On the diffuse AGN contribution to the extragalactic $\gamma$-ray background (EGRB)

$I_{\gamma > 100 \text{ MeV}} \sim 1.14 \times 10^{-5} \text{ ph cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}$
High energy blazars as guaranteed contributors

- 95 blazars detected at >100 MeV (~a few % of EGRB)
- EGRET identified blazars: ~20% BL Lacs, ~80% FSRQs
- 11 blazars (all of BL Lac type) detected at TeVs
Other **guaranteed** contributors to the 100 MeV-10 GeV extragalactic background:

- “normal” spiral galaxies [e.g. Strong et al. 1976]
- radio galaxies
- cascade radiation from GZK-CR propagation in extragalactic radiation fields [e.g. Strong et al. 1974]
- cascade radiation from distant TeV-AGN [e.g. Coppi & Aharonian 1997]

Other **proposed** contributors to the 100 MeV-10 GeV extragalactic background:

- galaxy clusters [e.g. Said et al. 1982]
- GRBs [Totani 1999]
- matter-antimatter annihilation, etc. [e.g. Stecker et al. 1971]
- ....
The AGN contribution to the EGRB - Many approaches to the problem:

- gamma ray luminosity function
  [Chiang et al. 1995, Chiang & Mukherjee 1998]

- scaling luminosity functions (based on cross-band luminosity correlations):
    - scaling typical blazar SED [Giommi et al. 2006]

- fluctuation analysis  [T. Willis (PhD-thesis)]

- AGN unification scheme & emission model
  [Mücke & Pohl 2000]
On the method of scaling luminosity functions

(1) \( GRL = \text{scaled RLF} \)

\[ \rho_\gamma(L_\gamma, z) = (1 - \xi) \eta \rho_\gamma(L_\gamma/\kappa, z) + \xi \eta \rho_\gamma(L_\gamma/A\kappa, z) \]

Ansatz: \( \rho_\gamma(L_\gamma, z) = (1 - \xi) \eta \rho_\gamma(L_\gamma/\kappa, z) + \xi \eta \rho_\gamma(L_\gamma/A\kappa, z) \)

with \( L_\gamma = \kappa L_\gamma, \eta = \theta_\gamma / \theta_\gamma, \xi = \text{flare duty cyle}, A = \text{L-amplification for flare/quiet state}, \)

\( p_f(q) = p(\alpha - \Delta \alpha_f,q) \) "spectral hardening in flares"

\[ \kappa = 4 \times 10^{-11}, \eta = 1, \xi = 0.03, A = 5, \Delta \alpha_q = 0.2, \Delta \alpha_f = -0.05 \]

100% blazar contribution to EGRB
On the method of scaling luminosity functions

\[ (2) \quad GRL = \text{scaled XLF} \]

[Narumoto & Totani 2006]

Ansatz: distr. fct. \( \sim \rho(L_{\gamma}, z) \varepsilon(L_{\gamma}, z) H[S_{\gamma}(L_{\gamma}, z) - S_{\gamma, \lim}(\Omega)] \)

prob. of source with \( L_{\gamma}, z \) be identified in radio band using \( L_{\gamma} = 10^p L_r \)

likelihood ratio method to estimate free parameters

diffuse source contrib.: \( F_{\text{diffuse}} = \int z_{\text{max}} dz \frac{dV}{dz} \int L_{\gamma, \text{min}} dL_{\gamma} S_{\gamma}(L_{\gamma}, z) \rho_{\gamma}(L_{\gamma}, z) \)

**PLE-model:** \( \rho_{\gamma}(L_{\gamma}, z) = \eta \frac{L_r}{L_{\gamma}} \rho_r(L_r, z) \) with \( \rho_r \sim (L_r^{\gamma_1} + L_r^{\gamma_2})^{-1} \) for FSRQs

plus lum. evolution [Dunlop & Peacock 1990]

\( \eta = \text{normalization}, \ L_{\gamma} = 10^p L_r \)

