GAMMA-RAYS FROM BEAMS IN ACTIVE GALAXIES

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Abstract

We have calculated the gamma-ray spectrum produced from hadronic interactions as a beam of relativistic particles composed of electrons and protons (ions) interacts with an interstellar cloud in the environment of an Active Galactic Nuclei (AGN). Energy losses by collisionless processes and Inverse Compton Scatering from the ambient radiation field must be such that the beam propagation lenght is sufficient to produce γ-ray fluxes. We use this fact to set constraints on the various beam and cloud parameters. Possible absorption effect on the shape of γ-ray spectrum is considered.

1. Introduction. The narrow, elongated features (jets) have been discovered in radio, optical and also X-ray observations of extra galactic sources [1]. They are probably produced by relativistic chaged particle (beam) emitted from the central object [2]. The identification of COS B gamma ray source 2CG 289+64 with the quasar 3C 273 [3] and MISO observations of Seyfert galaxies NGC 4151 [4] and MCG 8-11-11 [5] are the clear evidence that Active Galactic Nuclei (AGN) emit the major fraction of their power in the gamma-ray region of the photon spectrum. Recently the idea of using inelastic collisions as the gamma-ray source from π^{o} decay was discussed in two temperature spherically accretion model adopted to the quasar 3C 273 [6]. In this model the high energy gamma rays from the central region are strongly absorbed by surrounding X-ray in photon-photon pair production process. This difficulty can be avoid in the beam model. The beam electrons and the secondary electrons from the charged pions decay produced by inelastic collisions of relativistic proton-electron beam with cloud by Inverse Compton Effect and bremssthrahlung radiation give significant contribution to the hard X-rays radiation (<10 MeV) [7].

In this paper we have evaluated the expected photon energy spectrum from π^{o} decay produced in inelastic interactions of relativistic beam with cloud.

2. Gamma-ray production spectra. The relativistic electron-proton beam (e-p) passing through the cloud losses its energy by collisionless processes (resonant plasma waves, nonresonant plasma waves, ion acustic waves) [8] and by inelastic interactions of protons with the hydrogen cloud. In such case the γ radiation is produced from π^{o} decay in reaction $p + p \to \pi^{o}$ + anything. The photon emission spectra for given angle to the beam direction from the (e-p) beam interaction with the cloud gas can be described by:

$$\frac{dN}{dE d\Omega dV dt} = \beta \cdot c \cdot n_H \cdot n_b \iiint \frac{p_{\pi^o}}{E_{\pi^o}} \cdot \left\{ E_{\pi^o} \cdot \frac{d^3\sigma}{d^3 p_{\pi^o}} \right\} dp_{\pi^o} \cdot d\theta_{\pi^o} \cdot d\varphi_{\pi^o}, \quad (1)$$

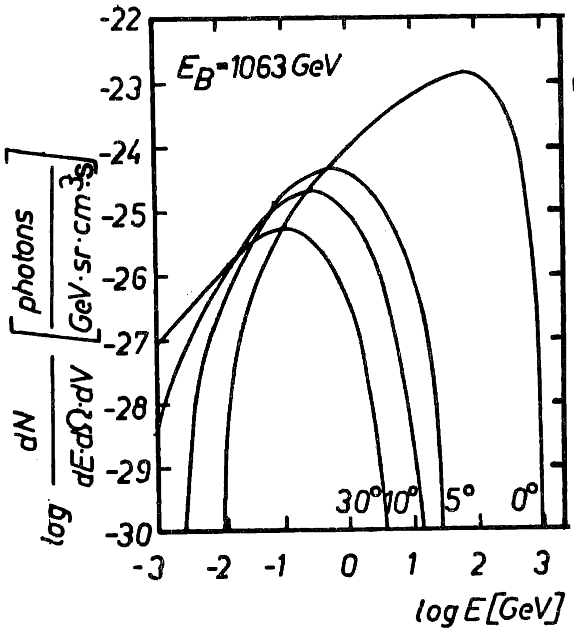
where:

n_H - concentration of the hydrogen in the cloud,
n_b- concentration of the proton in the beam,
β - the relative velocity of the beam,
c - velocity of light,
$p_{\pi^o}, \theta_{\pi^o}, \varphi_{\pi^o}$- the momentum of π^{o} and the angles of π^{o} emision to the beam

axis respectively.

$E_{\pi}\cdot\dfrac{d^3\sigma}{d^3p_{\pi^\circ}}$ – cross section for π° production (taken from Stephens and Badhwar [9])

As a example on the Figure 1 are shown gamma-ray energy production spectra (divided by $\beta\times c$) for: $n_H=1$ (cloud concentration) and $n_b=1$ (beam concentration), proton energy $E_B=1063$ GeV and for selected angles of the photon emision to the beam axis. We can notice that this spectra have maximum as usually spectra of gamma rays from π° decay but this maximum is shifted to high energy as a result of relativistic motion of the center of mass system.



