Extragalactic Diffuse Emissions

Chuck Dermer

GLAST IDS

Naval Research Laboratory

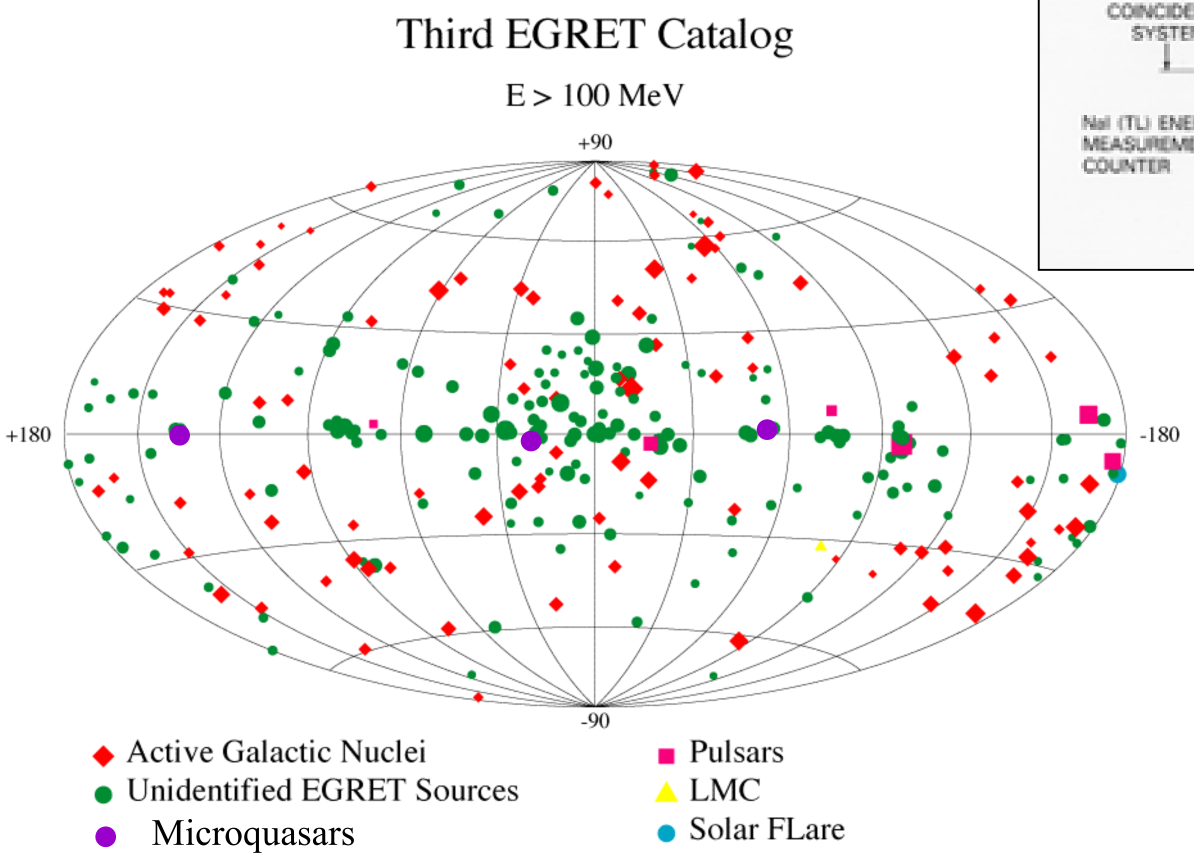
GLAST Symposium
Stanford U., West Palo Alto
February 8, 2007

1. GLAST Analysis of High Latitude Sources
2. EGRET blazar model statistics ⇒ predictions for GLAST
3. Sources of unresolved/diffuse extragalactic γ-ray intensity
4. Hadronic Signatures in Blazars and GRBs
5. Correlation of Fluxes: joint $\gamma\gamma$ and photohadronic ν constraints
6. Black hole demography, cosmic ray origin

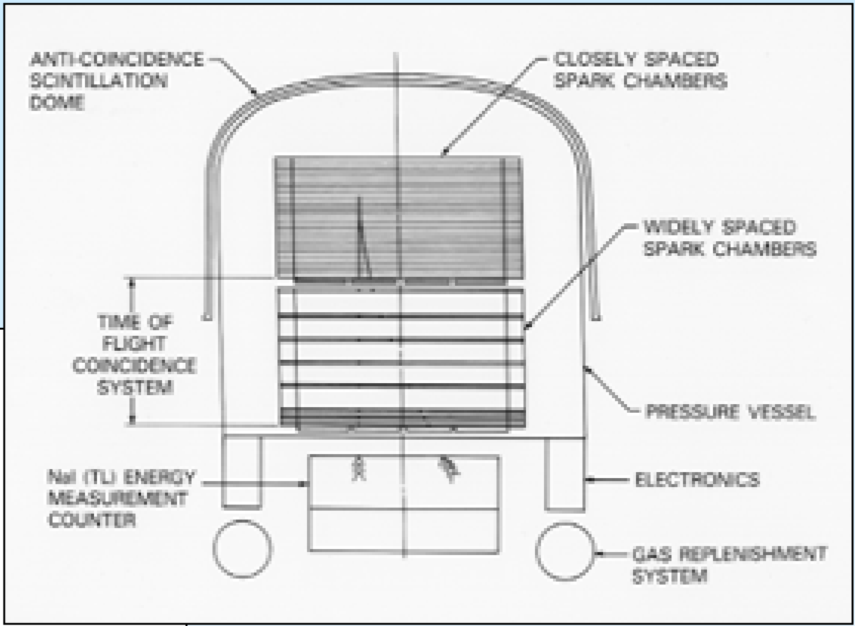
EGRET Legacy

3EG catalog: 270 sources, 66 high confidence blazars Hartman et al. (1999) (Cen A)

(~ 130 blazars: Romani)



EGRET



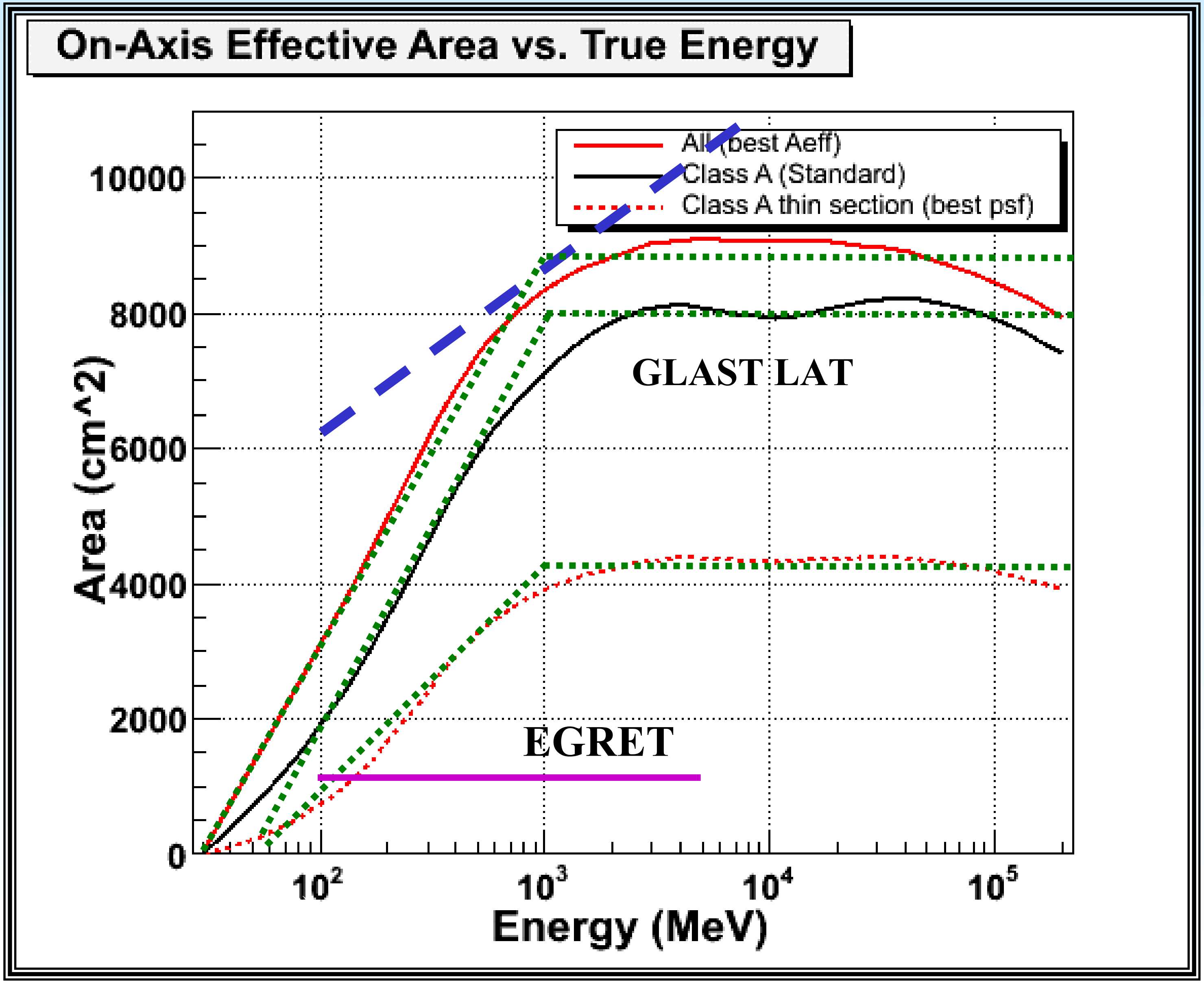
Ground γ Telescopes

> 15 TeV/XBL blazars

1 radio galaxy: M87

Galactic Plane Scan

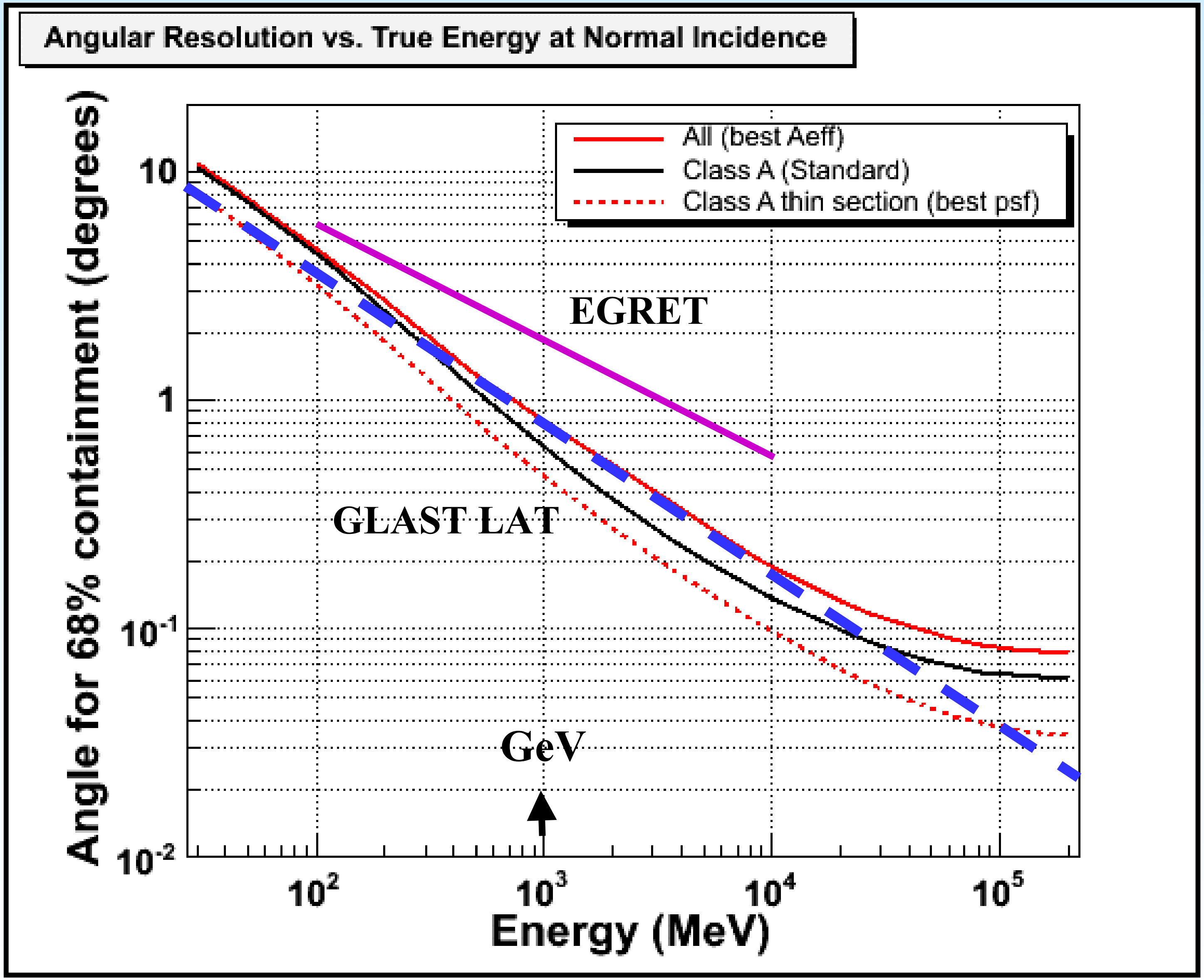
New LAT Performance Parameters: A_{eff}



EGRET: 100 MeV Telescope

GLAST: GeV Telescope

New LAT Perform. Parameters: PSF



GLAST data analysis

EGRET analysis: >100 MeV (*background*-limited for weak sources)

ϕ_{-8}=ϕ/10^{-8} ph(>100 MeV) cm^{-2} s^{-1}
(~7x10^{-12} ϕ_{-8} ergs cm^{-2} s^{-1} for a flat νF_ν spectrum with α_{ph} = 2)

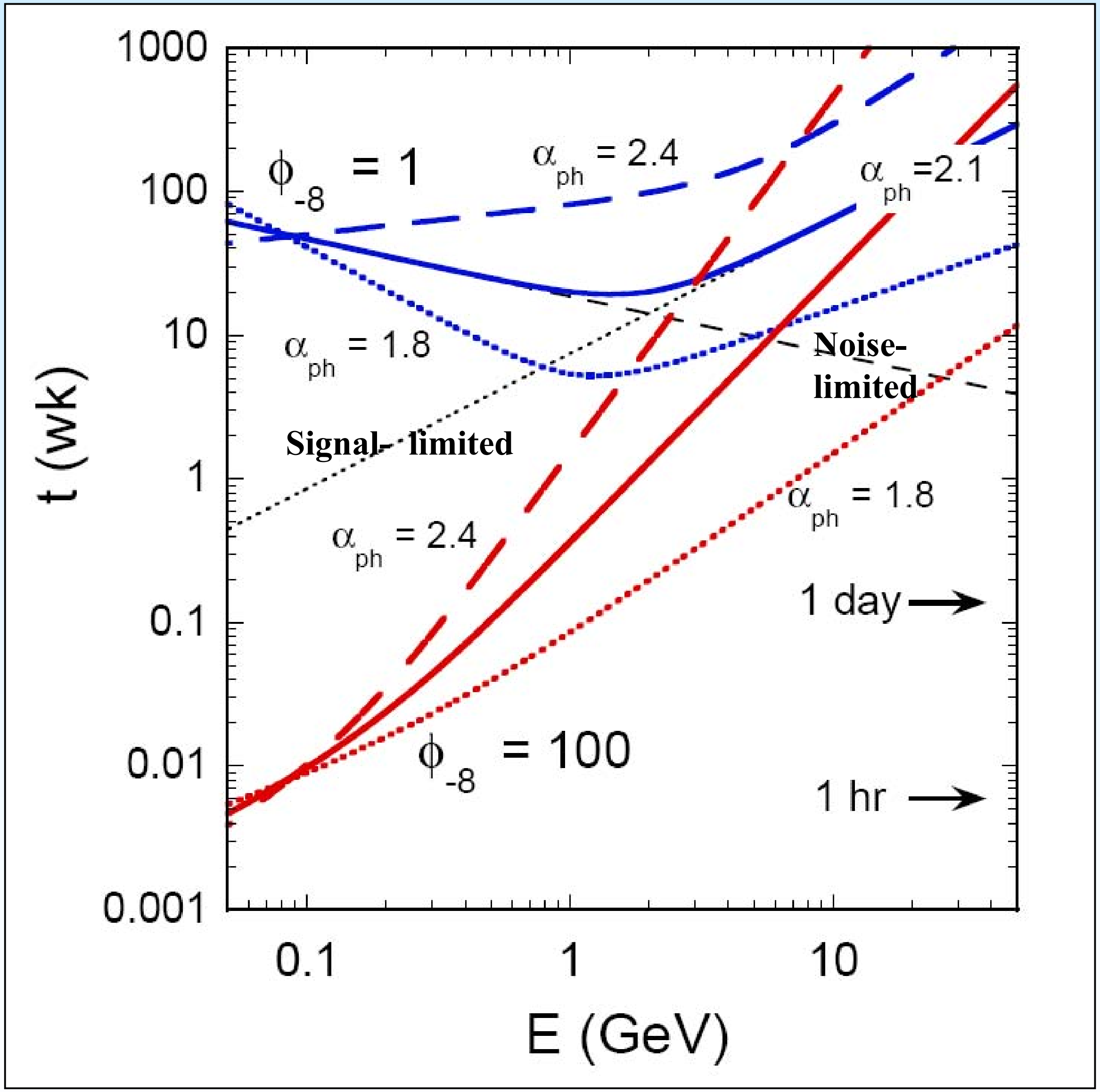
EGRET: $\phi_{-8} \approx 15$; 2-week pointing—1/24th of the full sky (νF_ν^{thr} ~10^{-10} ergs cm^{-2} s^{-1})

GLAST: $\phi_{-8} \approx 15$ in ~1 day over full sky (νF_ν^{thr} ~10^{-10} ergs cm^{-2} s^{-1})

Sub-hour scale variability when ϕ_{-8} > 200

of ϕ_{-8} > 200 blazar flares: few per week (Dermer & Dingus 2004)

Bias toward hard spectrum GeV sources at low fluxes: XBLs over FSRQs?



