Conference of Fundamental Research and Particle Physics, 18-20 February 2015, Moscow, Russian Federation

Space γ-observatory GAMMA-400 current status and perspectives

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Abstract

GAMMA-400 γ-ray telescope is designed to measure fluxes of γ-rays and the electron–positron cosmic ray component possibly generated in annihilation or decay of dark matter particles; to search for and study in detail discrete γ-ray sources, to examine the energy spectra of Galactic and extragalactic diffuse γ-rays, to study γ-ray bursts and γ-rays from the active Sun. GAMMA-400 consists of plastic scintillation anticoincidence top and lateral detectors, converter-tracker, plastic scintillation detectors for the time-of-flight system (TOF), two-part calorimeter (CC1 and CC2), plastic scintillation lateral detectors of calorimeter, plastic scintillation detectors of calorimeter, and neutron detector. The converter-tracker consists of 13 layers of double (x, y) silicon strip coordinate detectors (pitch of 0.08 mm). The first three and final one layers are without tungsten while the middle nine layers are interleaved with nine tungsten conversion foils. The thickness of CC1 and CC2 is $2\,X_0$ ($0.1\,\lambda_0$) and $23\,X_0$ ($1.1\,\lambda_0$) respectively (where X_0 is radiation length and λ_0 is nuclear interaction one). The total calorimeter thickness is $25\,X_0$ or $1.2\,\lambda_0$ for vertical incident particles registration and $54\,X_0$ or $2.5\,\lambda_0$ for laterally incident ones.

The energy range for γ-rays and electrons (positrons) registration in the main aperture is from ~0.1 GeV to ~3.0 TeV. The γ-ray telescope main aperture angular and energy resolutions are respectively ~0.01° and ~1% for 10^2 GeV γ-quanta, the proton rejection factor is ~5×10^5. The first three strip layers without tungsten provide the registration of γ-rays down to ~20 MeV in the main aperture. Also this aperture allows investigating high energy light nuclei fluxes characteristics.

Electrons, positrons, light nuclei and gamma-quanta will also register from the lateral directions due to special aperture configuration. Lateral aperture energy resolution is the same as for main aperture for electrons, positrons, light nuclei and gamma-quanta in energy range E>1.0 GeV. But using lateral aperture it is possible to detect low-energy gammas in the ranges 0.2 – 10 MeV and 10 MeV – 1.0 GeV with energy resolution 8% − 2% and 2% correspondingly accordingly to GAMMA-400 "Technical Project" stage results. Angular resolution in the lateral aperture provides only for low-energy gamma-quanta from non-stationary events (GRB, solar flares and so on) due segments of CC2 count rate analysis.

GAMMA-400 γ-ray telescope will be installed onboard the Russian Space Observatory GAMMA-400. The lifetime of the space observatory will be at least seven years. The launch of the space observatory is scheduled for the early 2020s.

1. Introduction

Space high energy gamma observatory GAMMA-400 is one of important scientific projects in the Russian Federal Space Program for 2009–2015 and the Russian Federal Space Program for 2016–2025. The main goal of the project is to clarify the Dark Matter nature via study of high energy gammas generated in decay or annihilation of possible Dark Matter constituents - Weakly Interacting Massive Particles (WIMPs). The idea of GAMMA-400 project was first presented by Nobel Laureate Academician V.L. Ginzburg at the 20th International Cosmic Rays Conference in Moscow [1] and developed up to now [2, 3]. Search for the signs of WIMPs decay or annihilation is the most promising method. GAMMA-400 scientific complex is designed to study γ-ray emissions in high energy range. 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; 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; energy spectrum of high energy light nuclei; high energy γ-ray emissions, fluxes of electrons and positrons, and nuclei in solar flares.

Important target of the GAMMA-400 observation is 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 possibly 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. In the energy range >10 GeV, the GAMMA-400 will have angular and energy resolutions much better than the Fermi-LAT [4–6] and AGILE [7] γ-ray telescopes currently operating in orbit, and the existing and planned ground based MAGIC [8], H.E.S.S. [9], VERITAS [10], and CTA [11] γ-ray telescopes.

