FIR galaxies and the gamma-ray background

Andrzej M. Sołtan[1] and Józef Juchniewicz[2]

[1] *Copernicus Astronomical Center, Bartycka 18, 00-716 Warsaw, Poland*
[2] *Space Research Center, Bartycka 18a, 00-716 Warsaw, Poland*

ABSTRACT Contribution to the gamma-ray background (GRB) by galaxies bright in the far-IR (FIR) is discussed. Using observational correlations between the FIR and synchrotron emission in radio wavelengths, it is shown that the concentration of cosmic ray electrons in FIR luminous galaxies is substantially higher than in the general population of galaxies. Microwave background and intrinsic galaxy radiation scattered via the inverse Compton (IC) effect by cosmic ray electrons into high energies makes the FIR galaxies relatively strong gamma-ray sources (in comparison with normal galaxies). Using the FIR galaxy luminosity function and the relationship between FIR and radio luminosities, the contribution (due to the IC only) of FIR luminous galaxies to the GRB above $\sim 1\,\mathrm{MeV}$ is estimated at $\sim 10\,\%$ to $25\,\%$ depending on the rate of cosmic evolution of star burst galaxies. This is substantially larger than the normal galaxies contribution. To obtain more accurate assessment of relationship between the GRB and FIR galaxies, gamma-ray observations of individual galaxies bright in the FIR are required.

KEYWORDS: background radiation, gamma-ray sources, infra-red sources

1. INTRODUCTION

The origin of extragalactic diffuse γ radiation is unknown (see Pohl 1998 for a recent review and earlier references). Various mechanisms producing the γ-ray background (GRB) have been proposed. They include rather exotic processes, like annihilation of miscellaneous particles formed in the early universe (Rudaz & Stecker 1991) or evaporation of primordial micro-black-holes (Page & Hawking 1976), as well as a superposition of large number of AGNs. However, spectra of "ordinary" Seyfert galaxies fall steeply above $\sim 100\,\mathrm{keV}$ and these objects contribute mostly to the diffuse background below $\sim 50\,\mathrm{keV}$ (Johnson et al. 1994). The most promising candidate producing the GRB above 10 MeV seem to be BL Lac objects. Several dozen blazars have been detected by EGRET and some of them are also strong sources at COMPTEL energies (von Montigny et al. 1995, Mukherjee et al. 1997). Quantitative estimates of the blazar contribution to the GRB rely on the speculative assumptions on the γ-ray evolution and vary between 20 and 90 % (e.g. Mücke & Pohl 1998, Sreekumar et al. 1997 and references therein). In the present paper we discuss γ-ray emission by galaxies luminous in the far-infrared (FIR) domain and the potential role of these objects for the GRB. We calculate the production of γ-rays by cosmic ray electrons scattering low energy photons. Energetic electrons produce the γ-rays: *a)* interacting with the interstellar medium (Bremsstrahlung) and *b)* scattering off the cosmic microwave background (CMB) and intrinsic galaxy radiation via the inverse Compton (IC) process. Although Skibo & Ramaty (1993) estimate that the former process dominates in the γ-ray band, we restrict our investigation to the IC mechanism only. This is because IC calculations are subject to smaller uncertainties. But one should note that the total contribution of the FIR galaxies to the GRB likely exceeds the figures obtained in the paper.

2. COSMIC-RAY ELECTRONS IN FIR GALAXIES

The dominant component of radio emission in galaxies is synchrotron radiation by cosmic ray electrons moving in the magnetic field which fills the interstellar space. If the electron energy spectrum has the power law form: $N(E) = N_\circ E^{-p}$, using standard formulae (e.g. Rybicki & Lightman 1979) one can get:

$$P(\nu) = 1.19 \times 10^{-33}\, N_\circ\, b^{1.75}\, \nu_9^{-0.75}\ \mathrm{erg\,s^{-1}Hz^{-1}}\,, \tag{1}$$

where $b = B/5\mu$G (B is the strength of magnetic field), ν_9 is radiation frequency in GHz and we have put $p = 2.5$. Galaxies with a high star formation rate (starburst galaxies) are bright in the far infrared. They are also rich in cosmic rays, what makes them relatively bright radio sources. The observational correlation between the luminosities in these two domains can be fitted using the power law approximation (Chi & Wolfendale 1990):

$$\log P_{1.49} = 1.17 \log L_{\mathrm{FIR}} + 9.97, \tag{2}$$

where $P_{1.49}$ is a luminosity in $\mathrm{W\,Hz^{-1}}$ at $\nu = 1.49\,\mathrm{GHz}$ and L_{FIR} is the luminosity (in solar units) integrated from 40 to 120 μm. Since there is a dependence of B on L_{FIR} (Chi & Wolfendale 1990)): $B \sim L_{\mathrm{FIR}}^{0.125}$, Eq. 1 and 2 could be combined to give the relationship between the L_{FIR} and the normalization of cosmic ray electron distribution:

$$N_\circ = 1.67 \times 10^{52}\, L_{\mathrm{FIR}}^{0.95}\,. \tag{3}$$

These cosmic ray electrons produce the γ-ray photons via the IC process on the radiation field in the galaxy. In effect, the most luminous FIR galaxies of $L_{\mathrm{FIR}} = 10^{12}\, L_\odot$ become also strong γ-ray sources with luminosities at 10 MeV of $L = 3.1 \times 10^{38} \mathrm{erg\,s^{-1}MeV^{-1}}$.