Blazar Statistics

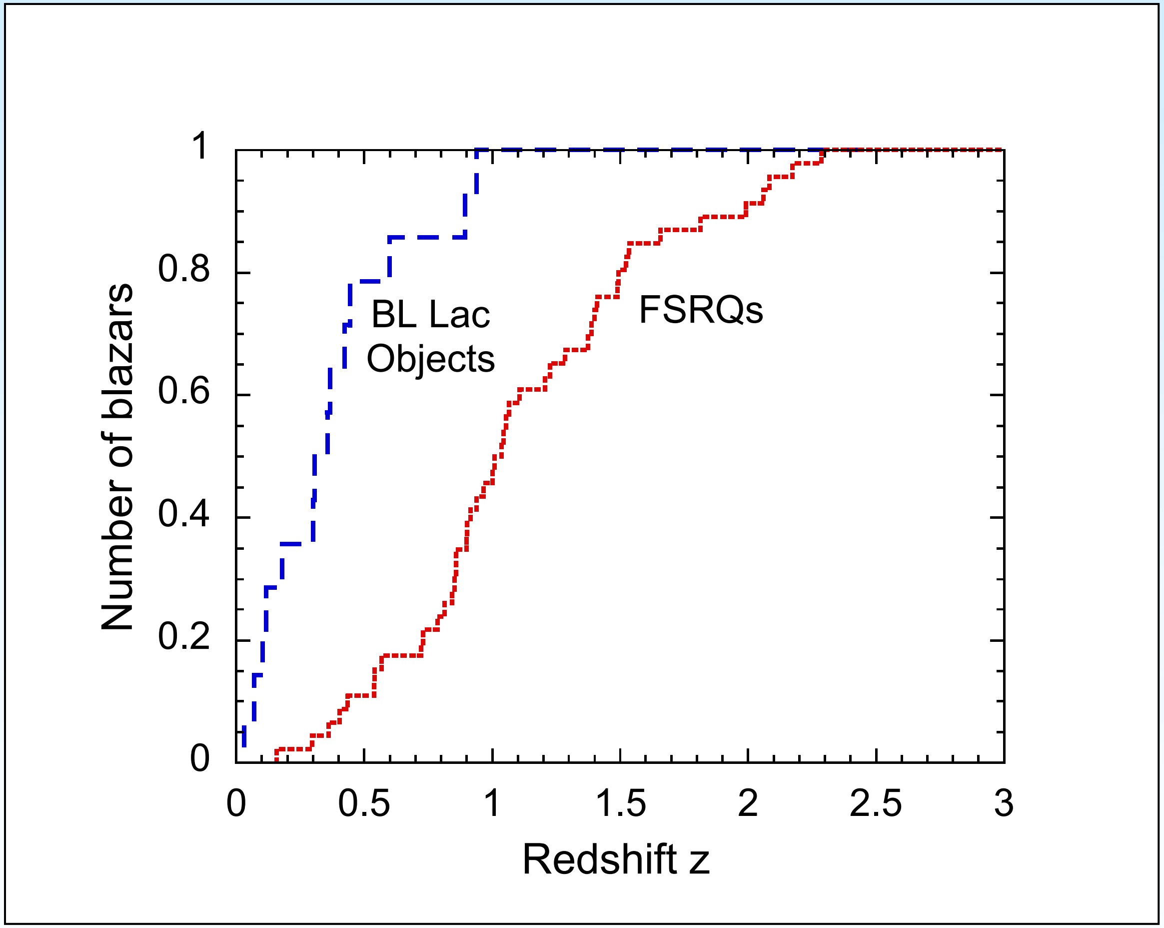
Redshift Distribution of EGRET γ-Ray Blazars

Uniform exposure:
EGRET all-sky survey
Fichtel et al. (1994):
1EG catalog

EGRET blazar sample:
46 FSRQs
14 BL Lac Objects

thanks to Stan Davis

thanks to Stan Davis

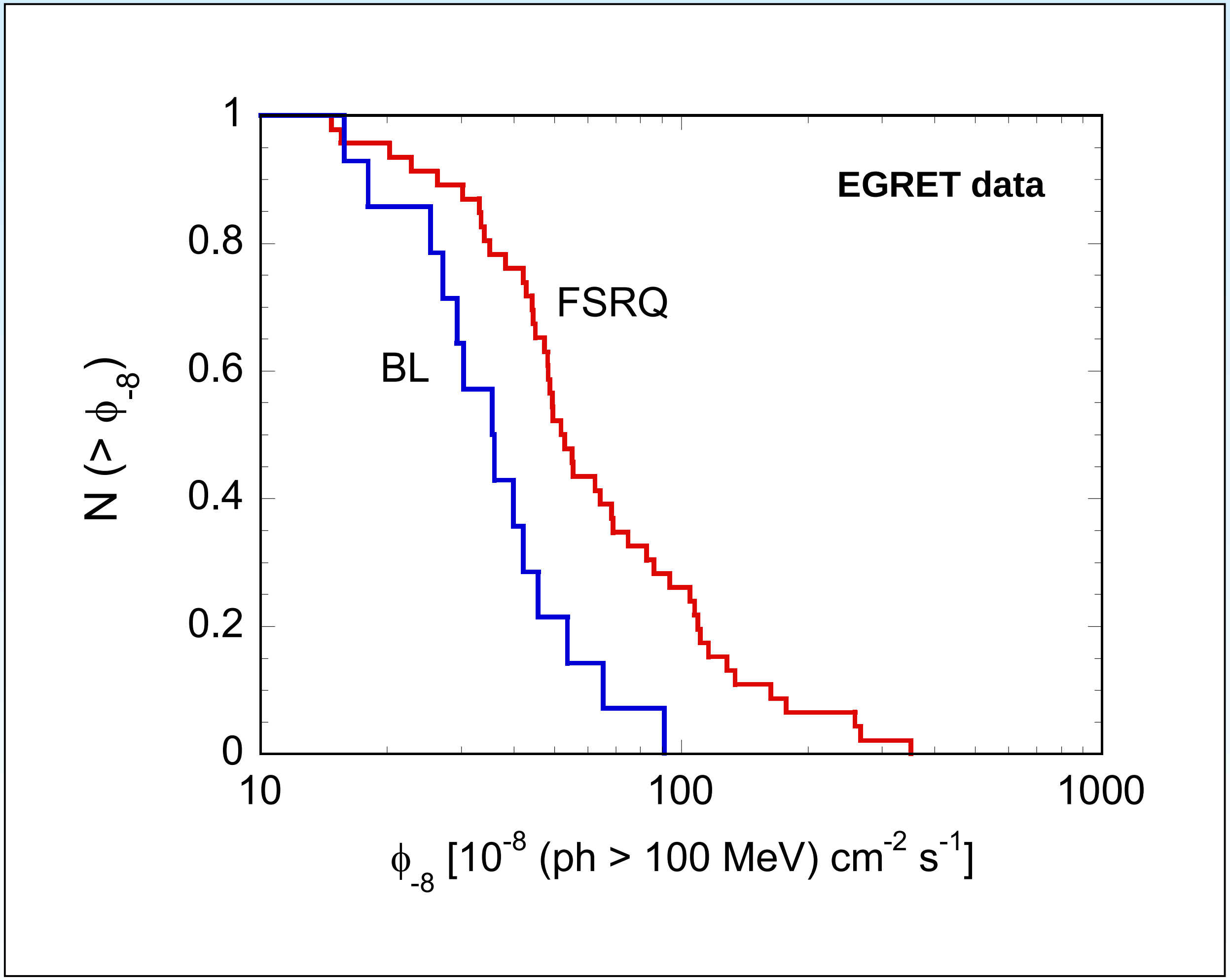


Size Distribution of EGRET γ-Ray Blazars

Two-week on-axis sensitivity of EGRET:

≈ 15×10^{-8} ph(>100 MeV) cm^{-2} s^{-1}

≈ 10^{-10} erg cm^{-2} s^{-1} (100 MeV – 5 GeV)



Blazars: the Platonic Ideal

Basic Radiation Physics:

$$\nu F_\nu = f_\varepsilon \; (ergs\ cm^{-2}\ s^{-1})$$

Threshold condition:

$$f_\epsilon^{proc} = \frac{\ell'_e \delta_D^q \epsilon_z^{\alpha_\nu}}{d_L^2(z)} \geq f_\epsilon$$

Telescope sensitivity

$$\varepsilon_z = (h\nu / m_e c^2)(1+z)$$

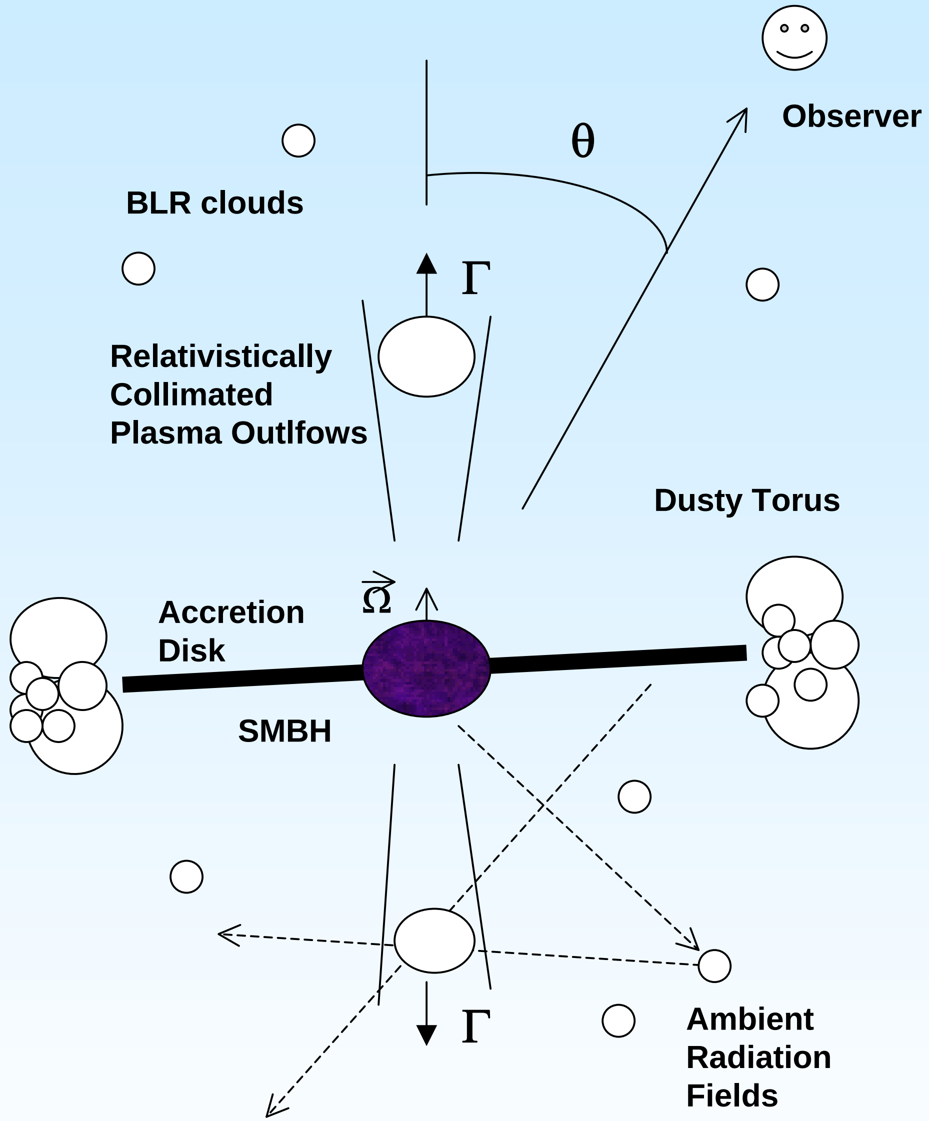
$$\delta_D = [\Gamma(1-\beta\mu)]^{-1}, \alpha_\nu = (3-p)/2$$

comoving directional luminosity

$$\ell'_e \; (ergs\ s^{-1}\ sr^{-1})$$

1. synchrotron/SSC
2. external Compton

$$q = \begin{cases} (p+5)/2, & \text{synchrotron/SSC} \\ p+3 & \text{EC} \end{cases}$$



Statistics of Blazars: Redshift and Size Distribution

Model redshift and size distributions of EGRET blazars

local rate density

BFR

$$\frac{d\dot{N}_{bl}}{d\Omega}(> f_\epsilon) = 2c\dot{n}_{bl} \int_0^\infty dz \, |\frac{dt_*}{dz}| \, \frac{d_L^2(z)\Sigma_{bl}(z)}{(1+z)^2}$$

$$\times \int_1^\infty d\Gamma \; N(\Gamma; z) \int_0^\infty d\ell'_e \; N(\ell'_e; z) \; [1 - \max(-1, \hat{\mu})]$$

