KFKI-1986-41/C

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Hungarian Academy of Sciences

**CENTRAL
RESEARCH
INSTITUTE FOR
PHYSICS**

BUDAPEST

KFKI-1986-41/C
PREPRINT

COSMIC RAY FLUCTUATIONS AT RIGIDITIES 4 TO 180 GV

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9th European Cosmic Ray Symposium
Kosice, Czechoslovakia, August 20-25, 1984

HU ISSN 0368 5330

ABSTRACT

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 $5x10^{-7}$ - $5x10^{-5}$ Hz and its value is equal to 2. The level of fluctuations shows a weak dependence on the rigidity (R) of the particles $P \sim R^{-2/3}$. The obtained experimental results are in agreement with the theoretical predictions.

АННОТАЦИЯ

Рассчитаны спектры мощностей флуктуации космических лучей измеренных под землей и на поверхности лля периода 1976-1980 гг. Показатель спектра не зависит от фазы солнечного цикла в интервале частот $5x10^{-7}$ - $5x10^{-5}$ Гц и имеет значение 2. Уровень флуктуаций показывает слабую зависимость от жесткости (P) частиц $P \sim P^{2/3}$. Полученные экспериментальные резултаты соответствуют теоретическим предсказаниям.

KIVONAT

Kiszámitották a kozmikus sugárzás fluktuációinak teljesitményspektrumát a földalatti és földfelszini megfigyelésekből az 1976-1980. évekre. A spektrum kitevője független a napciklus fázisától az $5x10^{-7}$ - $5x10^{-5}$ Hz frekvencia intervallumban és értéke egyenlő 2. A fluktuációk szintje gyenge összefüggést mutat a részecskék (R) merevségével $P R^{2/3}$. A kapott kisérleti eredmények megfelelnek az elméletileg várható értékeknek.

I. Introduction

Considerable progress has been made during the last several years in the theory of cosmic ray /CR/ intensity fluctuations together with new experimental investigations at various energies and for various components of cosmic rays /see refs. [1,2]/. However, the behaviour of the fluctuations at low frequences [3,4] as well as in the presence of disturbances in the interplanetary medium [2] show the necessity of further studies in this field.

In this paper, experimental results on fluctuations of cosmic ray intensity at intermediate /10^{-6} - 5×10^{-5}Hz/ and at low frequencies /below 10^{-6}Hz/ are presented. Power spectral densities /PSD/ during the period of 1976-1980 are determined based on intensity data from the underground muon telescopes in Budapest together with the time dependence of the spectral index of fluctuations. The fluctuation levels and their dependence on the cosmic ray particle energy, as well as the fluctuations at low frequencies $f<10^{-6}$ Hz have been investigated by using the neutron supermonitor data from the peak Lomnitz and Alma-Ata.

II. Experimental data

The power spectral analysis was performed using the following data basis:

/A/ bihourly intensity registrations of hard component of cosmic radiation measured by the Budapest muon telescopes /median rigidity: ~ 180 GV/ during 1976-1980. /For detailed description of the instrument see [5]/. The analysis is carried out for the two independent telescopes separately. The linear time trend was removed from the data.

/B/ hourly counting rates from neutron supermonitors at peak Lomnitz and Alma-Ata for the year 1979, the cut-off rigidity of which are 4.00 GV and 6.69 GV, respectively.

/C/ Daily averages of the Lomnitz neutron supermonitor data for the period 1978-1980.

III. Analysis and results

On the basis of the Budapest data /A/ the power spectral densities of the intensity fluctuations have been calculated separately for telescopes T1 and T2 for the years 1976 to 1980 /see Fig.1a., and Fig.1b/.

At a first glance one can see only a slight variation of the spectra during consecutive years. By making the usual assumption of power low frequency dependence $P(f) \sim f^{-\mu}$, the spectral indices μ have been obtained from the minimum to the maximum of solar activity. Table 1 summarizes the results showing no significant variation of μ with an average value of 2.0.

Values of spectral indices μ: Table 1

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 result can be obtained when performing a crosscorrelation analysis between the two telescopes /for 1979, see Fig.2./ Here again, a spectral exponent of 2.0 gives the best fit to the data in a good agreement with theoretical expectations.

