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INVESTIGATION OF ACCELERATION AND PROPAGATION OF SOLAR COSMIC RAY IN WIDE ENERGY REGION (10 MeV - 1000 GeV) GENERATED DURING 56 FLARES

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Abstract. The investigation results of solar cosmic ray (SCR) generation and propagation in wide energy region (10 MeV < E < 1000 GeV) are presented in the paper. There are investigated 56 flares detected on the Earth's surface from 1942 to 1998 years. Also for these flares in low energy region investigations were carried out on the base of data recieved on space ships and satellites. The energy spectra in sources and on the Earth's orbit and their change in time are calculated. SCR anisotropy and their radial gradients are determined. It is shown there are observed cases when two sources – two acceleration mechanisms in one flare take place. The strong anisotropy of SCR is observed and sometimes high energy particles generation (E > 100 GeV) takes place.

Analysis of recieved results on base of experimental data of neutron monitors (NM) and muon telescopes (MT) on the ground level and under ground and numerical solutions results of equation of SCR propagation let us give interpretation of observed effects, in particular the presence of 2-3 intensity maximums in one flare, strong anisotropy and acceleration mechanisms up to E ≤ 1000 GeV.

Introduction.

The investigation of SCR generated during the flares on the Sun was carried out on the base of experimental data of NM and MT located on different depths under ground and also on the base of data of satellites. There were selected all proton flares detected on the Earth surface with amplitudes > 5σ. The number of these flares in present day is 56 begining from 1942.

Results.

Fig.1 shows time profiles for selected flares with different shape of time of increase and decrease. For flare of 7.05.1978 moment of intensity maximum has come in a hour for one high latitudes station. For another one placed in other hemisphere but for those energies it has come in two hours. This fact can not be explained only by asymptotic directions taking into accounting that effective energies for these NM is about 8-10 GeV. There are observed 2-3 intensity maximums for flares 12.11.1960 and 29.09.1989. Taking into accounting that differences in t_{max} is more than 1.5 hours, this fact can not be explained by SCR anisotropy too. The time profile of flare 30.04.1976 is interested because times of increase and decrease are the same and equal 2 hours.

Fig.2 shows N-S asimmetry of SCR for number of flares. There were selected flares when A_{N-S}>0 and A_{N-S}<0 for all pair of stations. But we think that more interest cases when for one pair of stations A_{N-S}>0, for another pair of stations (distinction only in longitudes) A_{N-S}<0, that is mirror reflection of N-S asimmetry takes place. The cases when A_{N-S}=0 are infrequent.

For interpretation of observed effects we considered the equation of SCR propagation taking into accounting diffusion coefficient dependance on energy and distant, magnetic drift of particles and change of energy [1].

