GLAST and Black Hole Jets

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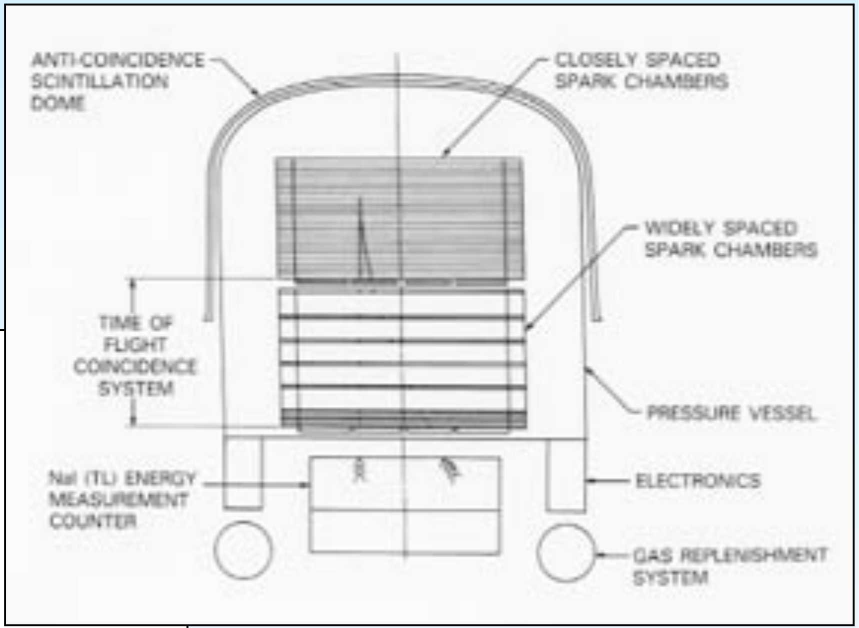
1. GLAST Analysis of High Latitude Sources
2. Microquasars/Pulsar Wind Nebulae
3. Blazar statistics
4. Unresolved/diffuse Extragalactic γ-ray Emission
5. Hadronic Signatures in Blazars and GRBs
6. Correlation of Fluxes: Joint $\gamma\gamma$ and photohadronic constraints

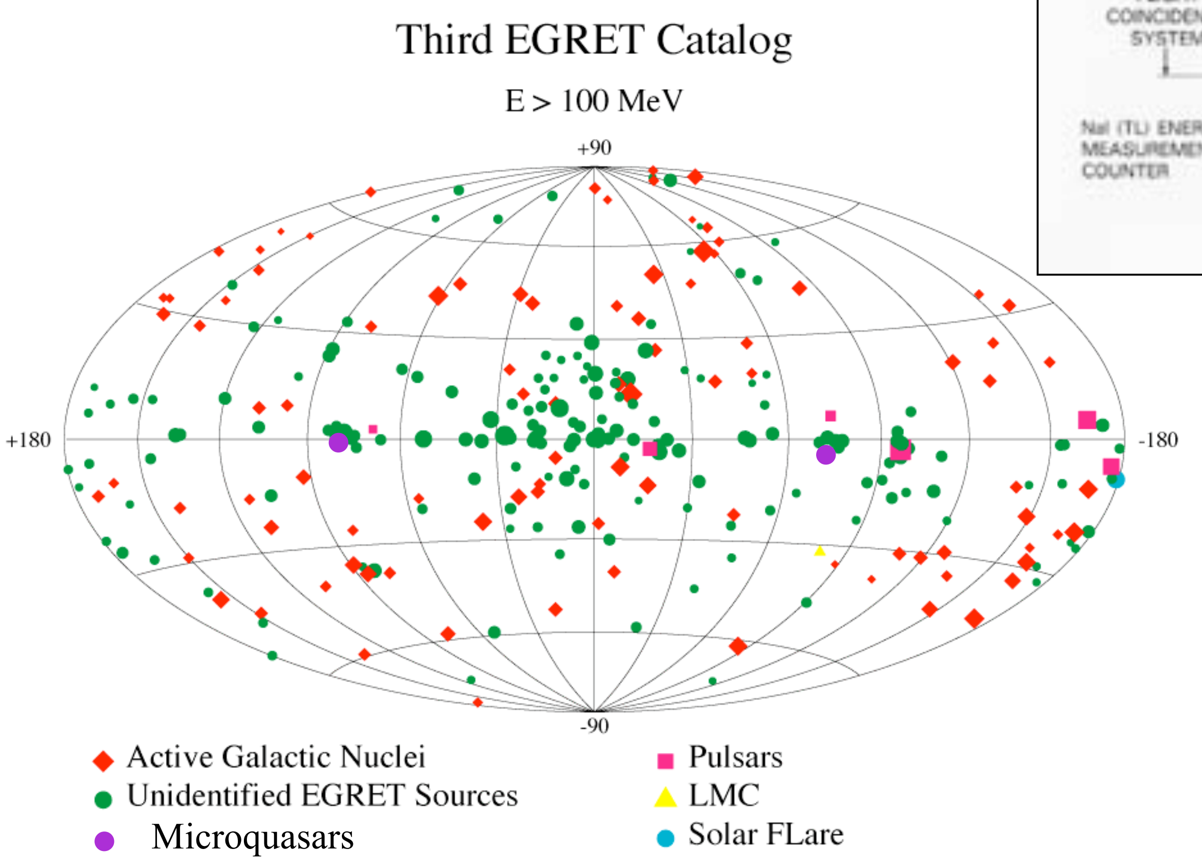
EGRET Legacy

3EG catalog: 270 sources, 66 high confidence blazars

Hartman et al. (1999)

EGRET





GLAST data analysis

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

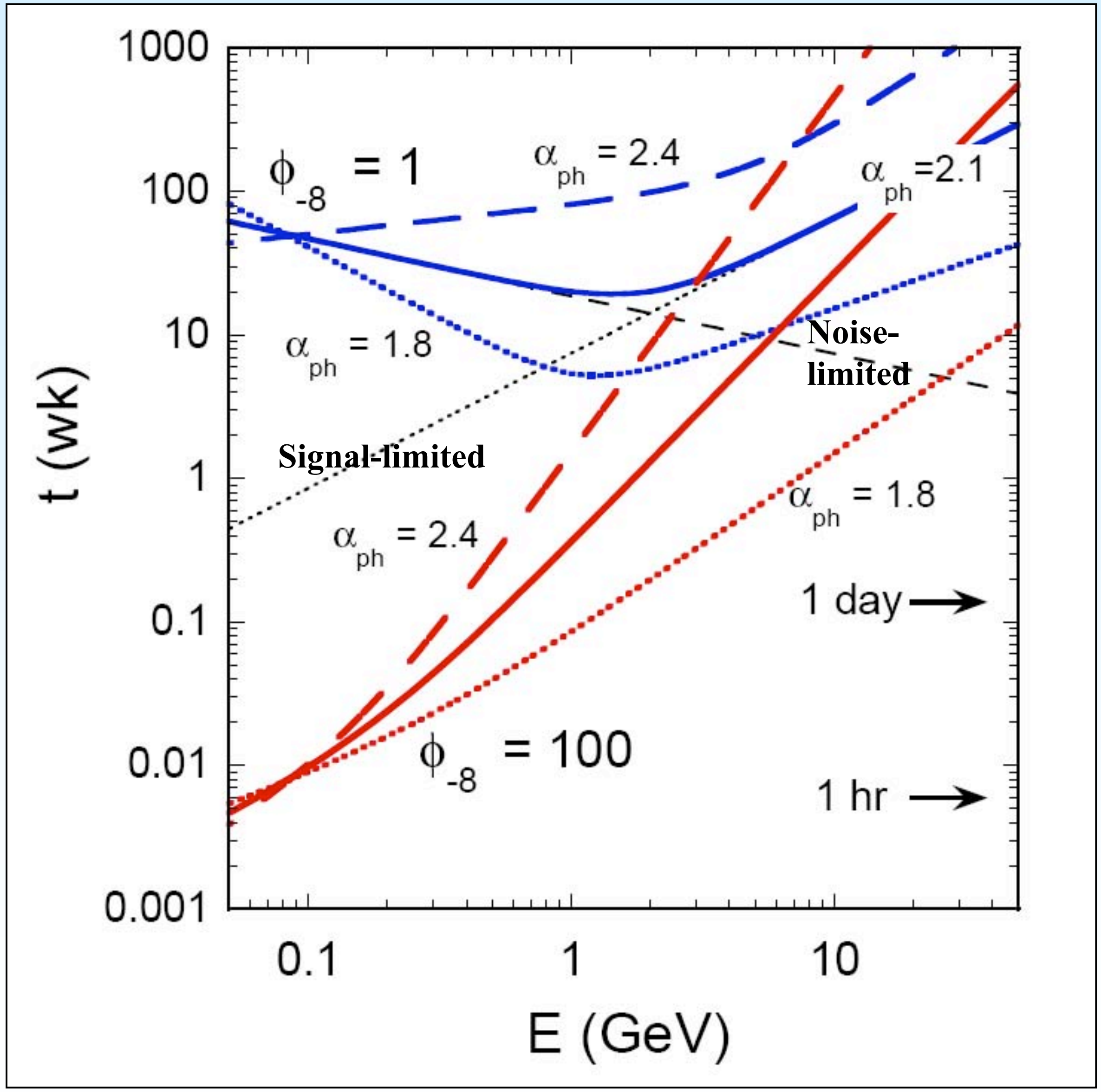
$\phi_{-8} = \phi/10^{-8}$ ph(>100 MeV) cm^{-2} s^{-1}
(~$7x10^{-12}$ ergs cm^{-2} s^{-1} for a flat νF_ν spectrum with $\alpha_{ph} = 2$)