According to the theory [4,6], the power spectral density /PSD/ of the intensity fluctuations has the form of

$$P(f) = A \{ 1+(f_1/f)^2 \} B(f) \qquad /1a./$$

where B(f) is the PSD of the interplanetary magnetic field /IMF/

$$B(f) = \frac{B_\nu}{(fo^2+f^2)^{\nu/2}} \qquad /1b./$$

where ν denotes the spectral index of IMF.

Taking into account that $AB_\nu fo^{-2} \approx 3 \div 5$ and $fo/f_1 \approx 5$ one can get from /1/ for the frequencies lower than 10^{-5}Hz: $P(f) \sim f^{-2}$

what is confirmed by the measurements.

The rigidity dependence of the level of the fluctuations is examined in the frame of diffusion model [7]. According to this theory, $P(f)$ is proportional to $(\Lambda \cdot \nabla N/R)^2$, where Λ stands for the mean free path of transport of CR in the inhomogeneous IMF, R denotes particle rigidity and ∇N is the density gradient of particles. In Fig. 3 the PSD calculated on the basis of /A/ and /B/ data sets are shown for the year 1979. The fluctuation level of particles of rigidities $R \sim 180$ GV is roughly by one order of magnitude lower than that of particles seen by neutron supermonitors.

It is seen from experimental results that at rigidities $R<10$ GV we have $P(f) \sim R^{\alpha}$, with $\alpha \approx 0$ while in the range $10 \text{ GV}<R<180$ GV $\alpha = -0.87 \pm 0.09$.

From the proportionality $(\Lambda \cdot \nabla N) \sim R^{\alpha/2+1}$ 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. For $R < 10$ GV: assuming $\Lambda \sim R^2$ one can get $\nabla N \sim R^{-1}$;
2. $10 \text{ GV}<R<180$ GV: assuming $\Lambda \sim R^2$ /or $\sim R^1$/ results in $\nabla N \sim R^{-1.4}$ /or $\sim R^{-0.4}$/, respectively.

As a remark we notice that in the paper of Bergamosco et al. [8] the experimentally observed power spectra of diurnal peaks and their rigidity dependence were studied. Assuming $P_d \sim R^{\alpha'}$ one can have in this case for α' a similar value of about 1.

Figure 4. compares theoretical predictions for the power spectra with measurements in the range of 10^{-7} Hz to 5×10^{-4} Hz for neutron supermonitor data /data set /B/-continuous line, data set /C/ - dashed line/. The heavy line represents theoretical result based on expression /1/ with $\nu=2$. Dashed heavy lines refer to the low-frequency /lf/ and the high-frequency /hf/ approximations from expression /1/, i.e. when $f \ll f_1$ and $f \gg f_0$, respectively.

The gap between the two curves /lf and hf/ yields a ratio of $f_0/f_1 \approx 5$ /see [9] /.

For further check of the hypothesis of $\nu=2$ the power spectrum calculations should be extended up to the range of $f > 5\times10^{-5}$ Hz. According to Attolini et al. [10] in this frequency range, too, the spectral index remains close to 2. As it was pointed out by Dorman et al. [2] the MHD turbulence model in some cases can produce spectral index $\mu=2$ even when $\nu<2$. This is in the case when MHD turbulence has the dimension less than three.

IV. Conclusions

The obtained power spectra of measurements are in good agreement with the theoretical predictions. The basis results from given paper can be summarized in the following:

1. Power spectra of CR-s calculated for years 1976 to 1980 in the period of increasing solar activity, till the maximum, show no significant variation of spectral index μ with the phase of solar activity cycle. The spectral index has a value of $\mu=2.0 \pm 0.1$ for frequencies above 5.10^{-5} Hz.
2. The rigidity dependence of fluctuation levels of cosmic rays is very weak in the sensitivity range of neutron supermonitors. From this it follows that for such particles the term $(\Lambda \cdot \nabla N)$ is proportional $\sim R^1$. However, in the higher rigidity range, up to 180 GV $(\Lambda \cdot \nabla N) \sim R^{0.6}$ in the frame of diffusion theory of fluctuations. Assuming $\Lambda \sim R^1$, $\nabla N \sim R^{-0.4}$ is obtained for this range.