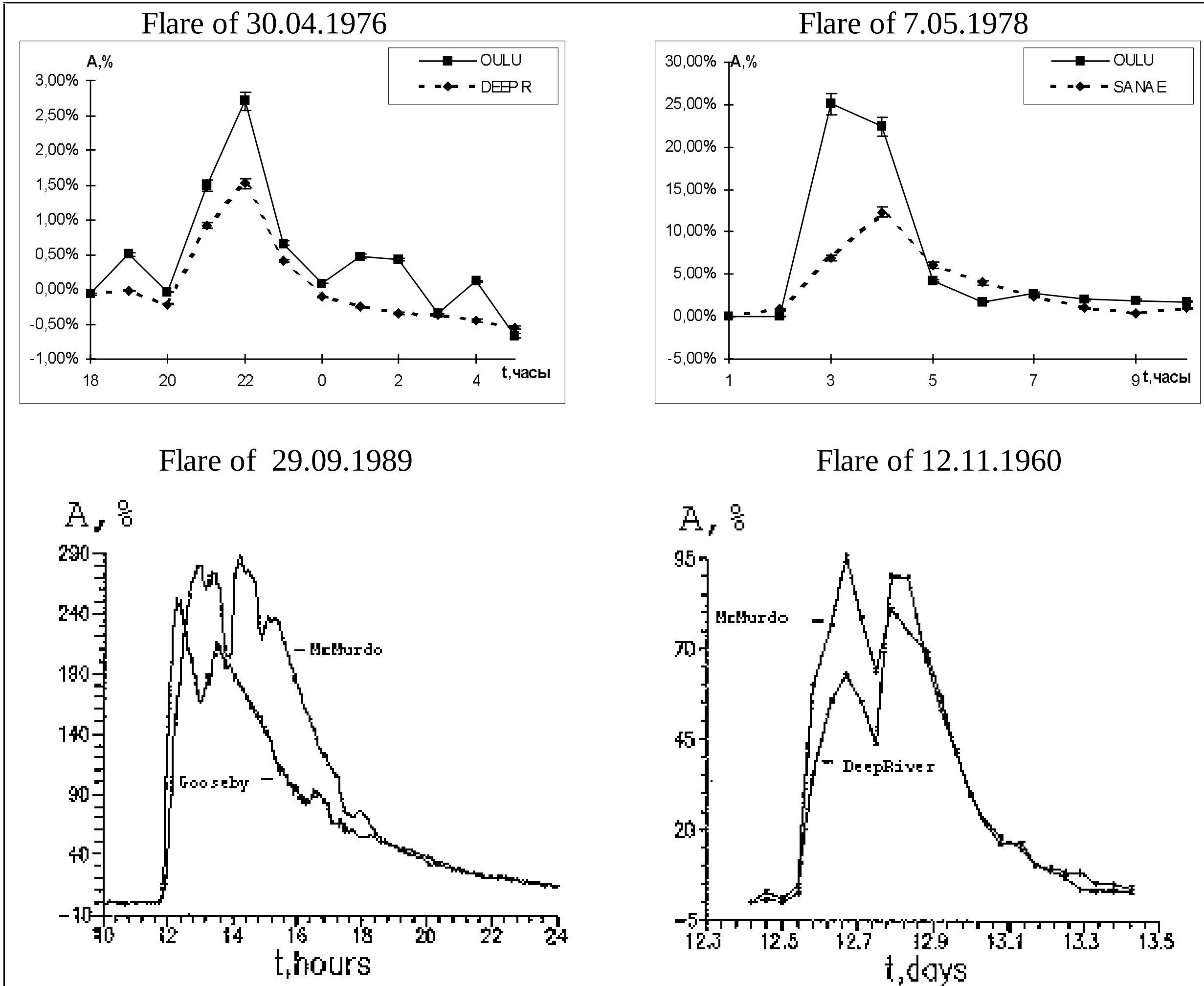

Fig. 1 Time profiles of flares

$$\frac{\partial f}{\partial t}+\mu V\frac{\partial f}{\partial z}+\frac{1-\mu^2}{2\xi}\frac{\partial f}{\partial \mu}=\frac{\partial}{\partial \mu}\left(\text{æ}\,\frac{\partial f}{\partial \mu}\right) \qquad (1)$$

where $\xi = \left(-\frac{1}{B}\right)\frac{\partial B}{\partial z}$, t – time, μ – cosinus of pitch angle, z – length of interplanetary magnetic field, æ – diffusion coefficient taking into accounting its dependance on energy and distant as æ ~ r^{β} and æ ~ $\varepsilon^{2-\nu}$ where ν – index of spectrum of magnetic discontinuities, V – velosity of particles, B – interplanetary magnetic field

Let A(z) be function characterized average IMF and taking into accounting that $A(z) \sim \frac{1}{B(z)}$ we can write (1) :

$$\frac{\partial F}{\partial t}+\frac{\partial}{\partial z}(\mu V F)+\frac{\partial}{\partial \mu}\left(\frac{1-\mu^2}{2\xi}VF\right)=\frac{\partial}{\partial \mu}\left(\text{æ}\,\frac{\partial F}{\partial \mu}\right) \qquad (2)$$

where F = Af. Let $\tau = V t / l$; $s = z / l$; $L=\xi / l$; $K = \text{æ}\, l / V$ where l is free unit of length, so equation (2) can be written as

$$\frac{\partial F}{\partial \tau}+\frac{\partial}{\partial s}(\mu F)+\frac{\partial}{\partial \mu}\left(\frac{1-\mu^2}{2L}F\right)=\frac{\partial}{\partial \mu}\left(\ \mathrm{K}\ \frac{\partial F}{\partial \mu}\ \right) \qquad (3)$$

It is seen from (1) – (3) strong anisotropy (focusing) of SCR in high energy region can be explained with high probability by strong change of intensity of general magnetic field $\left(-\frac{1}{B}\right)\frac{\partial B}{\partial z}$ and magnetic drift of particles.

