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Advanced GAMMA-400 γ-Ray Telescope for Recording Cosmic γ Rays with Energies up to 3 TeV

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Abstract—The results of calculation and measurements performed on prototypes of the calorimeter, time-of-flight, and coordinate systems of the advanced GAMMA-400 γ-ray telescope, designed for studying diffuse cosmic γ rays and search for γ-ray lines arising after annihilation of neutralinos (dark matter particles), are reported.

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The main purposes of the GAMMA-400 project [1–3] are to measure the spectrum of diffuse γ rays in the energy range of 30–3000 GeV (where direct measurements have not been performed) and search for γ-ray lines arising after annihilation of neutralinos (dark matter particles). The characteristics of the telescope under development are believed to solve these problems. However, research in this field has revealed additional possibilities for increasing the acceptance and resolution of this instrument. Modernization of the γ telescope improves its metrological characteristics, thus allowing to extend the energy range of recorded γ rays and search for high energy γ bursts.

1. MODERNIZATION OF THE GAMMA 400 TELESCOPE

When carrying out the studies aimed at referencing the telescope to the spacecraft, a possibility of increasing the area of the sampling calorimeter, which is the core of the telescope, were revealed. The number of modules of the calorimeter increases from 25 to 36 and its cross-sectional area reaches 660 × 660 mm^2 instead of 550 × 550 mm^2. The sampling ability of each module changes: the thickness of a lead sheet in an element (assembly of lead, polystyrene, and paper sheets) is 0.275 mm (0.05 rlu) instead of 0.55 mm (0.1 rlu). In addition, the number of elements increases to 400, which corresponds to 20 rlu. The investigations and calibrations [4] showed that these steps make it possible to increase the calorimeter energy resolution to 1.5%. In this case, the sizes of anticoincidence and control detectors in the GAMMA-400 γ-ray telescope (Fig. 1) change, and the telescope acceptance increases by a factor of 2. This circumstance makes it possible to improve the measurement statistics when detecting diffuse γ rays in the direction to the center of Galaxy and thus expand the energy range of recorded γ rays. The characteristics of the telescopes GAMMA-400 (before modernization) and GAMMA-400M (after modernization) are compared in the table, which contains also the main parameters of this instrument.

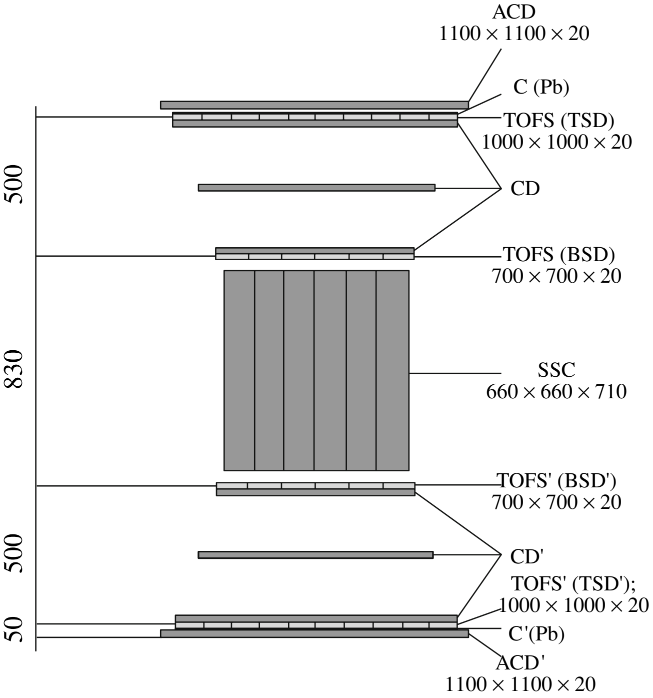

Fig. 1. Improved version of the telescope GAMMA-400: (ACD) anticoincidence scintillation detector, (C(Pb)) lead converter, (TOFS) time-of-flight system, (TSD) top scintillation detector of TOFS, (BSD) bottom scintillation detector of TOFS, (CD) coordinate detectors, and (SSC) scintillation sampling calorimeter (second set detectors are designated by primes).

