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Solar Cosmic Ray Acceleration as Space Diffusion in the Regular Electric Fields of Double-Layers Clusters in Random Resistors Network of the Turbulent Current Sheet

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Abstract

We present critical analysis of the solar cosmic ray acceleration during "phase transition" to the flare state, caused by frustration of current percolation in a random resistor's network of turbulent current sheet formed by current sheet instabilities. Principal sequence of the percolation's approach is conclusion about universal power character of distribution of effective cluster's volume with sizes of cluster's ("scaling"). A slope of this power spectrum depends on the dimension of clusters in the turbulent current sheet, its cross-connection and nonlinear influence of negative feedback between current value and plasma turbulence.

We show that the power spectrum observed in the solar cosmic ray events may be understood naturally as result of diffusion' propagation of particles through fractal clusters of turbulent elements with its electrostatic double layers (EDL). We estimate possible influence of different factors on the acceleration process and compare our conclusions with observational data.

We show that the percolation approach can explain preflare generation of the short time beams of accelerated particles observed as short time bursts-precursors observed in hard X-ray/microwave emission.

1 Introduction:

Paradigm of a "turbulent current sheet" is in the basis of numerous models of cosmic ray acceleration during solar flares. This approach is quite natural, since observed very fast conversion of magnetic energy into high-energy particles/hot plasma can't be happen without: a) strong current concentration in the narrow layer and b) strong plasma turbulence generation in it. As sequence of turbulence generation catastrophic variations of plasma kinetic properties in the current region must have place (anomalous resistance, anomalous heating-thermal conductivity).

As it is shown in the second report, presented to ICRC26 (SH.1.5.24, Pustil'nik, 1999a), instabilities of the turbulent current sheet disrupt it very fast into numerous strings by tearing modes with next disruption of the strings in numerous points of pinch-like instabilities. Resulted current sheet is mixture (network) of the random located "normal" and "turbulent" domains. These domains form clusters with some fractal properties caused by random distribution in network, its dimensions and character of connections and feedback between. Main specific property of fractal clusters is power dependence of clusters characteristic (volume, mass, number of elements) on cluster's sizes: $N \propto L^{-\alpha}$.

We will consider possible influence of this universal power dependence of cluster's characteristics in percolated random resistors network on power character of energetic spectra of observed solar cosmic ray.

2 Critical Analysis of Acceleration Models in Turbulent Current Sheet:

Solar flare's current sheets with its giant currents/electric fields and strong turbulence must work as very effective accelerator. Standard models of the solar cosmic ray acceleration are based on the two next processes:

1. Direct run away accelerated particles along regular electric field (Syrovatskii, 1972).
2. Turbulent acceleration as diffusion process in energy/momentum space in result of particles-plasma non-elastic interaction with energy exchange ("turbulent boil") (Kaplan, Pikel'ner, Tsytovich, 1974)

Both two these models have some limits for the solar flare conditions and meet with problems in explanation of observed acceleration up to observed energies 10 *Gev* with power energetic spectrum (Dorman, Venkatasan, 1993, Chupp, 1998, Pustil'nik, 1978). These limits are caused by very small thickness of accelerated region and its "transparency" for particles run away from acceleration region.

a) First group of models (direct run-away in regular global DC-electric field) refers to very high density of electric current $j_* = \left(\frac{\Delta H}{a}\right)\left(\frac{c}{4\pi}\right)$. In condition of high turbulent anomalous resistance r_* it has to lead to the very strong electric field in sheet:

$$E^* = J_* R_* = (c/4\pi)(\Delta H/\sigma_*)(L/d) \approx E^*_{Dr} = (m_e V_{T_e}/e)\cdot\nu_{eff}$$