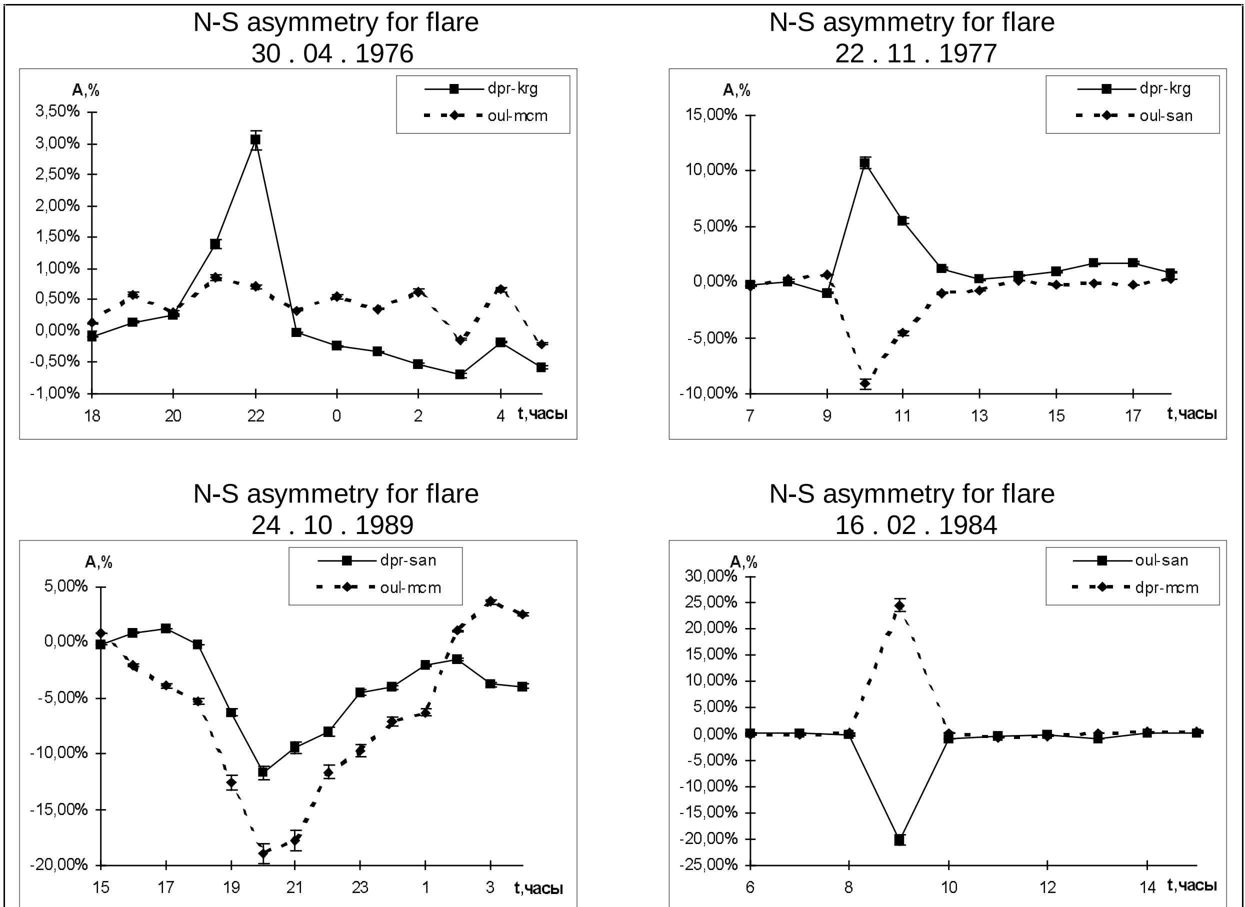

Fig. 2 N-S asymmetry during the flares.

