Search for flashes of cosmic γ rays at energy $E_\gamma \geq 100$ MeV

A. I. Belyaevskiĭ, V. L. Bokov, V. K. Bocharkin, I. F. Bugakov, G. M. Gorodinskiĭ, Yu. G. Derevitskiĭ, E. M. Kruglov, G. A. Pyatigorskiĭ, and E. I. Chuĭkin

A. F. Ioffe Physico-technical Institute, USSR Academy of Sciences

(Submitted November 24, 1974; resubmitted May 26, 1975)
ZhETF Pis. Red. **21**, No. 12, 729–733 (June 20, 1975)

The upper limit of the frequency of appearance of flashes of cosmic γ rays at energy $E_\gamma \geq 100$ MeV was estimated from data on the distribution of the number of time intervals with specified number of photons, as registered by a γ telescope on the satellite "Cosmos–561." Averaged energy and temporal characteristics of the flash are presented.

PACS numbers: 92.50., 94.40.Q

The construction of γ telescope with acoustic spark chambers is described in[1]. It is important to note here that the monitor that develops the pulse that triggers the spark chambers consists of three detectors (D1, D2, and "4") connected in a coincidence circuit. The detector D1 picks out two singly-charged particles. The detector D2 is triggered by one singly-charged particle. The detector "4" is a Cerenkov total-absorption spectrometer of thickness 4.3 radiation length units, tuned to separate the energy $E_\gamma \geq 100$ MeV. Thus, the monitor operates under the following conditions: 1) A high-energy γ quantum is converted into an electron-positron pair in a radiator placed directly above D1. 2) The pair crosses D1. 3) The pair or one of its components crosses D2. 4) The pair or one of its components releases in "4" an energy higher than 100 MeV. The registration of the charged particles is excluded by a scintillation screen that surrounds D1 and the spark chambers.

After each operation, the spark chambers are blocked for a time $\Delta t = 33.55$ sec, called the blocking interval. The counters C_γ and C_2 count the number of γ quanta and the number of double coincidence during the blocking interval.

The γ telescope was launched on the orbit of the "Cosmos-561" satellite on 25 May 1973.[2] The satellite was oriented in flight in such a way that the axis of the γ telescope was always directed towards the zenith. The solid lines in Fig. 1 show, in an equatorial coordinate system (in the range $\delta = \pm 45°$) the trail of the telescope axis on the celestial sphere for the second and 114th revolutions, and also the galactic equator. The section of the sky observed by the instrument is bounded by the dashed lines parallel to the trajectory. It is broken up into eight commensurate regions, but not of equal area, labeled by the index $i = 1, 2, \ldots, 8$. The points on the galactic equator in regions 1 and 5 show the directions to the center and anti-center of the galaxy, respectively.

Owing to geomagnetic effects, the mean values of the readings of C_γ, within the limits of each region, vary significantly with time. To exclude the influence of the magnetic field, we used a reduction method proposed in[3]. According to this method, each of the eight regions is broken up into 20 zones with indices

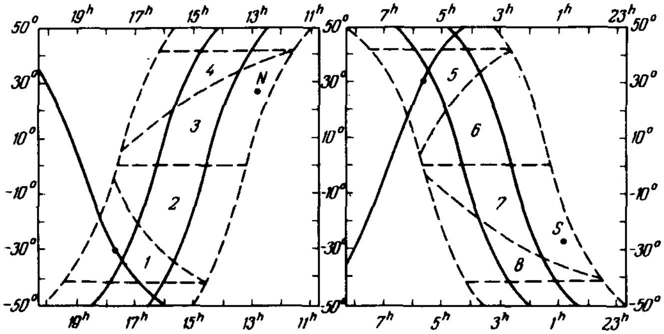

FIG. 1. Section of the sky scanned by the γ telescope in flight. N and S are respectively the northern and southern poles of the galaxy.

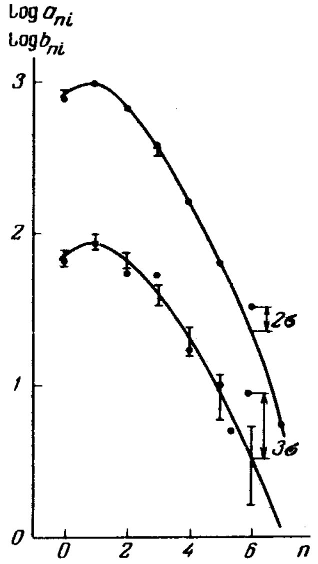

FIG. 2. Distribution density of the intervals for eight regions and for the fifth region (lower curve).

$j=1, 2, \ldots, 20$ in accordance with the gradations of the readings of the double-coincidence monitor C_2. At fixed i and j, the distribution density of C_γ in the absence of flashes should have a Poisson distribution, accurate to the statistical deviations,

$$a_{nij} = a_{ij} P_n(\lambda_{ij}), \qquad n = 0, 1, 2, \ldots, 7, \tag{1}$$

where a_{nij} is the calculated number of Δt intervals in which the readings of the counter C_γ are equal to n'; a_{ij} is the total number of intervals for the i-th region and the j-th zone; $P_n(\lambda_{ij}) = [(\lambda_{ij})^n/n!]\exp(-\lambda_{ij})$ is a Poisson distribution of the readings of C_γ, with a mean value λ_{ij}.

