Quick search for optical partners of bursts of very high energy gamma-ray radiation

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Abstract Quick search for optical partners of bursts of gamma radiation of high and ultrahigh energy range are conducted using the facilities of the Baksan Neutrino Observatory (BNO) of the INR RAS and a complex of astronomical telescopes at peak Terskol Observatory of the Institute of Astronomy of RAS. The bursts of cosmic ray intensity and cosmic gamma radiation are detected at the complex of BNO facilities. The search and subsequent study of optical flares associated with the detected BNO events are carried out with a complex of astronomical telescopes at the peak Terskol. To search by external target designations (from BNO installations, the GCN network, etc.) of transient phenomena in the optical range a universal program for managing a complex of astronomical telescopes was developed and created. The current state and preliminary results of the experiment are discussed.

Keywords: Gamma Radiation, Bursts, Optical Flares, Multimessenger Astronomy

1. Introduction

Currently, the methods of multimessenger astronomy are widely used in the study of astrophysical objects that emit a large amount of energy in a wide range of electromagnetic radiation spectrum. Our experiment is aimed at obtaining new experimental data on astrophysical objects generating bursts of cosmic gamma radiation of high energy together with optical flashes. Such bursts of radiation can be generated by processes in the nuclei of galaxies, by the interaction of astrophysical objects, at the last stage of the evolution of stars, including supernova bursts.

The search for bursts of cosmic ray intensity and cosmic gamma radiation is carried out by the method of a search for spatiotemporal concentrations (clusters) of showers recorded by EAS array. Previously this method was widely used to search for very high energy gamma radiation from cosmic gamma-ray bursts (CGRB) and from evaporating primordial black holes (PBH) at EAS arrays and underground telescopes [1 – 5].

2. The finding of shower clusters.

The algorithm for finding cluster of the showers is as follows: for each shower **i** having absolute time t_i and coordinates in the Equatorial system $(\alpha, \delta)_i$ there was a chain of events **i, i+1, i+2,. . . , i+N -1** such that the directions of the shower arrival differ by less than the a_r value from the weighted average direction. Thus, each cluster is characterized by multiplicity **k**, duration **Δt**, absolute time and coordinates of its center **(α, δ)**. Because the search is carried out within some interval **ΔT** (from 1 ms to 900 s), then **Δt ≤ ΔT**. This algorithm was used previously for searching of bursts with BNO facilities (Baksan Underground Scintillation Telescope – BUST, EAS arrays “Carpet-2” and “Andyrchy”). The problem is that the experimentally measured frequencies of cluster registration of different multiplicity are in agreement (within one standard deviation) with the frequencies expected from the background of random coincidences (i.e., background fluctuations of cosmic rays). Therefore to use as an alert to search for transient phenomena in the optical range the additional background suppression is needed. For additional selection of clusters the average angular distance of showers from the center of the cluster (a_{aver} parameter) is used. In Fig. 1 an example of a modeled cluster with **k = 6** from point source is shown. The true center of the cluster (the position of a point source) is placed at the origin of coordinates. The distances of showers (**a**) from true center are distributed in according to Rayleigh distribution. The restored center of cluster is at the distance a_c from true center and a_i is the distance from the restored center to the i-th shower. The average angle distance of showers from the cluster center is defined as:

$$a_{aver} = \frac{1}{k}\sum_{i=1}^{k} a_i \qquad (1)$$

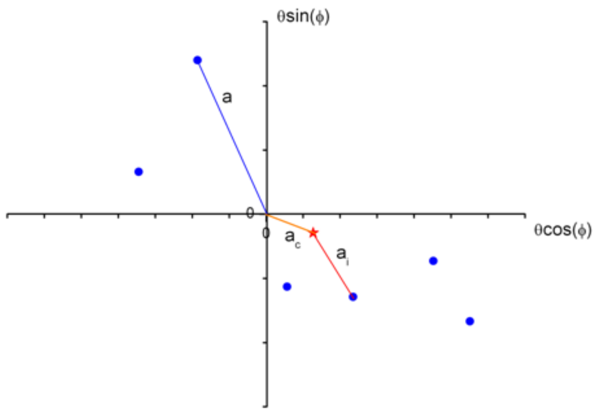

***Fig1**. An example of a modeled cluster with k = 6.*

The distributions of clusters with different multiplicities from point sources by a_{aver} parameter have been obtained by simulations. These distributions are notably dependent on cluster multiplicity. Comparisons of distributions of modeled and experimentally registered clusters are shown in Figures 2 – 4.

