ON THE GAMMA-ASTRONOMY OBSERVATIONS IN THE ENERGY RANGE 4 - 400 GEV

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ABSTRACT

Grounds for the neccessity to carry out observations in the energy range 1-400 GeV by gamma-telescope on the board of space vehicle are given. One of the possible versions of such telescope is discussed.

The detection of the cosmic γ-rays was carried out in wide energy range: from the lowest energies wich can be related to γ-range (some hundred keV) up to energies of 10^4 TeV. In the energy range from 50-70 MeV to some GeV the bulk of the γ-ray information was got by instruments on satellites SAS-2 and COS-B [1,2]. In the energy ranges 0.5-10 TeV and 100-10^4 TeV the detection of the γ-radiation is fulfilled with ground devices measuring accordingly Cherenkov radiation of the EAS particles generated by the primary γ-quanta in the atmosphere and charge particles themselves[3]. The last results are however not very reliable because of poor statistics and high background of events, initiated by cosmic ray protons.

As for the energy range 4-400 GeV there were no experiments at all though that interval is very interesting for the problem of the nature of the γ-radiation. Let us discuss three points: 1) diffuse γ-radiation of the Galaxy, 2) energy spectrum of some discrete sources, 3) γ-radiation of the molecular clouds.

1. According to present notion diffuse galactic γ-radiation with $E_\gamma > 0.1$ GeV is the result of the decay of the π^0 -mesons produced by the cosmic ray protons and nuclei in the process of the interaction with the interstellar gas. In this case the gamma-ray spectrum has to reflect the primary proton spectrum and its shape must be $E^{-2.75}dE$. But γ-ray spectrum obtained by COS-B team in the energy range 0.01 MeV - 4 GeV has $n \approx 1.9$ [4]. Such difference is connected perhaps with the nearness of that energy range to the threshold of the π^0-meson production and only at the higher energies the dependence with $n=2.75$ will appear what can be discovered if one makes γ-ray measurements in the range 1 - 400 GeV.

2. Information on the energy spectra of the discrete γ-sources is available only for limited number (4-5) of the discovered sources. We are giving here the short description of four most interesting objects.

VELA and CRAB are identified rather good with pulsars PSR

0833 and PSR0531 accordingly. Their γ-radiation in the range 70 MeV - 2GeV was detected very definitely, Vela being the most intense γ-source from all known ones. There are comparatively many data for Crab γ-radiation at energy $E_\gamma > 1$TeV but for Vela such measurements are very rare [5]. The spectrum exponent in the same energy region is for Vela and Crab n=1.89 and n=1.7 accordingly [2] ; but at $E_\gamma \approx (3-10)$ TeV for Vela radiation one has n=3.5 [13]. So we have apparent indication on the existence of some spectral peculiarities in the range 2GeV - 1TeV for Vela γ-radiation.

GEMINGA (2CG195+04) is the second γ-source on its intensity in the range (0.07 - 2)GeV. Its spectrum exponent is n=1.8 in that range[7], but in the range 5-100 MeV its radiation is negligible [6]. Comparison of the data on Geminga radiation at $E_\gamma > 1$TeV with the COS-B data gives n=2.3. But measurements [9] at energy $E_\gamma > 400$ MeV gave figures 6 times lower than one gets if n=2.3. There is some contradictory information [8,10] on the existence of the periodicity with T=60s; according the latest data [14] that period was not observed, so the fluxes given in [7] and [8] become rather doubtful. That confirm the necessity of the measurements in the energy range 1 - 400 GeV.

CYG X-3 is variable X-ray source; its γ-radiation was detected in the energy ranges 0.1 - 1 GeV, $E_\gamma > 1$ TeV and also at $E_\gamma >$ 1000 TeV [3], though results of different observers are not in agreement: for instance SAS - II observed radiation in the range of hundreds MeV, but COS-B did not. If one suppose the united spectrum slope from 0.1 MeV up to 1 TeV the spectrum exponent will be n=2. The measurements in the energy range 1-400 GeV may clear some peculiar characteristics of its radiation.

3. Among the γ-sources observed by COS-B there are some attributed to the molecular clouds (2CG353+16 for example). It is not excluded the most part of the unidentified γ-sources are gigantic molecular clouds [11]. In this case the expected spectrum will be (according to [12]) very gently sloping ($n \sim 1$) extending up to 40-100 GeV, where it is cut rather sharply.

