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Scientific Tasks and Present Status of the GAMMA-400 Project[1]

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Abstract—The GAMMA-400 telescope is designed to investigate discrete high-energy gamma-ray sources in the energy range of 0.1–3000 GeV, to measure the energy spectra of galactic and extragalactic diffuse gamma-ray emissions, and to study gamma-ray bursts and gamma-ray emissions from an active Sun. The gamma-ray telescope has an angular resolution of ~0.01°, an energy resolution of ~1%, and a proton rejection factor of ~10^6. Its special assignment is to measure fluxes of gamma rays, electrons, and positrons that could be associated with the annihilation or decay of dark matter particles.

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INTRODUCTION

Extraterrestrial observations of astrophysical objects in the high-energy gamma-ray range allow us to obtain extremely important information on the fundamental processes occurring both in discrete sources (pulsars, active galactic nuclei, blazars, and so on) and in intergalactic and interstellar space. The performing of extraterrestrial gamma-ray astronomical observations in the high-energy range is subject to the possibility of overcoming a variety of physical and technical difficulties connected with creating gamma-ray telescopes with high angular and energy resolutions and spacecraft that enable us to carry out these observations.

Several programs have been employed since the first extraterrestrial observations: ANNA-3 [1], SAS-II [2], COS-B [3], GAMMA-1 [4], EGRET [5], AGILE [6], and finally FERMI [7], the one now in use.

Note the following from the results of the first year of Fermi LAT observations in the energy range of 100 MeV–100 GeV:

(1) The number of discovered discrete gamma-ray sources has increased several times over in comparison with the EGRET data and now stands at ~1500 (a considerable number of sources have not been identified [8]).

(2) In the energy range of 100 GeV, there is no agreement with the measurement results from ground-based gamma-ray telescopes [9].

(3) The measured spectrum of diffuse gamma rays from the central part of the Milky Way galaxy does not coincide with the EGRET data [10].

(4) It was confirmed that a considerable number of discrete sources are variable in the gamma-ray range [11].

Fermi LAT also measured the total flux of electrons and positrons up to energies of a few hundred GeV [12]. A certain excess in the electron-positron flux was found that, using the results of the PAMELA experiment [13], was interpreted by some authors as a result of the annihilation or decay of dark matter particles.

For the successful development of gamma-ray astronomical observations, we must create gamma-ray telescopes of the next generation, which in comparison with Fermi LAT should be able to measure high-energy gamma rays in an energy range of at least several TeV with higher energy and angular resolutions, and should be more efficient in eliminating back-

[1] This article was translated by the authors.

Table 1. Main characteristics of the GAMMA-400 gamma-ray telescope

Energy range of gamma-ray detection	100 MeV–3000 GeV
Area of sensitivity, cm^2	6400
Sensitivity ($E_\gamma > 100$ MeV), photon/(cm^2 s)	2×10^{-9}
Angular resolution ($E_\gamma > 100$ GeV)	~0.01°
Energy resolution ($E_\gamma > 10$ GeV)	~1%
Calorimeter thickness	30.5 r.l.
Proton rejection factor	$\sim 10^6$
Accuracy of determining telescope attitude (according to stellar sensor)	0.005°
Downlink volume, Gbyte/day	100
Mass, kg	2600
Maximum dimensions, m^3	$2.0 \times 2.0 \times 3.0$
Power consumption, W	2000

ground events when measuring gamma rays and electrons and positrons.

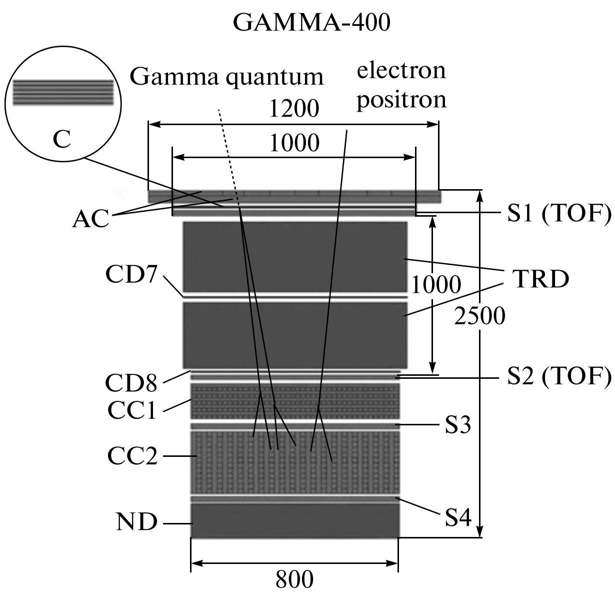

Fig. 1. Physical scheme of the GAMMA-400 gamma-ray telescope.

