"Physics of Auroral Phenomena", Proc. XXIX Annual Seminar, Apatity, pp. 187 - 190, 2006

Polar Geophysical Institute

USING THE EXTENSIVE AIR SHOWERS DETECTORS FOR STUDY OF SOLAR COSMIC RAYS

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Introduction

The worldwide network of neutron monitors (NMs) allows to determine the spectrum of Solar Cosmic Rays (SCR) in a majority of GLE events only up to energy 4-5 GeV [1]. Exceptions are huge events such as that of February,23, 1956 [2, 3] and September,29, 1989 [4, 5]. In addition to the NMs data, we suggest using the information of the existing detectors employed for registration of various components of Extensive Air Showers (EAS). Namely, we suggest using one-particle mode of registration at the specified detectors. The minimal energy is determined in this case by geomagnetic cutoff, as for NMs. The area and counting rate of such detectors are several orders of magnitude higher than that for NMs.

Baksan research complex

The Baksan EAS-arrays and Baksan Muon Detector (BMD) have the following sensitive areas (the areas of scintillator): ANDYRCHY – 37 m^2, CARPET – 196 m^2, and BMD – 175 m^2. The opposite effective area of the standard module of the neutron monitor (6-NM-64) makes up 1.8 m^2. While statistical accuracy of the standard neutron monitor by 5-minute data makes up about 1%, for the ANDYRCHY, CARPET and BMD it makes up 0.05%, 0.03% and 0.04%, respectively. It allows to measure a cosmic ray flux, which is ten times weaker [1]. Comparative characteristics of all sets of the Baksan research complex are presented in Table 1, where BNM is the Baksan Neutron Monitor (INR of RAS – KBSU). All above detectors are situated in Baksan valley in the Northern Caucasus (geographical coordinates 43.28° N, 42.69° E). The geomagnetic cutoff rigidity is equal 5.7 GV (according to Tsyganenko-1989 model) [6].

Table 1. Comparative characteristics of all sets of the Baksan research complex.

Sets of Baksan research complex	Height above sea level, m	Deep into atmo-sphere, g/cm^2	Barometri-cal coefficient, %/mbar	Mean counting rate, s^{-1}	Sensi-tive area of set, m^2	Dimensions of separate counter, cm^3	Thickness of matter above detector, g/cm^2
Andyrchy	**2050**	**800**	**–0.38**	**11500**	**37***	**100×100×5**	**4.7**
Carpet	**1700**	**835**	**–0.38**	**40000**	**196***	**70×70×30**	**21**
BMD	**1700**	**835**	**–0.16**	**19000**	**175***	**100×100×5**	**500**
BNM	**1700**	**835**	**–0.73**	**105**	**1.8**	**L=200, ∅15**	**21**

Solar cosmic rays registration and analysis

The increases of SCR (i.e. GLE events) were already observed by similar detectors earlier: at the Baksan CARPET – on 29 September 1989 [7, 8], MILAGRITO – on 6 November 1997 [9], GRAND – on 15 April 2001 [10]. Further analysis of GLE events using the data of three Baksan Detectors (ANDYRCHY, CARPET and BMD) shows that increases of the SCR flux with energy above 5 GeV are observed nearly in 50% of specified events [11]. The counting rate of each Baksan detector within several hours prior to the beginning of GLE and a few hours after were approximated by a polynomial function. It gives an average value of the background. The deviation of real counts of detectors from the polynomial function in percentage was calculated later. For illustration, the most powerful GLE event of 23rd solar cycle 20 January 2005 for the several last years according to the data of the Baksan CARPET is shown in Fig. 1.

In total 30 GLE events have been analyzed. The results, obtained over 5-minutes data of Baksan detectors, are presented in Table 2. GLE events, where an excess above the background of more than four standard deviations, was observed, are shown.

