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HIGH ENERGY NEUTRON AND GAMMA-RADIATION GENERATED DURING THE SOLAR FLARES

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Problem of high energy neutrons and gamma rays generation in the solar conditions is considered. It is shown that due to a peculiarity of generation and propagation of neutrons corresponding solar flares should be localized at high heliolongitudes.

Solar neutrons have been detected only for two flares: for June 21 1980 on board of the SMM satellite by Chupp et al. [1] and for June 3 1982 simultaneously in several experiments by SMM [1,2], neutron monitors [3,4,5] and registration of protons of solar neutron decay origin [6] .

Experimental data allow to establish that energy spectra of neutrons generated in a flare may be described as power law in wide energy interval 50 to 1000 MeV with the spectral indexes 3 and 3.5 for the flares 21.06.80 and 3.06.82 accordingly.

In contrast to γ-lines which are formed by low energy particles(10-30MeV)neutrons contain an information on energy spectra and angular distributions of accelerated particles in wider energy interval. Calculations of charged-particle energy spectra based on the observed neutron spectra have been made by Ramaty et al. and by us [7-13].Ramaty et al. considered thick-target model and assumed that in the interaction region the distribution of accelerated particles is isotropic.They have also assumed that after their production the neutrons escape freely from the Sun.But because the neutrons have mean free paths comparable to the stopping range of the protons which produce them,the protons should be trapped magnetically in the region at column depths significantly less than their ranges.It was shown that both γ-line and neutron experimental data might be explained if charged particle spectrum is described by the Bessel function.

In our calculations we tried to refuse the assumption on magnetic trap and considered a beam configuration of accelerated particles. In this case for any direction of beam the flux of solar neutrons increases with an increase of a flare heliolongitude. It can be easy shown for the beam directed to the observer. Really, the thickness of matter traversed by accelerated particles in the solar atmosphere into Earth's direction for limb flare is higher than for disc flare about $(\pi R_\odot / 2h_0)^{1/2} \simeq 30-100$ times (h_0 - is the scale height, R_0 - is the solar radius). If the accelerated particles move to the Sun the neutrons which are scattered on 90^o for the limb flare and on 180^o for the disc flare are detected. The probability of backscattering is less relative to the scattering on 90^o. However, as in this case nuclear reactions occur in deep regions of the solar atmosphere an absorption of neutrons may be essential. This effect was considered by us and it is shown that the limb retains an advantage.

All calculations of neutron generation and their escape from the Sun were made using Monte-Carlo method taking into account the angular and energy characteristics of (PP) and (pHe) reactions which are the main source of high energy (>50 MeV) neutrons. The beams with different angles relative to solar radius were considered. Particle spectra were presented as power law with different spectral indexes. For different heliolongitudes total yield of neutrons and their energy spectrum have been calculated. Fig. 1 shows the dependence of the fluxes of the neutrons (> 50 MeV) on flare heliolongitude for 3 cases. It is seen that for all cases the neutron fluxes are decreased strongly from the limb to the disk. If we consider the beam directed to the Sun the experimental spectra for the flares 21.06.80 and 3.06.82 may be explained if $\gamma_p = 3-3.5$ for $E_p>100$ MeV. In this case using experimental figures for total flux of neutrons: $2.8 \cdot 10^{28}$ and $2.5 \cdot 10^{29}$ we obtain for the total number of accelerated particles the following values: $N_p(>30)=7 \cdot 10^{32}$ and $7{,}5 \cdot 10^{33}$,

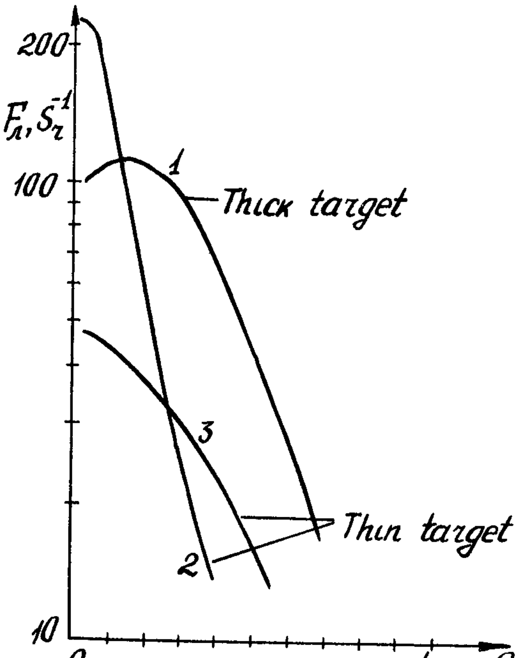

Fig. 1

Dependence of neutron fluxes on flare heliolongitude for the beams with different angles relative to solar radius.
1. $\alpha=0$, $\gamma_p=3,5$, $N_p(>30\text{MeV})=10^6$
2. $\alpha=90^o$. 3. Isotropic yield to upper hemisphere $\gamma_p = 2.5$, $n N_p(>30\text{ MeV}) h_o^{1/2} \gamma_p = 1.5 \cdot 10^{23}$, n is number density in an interaction region.