For each of the regions i, the distribution a_{ni} is obtained by summing (1) over the index j. Analogously, for the entire aggregate of values of C_γ over the eight regions, the distribution of a_n is obtained by summing (1) over the indices i and j. The experimental distributions for the regions i and for the entire aggregate were designated respectively b_{ni} and b_n.

If γ-ray flashes of high energy were registered during the time of telescope operation, then this should have been manifest in an increase of the values of "b" in comparison with "a" on the "tail" of the distribution, i. e.,

$$\begin{array}{l} b_{ni} > a_{ni} \\ b_n > a_n \end{array} \quad \text{for} \quad n = 6, 7$$

The solid curves of Fig. 2 show the calculated distribution densities of the intervals, constructed from the aggregate of the data of all eight regions (upper curve) and separately for the fifth region (lower curve). The points are the experimental values of b_n and b_{n5}. The "whiskers" correspond to one mean squared error σ. It is seen from Fig. 2 that at $n=6$ the experimental values exceed the calculated ones by two and three times σ, respectively, for the upper and lower curve. Excesses analogous to those of the fifth region were observed for the second and fourth region[1] (see Fig. 1). The observed spikes cannot be readily attributed to random fluctuations, since the probability of obtaining one deviation equal to 3σ is 0.0027.

Analysis of the operation of the setup and control experiments have shown that the appearance of the excess on the "tail" of the distribution can likewise not be attributed to systematic errors. It can therefore be assumed that during the course of the experiment we registered several flashes of γ rays with energy $E_\gamma \geqslant 100$ MeV. These γ-ray packets, corresponding to $n \geqslant 6$, might have arrived from remote astrophysical objects, although one cannot exclude fully the possibility of their generation in the shell of the satellite by jets of high-energy charged particles.

An estimate of the frequency at which the flashes appear, in accordance with the data of the table, yields for the aggregate of all the regions and upper bound $N_{\text{coin}} \leqslant 2.7 \times 10^{-4}$ flashes/sec-sr. The flash duration τ lies in the range $2 \times 10^{-5} < \tau < 33.55$ sec. The lower limit is set by the time constant at the input of the C_γ counter.

Assuming the number of quanta registered in the flash to be $n_\gamma = 4$, an effective γ-telescope area $S = 300$ cm^2, and a γ-ray registration efficiency ($E_\gamma \geqslant 100$ MeV) $\epsilon = 0.15$, we obtain $n_\gamma^0 \approx 0.1$ γ quanta and accordingly an energy $w = n_\gamma^0 E_\gamma \approx 10$ MeV $\approx 1.6 \times 10^{-5}$ erg per cm^2 and per flash. The lower estimates of the flash frequency and energy lead to the values $N_{\text{coin}} \sim 10^{-4}$ flash/sec-sr and $w = 3 \times 10^{-6}$ erg/cm^2-flash.

If we assume that the flashes in the fifth region originate in the Crab nebula ($R = 1700$ pc), then the upper limit of the flash energy in the source is $W_\gamma = 4\pi R^2 n_\gamma^\circ E_\gamma = 5 \times 10^{39}$ erg/flash, and the average energy radiated per unit time is $L_\gamma(> 100 \text{ MeV}) = W_\gamma \Delta a/t = 2 \times 10^{36}$ erg/sec, which is close in magnitude to the x-ray luminosity $L_x \approx 2.5 \times 10^{36}$ erg/sec of the pulsar NP0532.[5] The upper limit of the flux of γ rays with $E_\gamma \geqslant 100$ MeV from the flash of NP0532 is F_γ ($E_\gamma > 100$ MeV) $= n_\gamma \Delta a/S \epsilon t = 4 \times 10^{-5}$ cm^{-2}sec^{-1}.

By moving the flash source to the outside of the gal-galaxy, to a distance on the order of a megaparsec, we obtain for the upper limit of the energy $W_\gamma \sim 2 \times 10^{45}$ erg/flash.

---

[1] The estimate of σ was obtained by using Cochran's criterion.[4]

[1] A. I. Belyaevskiĭ, V. L. Bokov, V. K. Bocharkin, I. F. Bugakov, Yu. G. Derevitskiĭ, G. M. Gorodinskiĭ, E. M. Kruglov, G. A. Pyatigorskiĭ, and E. I. Chuĭkin, Izv. AN SSSR, ser. fiz. 38, 1838 (1974).

[2] Pravda, 26 May 1973.

[3] A. I. Belyaevskiĭ, V. L. Bokov, V. K. Bocharkin, I. F. Bugakov, Yu. G. Derevitskiĭ, G. M. Gorodinskiĭ, E. M. Kruglov, G. A. Pyatigorskiĭ, and E. I. Chuĭkin, Doklady Akad. Nauk SSSR **219**, 836 (1974) [Sov. Phys.-Doklady **19**, 805 (1975)].

[4] C. R. Rao, Nonlinear Statistical Methods and Their Applications (Russ. transl.), Nauka (1968), p. 344.

[5] J. D. Kurfess, Astrophys. J. 168, 39 (1971).