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GAMMA-400 space observatory

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Summary. — A new important step in high-energy gamma-ray astronomy has been made with the beginning of Fermi LAT observations. But, as usual, a lot of new problems arise, in particular, the number of unidentified discrete gamma-ray sources is about 40%. To solve them it is necessary to improve the angular resolution up to 0.01°, the energy resolution up to 1%, and to extend the observable energy range to 3000 GeV. A new generation instrument, the GAMMA-400 gamma-ray telescope, will correspond to these requirements. The instrument will be also equipped with transition radiation detector and neutron detector to measure electron and positron fluxes more reliably. The GAMMA-400 launch is planned in 2016-2017.

PACS `96.50.S-` – Cosmic rays.
PACS `98.70.Rz` – γ-ray sources; γ-ray bursts.
PACS `98.70.Sa` – Cosmic rays (including sources, origin, acceleration, and interactions).

1. – Introduction

Cosmic gamma-radiation in the energy range 0.1–3000 GeV belongs to the high-energy part of electromagnetic radiation spectrum and is connected with the processes of generation and acceleration in the Universe (pulsars, microquasars, active galactic nuclei, blazars, etc.), as well as with the processes of very high-energy cosmic-ray particle interaction with the matter of the Universe. From the other side, annihilation or decay of dark matter components can lead to the generation of high-energy gamma-rays, electrons, and positrons. The GAMMA-400 gamma-ray telescope [1-4] being the successor to the Russian gamma-ray investigations [5,6] will detect gamma-rays, as well as electrons, positrons in the energy range from 100 MeV up to 3000 GeV with fine angular and energy resolutions. The scientific problems of GAMMA-400 follow from the results obtained, mainly, in gamma-ray range by EGRET [7], AGILE [8], Fermi LAT [9], in electron-positron observations by PAMELA [10], as well as from the results of TeV ground-based gamma-ray telescopes [11-13].

From the previous gamma-ray observations we note the following:

- It is confirmed that a considerable part of discrete sources in gamma range is variable [14].
- The number of the discrete gamma-ray sources discovered by the Fermi LAT in comparison with the EGRET and AGILE data has increased by several times and has reached approximately 1500, but a considerable part of these sources remains unidentified.
- Gamma-ray energy spectra from Fermi LAT observations near 100 GeV and from observation of ground-based gamma-ray telescopes in the hundred GeV energy range have some discrepancies [15].

To explain many new problems occurred after the EGRET, AGILE, and Fermi observations it is necessary to:

1) Extend the energy range up to 3000 GeV (to explain the space-based and ground-based observation data).
2) Improve angular resolution up to 0.01° (to identify discrete gamma-ray sources).
3) Improve energy resolution up to 1% (to reveal features in the energy spectra of gamma-rays, electrons, and positrons, which are found to be connected with the dark matter [16]).
4) Increase the selection efficiency of gamma-rays, as well as, electrons and positrons.

2. – The GAMMA-400 description

The GAMMA-400 scientific complex includes the gamma-ray telescope, the KONUS-FG gamma-ray burst monitor [17], and a star tracker. The GAMMA-400 physical scheme is shown in fig. 1.

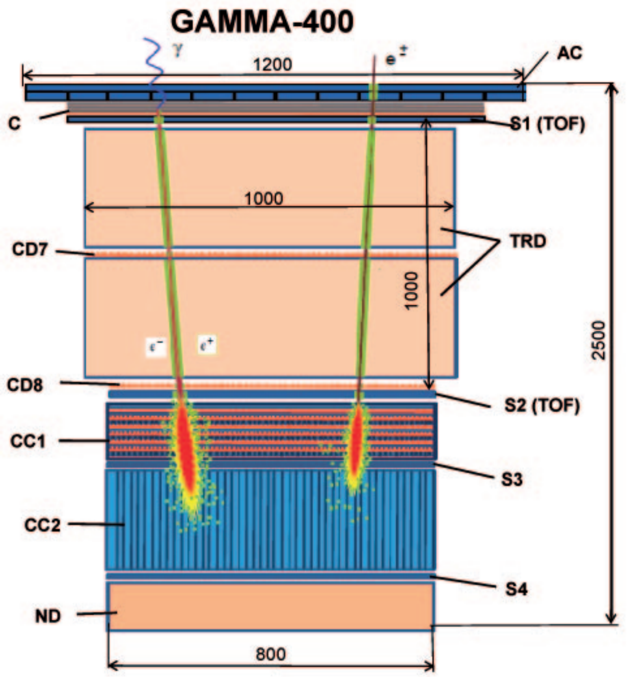

Fig. 1. – The GAMMA-400 physical scheme.