3. The theoretically predicted form of power spectra in the range of low and intermediate frequencies is well reproduced by the measurements. The gap in the "transient" range of frequencies lf and hf corresponds to the ratio $f_0/f_1 \approx 5$. It is worthwhile to note, that the absence of such a gap between the levels of PSD would give $f_0 \approx f_1$. This is not in contra-

diction with the theory that takes into account a higher value of diffusion coefficient, for example $\varkappa \sim 10^{22}$ cm^{2}s^{-1} as it was shown in [6].

Acknowledgments

The authors wish to acknowledge K. Kecskeméty and K.Kudela for their assistance in evaluating this paper.

References :

1. L.I.Dorman,I.A.Libin; Space Sci. Rev. 39. p.91 /1984/.
2. L.I.Dorman,M.E.Katz,S.F.Nosov,M.Stehlik,Yu.I.Fedorov, B.A.Sakhov; App.Sp.Sci. /in press/
3. A.J.Owens ; Proc.16th Int.Cosmic Ray Conf. Kyoto,Japan, vol.4. p.14./1979/
4. L.I.Dorman,M.E.Katz,S.F.Nosov,M.Stehlik,Yu.I.Fedorov, B.A.Shakhov; Proc. 18th Int.Cosmic Ray Conf.,Bangalore,India vol.3.p.282./1983/
5. A.J.Somogyi; Proc.Int.Cosmic Ray Symp.on High Energy CR Modulation, Tokyo,Japan; p.35. and Appendix 8. /1976/
6. M.E.Katz,S.F.Nosov,M.Stehlik; Acta Phys.Slov.34.p.69./1984/
7. L.I.Dorman,M.E.Katz,M.Stehlik; Proc.15th Int.Cosmic Ray Conf. Plovdiv,Bulgaria,vol.3.p.76./1977/
8. L.Bergamosco,A.R.Osborne,S.Alessio,G.Cini; Journ.Geophys.Res. 85, p.4238 /1980/
9. M.Stehlik,K.Kudela;Acta Phys.Slov.34.p.75 /1984/
10. M.R.Attolini,S.Cecchini,I.Guidi,M.Galli; Il Nuovo Cim. 1C, p.275 /1978/

Figures:

Fig.1a.	Power spectrum calculated from Budapest muon telescope T1 for 1976 to 1980.
Fig.1b.	Power spectrum calculated from Budapest muon telescope T2 for 1976 to 1980.
Fig.2.	Cross-correlation spectrum from Budapest muon telescopes T1,T2 for 1979.
Fig.3.	Power spectrum from Peak Lomnitz, Alma-Ata and Budapest for frequencies $2x10^{-6}$ Hz to $3x10^{-5}$ Hz in 1979.
Fig.4.	Comparison of theoretical and experimental power spectra for frequencies 10^{-7} Hz to $5x10^{-4}$ Hz.