Thus the observations in the γ-range 1-400 GeV give possibility to get answer on the following questions:
a) if the diffuse γ-spectrum in Galaxy corresponds to the cosmic ray proton spectrum or it is less steep; in the last case the question on the origin of the diffuse radiation arises: may be it is the combined radiation of the great number of unresolved discrete γ-sources;
b)if the γ-spectrum of the molecular clouds has the shape predicted by the modern theory; on the other hand such observations help (may be) to identify with molecular clouds some γ-sources;
c) how the flat spectrum of the Vela radiation (and perhaps of other discrete sources) in the energy range $E_\gamma < 1$GeV becomes steeper in the range 1 - 10 TeV.

Apart of that the direct observations of the intense sources in the range discussed give possibility to tie the results of the flux measurements got with the method of the Cherenkov radiation in the atmosphere with the results of the direct measurements in energy range 0.1-5 GeV with on-board γ-telescopes.

We want to emphasize here one important point: because the electrons produced by γ-quanta of high energy (>1 GeV) are characterised by the small angle of the multiple scattering there is possibility to design comparatively simple γ-telescope of high efficency: in such telescope one uses for coordinate determination rather thick scintillators (instead of spark or diffusion chambers) and diminishes the number of coordinate layers up to 3; on the same reason it is possible to use γ-ray converter of the thickness up to 1-1.5 radiation length (r.l.), that permits to get high efficiency of the γ-ray detection. Such telescope may consist of the following main elements (see Fig.1): scintillation separator of the charge particles (anticoincidence counter C1), γ-quantum converter (K), electron-positron coordinate detector (system of the scintillation counters C2-C7), energy measuring device (calorimetr C8-C15).

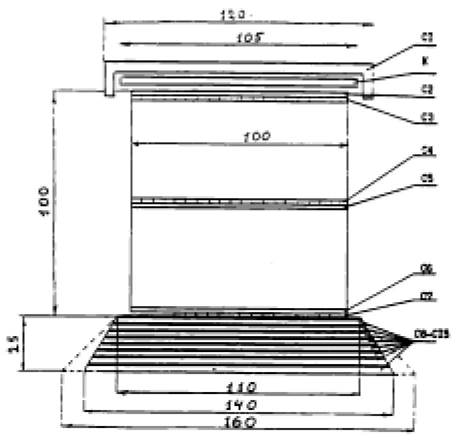

Fig.1

As coordinate detector one can use scintillation trays, mounted from long rods (length ~1m) with the width of 3cm. If we take 6 trays divided in 3 layers (two trays in each layer) two neighbouring trays being oriented in perpendicular directions, we shall have possibility to determine the position of the passing particle with accuracy 3cm. The distance between the 1-st and 3-rd layers is 1m and angle accuracy will be ~3.5°. In order to determine the velocity direction pulses from the 1-st and the 3-rd layers are fed to time-of-flight circute.

The calorimeter consists of 8 lead layers (the total thickness is 22 r.l.) separated one from other by plastic scintillators (thickness 1cm). The accuracy of the energy measurements in the range 1-10GeV is better than 20%.

The radiator is supposed to be tungsten slab 1r.l. thickness, that give possibility to detect γ-quanta with the efficiency 50%.

The most important part of the device is the charge particle separator. As the primary cosmic ray intensity is 5-6 orders of magnitude higher than γ-rays one it is necessary the separator unefficiency would be less than 10^{-6}-10^{-7} if one allows c.r. proton contribution is not more than 10% of the -ray intensity. The estimations made show that scintillator of 3cm thick can provide such efficiency. C.r. protons can be confused with γ-ray through the re-charge process when proton converts into neutron without emitting any charge fast particle which can be detected by scintillator C1. The calculations show the contribution of this effect at the energy $E_\gamma > 5$MeV constitute less than 10-20%. Besides the shape of the shower in calorimeter initiated by nucleon differs from one initiated by electron; this circumstance may help to eliminate the neutron contribution.

