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

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ABSTRACT

Grounds for the necessity 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 tele-
scope is discussed.

The detection of the cosmic y-rays was carried out in wide 
energy range: from the lowest energies which can be related to 
Eγ–range (some hundred keV) up to energies of 10^5 TeV. In the 
energy range from 50–70 MeV to some GeV the bulk of the y-ray 
information was got by instruments on satellites SAS–2 and COS–B 
[1, 2]. In the energy ranges 0.5–10 TeV and 100–10^7 TeV the de-
tection of the y–radiation is fulfilled with ground devices 
measuring accordingly Cherenkov radiation of the EAS particles 
genematically produced by the primary y–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 eve-
nts, 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 y–radiation. Let us discuss three points:
1) diffuse y–radiation of the Galaxy, 2) energy spectrum of so-
me discrete sources, 3) y–radiation of the molecular clouds.

1. According to present notion diffuse galactic y–radiation 
with Eγ > 0.1 GeV is the result of the decay of the Ξ^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^2.75dE. But y–ray spectrum obtained by 
COS–B team in the energy range 0.01 MeV – 4 GeV has n = 1.9 [4]. 
Such difference is connected perhaps with the nearness of that 
energy range to the threshold of the Ξ^0–meson production and 
only at the higher energies the dependence with n = 2.75 will 
appear what can be discovered if one makes y–ray measurements 
in the range 1 – 400 GeV.

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

Vela and Crab are identified rather good with pulsars PSR

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OS33 and FSR0531 accordingly. Their $\gamma$-radiation in the range 70 MeV - 2 GeV was detected very definitely, Vela being the most intense $\gamma$-source from all known ones. There are comparatively many data for Crab $\gamma$-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 $n=3.5$ [1]. So we have apparent indication on the existence of some spectral peculiarities in the range 20 GeV - 1 TeV for Vela $\gamma$-radiation.

GEMINGA (2CG195+04) is the second $\gamma$-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.

CGE X-3 is variable X-ray source; its $\gamma$-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 SAA - II observed radiation in the range of hundreds MeV, but COS-B did not. If one suppose the unified 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.

Among the $\gamma$-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 $\gamma$-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 $\gamma$-range 1-400 GeV give possibility to get answer on the following questions:
a) if the diffuse $\gamma$-spectrum in Galaxy corresponds to the cosmic ray proton spectrum or it is less steep; in the last case the discussion on the origin of the diffuse radiation arises; may be it is the combined radiation of the great number of unresolved discrete $\gamma$-sources;
b) if the $\gamma$-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 $\gamma$-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 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 $\gamma$-telescopes.

We want to emphasize here one important point: because the electrons produced by $\gamma$-quanta of high energy ($> 1$ GeV) are characterised by the small angle of the multiple scattering there is possibility to design comparatively simple $\gamma$-telescope of
high efficiency: 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 X-ray converter of the thickness up to 1–1.5 radiation length (r.l.), that permits to get high efficiency of the X-ray detection. Such telescope may consist of the following main elements (see Fig.1): scintillation separator of the charge particles (anticoincidence counter C1), X-quantnum converter (K), electron-positron coordinate detector (system of the scintillation counters C2–C7), energy measuring device (calorimeter C3–C15).

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 neighborhood 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 circuite.

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 1-100GeV is better than 20%.

The radiator is supposed to be tungsten slat r.l. thickness, that give possibility to detect X-quantna 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 X-rays one it is necessary the separator unefficiency would be less than 10^-6-10^-7 if one allows C.X protons contribution is not more than 10% of the X-ray intensity. The estimations made show that scintillator of 3cm thick can provide such efficiency. C.X. protons can be confused with X-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 Eₓ >3MeV 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 X-telescope discussed here has the area equal to 1 m² and geometric factor \( \Gamma = 0.6 \) 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 X-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 X-ray detection efficiency is \( \eta =0.5 \), total exposition \( \Gamma t = 1.1 \times 10^5 \text{cm}^2\text{c}\cdot \text{rad} \), integral energy spectrum \( \mathcal{N}(E_x) \propto E_x^{\delta} \).
Figures in Table 2 correspond to $\eta = 0.55$ and $\Gamma = 3.6 \times 10^3$ cm$^2$/s. In the case of discrete sources their $\gamma$-spectra supposed are AE, $n^{-3}$. In the case of molecular clouds spectra are $N(>E) = A \ln(E/E_0)$ if $E < E_M$ and $N(>E) = 0$ if $E > E_M$. Background figures shown in Table 2 reflect the diffuse radiation contribution if $n=1.9$ and the source region radius is 6°. Table 2 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 Table 1 that the measurements permit to choose real $n$.

<table>
<thead>
<tr>
<th>$E_\gamma$, GeV</th>
<th>Direction of the telescope axis</th>
<th>Proton contribution, Galactic center</th>
<th>Galactic anticen. if separator unfixed</th>
<th>$n=1.9$</th>
<th>$n=2.7$</th>
<th>$n=1.9$</th>
<th>$n=2.7$</th>
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<tr>
<td>1</td>
<td>4900</td>
<td>2500</td>
<td>1570</td>
<td>800</td>
<td>270</td>
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<tr>
<td>4</td>
<td>1400</td>
<td>250</td>
<td>460</td>
<td>76</td>
<td>25</td>
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<td></td>
</tr>
<tr>
<td>10</td>
<td>600</td>
<td>50</td>
<td>200</td>
<td>16</td>
<td>5.4</td>
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<td></td>
</tr>
<tr>
<td>100</td>
<td>75</td>
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<td>25</td>
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<td>0.11</td>
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<td>400</td>
<td>20</td>
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<td>8</td>
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<tr>
<th>$E_\gamma$, GeV</th>
<th>Discrete sources</th>
<th>$N_\gamma$</th>
<th>$N_\gamma/\sigma$</th>
<th>$N_\gamma$</th>
<th>$N_\gamma/\sigma$</th>
<th>$N_\gamma$</th>
<th>$N_\gamma/\sigma$</th>
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<tr>
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<td>157</td>
<td>960</td>
<td>87</td>
<td>425</td>
<td>57</td>
<td>125</td>
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<td>Geminga, $n=1.8$</td>
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<td>60</td>
<td>410</td>
<td>37</td>
<td>200</td>
<td>27</td>
<td>65</td>
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<td>Geminga, $n=2.3$</td>
<td>1250</td>
<td>60</td>
<td>205</td>
<td>19</td>
<td>63</td>
<td>8.4</td>
<td>10</td>
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<td>Crab, $n=2.2$</td>
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<td>16</td>
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<td>5.7</td>
<td>21</td>
<td>2.8</td>
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<td>0.5</td>
<td>2.8</td>
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<td>1.1</td>
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<td>55</td>
<td>15</td>
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<tr>
<th>$E_\gamma$, GeV</th>
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References

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