Γ-factor evolution

luminosity evolution

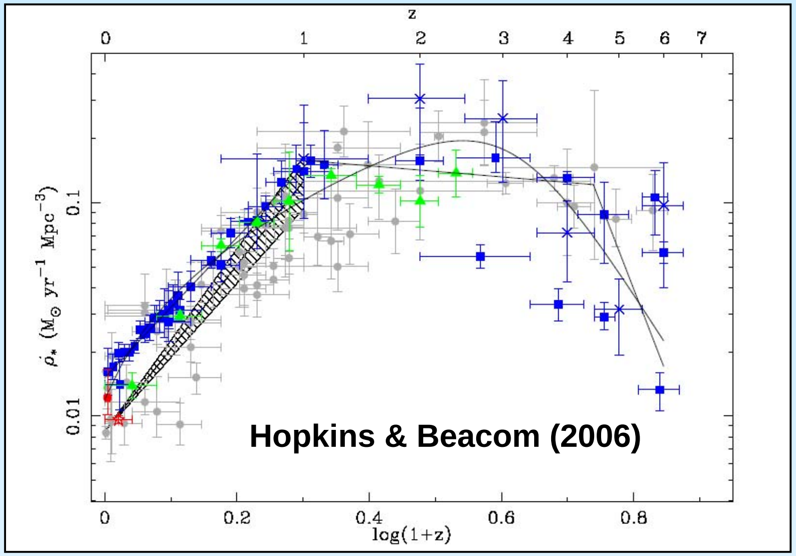
threshold term

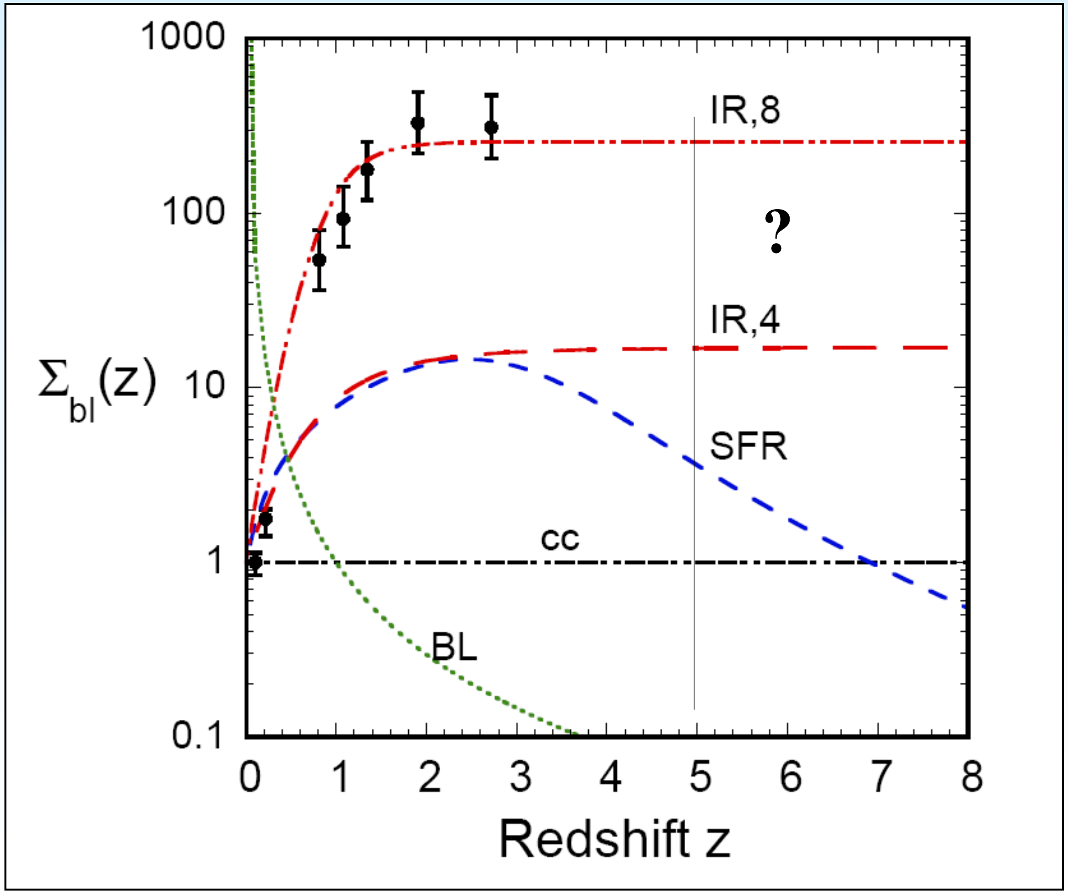
Simplest model: fixed Γ, fixed ℓ'_e (no luminosity evolution)

Blazar Formation Rate analytic

Blazar Cosmology

1. Comoving Density (or Rate Density) Evolution
2. Luminosity Evolution





Blazar Formation History (BFH)

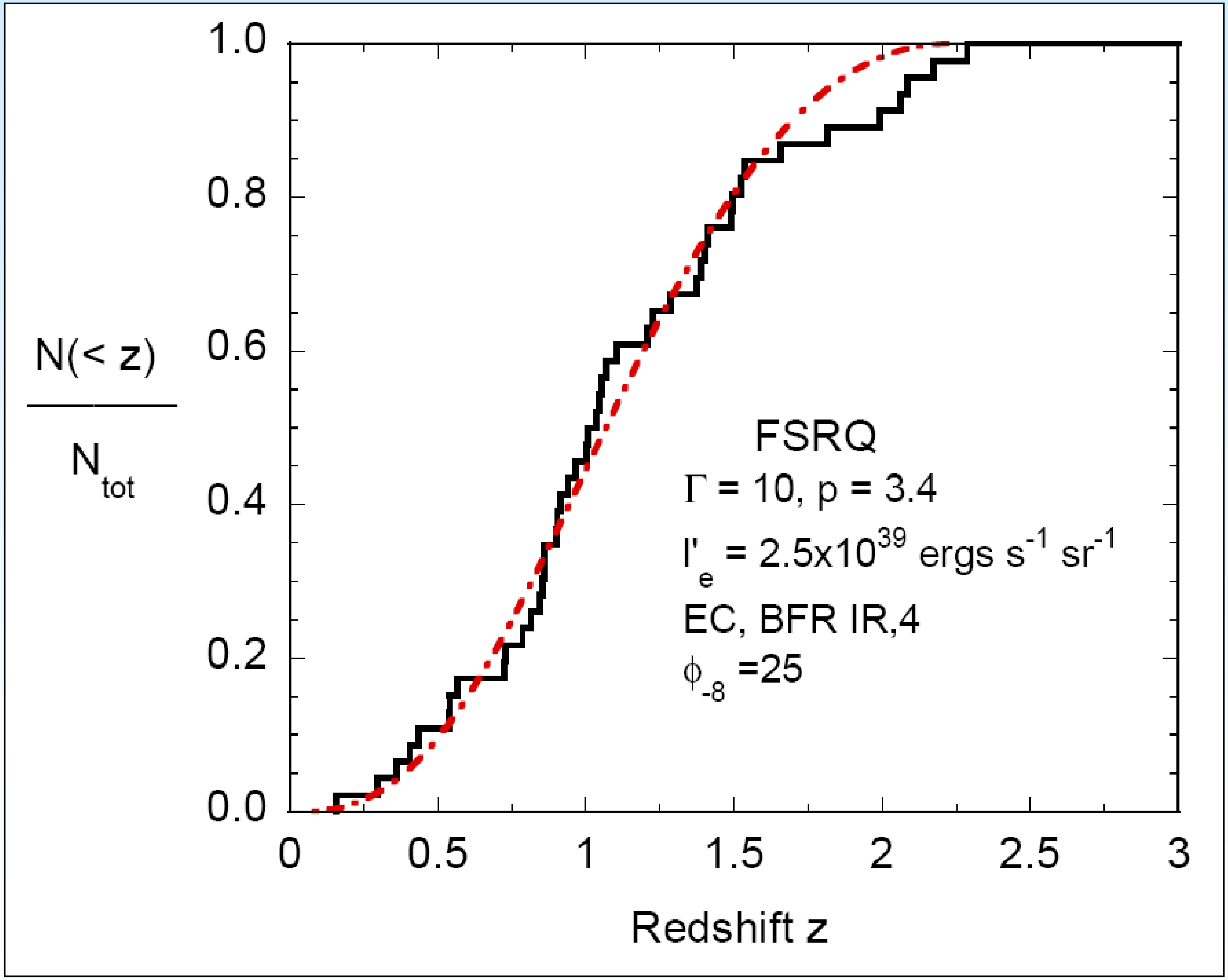
Constant Comoving Rate

Star Formation Rate (SFR)

IR,8 (Sanders 2004)

SFH BL

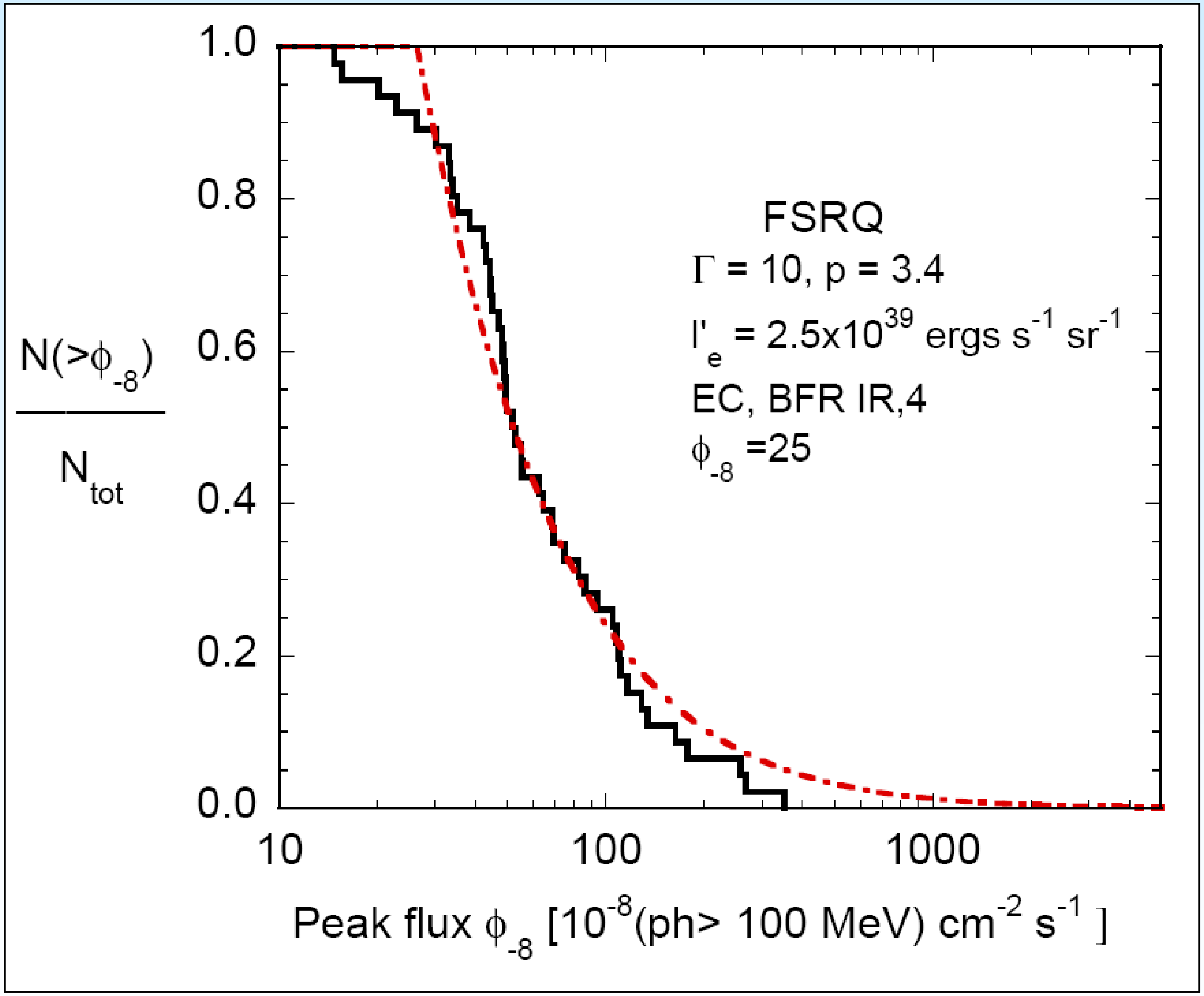
Fit of FSRQ Model to Redshift Distribution



