The contribution of radio galaxies lobes to the Extragalactic Gamma-ray Background

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1 Abstract

We consider the contribution to the EGB of lobes in FR II radio galaxies via IC/CMB.

2 Lobes in radio galaxies

The radio emission arising from the lobes of radio galaxies is widely interpret as due to synchrotron radiation, while the high-energy emission has been described as inverse Compton emission off the cosmic microwave background (IC/CMB).
Following the idea of Bergamini et al. (1967), the IC/CMB process of extended structures in radio galaxies could provide a significant contribution to the diffuse extragalactic γ ray background (EGB) in the keV - MeV energy range.

3 High Energy electrons in lobes

A population of energetic electrons is required to interpret the radio/millimeter observations of radio galaxy lobes (e.g. Hardcastle & Looney 2008), and recently, the WMAP and *Fermi* observations of the Centaurus A lobes (Hardcastle et al. 2009, Abdo et al. 2010). In addition, the *Chandra*, *XMM-Newton* and *Suzaku* observations of radio galaxy lobes (Isobe et al. 2002, 2005, 2009, Kataoka et al. 2003, Croston et al. 2005, hereinafter C05) show that their IC/CMB spectral energy distribution (SED) is rising in the X-rays and consequently a significant fraction of their high-energy emission is expected to be radiated in the hard X-rays and at low energy γ-rays.

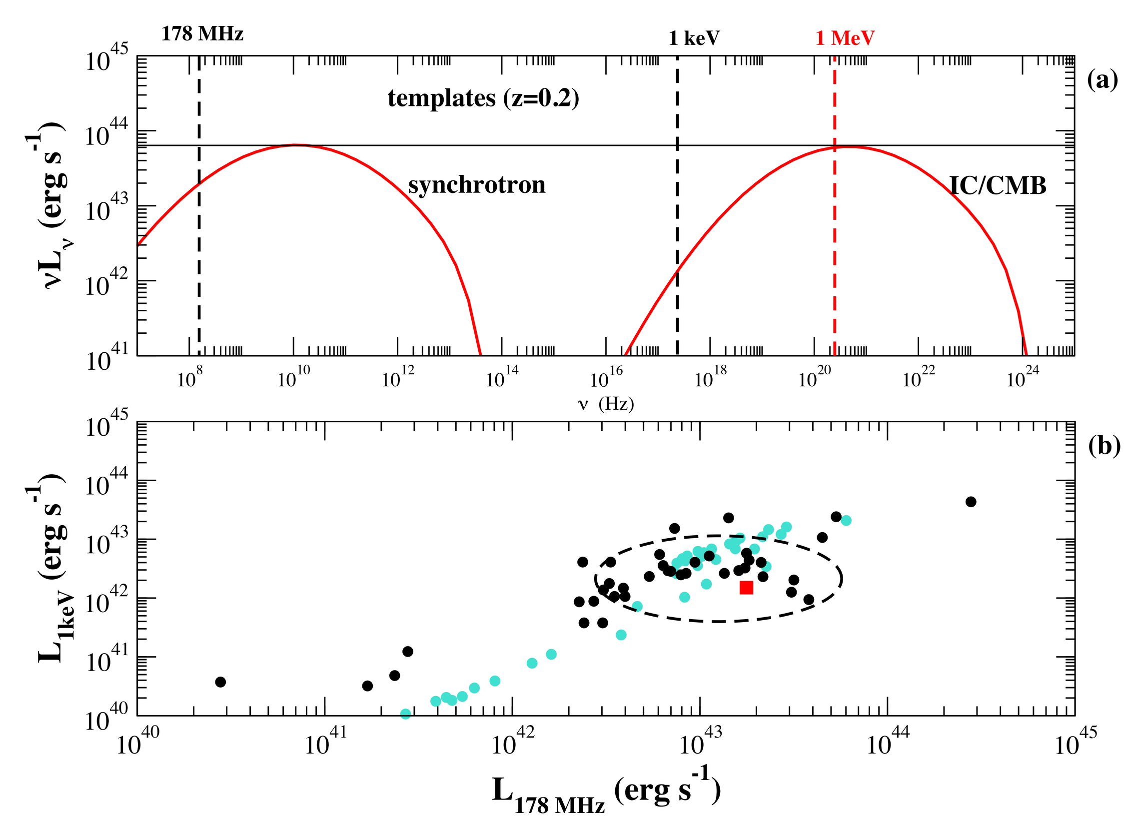


Fig. 1) a) The SED template of a FR II lobe adopted to estimate the contribution to the EGB (red line). b) The radio and X-ray luminosities of the lobes in the C05 FR II sample (black dots). The red square indicates the 1 keV and 178 MHz luminosities estimated from our SED template. The cyan dots show synthetic source generated from the model luminosity function described in Section 7.