EGRET: $\phi_{-8} = 15$; 2-week pointing

Energy-dependent analysis techniques depending on source integral flux levels

Sub-hour scale variability when $\phi_{-8} > 200$

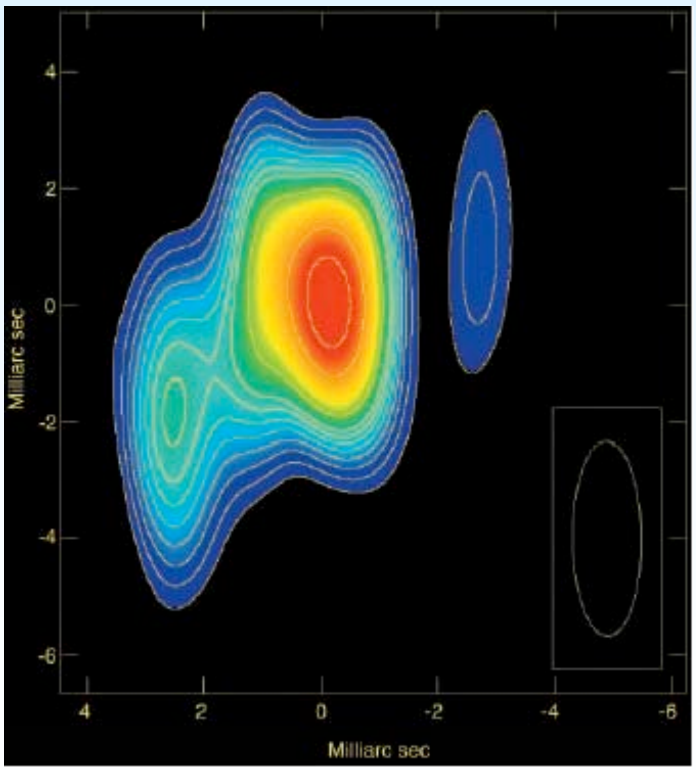
Detection of weak sources depends on spectra

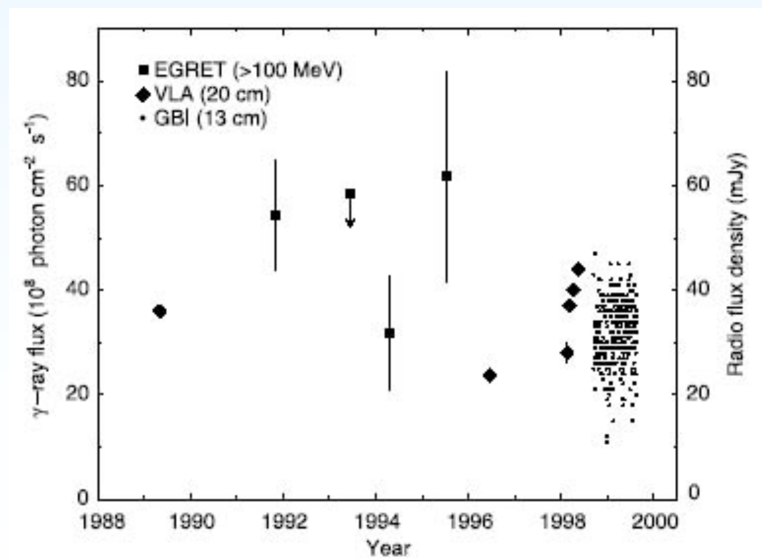


Microquasars and PWNe

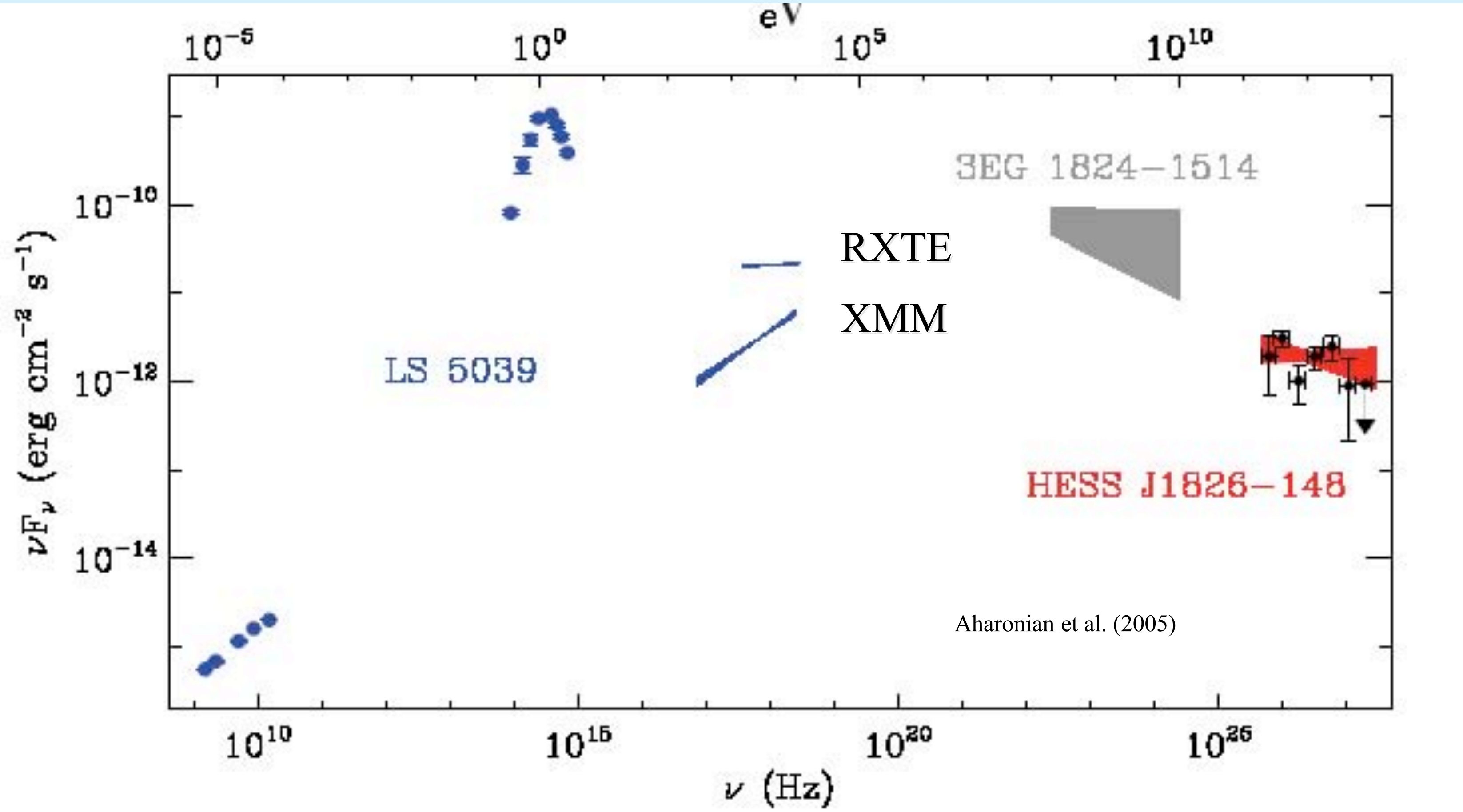
w/ Markus Böttcher,
S. Gupta **(Ohio University)**

