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Relativistic solar cosmic rays in January 20, 2005 event on the ground based observations

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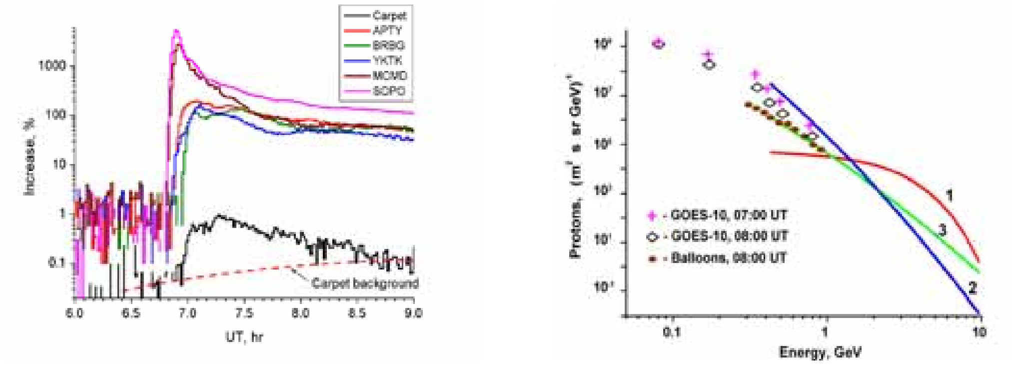
The characteristics of relativistic solar cosmic rays on data of ground level observations during the superevent 20.01.2005, second on power after the famous GLE 23.02.1956 have been studied. On the data of 32 neutron monitors of a worldwide network including the new opened stations Barentsburg (N 78.08 E 14.12) on Spitsbergen and Baksan (N 43.28, E 42.69) at Baksan Neutrino Observatory (BNO), North Caucasus, Russia were used in the analysis. In this work also were used the data of EAS arrays in BNO. By a least square (optimization) methods parameters of a relativistic solar protons: rigidity (energetic) spectra, anisotropy directions and pitch-angular distributions were obtained and their dynamics studied during the event.

1. Introduction

The super GLE 69 20 January 2005 was the greatest event since 23 February, 1956. The parent solar flare 2B/X7.1 has heliocoordinates N14 W61. The type II radio onset was reported at 06.44 UT. The GLE was extremely anisotropic as observed by the ground based cosmic ray detectors. The worldwide neutron monitor (NM) network may be considered as a united multidirectional solar proton spectrometer in the relativistic energy domain. With the modeling of the ground based detectors responses to an anisotropic solar proton flux and comparing them with observations the parameters of primary solar protons outside the magnetosphere by a least square technique (optimization) can be obtained and their dynamics studied (e.g., [1]). In this study for the first time the data of EAS arrays Carpet (200 m^2, 1700 m a.s.l.) and Andyrchi (37 m^2, 2050 m a.s.l.), as well as the Baksan Muon Detector (190 m^2) in BNO, North Caucasus were used. These instruments have the better, than standard neutron monitors, sensitivity to solar cosmic rays at geomagnetic cutoff ~ 6 GV [2].

2. Ground based observations and modeling results

With the modeling of the NM responses to an anisotropic solar proton flux and comparing those with observations the parameters of primary solar protons can be derived by a least square technique [1-3]. So the parameters of modified power rigidity spectrum with variable slope $J_{||}(R) = J_0 R^{-\gamma^*}$, $\gamma^* = \gamma + \Delta\gamma\cdot(R\text{-}1)$ where J_0 is a normalization constant, γ is a power-law spectral exponent at R = 1 GV, $\Delta\gamma$ is a rate of γ increase per 1 GV. The other parameters are the coordinates Φ and Λ, defining anisotropy axis direction in the GSE system; and a parameter C, characterizing the pitch-angle distribution (PAD) in form of a Gaussian: $F(\theta(R)) \sim exp(-\theta^2/C)$. So, 6 parameters are to be determined: J_0, γ, $\Delta\gamma$, C, Λ, Φ [1]. As the GLE of 20.01.2005 was very complicated we had to use a model with two completely independent particle fluxes, accordingly, the number of parameters in this model grows up to 12. In Table1 the parameters of these two fluxes are presented for 3 moments of time: from 7.00 to 7.30 UT. After this time anisotropy has dropped and than a unidirectional flux model was validated. Figure 1a shows increase profiles as registered by a number of neutron monitor stations and the EAS array "Carpet". The increase at McMurdo was of order 3000 % that exceeded 30 times the appropriate effect on the NM Apatity, which, in its turn was significant (>100 %).