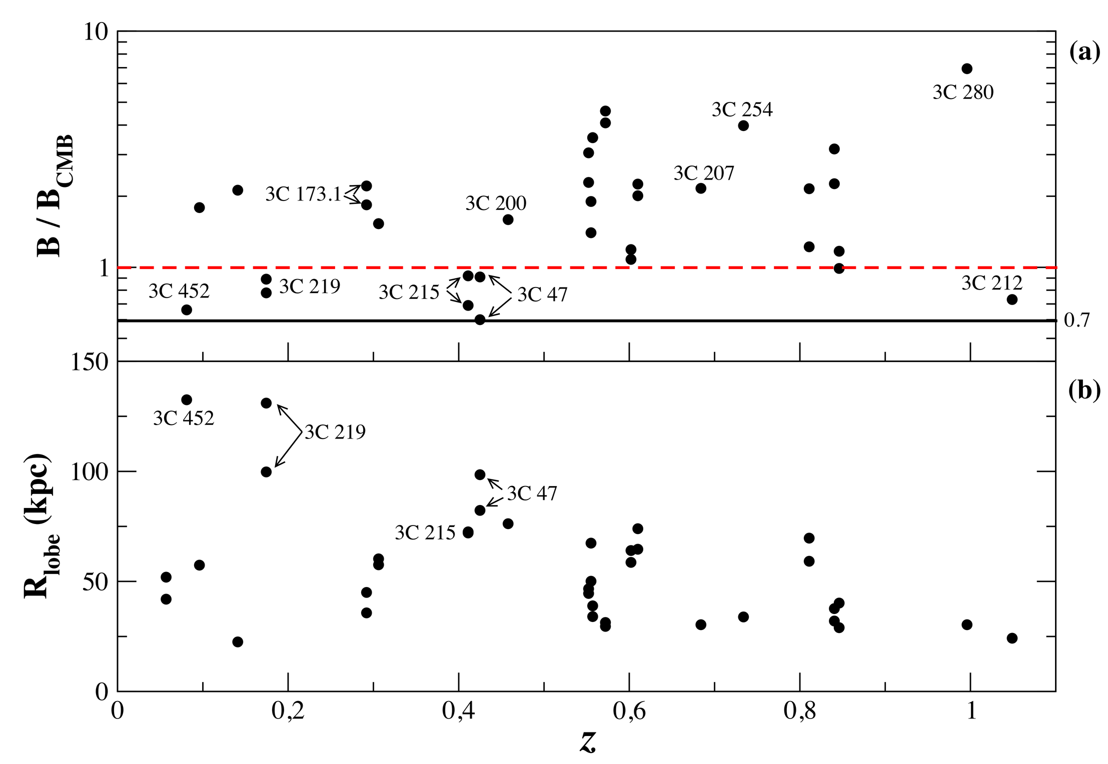
4 The radio lobe spectral energy distribution

We built a template SED of the lobe emission from radio to the γ-rays (see Fig. 1a). The template has been evaluated assuming a smooth log-normal PED: $N(\gamma) = N_0 (\gamma/\gamma_p)^{-2-r\log(\gamma/\gamma_p)}$, (e.g. Katz-Stone & Rudnick 1994).

The template is in agreement with the observed radio-to-X-ray luminosities and X-ray spectral indices measured in the lobe sample of C05 and with the models adopted for the X-ray detected lobes of other FR IIs (e.g. 3C 207, Brunetti et al. 2002, 3C 452, 3C 326, Isobe et al. 2002, 2009).

5 SED template assumptions

We calculate the SED template with the luminosity ratio between the synchrotron and the IC/CMB component L_{syn}/L_{ic} of the order of unity (Fig. 2a). This corresponds to the assumption that the energy losses for the radiative processes considered are equivalent, similar condition of $B/B_{CMB} \sim 1$, in agreement with the observations of FR IIs (see Fig. 1a). We did not assume that the IC/CMB emission is beamed, since there is no evidence of relativistic bulk motion in lobes. We chose the value of R_{lobe} to be consistent with the typical value of the C05 sample (see Fig. 1b).



a) The B/B_{CMB} ratio (upper panel) for the FR IIs lobes in the sample of C05. The dashed red line indicates the case B/B_{CMB} = 1, when synchrotron and IC/CMB losses have the same relevance. b) The equivalent spherical radius of the lobe volume, R_{lobe}, as a function of redshift estimated for the same sample.