Anticoincidence scintillation detector (AC); converter (C) consisting of 6 tungsten layers with a thickness of 0.14 r.l. (C1–C6) interlaid with double-sided (x, y) Si strip coordinate detectors with a pitch of 0.1 mm (CD1–CD6); time-of-flight scintillation detectors (S1(TOF) and S2(TOF)); double-sided (x, y) Si strip coordinate detectors with a pitch of 0.1 mm (CD7–CD8); position-sensitive calorimeter (CC1) consisting of 10 layers of BGO $1 \times 2 \times 40$ cm^3 crystals interlaid with double-sided (x, y) Si strip coordinate detectors with a pitch of 0.5 mm; position-sensitive calorimeter (CC2) consisting only from BGO $2 \times 2 \times 40$ cm^3 crystals; scintillation detectors (S3 and S4); transition radiation detector (TRD); neutron detector (ND).

THE GAMMA-400 GAMMA-RAY TELESCOPE

To improve the telescope's angular resolution, we have increased the distance between the converter and calorimeter. We use Si strip coordinate detectors with small pitch to measure the conversion point of gamma quanta in the multilayer converter and the point of entry into the calorimeter, and to determine the spatial pattern of electron–photon showers in the first part of the calorimeter.

To extend the energy range and increase the accuracy of measuring the energy of high-energy gamma rays, electrons, and positrons, we use a thick (~30 r.l.) position-sensitive calorimeter of BGO crystals interlaid with silicon strip detectors, the total thickness of which along the axis of the telescope exceeds the distance to an electromagnetic shower's maximum of development by a factor of 2–3.

To suppress the background produced by the proton–nuclear component of cosmic rays and form the telescope triggering signal when gamma rays are detected, we use a segmented anticoincidence detector and additional signals from a backsplash system (using time–amplitude analysis to eliminate the particles generated in interactions with the calorimeter matter and moving backward from calorimeter to converter). During the ground processing and analysis of

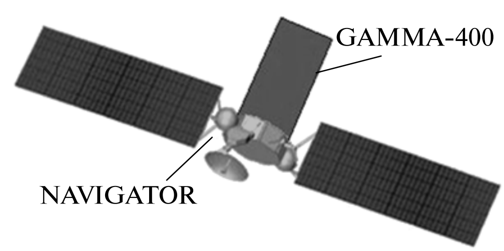

Fig. 2. The GAMMA-400 space observatory with the NAVIGATOR platform.

Table 2. Comparison of the main characteristics of the GAMMA-400 and Fermi LAT gamma-ray telescopes

	Fermi LAT	GAMMA-400
Orbit, km	560	500–300 000
Energy range of gamma-ray detection	0.1–100 GeV	0.1–3000 GeV
Area of sensitivity, m^2	1.6	0.64
Coordinate detectors	Si (x, y) strips with a pitch of 0.22 mm (converter and tracker)	Si (x, y) strips with a pitch of 0.1 mm (converter)
Angular resolution ($E_\gamma > 100$ GeV)	0.05°	~0.01°
Calorimeter	CsI	BGO + Si strips
– thickness, r.l.	8.5	30.5
Energy resolution ($E_\gamma > 10$ GeV)	10%	~1%
Proton rejection factor	10^4	$\sim 10^6$
Sensitivity ($E_\gamma > 100$ MeV), photon/($cm^2 \cdot s$)	$\sim 5 \times 10^{-9}$	$\sim 2 \times 10^{-9}$

recorded events, we also use readings from transition radiation and neutron detectors.