- Microquasars: X-ray binaries with jets
- LS 5039: Associated with 3EG J1824-1514 (Paredes et al. 2000) – new class of γ-ray sources
- LS 5039: High Mass Black Hole Binary
  $M_{BH} \approx 3.7\ M_o$, $D \approx 2.5$ kpc, $P = 3.906$ d, (Casares et al. 2005): HESS discovery
- LSI +61 303 (Albert et al. 2006: MAGIC)





Multiwavelength Spectrum of LS 5039



- Companion O7 Star ($L \approx 7\times10^{38}$ ergs s^{-1})
- Optical stellar radiation is highly absorbed
- Radio emission from jets reaches 10 AU

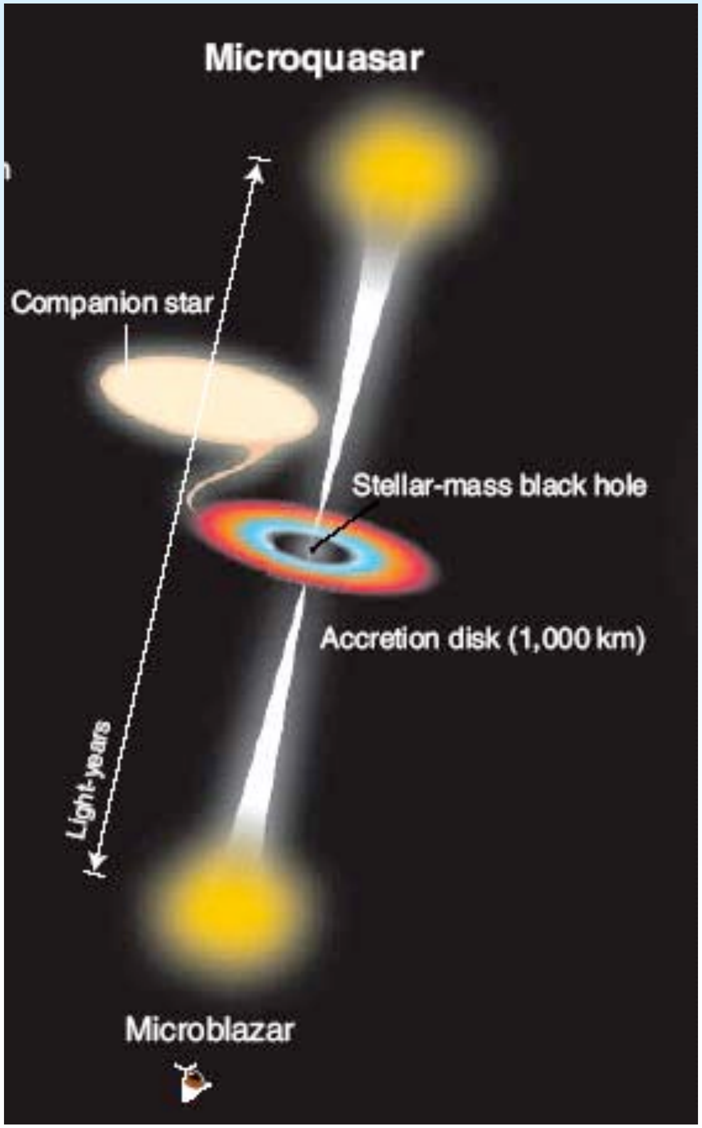
  Mean orbital separation $d \approx 2.5\times10^{12}$ cm (0.2 AU)

  Companion Mass $\approx 23\ M_o$ (Casares et al. 2005)

- HESS (> 7σ) Detection of LS 5039 at ≈ 200 GeV – 10 TeV
- Consistent with point source (< 50′′)

Blazar-Type Model for High Mass Microquasars

- Leptonic Jet Model (as in blazars)
- Predicts stochastic variability of jet γ-ray emission
- Synchrotron radio/optical/X-ray emission (plus thermal/nonthermal accretion disk and thermal stellar radiation)
- Compton-scattered origin of γ rays
  - Target Photons:
    - Accretion Disk
    - Stellar radiation field



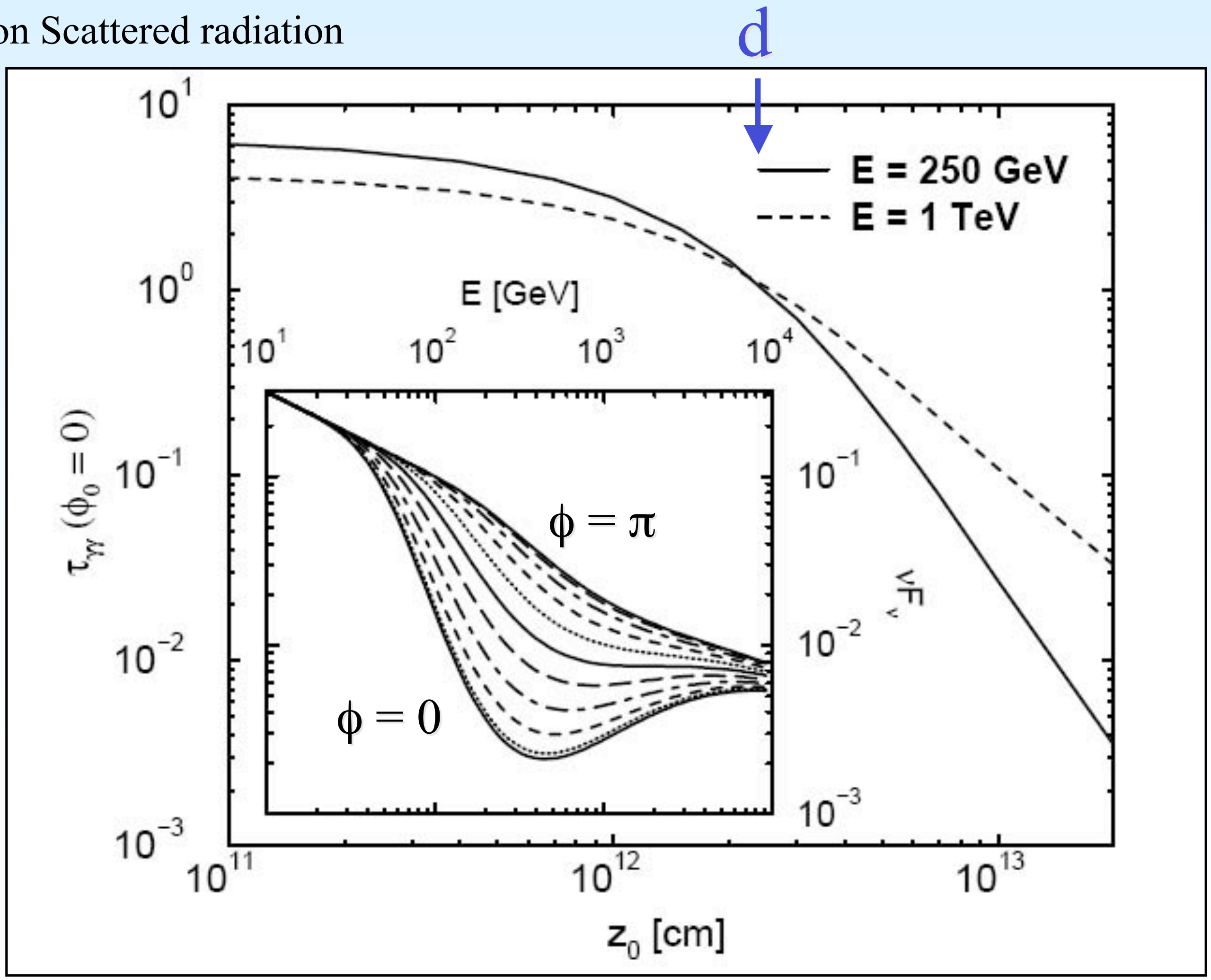
see also Paredes, Bosch-Ramon, and Romero (2006)

