Gamma-Radiation of the High Energy and GAMMA-400 Project

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Abstract

There are no experimental data on the high-energy gamma-radiation (30 GeV < E_γ < 1 TeV). This energy range is very important for understanding of the nature of the diffuse gamma-radiation. GAMMA-400 collaboration presents the project of the gamma-ray telescope for observations in the range mentioned. Some characteristics of GAMMA-400 instrument and estimations of possible statistics are given in this paper.

Recent decades investigations in the gamma-ray astronomy were performed world-widely both for high-energy gamma-rays (COS-B, GAMMA-1, and EGRET) and for VHE ones (ground-based observations of various scientific groups). Most impressive results were obtained with EGRET: discovery of many extragalactic discrete sources and measurements of energy spectra for the galactic diffuse gamma-radiation and most bright sources for energies up to 30 GeV [1]. As for VHE measurements, it should be noted that the number of trustworthy data is rather limited for this energy range: only gamma-rays from Crab and Mrk 421 were detected with high reliability [2, 3]. The energy range from several tens GeV up to TeV has not investigated at all. At the same time the data on the gamma-radiation for this intermediate range are of great importance for several reasons: (1) the energy spectrum of known discrete gamma-ray sources will give information for construction of source model; (2) energetic and galactic coordinate dependencies of the diffuse gamma-radiation will allow us to clear up if this radiation has the proton origin (even recent EGRET measurements gave the exponent of the energy spectrum less than that for cosmic-ray protons, though, as one would expect, exponents must be equal; such flattening of the gamma-ray spectrum is likely to be connected with the influence of the inverse Compton scattering of high-energy electrons by low-energy photons); (3) according to modern ideas, the annihilation radiation of neutralinos (hypothetical particles constituting the Dark Matter) has energy inside this energy range; (4) gamma-ray measurements in this interval overlapping with E_γ < 0.3 GeV and E_γ > 0.3 GeV ranges allow us to associate the experimental data in these ranges with great reliability. The significance of gamma-ray investigations in this intermediate range formulated by us some years ago [4, 5] is now generally recognized and many projects for such measurements are proposed [6 - 9]. The main point (common for all proposals) is the direct detection of primary gamma-rays with an instrument on board the satellite. Such instrument for the energy range discussed must have the sufficiently large sensitive area (as the gamma-ray flux is very low) and the heavy device for the energy measurement (calorimeter or magnetic analyzer). To be sure, such experiment needs the satellite with very heavy payload and this is the main problem in the realization of any project.

Our collaboration of several Russian Research Institutes presents the project of the gamma-ray telescope GAMMA-400 for direct measurements of the primary gamma-radiation in the energy range from several GeV to about 1 TeV. Figure 1 shows schematic view of the GAMMA-400 instrument including veto-detector, convertor, time-of-flight and coordinate systems, and calorimeter.

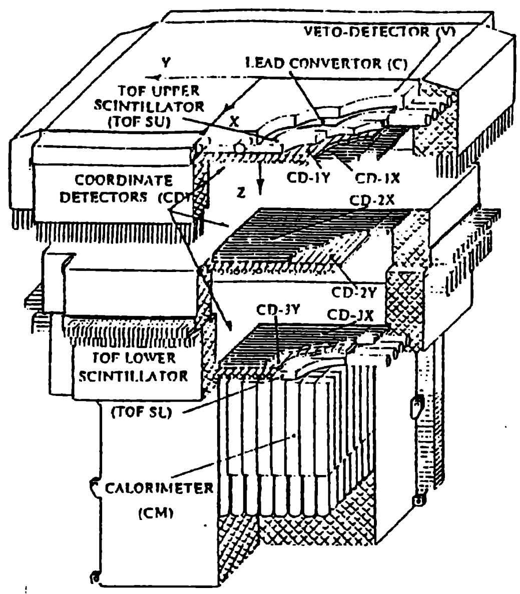

Fig. 1. Schematic view of GAMMA-400.

During the process of the GAMMA-400 planning we decided not to use such delicate detectors as spark or drift chambers because of some problems connected with their use and not so easy solved in the conditions of space flight: necessity to change continually gas in chambers, very high voltage and (as a consequence) high level of electrical interferences, strong requirements to the stability of experimental conditions and others.

Only solid scintillation and Cherenkov detectors are used in GAMMA-400 (even in the coordinate system). The coordinate system has three parallel layers, the distance between two neighbouring layers is 30 cm. Each of layers consists of two mutually perpendicular rows of scintillation bars with the section of 2×1 cm^2. The trajectory of high-energy charged particle going through detector system can be reconstructed because we have its coordinate in three levels. The coordinate accuracy is ±1.4 cm in this case and the corresponding angular resolution is not worse $\pm1.3^0$. The GAMMA-400 homogeneous calorimeter from lead glass or CsI(Tl) (depending on the financial possibilities) has the thickness of 16 radiation length and has the energy resolution better than 5% at the gamma-ray energy of 10 GeV.

The most important problem of the correct determination of the gamma-ray spectrum in the high-energy range is the elimination of the effect of the

"backscattering current" (BC) (low-energy electrons and photons moving backward from calorimeter). Such albedo photons coming into veto-detector may create charged particles and so reduce the gamma-ray flux. As the number of albedo particles produced increases with the energy, the flux reduction will be stronger at higher energies and one will have the spectrum distortion. To avoid this effect we introduced the special system (BC system) in GAMMA-400. As a matter of fact, the BC system is the time-of-flight system with the TOF SU detector as "start"-detector and veto-detector as "stop"-detector. The time difference between "start"- and "stop"-signals is about 0 and 4 ns for charged primary and albedo particles, correspondingly. So we have possibility to distinguish these two events and get correct spectrum.
The main characteristics of the GAMMA-400 telescope are given in Table 1.