Thorough analysis of fig.1b shows that presence 2-3 maximums of amplitudes in one flare when moments of maximums are distinguished more than in 1.5 hours can not be explained by SCR anisotropy and asimptotic directions. We think this fact can be explained by two sources (two acceleration mechanisms) in one flare [2].

Fig.3 shows energy spectra of SCR for number of flares calculated on the base of data of NM using atmosphere and magnetic field of the Earth as spectrometer [3-4]. It is seen from fig.3a that in most cases the energy spectra of SCR can not be described by power law function with one index in wide energy region. When characteristic γ-radiation on nuclear levels and γ from π^0 decay were detected energy spectrum in source could be determined. In most cases it is about 3. On the Earth orbit energy spectrum in low energy region changes significantly becoming harder. As we think it happens because of energy losses by adiabatic cooling and coulomb interactions. In high energy region energy spectrum becomes softer (γ~5) because of drift effects taking into accounting heliocoordinates of flare and the Earth. Fig.3b shows energy spectrum in high energy region for flare 29.09.1989. Energy spectrum was calculated by effective energy on base of data underground MT. It is seen from fig.3b that particles with energy about 1000 GeV can be generated during flares on the Sun.

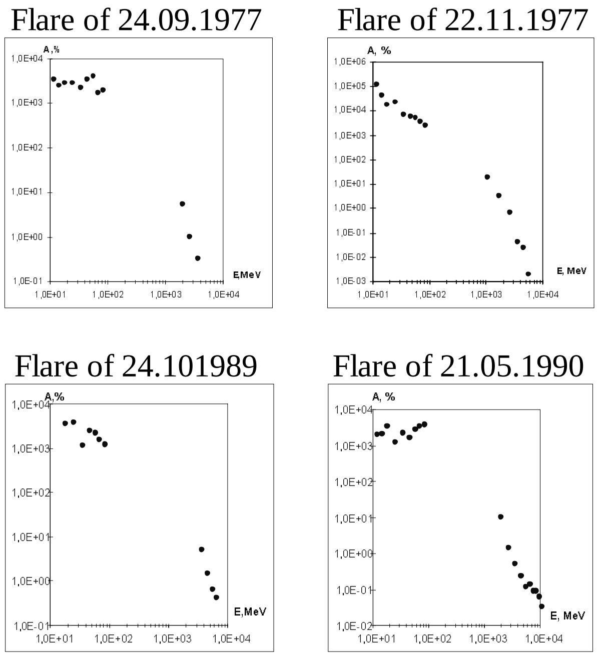

Figure 3a. Energy spectra of SCR in wide energy region based on the data of satellites and data of NM

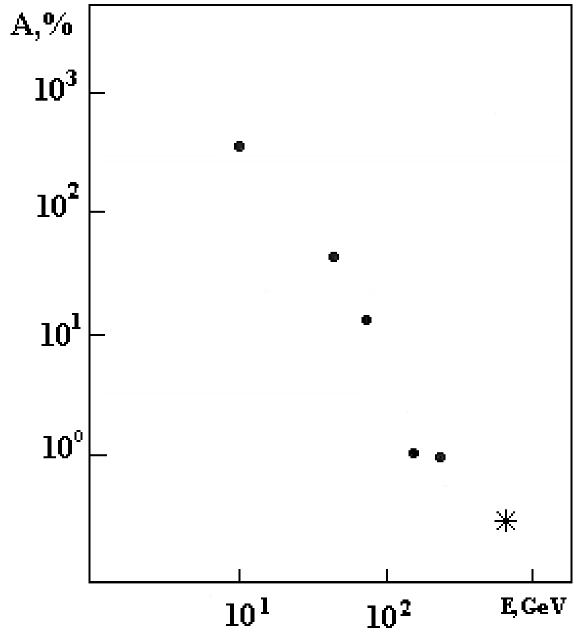

Figure 3b. Energy spectrum of SCR for flare of 29.09.1989 in high energy region based on the data of MT. Big point is the data of Baksan MT.

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