where $g \approx 10^{-1} \div 10^{-2}$ depends on the concrete conditions of plasma turbulence generation. Correspondent potential drop on the length of current sheet $\mathrm{L} \approx 10^{10}\,\mathrm{cm}$ is large enough for acceleration of particles up to highest observed energy $\varepsilon_{max} = eE^* L =$ 10 *Gev*. However, energetic spectrum of the accelerated particles for different kinds of particle's losses has to be an exponential (in contradiction with observed power one (Dorman, Venkatasan, 1993; Chupp,1998)). Main problem of these models is that it doesn't take into account existence of developed plasma turbulence with its strong reaction on the accelerated particles. First of all it is a processes of elastic scattering of accelerated particles by the waves with change of direction (but without change of energy). This scattering is very effective and as it was shown by Pustil'nik (1978), particles in current sheet are "collision's" up to energy $\varepsilon_1^{cr} \approx 5 \div 10$ *Gev*. It's mean that particle's motion in the turbulent current sheet is not free run away, but has to be like to space diffusion.

b) Alternative turbulent acceleration is based on non-elastic interaction between strong plasma wave turbulence (first of all ion-acoustic, Lengmiur and cyclotron waves) and accelerated particles with energy exchange. This interaction is happen "step by step" with small deviation of energy in individual event. Resulted variation of energy may be described as diffusion in energy space

$$\frac{\partial f\varepsilon}{dt} = \frac{\partial}{\partial\varepsilon}\left(D_\varepsilon \frac{\partial f_\varepsilon}{\partial\varepsilon}\right) - \dot{f}_{\varepsilon(-)} \,,$$

where D_ε -diffusion coefficient in energy space, $\dot{f}_{\varepsilon(-)}$ - describe losses process. For standard section of non-elastic scattering particle-wave it was obtained (Kaplan, Pikel'ner, Tsytovich, 1974) that obtained energetic spectrum is power law with slope depended on efficiency of interaction and particle loss. This approach is much more realistic then the first one (direct run away), but in this approach some "hidden" assumptions exist, too. Main defect of this group of models in application to solar flare's current sheet is fact, that it doesn't take into account elastic scattering particles-waves and corespondent energy variation, caused by space diffusion in the strong DC electric field of current sheet.

c) Some intermediate case of space diffusion (caused by elastic scattering "particle-plasmon") in the regular electric field (caused by anomalous resistance in turbulent current sheet) was investigated by Pustil'nik, (1978). It was shown that this process act more effectively then pure "non-elastic" diffusion in energy space (at least for observed energies). Resulted energetic spectrum was obtained as power with slope depended on concrete geometry of magnetic field in sheet. But very essential question about influence of strong inhomogeneous of the current sheet (and anomalous resistance/electric field, correspondingly) remained open.

3 Influence of Fractal Character of Random Resistor Network in Turbulent Current Sheet on the Acceleration Processes:

a) Diffusion' acceleration in electric field of current sheet.

Main sequence of the percolation approach to the flare's current sheet is conclusion about its similarity to random resistor's network with "bad" resistors clusters (turbulent domains in the regions of current disruption and plasma turbulence generation caused by high local current $j > j_{cr}$) and "good" resistors clusters (into undisrupted regions). The ratio between resistance in these two kinds of resistors is extremely high: $r_* / r_0 = \sigma_0 / \sigma_* = \nu^*_{eff} / \nu^{(0)}_{ei} \approx 10^6 \div 10^7 n_{10}^{-1/2} T_7^{3/2}$ and in the first approximation "good" resistors may be considered as ideal conductors. Here r_* – anomalous resistance of turbulent plasma, r_0 - the "normal" Coulon's one, $\nu^*_{eff}, \nu^{(0)}_{ei}$ - corespondent "collisions" frequency.