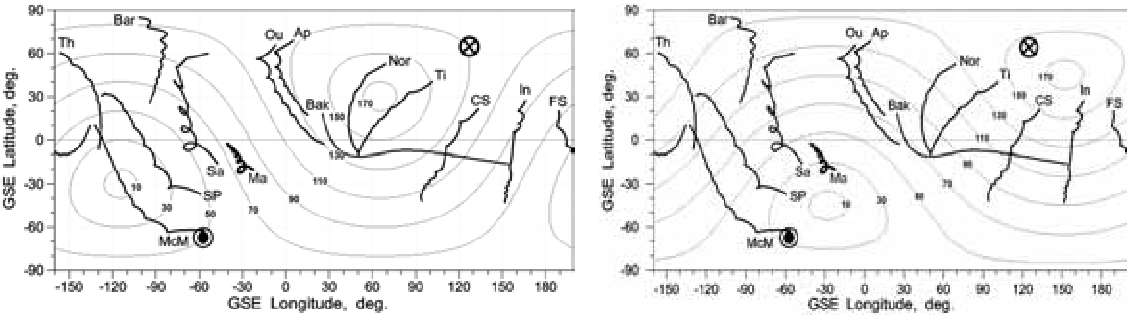
a b

Figure 1. **a:** increase profiles of ground based detectors: neutron monitors: Apatity (Ap), Barentsburg (BRBG), Yakutsk (YKTK), McMurdo (MCMD), South Pole (SOPO), EAS array Carpet. **b:** derived energy spectra of RSP: 1-:7.00 UT:Flux 1, 2- 7.00 UT, Flux 2,. 3- 8.00 UT. Points are direct solar proton data of GOES-10 (crosses and open rhombs) and balloons (blacked rhombs).

Figure1b shows the derived from ground based observations energy spectra of RSP recalculated from rigidity ones (Table 1) for 2 moments of time. The spectra 1 and 2 correspond to Flux 1 and Flux 2, 7.00 UT, when strong anisotropy and intensity maximum at South Pole and McMurdo were observed. Spectrum 3 is derived for 8.00 UT, in a period after intensity maximum with weak anisotropy. The spectra of two fluxes for 7.00 UT strongly differ. The spectrum (1) flattens at its low energy side and, as can be shown [3], has exponential dependence on energy. The spectrum (2) has a power-law form and an extension with the same slope into the region of moderate energies (tens-hundreds MeV) as direct solar proton data show. In Figure 1 b also the data of direct solar protons measured by GOES-10 spacecraft and balloons launched in Apatity (joint Lebedev Physical Institute and Polar Geophysical Institute balloon experiment [4]) are shown, for details see [5]. It is notable that spectrum (1) is cut from low energy end and has no extension to low energies The spectrum 3 (8.00 UT) has a power law form and may be extended into the moderate energy region.

Table 1. Derived parameters of relativistic solar protons: model of two independent fluxes

		Flux I						Flux 2					
No	Time	γ1	Δγ1	C1	Θ deg	Φ1 deg	J1	γ2	Δγ2	C2	θ2 deg	Φ2 deg	J2
1	07:00	-0.20	0.43	0.20	-26	118	3.5 10^4	9.0	0	1.2	-45	-28	2.3 10^7
2	07:10	-0.66	3.6	0.10	-24	117	7.4 10^3	-7.6	0	1.3	-67	-20	2.0 10^7
3	07:30	-4.40	1.9	0.16	17	-77	1.1 10^6	-7.6	0	25.	-7	0	5.1 10^6
4	08:00	-6.1	0	14.7	-35	9	9.8 10^5	-	-	-	-	-	-



a **b**

Figure 2. The symmetry axes and pitch angle grid lines for two solar proton fluxes (Table 1): **a,** Flux 1 caused impulsive giant increase at South Pole and McMurdo stations. **b,** Flux 2 responsible for increase at majority other NM stations. IMF direction is indicated by rounded cross and dot. The asymptotic cones (1-20 GV), the title is at 20 GV end, are shown for next NM stations: Th-Thule, Bar-Barentsburg, McM-McMurdo, SP-South Pole, Sa-SANAE, Ma-Mawson, Ou-Oulu, Ap-Apatity, Bak-Baksan, Nor-Norilsk, Ti-Tixie, CS-Cape Shmidt, In-Inuvik, FS-Fort Smith.