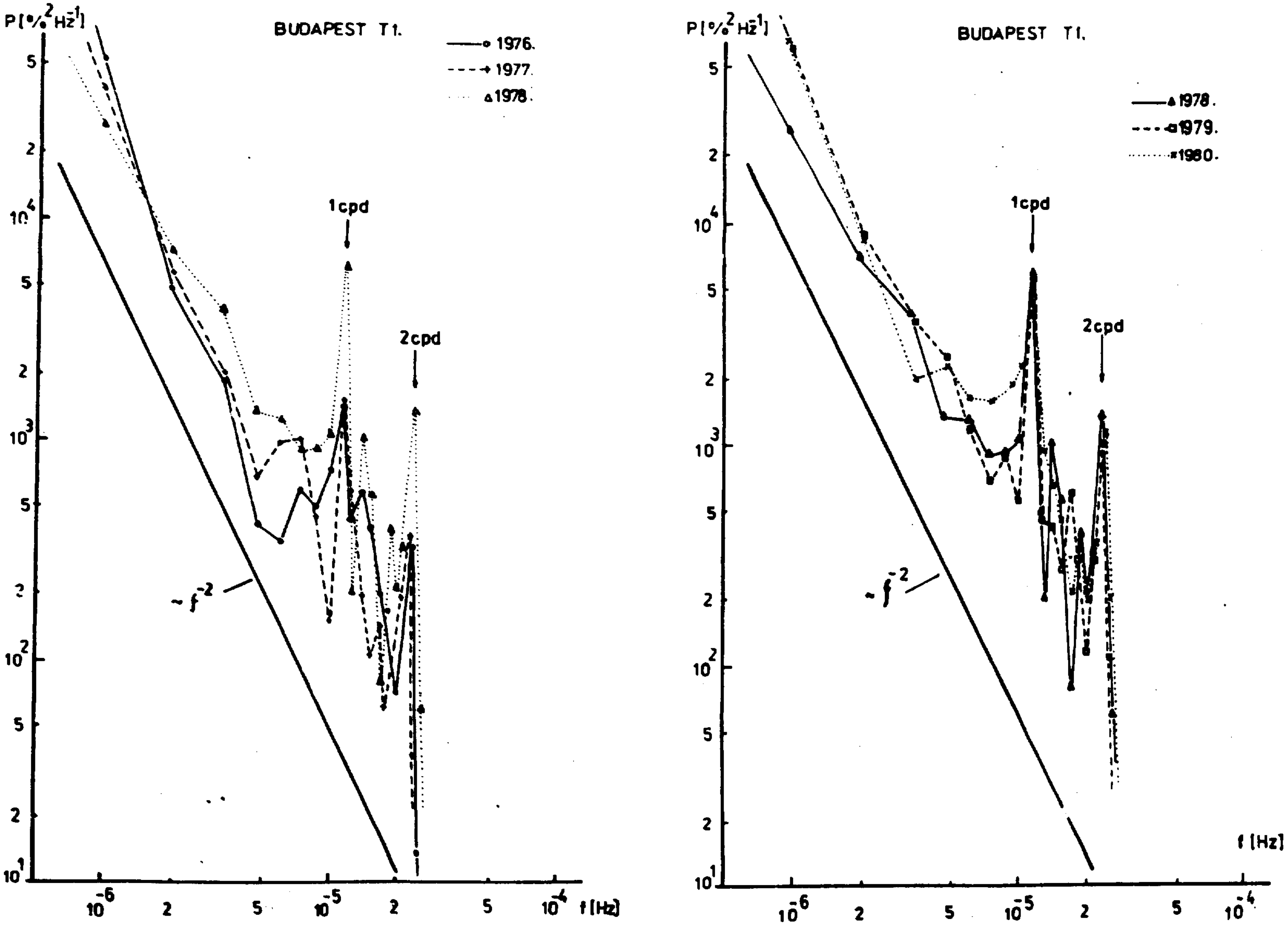
P[%²Hz⁻¹]
BUDAPEST T1.
1976.
1977.
1978.
1cpd
2cpd
~f⁻²
5
2
10⁴
5
2
10³
5
2
10²
5
2
10¹
10⁻⁶
2
5
10⁻⁵
2
5
10⁻⁴
f [Hz]
P[%²Hz⁻¹]
BUDAPEST T1.
1978.
1979.
1980.
1cpd
2cpd
~f⁻²
f [Hz]

Fig.1a.