Table

Parameter	GAMMA-400	GAMMA-400M
γ-ray telescope		
Energy range	30–1000 GeV	30–3000 GeV
Geometric factor	$0.92\ \mathrm{m}^2 \cdot \mathrm{sr}$	$1.96\ \mathrm{m}^2 \cdot \mathrm{sr}$
Angular resolution	1°–2°	1°–2°
Time resolution	0.6 ns	0.6 ns
Coordinate resolution	1–2 cm	1–2 cm
ACD area	$800 \times 800\ \mathrm{mm}^2$	$1100 \times 1100\ \mathrm{mm}^2$
TSD TOFS area	$800 \times 800\ \mathrm{mm}^2$	$1000 \times 1000\ \mathrm{mm}^2$
BSD TOFS area	$600 \times 600\ \mathrm{mm}^2$	$700 \times 700\ \mathrm{mm}^2$
Distance between TSD and BSD	500 mm	500 mm
Mass	1200 kg	1700 kg
Data downlink	500 Mb/day	500 Mb/day
Energy consumption	500 W	800 W
Lifetime	not less than 5 yr	not less than 5 yr
Estimated statistics of measuring diffuse γ rays toward the Galaxy center (time of observation 1 year, spectrum exponent $k = 2.6$)		
$E_\gamma > 1000$ GeV	38	81
$E_\gamma > 2000$ GeV	13	27
$E_\gamma > 3000$ GeV	7	14
Sampling calorimeter		
Calorimeter area	$550 \times 550\ \mathrm{mm}^2$	$660 \times 660\ \mathrm{mm}^2$
Calorimeter mass	615 kg	820 kg
Number of modules	25	36
Calorimeter thickness	18 rlu	20 rlu
Energy resolution ($E_\gamma = 1$ TeV)	2.5%	1.5%
Calorimeter module		
Module area	$110 \times 110\ \mathrm{mm}^2$	$110 \times 110\ \mathrm{mm}^2$
Module length	370 mm	700 mm
Module mass	17 kg	23 kg
Module thickness	18 rlu	20 rlu
Number of elements	180	400
Module element (lead + polystyrene + paper)		
Lead thickness	0.55 mm (0.1 rlu)	0.275 mm (0.05 rlu)
Polystyrene thickness	1.5 mm	1.5 mm

2. OPTIMIZATION OF THE SYSTEM FOR DETECTING BACKSPLASH EVENTS

In measurements of high-energy (above 30–50 GeV) γ-ray fluxes, the anticoincidence detector (ACD) may record with high probability albedo particles, which arise in the calorimeter when an electromagnetic shower (backsplash) passes through the latter. In this case, ACD generates the same blocking signal as for a primary charged particle. At energies above 100 GeV, the fraction of such events approaches 100%; i.e., in this energy range the instrument ceases to select γ rays from the flux of all (charged and neutral) particles.

To prevent blocking of the telescope by albedo particles, we have developed a method based on measuring the time interval between the response ACD and bottom scintillation detector (BSD) [5]. When a charged particle passes by, ACD is triggered with some advance with respect to BSD. When a primary γ photon is detected, BSD is first triggered by the conversion electron–positron pair, which propagates toward the calorimeter, while an albedo particle from the calorimeter, moving in the reverse direction, can be converted in ACD and imitate a charged particle. In the latter case, the ACD

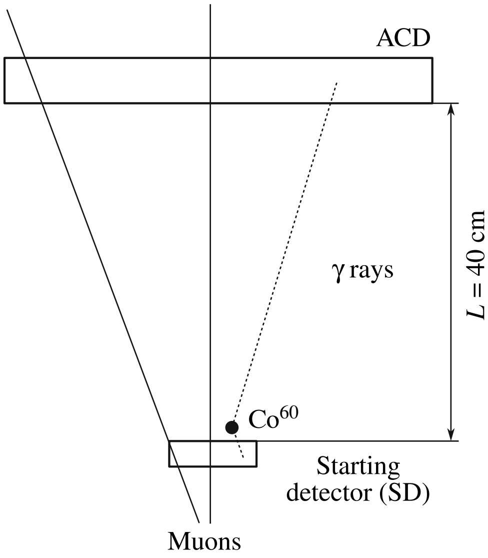

Fig. 2. Block diagram of the system for imitating albedo events.

