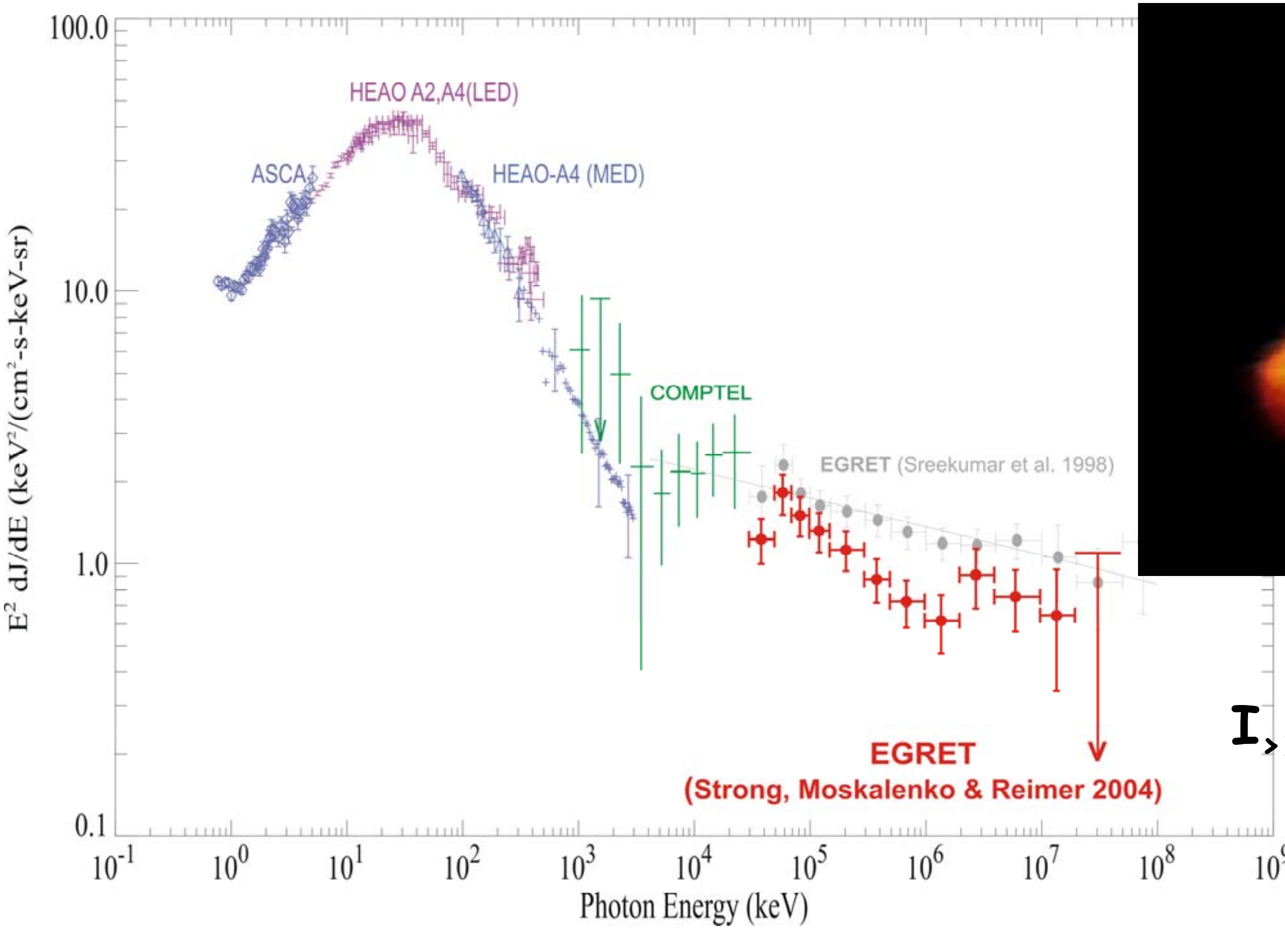
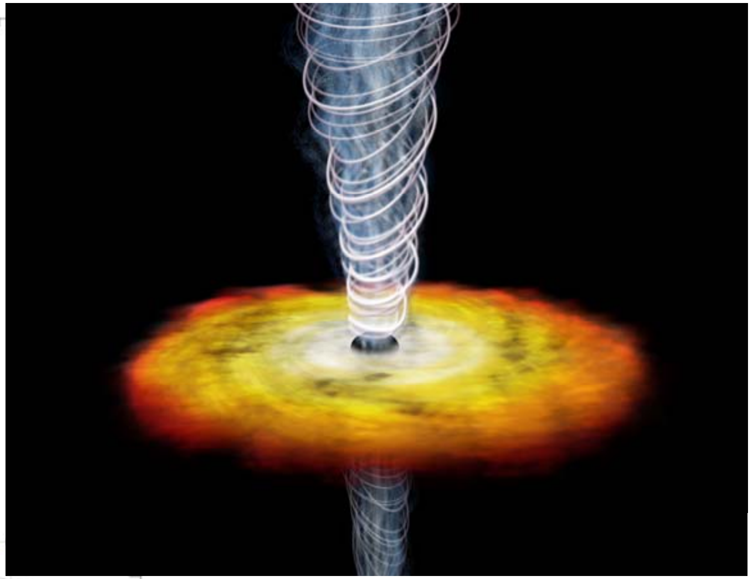
On the diffuse AGN contribution to the extragalactic γ-ray background (EGRB)



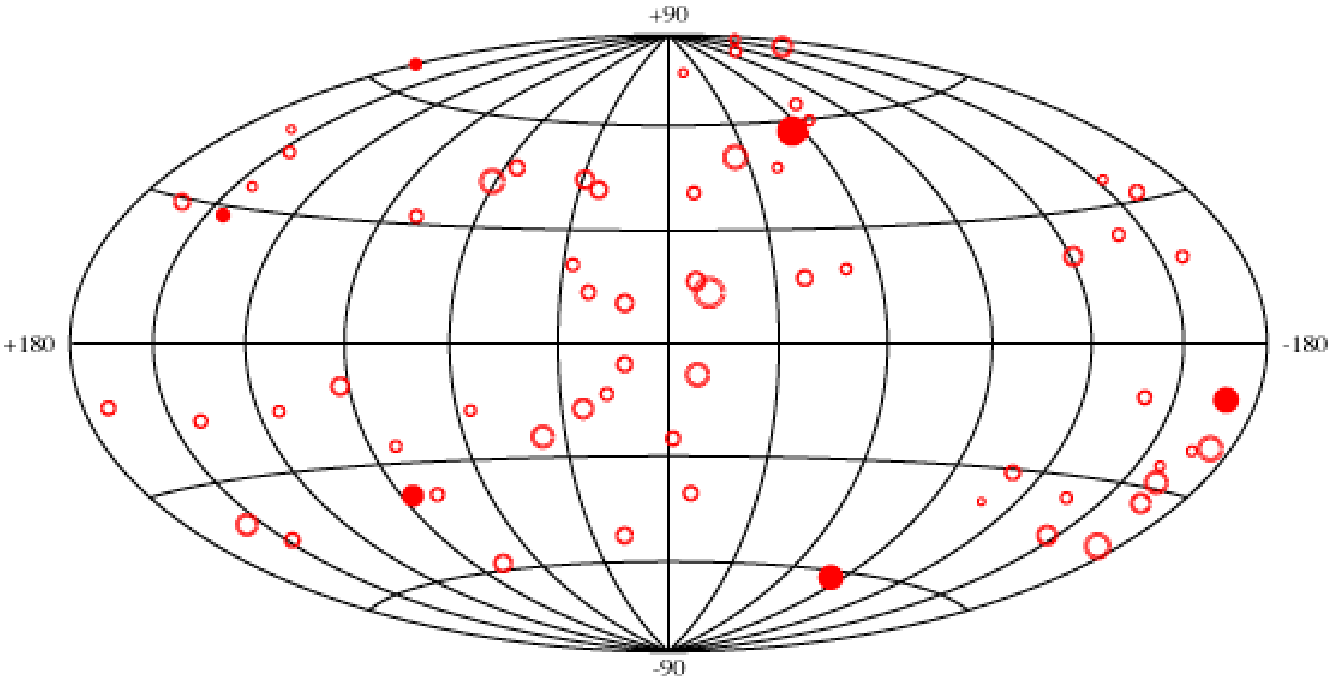


$I_{>100\ MeV} \sim 1.14\ 10^{-5}$ ph $cm^{-2}\ s^{-1}\ sr^{-1}$

Anita Reimer, HEPL/Stanford University

GLAST-lunch talk, 23 February 2006

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):**
[Padovani et al. 1993, Stecker et al. 1993, 1996, Salamon & Stecker 1994, ..., Narumoto & Totani 2006]

