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GAMMA-400 experiment: perspectives of observation of the discrete astrophysical gamma-ray sources in the Milky Way disk

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Abstract. The GAMMA-400 space experiment is aimed for the study of gamma rays in the energy range from ~20 MeV up to several TeV. The observations will carry out with GAMMA-400 gamma-ray telescope installed onboard the Russian space observatory. GAMMA-400 has unique angular and energy resolutions for gamma rays with energy more than few GeV, which are significantly better than the Fermi-LAT ones. The orbit of the GAMMA-400 space observatory (near-Earth, circular with altitude about 200000 km) will be without the occultation by the Earth and outside the radiation belt. Thus it will be possible to carry out the continuous long-term observations of gamma-ray sources on the sky. In this work we present the expected statistics of gamma quanta that can be collected with GAMMA-400 from known discrete astrophysical gamma-ray sources in the disk of our galaxy during observations in orbit. 3FGL and 3FHL catalogs of discrete gamma-ray sources obtained in the Fermi experiment were used to calculate the number of gammas. It is shown that the accumulated statistics will allow us to carry out detailed investigation of characteristics (such as spatial distribution, energy spectrum, variability) of discrete gamma-ray sources in the Milky Way disk.

1. Introduction

The GAMMA-400 space mission is aimed for the study of gamma rays in the energy range from ~20 MeV up to several TeV. The experiment main scientific goals are: dark matter searching by means of gamma-ray astronomy; precise detailed observations of discrete gamma-ray sources and diffuse gamma-ray emission in the Milky Way disk (primarily, in the bulge) and beyond.

The observations will carry out with the GAMMA-400 gamma-ray telescope. The physical scheme of the instrument is presented in figure 1. GAMMA-400 consists of plastic scintillation anticoincidence top and lateral detectors (AC top and AC lat), converter-tracker (C), plastic scintillation detectors (S1 and S2) for the time-of-flight system (ToF), calorimeter (CC1, CC2), plastic scintillation detectors (S3, S4). The signals from anticoincidence detectors (AC top, AC lat) and S1, S2, S3 detectors are used for generation of the trigger. The instrument detailed description is presented in [1, 2]. Figure 2 shows the dependences of the instrument effective area A_{eff} for on-axis gammas vs. energy E and it efficiency of gamma-ray detection $\eta=A_{eff}(\theta)/A_{eff}(\theta=0°)$ vs. incident angle θ.

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GAMMA-400 has unique angular and energy resolutions for gamma rays with energy more than few GeV, which are significantly better than the Fermi-LAT ones. The GAMMA-400 telescope will be installed onboard of the Navigator space platform, which is designed and manufactured by the Lavochkin Association. The GAMMA-400 observatory will be initially launched into a highly elliptical orbit (with an apogee of 300,000 km and a perigee of 500 km, with an inclination of 51.4°), with 7 days orbital period. After ~6 months the orbit will transform to about an approximately circular one with a radius of ~200000 km and will not suffer from the Earth's occultation and shielding by the radiation belts.

In this work we present the expected statistics of gamma quanta that can be collected with GAMMA-400 from known discrete astrophysical gamma-ray sources in the disk of our Galaxy during observations in orbit.

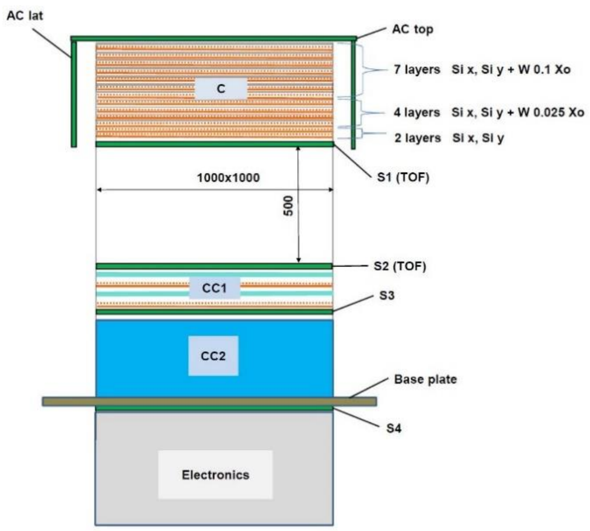

Figure 1. The GAMMA-400 telescope physical scheme. AC top, AC lat - anticoincidence top and lateral detectors; C - converter-tracker; S1, S2 – TOF detectors; CC1, CC2 – calorimeter; S3, S4 – scintillator detectors.