The γ-telescope discussed here has the area equal to 1 m^2 and geometric factor Γ=0.6 sq.m ster. We have made some estimations of the statistics expected if measurement time is 100 hours. The results are given in Table 1 (for diffuse galactic γ-radiation) and Table 2 (for discrete sources and for sources suspected to be molecular clouds). Figures in Table 1 were got for the case, when γ-ray detection efficiency is η=0.5, total exposition $\Gamma t = 1.1\cdot10^9 cm^2 c\cdot rad$, integral energy spectrum $N(>E_\gamma) \sim AE_\gamma^{(1-n)}$.

Figures in Table2 correspond to η =0.55 and Γt=3.6 $10^9 cm^2 s$. In the case of discrete sources their γ-spectra supposed are $AE_\gamma^{(1-n)}$. In the case of moleculare clouds spectra are $N(>E_\gamma)=A \ln(E_M/E_\gamma)$ if $E_\gamma < E_M$ and $N(>E)=0$ if $E_\gamma > E_M$. Background figures shown in Table2 reflect the difuse radiation contribution if n=1.9 and the source region radius is 6°. Table2 shows the possibility to measure spectra for Vela, Geminga and Crab. The statistics may be better if measurements are carried out for longer period. It is seen from Table1 that the measurements permit to choose real n.

TABLE 1

E_γ, GeV	Direction of the telescope axis: Galactic center, n=1.91	Galactic center, n=2.7	Galactic anticen., n=1.89	Galactic anticen., n=2.7	Proton contribution if separator unefficiency is 10^{-7}
1	4900	2600	1570	800	270
4	1400	250	460	76	25
10	600	50	200	16	5.4
40	170	5	60	1.5	0.5
100	75	1	25	0.3	0.11
400	20	0.1	8	0.03	0.01

TABLE 2

E_γ, GeV	1		4		10		40		100	
Discrete sources	N_γ	N_γ/σ	N_γ	N_γ/σ	N_γ	N_γ/σ	N_γ	N_γ/σ	N_γ	N_γ/σ
Vela, n=1.89	3300	157	960	87	425	57	125	32	55	21
Geminga, n=1.8	1250	60	410	37	200	27	65	17	32	12
Geminga, n=2.3	1250	60	205	19	63	8.4	10	2.6	3	1.1
Crab, n=2.2	330	16	63	5.7	21	2.8	2	0.5	1.3	-
Cyg X-3, n=2	11	0.5	2.8	0.2	1.1	-	0.3	-	0.1	-
Background	446		126		55		15		7	
σ	21		11		7		4		2.5	

Mol. clouds	E_M= 40GeV			E_M=100 GeV			
E_γ, GeV	1	4	10	1	4	10	40
2CG353+16	1360	850	510	1470	1020	730	290
2CG078+01	3080	1920	1150	3330	2330	1670	660
2CG288-00	1980	1240	740	2140	1480	1060	420
σ	21	11	7	21	11	7	4

References

1. Fichtel C.E.,Hartman R.C. et al.,Astroph.J.,1975,198,163.
2. Bignami G.P.,Hermsen W.A. et al.,Rev. Astron.Astroph.,1982,21.
3. Vladimirsky B.M.,Galper A.M. et al.,UFN (Soviet),1985,145,255.
4. Sacher W.,Schönfelder V., Space Sci.Rev., 1983,36,249.
5. Houston B.,Wolfendale A.W., Vistas in Astron.,1982,26,107.
6. GlyanenkoA.S.,IyudinA.F. et al.,Trudy FIAN (Soviet),1985,162,6.
7. ZuskinYu.,MukanovD., Proc.18-th ICRC,1983,XG-1,122;Proc. 19-th ICRC, 1985,v.1,177.
8. KaulR.,Ramat H. et al.,Proc. 19-th ICRC, 1985, v.1, 165.
9. Gawly M.,Fega D. et al.,Proc. 19-th ICRC, 1985, v.1, 173.
10. Buccheri R. et al., Proc. 19-th ICRC, 1985,v.1, 169.
11. Berezinsky W., Bulanov S., et al., Cosmic Ray Astrophysic, 1984,Moscow, Publ. Company "Nauka",
12. Gurevich A.,Dogiel V., Letters to AJ,(Soviet),1985,11,675.
13. BhatP., Gupta S. et al., Astronomy and Astrophys. (in press).
14. Bhat P., Gopalakrishna N. et al.,Astron. and Astroph. (in press).