A Search for the 200 GeV Muon Intensity Bursts during Powerful Solar Flares of 23rd Solar Cycle

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Abstract

In 21st and 22nd cycles of solar activity the Baksan Underground Scintillation Telescope (BUST) registered three short-term bursts of muon intensity in correlation with the Ground Level Enhancements (GLE). Now the BUST data were analyzed during 10 GLE, which were recorded in current 23rd cycle. Similar analysis realized now for the large X-ray flares and for Solar Proton Events (SPE). Analogous muon bursts were found also in these cases.

1. Introduction

In current 23rd cycle of solar activity the study of the short-term muon bursts on the BUST has been continued during powerful solar flares. Three significant bursts correlating with GLE have been found on the BUST during 21-22 cycles [1, 2]. The 200 GeV muon bursts are caused by primary protons with energy >500 GeV. Those researches were stimulated by first reliable registration of Solar Cosmic Rays (SCR) on the Baksan shower array Carpet during GLE on Sep.29, 1989 [3, 4]. In the current cycle, which has begun in 1996, a number of powerful flares were observed. In 10 of them the world-wide network of standard neutron monitors and muon telescopes has fixed GLE. Increases of SCR have been also recorded on several shower arrays: Baksan (Andyrchy and Carpet) – in all 6 GLE [5], MILAGRITO – Nov.6, 1997 [6] and GRAND – Apr.15, 2001 [7]. Threshold energy of all those detectors is less, than on the BUST in 10 times and more. All GLE events and also 44 solar X-ray flares of X class and 38 SPE have been investigated on the BUST in current cycle.

2. Baksan Underground Scintillation Telescope

The BUST is located in a point with geographical coordinates 43.28°N and 42.69°E, at height of 1700 m a.s.l., in rocky excavation. Effective thickness of a ground above BUST makes 850 m w.e. The telescope is a parallelepiped in size 17×17×11 m^3. All its sides are continuously covered with standard detectors in size 70×70×30 cm^3, which filled with liquid scintillator. Inside the telescope two horizontal layers of detectors are located with an interval on height of 3.6

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m. Cellular structure of the BUST allows to restore trajectories of muons. The angular resolution on the average makes 2°. Counting rate of the single muons with length of a trajectory not less than 7 m is 7.5 s^{-1}.

3. A Search for Muon Bursts during GLE Events of 23rd Cycle

The method of the muon bursts search on the BUST during solar flares has been developed at analysis GLE on Sep.29, 1989 [1]. Then it used for the analysis of other GLE of 21-22 cycles [2]. By the same technique have been analyzed 10 GLE of current cycle. A search for possible signal is made by 15-min data of the BUST during 3-hour interval (1h before maximum of X-ray flare and 2h after it). Thus 680 angular cells in size 10°×15° on zenith and azimuth are used. Cells are overlapped, that there was no loss of a possible signal on border between them. One maximal burst in each GLE was took out of all increases above a background. These bursts are considered, as possible increases of the SCR.

In a new cycle it is not found the events comparable on amplitude with greatest muon burst fixed on the BUST on Sep.29, 1989. The burst of Apr.18, 2001 is the greatest in current cycle. On amplitude it is comparable with bursts of Oct.12, 1981 and of Jun.15, 1991 which are the following on the importance after Sep.29, 1989. The others muon bursts of 23rd cycle have the smaller importance and are comparable to small bursts of previous cycles. Some part of them can be background fluctuations. Distribution of bursts within observation interval has kept the asymmetry. Delay of bursts prevails: at the first 1.5h are fixed 2 bursts, and in the following 1.5h – 8 bursts. Spatial distribution of bursts in 23rd cycle is more uniform, than earlier. The expressed spatial structure is not observed.

4. Muon Bursts during X-ray Flares

The most energetic particles are generated on the Sun during powerful flares. But only in a small number of cases they reach the Earth [8]. The path of protons with energy >500 GeV and 1-15 GeV can strongly differ. The first of them can reach the Earth even at ”adverse” position of a source on solar disk. Protons of lower energy would not reach ground level (GLE is absent) and would not be registered on satellites (there is no SPE). Therefore search for the muon bursts was made also during X-ray flares of X class. Three significant muon bursts in previous cycles are found in GLE which were connected with the same flares.

The method of research was changed, because other class of solar events is considered and additional opportunities have appeared after modernization of registration system of the BUST. Within 3 hours during flare (1h before a flare maximum and 2h after) were looked through 520 overlapped cells with radii of 5, 10, 15, 22.5, 30 and 45 degrees. Average counting rate λ of each cell was calculated beforehand on the day previous to flare. During flare the real count n

was defined for each cell in each 15-minute interval. Then the probability to find such or the greater quantity of muons was calculated:

$$p(\geq n) = 1 - \sum_{k=0}^{n-1} p(k, \lambda), \tag{1}$$

where $p(k, \lambda)$ is Poisson probability to find count k in a cell with the average counting rate λ. All events are summarized in distribution on probability $p(\geq n)$. The same distribution was received for the control 3-hour interval shifted equally for day after flare.