We have to point here that this pattern is not in steady state in local mean because of some nonlinear properties caused by strong and complex connection between current and resistance both in time and space. As example of this feedback we would point to fast redistribution of the currents as sequence of creation of "bad" resistor. It leads immediately to increasing of current in its neighborhood and stimulates here creation of new "bad" turbulent resistors. Simultaneously it leads to decreasing of current density in turbulent region lower then threshold with conversion into the "normal" state. This redistribution is controlled by the high self-induction of the normal plasma in and around current sheet, which strive for conservation input current distribution in spite of its dissipation in the "bad" elements. Another nonlinear process, what limit lifetime of "bad" elements is overheating plasma in it in result of current dissipation (Pustil'nik, 1980). Increasing of temperature with correspondent decreasing of ratio "current velocity/phase velocity of plasma waves" lower then threshold will turn-off turbulence in plasma and will convert it in normal state with next current redistribution. These processes lead to very dynamical state of resistor's distribution in this network like to boiled soap, but in average (on the time more then relaxation times of plasma waves and currents disturbances) it is like to standard resistors network.

What does fractal structure of turbulent "bad" resistors mean for acceleration processes? In this approach each "bad" resistor of turbulent plasma forms electrostatic double layer and accelerates up to energies order of potential drop $\Delta\varepsilon_* = e\Delta\varphi_* \approx eE^*_{Dr} d_0 \approx mV_{T_e} \nu_{eff} d_0 \approx 3Mev \cdot T_7^{1/2} n_{10}^{1/2} (d_0 / 10^5 cm)$.
Energetic spectrum of the accelerated particles is caused by equilibrium between energy increasing during space diffusion of the accelerated particles in random network of EDLs and particle's losses in result of its escaping from the boundaries of current sheet. Dependence of the effective collision frequency on the energy $\nu_{eff} \propto V^{-3}$ leads to additional anisotropy in diffusion flux, like to thermodiffusion, caused by different variation of velocity between collisions for particles propagated along electric field and in the opposite one. Resulted spectra, calculated uniform turbulent domain in current sheet is

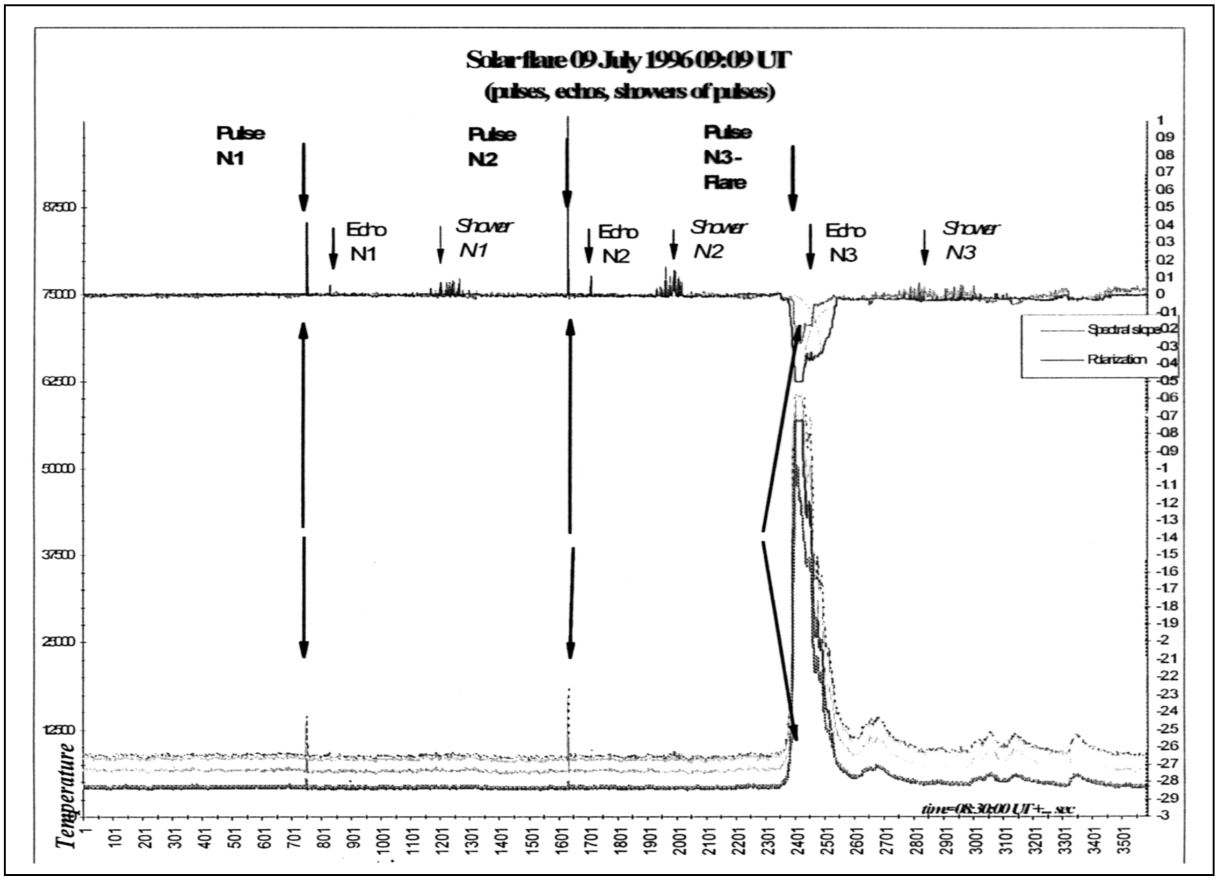
$$n(\varepsilon) \propto \varepsilon^{-2} exp\left(-\varepsilon_0 / \varepsilon\right)$$