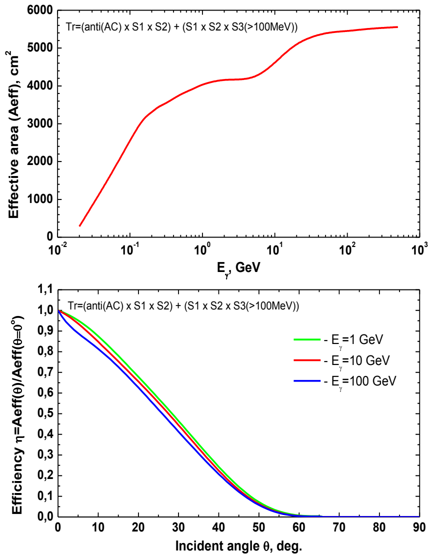

Figure 2. The dependences of the GAMMA-400 telescope effective area A_{eff} vs. energy E (top) and it efficiency $\eta=A_{eff}(\theta)/A_{eff}(\theta=0°)$ vs. incident angle θ (bottom).

2. The discrete gamma-ray sources

Since 2008 Fermi-LAT is operating in a near-Earth orbit in the scanning mode and surveying full sky every three hours. Up to time, the following catalogs of discrete gamma-ray sources have been published based on the Fermi-LAT observational results: 1FGL, 2FGL, 3FGL for the energy range from 100 MeV to 100 GeV; 1FHL for the energy above 10 GeV, 2FHL for the energy range of 50 GeV –2 TeV, and 3FHL for the energy range of 10 GeV –2 TeV.

In this work the 3FGL [3] and 3FHL [4] catalogs were used to estimate the expected statistics of gamma quanta that can be collected with GAMMA-400 from known discrete astrophysical gamma-ray sources. The main features of these catalogs are presented in table 1.

Table 1. The main features of 3FGL and 3FHL catalogs.

	3FGL	3FHL
Energy range	100 MeV – 100 GeV	10 GeV – 2 TeV
Number of sources	3034	1556
Period of observation	4 years	7 years

Data processing software version	Pass 7	Pass 8
Experimental energy spectrum bins	100 MeV – 300 MeV 300 MeV – 1 GeV 1 GeV – 3 GeV 3 GeV – 10 GeV 10 GeV – 100 GeV	10 GeV – 20 GeV 20 GeV – 50 GeV 50 GeV – 150 GeV 150 GeV – 500 GeV 500 GeV – 2 TeV
Interpolation energy spectrum types [a]	PowerLaw (2523 sources) LogParabola (395 sources) PLExpCutoff (110 sources) PLSuperExpCutoff (6 sources)	PowerLaw (1524 sources) LogParabola (32 sources)

[a]The mathematical formulas of interpolation energy spectra are given in [3, 4].

3. The considered GAMMA-400 observational programs

Taking into account the scientific goals of the GAMMA-400 experiment, we considered two possible programs of observations. The first one is the continuous rotation of the instrument axis in the Galactic plane with permanent angular velocity. The second one is the continuous orientation of telescope axis to the center of the Galaxy. The observational period was chosen the same and equal 1440 days.

Figure 3 illustrates the evaluated GAMMA-400 exposure at E_γ = 10 GeV in Galactic coordinates for two programs of observations and the 1440-day period. The units are equivalent on-axis observing time in seconds. The exposures for the other energies are close to the exposure at 10 GeV because the dependence of the instrument efficiency vs. gamma-ray incident angle demonstrates the weak dependence from the energy of gamma quanta (see figure 2).