γ Rays from Microquasars: Production and Attenuation

- Compton Scattering in KN regime for TeV γ rays
  - Companion Star Temperature = 39000 K = 3.4 eV
- Orbital Modulation of Compton Scattered radiation
  - Anisotropic stellar radiation field
- γγ Attenuation

Phase $\phi = 0$
(Companion star closest to observer)

Böttcher and Dermer, ApJL (2005)

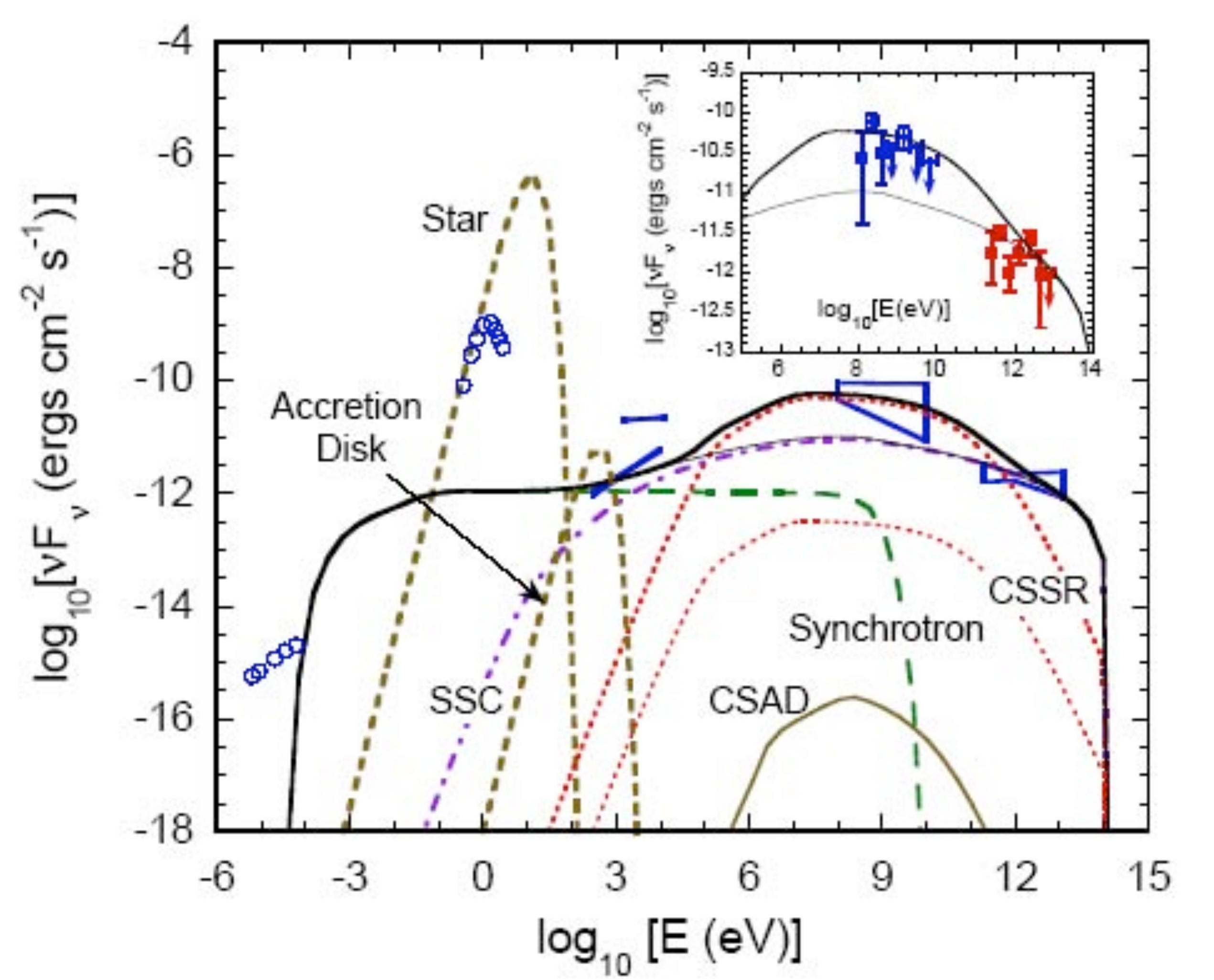


Model Fit to the Multiwavelength Spectrum of LS 5039

Fit assuming that EGRET and HESS data *are different* between two epochs of measurement

- In accord with variability expected from leptonic model
- Orbital modulation of TeV γ-rays for inner jet;-- discovered by HESS and MAGIC for LSI +61 303
- Orbital modulation of GeV γ-rays for inner or extended jet model
- GLAST will quickly test this prediction