  - **scaling typical blazar SED** *[Giommi et al. 2006]*

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

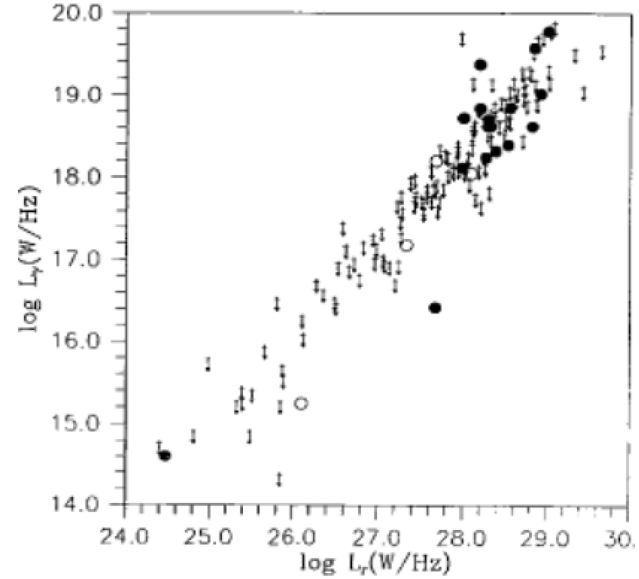
- **AGN unification scheme & emission model**
[Mücke & Pohl 2000]

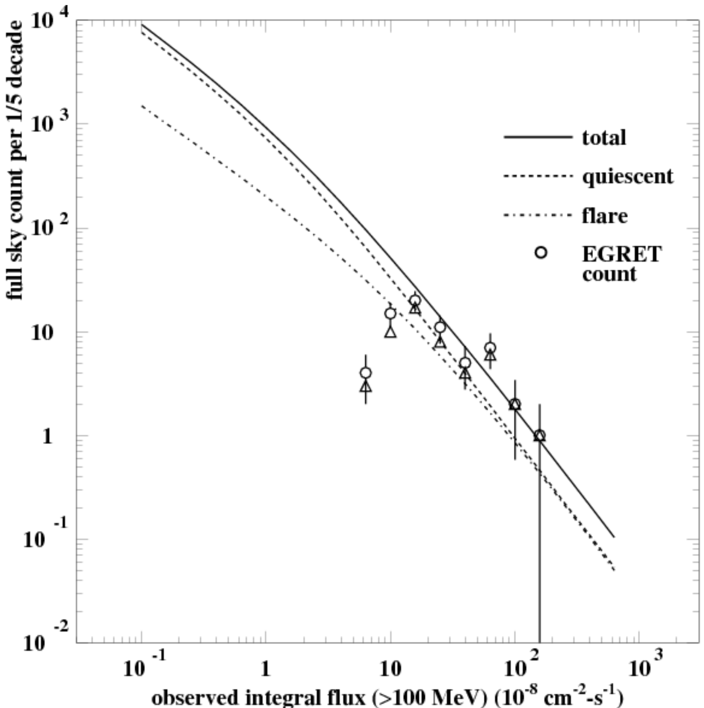
On the method of scaling luminosity functions

(1) GRL = scaled RLF

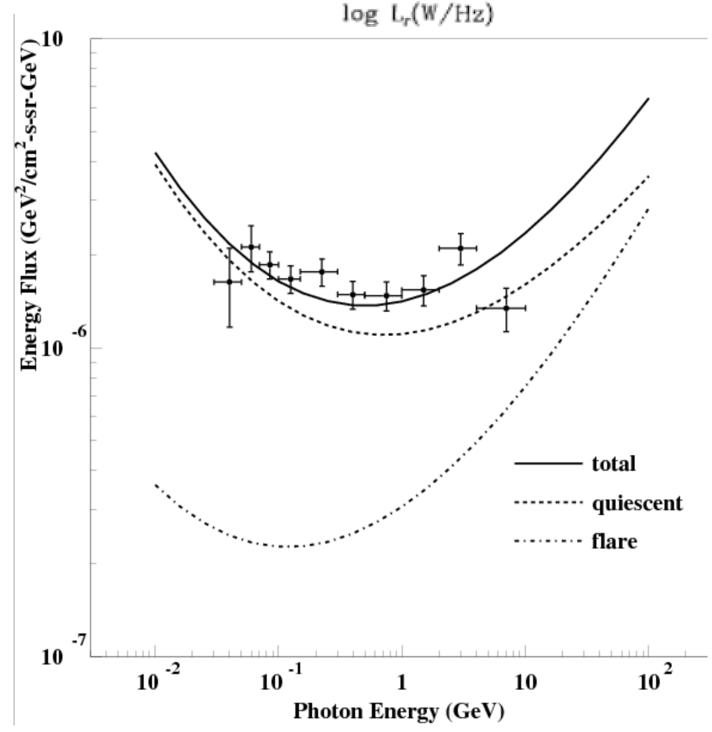
[e.g. Stecker et al. 1996]

Ansatz: $\rho_\gamma(L_\gamma,z)=(1-\xi)\eta\rho_r(L_\gamma/\kappa,z)+\xi\eta\rho_r(L_\gamma/A\kappa,z)$
with $L_\gamma=\kappa L_r$, $\eta=\theta_\gamma/\theta_r$, ξ=flare duty cyle, A=L-amplification for flare/quiet state,
$p^{f,q}(\alpha)=p(\alpha-\Delta\alpha^{f,q})$ "spectral hardening in flares"
$\kappa=4\ 10^{-11}, \eta=1, \xi=0.03, A=5, \Delta\alpha^q=0.2, \Delta\alpha^f=-0.05$





100% blazar contribution to EGRB



On the method of scaling luminosity functions

(2) GRL = scaled XLF

[Narumoto & Totani 2006]

Ansatz: distr.fct. ~ $\rho_\gamma(L_\gamma,z)\ \varepsilon(L_\gamma,z)\ H[S_\gamma(L_\gamma,z)-S_{\gamma,\mathrm{lim}}(\Omega)]$

prob. of source with L_γ,z be identified in radio band using $L_\gamma=10^p\,L_r$

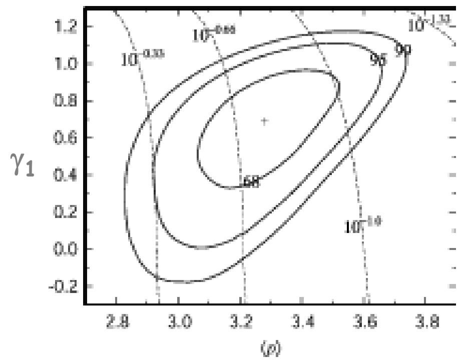
likelihood ratio method to estimate free parameters

diffuse source contrib.: $F_{diffuse}=\int^{zmax}dz\ dV/dz\ \int_{L\gamma,min} dL_\gamma\ S_\gamma(L_\gamma,z)\ \rho_\gamma(L_\gamma,z)$

