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STUDY OF COSMIC RAY SCINTILLATIONS FROM 5-MINUTE DATA OF THE SCINTILLATOR TELESCOPE "IZMIRAN" AND WORLD-WIDE NEYWORK STATIONS

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During cosmic ray propagation in interplanetary space there appear characteristic cosmic-ray intensity scientillations /I/ which are due to charged particle scattering on random inhomogeneities of the interplanetary magretic field (IMF). Particles of rather low energies which are sensitive not only to IMF inhomogeneities, but also to the fine structure of approaching shock fronts, undergo the largest scintillations. Nonetheless, the high-energy (more than several Gev) cosmic ray scintillations, which are registered in the most sensitive way be ground-based devices used for recording cosmic radiation, are similarly informative. From the physical point of view this is also connected with the fact that a particle with a large Larmor radius ($R = cp/eH \gg R_C$, R_C is the correlation radius of a random magnetic field) "sses" a wide spectrum of IMF inhomogeneities, whereas when interacting with the high-frequency part of the magnetic inhomogeneity spectrum, low-energy particles bring information about a comparatively narrow region of the IMF turbulence spectrum.

The smallness of scintillation amplitude in the high-energy range is compensated by the fact that measurements in this energy range are made by ground-based devices with a significant statistics and a high accuracy /2/.

The power spectra of cosmic ray scintillations on the Earth during some intervals from I977 to I982 (for quiet periods, for solar flares and Forbush decreases due to power shock waves, Fig. I) have been calculated from five-minute, one- and two-hour values of the cosmic-ray intensity measured by the scintillator supertelescope IZMIRAN and in stations of the world-wide network (Moscow, Utrecht, Kerguelen, Apatity, Tixie Bay, Norikura). The spectra were estimated by the methods of spectral analysis and by autoregressive methods which mutually control each other /3/ and make it possible not only to analyze scintillation powers at distinguished frequencies, but also to determine the behavior of spectrum slopes in some frequency ranges.

Il the power-law spectrum of cosmic ray scintillations is described by the power function $P(f) \sim A \cdot f^{-\gamma}$, then using the ratio of the spectrum values in different frequency ranges $f < 8 \cdot \mathrm{I0}^{-6}$ Hz and $\mathrm{I0}^{-5} \leq f \leq \mathrm{I0}^{-4}$ Hz (for neutron monitors and scintillator telescopes of the world-wide net of stations), one can evaluate the product H_0V (in the assumption that the IMF spectrum remains unchanged in the entire frequency range):

$$300 H_0 \cdot V = \frac{2\pi}{\cos\psi}\left[\frac{n-1}{n+3}\cdot\frac{A_1}{A_2}\cdot f^{\gamma_2-\gamma_1+2}\right]^{1/2}\cdot\left[\frac{\int_{R_c}^{\infty} R^{-2}\, W(R)\,dR}{\int_{R_c}^{\infty} W(R)\,dR}\right]^{-1/2}$$

The IMF scintillation spectrum is determined as

$$B(f) = \left(\frac{2}{n+3}\right)^{-1}\frac{4\pi V_{\parallel}^{2}}{(2\pi)^4 (V_{\perp}\cdot\delta)^2}\cdot f^2\cdot P(f)$$

where H_0 is the mean IMF strength, V is the solar wind velocity, n is the index of pitch-angular distribution, W(R) are coupling coefficients of the devices.