- New Model: G. Dubus (2006) PSR B1259-63

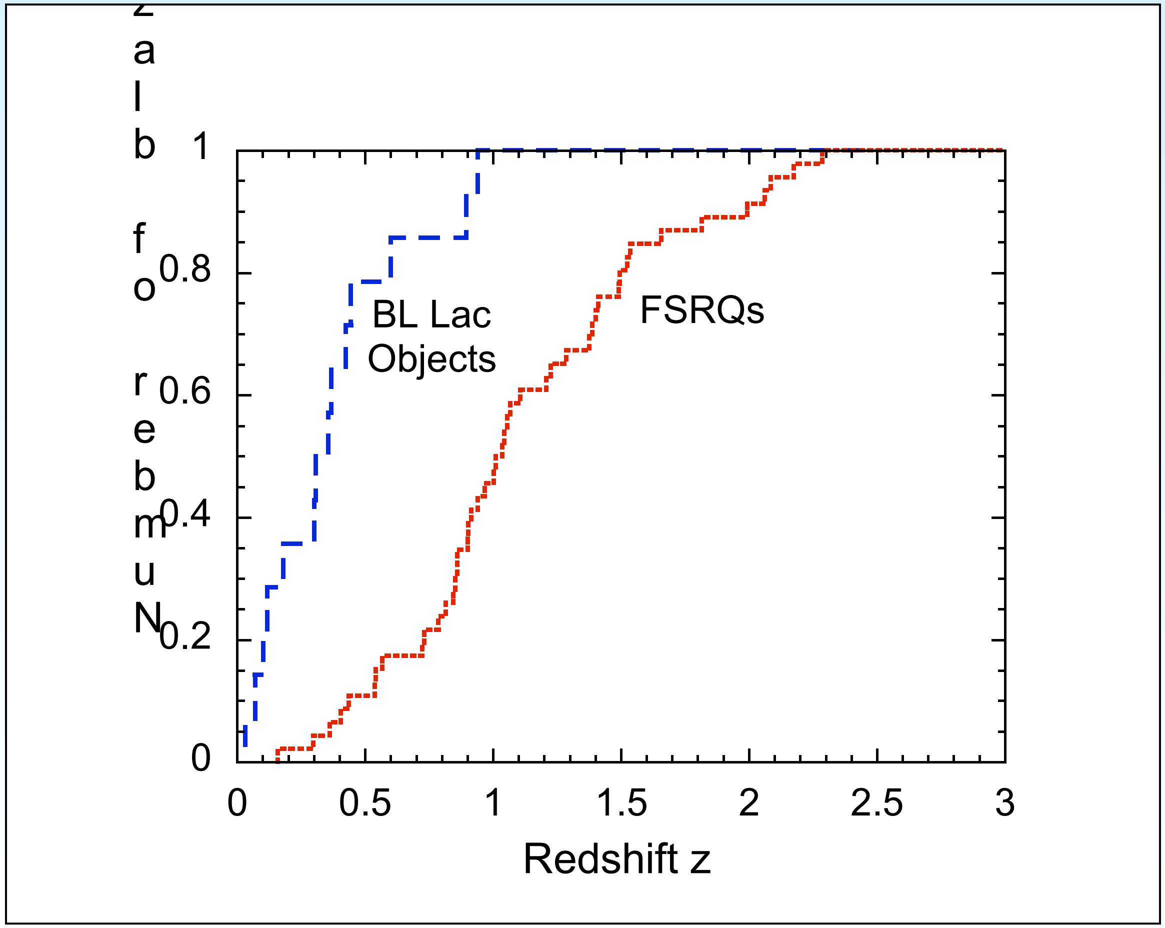


Blazar Statistics

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

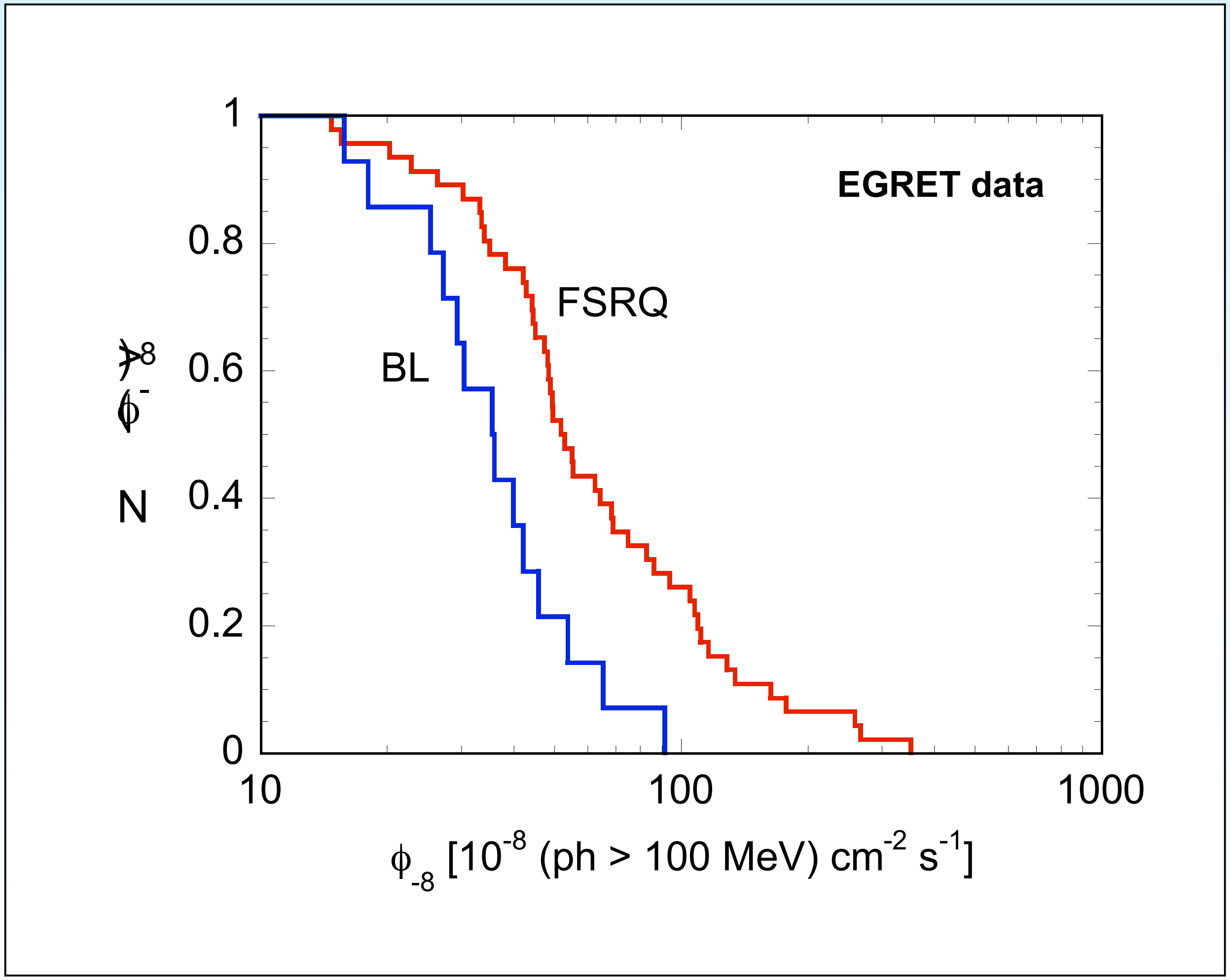


Size Distribution of EGRET γ-Ray Blazars

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

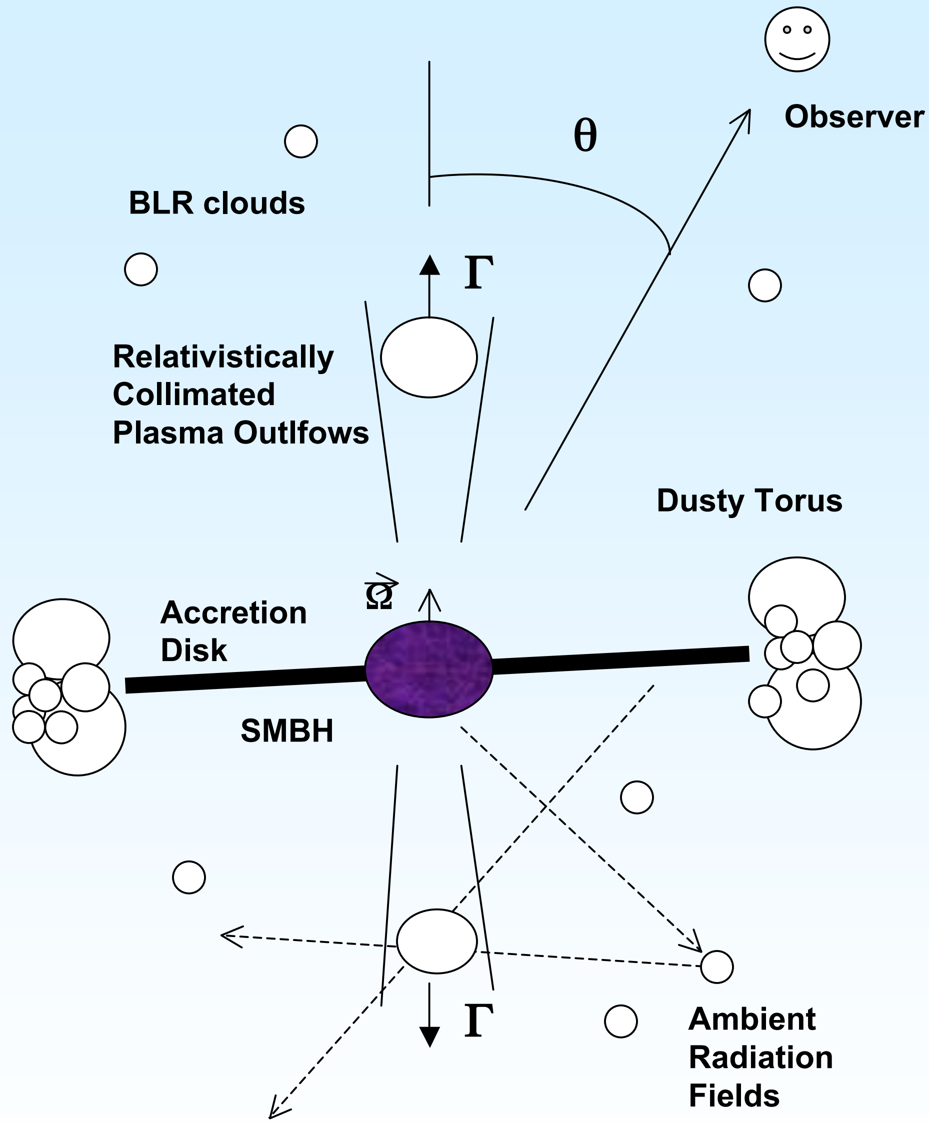
Basic Radiation Physics:

