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Direct and reprocessed γ-ray emission of kpc-scale jets in FR I radio galaxies

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Abstract. We discuss the contribution of kiloparsec-scale jets in FR I radio galaxies to the diffuse γ-ray background radiation. The analyzed γ-ray emission comes from inverse-Compton scattering of starlight photon fields by the ultrarelativistic electrons whose synchrotron radiation is detected from such sources at radio, optical and X-ray energies. We find that these objects, under the minimum-power hypothesis (corresponding to a magnetic field of $300\,\mu$G in the brightest knots of these jets), can contribute about one percent to the extragalactic γ-ray background measured by EGRET. We point out that this result already indicates that the magnetic fields in kpc-scale jets of low-power radio galaxies are not likely to be smaller than $10\,\mu$G on average, as otherwise the extragalactic γ-ray background would be overproduced.

Keywords: radiation mechanisms: non-thermal — galaxies: active — galaxies: jets — gamma-rays: theory

INTRODUCTION

Observations by the EGRET instrument on board the CGRO have established presence of isotropic extragalactic background radiation in the 100 MeV – 10 GeV photon energy range, with an integrated flux $I(> 100\,\mathrm{MeV}) \leq 10^{-5}\,\mathrm{ph\,cm^{-2}\,s^{-1}\,sr^{-1}}$ and a curved (concave) spectrum [8]. Here we discuss the issue of high-energy γ-ray emission from the kiloparsec-scale jets in FR I radio galaxies, and in particular its contribution to the γ-ray background radiation as measured by EGRET. Our study is stimulated by recent results from the Chandra X-ray Observatory, which have shown that X-ray jet emission is common in FR I sources. The established synchrotron origin of this X-ray emission implies that the kpc-scale jets in FR I radio galaxies will, at some level, be sources of high- and very high-energy γ-ray emission due to the inverse-Compton scattering of ambient (galactic) photon fields by the synchrotron-emitting electrons. This problem was discussed by Stawarz et al. [5, 6]. The aim of the following study presented in Stawarz et al. [7] and summarized here is twofold, namely an estimation of the aforementioned contribution (taking into account effects of absorption and subsequent re-processing of γ-ray photons by infrared-to-ultraviolet background radiation), and discussion of the constraints on the jet parameters which can be imposed in this way.

We assume that all of the kpc-scale jets in FR I radio galaxies have similar properties, and that the detection rate of their brightest knots at optical and X-ray frequencies depends solely on the amount of relativistic beaming. Within this approach, we find the 'universal' electron energy distribution in the brightest knots of these jets by fitting a broken power-law to the radio–to–X-ray synchrotron continua of the FR I jet sources collected in Kataoka & Stawarz [2]. Next, we compute the γ-ray emission due to inverse-Compton (IC) scattering of the re-constructed universal electron energy distribution on the starlight radiation of the host galaxies. We include both the Klein-Nishina effects and the relativistic bulk velocity of the emitting plasma in the analysis, and assume universal value of the equipartion magnetic field for kpc-scale FR I jets $B \approx 300\,\mu$G [see 2]. Next, we relate the γ-ray output of the jets with the total radio luminosities of the analyzed sources, and hence the γ-ray luminosity function of kpc-scale FR I jets with the radio luminosity function of low-power radio galaxies as given by Willott et al. [9, and converted to the assumed here modern cosmology $\Omega_{\mathrm{M}} = 0.27$, $\Omega_{\Lambda} = 0.73$, and $H_0 = 71\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$]. Finally, we include absorption of the emitted high-energy γ-ray photons by the infrared-to-ultraviolet metagalactic radiation field, taking into account evolution of the background photon field up to high redshifts as discussed in Kneiske et al. [3, 4], and also re-processing of the absorbed γ-ray photons to lower energies by the cascading processes. We note, that the γ-ray emission due to inverse-Compton scattering of starlight photons in the kpc-scale jets of FR I radio galaxies is relatively weak, accounting for only a small fraction of the direct EGRET measurement in the $0.1 - 10\,$GeV photon energy range, consistent with the analysis presented by Cillis et al. [1].