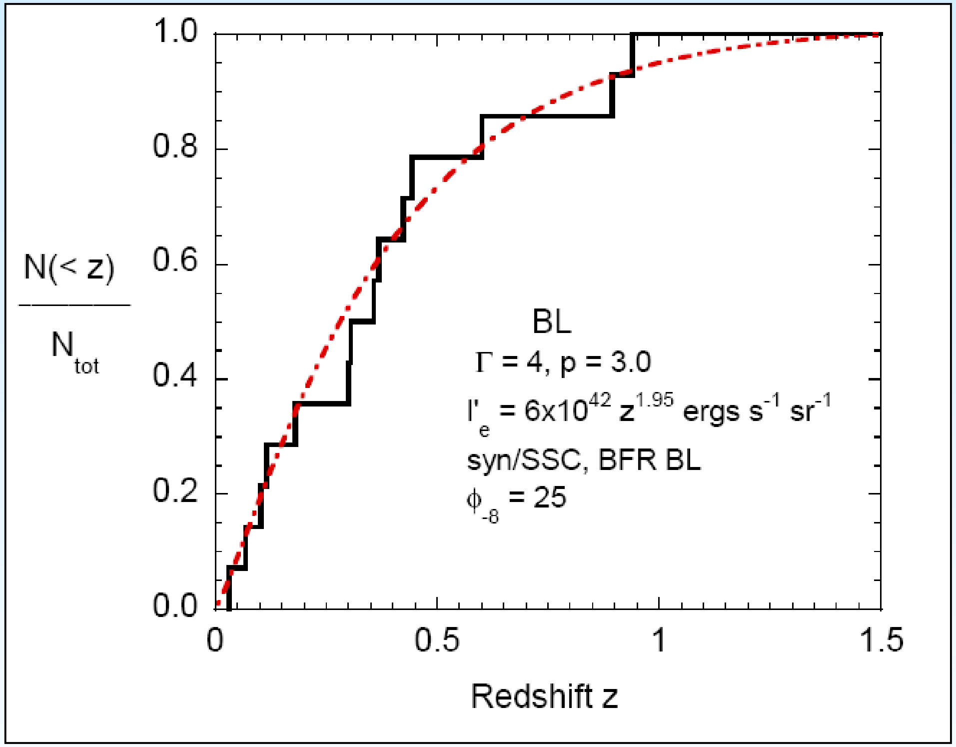
Mono-parameter L_* Blazar

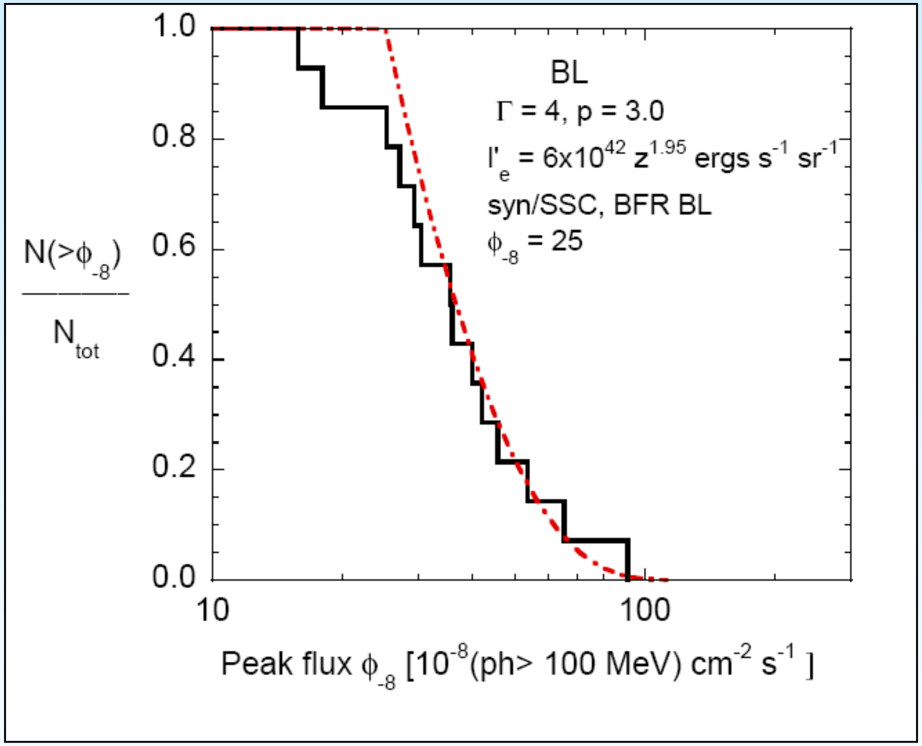
SFR IR,4

Size Distribution of Model FSRQ



Redshift and Size Distributions of BL Lac Objects

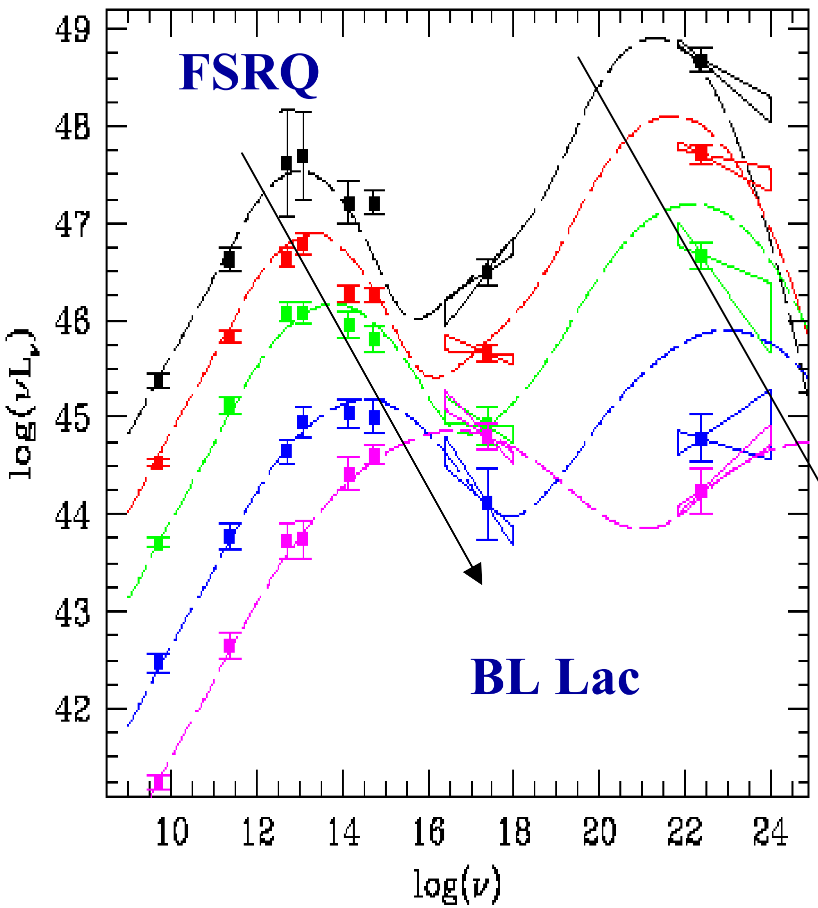


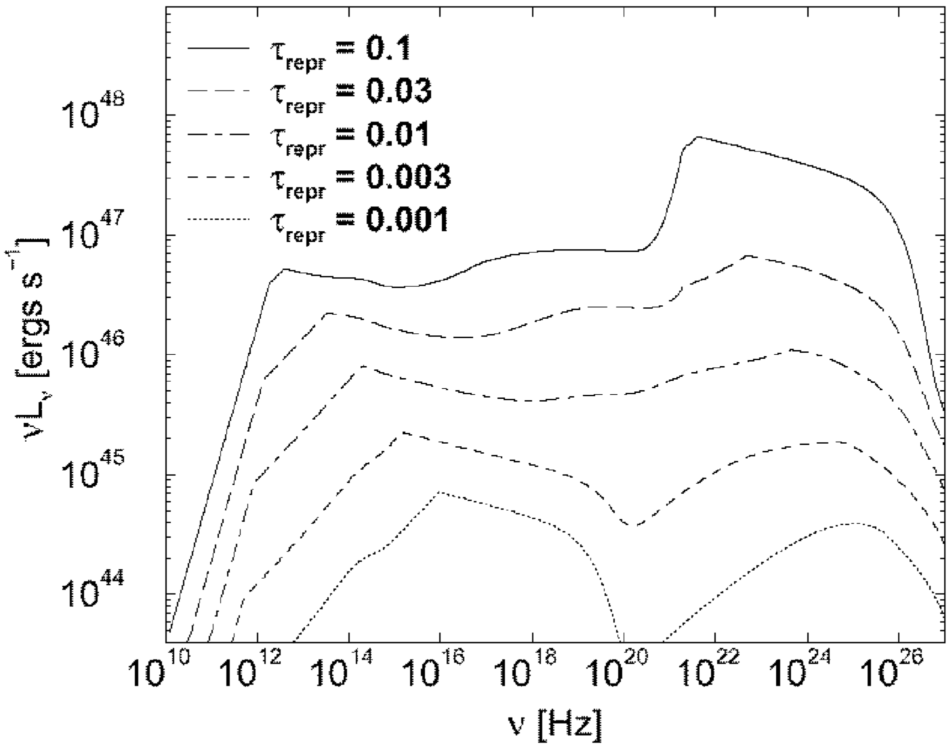


Require negative density evolution (fewer BL Lacs at early times)

Positive luminosity evolution (brighter at early time)

Blazar Main Sequence





Evolution from FSRQ to BL Lac Objects in terms of a reduction of fuel from surrounding gas and dust

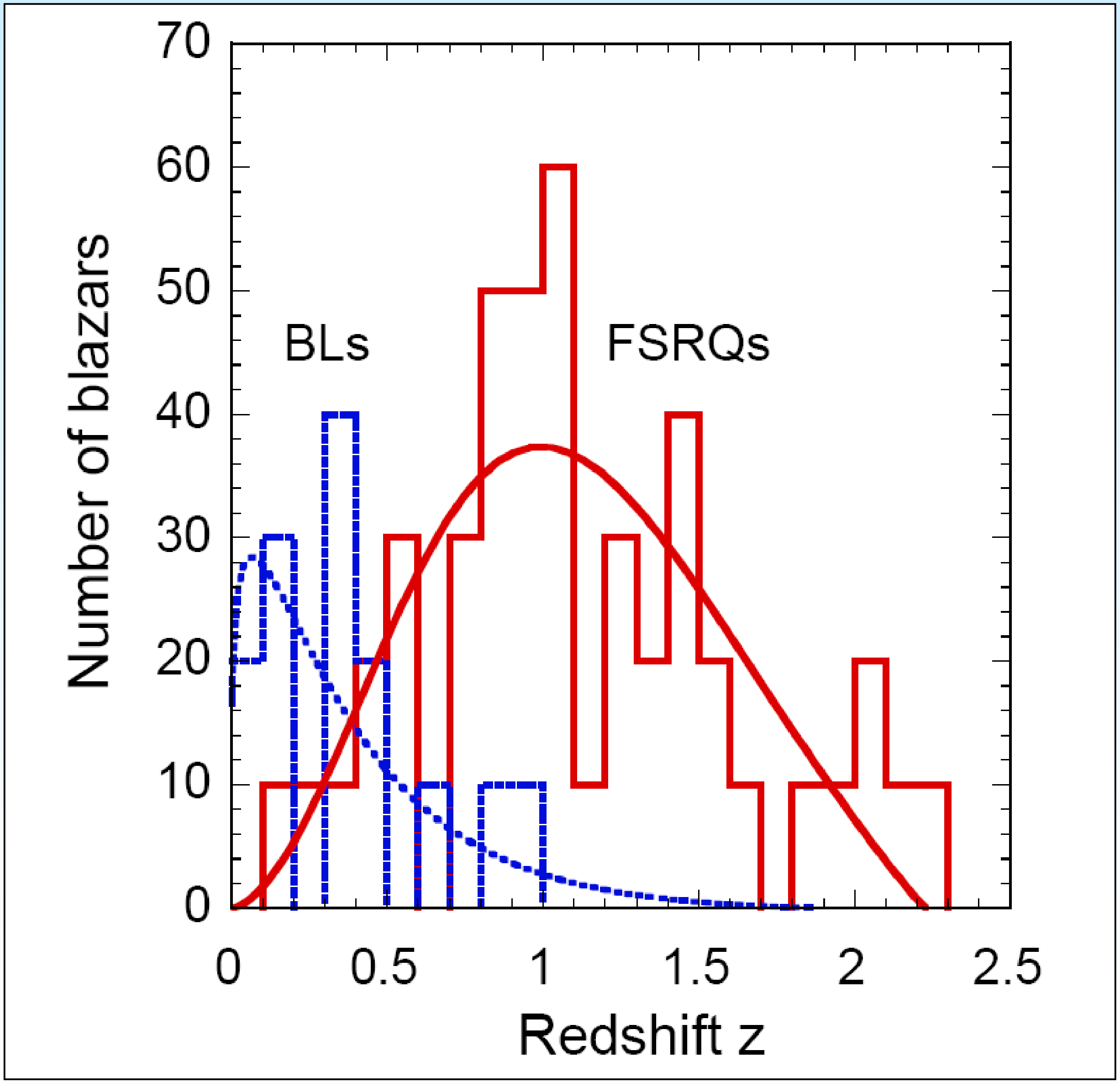
Sambruna et al. (1996); Fossati et al. (1998)
Ghisellini et al. (1998)

Böttcher and Dermer (2000)
Cavaliere and d'Elia (2000)

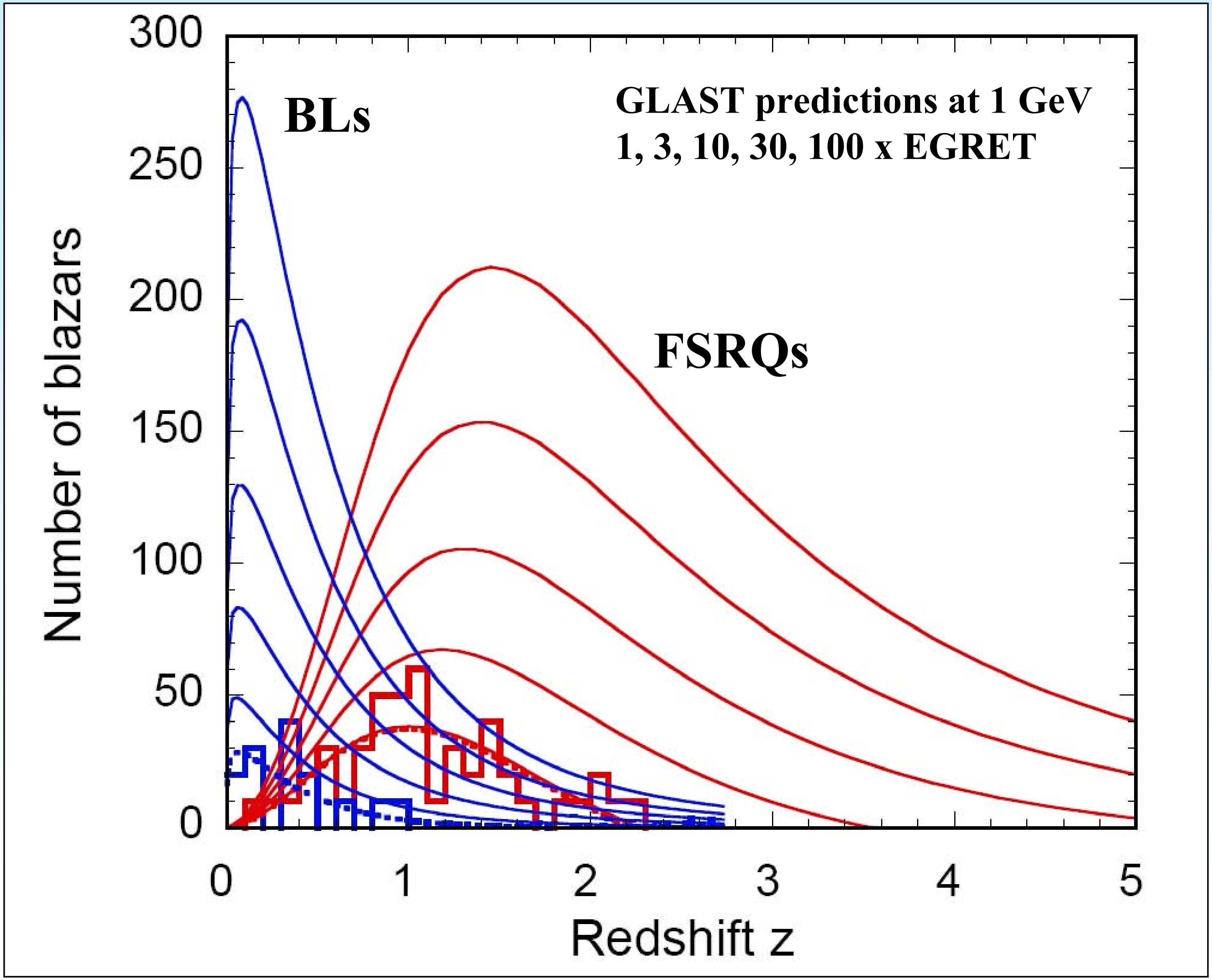
BL Lac objects are late stages of FSRQs: in accord with analysis of EGRET data

(1) Blazar main sequence valid? (2) BL Lac BH Masses > FSRQ BH masses?

