ s$ are obtained in the range $\alpha = (0.03 - 0.037)\ s^{-1}$ for the first event and $\alpha = (0.034 - 0.065)\ s^{-1}$ for the second one. It should be noted that the fitting was carried out without taking into account a possible interplanetary modulation of observational spectra.

4 Conclusions

On basis of observational data summarized in [1] we discuss here a qualitative scenario for a particular kind of solar events for which two relativistic components seem to proceed from two different sources. One of them produces relativistic particles during the impulsive phase of flares, deeply inside the corona, and another one operates later in the upper corona, where the conditions of particle escape are relatively easy, allowing particles to drift azimuthally through the corona. Hence, during the development of the event both sources can contribute to a superposition of the observed fluxes.

The advantage of this scenario states on the fact that it does not need the assumption of continuous acceleration and/or prolonged trapping of particles to produce delayed particle arrival at the Earth's orbit. However, in order to build a model from such a scenario some of the hypothesis must be substantiated. In [6] it was shown that the energy spectra of the PC may be satisfactory reproduced assuming impulsive acceleration in a NCS. Here we have shown that DC spectra may be satisfactory reproduced assuming stochastic acceleration by MHD turbulence. The source parameters for fitting the theoretical to the observational spectra turn to be within the order of the high and low corona values, respectively. Similarly, the acceleration parameters range within the order of values inferred in other works on basis of the secondary radiation of flare emissions.

References

[1] Miroshnichenko L.I. et al. Part I. This Conference.

[2] Borovkov L. P. et al. Proc. 20th Int. Cosmic Ray Conf.**3** (1987)124.

[3] Ramaty R. et al. Ap.J.**316** (1987)L41.

[4] Torsti J.J. et al. Proc. 22nd Int. Cosmic Ray Conf.**3** (1991)141.

[5] Vashenyuk E. V. et al. Geomagnetism and Aeronomy.**33**-5 (1993)1.

[6] Pérez-Peraza J. et al. Geomagnetism and Aeronomy.**32**-2 (1992)1.

[7] Pérez-Peraza J. et al. Adv.Space.Res.**18** (1978)365.

[8] Cliver E.W. et al. Ap.J.**260**-1 (1982)362.

[9] Pérez-Peraza J. and Gallegos-Cruz A. Ap.J. (Supp.)**90**-2 (1994)669.

[10] Gallegos-Cruz A. and Pérez-Peraza J. Ap.J.**446**-1 (1995).

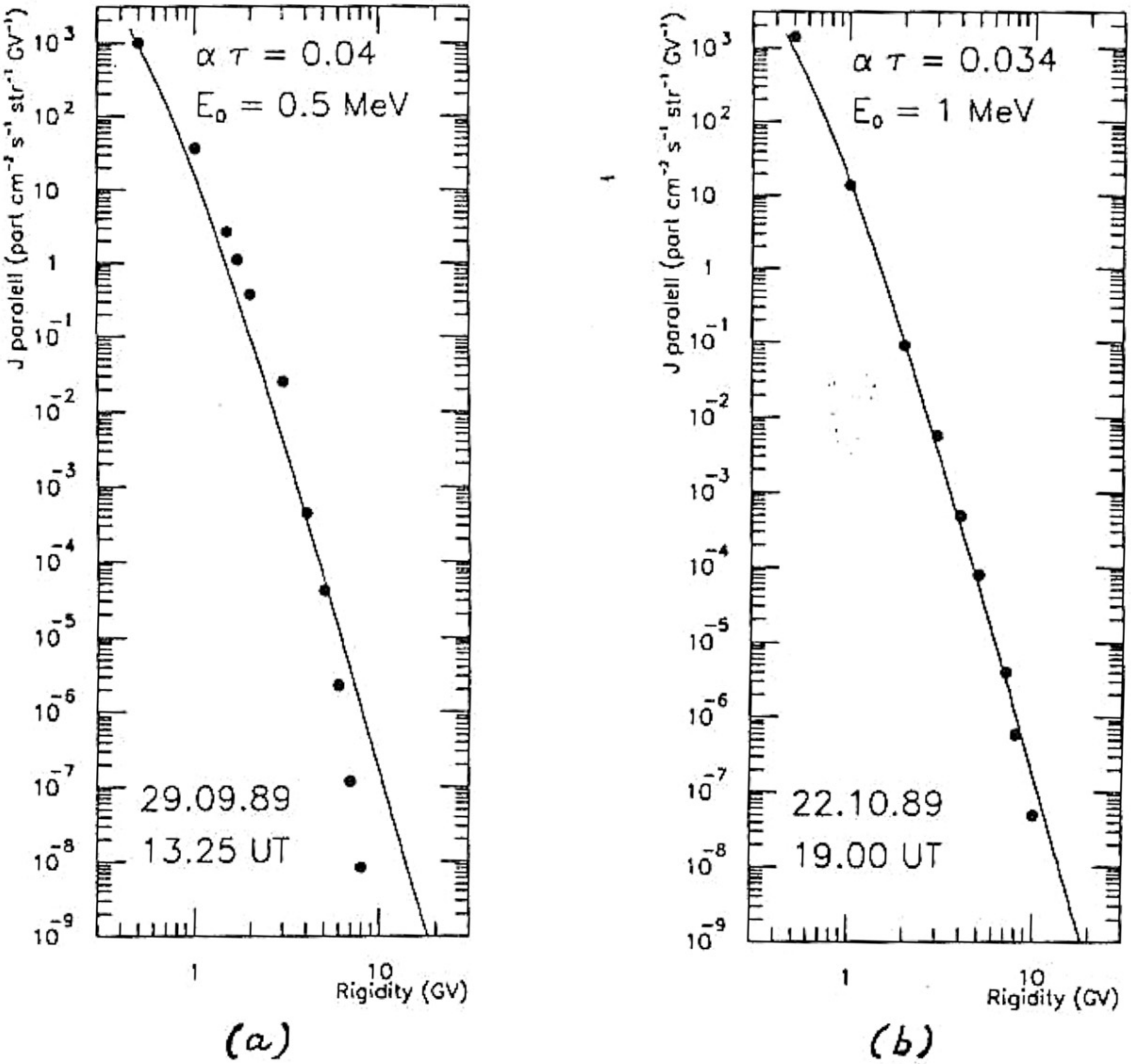

Figure 1: *a) Energy spectra of delayed component for SPE of 29.09.89 - 13:25 UT [11]; solid line calculated in this work; b) Energy spectra of delayed component for SPE of 22.10.89 - 19:00 UT [12], solid line calculated in this work.*

[11] Cramp J. L. et al. Proc. 23rd Int. Cosmic Ray Conf.**3** (1993)47.

[12] Cramp J. L. et al. Proc. 23rd Int. Cosmic Ray Conf.**3** (1993)51.