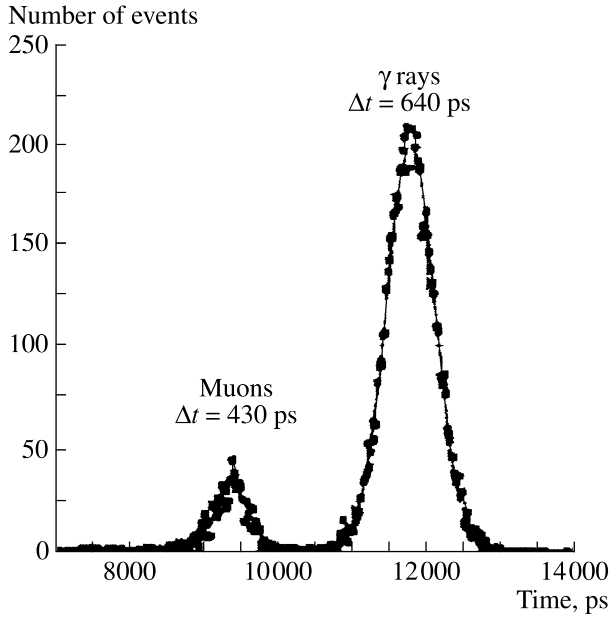

Fig. 3. Time spectra of muons and γ rays.

signal is delayed with respect to the ASD signal when passing a charged particle signal by the time $t = 2L/c$, where L is the distance between ACD and calorimeter and c is the speed of light.

The method proposed for selecting backsplash events was experimentally verified on a specially designed system (Fig. 2), which makes it possible to imitate the albedo effect [5]. To this end, a Co^{60} source is placed on the starting detector (SD) surface; the cobalt source decay yields two γ photons.The events in which one of the photons is converted in SD and the other is converted in ACD are considered as albedo ones, and the coincidences of the ACD and SD signals in the absence of Co^{60} in muon detection correspond to primary charged particles. The time between the SD and ACD responses was measured for each event and time spectra were plotted (Fig. 3). It can be seen that the events of these two types are separated well.

3. SUPPLEMENT OF THE RESEARCH PROGRAM

Since the space observatory GAMMA-400, which is under design now, has a large potential, it is expedient to consider the possibility of expanding its research program. A very interesting issue is γ bursts, which have been observed for 40 years in the range from several keV to several tens of MeV and whose mechanism is still unknown. Observations by the γ-ray telescope EGRET revealed γ rays with energies up to 18 GeV, which correlate with low-energy γ bursts [6]. In this context, the observatory GAMMA-400 can be used to search for correlations between a recorded γ burst and high-energy γ rays. To realize such studies on the space observatory, it can be supplemented with an instrument for recording γ bursts (of the Cone type), whose signal will serve as a trigger of the system of time analysis of pulses from the telescope GAMMA-400.

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REFERENCES

1. Ginzburg, V.L., Kurnosova, L.V., Razorenov, L.A., et al., *Preprint of Lebedev Phys. Inst.*, Moscow, 1995, no. 3, p. 54.
2. Ginzburg, V.L., Kaplin, V.A., Karakash, A.I., et al., *Izv. Ross. Akad. Nauk, Ser. Fiz.*, 2005, vol. 69, no. 3, p. 428.
3. Ginzburg, V.L., Kaplin, V.A., Karakash, A.I., et al., *Kosm. Issled.*, 2007, vol. 45, no. 5, p. 475.
4. Kharlov, Yu.V., et al., *Preprint of Inst. Phys. High Energ.*, Protvino, no. 2008-21.
5. Kaplin, V.A., Runtso, M.F., Topchiev, N.P., and Fradkin, M.I., in *Proc. of Science Session “MEPHI-2008,”* Moscow, 2008, vol. 9, p. 150.
6. Schneid, E.J., Bertsch, D.L., Fichtel, C.E., et al., *Astron. Astrophys.*, 1992, vol. 255, p. L13.