The main characteristics and physical scheme of the GAMMA-400 are presented in Table 1 and Fig. 1. Gamma rays pass through anticoincidence detector AC without interaction and are converted into electron–positron pairs in multilayer converter C (0.84 r.l.). Time-of-flight system TOF, consisting of detectors S1 and S2 separated by ~100 cm, determines the direction of a gamma quantum's arrival. Coordinate detectors CD7 and CD8 determine the points at which the electron-positron pair formed during gamma-ray conversion passes through them. The electron–positron pair then creates electromagnetic showers in two parts of position-sensitive calorimeters CC1 and CC2 (30.5 r.l. or 1.5 n.l.). Detectors S3 and S4 are installed to determine the number of particles escaping from CC1 and CC2. To separate gamma rays, electrons, and positrons from the background of cosmic-ray protons, we use transition radiation detector TRD; CC2, using the difference in longitudinal and transverse profiles of the electromagnetic and hadron showers; and neutron detector ND, using the number of neutrons produced in the calorimeter for electromagnetic and hadron showers. The total proton rejection factor is $\sim 10^6$. When measuring, we use the two main triggering systems in the gamma-ray telescope simultaneously: the first, in order to measure gamma rays (when there is no AC signal); the second, in order to measure electrons and positrons (when there is an AC signal).

A comparison of the main characteristics of the GAMMA-400 and Fermi LAT gamma-ray telescopes is presented in Table 2. It is seen that along with proton rejection, the GAMMA-400 has much better angular and energy resolutions.

THE GAMMA-400 SPACE OBSERVATORY

The GAMMA-400 space observatory (Fig. 2), in which the GAMMA-400 will be installed on the NAVIGATOR platform (designed at Lavochkin Research and Production Association), will be launched into space into a high elliptical orbit with the following initial parameters: apogee, 300 000 km; perigee, 500 km; inclination, 51.8°. The spacecraft's lifetime will be no fewer than 7 years. The observational time will be no less than 90%. We expect that three main observational modes will be employed: (1) celestial gamma-ray monitoring (searching for new discrete sources and monitoring known variable sources); (2) long-term continuous observation of the most interesting discrete sources; (3) automatic reorientation of observation by a signal from the KONUS device installed on the GAMMA-400 space observatory to detect gamma-ray bursts, and by a command from Earth associated with important information from other astronomical observations (e.g., information on solar activity).

Observations are scheduled to begin in 2016–2017.

REFERENCES

1. Volobuev, S.A., Gal'per, A.M., Kirillov-Ugryumov, V.G., et al., *Izv. Akad. Nauk SSSR, Ser. Fiz.*, 1970, vol. 34, no. 11, p. 2259.
2. Fichtel, C., et al., *Astrophys. J.*, 1975, vol. 198, p. 163.
3. Bignami, G., et al., *Space Sci. Instr.*, 1975, vol. 1, p. 245.
4. Akimov, V., et al., *Space Sci. Rev.*, 1988, vol. 49, p. 125.
5. Kanbach, G., et al., *Space Sci. Rev.*, 1988, vol. 49, p. 69.
6. Tavani, M., et al., *Nucl. Instrum. Methods A*, 2008, vol. 588, p. 52.
7. Atwood, W.B., et al., *Astrophys. J.*, 2009, vol. 697, p. 1071.
8. Abdo, A.A., et al., *Astrophys. J. Suppl.*, 2010, vol. 188, p. 405.
9. Abdo, A.A., et al., *Astrophys. J.,* 2009, vol. 707, p. 1310.
10. Tibaldo, L., et al., *Proc. Workshop SciNeGHe 2009/Gamma–Ray Physics in the LHC Era*, Assisi, Oct. 7–9 2009.
11. Gal'per, A.M., Kirillov-Ugryumov, V.G., and Luchkov, B.I., *Usp. Fiz. Nauk*, 1974, vol. 112, no. 3, p. 491.
12. Di Bernardo, G., et al., *Proc. 2009 Fermi Symp.*, Washington, Nov. 2–5 2009.
13. Adriani, O., et al., *Nature*, 2009, vol. 458, p. 607.