**LDDE-model:** \( \rho_{\gamma}(L_{\gamma}, z) = \kappa \frac{L_x}{L_{\gamma}} \rho_x(L_x, z) \) with \( \rho_x \sim (L_x^{\gamma_1} + L_x^{\gamma_2})^{-1} \) for type-1 AGN

plus lum.-dependent density evolution [Hasinger et al. 2005]

\( \kappa = \text{normalization}, \ L_{\gamma} = 10^q L_x \)
On the method of scaling luminosity functions

\[ L_\gamma = 10^{3.52} L_x \]

2.7GHz

\[
\log_{10}(F_\gamma \text{ [erg s}^{-1} \text{ cm}^{-2}])
\]

EGRET blazars

\[ L_\gamma = 10^{3.23} L_r \]

0.5-2keV

\[
\log_{10}(L_r \text{ [erg s}^{-1}])
\]

\[
\log_{10}(\nu F_{\nu \text{ [Jy Hz]}})
\]

\[
\log_{10}(\nu L_{\nu > 100 \text{ MeV} \text{ [erg s}^{-1}])
\]
On the method of scaling luminosity functions

Results

**PLE-model:** best-fit \((p, \gamma_1) = (3.28, 0.69), \eta = 10^{-0.7}\),

50\((-100)\)% source contribution to the EGRB

**LDDE-model:** best-fit \((q, \gamma_1) = (3.52, 1.04), \kappa = 10^{-4.7}\),

20-25\% source contribution to the EGRB

LDDE-model reproduces \(z\)- & \(L\)-distr. of E-blazars better than PLE-model
On the method of scaling luminosity functions

Predictions for GLAST

- dominant blazar contribution to EGRB below GLAST detection limit
- ~1750 blazars (~14% of EGRET-EGRB) detectable with GLAST
Scaling typical blazar SED

[Giommi et al. 2006]

**Method:**

- scale typical (3C 279) EGRET-blazar SEDs, interpreted in a simplistic SSC, to the integrated blazar flux intensity at CMB energies

- SSC constrained by $F_{\text{diff,blazar}}(94\text{GHz})$, $\alpha_{r,\mu}$, $\alpha_{\mu,x}$; $\alpha_{\mu,\gamma}$

**Result:**

either sources like 3C 279 or SSC-LBLs are not representative of blazars contributing to the EGRB, or their duty cycles @ $\gamma$-rays is low
Critical assessment of the radio - gamma ray luminosity correlation

[Mücke et al. 1997]

Why?

Biases expect to contaminate:

- redshift dependence of quantities ($L_\gamma - L_r$):
  
  answer: partial correlation analysis $R_{12.3} \sim R_{12} - R_{13}R_{23}$
  
  flux correlation

- instrument sensitivity limits/incomplete samples

- (non-periodic) flux variability of sources

  comment: Do not use mean flux values, more appropriate contemporaneous data!
The effect of sample flux limits in L-correlations

Ingredients: - sample $L_r$, $L_\gamma$ from radio/$\gamma$-ray lum. function

- sigmoidal probability distribution for sample flux limit:
  - radio: $\sim 0.5 \ldots 2$ Jy (flux-limited sample), $\sim 0.1$ mJy (complete sample)
  - gamma: $\sim 0.5 \ldots 5 \times 10^{-7}$ cm$^{-2}$s$^{-1}$, $\sim 10^{-11}$ cm$^{-2}$s$^{-1}$
correlation relation: \( \log L_\gamma = A + B \log L_r + \varepsilon(\sigma) \), \( B=0.8...1.5, \sigma=0.05 \)

- partial correlation analysis can recover simple PL correlations for complete & flux-limited samples on a >99.5% significance level, however:
  there is a stronger redshift-dependence of the luminosity in flux-limited samples as in complete samples

- the use of averaged flux values induce a bias caused by the restriction of the dynamical range in the correlation diagram (i.e. \( R \) is not distributed in the Null hypothesis as expected from statistics)

\( \rightarrow \) chance probab. are underestimated by \( \sim \)factor 3!
The effect of sample flux limits in L-correlations

Be aware of biases when studying cross-band luminosity correlations in flux-limited samples!
The effect of sample flux limits in L-correlations

• $L_\gamma - L_r$ problematic for EGRET-blazars?