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

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

SF H

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

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

Γ-factor evolution

luminosity evolution

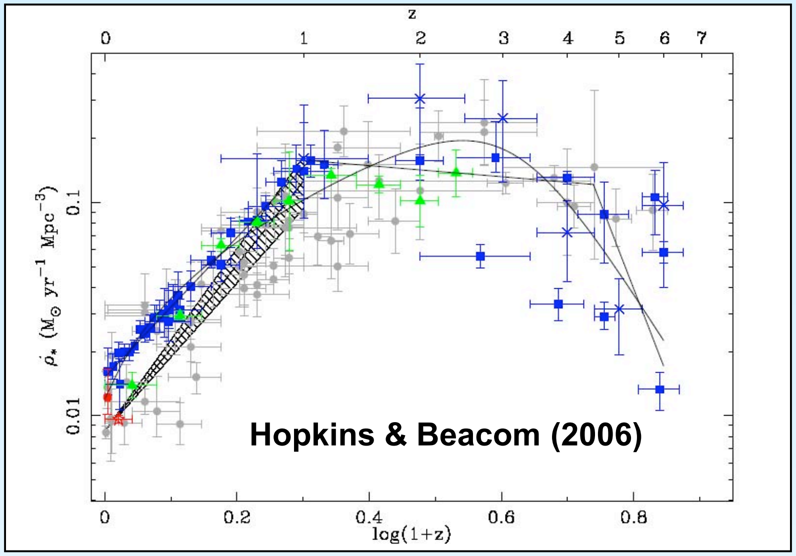
threshold term

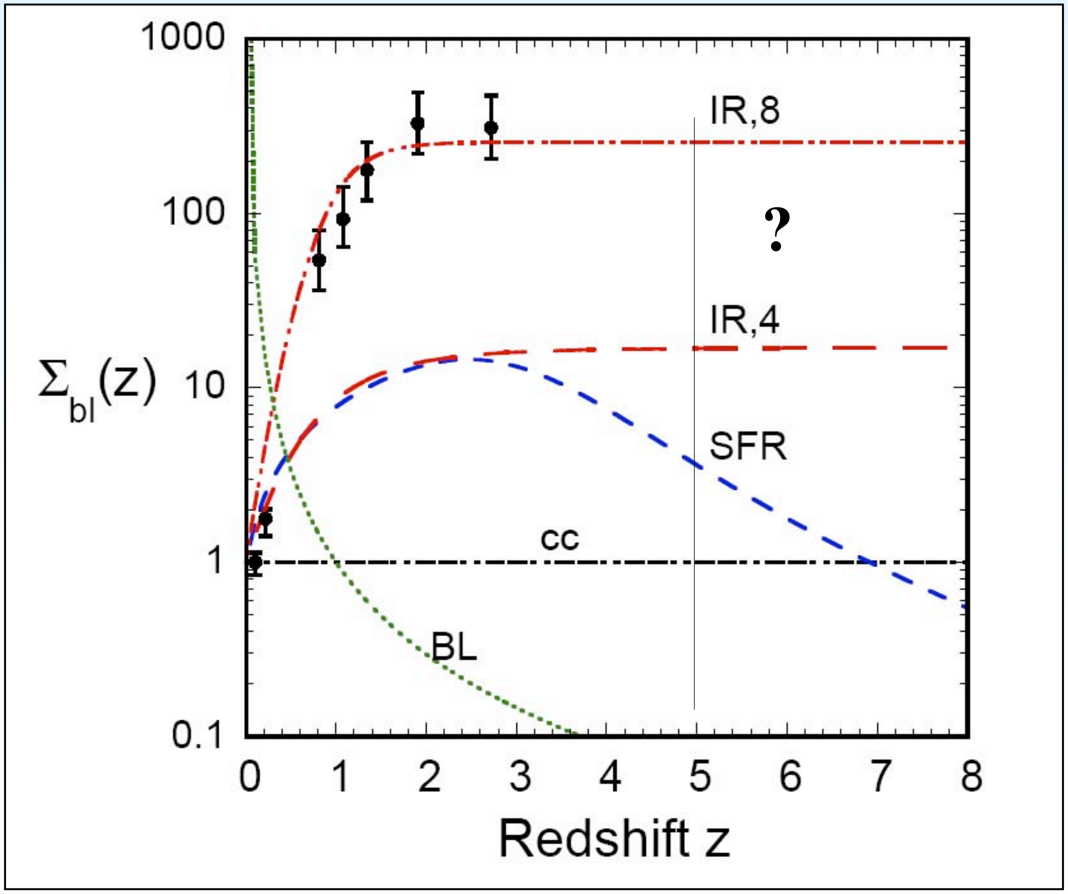
Simplest model: fixed Γ, fixed ℓ'_e (no luminosity evolution), analytic SFH

z distribution analytic

Blazar Cosmology

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





Blazar Formation History (BFH)

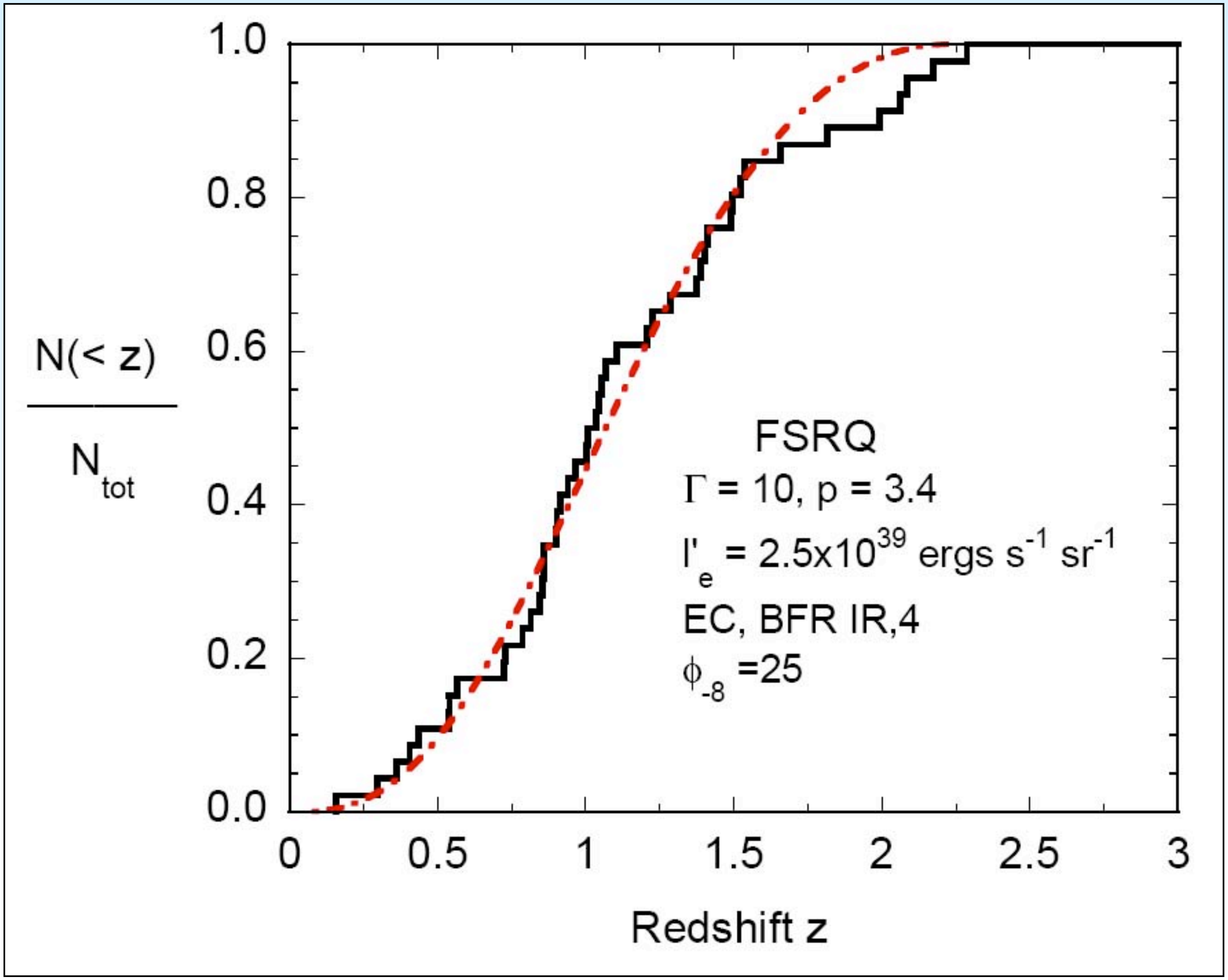
Constant Comoving Rate

Star Formation Rate (SFR)

IR,8 (Sanders 2004)