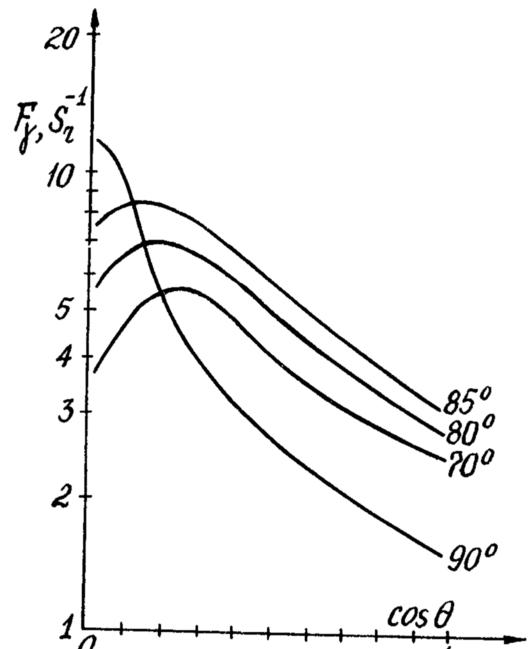

Fig. 2

Dependence of gamma-ray flux on flare heliolongitude for beams with different angles relative to solar radius.

accordingly. These figures are in good agreement with the total number of accelerated particles obtained by using γ-line data (see [13] and references therein). So, supposing a beam configuration it is possible to explain particle spectrum as power law from 10 MeV to 1000 MeV with single spectral index. Definitive conclusion can be made after obtaining of experimental distribution on heliolongitude for flares with measurable neutron fluxes.

Now we concern with the problem of high energy γ-rays. At the present time 14 solar flares with high-energy (> 10 MeV) γ-rays are registered [14]. These events have a strong solar limb preference with 13 of 14 occurring in flares with a heliocentric angle $>72^0$ [14].

If high energy gamma-rays are generated by ultrarelativistic electrons then the radiation is directed along of electron velocity and above considered arguments are correct. Let us consider the case when the source of high energy gamma-rays are π^0-mesons, which are generated in the same reactions as energetic solar neutrons.

It is seen (Fig.2)that the dependence for $\alpha < 90^0$ is weaker than for the neutrons.For tangent beams an advantage of limb is obvious.But in this case the flare should occur in dense region $n \geq 10^{13}cm^{-3}$.According to [14] all high energy γ-ray flares are characterized by fast impulses ($\leq$ 2s)which is in favour of high density of interaction region. Thus we cannot exclude a nuclear origin of high energy γ-rays.To made a definitive conclusion on the source of high-energy γ-rays it is very important to measure an energy spectrum of gamma-radiation.

References.

1. Chupp E.L. et al.Astrophys.J.Letts.,1982,v.263,p.135.
2. Chupp E.L. et al.Proc.18-th ICRC,Bangalore,1983,v.4,p.97.
3. Efimov Yu.E. et al.,ibid.,v.13,p.240.
4. Debrunner H.et al.,ibid.,v.4,p.75.
5. Iucci N. et al.,1984,Preprint,IFSI,Italio,N 84-1.
6. Evenson P. et al.Astrophys.J.,1983,v.274,p.875.
7. Ramaty R. et al. Astrophys.J.,1983,v.273,p.L41.
8. Ramaty R. et al.,Solar Phys.,1983,v.86.
9. Lingenfelter R.E. et al.Proc.18-th ICRC,Bangalore,1983, v.4,p.101.
10. Ramaty R.,Murthy R.J.,Proc.of the Plasma Astrophys.School and Workshop,Varenna,1984,p.83.
11. Kocharov G.E.,Mandzhavidze N.Z.Izv.AN SSSR,ser.fiz.,1984, v.48,N.11,p.2212.
12. Kocharov G.E.,Mandzhavidze N.Z.,Pis'ma v Astron.Journ., 1984,v.10,p.771.
13. Kocharov G.E.,Proc.of the Plasma Astrophys.School and Workshop,Varenna,1984,p.65.
14. Rieger E. et al. Proc.18-th ICRC,Bangalore,1983,v.4,p.83, paper presented at 164-th AAS Meeting,Baltimore,Maryland, 1984.