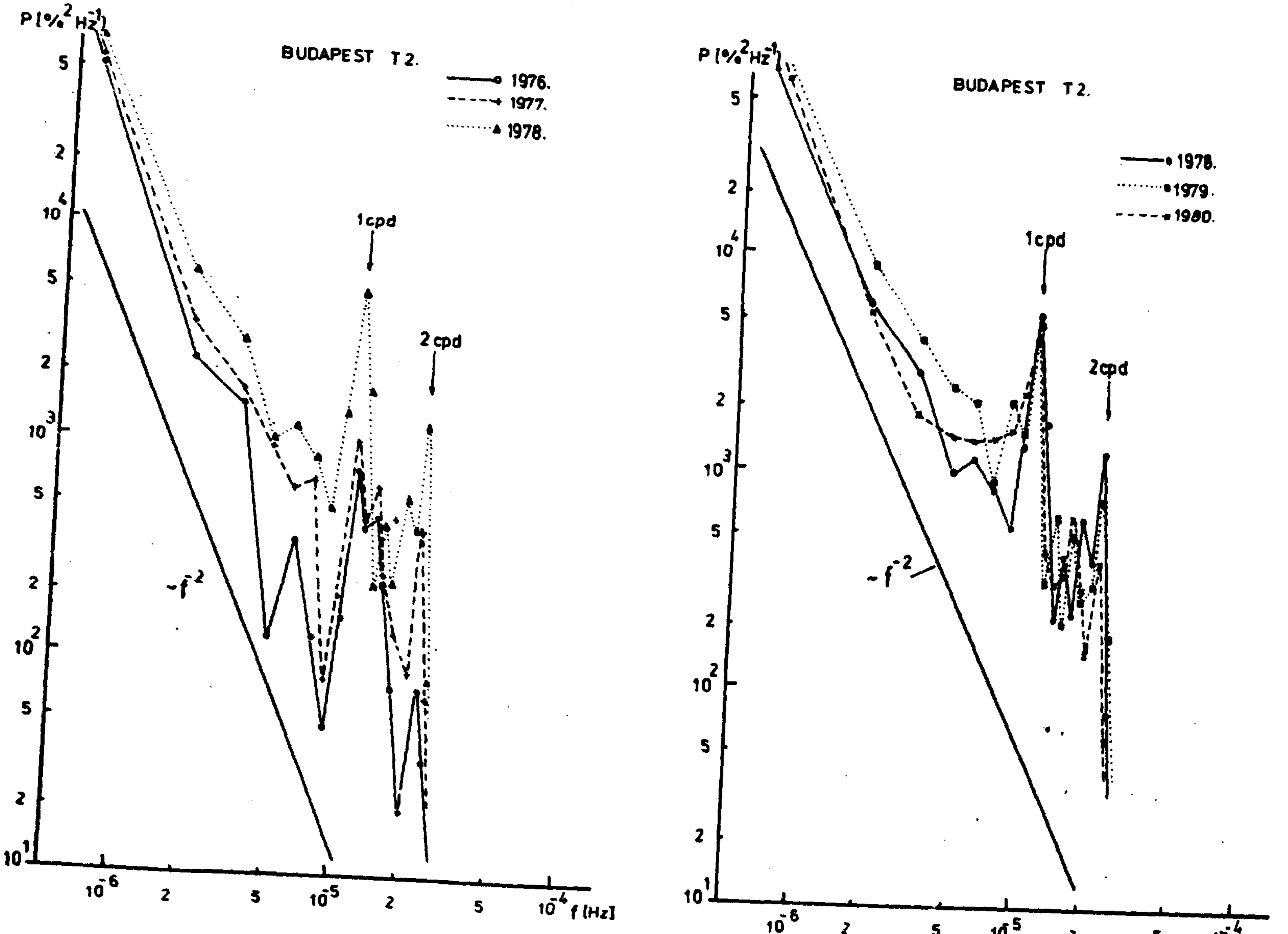
P [%² Hz⁻¹]
BUDAPEST T2.
1976.
1977.
1978.
1cpd
2cpd
~f⁻²
10⁴
10³
10²
10¹
5
2
10⁻⁶
10⁻⁵
10⁻⁴
f [Hz]
BUDAPEST T2.
1978.
1979.
1980.
1cpd
2cpd
~f⁻²

Fig.1b.