Mean estimations of the indices of the slopes of CR scintillation power spectra for different devices in the stations Moscow, Utrecht, Kerguelen, Lomnicky Stit, Vostok, Baksan, Apatity in quiet periods give the following results: for frequencies $f < 3\cdot \mathrm{IO}^{-6}$Hz the spectral index γ lies in the interval I.45 $\leq \gamma \leq$ I.75, for frequencies $4\cdot\mathrm{IO}^{-6} \leq f \leq \mathrm{IO}^{-4}$ the index lies within I.95 $\leq \gamma \leq$ 3.35 and, finally, for frequencies $f > 3\ \mathrm{IO}^{-4}$ Hz I.55 $\leq \gamma \leq$ 2.IO (the latter is due to the competition between the CR scintillation power and the noise power $P(f)/n_0^2 = 2/n_0$). The calculations of the power spectra ($B\cdot f^{-\nu}$) of IMF fluctuations give the values of ν of the order of I.8+0.I, which agrees well both with the results of field experiments and of ref./4/ (the relation between the spectral indices of IMF, ν and CR, γ, has the form $\gamma = \nu + 2$ in the frequency range $4\cdot\mathrm{IO}^{-6} \leq f \leq \mathrm{IO}^{-4}$ and $\gamma = \nu$ for frequencies $f \leq 3\ \mathrm{IO}^{-6}$Hz). Figure 2 presents the power spectra for CR scintillations averaged over the investigated stations for different periods of the maximum (curve I) and the minimum (curves 2,3) of solar activity. For all the frequencies the power values coincide well with the theoretically calculated values /4/ (for $H_0 = 5\cdot\mathrm{IO}^{-5}$ Gs and $v = 5\cdot\mathrm{IO}^{7}\ \mathrm{cm\cdot s^{-1}}$) both in the absolute values (in the high-frequency range they differ by a factor of I.2-I.5 and in the low-frequency range by a factor of I.5-2) and in the behaviour of the spectra: the values of the indices coincide with an accuracy to IO %.

There exist also other possibilities for studying the CR scintillation spectrum: one can not only estimate the power spectrum of IMF fluctuations, but also establish a one-to-one correspondence with the level of perturbation in interplanetary medium of both distinguished scintillations at certain frequencies and the spectrum as a whole - the slope of the CR scintillation spectrum in the range $f < \mathrm{IO}^{-4}$Hz increases gradually up to the maximum value several hours before the perturbation of interplanetary medium comes to the Earth. Figure 3 shows the behaviour of the index of the power spectrum of CR scintillations for the events in September 1977 from the data of the Utrecht and Kerguelen stations. It is seen from the figure that at least 18 hours before perturbation the spectral index in the range $10^{-6} \leq f \leq 10^{-4}$ Hz starts increasing whereas the quantity A (if the spectrum is given in the form $A \cdot f^{-\gamma}$) decreases. That CR go ahead of perturbation can be easily explained: CR feel inhomogeneities at a distance of their free path for scattering (about 10^{12} - 10^{13} cm) and their velocity is a thousand times larger than the velocity of propagation of perturbation. Hence, CR bring information practically instantaneously, whereas perturbation travels to the Earth long hours. Therefore, the distances between perturbations approaching the Earth can be essentially different: recording particles of different energies, one can observe inhomogeneities at distances up to several AU.

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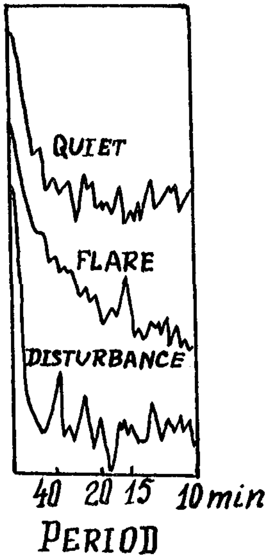