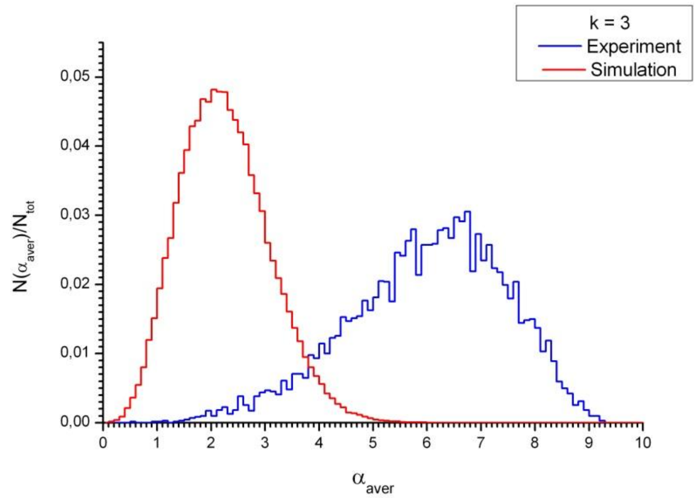

Fig2*. Distributions of modeled and experimentally registered clusters with k = 3 by the a_{aver} parameter for the EAS array "Carpet-2".*

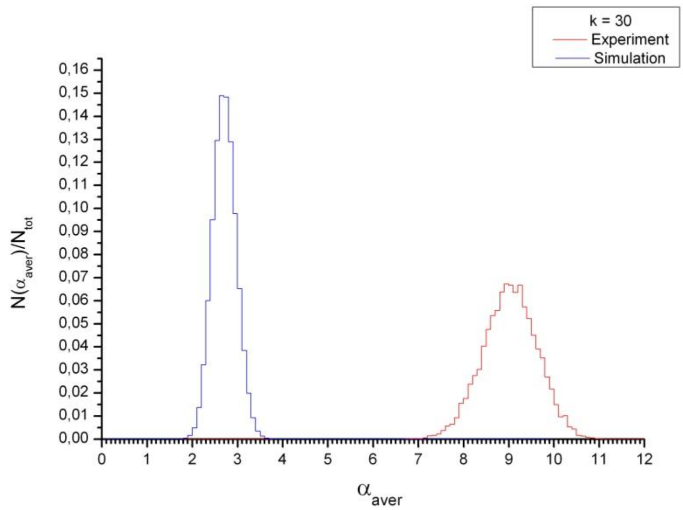

Fig3*. Distributions of modeled and experimentally registered clusters with k = 30 by the a_{aver} parameter for the EAS array "Carpet-2".*

It is obvious that using of $\mathbf{a_{aver}}$ parameter allows entirely separating clusters of large multiplicities from point sources and from background fluctuations of cosmic rays. It should be noted that multiplicity distribution of experimentally registered clusters depends on $\mathbf{\Delta T}$. Multiplicity distributions of clusters registered at BUST during 953.8 days of data taking are shown in Fig. 5 for a number of $\mathbf{\Delta T}$ values.

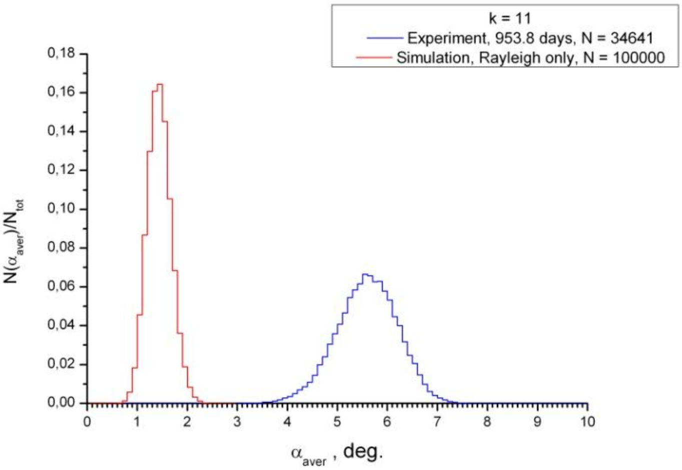

***Fig4**. Distributions of modeled and experimentally registered clusters with k = 11 by the a_{aver} parameter for BUST.*