PLE-model: $\rho_\gamma(L_\gamma,z)=\eta\ L_r/L_\gamma\ \rho_r(L_r,z)$ with $\rho_r \sim (L_r^{\gamma 1}+L_r^{\gamma 2})^{-1}$ for FSRQs

plus lum.evolution *[Dunlop & Peacock 1990]*

η=normalization, $L_\gamma=10^p L_r$



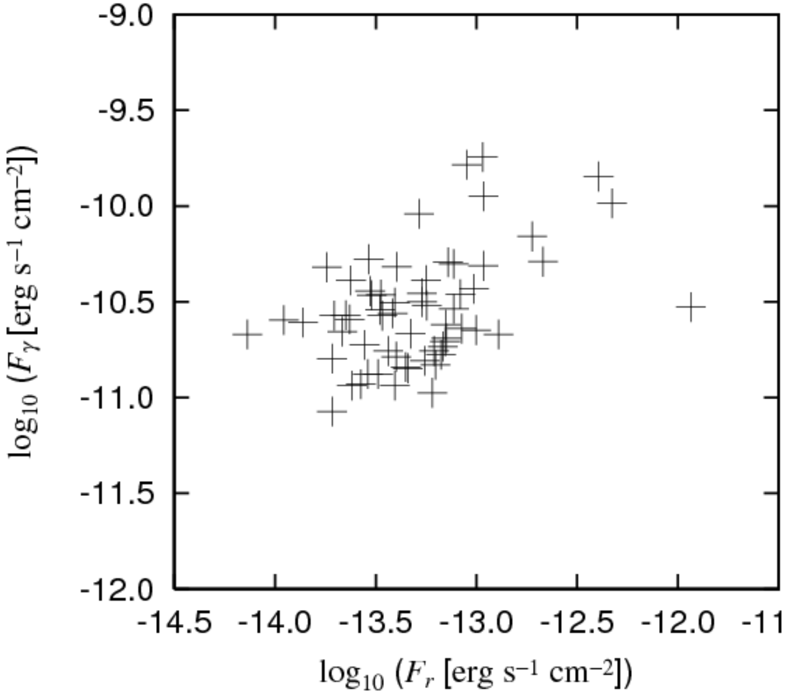
LDDE-model: $\rho_\gamma(L_\gamma,z)=\kappa\ L_x/L_\gamma\ \rho_x(L_x,z)$ with $\rho_x \sim (L_x^{\gamma 1}+L_x^{\gamma 2})^{-1}$ for type-1 AGN

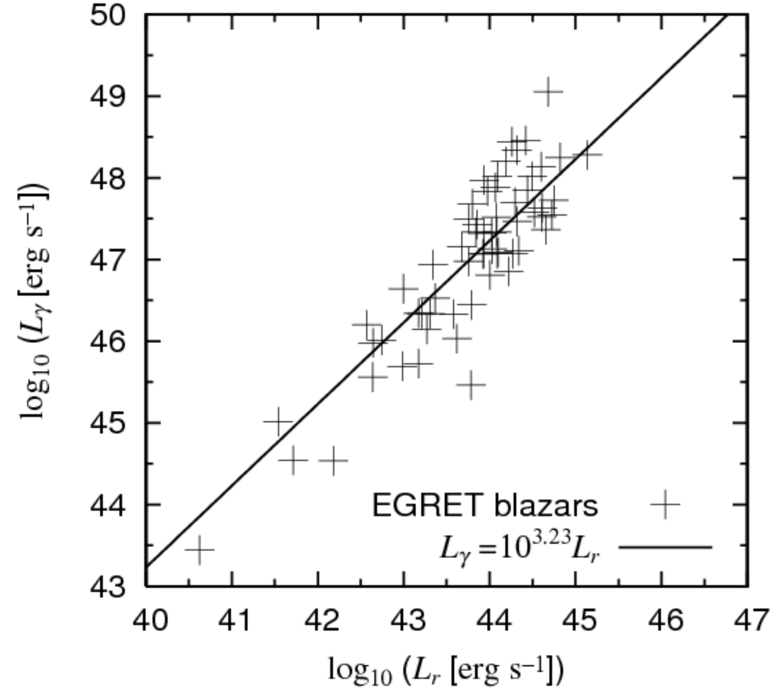
plus lum.-dependent density evolution *[Hasinger et al. 2005]*

κ=normalization, $L_\gamma=10^q L_x$

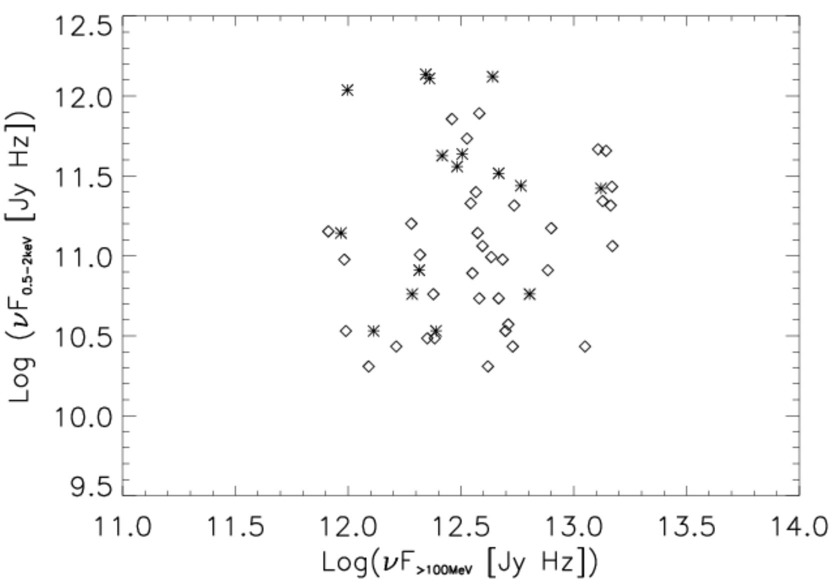
On the method of scaling luminosity functions