Fig. 1

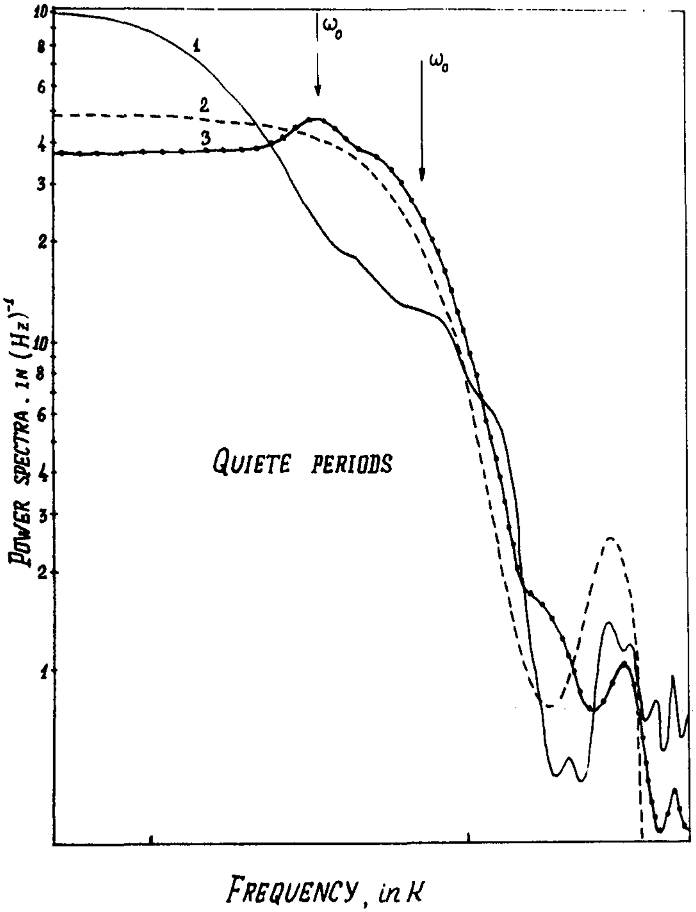
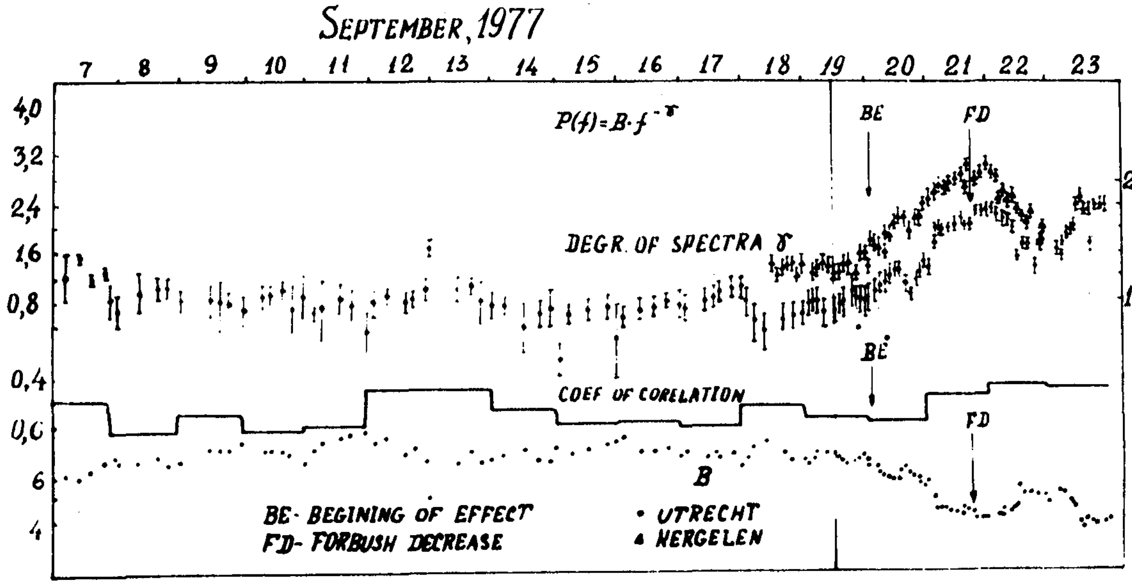

10
8
6
4
3
2
10
8
6
4
3
2
1
POWER SPECTRA. IN $(Hz)^{-1}$
1
2
3
ω_0
ω_0
QUIETE PERIODS
FREQUENCY, in K

Fig. 2

Fig. 3


SEPTEMBER, 1977
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4,0
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6
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$P(f)=B\cdot f^{-\gamma}$
BE
FD
DEGR. OF SPECTRA γ
BE
COEF OF CORELATION
FD
B
BE - BEGINING OF EFFECT
FD - FORBUSH DECREASE
• UTRECHT
▲ KERGELEN