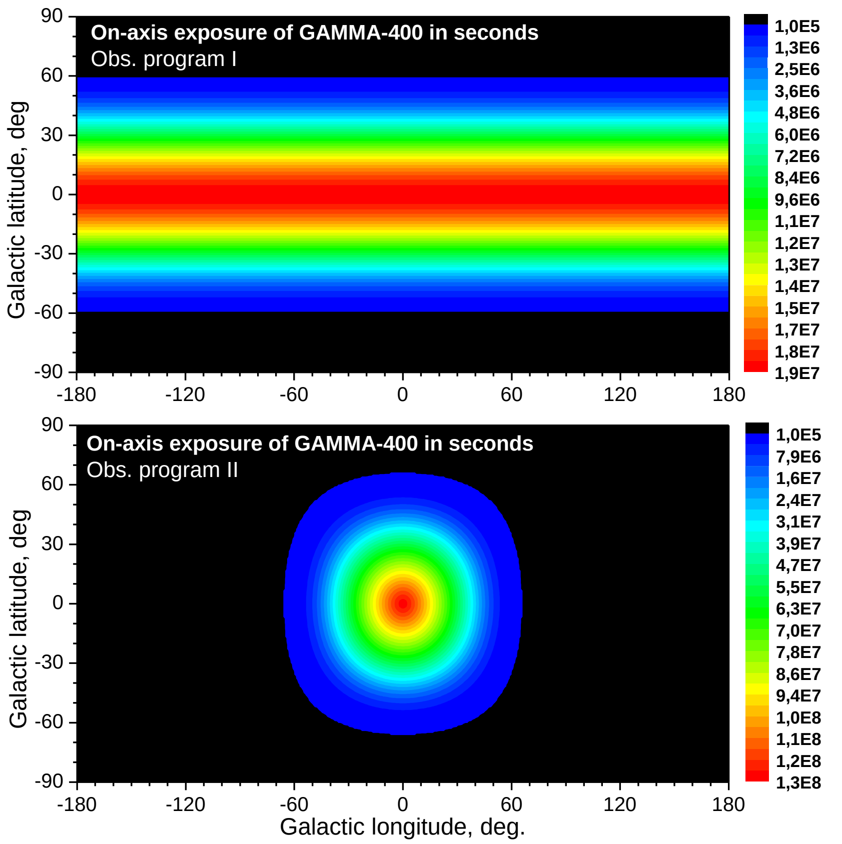

Figure 3. The evaluated GAMMA-400 on-axis exposure in seconds at E_γ = 10 GeV in Galactic coordinates for the first (*top*) and second (*bottom*) observational programs.

As it can be seen from figure 3, for the first program of observations GAMMA-400 will observe the Galactic disk with exposure about 20 Ms. For the second observational program GAMMA-400 will observe the center of the Galaxy only but the exposure will be in six times more – about 120 Ms.

4. The expected statistics of gamma-quanta from discrete sources

The estimated statistics of gamma quanta in 100 MeV - 100 GeV and 10 GeV - 2 TeV energy ranges from 3FGL and 3FHL discrete sources collected with GAMMA-400 telescope during the first and second observational programs are presented in figures 4 and 5, respectively.