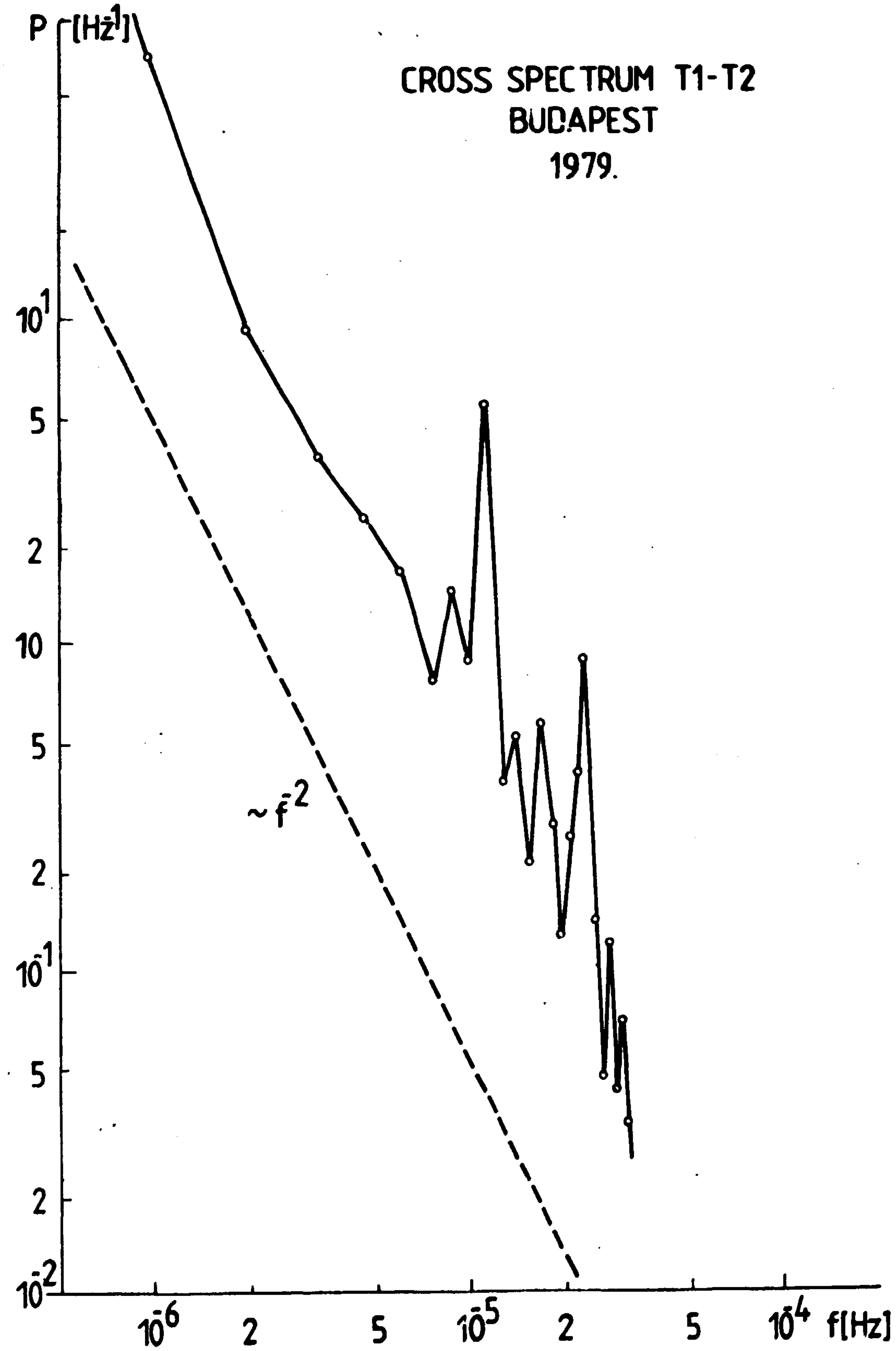
P [Hz⁻¹]
CROSS SPECTRUM T1-T2
BUDAPEST
1979.
10¹
5
2
10
5
2
10⁻¹
5
2
10⁻²
~f⁻²
10⁻⁶
2
5
10⁻⁵
2
5
10⁻⁴
f[Hz]