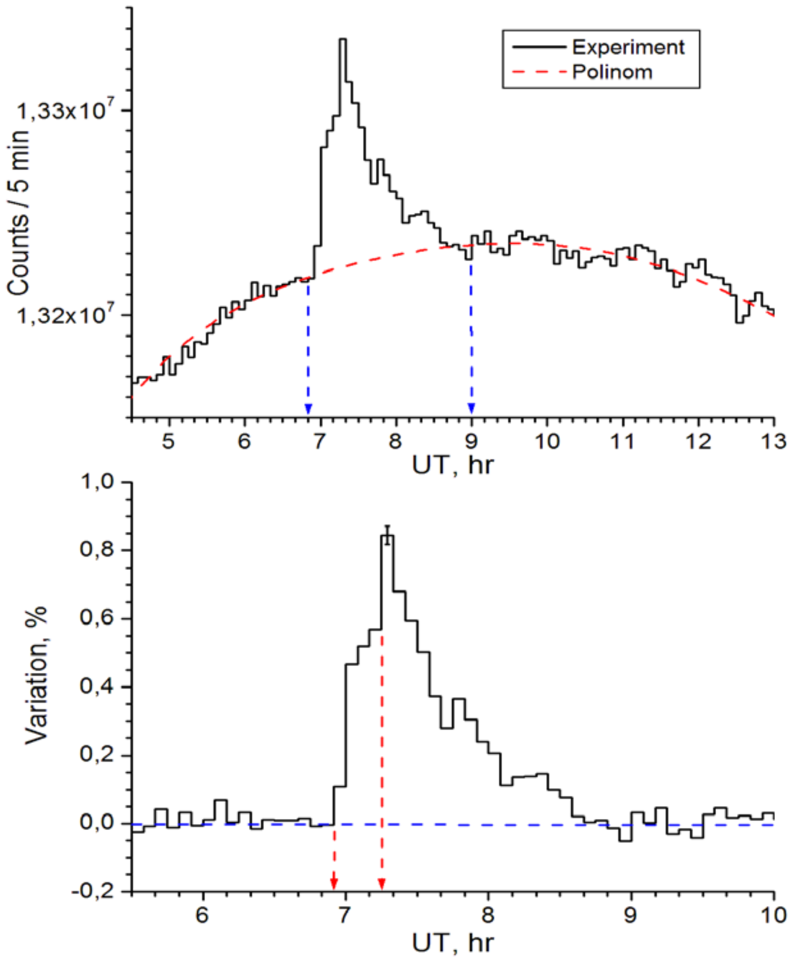

Fig.1. GLE event of 20 January 2005 according to the data of the Baksan CARPET. Top panel is a real counting rate of the CARPET and polynomial approximation of the background. Bottom panel is a deviation of counting rate from the background.

All interesting results obtained over 5-minutes data of three Baksan detectors are summarized in Table 2 only for those GLE events, where an excess above the background of more than four standard deviations was observed at least at one of Baksan installations.

Table 2. The Ground Level Enhancements (GLE) by the 5-minute data of the CARPET, ANDYRCHY and BMD.

No.	Date		Carpet *				Andyrchy **				BMD ***		
GLE		Start	Max.	Inc.%	s	Start	Max.	Inc.%	s	Start	Max.	Inc.%	s
36	811012	0736	0822	0.26	8.7								
38	821207	2356	2410	0.28	9.3								
39	840216	0856	0910	0.14	4.7								
42	890929	1148	1212	43.30	1443								
45	891024	1816	1834	0.48	16								
48	900524	2056	2114	0.36	12								
49	900526	2128	2214	0.76	25								
52	910615	0850	0920	0.66	4.1								
55	971106	—	—	—	—	1205	1235	0.27	5.0				
56	980502	1330	1350	0.43	14	1335	1400	0.40	7.4				
60	010415	1355	1420	0.47	16	1350	1415	0.59	10	1355	1550	0.18	4.4
61	010418	0215	0320	0.58	19	0220	0315	0.60	11	0215	0300	0.35	8.2
65	031028	1105	1145	0.66	22	1115	1140	0.81	15	1100	1145	0.21	5.2
66	031029	2140	2150	0.56	19	2140	2155	0.50	8.7	2140	2150	0.29	7.2
69	050120	0655	0715	0.85	28	—	—	—	—	0655	0710	0.25	6.2

* Base statistical accuracy of the CARPET is 0.03% by 5-min data. During GLE52 accuracy of the CARPET is 0.16%.
** The ANDYRCHY has been operating since 1996. The base accuracy of the ANDYRCHY is 0.055% by 5-minute data.
*** The BMD data is available since 2000. The base accuracy of the BMD is 0.04% by 5-minute data. σ – the magnitude of the GLE increase in standard deviations at the Baksan detectors.

