ISSN 1062-8738, Bulletin of the Russian Academy of Sciences. Physics, 2015, Vol. 79, No. 3, pp. 417–420. © Allerton Press, Inc., 2015.
Original Russian Text © N.P. Topchiev, A.M. Galper, V. Bonvicini, O. Adriani, R.L. Aptekar, I.V. Arkhangelskaja, A.I. Arkhangelskiy, L. Bergstrom, E. Berti, G. Bigongiari, S.G. Bobkov, E.A. Bogomolov, M. Boezio, M. Bongi, S. Bonechi, S. Bottai, K.A. Boyarchuk, A. Vacchi, E. Vannuccini, G.I. Vasilyev, G. Castellini, P.W. Cattaneo, P. Cumani, G.L. Dedenko, V.A. Dogiel, C. De Donato, B.I. Hnatyk, M.S. Gorbunov, Yu.V. Gusakov, N. Zampa, V.G. Zverev, V.N. Zirakashvili, V.V. Kadilin, V.A. Kaplin, A.A. Kaplun, V.E. Korepanov, J. Larsson, A.A. Leonov, V.A. Loginov, F. Longo, P. Maestro, P.S. Marrocchesi, V.V. Mikhailov, E. Mocchiutti, A.A. Moiseev, N. Mori, I.V. Moskalenko, P.Yu. Naumov, P. Papini, P. Picozza, M. Pearce, A.V. Popov, F. Ryde, A. Rappoldi, S. Ricciarini, M.F. Runtso, O.V. Serdin, R. Sparvoli, P. Spillantini, S.I. Suchkov, M. Tavani, A.A. Taraskin, A. Tiberio, E.M. Tyurin, M.V. Ulanov, Ch. Fuglesang, M.D. Kheymits, Yu.T. Yurkin, 2015, published in Izvestiya Rossiiskoi Akademii Nauk. Seriya Fizicheskaya, 2015, Vol. 79, No. 3, pp. 454–457.

The GAMMA-400 Experiment: Status and Prospects

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Abstract—The development of the GAMMA-400 γ-ray telescope continues. The GAMMA-400 is designed to measure fluxes of γ-rays and the electron–positron cosmic-ray component possibly associated with annihilation or decay of dark matter particles; and to search for and study in detail discrete γ-ray sources, to measure the energy spectra of Galactic and extragalactic diffuse γ-rays, and to study γ-ray bursts and γ-rays from the active Sun. The energy range for measuring γ-rays and electrons (positrons) is from 100 MeV to 3000 GeV. For 100-GeV γ-rays, the γ-ray telescope has an angular resolution of ~0.01°, an energy resolution of ~1%, and a proton rejection factor of $\sim 5 \times 10^5$. The GAMMA-400 will be installed onboard the Russian Space Observatory.

DOI: 10.3103/S1062873815030429

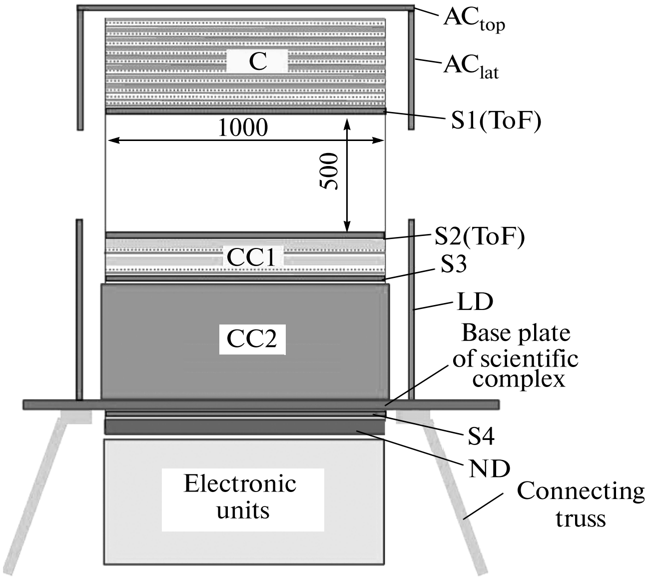

Fig. 1. Physical scheme of the GAMMA-400 gamma-ray telescope: AC_{top}, top anticoincidence detector; AC_{lat}, lateral anticoincidence detectors; C, converter–tracker; S1 (ToF) and S2 (ToF), scintillation detectors of the time-of-flight system; CC1 and CC2, coordinate-sensitive calorimeter; S3 and S4, scintillation detectors; ND, neutron detector.