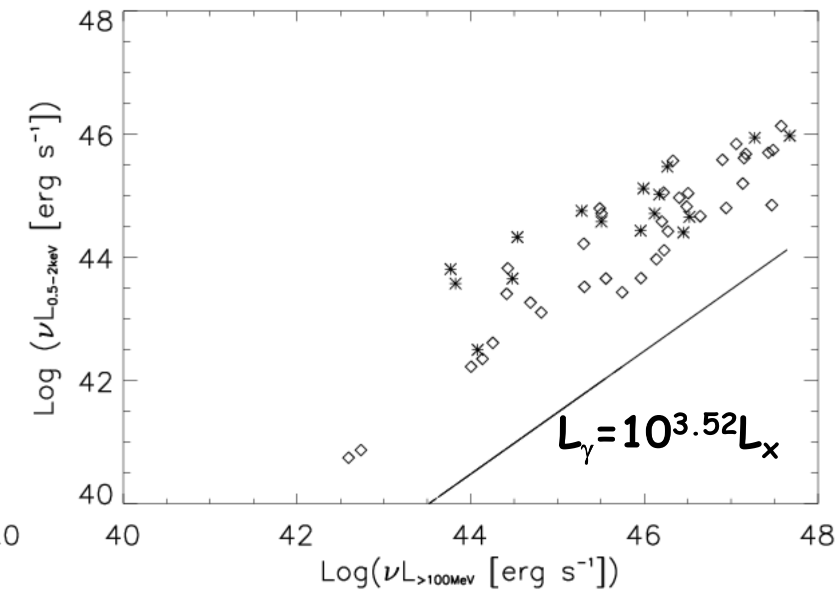
2.7GHz





0.5-
2keV



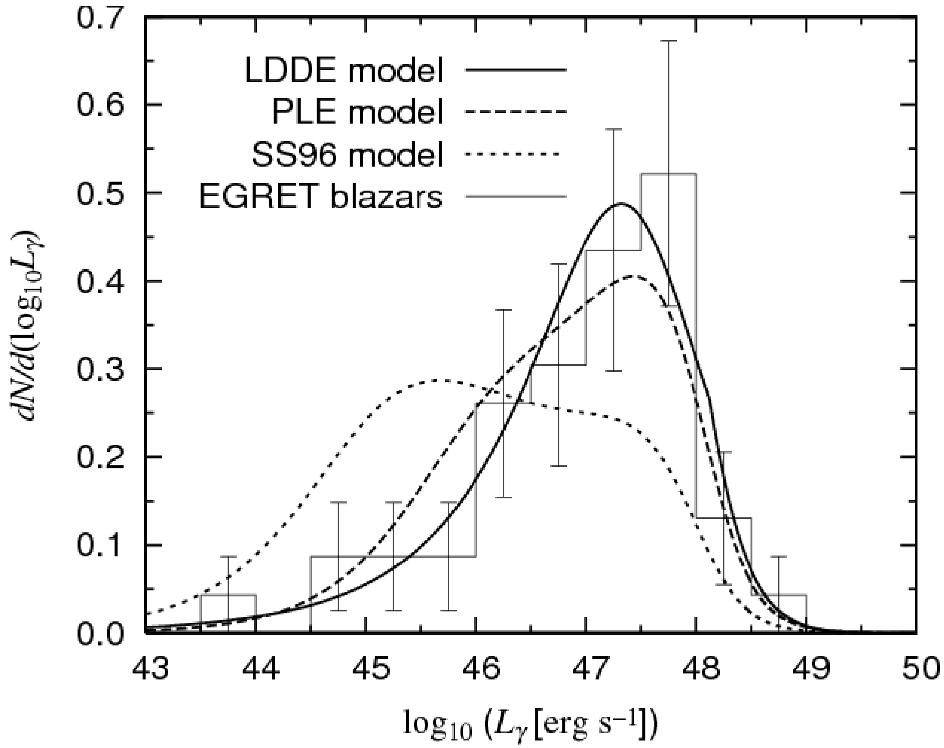


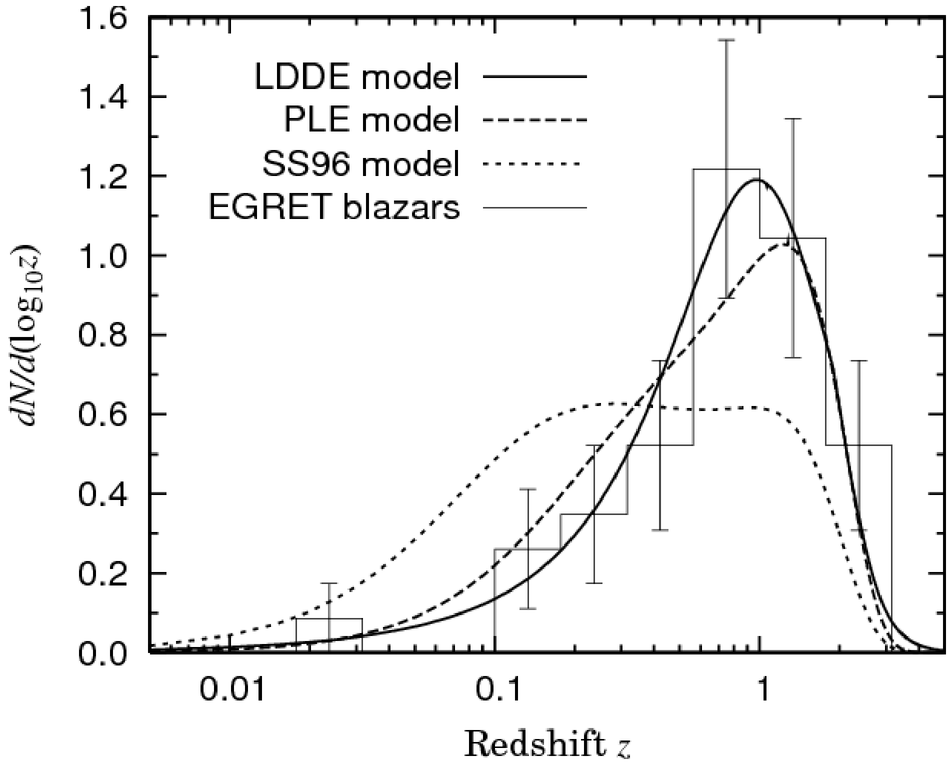
On the method of scaling luminosity functions

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

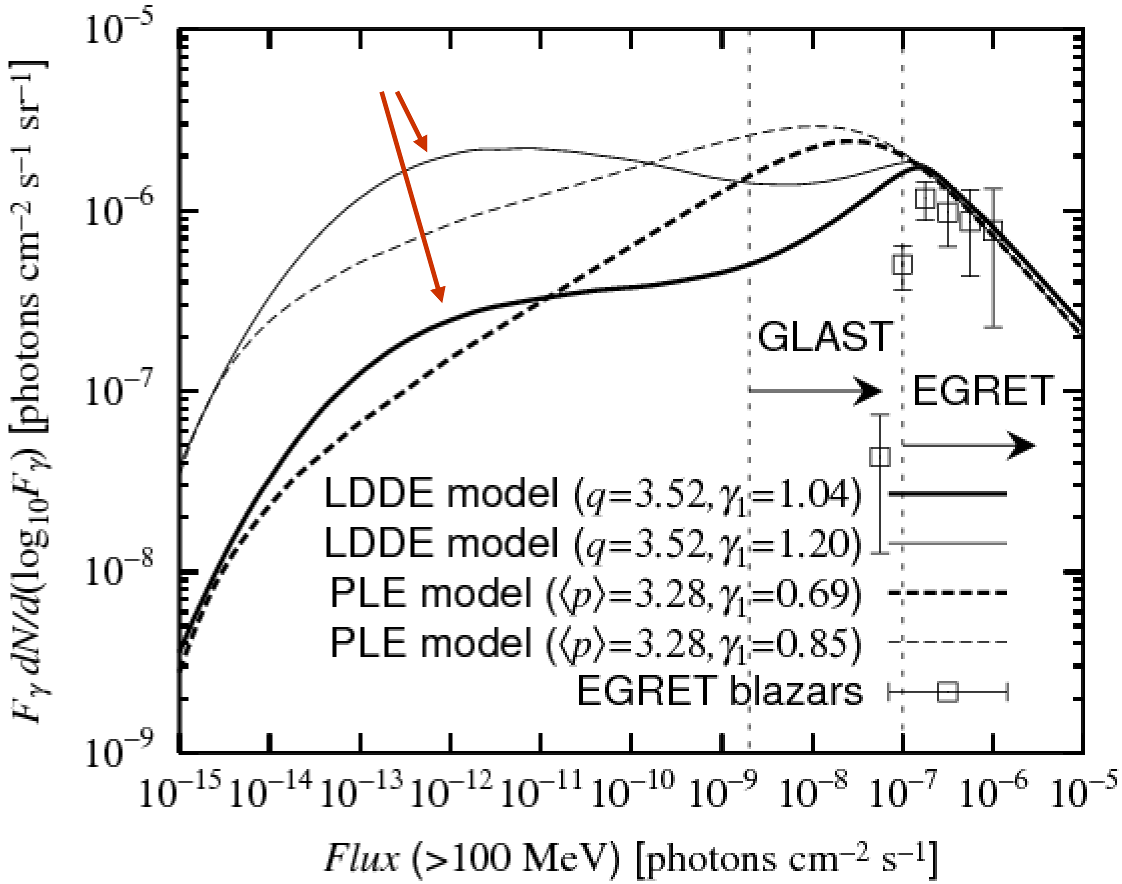




LDDE-model reproduces z- & L-distr. of E-blazars better than PLE-model

On the method of scaling luminosity functions

Predictions for GLAST



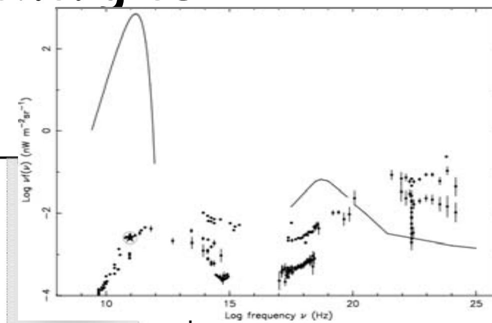
- dominant blazar contribution to EGRB below GLAST detection limit
- ~1750 blazars (~14% of EGRET-EGRB) detectable with GLAST

Scaling typical blazar SED

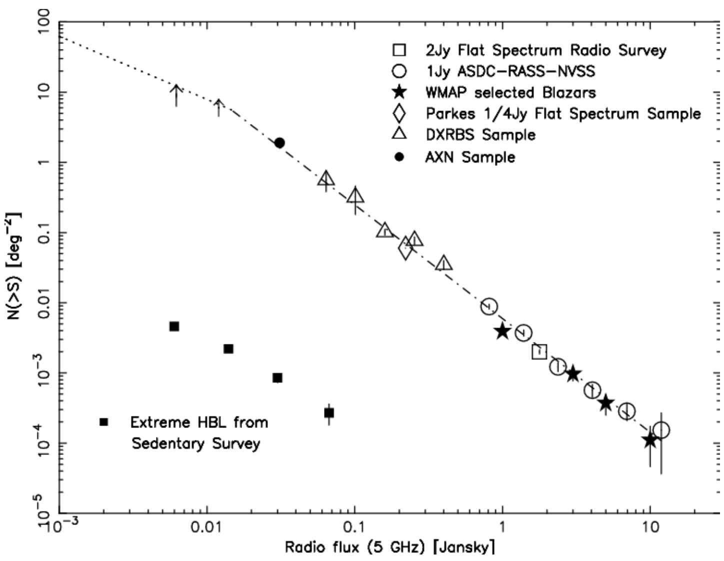
[Giommi et al. 2006]