Table 1.

Sensitive area	0.4 m^2	Coordinate accuracy	±1.4 cm
Geometric factor	0.64 m^2sr	Angle resolution	$\pm 1.3^0$
Angle aperture	80^0	Conversion efficiency	0.7
Converter thickness	0.6 cm	TOF efficiency	~ 1000
Calorimeter thickness	30 cm	TOF time resolution	~ 1 ns
Size	1.25 m × 1.1 m	Energy resolution (E_γ > 10 GeV)	5%
Weight	700 kg	Power	700 W

We made some estimations of possible statistics for the diffuse radiation, several bright sources, and gamma-ray line from neutralino annihilation. The results for the diffuse radiation are given in Table 2 (J(E) is the flux in $m^{-2}s^{-1}sr^{-1}GeV^{-1}$, N is the number of couns per year in the range ΔE=0.1E).

Table 2.

	k=1.9	A=0.07686	k=2.6	A=0.8312	k=2.8	A=1.6411
E, GeV	J(E)	N	J(E)	N	J(E)	N
30	$1{,}2 \cdot 10^{-4}$	7258±85	$1{,}2 \cdot 10^{-4}$	7258±85	$1{,}2 \cdot 10^{-4}$	7258±85
100	$1{,}2 \cdot 10^{-5}$	2460±50	$5{,}2 \cdot 10^{-6}$	1060±32	$4{,}1 \cdot 10^{-6}$	830±29
400	$8{,}7 \cdot 10^{-7}$	706±27	$1{,}4 \cdot 10^{-7}$	115±11	$8{,}5 \cdot 10^{-8}$	68±8
1000	$1{,}5 \cdot 10^{-7}$	308±17	$1{,}3 \cdot 10^{-8}$	27±5	$6{,}5 \cdot 10^{-9}$	13±4
2000	$4{,}1 \cdot 10^{-8}$	166±13	$2{,}2 \cdot 10^{-9}$	9±3	$9{,}4 \cdot 10^{-10}$	4±2
3000	$1{,}9 \cdot 10^{-8}$	115±11	$7{,}6 \cdot 10^{-10}$	5±2,2	$3{,}0 \cdot 10^{-10}$	2±1,4

We have used in our calculations the energy spectrum $J(E)=AE^{-k}$ extrapolated up to 1 TeV from the region investigated E_γ < 30 GeV and normalized to experimental values at E_γ=30 GeV. We have taken three different values k in the case of diffuse radiation and the value k corresponding to one obtained in the energy range 100 MeV - 30 GeV for discrete sources.
Make some comments on the possibility to detect gamma-ray line produced by the annihilation of neutralinos. According to modern ideas, the flux of such quanta, if they exist, does not depend on the mass of neutralino. Its

value is not known exactly and we have only mass estimations of different authors, results differing one another up to ten times. The number of counts in GAMMA-400 in one year of observation is equal to 40 and less than 4 in the case of the most optimistic and pessimistic estimation, correspondingly.
We believe there is a possibility: (1) to measure the spectrum of the diffuse gamma-radiation up to energy 1 TeV with reasonable statistic accuracy even at k=2.8; (2) to measure the gamma-ray spectrum from Vela, Crab, Geminga, and Mrk 421 up to energy 1 TeV, if the diffuse radiation spectrum has $k > 2.0$; (3) to get some indications on the annihilation gamma-ray line (with the standard deviation of 4σ), if its energy is greater than 300 GeV and the diffuse gamma-radiation spectrum has $k > 2.8$ (even though the energy resolution of GAMMA-400 is only 10%).
We would like to give some comments concerning the GAMMA-400 angle resolution. As mentioned above, our scientific goal in the investigation of the discrete gamma-ray sources is the study of the energy spectra from known bright objects and not the looking for new ones or clearing up any spatial details. For this reason we does not need very high angle resolution, but it is sufficient to have only such that gives us possibility to see the source on the background of the diffuse radiation. The same angle detection accuracy is also sufficient for measurements of the diffuse radiation. At the same time the satellite, on which GAMMA-400 is supposed to install, will operate in the sky-scanning mode and it is obvious that the high angle accuracy is superfluous in this case. Estimations given above show the GAMMA-400 angle resolution is adequate to aims of the experiment.
More important problem is the good energy resolution. It would be very desirable to get $\Delta E/E$ less than 5%, but it requires thicker calorimeter and, consequently, that is more payload weight and more money.
The authors would like to have some comments from ICRC participants and will welcome scientific contacts with all scientists (theorists and experimenters) touched on this problem.
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References
[1] Fichtel C.F. et al. Astron. Astrophys. **97** (1993) 13.
[2] Reinolds P.T. et al. Ap. J. **404** (1993) 206.
[3] Punch M. et al. Nature **358** (1992) 477.
[4] Dogiel V.A. et al. Proc. 20th ICRC (Moscow) **2** (1987) 356.
[5] Dogiel V.A. et al. Space Sci. Rev. **49** (1988) 215.
[6] Adams J.N et al. Ap. J. **317** (1987) 551.
[7] Carlson P. et al., Project Susysky, Preprint Inst. Phys. (Sweden) (1988).
[8] Godfrey G.L. (GLAST Working Group), Proc. Intern. Workshop "Toward a Major Atmospheric Cherenkov Detector for TeV Astro/Particle Physics", Iowa State Univ. (1993).
[9] Torii S. et al. SPIE **1734** (1992) 220.