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Characteristics of the GAMMA-400 Gamma-Ray Telescope for Searching for Dark Matter Signatures

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Abstract—The GAMMA-400 gamma-ray telescope currently under development is designed to measure fluxes of gamma rays and electron–positron cosmic-ray components, which could be associated with the annihilation or decay of dark matter particles, and to survey in detail the celestial sphere in order to search for and investigate discrete gamma-ray sources; to measure the energy spectra of Galactic and extragalactic diffuse gamma-ray emissions; and to study gamma-ray bursts and the gamma-ray emissions of active Sun. The GAMMA-400 energy range is 100 MeV to 3000 GeV. The gamma-ray telescope has an angular resolution of ~0.01°, an energy resolution of ~1%, and a proton rejection factor of ~10^6. The GAMMA-400 will be installed on Russia's *Navigator* space platform. Observations are planned to commence in 2018.

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INTRODUCTION

Among the important issues in modern cosmology at the beginning of the 21st century, Nobel Laureate Academician V.L. Ginzburg has noted “the problem of dark matter and its detection” [1]. It is well known today that the density of dark matter in the universe (~25%) is several times greater than that of normal (baryonic) matter (~5%). One candidate for the role of dark matter is WIMPs (Weakly Interacting Massive Particles). Scientists around the world are now conducting experiments to search for WIMPs, using both direct and indirect means of detection. Indirect methods are based on detecting in cosmic radiation the annihilation or decay products of WIMPs, which could be either normal particles or their antiparticles (including neutrinos, electrons, and positrons), along with gamma rays. Gamma rays play an important role here, since they propagate in space with virtually no interaction and can therefore be used to determine the direction to a source of gamma-ray emission.

The processing of results from measurements using the Fermi-LAT gamma-ray telescope in the region of

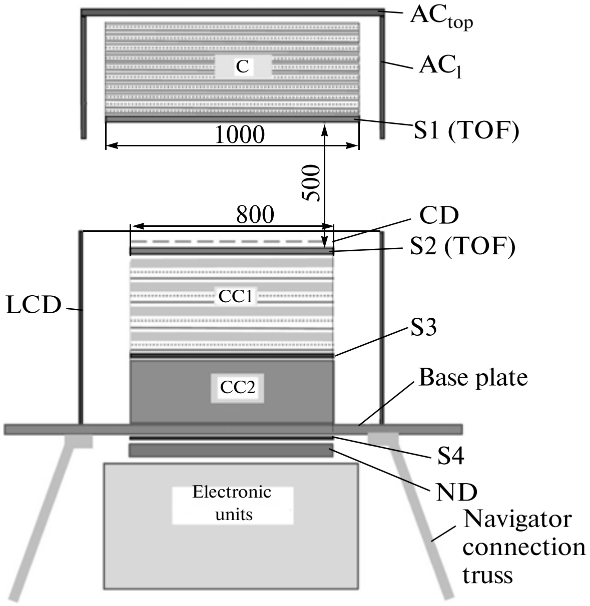

Fig. 1. Scheme of the GAMMA-400 gamma-ray telescope: upper anticoincidence scintillation detector, AC_{top}; lateral anticoincidence scintillation detectors, AC_l; converter–tracker, C; time-of-flight system's scintillation detectors, S1 (TOF) and S2 (TOF); coordinate-sensitive calorimeters, CC1 and CC2; scintillation detectors, S3 and S4; lateral calorimeter detectors, LCD; neutron detector, ND.

the Galactic center shows a feature in the spectrum of gamma-ray emission in the energy range of 130 GeV [2]. Theoretical studies of this feature suggest the existence of narrow gamma-ray lines from WIMP annihilation or decay. This issue can be reliably resolved only by future experiments with significantly better angular and energy resolutions [3–7].