Fractal character of distribution of the turbulent EDLs-accelerators in the current sheet changes this spectrum to another power-like, but with harder slope with $\Delta\gamma = D - d$, where D - is fractal dimension, and d - is space dimension of network. For classic type of cubic network (d=3) it was estimated fractal dimension as D=2.52 with correspondent $\Delta\gamma \approx -0.5$. For case of square-like lattice on 2-d plane it led to $\Delta\gamma \approx -0.1$. We see that obtained spectrum of accelerated particles in the turbulent current sheet with fractal-like distribution of turbulent clusters in space is power: $n(\varepsilon) \propto \varepsilon^{-\gamma}$ with $\gamma \approx -2.1 \div -3$ depended on fractal dimensions of clusters. These values are in agreement with observed spectrum of cosmic rays in the space and active astrophysical objects. As it was shown in Pustil'nik (1978) for specific conditions of solar current sheet, taking into account 3-d distribution of mean magnetic fields in current sheet may lead to additional slope increasing on $\Delta\gamma_{3d} \approx -1$. Resulted scale of slope $\gamma = -2 \div -4$ is in good agreement with wide range of observed slopes (Dorman, Venkatasan, 1993, Chupp, 1993): $\gamma_{obs} = -2 \div -5$.

In really we have to take into account real distribution of the currents in the resistor's network with its permanent dynamical rebuilding. This effect may be estimate only by numerical simulation in the simple models of negative feedback "current-resistance-current" in percolated system of resistors and inductivities and this work in progress now.

b) ***Preflare bursts-precursors of accelerated beams***.

Some new property of percolated system on the threshold state is its ability to short lifetime transition of local region in turbulent current sheet in flare-like state. We discussed this property in the first report (SH 1.5.24) as a divergence of fluctuation's amplitude near threshold. This effect is well known for another percolated system like to mixture of gelation, para/ferromagnetic domains, insulation/conductor networks. The physical nature of these precursors is high sensitivity of the system near threshold state to disruption of last bonds and its next restoration. Flare's current sheet as percolated system must generate similar preflare bursts of accelerated particles with its emission in radio/X-ray range. As example of similar event we demonstrate in the Fig.1 two short lifetime narrow-band bursts-precursors ($\tau \approx 1 sec$) during 30 min before flare 09.07.96 (Pustil'nik, 1999b). Non-thermal nature of emitted particles appears in much more strong manifestations of precursors observed in the spectral slope/polarization (high part of Fig.1) than in a flux itself (lower part).



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