Fig. 2

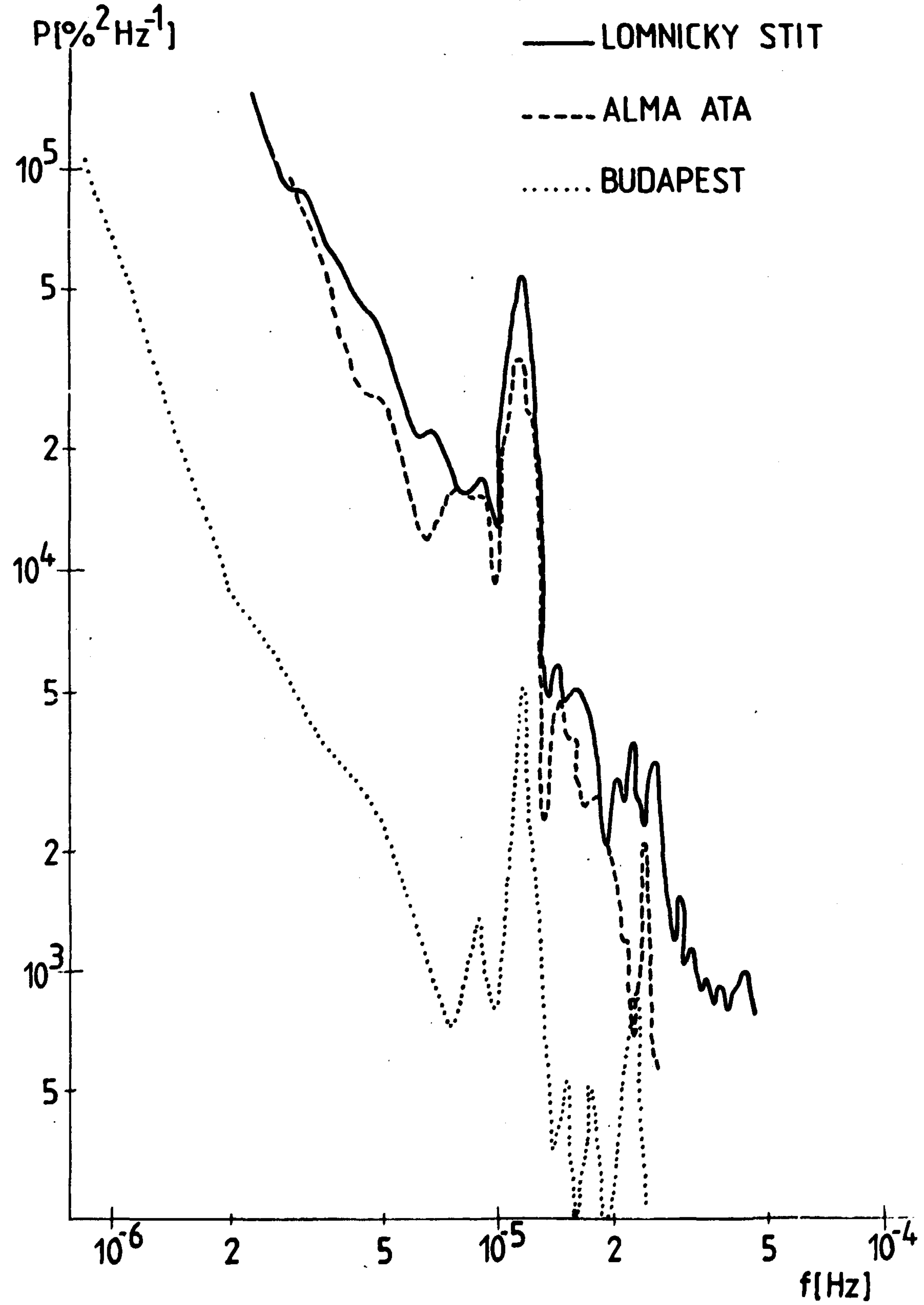
P[%²Hz⁻¹]
LOMNICKY STIT
ALMA ATA
BUDAPEST
10⁵
5
2
10⁴
5
2
10³
5
10⁻⁶
2
5
10⁻⁵
2
5
10⁻⁴
f[Hz]