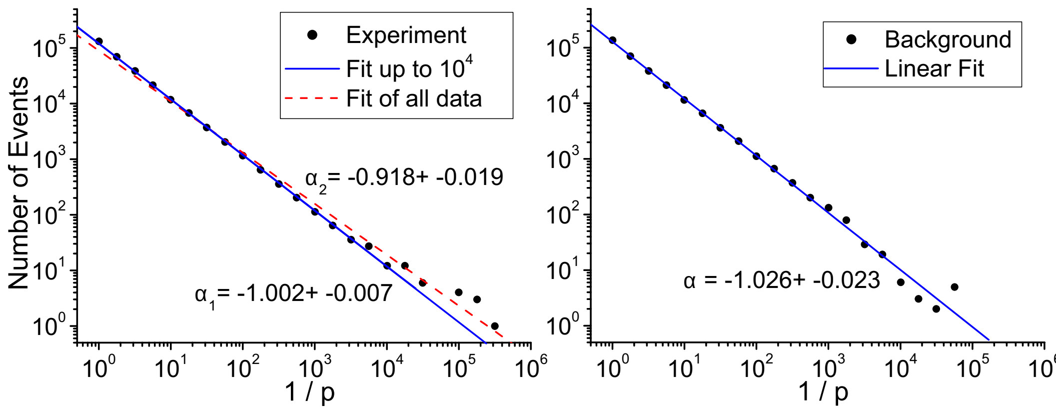

Fig. 1. The probability distributions of events during X-ray flares and during background control intervals.

Total distributions for 44 flares of X class since Jun.2000 till Dec.2002 are submitted on fig.1. On the left panel the distribution for 3 hours during flares is shown, and on right – for control intervals. In double logarithmic scale the dependence of number of events from value $1/p$ for pure Poisson background should be described by a direct line with inclination equal -1. For control intervals there is a fine agreement of experiment with the Poisson. Appreciable surplus of bursts with big amplitude is observed during flares. 8 events have probability $<10^{-5}$. In control intervals there are no events with probability $<1.8{\cdot}10^{-5}$. Up to a point $1/p = 10^4$ distribution of events during flares is perfectly described by direct line with an inclination $\alpha_1 = -1$ (a solid line). After this point the surplus number of events is observed. At approximation by direct line (dash) of all points the inclination factor equals $\alpha_2 = -0.92 \pm 0.02$, that on 4σ differs from expected one. From 8 events having probability $<10^{-5}$ only one or two would be possible to explain by fluctuations of a background, but not all 8. These bursts on importance and properties are similar to three significant increases which have been found during GLE events of previous cycles. 7 bursts are fixed with delay at 0.5-1 hour after maximum of flare. Also 7 events are registered from a hemisphere looks towards the interplanetary magnetic field (interval of ecliptic longitudes from 45° to the East from the Sun up to 135° to the West).

The similar analysis has been carried out for the same calendar period for 38 SPE (including 6 GLE) with the importance >10 Particle Flux Units ($E_p > 10$ MeV). In the SPE events are found only 4 big bursts ($p < 10^{-5}$). Bursts of such importance are absent in control intervals. The inclination of a direct line $\alpha = -0.97 \pm 0.02$ not so strongly differs from -1, as in case of X-ray flares. But the number of bursts is not enough, that it would be possible to draw the certain conclusions on the reasons of difference of these two classes of events.

5. Conclusions

The results received at the analysis of the BUST data during GLE of 23rd cycle do not contradict information of the previous cycles of solar activity. The number of investigated events has increased now from 18 up to 28 GLE. The burst of Apr.18, 2001 is the greatest in the current cycle. On amplitude it is comparable with bursts of Oct.12, 1981 and of Jun.15, 1991 which are the following on the importance after the greatest event on Sep.29, 1989.

The unexpected result is received at the analysis of the BUST data during X-ray flares. It is revealed 8 muon bursts correlating with flares. They can not be explained by background fluctuations. On magnitude they are comparable to three muon bursts of 21-22 cycles and with burst of Apr.18, 2001. Their spatial and time properties also are similar. In SPE events the number of similar muon bursts is some less. For accurate definition of the bursts properties and for clarification of their nature it is necessary to increase statistics of events. So it is supposed to realize the retrospective analysis of the BUST data for 1981-2000.

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6. References

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