2. GAMMA-400 performance and status

The physical scheme of the GAMMA-400 γ-ray telescope is shown in Fig. 1. The converter–tracker consists of 13 layers of double (x, y) silicon strip coordinate detectors with pitch of 0.08 mm. The first three and final one layers are without tungsten while the middle nine layers are interleaved with eight tungsten conversion foils. The total converter-tracker thickness is about 1 X_0 (where X_0 is the radiation length). The imaging calorimeter CC1 consists of 2 layers of double (x, y) silicon strip coordinate detectors (pitch of 0.08 mm) interleaved with planes from CsI(Tl) crystals, and the electromagnetic calorimeter CC2 consists only of CsI(Tl) crystals. The thickness of CC1 is 2 X_0 and one of CC2 is 23 X_0 corresponds to 0.1 λ_0 and 1.1 λ_0 respectively (where X_0 is radiation length and λ_0 is nuclear interaction one). The total calorimeter thickness is 25 X_0 or 1.2 λ_0 for vertical incident particles registration and 54 X_0 or 2.5 λ_0 for laterally incident particles observations [12 - 14].

Anticoincidence detectors located around the converter–tracker make it possible to identify γ-rays, while the time-of-flight system determines the direction of the incident particles. All scintillation detectors consist of two independent layers each is 1 cm thick.
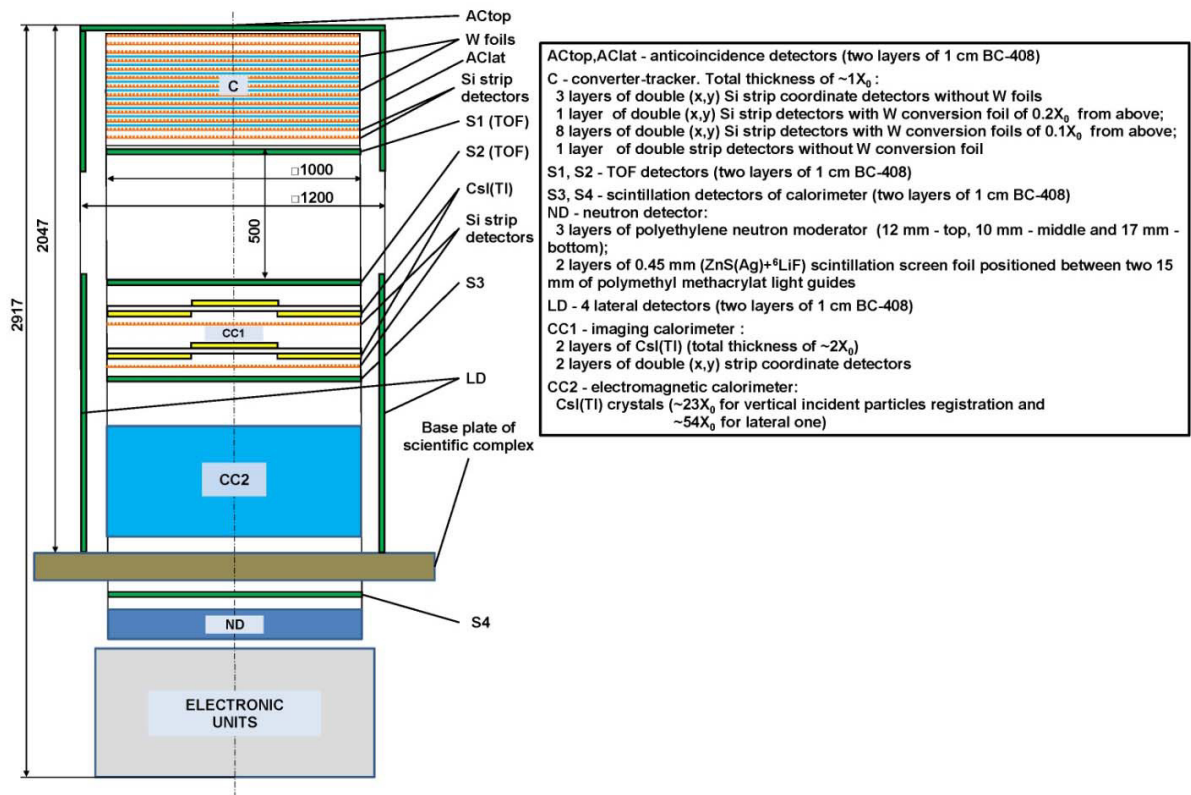

Fig. 1. Physical scheme of the GAMMA-400 gamma ray telescope.