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

Energy range of gamma-ray detection	100 MeV–3000 GeV
Field of view, sr	~1.2
Effective area, cm^2	~4000
Energy resolution ($E_\gamma > 100$ GeV)	~1%
Angular resolution ($E_\gamma > 100$ GeV)	~0.01°
Calorimeter thickness, r.l.	~25
Proton rejection coefficient	~10^6
Telemetry downlink volume, GB/day	100
Mass, kg	2600
Dimensions, m	2.0 × 2.0 × 3.0
Power consumption, W	2000

The GAMMA-400 gamma-ray telescope now under construction in Russia will be capable of meeting these goals. In addition, a program has been drawn up for performing extra-atmospheric observations in gamma-ray astronomy with simultaneous measurement of the fluxes of the electron–positron component of cosmic rays. The GAMMA-400 will have unique opportunities both to resolve gamma-ray lines in the energy spectra of dark matter particles and to determine the directions to sources of these emissions.

THE GAMMA-400 GAMMA-RAY TELESCOPE

The GAMMA-400 gamma-ray telescope is designed to measure the fluxes of gamma rays and the electron–positron component of cosmic rays, which could be associated with the annihilation or decay of dark matter particles. It will also scan in detail the celestial sphere in order to search for and study discrete gamma-ray sources, measure the energy spectra of diffuse Galactic and extragalactic gamma-ray emissions, and study gamma-ray bursts and gamma-ray emissions of active Sun in the energy range of 100 MeV to 3000 GeV.

The main GAMMA-400 characteristics are shown in Table. 1. The GAMMA-400 layout described in [8, 9] has been changed and is shown in Fig. 1. The GAMMA-400 gamma-ray telescope incorporates the following systems and detectors:

—top (AC_{top}) and lateral (AC_l) anticoincidence detectors;

—a converter–tracker (C) consisting of 10 tungsten-interleaved sheets of double-layer silicon coordinate strip detectors with a mutually perpendicular arrangement of strips and a pitch of 0.1 mm. The total thickness of the converter–tracker is $1.0X_0$;

—time-of-flight (TOF) system with scintillation detectors S1 and S2 spaced 500 mm apart;

—a coordinate-sensitive calorimeter in two parts:

(a) CC1 consisting of four layers, each of which is a set of CsI(Tl) crystals and double-layer silicon strip detectors with a mutually perpendicular arrangement of strips and a pitch of 0.5 mm pitch. CC1 thickness is $3X_0$.

(b) CC2 containing BGO crystals (25 × 25 × 250 mm^3). CC2 thickness is $22X_0$.

The total calorimeter thickness for normal particle incidence is $25X_0$ or $1.2\lambda_0$. The total calorimeter thickness for lateral particle incidence is $70X_0$ or $3.5\lambda_0$.

—scintillation detectors S3 and S4;

—lateral calorimeter detectors (LCD);

—neutron detector (ND).

Gamma rays are converted into electron–positron pairs in the converter–tracker and are subsequently recorded in the detectors. Anticoincidence detectors help identify gamma rays, and the time-of-flight system determines the direction of incident particles and controls the telescope's aperture. The electromagnetic showers created by electron–positron pairs develop in the two parts of the calorimeter and are detected in the calorimeter and scintillation detectors S3 and S4.

Gamma rays are detected when there is no signal from AC. Electrons (positrons) are detected when there is a signal from AC, and when particles travel both from the top down and laterally.

Using calorimeter with a thickness of $\sim 25X_0$ allows us to expand the energy range of detected particles up to several TeV, and to improve the gamma-ray telescope's energy resolution up to ~1% at energies of more than 10 GeV. We calculated the dependence of the GAMMA-400's energy resolution vs. the energy of incident gamma rays using the Monte Carlo method. It is shown in Fig. 2a (for comparison, we also present the same dependence for the Fermi-LAT [10]). It can be seen that in the energy range of 10 to 10000 GeV, the energy resolution is ~1%; this is extremely important when resolving the gamma-ray lines of dark matter particles.

High angular resolution is achieved by determining the point of conversion in the multilayer converter and reconstructing the shower axis in CC1. This ensures a high angular resolution of ~1% at energies above 100 GeV (Fig. 2b) that will allow us to determine the direction to a source of gamma-ray lines from dark matter particles.