·Fig.1. The gamma-ray energy production spectra for $n_H=1$, $n_b=1$, $E_B=1063$ GeV and different angles

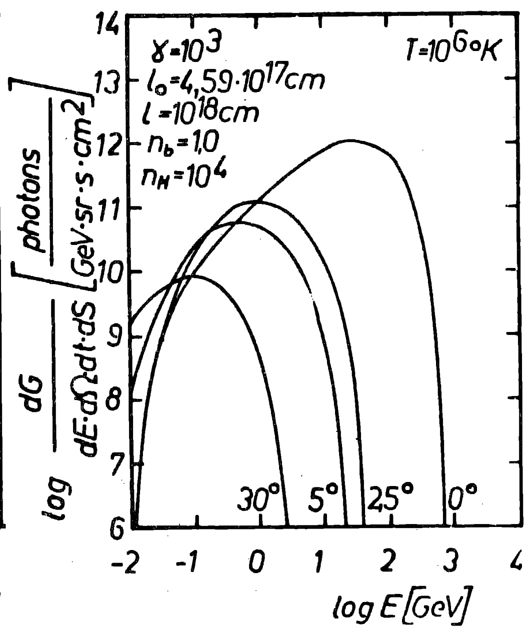


Fig.2. The gamma-ray energy spectra from the beam-cloud interaction

3. The expected gamma-ray spectra from the beam interaction. A simple beam model for AGN have been considered. It was assumed:

i) monoenergetic, highly collimated electron-proton (e-p) beam is emited from the central engine with Lorentz factor (γ_o), the cross-section of beam (S), and the concentration of the protons in the beam (n_b),

ii) the beam traverses the hydrogen cloud with diameter (L), concentration (n_H) and temperature (T),

iii) the electrons of the beam losses energy by collisionless processes [8].

This mechanism changes the Lorentz factor of the beam during its propagation in the cloud according to the law $\gamma(x)=\gamma_o\times 2^{-x/L_o}$, where L_o -the propagation length [8], x - traversed distance in the cloud. The energy losses of the beam protons by the inelastic collisions are less than electrons energy losses for collisionless processes.

The gamma-ray emission spectra from such beam-cloud interaction can be described by the formula:

$$\frac{dG(E)}{dE d\Omega dt} = \int_0^L S\cdot\frac{dN(E,\gamma,\theta)}{dE d\Omega dt dV}\cdot dx \,, \qquad (2)$$

where: $\dfrac{dN(E,\gamma,\theta)}{dE d\Omega dt dV}$ -the gamma-ray energy production spectra described by formula 1.

The calculation have been made for events in which interaction length for inelastic collisions is much greater than column density traversed by beam. In such case the beam propagation is determined by collisionless processes and is remained its monoenergetic structure. The gamma-ray spectra have been obtained from the formula 2 for different selected angles of emission to the beam axis and parameters taken from the paper Rose et al.,[8]: $n_H=10^4$ particles/cm^3, $n_b=1$ particles/cm^3, $S=1cm^2$, $\gamma_0=1000$, $L_0=4.59\times10^{17}$cm, $T=10^6$K (Fig.2). For such parameters the (e-p) beam is not fully absorbed in the cloud and goes out with Lorentz factor about 200.

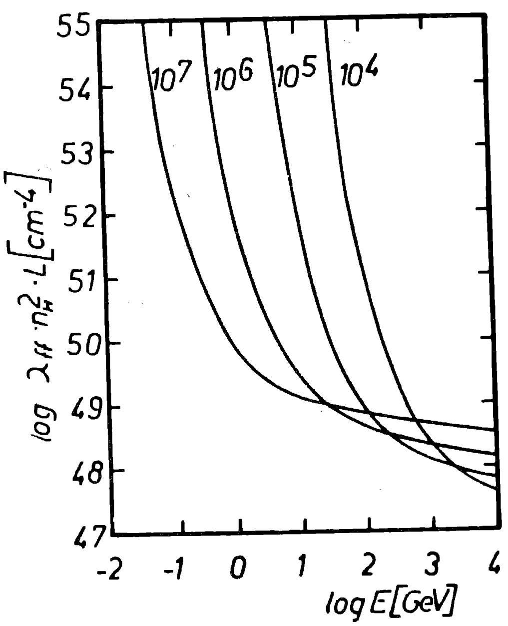


Fig.3. The photon mean free path lenght multiplied by n_H^2L versus energy for photon-photon pair production