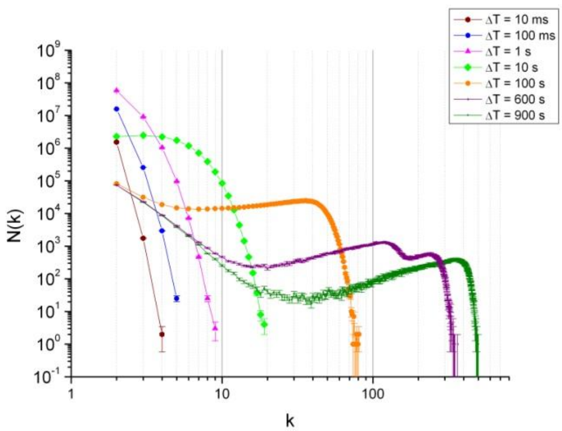

***Fig5**. Multiplicity distributions of clusters experimentally registered at the BUST.*

3. Search for clusters of showers in the near-real-time mode

Primary experimental data of BNO installations are accumulated in the memory of an on-line computer of the registration system of each facility for a fixed time, which is 15 minutes (20 minutes for the "old" registration system of the "Carpet-2" installation), and then recorded to the hard disk of a file-server. After data recording the information is processed at dedicated workstations and for each of registered showers the direction of arrival in the horizontal coordinate system (zenith and azimuth angles) is obtained. After that the search for clusters of showers is conducted using the method described above. At first the selection of clusters as alerts for astronomical telescopes is carried out using the condition $\boldsymbol{\alpha_{aver} \leq \alpha_b(k)}$. The $\boldsymbol{\alpha_b(k)}$ values are chosen thus that within $\boldsymbol{\alpha_b(k)}$ is placed 99% of events with relatively low multiplicity (k < 10), for which there is no complete separation of simulated and recorded events. For clusters with complete separation of the simulated and experimentally recorded events (large multiplicity clusters) all clusters from the point sources are inside $\boldsymbol{\alpha_b(k)}$. To use clusters of small multiplicity as alerts for searching for transient phenomena in the optical range, an additional selection is made for duration of clusters (depending on their multiplicity) so that the frequency of alerts from the "Carpet-2" and BUST installations is ~ 1 per day. Alerts information (coordinates, time, etc.) is recorded to a data collection server in BNO.

Access to these data is realized by means of two communications paths. The first one unites the local networks of the BNO and the observatory at the Terskol peak through a radio channel based on three CiscoAironet 1410 modules at a distance of about 20 km. One module operates at Cheget peak in the access point mode. Two others modules operate in bridge mode at the "Andyrchy" EAS array and at the Terskol peak. The module operated at the "Andyrchy" EAS array is connected with BNO laboratory building by an optical cable. Second one is routing through the Internet with a fixed IP address. Both communications paths allow us to connect with dedicated server via HTTP and FTP, and over the local network using the SMB protocol. The communications paths and the dedicated server are protected from the extraneous access.

4. Search for optical partners of clusters of showers

Search for transient phenomena in the optical range by target designations from BNO facilities will be carried out with a telescope complex at the Terskol peak, including the automatic telescope "Meade 14" f / 10 LX200. A universal program for controlling the complex of astronomical telescopes has been developed and created for this.

The search for optical transients on alerts from BNO facilities have been conducted in test mode using the Officina Stelare RH-200 wide-angle (with a field of view of 3.5 degrees) robotic telescope installed at the Zvenigorod Observatory of INASAN. As an example for one of alerts from EAS array "Carpet-2" 61 images were taken. The coordinates of the frame center are approximately R.A. = 08h45m и Decl. = +70º10'. The overlap of images is presented in Fig. 6. There is some shift of the frame center due to errors of telescope driving at high declinations. The detailed analysis of this frame gives 55 galaxies, 67 radio source, 7 infrared and 7 X-ray sources. No optical transients were discovered in this event.

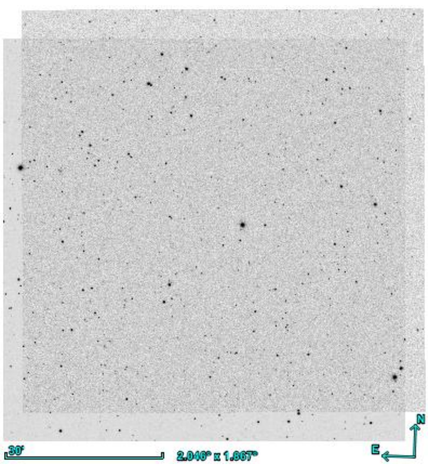

***Fig6**. The overlap of images obtained by the Officina Stelare RH-200 wide-angle telescope on "Carpet-2" alert.*

5. Conclusion

The experiment under development is aimed at obtaining new experimental data on astrophysical objects generating bursts of ultrahigh-energy cosmic gamma radiation in conjunction with optical flashes. At the moment the search for bursts of cosmic ray intensity and cosmic gamma radiation by means of detection of clusters of showers is implemented in the near-real-time mode. Because the experimentally measured frequencies of cluster registration of different multiplicity are in agreement with the frequencies expected from the background fluctuations of cosmic rays the new method of background suppression was developed. This method of background suppression allows us using selected clusters of showers as alerts to search for transient phenomena in the optical range.

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