The counting and triggers signals formation system is used to recognize particles moving from top to bottom: γ-rays identified with no signal in the ACs and electrons (positrons) and nuclei with signals in the ACs. The individual anticoincidence system detectors signals analyzed by the counting and triggers signals formation system taking into account specially designed for GAMMA-400 algorithms of backsplash rejection. Time and segmentation methods are used to reject backsplash (backscattering particles created when high energy γ-rays interact with the calorimeter's matter and move in the opposite direction) [14]. Both methods together make possible to avoid effective area decrease at high energy and keep high efficiency for photons with energy more than several tens GeV.

The particles registration in the main aperture started with TOF signal from S1 and S2 detector systems. Photons are converted into electron–positron pairs in the converter–tracker and TOF signal formed due its registration in the S1 and S2. Electron–positron pair tracks are registered with silicon microstrip detectors. The converter-tracker information is used to precisely determine the conversion point and the direction of each incident particle during ground data processing. Electromagnetic showers develop inside the calorimeter and generate signals in CC1, CC2 and S3, S4 scintillation detectors. The two-part calorimeter measures particle energy. The system of counting and triggers signals formation provides particle identification and started the data acquisition.
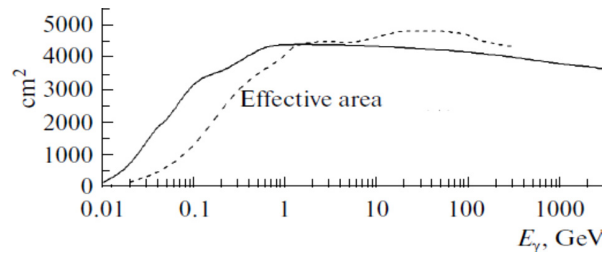

Fig. 2. Dependences of the effective area on the energy of detected gamma rays for the Fermi-LAT (dotted line) and the GAMMA-400 main aperture (solid one).
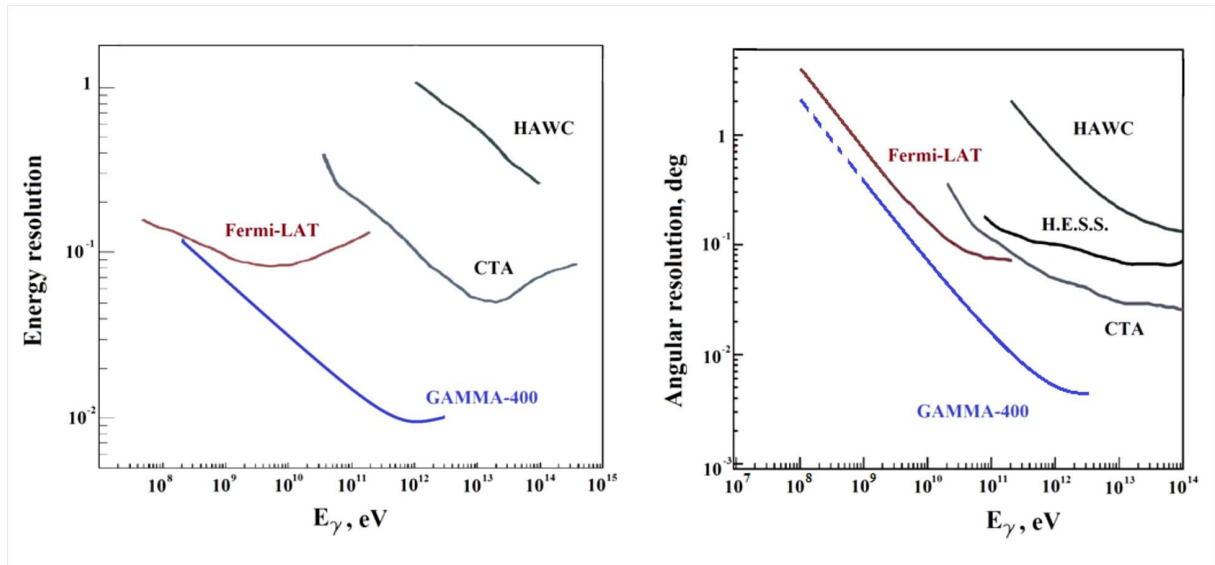