INTRODUCTION

Under the RF Space Program for 2009–2015 and the RF Space Program developed for 2016–2025, work is now under way to create a space observatory with the GAMMA-400 scientific complex. The GAMMA-400 scientific complex is designed to study γ-ray emissions in the high-energy range and acquire data that will allow us to determine the nature of dark matter in the Universe and develop a theory of the origin of high-energy cosmic rays. The GAMMA-400 will provide information on

—features in the energy spectra of high-energy γ-ray emissions from discrete and extended sources and the electron–positron component possibly associated with particles of dark matter;

—the variability of high-energy γ-ray emissions from discrete sources in order to clarify the nature of particle acceleration in such sources;

—γ-ray bursts, including high-energy bursts;

—the energy spectrum of high-energy light nuclei;

—high-energy γ-ray emissions, fluxes of electrons and positrons, and nuclei in solar flares.

One important goal of the GAMMA-400 experiment is to observe high-energy γ-ray emissions from the central region of our Galaxy that will provide unique information about the Galactic center and the area near the center's supermassive black hole and its accretion disk, which (like the Galactic center) could contain hypothetical dark matter particles. To resolve linear γ-ray emissions from dark matter particles against the background emissions from other sources in the Galactic center, telescopes must have high angular and energy resolutions. It is believed that in the energy range of >10 GeV, the GAMMA-400 will have angular and energy resolutions much better than the Fermi-LAT [1–3] and AGILE [4] γ-ray telescopes currently operating in orbit, and the existing and planned ground-based MAGIC [5], H.E.S.S. [6], VERITAS [7], and CTA [8] γ-ray telescopes.

THE GAMMA-400 SCIENTIFIC COMPLEX

The main instrument of the GAMMA-400 scientific complex is the GAMMA-400 γ-ray telescope [9–11]. The GAMMA-400 scientific complex also contains magnetometers (2 pcs.) for measuring the magnetic field; star sensors (2 pcs.) for determining the γ-ray telescope axis with an accuracy of ~5″; and the Konus-FG system (four directional detectors and two spectrometric detectors) for detecting γ-ray bursts over virtually the entire celestial sphere in the energy range of 10 keV–10 MeV in simultaneous operation with the GAMMA-400 γ-ray telescope.

The GAMMA-400 γ-Ray Telescope

The physical scheme of the GAMMA-400 γ-ray telescope is shown in Fig. 1. Compared to the scheme presented in [9–11], the dimensions of the calorimeter (CC1 and CC2), S2, S3, S4, and ND have grown to 1000 × 1000 mm instead of the previous 800 × 800 mm. As a result, the mass of scientific complex is now 4100 kg instead of 2600 kg, made possible by the transition to the more powerful *Proton-M* launch vehicle.

The GAMMA-400 γ-ray telescope contains

—a top (AC_{top}) and four lateral (AC_{lat}) anticoincidence detectors;

—a converter-tracker (C) with ten plates of twin-layer silicon strip coordinate detectors (with mutually perpendicular strips; strip pitch, 0.1 mm). Eight layers also contain tungsten plates $0.1X_0$ thick (where X_0 is the radiation length). The total thickness of the converter–tracker is $\sim 1.0X_0$;

—the time-of-flight system (ToF) of the S1 and S2 scintillation detectors, separated by a distance of 500 mm;

—a coordinate-sensitive calorimeter (CC) consisting of CC1 and CC2. CC1 contains two groups of detectors, each of which includes detectors with CsI(Tl) and twin-layer silicon strip detectors (with mutually perpendicular located strips; strip pitch, 0.1 mm). CC1 is $\sim 2X_0$ thick. CC2 consists of CsI(Tl) crystals and is $\sim 23X_0$ thick. The total thickness of the calorimeter for normal particle incidence is $\sim 25X_0$ or $1.2\lambda_I$ (where λ_I is the nuclear interaction length). The total thickness of the calorimeter when detecting particles from lateral directions is $54X_0$ or $2.5\lambda_I$;

—S3 and S4 scintillation calorimeter detectors;

—lateral calorimeter detectors (LDs);

—a neutron detector (ND).

Gamma rays are converted into electron–positron pairs in the converter–tracker. Electromagnetic showers develop inside the calorimeter and are recorded in CC1, CC2 and S3 and S4 scintillation detectors. Anticoincidence detectors located around the converter–tracker help to identify γ-rays, while the time-of-flight system determines the direction of the incident particles. Two trigger systems are used to record particles moving from top to bottom: one for γ-rays with no signal in the ACs, and one for electrons (positrons) and nuclei with signals in the ACs. Electrons, positrons, and light nuclei can be also detected from the lateral directions.

Time and segmentation methods are used to reduce the influence of backscattering particles created when incident γ-rays interact with the calorimeter's matter and move in the opposite direction [12].