2˙1. *Main systems of the gamma-ray telescope*

- Anticoincidence detector (AC).
- Multilayer converter (C) consists of 6 layers of 0.14 radiation lengths (r.l.) of tungsten interlaid with Si (x, y) strip coordinate detectors (CD1-CD6) with pitch 0.1 mm. Total converter thickness is 0.84 r.l. Such converter scheme allows us to determine precisely a conversion point and to measure particle energy up to 100 MeV.
- Time-of-flight system (TOF) consists of two scintillator detectors S1 and S2 at a 1 m distance and identifies particles moving from AC to CC.
- Transition radiation detector (TRD) improves proton rejection by 20–50 times.
- Coordinate detectors (CD7, CD8), Si (x, y) strip coordinate detectors with pitch 0.1 mm are the same as in converter.
- Coordinate calorimeter (CC) consists of two parts:
  - Imaging calorimeter (CC1): 10 layers of 1 cm BGO crystals and Si (x, y) strip coordinate detectors with pitch 0.5 mm. Total thickness is ~ 9 r.l.
  - Electromagnetic calorimeter from only BGO crystals. Total thickness is ~ 21 r.l.
- Scintillation detectors S3 and S4 are additional trigger detectors.
- Neutron detector (ND) improves proton rejection up to 10 times.

TABLE I. – *Comparison of the main parameters of space-based and ground-based telescopes.*

	Space-based					Ground-based		
	EGRET [18]	AGILE [19]	Fermi -LAT [20]	CALET [21]	**GAMMA -400**	H.E.S.S. [22]	MAGIC [23]	VERITAS [13]
Energy range (GeV)	0.03–30	0.03–50	0.1–300	10 – 10000	**0.1–3000**	> 100	> 50	> 100
Angular resolution (deg) $E_\gamma > 100\,\text{GeV}$	0.5 E_γ 10 GeV	0.1 E_γ 1 GeV	0.05	0.1	**0.01**	0.2	0.1	0.1
Energy resolution (%) $E_\gamma > 100\,\text{GeV}$	20 $E_\gamma < 10\,\text{GeV}$	50 $E_\gamma < 1\,\text{GeV}$	10	2	**1**	20	12	10

2˙2. *Main features of the GAMMA-400 scheme.* – To increase angular resolution we apply:

1) Multilayer converter.

2) Imaging calorimeter CC1.

3) Large distance between converter and calorimeter (1 m).

To extend the energy range up to 3000 GeV and increase the energy resolution of high-energy gamma-rays, electrons, and positrons, we use a thick calorimeter (~ 30 r.l.) consisting of two parts: imaging calorimeter and electromagnetic calorimeter. The imaging calorimeter from BGO crystals interlaid with Si strip detectors (pitch 0.5 mm) allows us to reconstruct the axis of cascade and together with precise knowledge of the conversion point in the multilayer converter at a large 1 m distance to obtain the superangular resolution $\sim 0.01°$ at an energy more than 100 GeV. The position-sensitive electromagnetic calorimeter from only BGO crystals allows us to improve the energy resolution up to 1% at an energy more than 10 GeV and provide proton rejection up to 10^4. Together with transition radiation detector and neutron detector the total proton rejection reaches $\sim 10^6$. To prevent telescope blocking by backsplash particles, a temporal method is used that allows us to considerably decrease the backsplash effect. For comparison, we present the main parameters of space-based and ground-based telescopes in table I. It is seen that the GAMMA-400 gamma-ray telescope will have the best angular and energy resolutions.

3. – Spacecraft

The Gamma-400 space observatory will be installed on the Navigator space service platform with the Fregat booster produced by Lavochkin Research and Production Association. The initial orbit parameters are: apogee 300000 km, perigee 500 km, and inclination 51.8°. The orbit period is 7 days. After approximately 230 days the GAMMA-400 orbit will leave the Earth's radiation belts and then will change from elliptical to approximately circular with radius 150000 km. We expect to use three basic modes of observations:

- The sky gamma-ray monitoring (searching for new discrete sources and monitoring the discovered variable sources).
- Long-term monitoring for the most interesting discrete sources.
- GeV gamma-ray burst observation after reorientation of the GAMMA-400 telescope according to the signal from the KONUS-FG gamma-ray burst monitor, as well as to the indications from the Earth connected with extraordinary information from other astronomical observations, for example, information on solar flares.

The spacecraft lifetime is more than 7 years. The launch of the GAMMA-400 space observatory is planned in 2016-2017.

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