acta phys. slov. 37 (1987), No. 3

COSMIC RAY FLUCTUATIONS AT RIGIDITIES 4 — TO 180 GV

BENKÓ, G.,[1]) ERDÖS, G.,[1]) Budapest, KATZ, M. E.,[2])
NOSOV, S. F.,[2]) Kiev, STEHLÍK, M.,[3]) Košice

The power spectral density of cosmic ray fluctuations observed at both underground and ground level during the years 1976—1980 has been calculated. The spectral index is independent of the phase of solar cycle in the frequency range of 5×10^{-7} to 5×10^{-5} Hz and its value is equal to 2. The level of fluctuations P has no significant dependence on the rigidity R of the particless in the sensitivity range of neutron monitors. However, in the rigidity range of up to 180 GV, P is proportional to $R^{-0.87 \pm 0.09}$. The obtained experimental results are in agreement with theoretical predictions.

I. INTRODUCTION

Considerable progress has been made during the past few years in the theory of cosmic ray (CR) intensity fluctuations together with new experimental investigations at various energies and for various components of CR [1, 2]. However, the behaviour of the fluctuations at low frequencies [3, 4] as well as in the presence of disturbances in the interplanetary medium [2] shows the necessity of further studies in this field. Namely, the value of the spectral index μ (the power spectrum density index) has not been unambiguously determined and the dependence of μ on the change of the solar activity has not been fully investigated. Even the theory [2, 4] puts forward different values of μ for both various models of the fluctuation generation and the magnetoturbulence models.

In the present paper experimental results on fluctuations of CR intensity at intermediate frequencies (i.e. 10^{-6} to 5×10^{-5} Hz) are presented.

Power spectrum densities (PSD) during the period of 1976—1980 have been determined on the basis of the intensity data from the underground muon telescope in Budapest together with the temporal dependence of the spectral index of fluctuations. The fluctuation levels and their dependence on the CR particle energy were investigated by using the neutron monitor data from Lomnický štít and Alma-Ata.

[1]) Central Research Institute for Physics, Hungarian Academy of Sciences, BUDAPEST, Hungary
[2]) Main Astronomical Observatory, Ukranian Academy of Sciences, KIEV, USSR.
[3]) Institute of Experimental Physics, Slovak Academy of Sciences, KOŠICE, Czechoslovakia.

II. EXPERIMENTAL DATA

The power spectral analysis was performed using the following data basis:
(i) Bihourly intensity registrations of the hard component measured by the Budapest muon telescopes (median rigidity of 180 GV) during 1976—1980. The analysis was carried out for the two independent telescopes separately. The linear trend from the data was removed.
(ii) Hourly counting rates from neutron monitors at Lomnický štít and Alma-Ata for the year 1979, the cut off rigidities of which are 4.00 GV and 6.69 GV, respectively.

III. ANALYSIS AND RESULTS

On the basis of the Budapest data (i) the power spectral densities of the CR intensity fluctuations were calculated separately for the T1 and the T2 telescopes for the years 1976—1980 (see Fig. 1a, and Fig. 1b). At the first glance one can

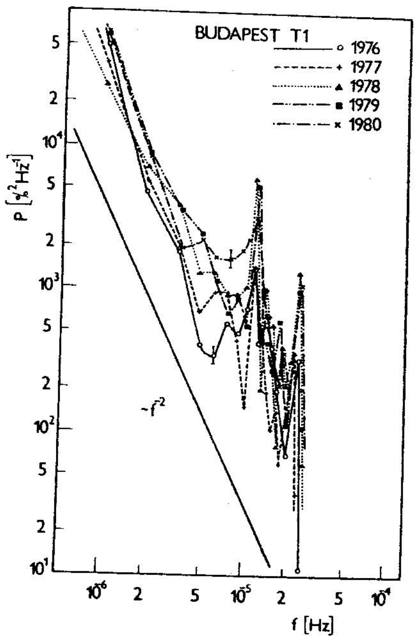

Fig. 1a. Power spectrum calculated from the Budapest muon telescope T_1 for 1976 to 1980.

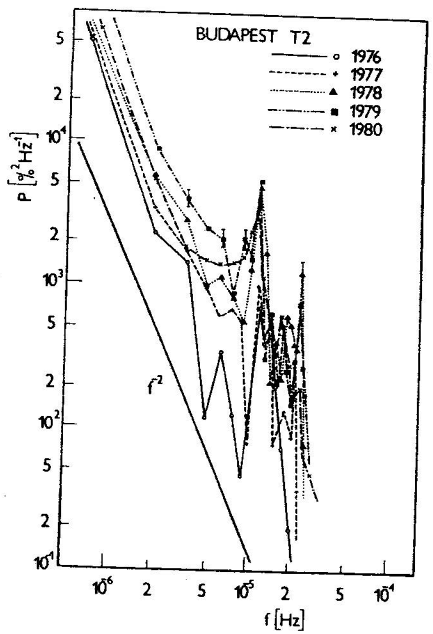

Fig. 1b. Power spectrum calculated from the Budapest muon telescope T_2 for 1976 to 1980

see only a slight variation of the spectrum between the consecutive years. Making the usual assumption of power law frequency dependence $P(f) \sim f^{-\mu}$, the spectral indices were obtained from the minimum to the maximum of solar activity. Table 1 summarizes the results showing no significant variations of μ with an average value of 2.