Model Redshift Distribution of EGRET γ-Ray Blazars



Redshift Predictions for GLAST γ-Ray Blazars

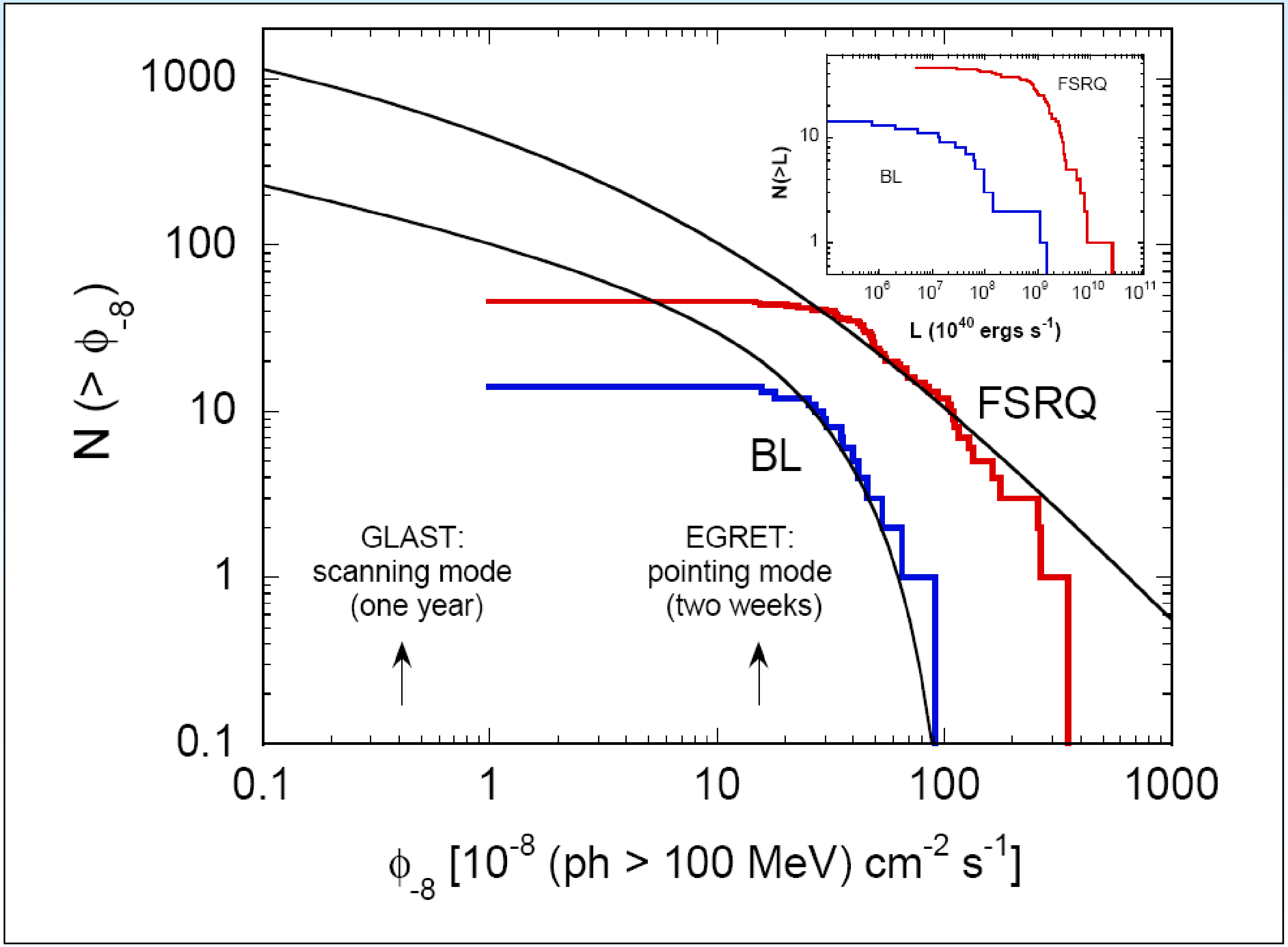


Predicted Number of Blazars with GLAST

GLAST reaches sensitivity of 0.4×10^{-8} ph(>100 MeV)/cm^2 s in one year

~700 FSRQ/FR2s and ~150 BL/FR1s by end of first year of operation

see Dermer (2006), ApJ, in press (see astro-ph) for details

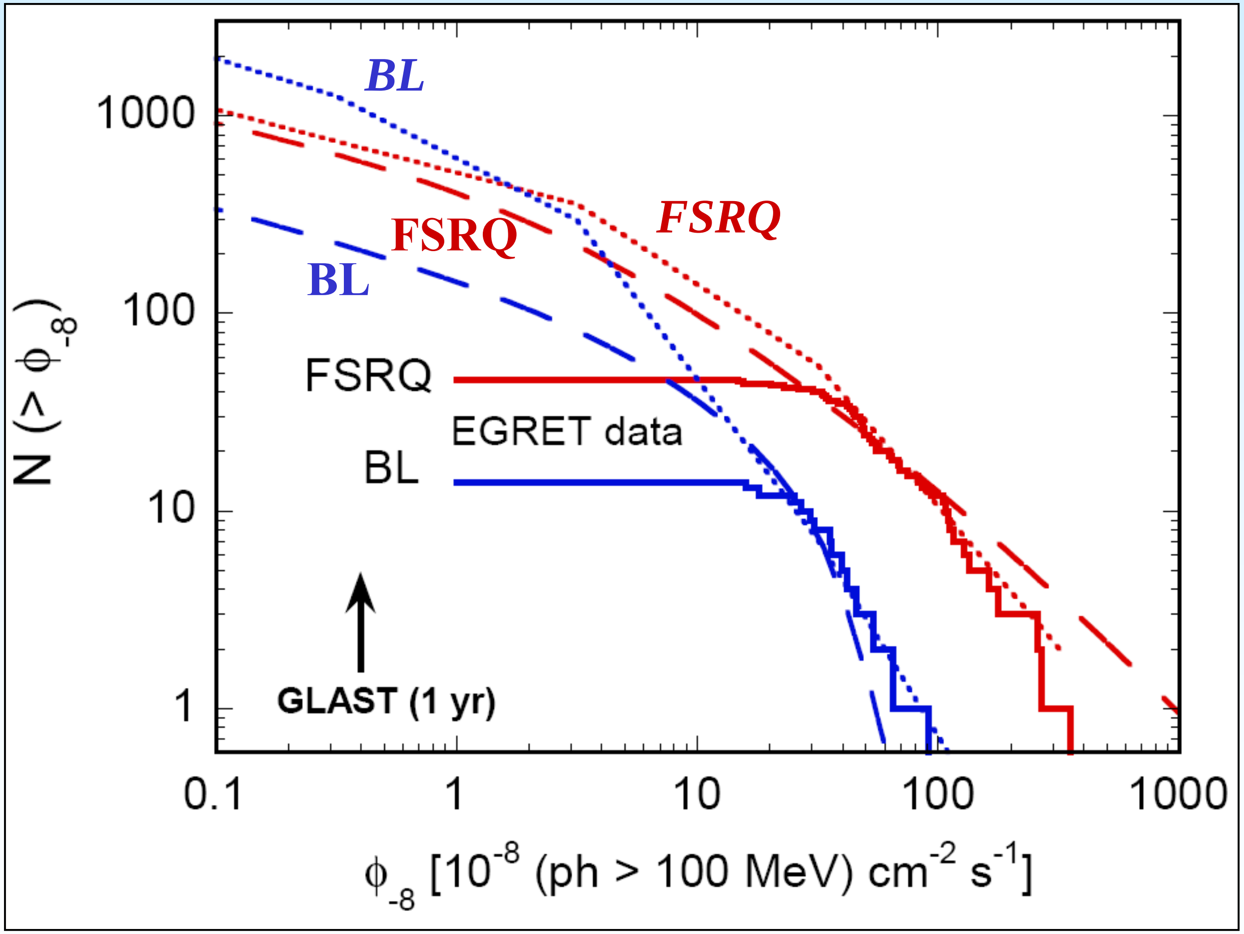


Predicted Number of Blazars with GLAST

Peak flux size distribution of EGRET blazars for two-week pointings during the all-sky survey

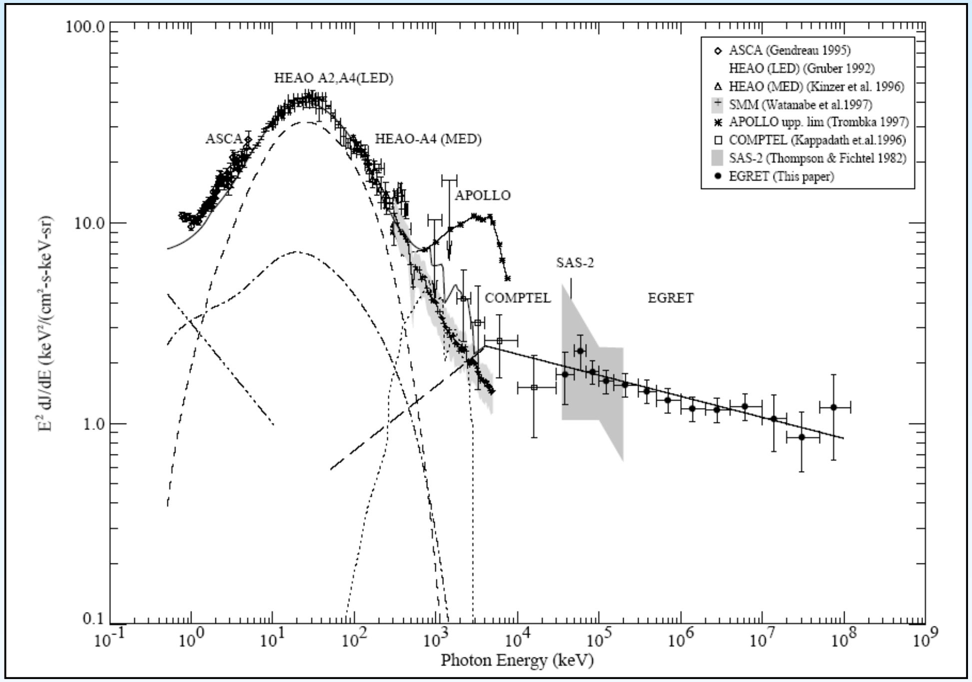
Dotted curves: Mücke and Pohl (2000)

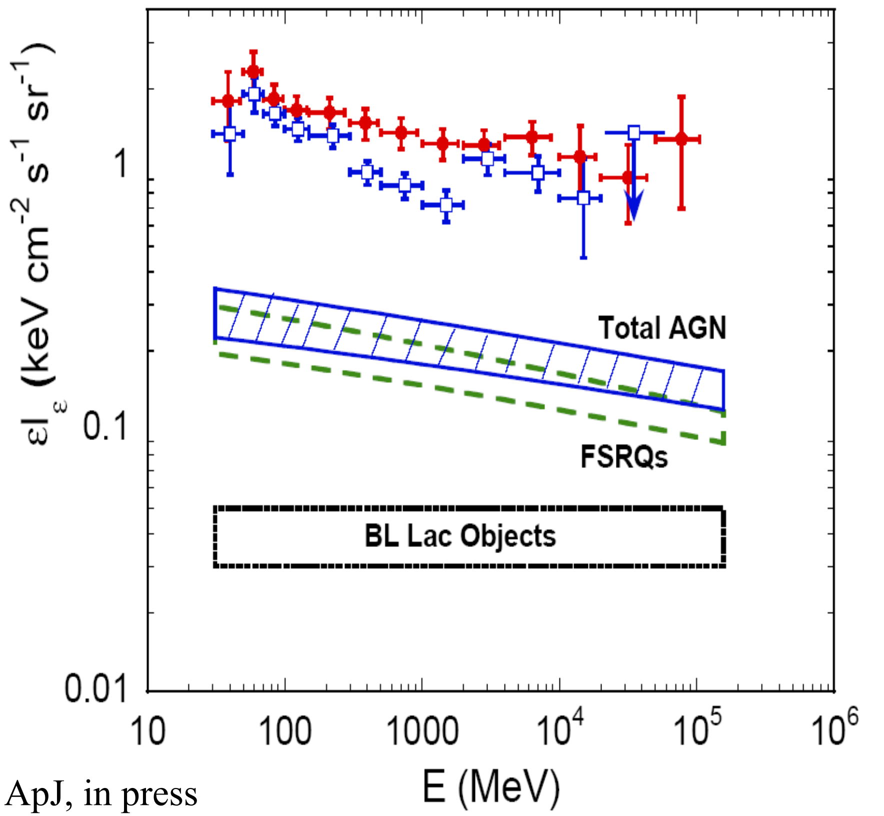
Stecker (priv. comm., this conference) predicts 8000-10000 GLAST blazars based on Stecker & Salamon (1996) treatment



Blazar Contribution to Unresolved/Diffuse γ-Ray Background

Data: Sreekumar et al. (1998)
Strong, Moskalenko, & Reimer (2000)





ApJ, in press

- **EGRET Analysis** (Sreekumar et al. 1998)
  (Atwood GLAST symposium talk 2007)
- **GALPROP Model** (Strong, Moskalenko, & Reimer 2000)

Analysis herein:
BL Lacs: ~2 - 4% (at 1 GeV)
FSRQs: ~ 10 - 15%

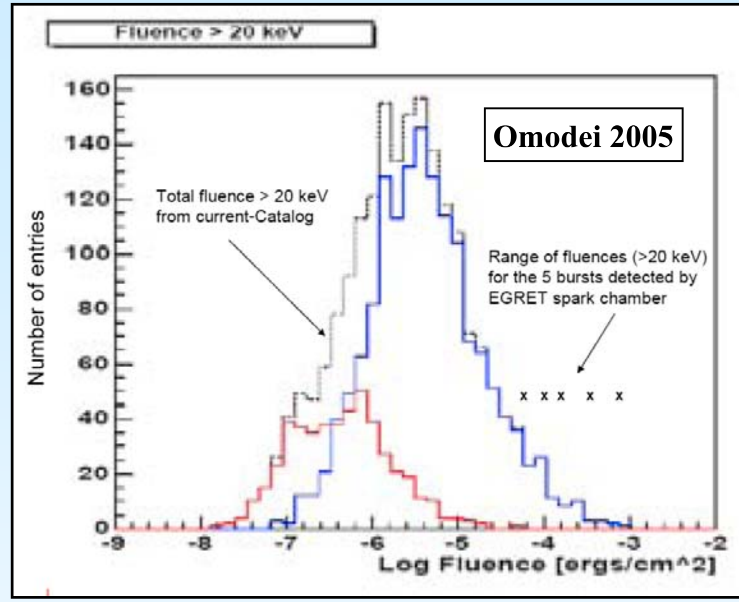
GRB Contribution to the Diffuse Extragalactic γ-Ray Background

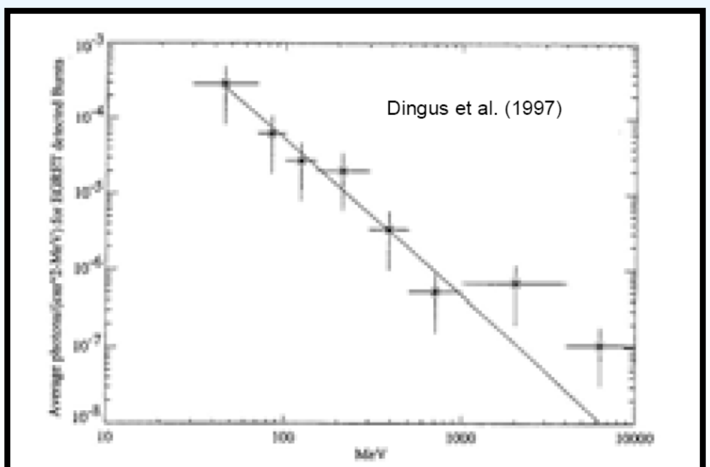
Truong Le poster

- Ratio of EGRET spark chamber fluence to >20 keV BATSE fluence: (Dingus 1995, Catelli & Dingus 1997)

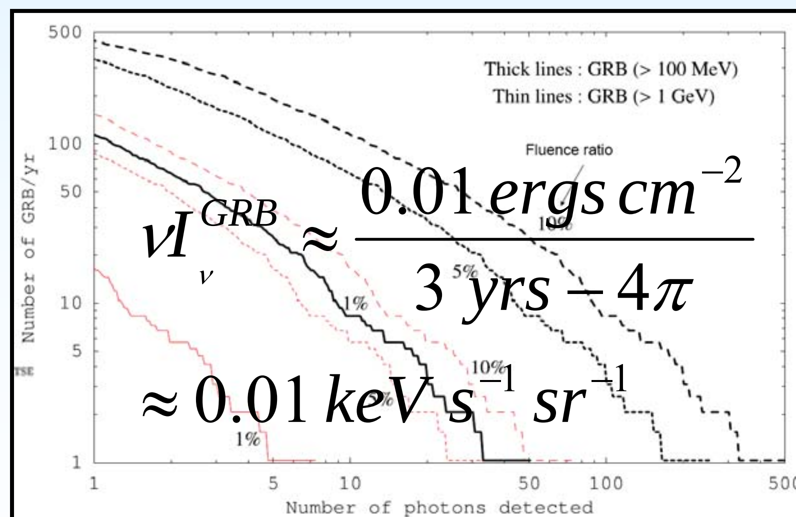
1. GRB 910503: ρ = 1.7%
2. GRB 910601: ρ = 2.8%
3. GRB 930131: ρ = 15%
4. GRB 940217: ρ = 0.8-2%
5. GRB 940301: ρ = 3.4%

Average: $\langle\rho\rangle \approx 5\%$





Small!



$$\nu I_\nu^{GRB} \approx \frac{0.01\, ergs\, cm^{-2}}{3\, yrs - 4\pi}$$

$$\approx 0.01\, keV\, s^{-1}\, sr^{-1}$$

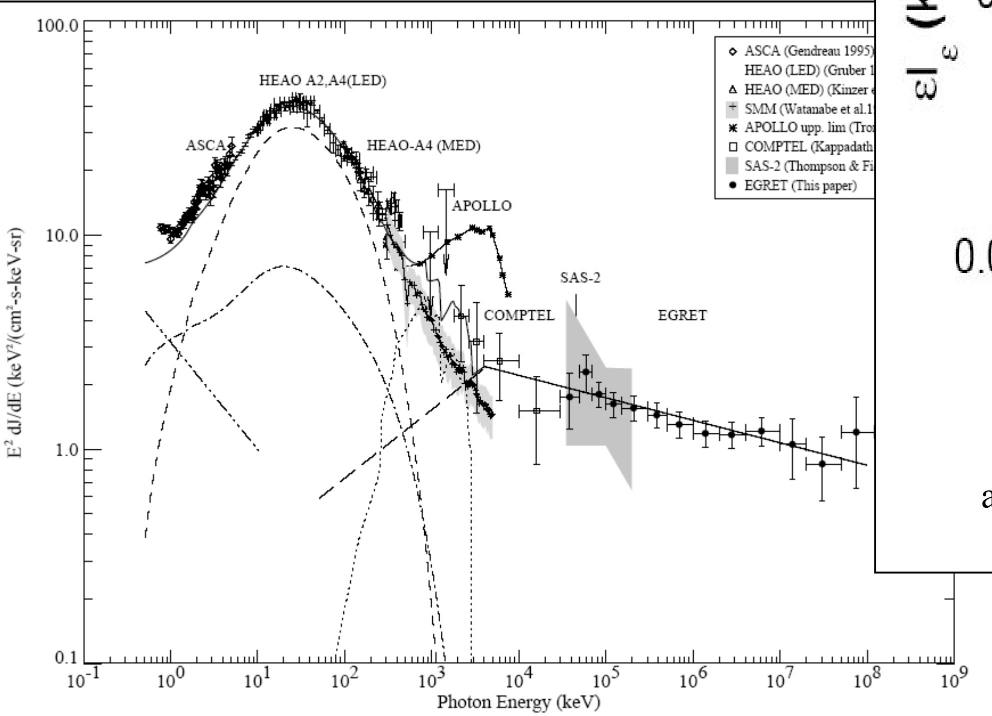
until $\rho \approx 10$, cf. Casanova Dingus & Zhang (2006)