Analysis of the baksan detectors' data

The analysis of the Baksan detectors data in combination with the data of the worldwide network of neutron monitors allows to extend spectra of SCR for various GLE events above 5 GeV. The data of neutron monitors are often absent at that energy in the majority of GLE. To obtain the primary SCR spectra we need to do a reverse transformation from the recorded counting rate of the secondary particles to the primary SCR intensity. The Multiplicity Functions of the secondary particles' generation and Yield Functions of specified detectors for the one-particle mode of registration are necessary for similar analysis. These functions were calculated for the ANDYRCHY [12], CARPET and BMD for vertical and isotropic primary fluxes. The vertical Specific Yield Function relation is as follows [13]:

$$\frac{dN(p,x,t)}{dp} = S(p,x)\cdot\frac{dJ(p,t)}{dp}, \qquad (1)$$

where *dN(p,x,t)/dp* is the contribution to the counting rate of the detector, located at depth *x* at the time *t*, from the primary particles with the rigidity of *p* to *p* + *dp,* arriving within a small solid angle near the vertical direction. *S(p,x)* is a Specific Yield Function (SYF) of detector for primary particles; *dJ(p,t)/dp* is the primary cosmic ray spectrum [14].

Results of calculations

Passage of particles through the atmosphere down the level of Baksan detectors was modeled with a well-known software package CORSIKA (v.6.031, QGSJET). To obtain the Yield Functions, the processes of particles registration at the Baksan detectors were simulated by Monte Carlo method using the authors' programs. The real configuration of arrays and the construction of their separate counters were taken into account.

The more detailed method of calculations was used in the paper [15]. You can see the results in Fig. 2. The Specific Yield Functions of EAS-arrays and of the BMD are a few orders of magnitude higher than one of the BNM at rigidities exceeding the geomagnetic cutoff at Baksan.

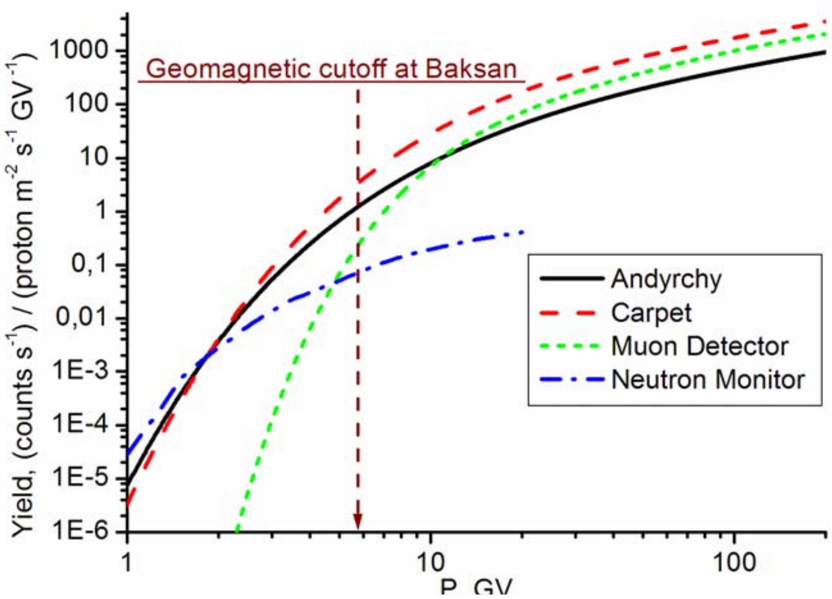

Fig. 2. Specific Yield Functions (SYFs) of EAS-arrays the ANDYRCY and CARPET and the Baksan Muon Detector in comparison with SYF of Neutron Monitor.

This provides a higher counting rate and a better sensitivity of the Baksan Detectors to SCR with energy above 5 GeV. At the same time, the neutron monitor is more effective at smaller rigidities.