Table 1

Values of spectral indices μ

YEAR		1976	1977	1978	1979	1980
μ	T_1	2.1 ± 0.2	2.2 ± 0.1	1.9 ± 0.1	2.0 ± 0.1	1.9 ± 0.1
	T_2	2.3 ± 0.2	2.0 ± 0.1	1.9 ± 0.1	1.9 ± 0.1	1.8 ± 0.1

The same results can be obtained when the cross-correlation analysis is performed for the two telescopes. It is seen for 1979 in Fig. 2. Here again, the spectral index of 2.0 gives the best fit to the data in good agreement with theoretical expectations.

According to the theory [4—5] the power spectrum density of the CR intensity fluctuations

$$P(f) = A\left[1 + \left(\frac{f_1}{f}\right)^2\right] B(f), \quad (1)$$

where the function A is independent of the frequency f; $B(f)$ is the PSD of the interplanetary magnetic field of the form of

$$B(f) = \frac{B_\nu}{(f_0^2 + f^2)^{\frac{\nu}{2}}}, \quad (2)$$

and ν denotes the spectral index of the interplanetary fields.

Taking into account that $ABf_0^{-2} \approx 3 \div 5$ and $f_0/f_1 \approx 5$, (see ref. [6]) one can easily get from equations (1) and (2) for the frequencies lower than 10^{-5} Hz that $P(f) \sim f^{-2}$. This law is confirmed by the measurements. For a further check of the hypothesis of $\nu = 2$ the power spectrum calculations should be extended up to the range of $f > 5 \times 10^{-5}$ Hz. According to [7] in this frequency range the spectral index remains close to 2, as well. As it was pointed out by Dorman et al. [2] the MHD turbulence model in some cases can produce the spectral index $\mu = 2$ even when $\nu < 2$. This is in the ease when the MHD turbulence has the dimension of 2, for example.

The rigidity dependence of the level of the fluctuations was examined by Dorman et al. [8] in the framework of the diffusion model. According to is theory, A in (1) is proportional to $[(\Lambda \nabla N)/R]^2$, where Λ has the meaning of the mean free path of transport of CR in the inhomogenenous interplanetary magnetic fields, R denotes particle rigidity and ∇N is the density gradient of particles. In Fig. 3 the PSD calculated on the basis of data sets of both (i) and (ii) are shown for year 1979. The fluctuation level of particles of the rigidiries $R = 180$ GV is roughly by one order of magnitude lower than that of particles seen by neutron monitors.

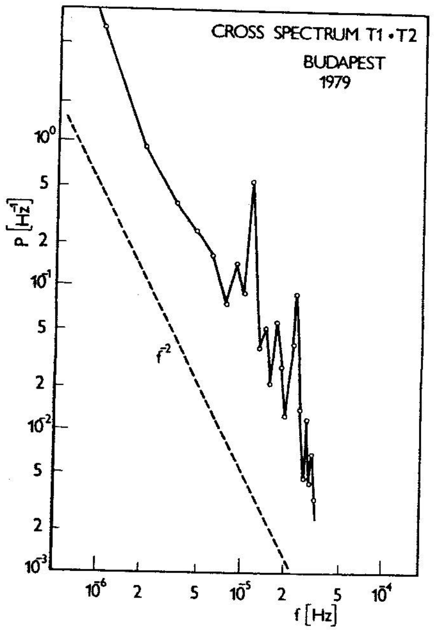

Fig. 2. Cross-correlation spectrum from the Budapest muon telescopes T_1, T_2 for 1979.

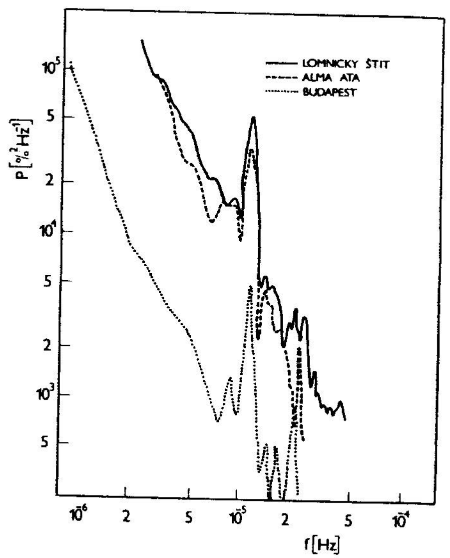

Fig. 3. Power spectrum from Lomnický štit, Alma-Ata, and Budapest for frequencies 2×10^{-6} Hz to 3×10^{-5} Hz in 1979.