SFH BL

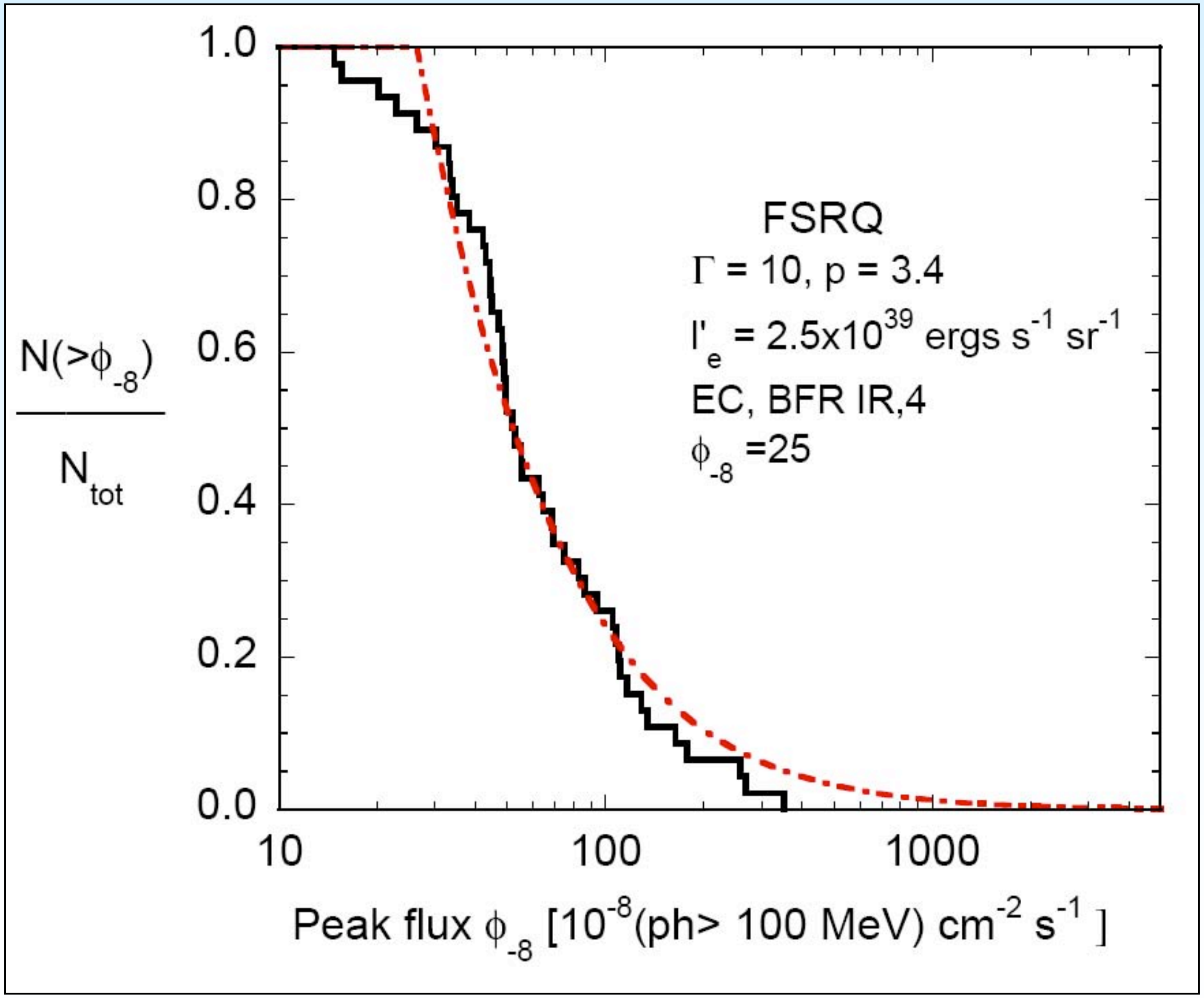
Fit of FSRQ Model to Redshift Distribution