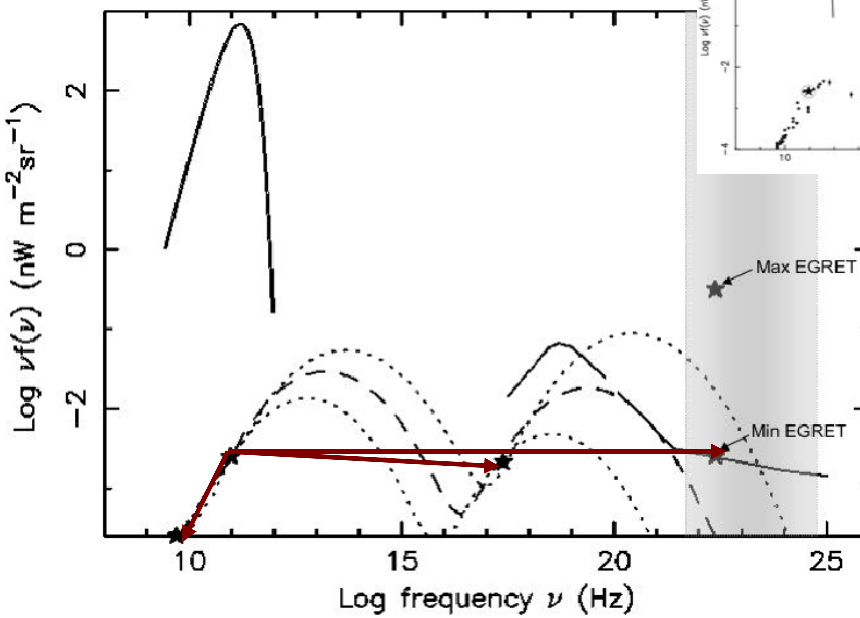
Method:

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



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





Result:

either sources like 3C 279 or SSC-LBLs are not representative of blazars contributing to the EGRB, or their duty cycles @ γ-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_γ–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!

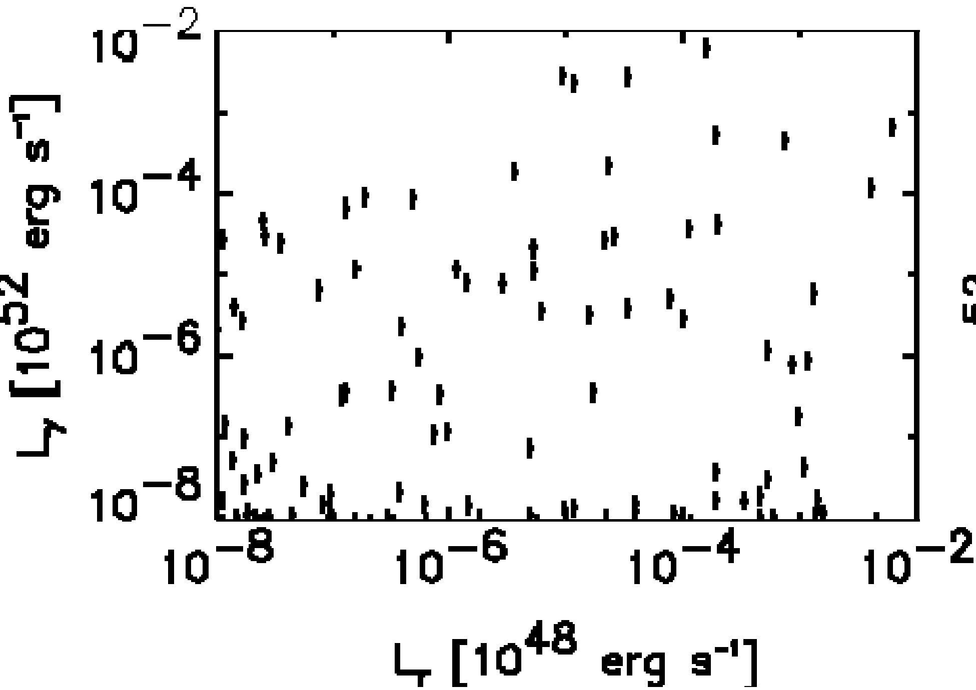
The effect of sample flux limits in L-correlations

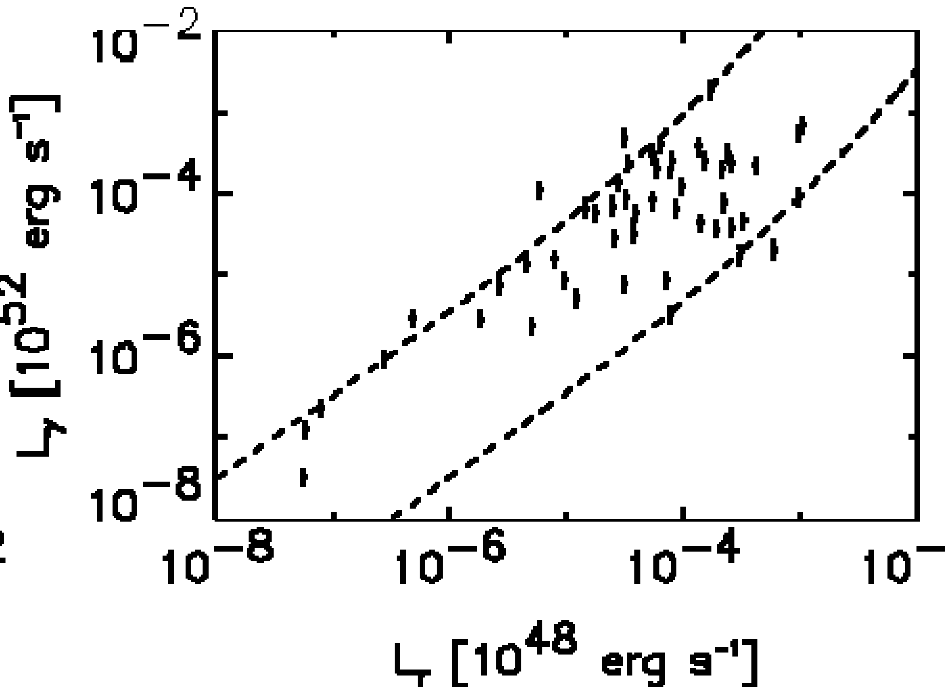
Ingredients: - sample L_r, L_γ from radio/γ-ray lum. function

- sigmoidal probability distribution for sample flux limit:

radio: ~0.5…2Jy (flux-limited sample), ~0.1mJy (complete sample)