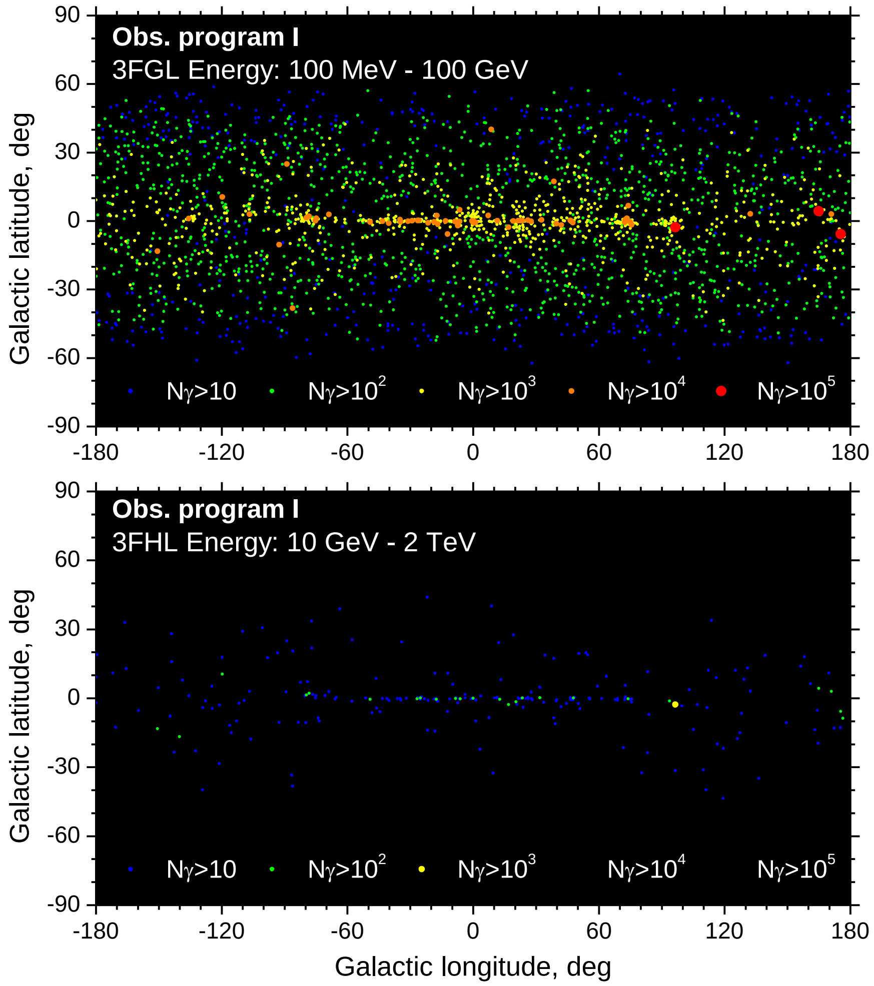

Figure 4. The estimated statistics of gamma quanta in 100 MeV - 100 GeV (top) and 10 GeV - 2 TeV (bottom) energy intervals from 3FGL and 3FHL discrete sources collected with GAMMA-400 during the first observational program.

For the first observational program the number of gamma quanta in the energy range 100 MeV - 100 GeV from single sources such as Vela, Crab, Geminga will be more than 10^5, and for the most sources in Galactic disk the number of gammas will be in the range 10^3 - 10^5. For the second program the number of gammas in 100 MeV - 100 GeV energy range from the several sources in the Galactic bulge will be > 10^5 and for the most sources the number of gammas will be more than 10^4. The statistics in the higher energy range 10 GeV – 2 TeV will be in about one hundred times less.

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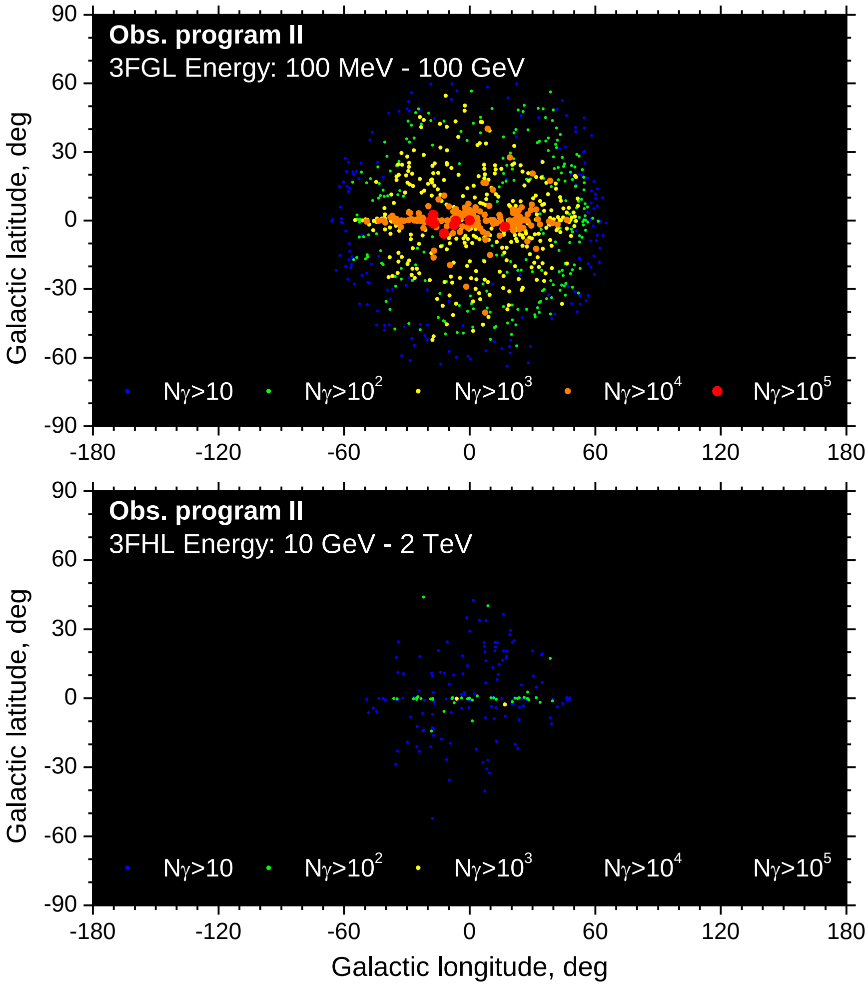