  No! - Intrinsic relation might be hidden in large scatter of $L_\gamma - L_r$ diagram (e.g. from rapid variability, diff. Doppler factors, emission components, etc.);
  energy content of particles in radio-to-$\gamma$ray band may still be correlated

• derivation of gamma ray luminosity function from radio luminosity function often based on biased correlation studies

Be aware of biases when studying cross-band luminosity correlations in flux-limited samples!
Unification scheme based modeling

[Mücke & Pohl 2000]

Basic Idea:

If beaming due to relativistic bulk motion of a plasma blob near to the line-of-sight occurs in blazars, there must exist a population of sources with a jet pointing away from us, contributing to the EGRB.

Unification scheme [e.g. Urry & Padovani 1995]:

FSRQs = beamed population of FR-II radio galaxies
BL Lacs = beamed population of FR-I radio galaxies

→ model observed LogN-LogS of BL Lacs/FSRQs; extrapolate to flux values below instrument-threshold

Model constraints:
observed LogN-LogS, \( N_{\text{BL Lacs}} / N_{\text{FSRQ}} \) & redshift distribution of blazars
Unification scheme based modeling

Ingredients: - template source spectrum from:
  extended DS93 EIC-loss dominated emission model
  with instan.&cont. particle injection, time-integrated $\gamma$-fluxes
Unification scheme based modeling

Ingredients (contd):

- distribution of bulk Lorentz factors: $P(\Gamma) \sim \Gamma^{-\alpha_{\Gamma}}$
  
  from unification scheme: $\alpha_{\Gamma} = 4/2.3$ for FRI/FRII

- uniform distribution of viewing angles

- luminosity evolution: $L \sim \exp(T(z)/\tau)$, $\tau = 0.3/0.2$ for FRI/FRII

- injected particle energy distrib.: $\rho_{FR}(E_{in}) \sim E_{in}^{-\delta}$, $\delta = 3/3.9$ f. FRI/FRII

- homogeneous distribution of sources

- sigmoidal distribution for sensitivity limit: $0.4...2.1 \times 10^{-7}$ cm$^{-2}$ s$^{-1}$

- fixed parameters: $B, R_b, L_{acc},$ inj. e$^{-}$ spectrum, integr. time $10^6$s

- free parameters: $E_{in,1}$, normalization of $\rho(E_{in})$

  → generate data sets using MC; determine free parameters by model constraints
Unification scheme based modeling

Results

FSRQs

BL Lacs

FSRQs

BL Lacs
Unification scheme based modeling

Results & Predictions

- main power to EGRB from AGN at $\sim 10^{-8}$ cm$^{-2}$ s$^{-1}$
- $\sim 10^3$ more AGN with GLAST

$\textbullet$ 20-40% ($z_{\text{max}}=3$) bzw. 35-85% ($z_{\text{max}}=5$) of the EGRB explainable by unresolved radioloud AGN, of which 70-90% are of BL Lac/FR-I type

*in 10$^{-6}$ cm$^{-2}$ s$^{-1}$ (>100MeV)
Summary

- gamma ray luminosity function: [Chiang et al. 1995, Chiang & Mukherjee 1998]
  < 25% blazar contribution

- scaling luminosity functions (based on cross-band luminosity correlations):
  ~ 20-100% blazar contribution

- fluctuation analysis: [T. Willis (PhD-thesis) 1996]
  ~ 5-100% point source contribution

- AGN unification scheme & emission model: [Mücke & Pohl 2000]
  ~ 20-85% radio-loud AGN contribution
  (of which 70-90% are of BL Lac/FR-I type)
The cascade contribution of TeV-blazars

- cosmological TeV-blazars guaranteed to contribute to EGRB @ GeVs
- typical blazar spectra must break below <100GeV, or blazars do not explain entirely the EGRB @ GeVs