gamma: ~0.5…5 $10^{-7}cm^{-2}s^{-1}$, ~$10^{-11}cm^{-2}s^{-1}$





The effect of sample flux limits in L-correlations

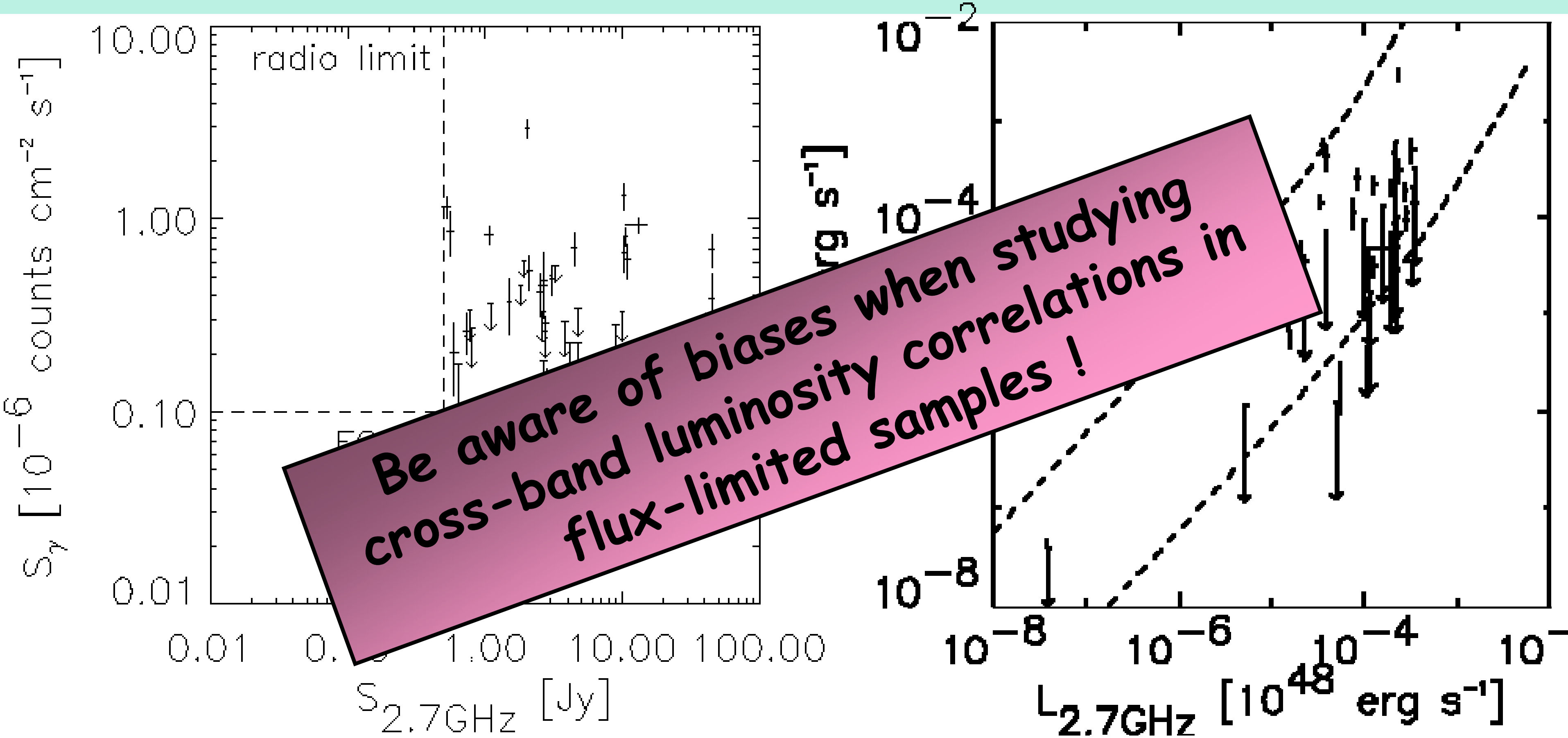
correlation relation: $\log L_\gamma = A + B \log L_r + \varepsilon(\sigma)$, $B=0.8\ldots1.5$, $\sigma=0.05$

- 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)

→ **chance probab. are underestimated by ~factor 3 !**

The effect of sample flux limits in L-correlations



data	N	corr. coeff.	prob.*	corr. ?	χ^2_{min}	signif.**	slope b	corr. ?
10 GHz - γ-ray obs. (simult. det.)	25	0.158	0.465	NO	352.9	0.	-0.109 ± 0.029	NO
10 GHz - γ-ray obs. (simult. det.+UL)	42	0.079	0.288	NO	-	-	-	-
2.7 GHz - γ-ray obs. (simult. det.)	22	0.046	0.751	NO	298.5	0.	-0.031 ± 0.026	NO
2.7 GHz - γ-ray obs. (simult. det.+UL)	41	0.063	0.426	NO	-	-	-	-
max. 4.8 GHz - γ-ray obs.	12	0.594	0.053	marg.	225.9	$6 \cdot 10^{-13}$	0.450 ± 0.029	NO
max. 8 GHz - γ-ray obs.	11	0.363	0.314	NO	238.0	0.	0.477 ± 0.036	NO
4.8 GHz - γ-ray obs. (mean values)	38	0.347	0.114*	NO	159.3	$2 \cdot 10^{-17}$	-0.225 ± 0.041	NO
8 GHz - γ-ray obs. (mean values)	28	0.405	0.108*	NO	144.4	$2 \cdot 10^{-18}$	0.316 ± 0.073	NO

The effect of sample flux limits in L-correlations

- L_γ – L_r problematic for EGRET-blazars ?

No ! – Intrinsic relation might be hidden in large scatter of L_γ-L_r diagram (e.g. from rapid variability, diff.Doppler factors, emission components, etc.);

energy content of particles in radio-to-γray 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:

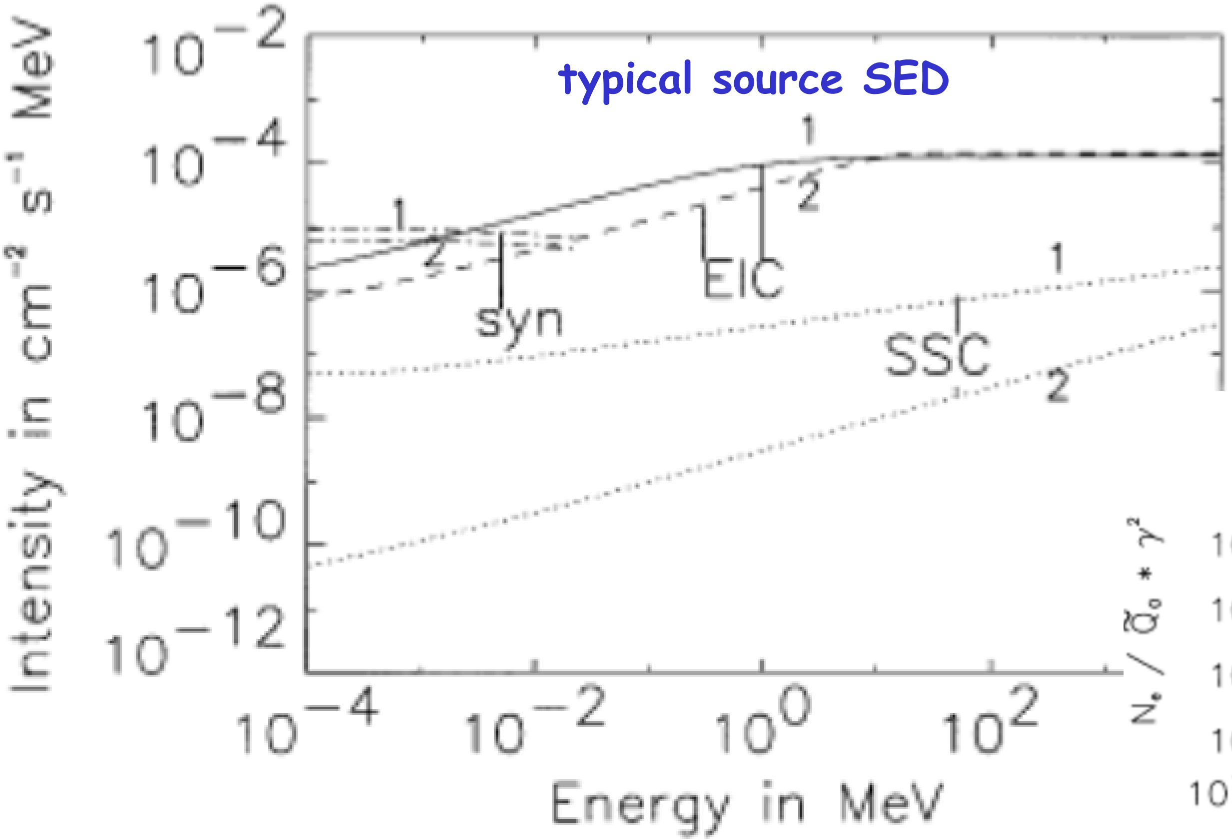
observed LogN-LogS, N_{BLLac}/N_{FSRQ} & redshift distribution of blazars