Figure 5. The estimated statistics of gamma quanta in 100 MeV - 100 GeV (top) and 10 GeV - 2 TeV (bottom) energy intervals from 3FGL and 3FHL discrete sources collected with GAMMA-400 during the second observational program.

Table 2 presents the number of sources with collected number of gammas more than 30 in the energy range from E_{min} to E_{max} for both observational programs.

The number of gamma quanta in nine bines in the 100 MeV – 2 TeV energy interval accumulated during the first and second GAMMA-400 observational programs is illustrated in figure 6.

Table 2. The number of sources with collected number of gammas more than 30 in the energy range from E_{min} to E_{max} for the first and second observational programs.

Catalog	**Energy interval** $E_{min} \div E_{max}$	**Number of sources with $N_\gamma > 30$**	
		Observation program I	Observation program II
3FGL	100 MeV – 100 GeV	2331	848
3FGL	300 MeV – 100 GeV	2039	775
3FGL	1 GeV – 100 GeV	1293	642
3FGL	3 GeV – 100 GeV	432	425
3FHL	10 GeV – 2 TeV	83	106
3FHL	20 GeV – 2 TeV	34	46
3FHL	50 GeV – 2 TeV	8	18

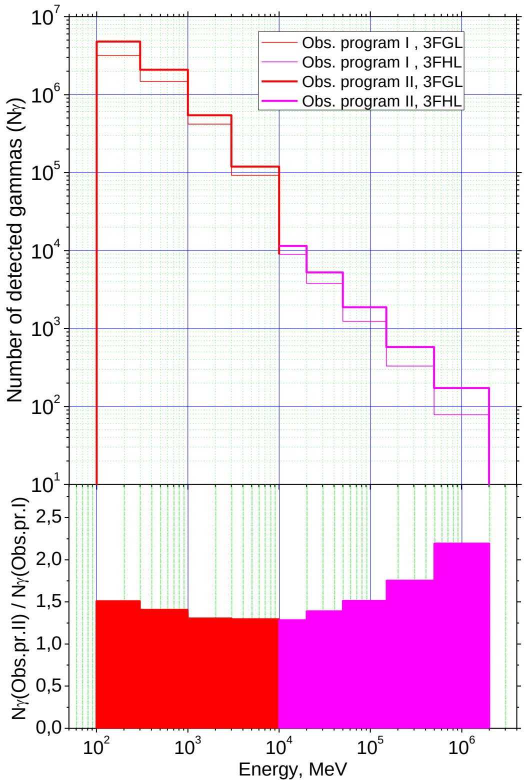

Figure 6. The total number of detected gammas in nine bins in the 100 MeV – 2 TeV energy range for the first and second observational programs.

As can be seen from table 2, for E_{min} < 1 GeV the number of observed sources for the first program is 2-3 times higher than the number of sources observed during the second program. At E_{min} > 3 GeV, more sources will be observed for the second program. In this case, the total number of observed gammas from sources for the second program will be ~1.5 times larger (see figure 6). Thus, the average number of gammas collected from separate sources during the second observational program will be 3-5 times greater than during the first program.

5. Conclusion

In this work we estimated the expected statistics of gamma quanta that can be accumulated with GAMMA-400 telescope from known discrete astrophysical gamma-ray sources in the disk of our Galaxy during observations in orbit. 3FGL and 3FHL catalogs of discrete gamma-ray sources obtained in the Fermi experiment were used to calculate the number of gammas. We considered two possible observational programs. The first program is the scanning of the Galactic plane, the second is the continuous observation of the Galactic center.

As it is followed from obtained results, from statistical point of view the second observational program is more effective. This program will allow us to observe about 800 discrete gamma-ray sources with unprecedented continuous exposure up to 120 Ms. The unique angular and energy resolutions of the GAMMA-400 instrument will permit to investigate in details these sources at very hard background conditions in Galactic bulge.

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