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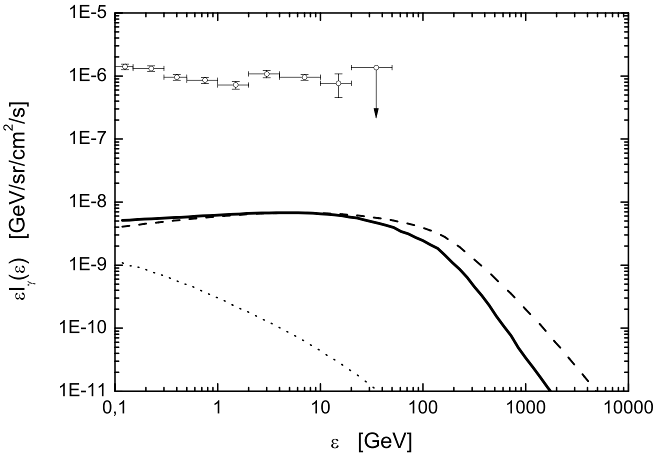

FIGURE 1. Contribution of FR I kpc-scale jets to the extragalactic γ-ray background for $z_{\rm min} = 0$, $z_{\rm max} = 5$, $L_\gamma^{\rm low} = 10^{38}$ erg s^{-1}, and $L_\gamma^{\rm high} = 10^{44}$ erg s^{-1} (lines denoted as in figure 1). Open circles correspond to the extragalactic EGRET γ-ray background as determined by Strong et al. [8]. Dashed lines indicate emission intrinsic to the source, thick solid lines correspond to the emission which would be measured by the observer located at $z = 0$ (with absorption/re-emission effects included), while dotted lines illustrate the reprocessed flux alone.

RESULTS

The contribution of FR I jets to the extragalactic EGRET γ-ray background can be evaluated for unresolved sources as

$$[\varepsilon I_\gamma(\varepsilon)] = \frac{4\pi}{\Omega_{\rm EG}} \int_{z_{\rm min}}^{z_{\rm max}} \frac{dV}{d\Omega\, dz}\, dz \int_{L_\gamma^{\rm low}}^{L_\gamma^{\rm high}} \frac{\rho(L_\gamma, z)}{L_\gamma \ln 10}\, [\varepsilon S_\gamma(\varepsilon)]\, dL_\gamma\,, \tag{1}$$

where $\Omega_{\rm EG} = 10.4$ is the solid angle covered by the survey, $[\varepsilon S_\gamma(\varepsilon)]$ is the observed IC flux in erg cm^{-2} s^{-1} with absorption and re-procession effects included, $dV/d\Omega\, dz$ is the comoving volume element of the Universe, and $\rho(L_\gamma, z)$ is the constructed γ-ray luminosity function of FR I sources [for details see 7]. The results are presented in Figure 1: the jets in FR I radio galaxies (their brightest kpc-scale knots in particular) can contribute about one percent to the observed extragalactic γ-ray background in the $0.1 - 10$ GeV photon energy range. It indicates that the magnetic fields in the analyzed jet regions is not likely to be much smaller *on average* than the equipartition value, as otherwise the contribution of the considered objects would be uncomfortably high. Note that the IC jet luminosity scales roughly as $L_\gamma \propto B^{-2}$, and hence a magnetic field as low as $10\,\mu$G would cause overproduction of the diffuse γ-ray background by the FR I jets on their own. Therefore, weak magnetic fields in the brightest kpc-scale knots in FR I jets can be excluded. Note also, that GLAST is expected to put even stronger constraints by means of resolving some part of the EGRET γ-ray background.

REFERENCES

1. Cillis, A. N., Hartman, R. C., & Bertsch, D. L. 2004, ApJ, 601, 142
2. Kataoka, J., & Stawarz, Ł. 2005, ApJ, 622, 797
3. Kneiske, T. M., Mannheim, K., & Hartmann, D. H. 2002, A&A, 386, 1
4. Kneiske, T. M., Bretz, T., Mannheim, K., & Hartmann, D. H. 2004, A&A, 413, 807
5. Stawarz, Ł., Sikora, M., & Ostrowski, M. 2003, ApJ, 597, 186
6. Stawarz, Ł., Siemiginowska, A., Ostrowski, M. & Sikora, M. 2005, ApJ, 626, 120
7. Stawarz, Ł., Kneiske, T.M., & Kataoka, J. 2006, ApJ, 637, 693
8. Strong, A. W., Moskalenko, I. V., & Reimer, O. 2004, ApJ, 613, 956
9. Willott, C. J., Rawlings, S., Blundell, K. M., Lacy, M., & Eales, S. A. 2001, MNRAS, 322, 536