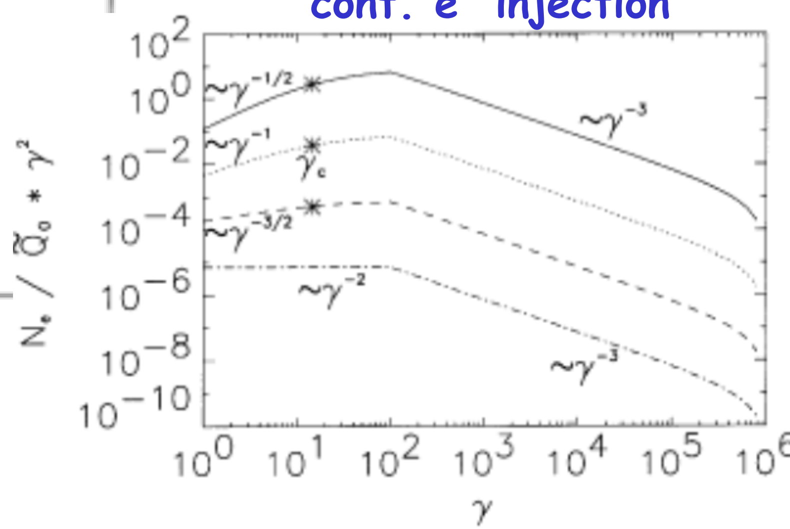
Unification scheme based modeling

Ingredients: - **template source spectrum** from:

extended DS93 EIC-loss dominated emission model

with instan.&cont. particle injection, time-integrated γ–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 distr.: $\rho_{FR}(E_{in}) \sim E_{in}^{-\delta}$, $\delta = 3/3.9$ f. FRI/FRII
- homogeneous distribution of sources
- sigmoidal distribution for sensitivity limit: 0.4…2.1 10^{-7} cm^{-2} s^{-1}

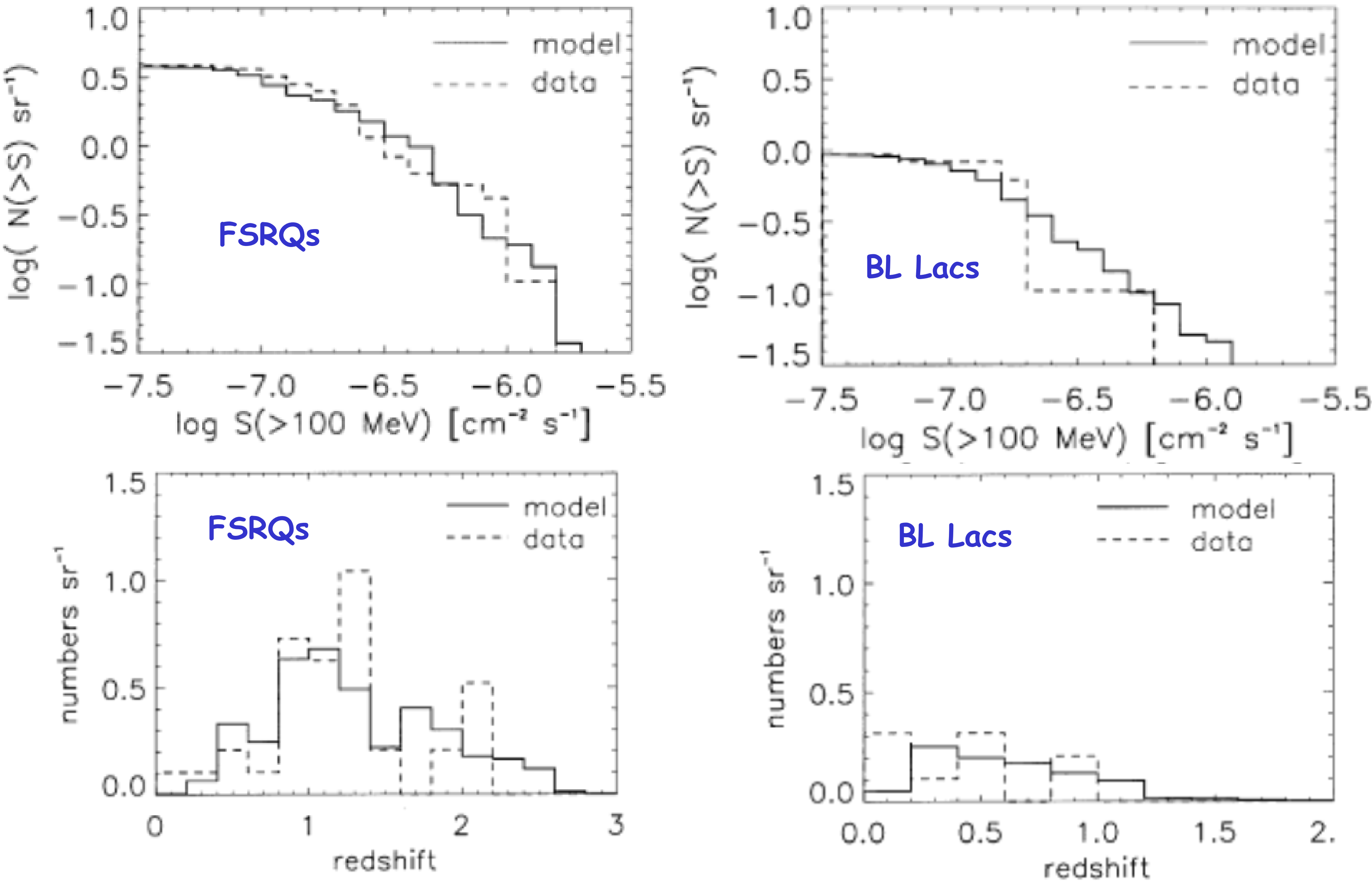
-fixed parameters: B, R_b, L_{acc}, inj. e^- spectrum, integr. time 10^6s

-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



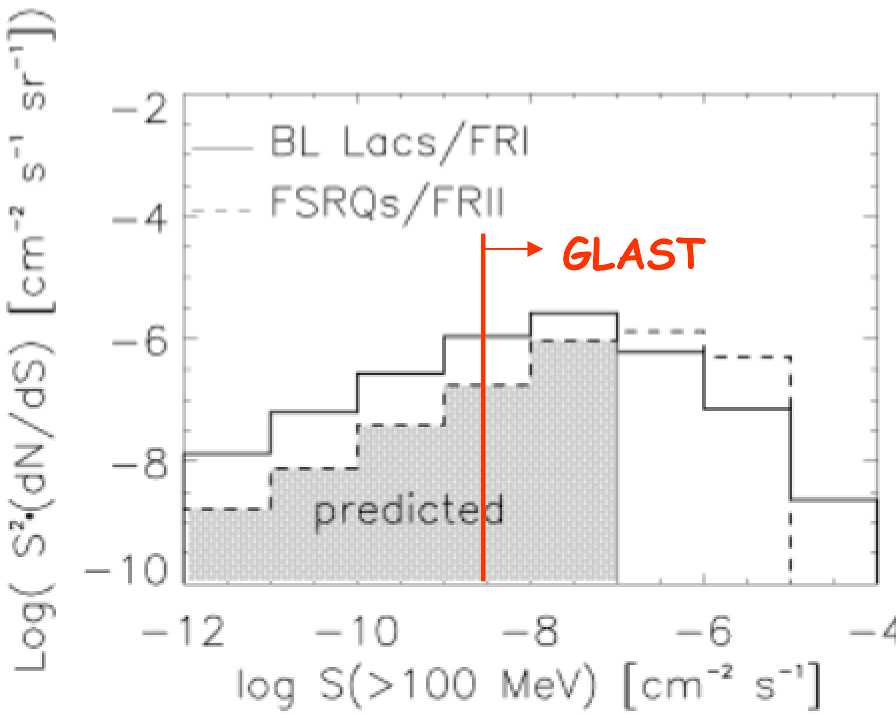
Unification scheme based modeling

Results & Predictions

	FSRQs		BL Lacs	
	inst.inj.	cont.inj.	inst.inj.	cont.inj.
$E_{\mathrm{in},1}$	$10^{44.3}$ erg s^{-1}	$10^{44.2}$ erg s^{-1}	$10^{43.6}$ erg s^{-1}	$10^{43.6}$ erg s
ρ_0	$(3.4 \pm 0.5) \cdot 10^6$	$(1.4 \pm 0.2) \cdot 10^6$	60.7 ± 20.2	39.5 ± 13
$d\mathcal{N}/dV$	393 ± 64	311 ± 50	1913 ± 638	1246 ± 4
$\mathcal{N}$ [%]	17^{+3}_{-2}	20^{+4}_{-2}	83^{+2}_{-3}	80^{+2}_{-4}
P_{NS}	0.63	0.98	0.42	0.56
P_Z	0.98	0.92	0.59	0.47
S_{unres} *	1.21 ± 0.20	1.22 ± 0.20	3.24 ± 1.08	$3.16 \pm 1.$
S_{unres} [%]	8 ± 1	8 ± 1	22 ± 8	22 ± 7
$\frac{S_{\mathrm{unres}}}{S_{\mathrm{unres,tot}}}$ [%]	27^{+5}_{-3}	28^{+5}_{-3}	73^{+3}_{-5}	72^{+3}_{-5}