From experimental results it follows that at rigidities $R \gtrsim 10$ GV we have $P(f) \sim R^{\alpha}$, $\alpha \approx 0$ and in the range of 10 GV to 180 GV there is $\alpha = -0.87 \pm 0.09$. From the proportionality

$$(\Lambda \nabla N) \sim R^{\left(\frac{\alpha}{2} + 1\right)}$$

the following conclusions can be obtained for the rigidity dependence of Λ and ∇N in the frequency range of 2×10^{-6} Hz to 10^{-5} Hz:

1. In the range of $R \gtrsim 10\,GV$, assuming $\Lambda \sim R^2$ one can obtain $\nabla N \sim R^{-1}$;
2. In the range of $10\,GV < R < 180\,GV$, assuming $\Lambda \sim R^2$ (or $\Lambda \sim R$) the results $\nabla N \sim R^{-1.4}$ (or $\nabla N \sim R^{-0.4}$), respectively.

We wish to mention Bergamasco et al. [9] studied experimentally observed power spectra of diurnal peaks P_d and their rigidity depeendence. Assuming $P_d \sim R^{\alpha'}$ they could for α' a similar value of about -1.

IV. CONCLUSIONS

The obtained power spectra from measurements are in good agreement with the theoretical predictions. The basic results of the submitted paper can be summarized as follows:

a. Power spectra of cosmic rays calculated for the years 1976 to 1980 in the period of increasing solar activity up to the maximum show no significant variation of the spectral index μ with the phase of the solar activity. The spectral index has a value $\mu = 2.0 \pm 0.1$ for the frequencies $f < 5 \times 10^{-5}$ Hz.

b. The rigidity dependence of the fluctuation level of cosmic rays is very weak in the sensitivity range of neutron monitors. From this it follows that for such particles the term $(\Lambda\nabla N)$ is proportional to R. However, in the higher rigidity range, up to 180 GV $(\Lambda\nabla N) \sim R^{0.6}$ in the frame of the diffusion theory of fluctuations. Assuming $\Lambda \sim R$, $\nabla N \sim R^{-0.4}$ is obtained for this range.

c. The theoretically expected form of the power spectrum in the range of low and intermediate frequencies is confirmed by the measurements.

ACKNOWLEDGEMENTS

The authors wish to express greateful acknowledgements to K. Kecskemety and K. Kudela for their assistance in preparing this paper.

REFERENCES

[1] Dorman, L. I., Libin, I. A.: Space Sci. Rev. *39* (1984), 91.
[2] Dorman, L. I., Katz, M. E., Nosov, S. F., Stehlík, M.: (to be submitted to Astrophys. Space Sci.)
[3] Owens, A. J.: *Proc. 16th Intern. Cosmic Ray Conf.*, Vol. *4*, Kyoto 1979, p. 14.
[4] Dorman, L. I., Katz, M. E., Nosov, S. F., Stehlík, M., Fedorov, Yu. I., Shakhov, B. A.: *Proc. 18th Intern. Cosmic Ray Conf.* Vol. *3*, Bangalore 1983, p. 282.
[5] Katz, M. E., Nosov, S. F., Stehlík, M.: Acta Phys. Slov. *34* (1984), 69.
[6] Stehlík, M., Kudela, K.: Acta Phys. Slov. *34* (1984), 75.
[7] Attolini, M. R., Cecchini, S., Guidi, I., Galli, M.: Il Nuovo Cim. *1C* (1978), 275.
[8] Dorman, L. I., Katz, M. E., Stehlík, M.: *Proc. 15th Intern. Cosmic Ray Conf.*, Vol. *3*, Plovdiv 1977, p. 76.

[9] Bergamasco, L., Osborne, A. R., Alessio, S., Cini, G.: J. Geophys. Res. *85* (1980), 4288.

Received August 27th, 1986
Revised version received November 14th, 1986

ФЛУКТУАЦИИ КОСМИЧЕСКИХ ЛУЧЕЙ ПРИ ЖЕСТКОСТЯХ В ДИАПАЗОНЕ 4 — 180 ГВ

В работе рассчитана удельная спектральная мощность флуктуаций космических лучей, которые наблюдались на поверхности земли и под землей в течение 1976—80 гг. Спектральный индекс не зависит от фазы цикла солнечной активности в диапазоне частот от $5 \cdot 10^{-7}$ Гц до $5 \cdot 10^{-5}$ Гц, и его значение равно двум. В области чувствительности нейтронного монитора не обнаружена существенная зависимость уровня флуктуаций P от жесткости частиц R. Однако в области жесткостей вплоть до 180 ГВ уровень флуктуаций P пропорционален величине $R^{-0.87 \pm 0.09}$. Полученные экспериментальные результаты находятся в хорошем согласии с теоретическими предположениями.