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Absolute Proton Fluxes from the Sun at Rigidity Above 1 GV By Ground-Based Data

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Abstract

Based on Ground Level Event (GLE) observations of solar comic rays (SCR) since 1942 we summarize available data on absolute spectra of relativistic protons at the Earth's orbit. Different methodics for determination of absolute proton fluxes at rigidity above 1 GV are discussed with the purpose of evaluation of their accuracy. A distribution of GLEs by proton fluxes at rigidity above 1 GV is obtained to demonstrate maximum capacity of solar accelerators.

1 Introduction

A problem of the energy spectrum and maximum energy of SCR is of great significance for the formulation of self-consistent model of particle acceleration in solar flares. In its turn, the main problems of fundamental interest in the theory of particle acceleration at the Sun are concentrated now at the edges of SCR spectra, namely, in very low-energy and high-energy ranges. The most important of them are: initial acceleration from the thermal background [1,2], and final stage of acceleration to extremely high energies [3].

The problem of SCR generation in relativistic range was recently actualized due to first confident observations of underground effects correlated with solar flares. In particular, significant increases of counting rate at several muon telescopes were registered during GLE of September 29, 1989 including one very peculiar muon burst [4] at the Baksan Underground Scintillation Telescope (BUST). These new findings give a challenge to our present understanding of utmost capacities of particle accelerators at the Sun. In this context, SCR spectral data (in absolute units of proton flux) at rigidity $R > 1\ GV$ are of special interest [5].

2 Methodics

To restore SCR spectrum in absolute units of proton flux at the atmosphere boundary by the ground observation data, the authors [6] suggested a procedure which is based on the following relationship:

$$I_i(> R_c, h) = \int_{R_c}^{\infty} m_i(R) D_g(R) dR \qquad (1)$$

where I_i is an integral intensity of secondary particles of the i kind at the h depth

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Table 1: Absolute fluxes of relativistic solar protons near the Earth.

GLE date	R GV	D_0 $(cm^2sGV)^{-1}$	γ	GLE date	Rigitity GV	D_0 $(cm^2sGV)^{-1}$	γ
28.02.42	≥ 1	$8.3 \cdot 10^2$	4-5	19.09.77	1.0	$2.4 \cdot 10^{-1}$	4.0
07.03.42	≥ 1	$1.0 \cdot 10^3$	4-5	24.09.77	1.0-6.3	4.0	3.4
19.11.49	≥ 1	$2.8 \cdot 10^3$	4-5	22.11.77	2.29-4.0	$5.0 \cdot 10^2$	5.5
23.02.56	1.5-5.0	$1.3 \cdot 10^4$	6.8	07.05.78	2.15-6.20	$4.1 \cdot 10^2$	4.1
04.05.60	2-5	$6.3 \cdot 10^1$	3.4	23.09.78	≥ 1	$1.9 \cdot 10^1$	4.8
12.11.60	0.98-3.45	$1.7 \cdot 10^2$	5.2	21.08.79	≥ 1	5.7	4.6
15.11.60	1.5-4	$1.6 \cdot 10^2$	5.0	10.04.81	≥ 1	1.7	4.5
28.01.67	0.44-10	$1.3 \cdot 10^1$	4.5	10.05.81	≥ 1	2.0	4.3
18.11.68	1.6-5	$1.6 \cdot 10^1$	5.0	12.10.81	≥ 1	$1.4 \cdot 10^1$	4.4
25.02.69	1.02-4.35	9.5	4.1	26.11.82	≥ 1	5.7	4.1
30.03.69	1-3	2.5	4.0	08.12.82	≥ 1	$8.6 \cdot 10^1$	5.5
24.01.71	1.0-5.0	$1.7 \cdot 10^1$	5.0	16.02.84	≥ 1	7.3	4.3
25.01.71	1.02-4.35	9.5	4.1	29.09.89	≥ 1	9.3	2.9
01.09.71	1-5	$1.6 \cdot 10^1$	5.5	11.06.91	1-4	$1.6 \cdot 10^1$	5.5
04.08.72	1-1.6	$2.0 \cdot 10^1$	8.0	15.06.91	1-4	$6.2 \cdot 10^1$	6.0
07.08.72	1.02-3.0	7.0	4.0				

in the atmosphere at the point with a geomagnetic cutoff rigidity R_c; $D_g(R)$ is the differential spectrum of galactic cosmic rays (GCR); m_i is an integral multiplicity of generation, i.e., the number of secondary particles of the i kind generated by a primary particle with the rigidity R and registered at the h depth (e.g., at the sea level). Differentiating (1) with respect to R, we obtain two formulae (2) and (3), describing a latitude variation of GCR and giving a relationship for estimating integral multiplicities, respectively:

$$\left|\frac{\partial I}{\partial R}\right| = m(R,h)D_g(R) \quad (2)$$

$$m(R,h) = \left|\frac{\partial I}{\partial R}\right| / D_g(R) \quad (3)$$

The values $m(R,h)$ may also be calculated theoretically taking into account nuclear-cascade processes in the atmosphere. If the values $m(R,h)$ are known, we get from (1)-(3) a simple formula for determining absolute SCR spectrum:

$$D_s(R) = \frac{\left|\frac{\partial I_s}{\partial R}\right|}{m(R,h)} \quad (4)$$

where the "s" index refers to solar particles, and $m(R,h)$ to the total GCR flux, irrespectively to the content of the nuclei with different charge Ze. Meanwhile, the protons are the dominant part of SCR, their content being much more in respect to