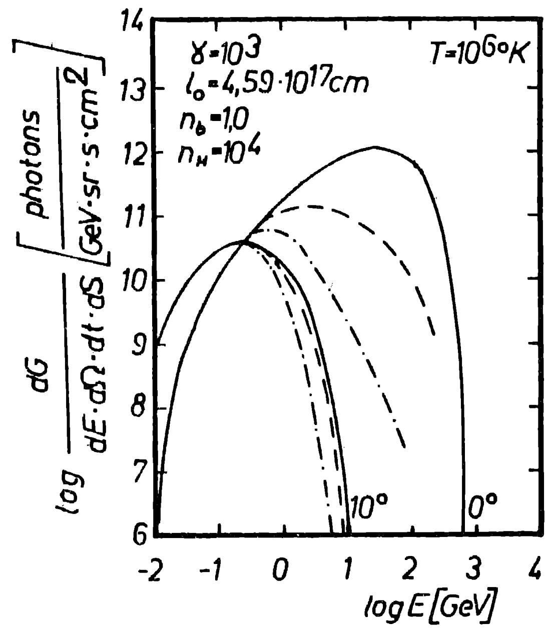


Fig.4. The gamma-ray energy spectra from the beam cloud interacion corrected on photon-photon interaction:
——— without absorption,
with absorption
– – – – for $L=3\times10^{20}$cm,
—·—·— for $L=5\times10^{20}$cm

4. The absorption of the gamma-ray in the cloud. The X-ray radiation from beam should be collimated in the same way as gamma radiation [10], so the absorption of gamma-rays (emited in the small angle to the beam axis) on this X-ray radiation is neglected. For analysed beam and cloud parameters only absorption on background thermal bremsstrahlung photons from cloud plasma can be efficient. Photon-particle absorption is less significant [11]. On the Fig.3 we have been presented mean free path length for photon-photon pair production process in the cloud (concentration n_H, diameter L) on the background thermal bremsstrahlung multiplied by $n_H^2\times L$ for different plasma temperature. The gamma-ray spectra corrected on this process are presented on Fig.4 . The energy losses of high energy positrons (created in photon-photon interactions) on the annihilation process are less than on the other processes [12,13,14], so photons from annihilation of positrons can give significant contribution in the energy range about 10 MeV.

5. Discussion and conclusions. We have presented gamma-ray spectra from hadronic (e-p) beams interactions with ambient gas whose physical conditions are similar to those deducted on the base of emission lines observations from

regions surrounding AGN. In Table 1 have been presented power output in gamma-ray range (π^0 decay) for following beam and cloud parameters: $\gamma=10^3, n_b=1$, $n_H=10^4$, $L_0=5\times10^{21}$cm, $T=10^4$K, $S=10^{32}$cm^2 (i.e. beam radius $r=3\times10^{15}$cm), $L=3\times10^{20}$ cm (i.e. 5g/cm^2) and for different angles to the beam axis (α). The calculation show (Table 1) that this mechanism can supply power output of AGN in the case of small observational angles to the beam axis.

Table 1

α	0°	2.5°	5°	10°
I(erg$\times$s$^{-1}\times$sr^{-1})	4×10^{48}	3×10^{44}	3.5×10^{43}	4×10^{42}

Intensity of produced gammma-ray spectra strongly depends on the beam Lorentz factor (γ_0) and angle of observations (α). It is possible that the beam is produced with large Lorentz factor $\gamma_0 > 10^3$ but interacting with plasma surrounding central engine (black hole?) can reduce its γ to a few (as a result of collisionless processes) and form large scale radio and optical jet. For certain parameters, beam can be completely absorbed by cloud but can produce efficient gamma-ray and neutrino flux. If the cloud column density is greater than 10^{24} particles/cm^2 (Fig.3) the absorption of high energy gamma-ray on background cloud thermal bremsstrahlung radiation can change the spectrum shape in the wide energy range (Fig 4.). Our preliminary results concern only high energy gamma range $E_\gamma > 10$MeV. The electrons of relativistic beam and secondaries from $\pi^\pm$ decay by Inverse Compton Effect and bremsstrahlung can produce hard X-ray spectrum (E<10 MeV).

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References

1. Bridle A.H. and Purley R.A.,1984, Ann. Rev. Astr. Astrophys., 22, 319.
2. Pearson T.J. et al., 1981, Nature, 290, 365.
3. Swanenburg B.N. et al., 1981, Astrophys J., 243, L69.
4. Perotti M. et al., 1981, Astrophys J., 247, L63.
5. Perotti M. et al., 1981, Nature, 292, 133.
6. Tkaczyk W. et al., 1984, Proc. Int. Symposium on X-Ray Astrnomy, Bologna (Italy), 499.
7. Morrison P. et al., 1984, 280, 483.
8. Rose W.K. et al., 1984, Astrophys. J., 280, 550-560.
9. Stephens S.A., Badhwar G.D., 1981, Ap. Space Sci., 76, 213-233.
10. Bassani L., Dean A.J., 1981, Nature, 294, 332.
11. Lang K.R., 1974, Astrophysical Formulae (New York: Springer-Verlag).
12. Karakula S., Tkaczyk W., 1985, Multifrequency Behaviour of Galactic Accreting Sources, ed. F.Giovannelli, 243.
13. Stepney S., 1983, M.N.R.A.S., 202, 467.
14. Begelman M.C. et al., 1984, Rev.Mod.Phys., 56, 321.