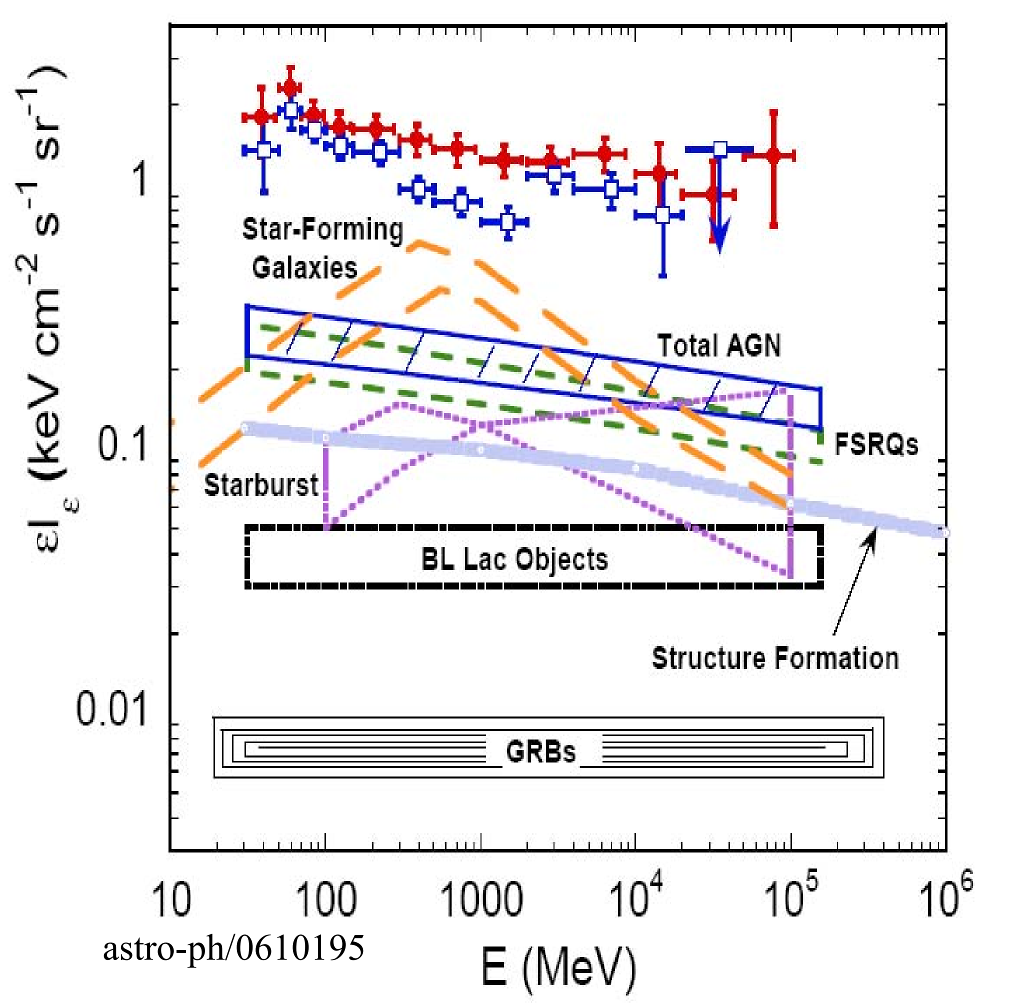
Unresolved γ-Ray Background

Two puzzles: deficit << 1 GeV
deficit >> 1 GeV

BL Lacs: ~2 - 4% (at 1 GeV)
FSRQs: ~ 10 - 15%

Star-forming galaxies (Pavlidou & Fields 2002)
Starburst galaxies (Thompson et al. 2006)
Pulsar contribution near 1 GeV
Galaxy cluster shocks (Keshet et al. 2003, Blasi Gabici & Brunetti 2007)

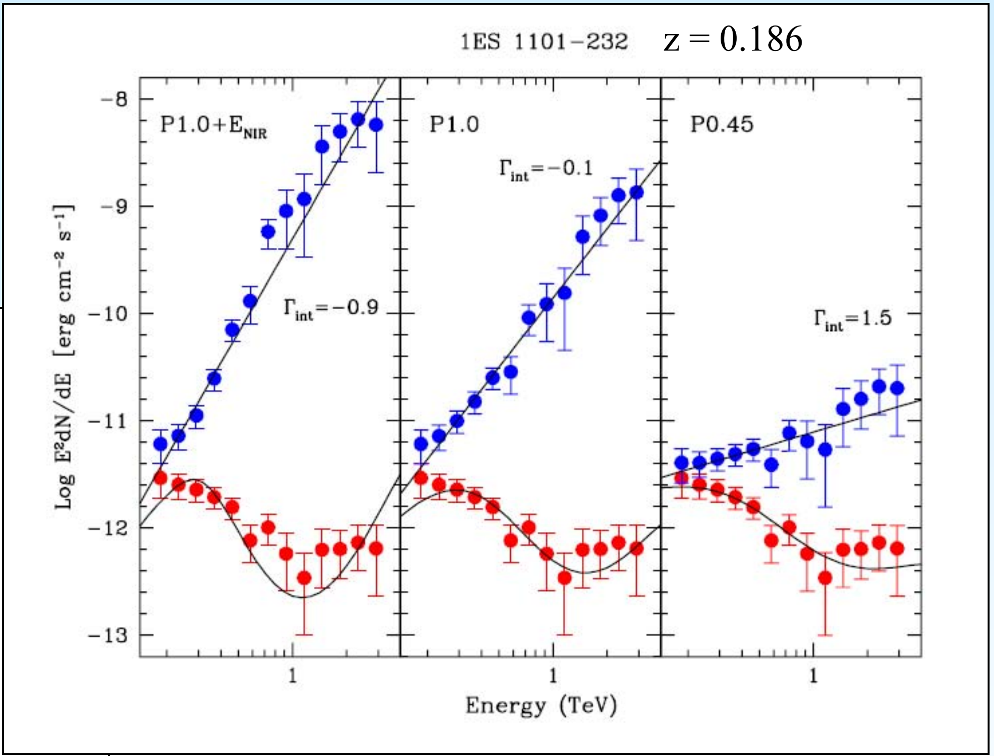




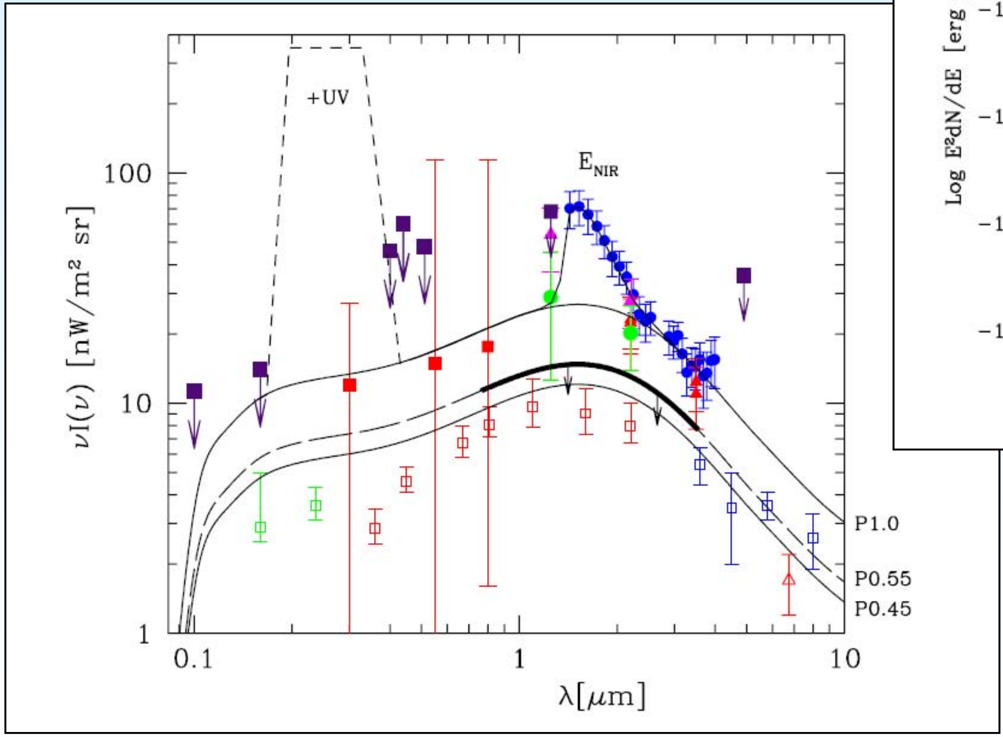
Data: Sreekumar et al. (1998)
Strong, Moskalenko, & Reimer (2000)

Other Evidence for High Energy γ-Ray Components in Blazars

- Inferring intrinsic spectrum after subtracting out absorption on EBL
- Implied large Doppler factors of TeV blazars
- Orphan TeV flares
- Linear jets



Aharonian et al., Nature, 2005

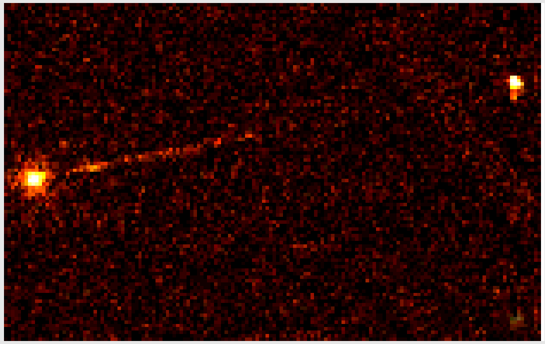


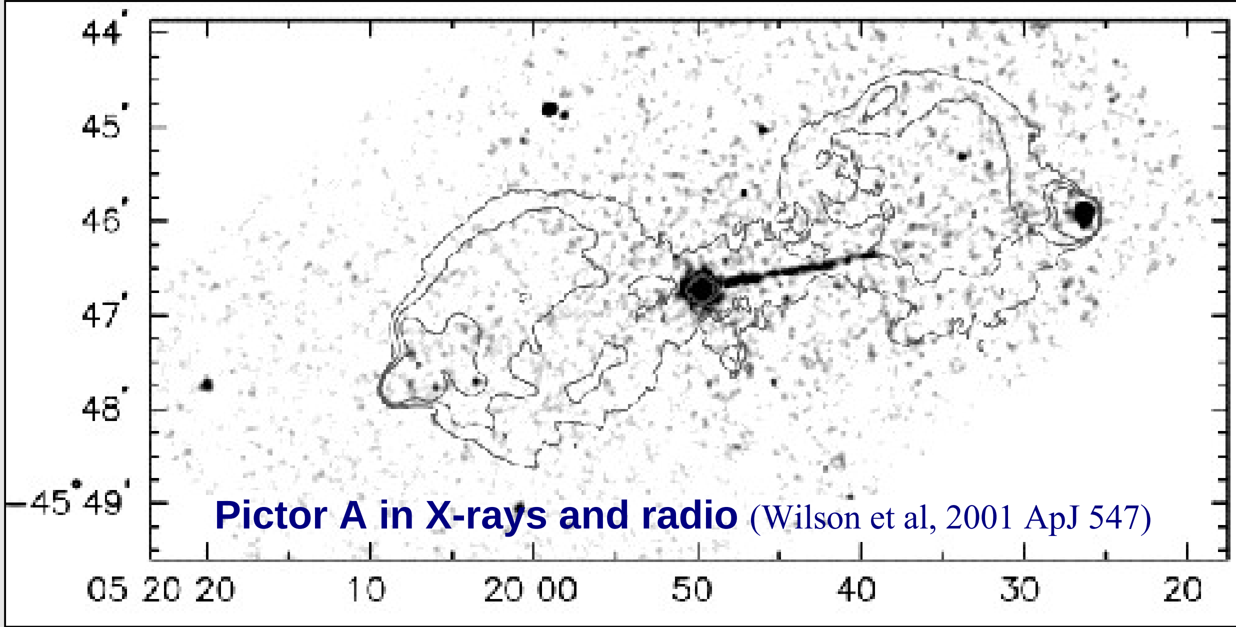
Pictor A

d ~ 200 Mpc

l_{jet} ~ 1 Mpc   (l_{proj} = 240 kpc)

Deposition of energy through ultra-high energy neutral beams (Atoyan and Dermer 2003)

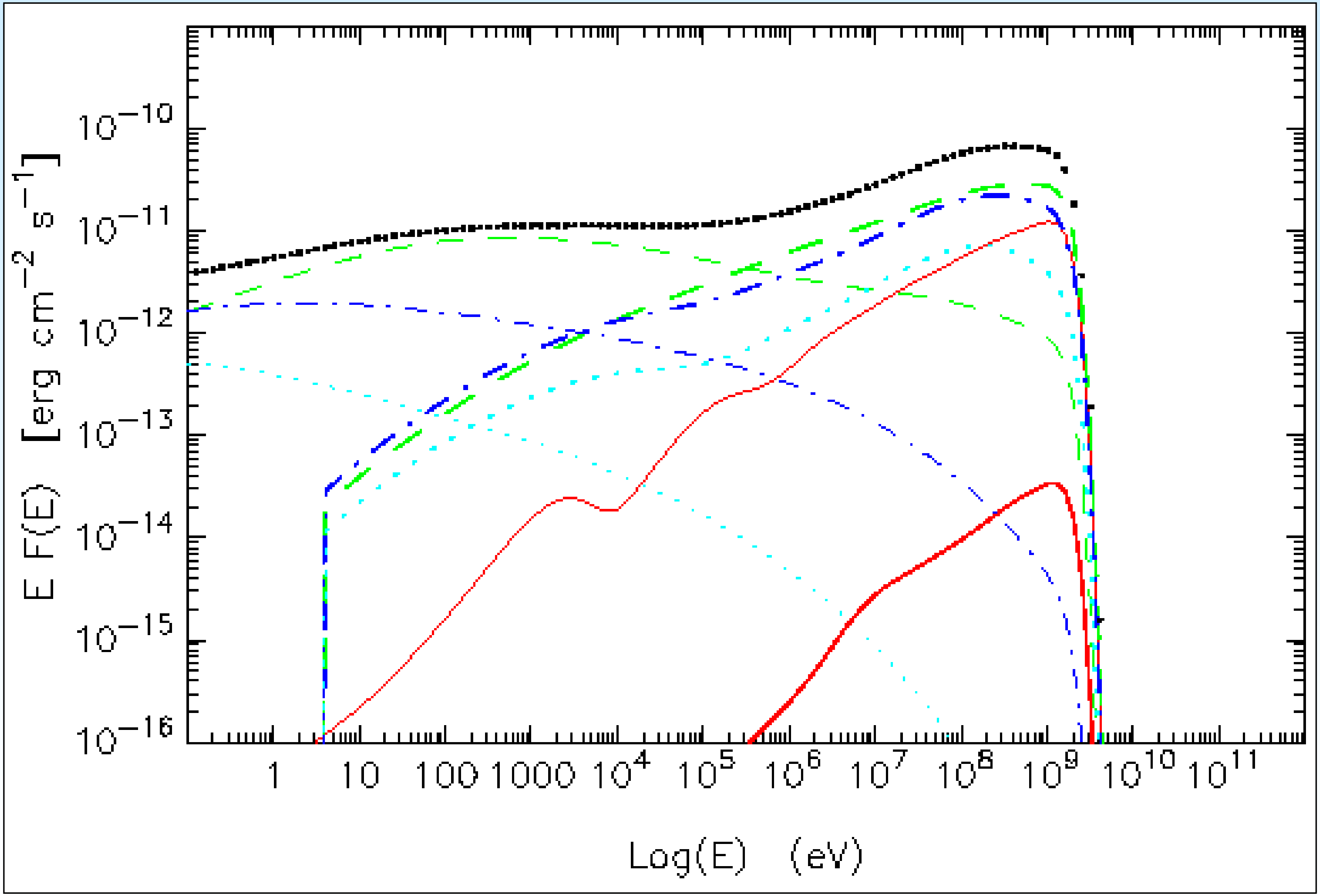




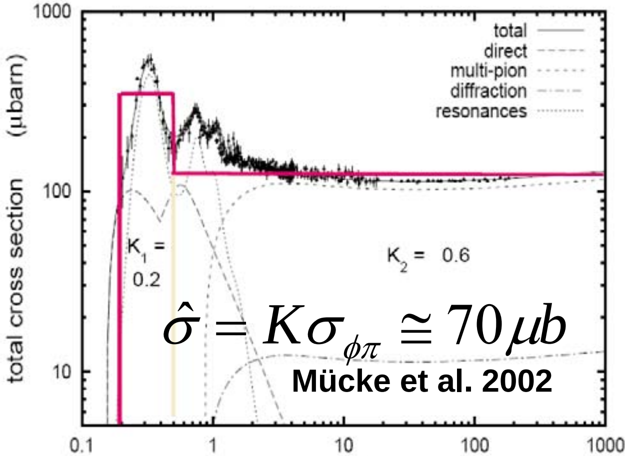
Pictor A in X-rays and radio (Wilson et al, 2001 ApJ 547)