Fig. 3

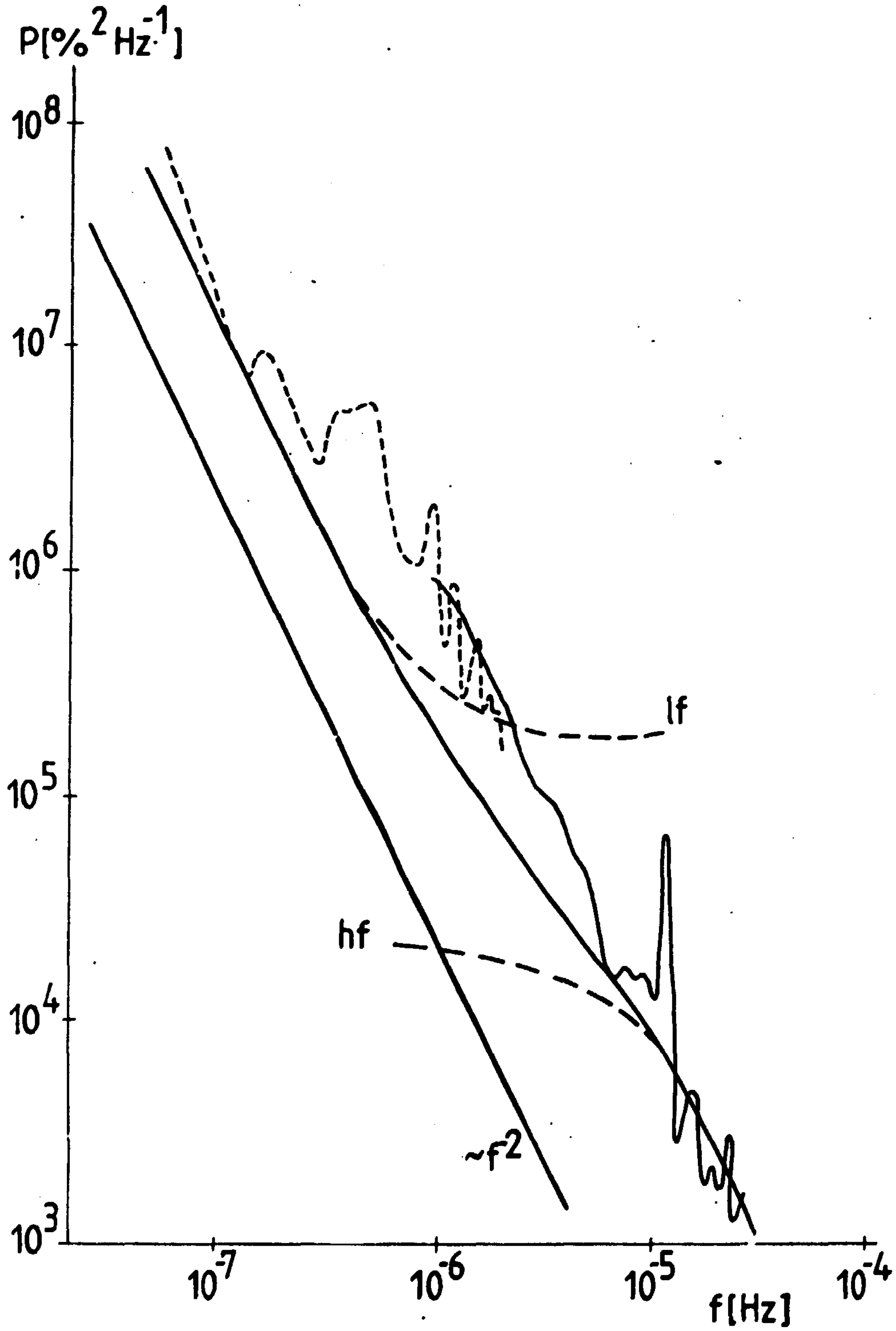

Fig. 4

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Nyelvi lektor: Lorencz Kinga
Példányszám: 275 Törzsszám: 86-414
Készült a KFKI sokszorosító üzemében
Felelős vezető: Töreki Béláné
Budapest, 1986. julius hó