Fig. 3: Comparison of energy and angular resolutions for the Fermi-LAT, H.E.S.S., HAWC, CTA [17] and the main aperture of GAMMA-400.

The energy range for γ-rays and electrons (positrons) registration in the main aperture is from ~0.1 GeV to ~3.0 TeV. Using the first three layers without tungsten allows gamma rays observation down to ~20 MeV in this aperture.

Independent groups simulated GAMMA-400 physical characteristics: LPI, MEPhI, Ioffe Physical Technical Institute (Russia) and Istituto Nazionale di Fisica Nucleare (Italy). Fig. 2 - 3 shows the simulation results of effective area, energy resolution and angular resolution in the main aperture. For comparison, the corresponding parameters are presented on the same figures for the thin (front) converter of the Fermi-LAT γ-ray telescope (due which Fermi-LAT best angular resolution is achieved) [15] together with H.E.S.S., HAWC and CTA characteristics [16]. It can be seen from Fig. 2 that GAMMA-400 main aperture effective area (~4000 cm^2) for Eγ > 1.0 GeV is almost the same as Fermi-LAT effective area (~4500 cm^2). Nevertheless, GAMMA-400 main aperture angular and energy

resolutions are better than other experiments ones for Eγ > 10 GeV and at Eγ = 10^2 GeV attain the values of ~0.015° and ~1%, respectively – see Fig. 3.

Electrons, positrons, light nuclei and gamma-quanta will also register from the lateral directions due to special aperture configuration. The lateral aperture energy resolution is the same as for main aperture for electrons, positrons, light nuclei and gamma-quanta in energy range E>10 GeV. But it is possible to detect low-energy gammas in the range 0.2 - 10 MeV and photons with energy of 10 MeV – 10 GeV. The energy resolutions in these cases are 8% - 2% and 2% correspondingly using lateral aperture accordingly to GAMMA-400 "Technical Project" stage results. Angular resolution for low-energy gamma-quanta in the lateral aperture obtained due segments of CC2 count rate analysis looks like BATSE detector onboard CGRO observatory algorithm for transient sources differ from occultation analysis technique (see [17] and references therein) and could be used only for investigation of non-stationary events (GRB, solar flares and so on).

To study cosmic ray nuclei, electrons and positrons, much more abundant protons should be rejected. They are recognized both onboard and ground processing methods. Onboard particles identification provides using the signals configuration analysis from fast BC-408 based scintillation systems ACtop, AClat, S1-S4, LD and amplitude discriminators of both calorimeters. The ground processing provides by data analysis from the ACtop, AClat, S1 and S2 detectors of the time-of-flight system, CC1 and CC2 calorimeters, S3 and S4 detectors, LD and ND. The main aperture simulated total rejection factor is ~5×10^5 in the 50 GeV to 1.0 TeV range of proton energies.

The space observatory GAMMA-400 will be installed on the Navigator space platform developed by the Lavochkin Association and 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 at the early 2020s.

3. Conclusion

GAMMA-400 (Gamma Astronomical Multifunctional Modular Apparatus) research works were funded by the Russian Space Agency (Roscosmos) since 2000 and design and development works only since 2009. GAMMA-400 was included in the Russian FSP (Federal Space Program) 2006-2015. Today GAMMA-400 stage "Technical Project" was finished and all technical problems were solved. Now we begin the next stage: "Final Design Documentation Development" and GAMMA-400 is included in new FSP 2016-2025 to be approved by Russian Government this year.

GAMMA-400 will provide very important new results in study of dark matter nature, origin of high energy cosmic rays and structure of astrophysical objects emitting high energy gamma-rays.

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