Blazars as High Energy Hadron Accelerators

Armen Atoyan **(UdeM, Concordia)**



Guaranteed Strong Photohadronic Losses

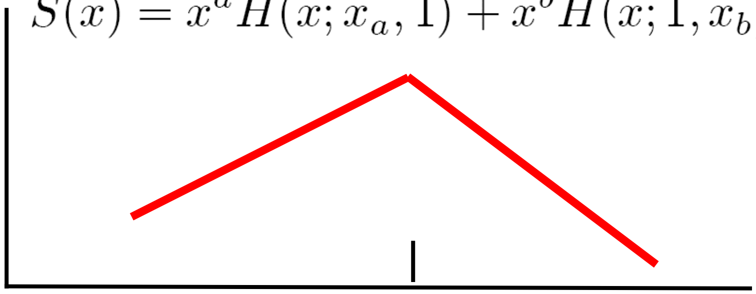


$$\rho_{\phi\pi} > (1+z)/\delta_{\rm D} t_v$$

Do GRBs/blazars have hard photohadronic tails?

$$\rho_{\phi\pi} = \frac{3\hat{\sigma} d_L^2 f_{\epsilon_{pk}} (1+z)}{m_e c^4 \delta_{\rm D}^5 t_v^2 \epsilon_{pk}}$$

$$S(x) = x^a H(x; x_a, 1) + x^b H(x; 1, x_b)$$



$$x = \epsilon/\epsilon_{pk} = \epsilon'/\epsilon'_{pk}$$

$$\delta_{\rm D} < \delta_{\phi\pi} \equiv \left(\frac{3\hat{\sigma} d_L^2 f_{\epsilon_{pk}}}{m_e c^4 t_v \epsilon_{pk}}\right)^{1/4}$$

$$E_p^{\phi\pi} = \frac{m_p c^2 \delta_{\phi\pi}^2 \epsilon'_{thr}}{2(1+z)\epsilon_{pk}}$$

$$E_\gamma^{\gamma\gamma} = \frac{2 m_e c^2 \delta_{\phi\pi}^2}{(1+z)^2 \epsilon_{pk}}$$

$$\tau_{\gamma\gamma}^{\phi\pi} = \frac{\sigma_{\rm T}}{12\hat{\sigma}} \cong 800$$

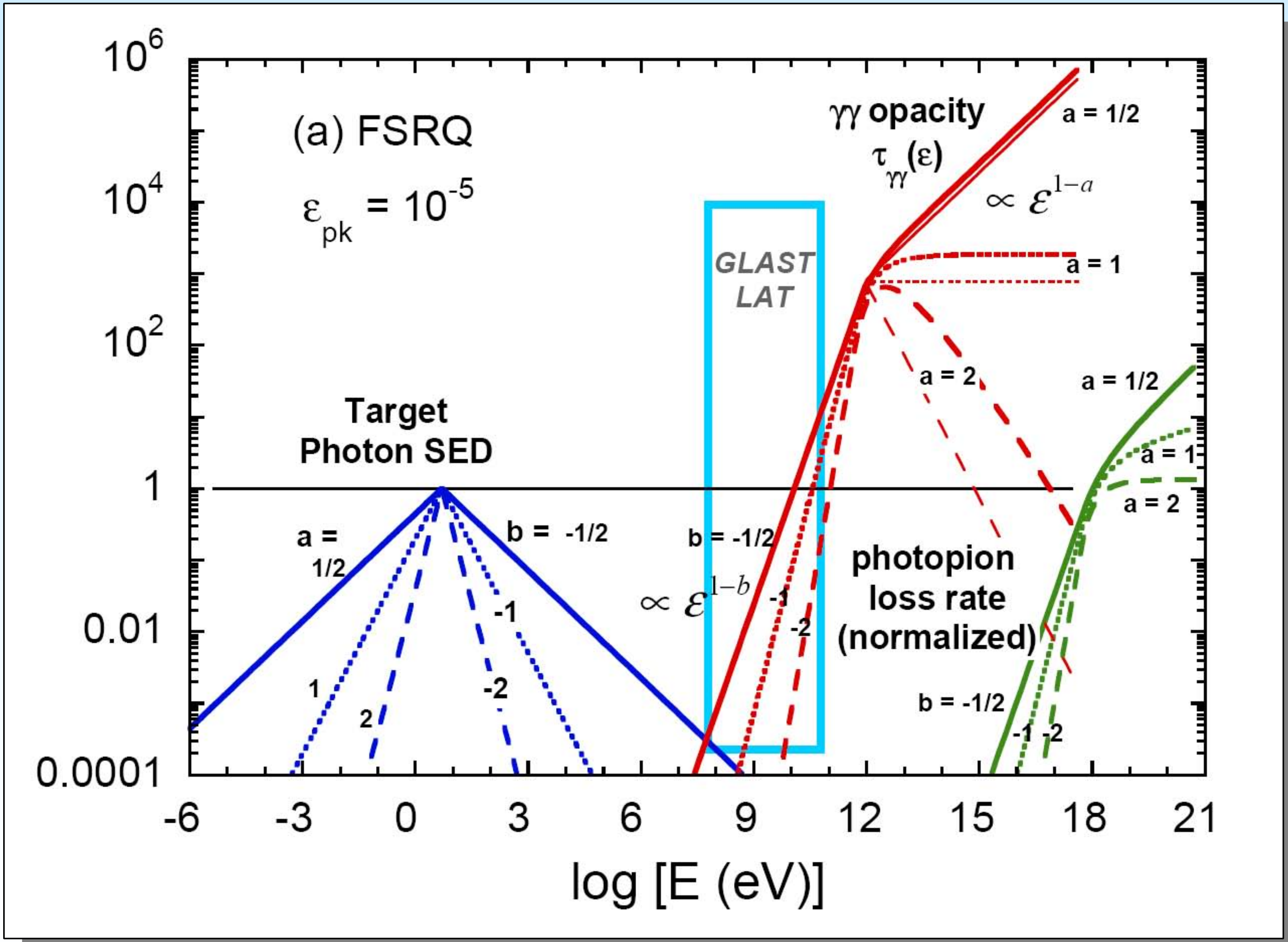
w/ Truong Le **(NRL),**
Enrico Ramirez-Ruiz **(UCSC)**
to be submitted to PRL

Table of Requirements for Photopion Losses

TABLE I: Doppler factor $\delta_{\phi\pi}$ for guaranteed photopion losses, γ-ray photon energy $E_\gamma^{\gamma\gamma}$ for $\gamma\gamma$ attenuation with photons at the peak of the target photon SED, and cosmic ray energy $E_p^{\phi\pi}$ for photopion interactions with peak target photons (sources at $z = 2$ except for XBL, at $z \approx 0.08$, $d_L = 10^{27}$ cm).

	ℓ	η	τ	j	$\delta_{\phi\pi}$	$E_\gamma^{\gamma\gamma}$(GeV)	$E_p^{\phi\pi}$(eV)
FSRQ	28.7	-11	5	-5 (5 eV)	9	92	5×10^{17}
IR/optical				-6 (0.5 eV)	16	30×10^3	1.6×10^{19}
FSRQ	28.7	-11	5	-2 (5 keV)	1.6	0.03	1.6×10^{13}
X−ray				-3 (0.5 keV)	2.8	0.92	5×10^{14}
XBL	27	-10	3	-2 (5 keV)	1.3	0.14	3×10^{13}
X−ray				-3 (0.5 keV)	2.3	4.7	9×10^{14}
GRB	28.7	-6	0	0 (511 keV)	160	2.9	2×10^{15}
γ ray				-1 (51 keV)	280	92	5×10^{16}
X−ray flare		-9	2	-3 (0.5 keV)	50	290	1.6×10^{17}

Correlation of Fluxes for FSRQs



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Correlation of Photon and Neutrino Fluxes

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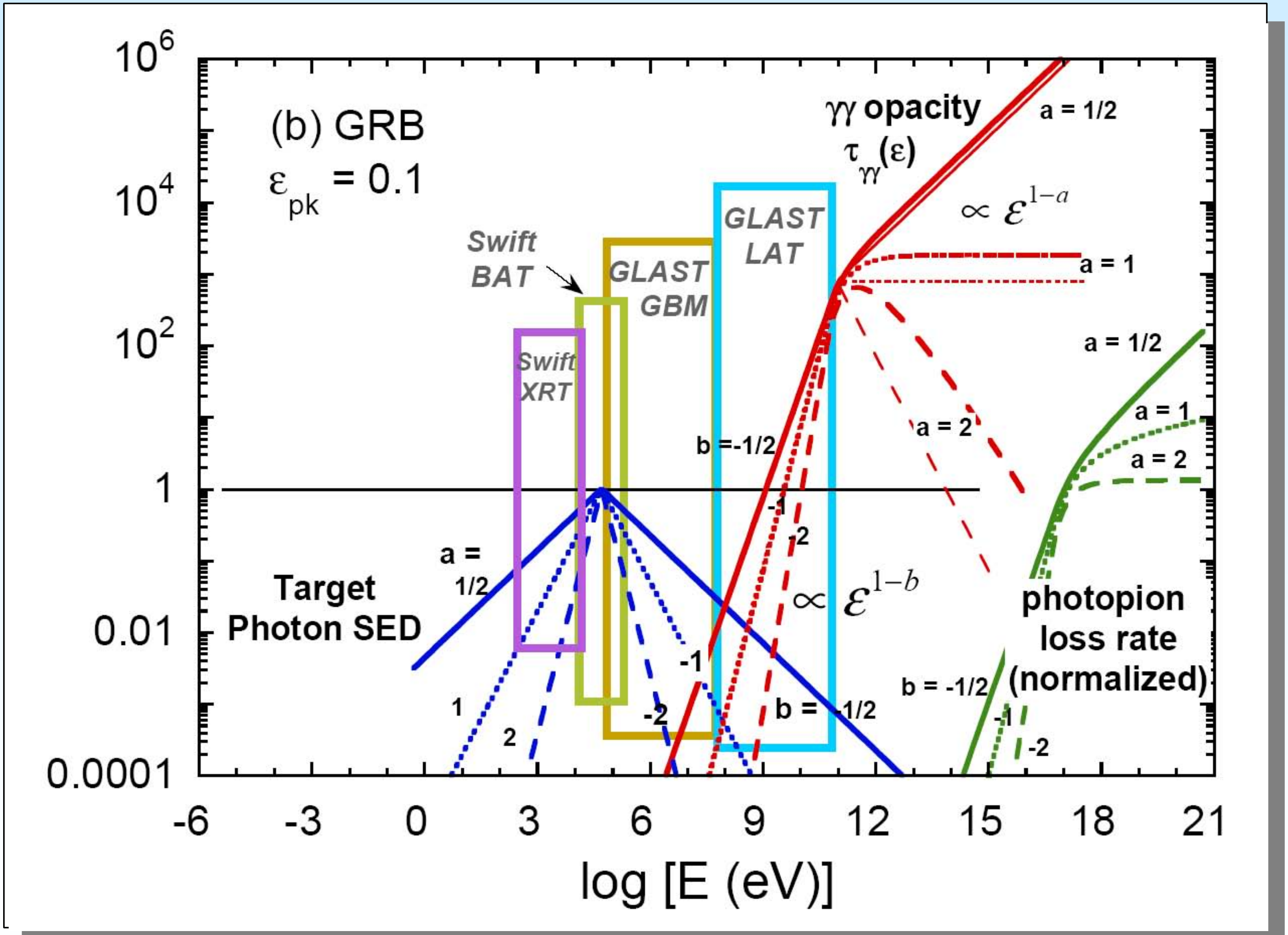
Correlation of Fluxes for GRBs



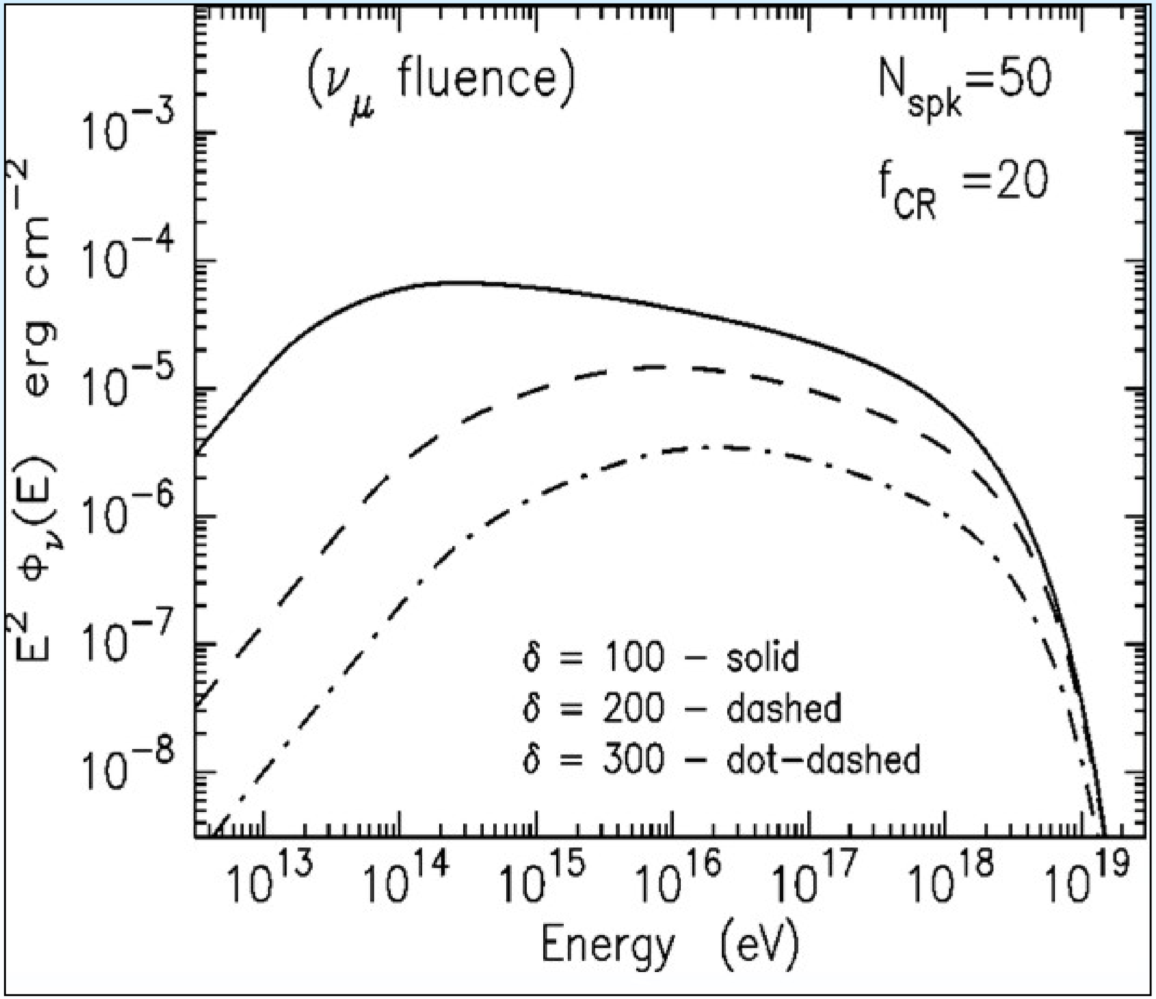
Neutrino Detection from GRBs with Large Baryon-Loading

For a fluence of 3×10^{-4} ergs/cm^2, (~2/yr)

N_ν predicted by IceCube:

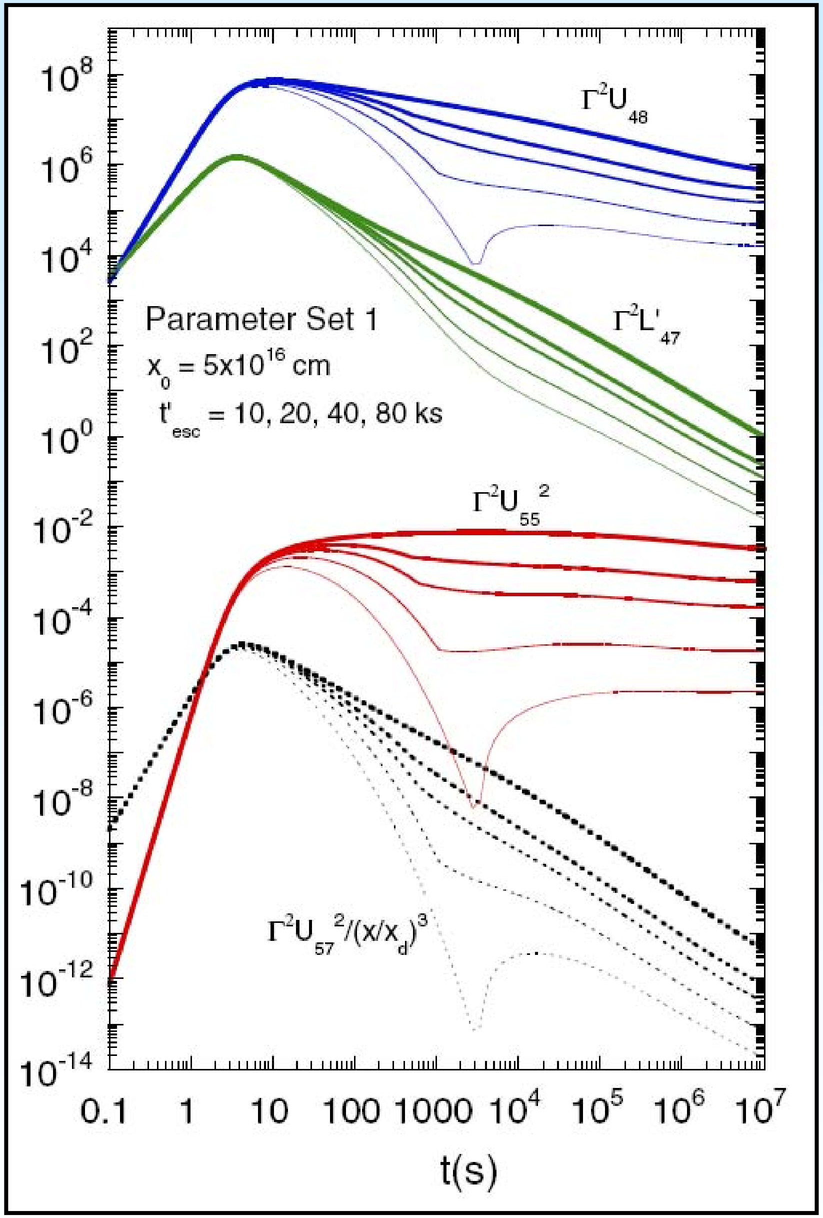
$N_\nu \approx 1.3, 0.1, 0.016$ for $\delta = 100, 200$, and 300, respectively in collapsar model for $f_{CR} = 20$

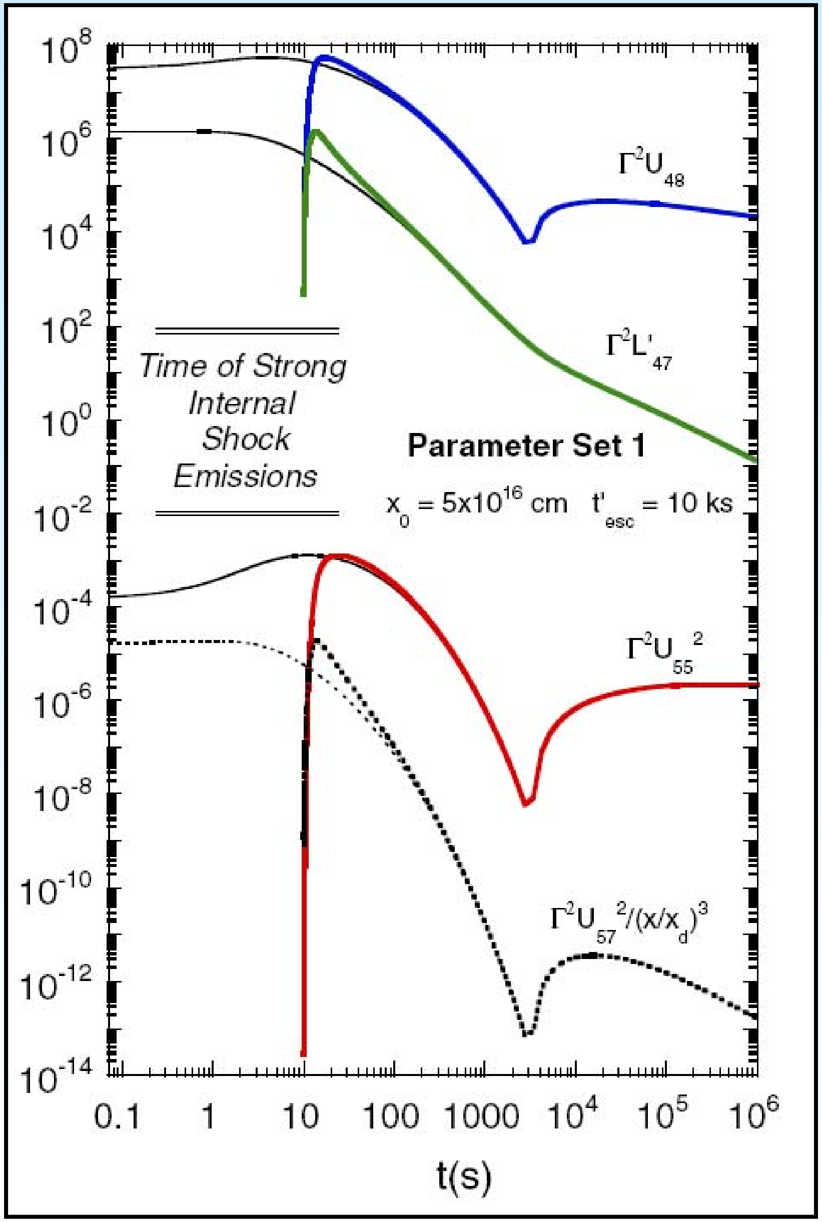
Nonthermal Baryon Loading Factor $f_b = 20$



Dermer and Atoyan (PRL, 2003)

Swift GRB Light Curves

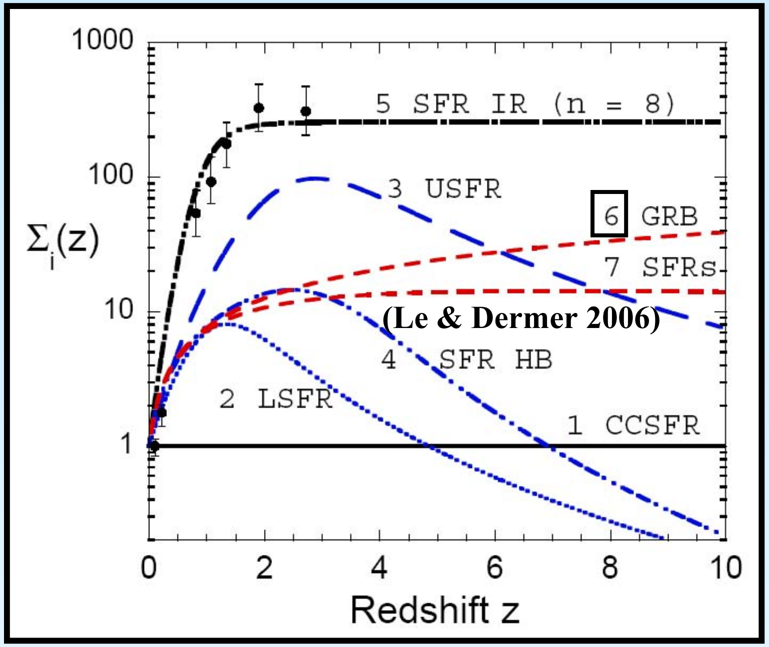


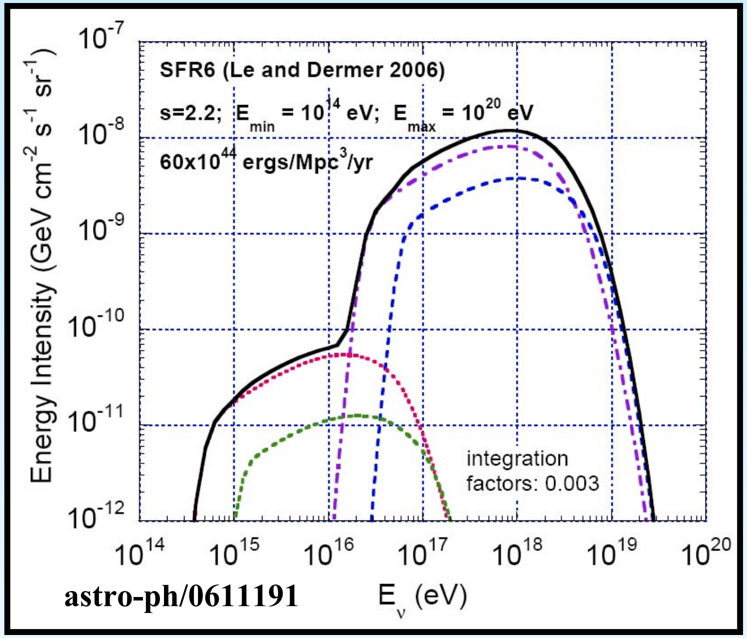


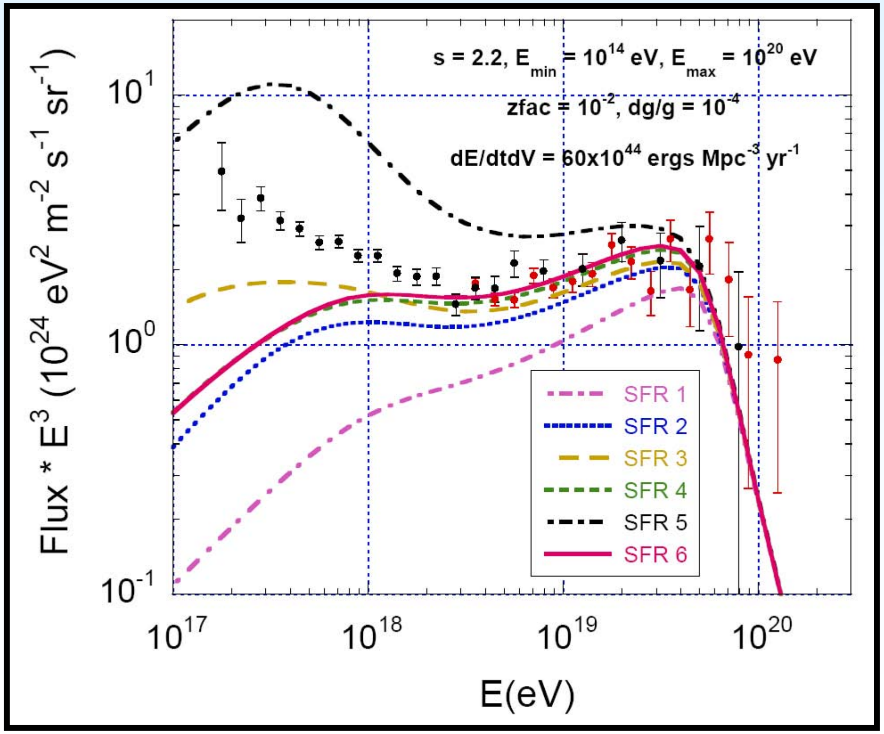
photohadronic fluorescence GeV emission

submitted to ApJ (a-ph/0606320)

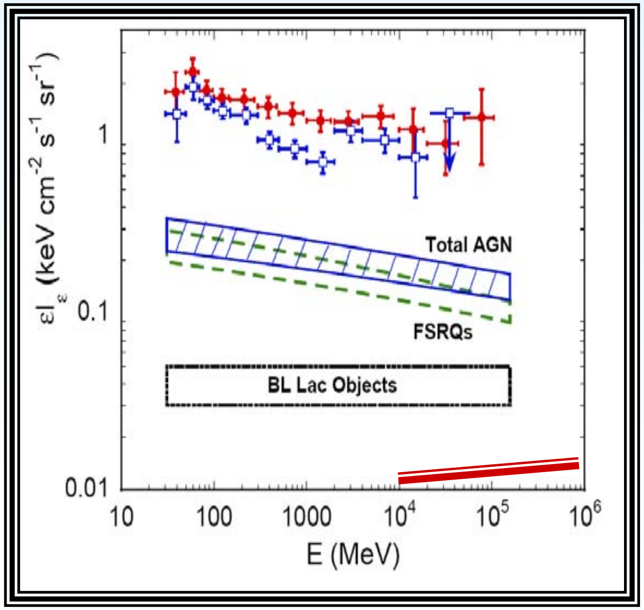
Cosmogenic GZK γ-Ray Intensity







Dermer, unpublished calculations, 2007

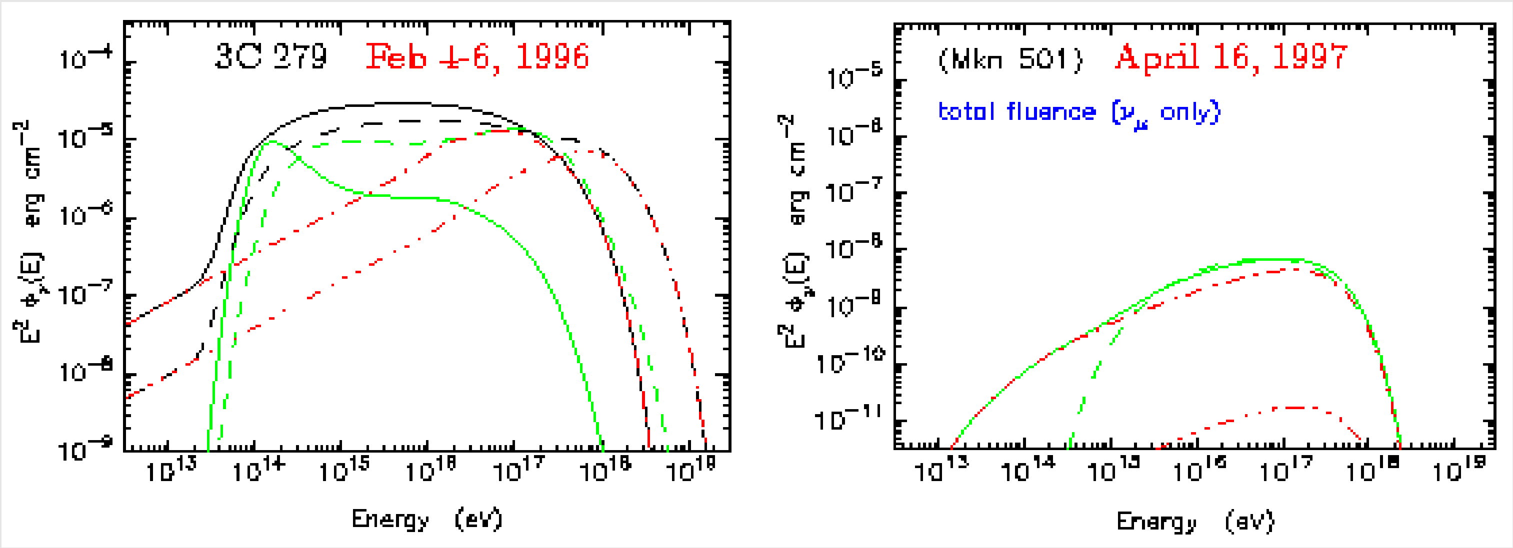


Dark Matter

every dark matter model
makes a prediction for the diffuse
γ-ray background

Neutrinos: expected fluences/numbers

Crucial assumption: same energy injected in protons as observed in radiation modulo Doppler factor δ



Expected ν - fluences calculated for 2 flares, in 3C 279 and Mkn 501; red curves – from internal photons, black& green curves - external component (Atoyan & Dermer 2003) .

Expected numbers of ν_μ for *IceCube* - scale detectors, *per flare*:

3C 279: $N_\nu = 0.35$ for δ = 6 (solid curve) and $N_\nu = 0.18$ for δ = 10 (dashed)

Mkn501: $N_\nu = 1.2\ 10^{-5}$ for δ = 10 (solid) and $N_\nu = 10^{-5}$ for δ = 25 (dashed)

(`*persistent*') γ -level of 3C279 ~ 0.1 F_γ (*flare*) , (+ external UV for *p*γ)

⇒ N_ν ~ few- several per year can be expected from poweful HE γ blazars.

N.B. **:** all neutrinos are expected at E>> 10 TeV

Detection of one ν implies large energy in neutrals

Summary

• GLAST predictions of number and evolution of blazars

• Residual diffuse isotropic γ-ray background:
hard blazar emission components?
new populations of γ-ray sources?

• Photohadronic cascades make hadronic γ-ray emission component from FSRQs, not BL Lac objects

• GLAST can detect anomalous γ-ray emission signatures associated with hadronic acceleration in blazar or GRB jets

• Diffuse emission from cosmogenic γ-ray, dark matter