	FSRQs		BL Lacs	
	inst.inj.	cont.inj.	inst.inj.	cont.inj.
$E_{\mathrm{in},1}$	$10^{44.3}$ erg s^{-1}	$10^{44.2}$ erg s^{-1}	$10^{43.6}$ erg s^{-1}	$10^{43.6}$ erg s
ρ_0	$(2.3 \pm 0.4) \cdot 10^6$	$(1.0 \pm 0.2) \cdot 10^6$	59.1 ± 19.7	63.9 ± 21
$d\mathcal{N}/dV$	269 ± 44	233 ± 38	1864 ± 621	2016 ± 6
$\mathcal{N}$ [%]	12^{+3}_{-1}	10^{+2}_{-1}	87^{+1}_{-3}	90^{+1}_{-2}
P_{NS}	0.94	0.94	0.40	0.59
P_Z	0.99	0.83	0.75	0.48
S_{unres} *	1.31 ± 0.21	1.28 ± 0.21	5.49 ± 1.83	8.50 ± 2.53
S_{unres} [%]	9 ± 2	9 ± 1	38 ± 13	59 ± 20
$\frac{S_{\mathrm{unres}}}{S_{\mathrm{unres,tot}}}$ [%]	19^{+4}_{-2}	13^{+3}_{-2}	81^{+2}_{-4}	87^{+2}_{-3}

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



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

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

Summary

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

  < 25 % blazar contribution

- **scaling luminosity functions (based on cross-band luminosity correlations):**
[Padovani et al. 1993, Stecker et al. 1993, 1996, Salamon & Stecker 1994, ..., Narumoto & Totani 2006; scaling SED*: Giommi et al. 2006]*

  ~ 20-100% blazar contribution

- **fluctuation analysis:** *[T. Willis (PhD-thesis) 1996]*

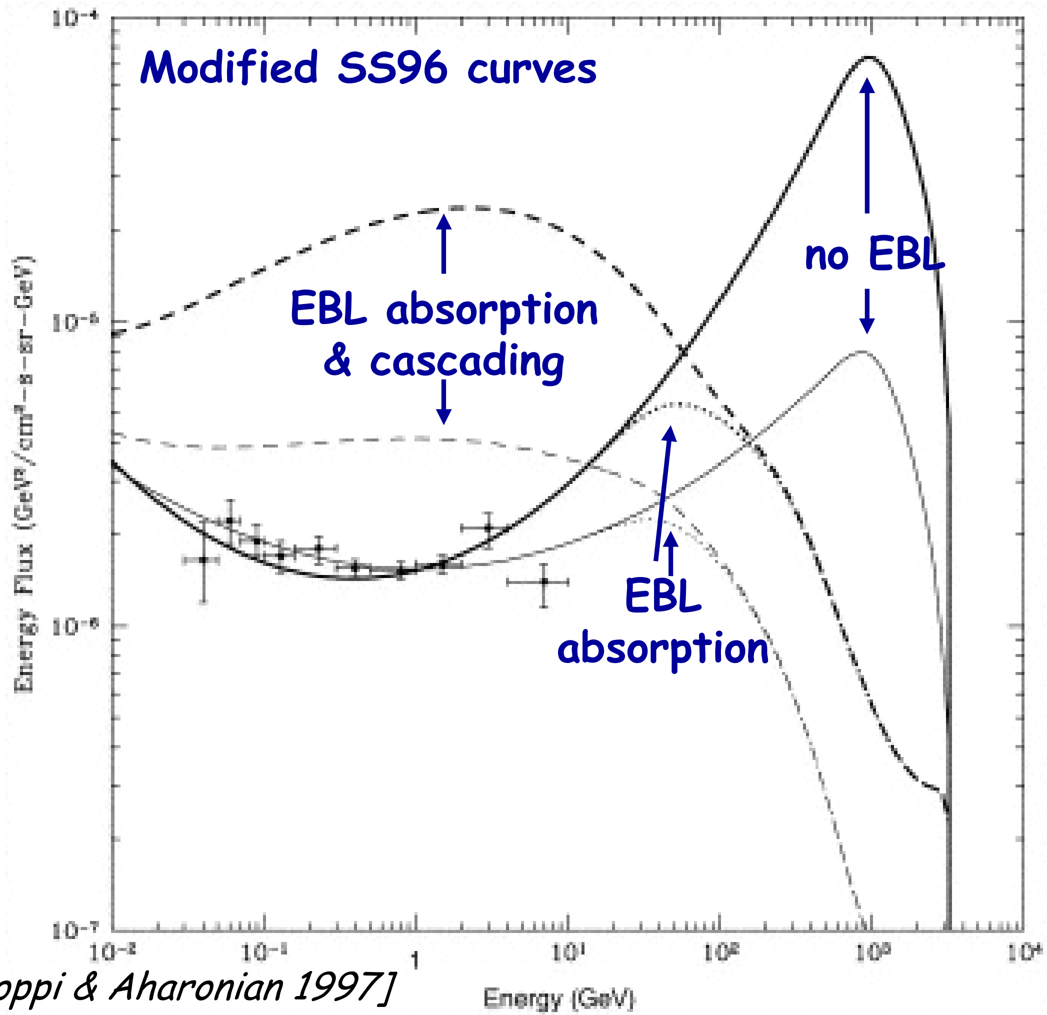
  ~ 5-100% point source contribution

- **AGN unification scheme & emission model:**
[Mücke & Pohl 2000]

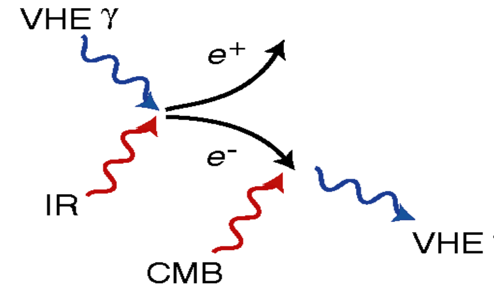
  ~ 20-85% radio-loud AGN contribution

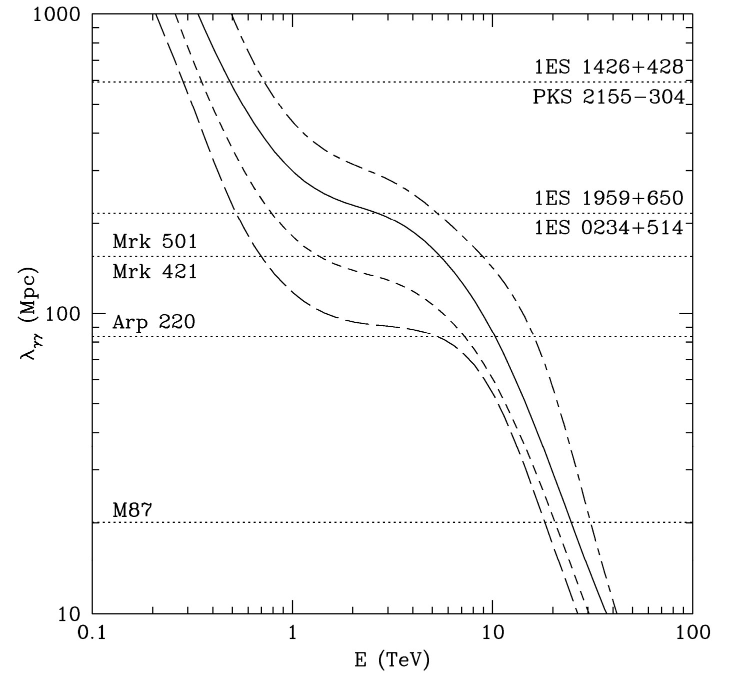
  (of which 70-90% are of BL Lac/FR-I type)

The cascade contribution of TeV-blazars



[Coppi & Aharonian 1997]





6 TeV-blazars with z>0.1 known so far !

- 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