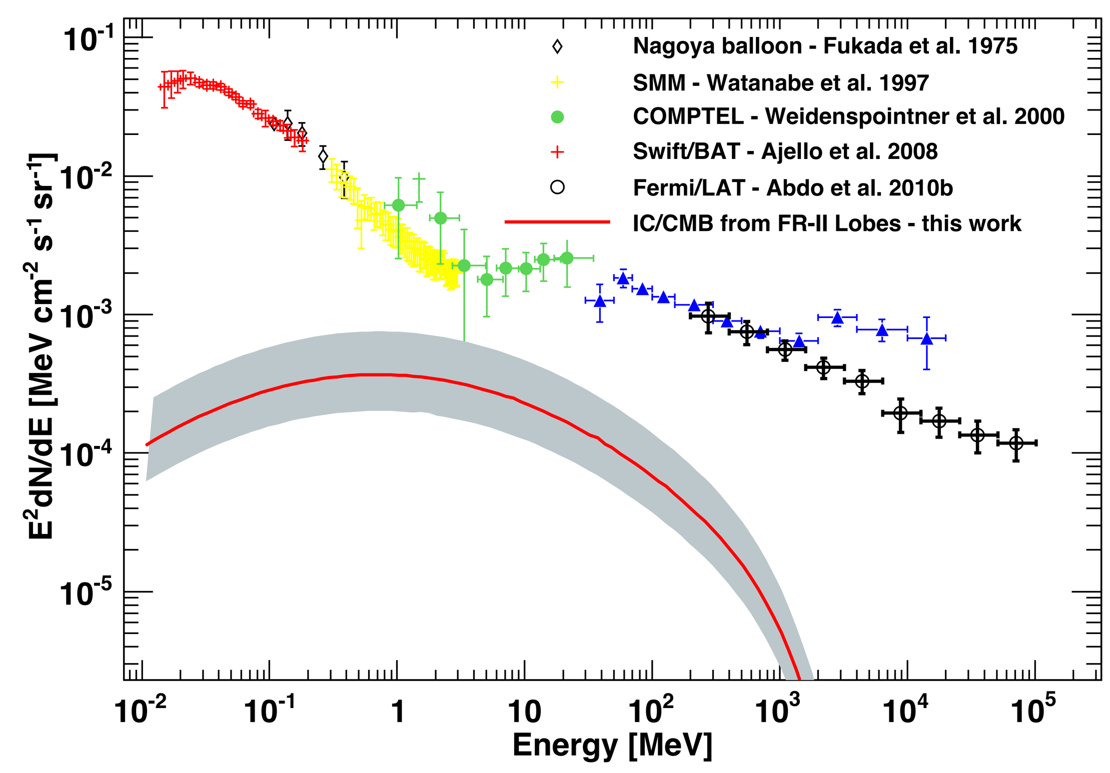
6 The contribution to the EGB

The estimate of the total diffuse flux arising from the FR II radio galaxy population can be evaluated adopting the following relation, as reported in Ajello et al. (2008, 2009):

$$F_{EGB}(E_0) = \int dz \int dL \, \Phi(L,z) \frac{dV}{dz} \frac{dN}{dE_0} \qquad (1)$$

where $F_{EGB}(E_0)$ is the diffuse flux in units of ph cm^{-2} s^{-1} sr^{-1} MeV^{-1}, $\Phi(L,z)$ is the luminosity function (LF), $\frac{dN}{dE_0}$ is the derived from our SED template of the lobes in the observer's frame at energy E_0 and dV/dz is the comoving volume element per unit redshift and unit solid angle.
The knowledge of the source luminosity function is crucial to estimate correctly this contribution. Indeed, it gives the space density of objects with luminosity L at redshift z. We adopt the FR II radio galaxy LF at 15 GHz (Cara & Lister 2008).

The SED template used in Eq. (1) is renormalized such that at a given redshift z the luminosity in the native radio band of the LF is L. The IC component is multiplied by an additional factor $(1+z)^4/(1+0.2)^4$ to account for the fact that the energy density of the CMB scales like $\propto (1+z)^4$.
The luminosity of the LF of Cara & Lister (2008) refers to the luminosity of the FR II core while our SED template applies to the lobe emission.
To convert the core luminosity into a proxy for the lobe luminosity at 15 GHz we have used the available observations of FR II (C05). We have found that rescaling the core luminosity by a factor $K \approx 0.03$ (and re-normalizing the SED template as described above) produces SEDs that reproduce well the available data on FR IIs for the range of source luminosities and redshifts reported in C05.



The keV to GeV diffuse extragalactic background. The red line shows our estimate of the contribution due to the IC/CMB arising from lobes. The gray area represents the uncertainty in the estimate of the contribution to the EGB and arises mainly from the uncertainties related to the SED template.

Fig. 3 shows the contribution to the diffuse EGB emission arising from the extended structures of FR II lobes and its uncertainty. It is apparent that lobes give a significant, ~10 % contribution to the EGB in the MeV energy range.

7 Test for the synthetic luminosity function

We extracted randomly sources from our model and we selected only those with flux at 1 keV $\geq 10^{-15}$ erg cm^{-2} s^{-1} and $z \leq 1$. Thus, we are able to reproduce successfully the range of observed radio and X-ray luminosities (see Fig. 1b).
We performed an additional test integrating the LF coupled to our SED model over luminosity and redshift and we counted how many objects would be detectable in an all-sky survey above a flux of 10^{-15} erg cm^{-2} s^{-1} (at 1 keV). The number of detectable sources is ~100 and they display a typical (average) X-ray luminosity of 5×10^{42} erg cm^{-2} s^{-1}. These numbers appear to be consistent with the *Chandra* and *XMM-Newton* observations.

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