3. THE GAMMA-RAY BACKGROUND

The total number of cosmic ray electrons in FIR galaxies within 1 Mpc^3 is given by the integral over the FIR luminosity function and the corresponding local luminosity density at 10 MeV produced via the IC effect by these electrons $\mathcal{L} \approx 1.4 \times 10^{40}\,\mathrm{MeV/(s\,MeV\,Mpc^3)}$. One can calculate the intensity of the X-ray background (XRB) and GRB produced by the luminosity density taking into account evolutionary effects:

$$I(E) = \frac{1}{4\pi}\,\frac{c}{H_\circ} \int_0^{z_{max}} \frac{\mathcal{L}[E(1+z), z]}{(1+z)^2\sqrt{1+2q_0 z}} dz, \tag{4}$$

where $\mathcal{L}(E, z)$ denotes the luminosity density at energy E at redshift z and all other symbols have their usual meaning.

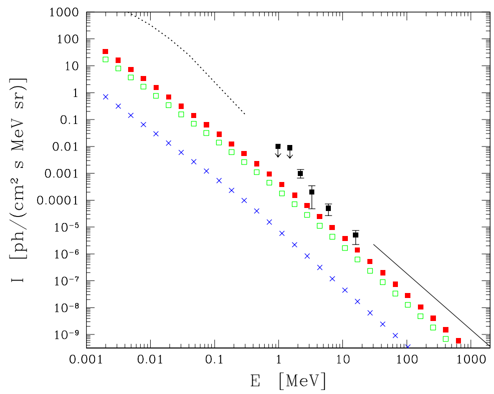

FIGURE 1. Compiled observations of the XRB and GRB: dotted line - schematic shape adapted from Marshall et al. (1980), full squares with error bars - COMPTEL measurements (Kappadath et al. 1995), solid line - EGRET (Sreekumar et al. 1997). Expected background flux produced by FIR galaxies: crosses - CMB photons only, no evolution; open squares - all photons, $\beta = 2.5$; full squares - all photons, $\beta = 3.0$ (see the text for details).

Evolution of the luminosity density $\mathcal{L}(E, z)$ results from the dependence of the CMB temperature on redshift, evolution of the FIR radiation field and the variations of the cosmic electron concentration in galaxies. In Fig. 1 we show the predicted background for selected models. Crosses denote the background produced by scattering of CMB photons only assuming *no evolution* of cosmic ray electrons. At 10 MeV the model produces roughly 0.5 % of the observed background. However, it is likely that the population of galaxies luminous in the FIR is subject to strong evolution. The redshift distribution of IRAS galaxies (e.g. Saunders et al. 1990) is consistent with the density evolution $\sim (1+z)^{6.7\pm2.3}$ for $z < 0.25$. Samples are not deep enough to provide direct information on the FIR evolution at higher redshits, but it is generally accepted that starburst galaxies, which are the major constituent of the FIR galaxies, exhibit a strong increase of the spatial density and/or luminosity up to $z \approx 2.5$ with a decay at higher redshifts (e.g. Moorwood 1996, Franceschini et al. 1997, Bechtold et al. 1998). In agreement with the available data we have used the following parametrization of the evolution of the FIR luminosities:

$$L_{\rm FIR}(z) = L_{\rm FIR}(0) \left\{ \begin{array}{lll} (1+z)^{\beta} & \text{for} & z \le z_{\star}\,, \\ (1+z_{\star})^{\beta} \exp\{-a(z-z_{\star})\} & & z > z_{\star}\,. \end{array} \right. \quad (5)$$

where we put $z_{\star} = 2.5$, $a = 1.25$. We have considerd two rates of evolution: $\beta = 2.5$ and 3.0. The XRB and GRB produced by galaxies subjected to these evolution models is shown in Fig. 1 with open squares for $\beta = 2.5$ and with full squares for $\beta = 3.0$. It is conspicuous that at energies above ~ 5 MeV the model with $\beta = 3.0$ produces 20 - 25 % of the observed background.

4. PROSPECTS FOR THE FUTURE

Indirect methods, which use objects selected at one energy band to predict the background at another energy and exploit correlations between luminosities in these two bands are not capable to provide accurate estimates of the background. Studies of the soft X-ray background in the last 20 years clearly show that. However, the present calculations demonstrate that the FIR galaxies potentially are an important constituent of the GRB. To determine the contribution of these objects to the GRB one should make direct observations in the γ-ray band of nearby IRAS sources – known bright starburst galaxies. Unfortunately, prospects for the detection of these galaxies in the γ-ray range with the present day instruments are discouraging. This is because in the present model a substantial fraction of the GRB is produced by a large number of relatively weak γ-ray sources. EGRET observations show that some AGNs reach luminosities of $10^{47} - 10^{49}\,\mathrm{erg\,s^{-1}}$ (von Montigny et al. 1995), while in our model local γ-ray luminosities due to the IC process cover the range of $10^{36} - 10^{39}\,\mathrm{erg\,s^{-1}}$. The total γ-ray luminosities of FIR galaxies are most probably substantialy larger because of the Bremsstrahlung, but still are several orders of magnitude below blazar luminosities. However, it is likely that the relatively high spatial density of FIR galaxies makes them dominant contributors to the GRB.

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