When incident high-energy particles interact with the calorimeter's matter, backsplash particles are created that move in the opposite direction. To exclude such events from detection, we will use the time-of-flight separation of incident and backsplash particles in combination with traditional segmentation (Fermi-LAT [10, 11], AGILE [12]).

When detecting electrons and positrons using the calorimeter, neutron detector, and other detectors, we are provided proton rejection of up to $\sim 10^6$.

The GAMMA-400's resulting performance will enable us to resolve the gamma-ray lines of dark matter particles reliably. For comparison, Table 2 shows the main characteristics of the current and planned space-based Fermi [10] and AMS-2 [13] experiments, and those of the ground-based MAGIC [14], HESS-II [15], and CTA [16] experiments. We can see that the GAMMA-400's characteristics considerably exceed those of the above experiments.

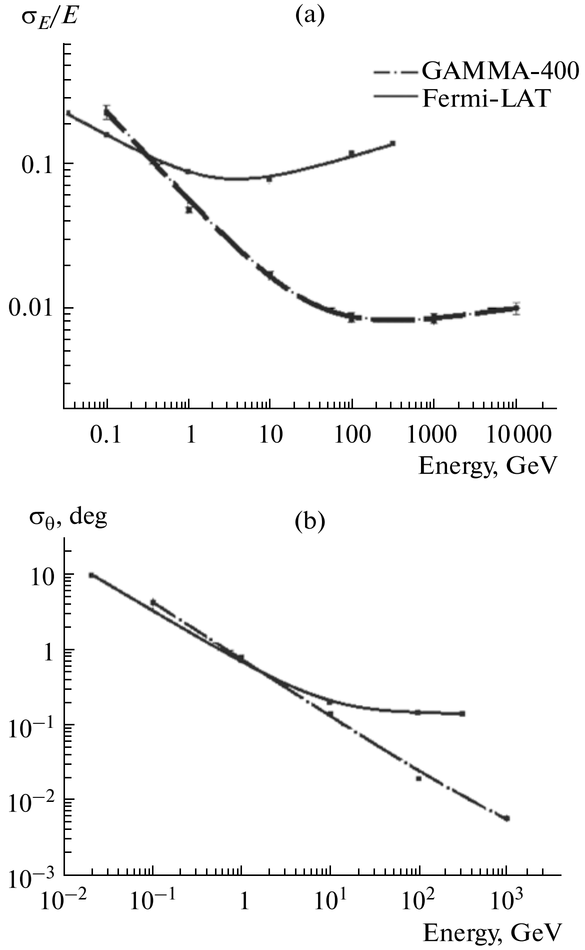

Fig. 2. Dependences of (a) energy and (b) angular resolutions vs. energy for the GAMMA-400 and Fermi-LAT gamma-ray telescopes.

The space observatory where the GAMMA-400 will be installed on the *Navigator* service module designed by the Lavochkin Association will be launched into a high elliptical orbit with initial parameters of an apogee at 300000 km, a perigee at 500 km, and an inclination of 51.8°. After about six months, the orbit will evolve to become nearly circular with a radius of ~150000 km; i.e., the observatory will leave the Earth's radiation belt completely. The lifetime of

Table 2. Comparison of the main characteristics of current and planned space-based and ground-based experiments

	Space-based experiments			Ground-based experiments		
	Fermi	AMS-2	GAMMA-400	H.E.S.S.-II	MAGIC	CTA
Energy range, GeV	0.02–300	10–1000	0.1–3000	>30	>50	>20
Field of view, sr	2.4	0.4	1.2	0.01	0.01	0.1
Effective area, cm^2	0.8	0.2	0.4	10^5	10^5	10^6
Angular resolution ($E_\gamma > 100$ GeV)	0.2°	1.0°	~0.01°	0.07°	0.05°	0.06°
Energy resolution ($E_\gamma > 100$ GeV)	10%	3%	~1%	15%	15%	10%

the space observatory is no less than seven years. The launch of the space observatory is planned for 2018.

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