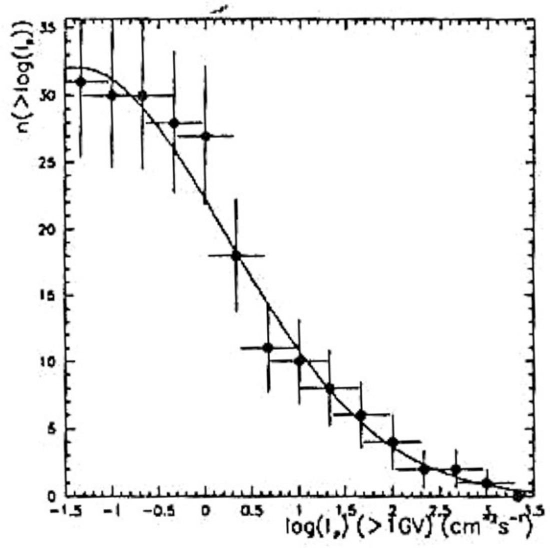

Figure 1: Distribution function of GLEs (1942-1992) on the integral flux of solar protons with the rigidity above 1 GV.

nuclei with $Z > 2$ in comparison with the GCR. It implies that instead of empirical values of m derived from the latitude survey of GCR intensity (for example, for neutron component, m_n) an integral multiplicity for protons, m_p, ought to be used in determining the SCR spectrum (4). It imposes a serious limitation on the accuracy of SCR spectrum determination by ground-based data. Indeed, about one half of total amount of nucleons in the GCR flux are free protons. Hence it follows [6]:

$$m_p(R,h) < m(R,h) < 2m_p(R,h) \quad (5)$$

i.e., the integral multiplicities m calculated by GCR observations (3) may be differ from the m_p values no more than by factor 2.

3 Statistics of spectral data above 1 GV

Since February 28, 1942 (an historical beginning of SCR observations) the generous data have been obtained on the SCR fluxes, and their spectra have been intensively studied in the energy range from $\sim 1\ MeV$ to $10\ GeV$ and even more. By now, there are registrated data for 54 GLEs [7], however, spectral data at the rigidities above 1 GV ($\geq 500\ MeV$) are fairly scarce, uncertain and controversial [3]. Absolute SCR spectra above 1 GV estimated by different researchers at the moments of maximum increase for 31 events are listed in Table 1. The procedure of estimations was, in essence, identical. However, in [6,8] (for example) the integral multiplicities (3) of $m(R)$ were used, while the authors [9-11] and some other researchers preferred so-called specific yield functions, $s(R)$, i.e., multiplicities normalized to the counting rate of the neutron monitor (NM) at the equator in the minimum of solar activity (see, e.g., [12]).

The normalized values of s(R) may be overestimated as compared with integral ones by ≤ 2 orders [8]. This may affect, in particular, estimates of the supposed upper limit, R_m , of SCR spectrum when using the procedure suggested in [13].

4 Distribution function of GLEs 1942-1992

A summary of spectral data [5] in relativistic range (Table 1) raises a question about GLE distribution on absolute fluxes of solar protons above 1 GV. This problem is of fundamental interest because it clarifies our knowledge of utmost capacity of solar accelerators (maximum values of R and a number of accelerated relativistic particles). Because of the statistics is rather poor we were able to construct a distribution function only for an integral number of GLEs with the integral flux of solar protons at $R \geq 1\ GV$ (Figure 1). The results show that in spite of significant methodical uncertainties the distribution may be fitted by Gaussian curve with the proper parameters: constant=32 ± 5, mean=-1.4 ± 0.7 and sigma= 1.6 ± 0.3. In more details we discussed the problems involved elsewhere [5].

References

[1] Vlahos L. et al. ENERGETIC PHENOMENA ON THE SUN - Kluwer Academic Publishers, Dordrecht/Boston/London (1989).

[2] Miroshnichenko L.I. Solar Phys.**156** (1995)119.

[3] Miroshnichenko L.I. Geomagnetism and Aeronomy**34** (1994)29.

[4] Alexeyev E.N. et al. Geomagnetism and Aeronomy**32** (1992)192.

[5] Miroshnichenko L.I. et al. J.Geophys.Res.1995(subm.).

[6] Dorman L.I. and Miroshnichenko L.I. Geomagnetism and Aeronomy**6** (1966)215.

[7] Shea M.A. and Smart D.F. Solar-Terrestrial Prediction-IV. Proc. of a Workshop at Ottawa, Canada, May 18-22, 1992. U.S.Department of Commerce, NOAA, SEL, Boulder, Co. 2 (1993)48.

[8] Bednazhevsky V.M. and Miroshnichenko L.I. Geomagnetism and Aeronomy**22** (1982)125.

[9] Lockwood J.A. et al. J.Geophys.Res.79 (1974)4149.

[10] Bazilevskaya G.A. et al. Geomagnetism and Aeronomy**23** (1983)373.

[11] Kohno T. Proc. 22nd Int. Cosmic Ray Conf.**3** (1991)125.

[12] Debrunner H. et al. 8th European Cosmic Ray Symp. 1982(unpublished).

[13] Heristchi Dj. et al. Solar Phys.**49** (1976)151.