The GAMMA-400's physical characteristics were simulated by three independent groups of institutions: LPI + MEPhI, the Ioffe Institute, and INFN (Istituto Nazionale di Fisica Nucleare, Italy). Figure 2 shows the results from simulations of its effective area, energy, and angular resolutions. For comparison, the corresponding characteristics are presented for the thin (front) converter of the Fermi-LAT γ-ray telescope (http://www.slac.stanford.edu/exp/glast/groups/canda/lat_Performance.htm), in which the best angular resolution is achieved. It can be seen from Fig. 2 that for $E_\gamma > 1$ GeV, the GAMMA-400 effective area (~4000 cm^2) is almost comparable to the Fermi-LAT effective area (~4500 cm^2), while the GAMMA-400 angular and energy resolutions from $E_\gamma > 10$ GeV are

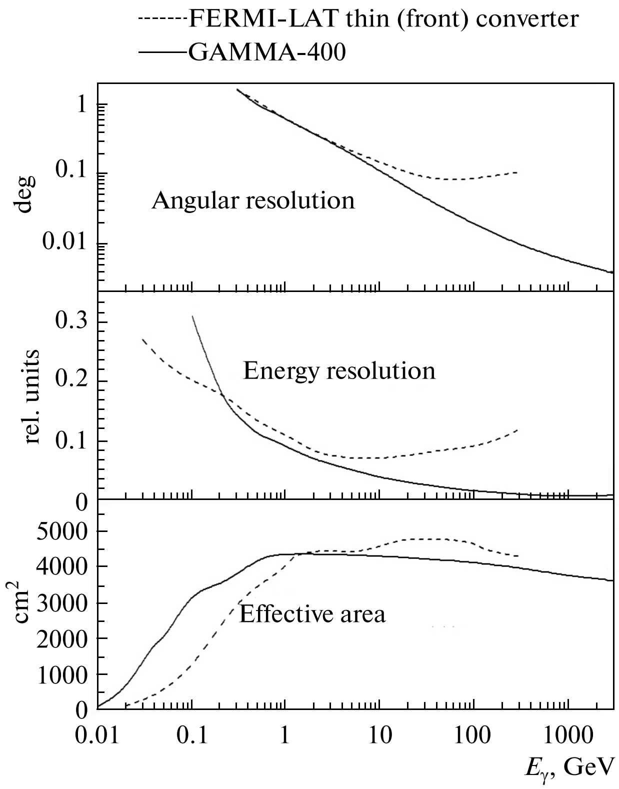

Fig. 2. Dependences of the effective area, energy, and angular resolutions on the energy of detected gamma rays for the GAMMA-400 and Fermi-LAT.

Comparison of the GAMMA-400 and Fermi-LAT's main characteristics

	Fermi-LAT (front)	GAMMA-400
Orbit	circular, 565 km	highly elliptical, 500–300 000 km (without occultation of the Earth)
Energy range	20 MeV–300 GeV	100 MeV–3000 GeV
Effective area		
$E_\gamma = 10$ GeV	4500 cm^2	4000 cm^2
$E_\gamma = 100$ GeV	4500 cm^2	4000 cm^2
Coordinate detectors	Si strips (pitch of 0.23 mm)	Si strips (pitch of 0.1 mm)
Angular resolution		
$E_\gamma = 10$ GeV	0.2°	0.09°
$E_\gamma = 100$ GeV	0.08°	0.015°
Calorimeter	CsI	CsI(Tl)+Si strips
thickness	$8.5X_0$	$25X_0$
Energy resolution		
$E_\gamma = 10$ GeV	8%	3.5%
$E_\gamma = 100$ GeV	10%	1.5%
Rejection coefficient	~10^4	~5×10^5
Telescope mass	2800 kg	4100 kg
Data volume	15 Gbyte/day	100 Gbyte/day

better and at $E_\gamma = 100$ GeV attain values of ~0.01° and ~1%, respectively.

The GAMMA-400 and Fermi-LAT's main characteristics are compared in the table.

Protons must be rejected when detecting primary cosmic-ray charged particles, including electrons and positrons. They are rejected by analyzing the signals from the S1 and S2 detectors of the time-of-flight system, the CC1 and CC2 calorimeters, the S3 and S4 detectors, and the ND. The calculated total rejection coefficient was $\sim 5 \times 10^5$ in the 50 to 1000 GeV range of proton energies.

The space observatory in which the GAMMA-400 scientific complex is to be installed on the Navigator space platform developed by the Lavochkin Association will be launched into highly elliptical orbits with initial parameters of 300000 km (apogee), 500 km (perigee), and an inclination of 51.4°. The lifetime of the space observatory will be at least seven years. The launch of the space observatory is scheduled for the early 2020s.

ACKNOWLEDGMENTS

This work was supported by the Space Council of Russian Academy of Sciences, the Russian Federal Space Agency, the Istituto Nazionale di Fisica Nucleare in Italy (INFN), and the Italian Space Agency (ASI).

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Translated by N. Topchiev