Figure2 shows asymptotic directions map for 7.00 UT with anisotropy axes and corresponding pitch angle grids for Flux1 (a) and Flux2 (b) in accordance with Table 1. The symmetry axes of Flux1 pass through asymptotic cones of South Pole and Mc Murdo stations registered the maximal increase. The Flux 1 was extremely anisotropic as the stations with asymptotic cones being out of 30^0 limits: Thule, Fort Smith, SANAE, Barentsburg, did not respond it (Figure 2 a). The Flux 2 (Table 1) with a steep and power law spectrum had the PAD wider, than Flux 1 and caused an increase effect on majority neutron monitor stations during the anisotropy phase (up to 7.30 UT). It should be noted the large deviation (60^0) of the symmetry axis of Flux 1 from IMF direction. The symmetry axis of Flux 2 is more aligned with the IMF, and did not change notable its direction after 07.30 UT, when the Flux 1 has disappeared.

3. Discussion.

As observational data and modeling study show the GLE 20 January, 2003 was formed by two fluxes of relativistic solar protons (RSP) with different characteristics. The shortlived and extremely anisotropic Flux 1 with very hard, exponential energetic spectrum caused the giant impulselike increase at two southern polar stations South Pole and Mc Murdo. We note also the marked deviation of Flux 1 from the estimated IMF direction. The Flux 2 had the energetic spectrum of power law form that could be extended into the moderate energy region covered by direct solar proton measurements on balloons and spacecrafts. The flux 2 had rather wide pitch angle distribution so it was responsible for increase effect on a majority NM stations. The increase onset at these stations delayed relative to the South Pole and Mc Murdo on average for 10-15 min. As one can see the properties of fluxes 1 and 2 as a whole correspond to the prompt and delayed components of relativistic solar protons [5, 6]. According to proposed scenario [6] the prompt component (PC) of RSP is produced during initial energy release in a low-coronal magnetic null point. This process is linked with the H-alpha eruption, onset of CME and type II radio emission [7]. The particles of PC presumably accelerated in impulsive process of magnetic reconnection have exponential energetic spectrum and leave the corona along open field lines with diverging geometry that results in strong focusing of a bunch. Particles of DC originally are trapped in magnetic arches in the low corona and accelerated by a stochastic mechanism at the MHD turbulence in expanding flare plasma. Accelerated particles of DC can be then carried out to the outer corona by an expanding CME. They are released into interplanetary space after the magnetic trap is destroyed giving rise to the source of accelerated particles that is extended in time and azimuth. What about the deviation of PC particle flux from IMF direction (Figure2a) it may be related with IMF irregularities observed in Phi component from about 8.30 to 10.20 UT (Figure 3) indicating the sharp kinks on the IMF line which were on the way of collimated particle Flux 1 directly in front of Earth. The curvature radii of these kinks are of order of 10^6 km that in its turn is of order of larmor radii of relativistic protons in the 5 nT field. As our trajectory calculations show the collimated particle beam is strongly deviates at such IMF kink. On the contrary, the particles with large pitch angles are scattered a little on the kink and pass through it keeping the direction of movement along the magnetic field. Similar situation was observed in GLE 28.10.2003 [6].

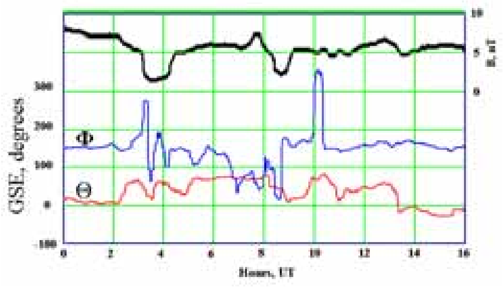


Figure 3. IMF components: |B|, Phi, Theta (GSE) variations on 5 min data of ACE spacecraft over a period before and after the onset of the 20 January, 2005 GLE. Note the strong variations in Phi indicating the kinks in IMF at distances 2-6x10^6 km ahead of the Earth during GLE onset.

4. Conclusions

Relativistic solar cosmic rays responsible for the GLE 20 January, 2005 were presented by two components: prompt and delayed ones. The prompt component (PC) was very shortlived and extremely anisotropic. It had exponential energetic spectrum and caused the giant impulselike increase effect at Antarctic NM stations South Pole and McMurdo. The arrival direction of PC was markedly declined from the IMF direction. Possible cause of this effect could be scattering of narrow particle beam on the sharp kinks of IMF existing in front of the Earth during GLE onset. The delayed component had the power law energetic spectrum and wider pitch-angle distribution. It was responsible for increase effect at most NM stations of the worldwide network. The PC has disappeared about 7.30 UT. After that time in the RSP flux was dominated the delayed component.

5. Acknowledgements

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