Conclusions

Thus, three Baksan Detectors (ANDYRCHY, CARPET and BMD) have registered 15 increases of SCR from 30 GLE events under investigation. It means that SCRs with the rigidity above 5.7 GV were observed in at least 50% of GLE events. The amplitude of the signal in all cases (except 29 September 1989) makes up to the tenth of a percent. Such increases cannot be found at standard neutron monitors with a similar geomagnetic cutoff rigidity. Only high statistical accuracy of Baksan Detectors allows to register significant increases of SCR of such rigidity. Due to this there is an opportunity to extend the spectrum of SCR for the specified events above 5 GeV. With that purpose the Multiplicity and Specific Yield Functions have been calculated for all three Baksan detectors: the ANDYRCHY, CARPET and BMD. They differed considerably from the respective functions of Neutron Monitors at higher and lower energies.

Acknowledgements. This study is supported by the Russian Foundation of Basic Research (project 04-02-16952) and by the State Program of Support of Leading Scientific School (grant SS-1828, 2003, 02).

References

[1] S.N. Karpov, V.V. Alexseenko, D.D. Djappuev, Z.M. Karpova, N.S. Khaerdinov, V.B. Petkov, A.V. Radchenkov, A.N. Zaichenko, GLE Observations in 23rd Solar Cycle at the Baksan Air Arrays Andyrchy and Carpet. // 2003, Proc. 28th ICRC, Tsukuba, SH1.4, p.3427-3430.

[2] L.I. Miroshnichenko, *Catalogue of Solar Cosmic Ray spectra near the Sun,* Moscow, AN SSSR, IZMIRAN, Preprint №15 (548), 1985.

[3] W.R. Webber. – In: AAS-NASA Symposium on the Physisics of Solar Fkares (ed. By W.N. Hese). NASA, Washington, D.C., 1964, p. 215.

[4] G. A. Bazilevskaya, E.V. Vashenuk, V.N. Ishkov et al. *Solar Proton Events 1980-1986, Catalogue*, edited by Yu. I. Logachev (Moscow, World Data Center-B-2), 1990

[5] A.I. Sladkova, G.A. Bazilevskaya, V.N. Ishkov, M.N. Nazarova, N.K. Pereyaslova, A.G. Stupishin, V.A. Ulyev, I.M. Chertok, *Catalogue of Solar Proton events 1987-1996,* Edited by Yu. I. Logachev, Moscow University Press, 1998, p. 205-206.

[6] V.A. Tsyganenko, Planet. Space Sci., 37, 5 (1989).

[7] E.N. Alexeyev et al., 1991, Izv. AN SSSR, Phys. Ser. 55, 1874.

[8] V.V Alexseenko. et al., 1993, Proc. 23rd ICRC, 3, 163.

[9] J.M. Ryan, 1999, Proc. 26th ICRC, 6, 378.

[10] J. Poirier and C. D'Andrea, 2002, J. Geophys. Res., 107, 1815.

[11] S.N. Karpov, Z.M. Karpova, Yu. V. Balabin and E.V. Vashenyuk, Study of the GLE events with use of the EAS-Array data. // 2005, Proc. 29th ICRC, Pune, SH.1.5, 1, p. 193-196.

[12] S.N. Karpov, V.V Alexseenko, Z.M. Karpova, N.S. Khaerdinov, V.B. Petkov, Yield and Response Functions of Baksan EAS-Arrays Andyrchy for Single Component. //2003, Proc. 28th ICRC, SH1.5, p. 3457-3460.

[13] J.A. Lockwood, W.R. Webber and L. Hsieh, J. Geophys. Res., 79, 4149 (1974).

[14] T.K. Gaisser et al. 27th ICRC, Humburg (2001) OG1.01, 1643.

[15] S.N. Karpov, Z.M. Karpova and A.B. Chernyaev, Multiplicity, Yield and Response Functions for Baksan EAS-Arrays and Muon Detector in comparison with similar functions of Neutron Monitors. //2005, Proc. 29th ICRC, Pune, SH1.6, 1, p. 261-264.