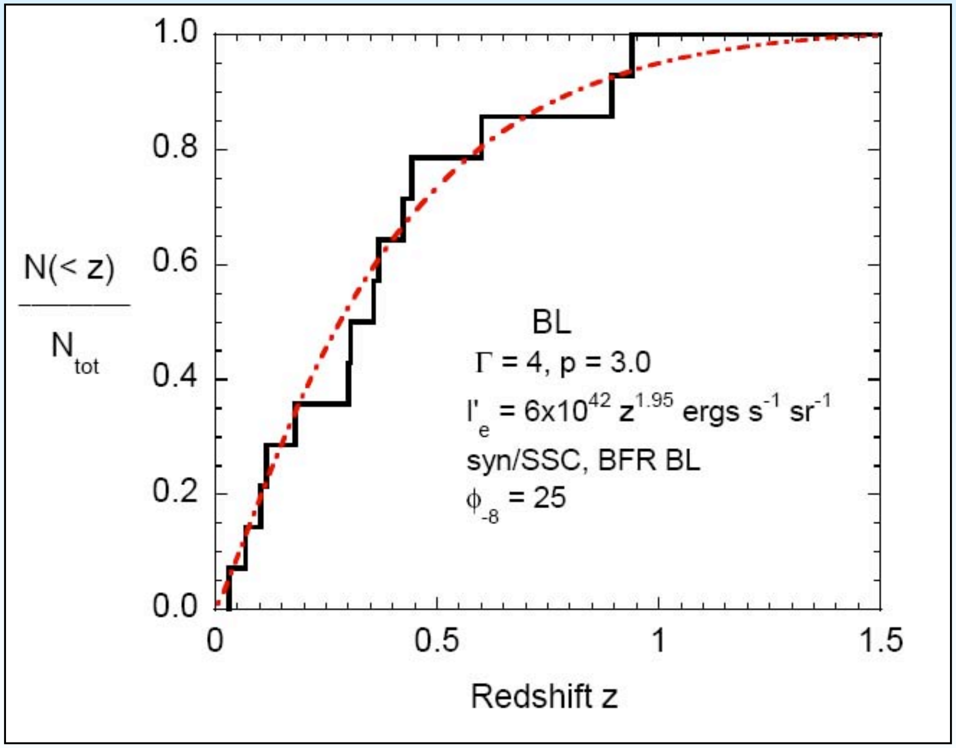
Mono-parameter L_* Blazar

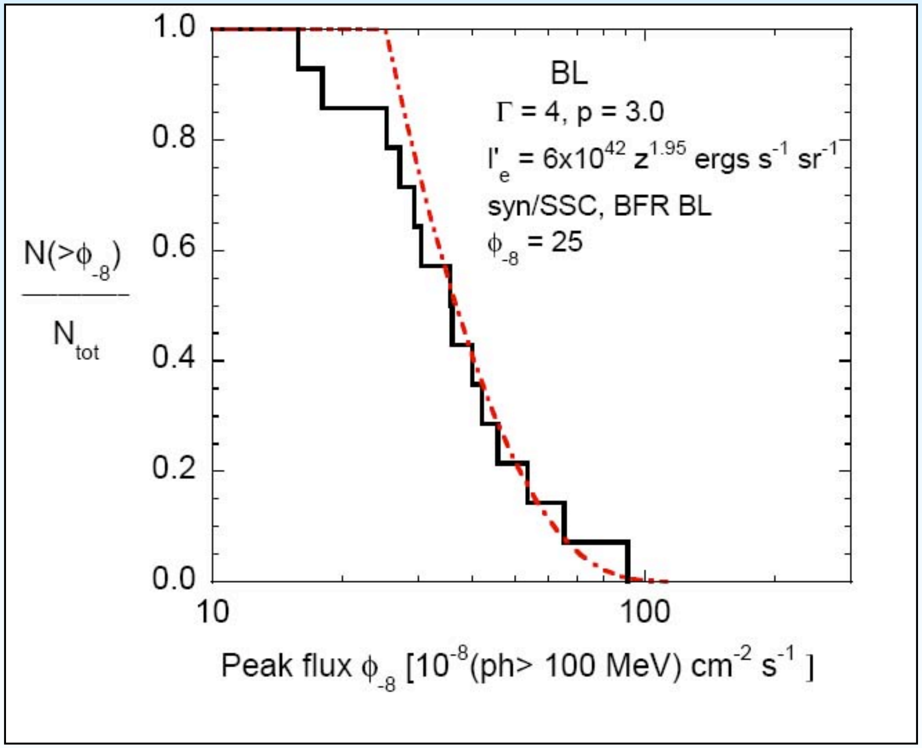
SFR IR,4

Size Distribution of Model FSRQ



Redshift and Size Distributions of BL Lac Objects

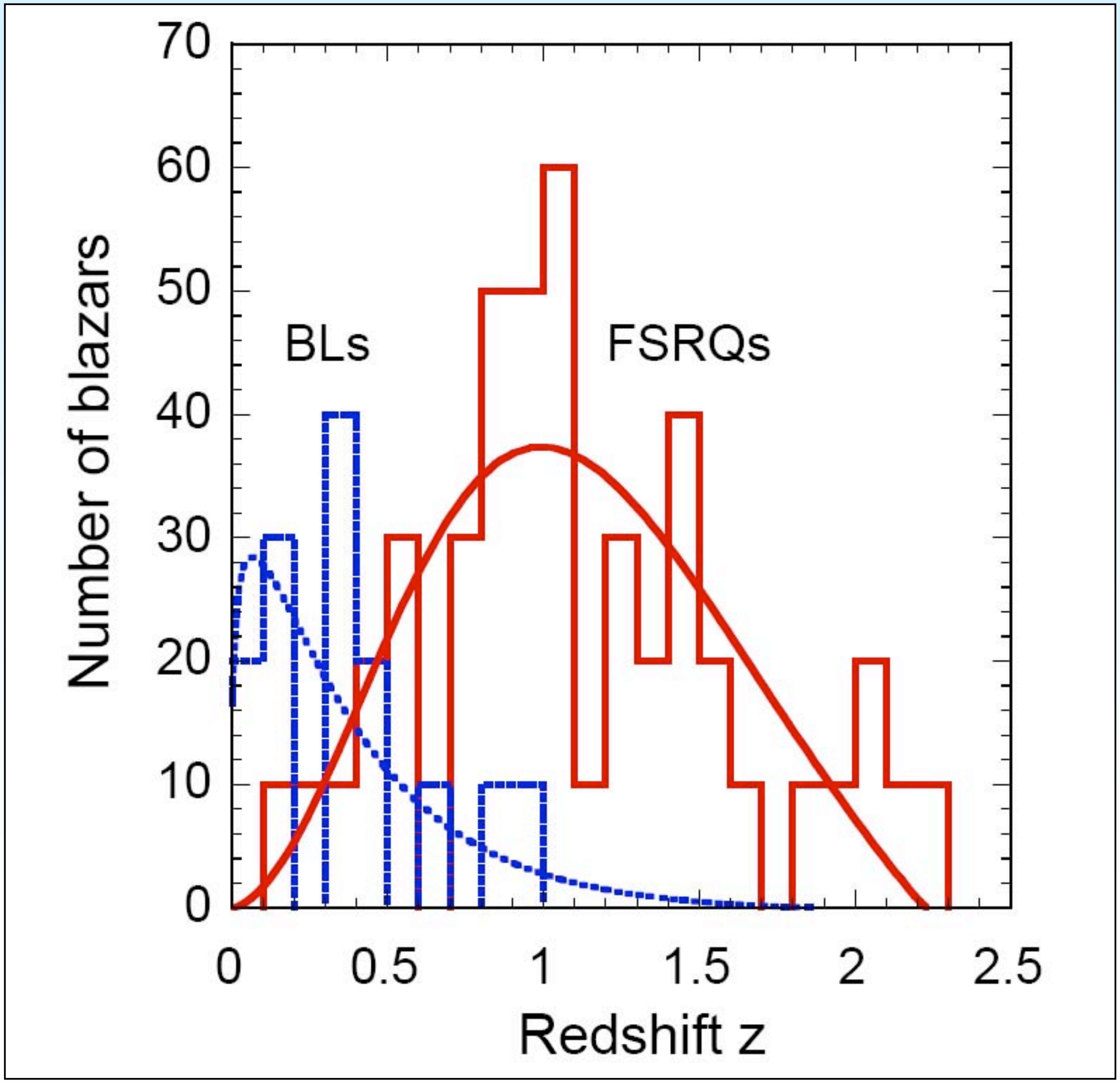




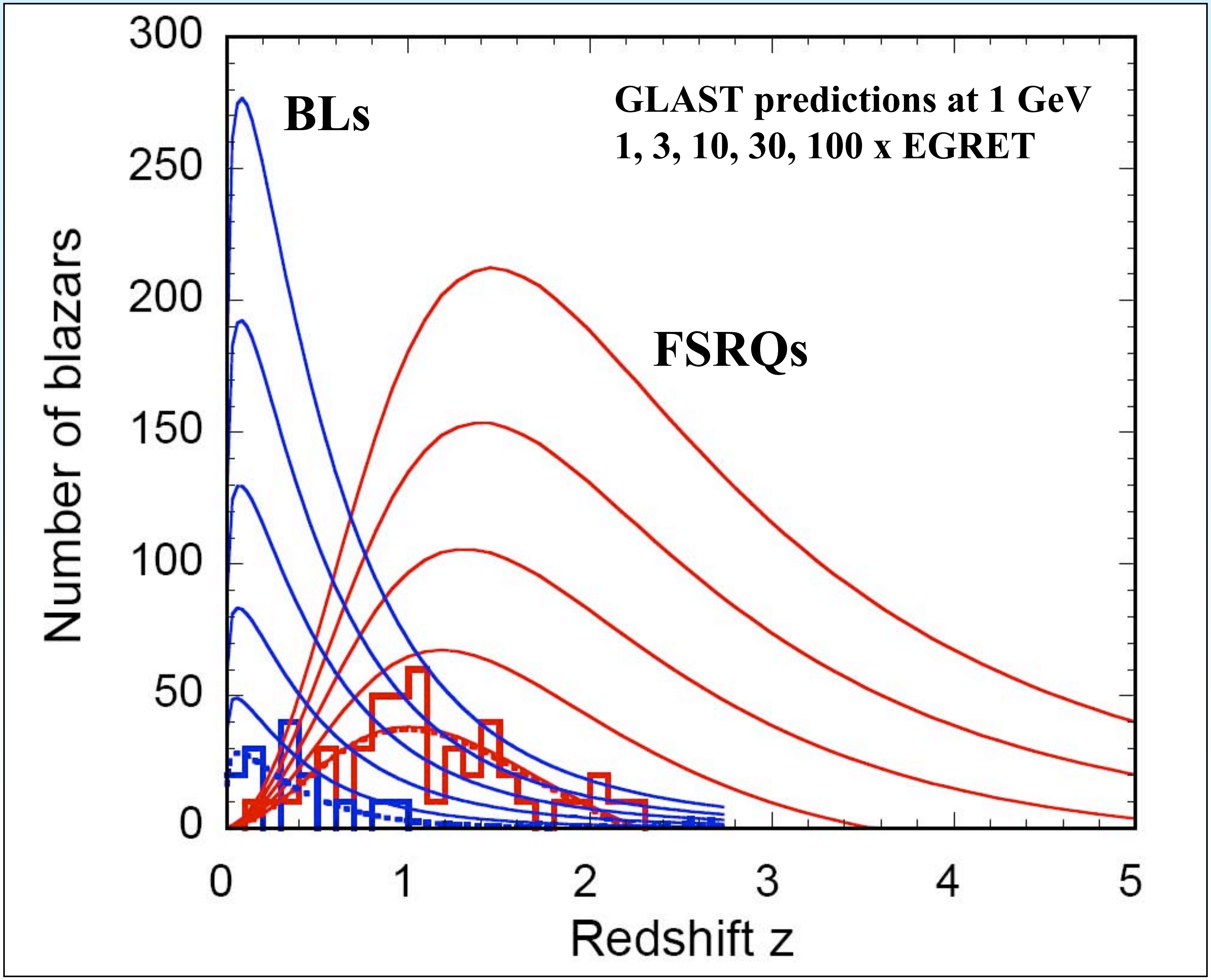
Require negative density evolution (fewer BL Lacs at early times)

Positive luminosity evolution (brighter at early time)

Model Redshift Distribution of EGRET γ-Ray Blazars



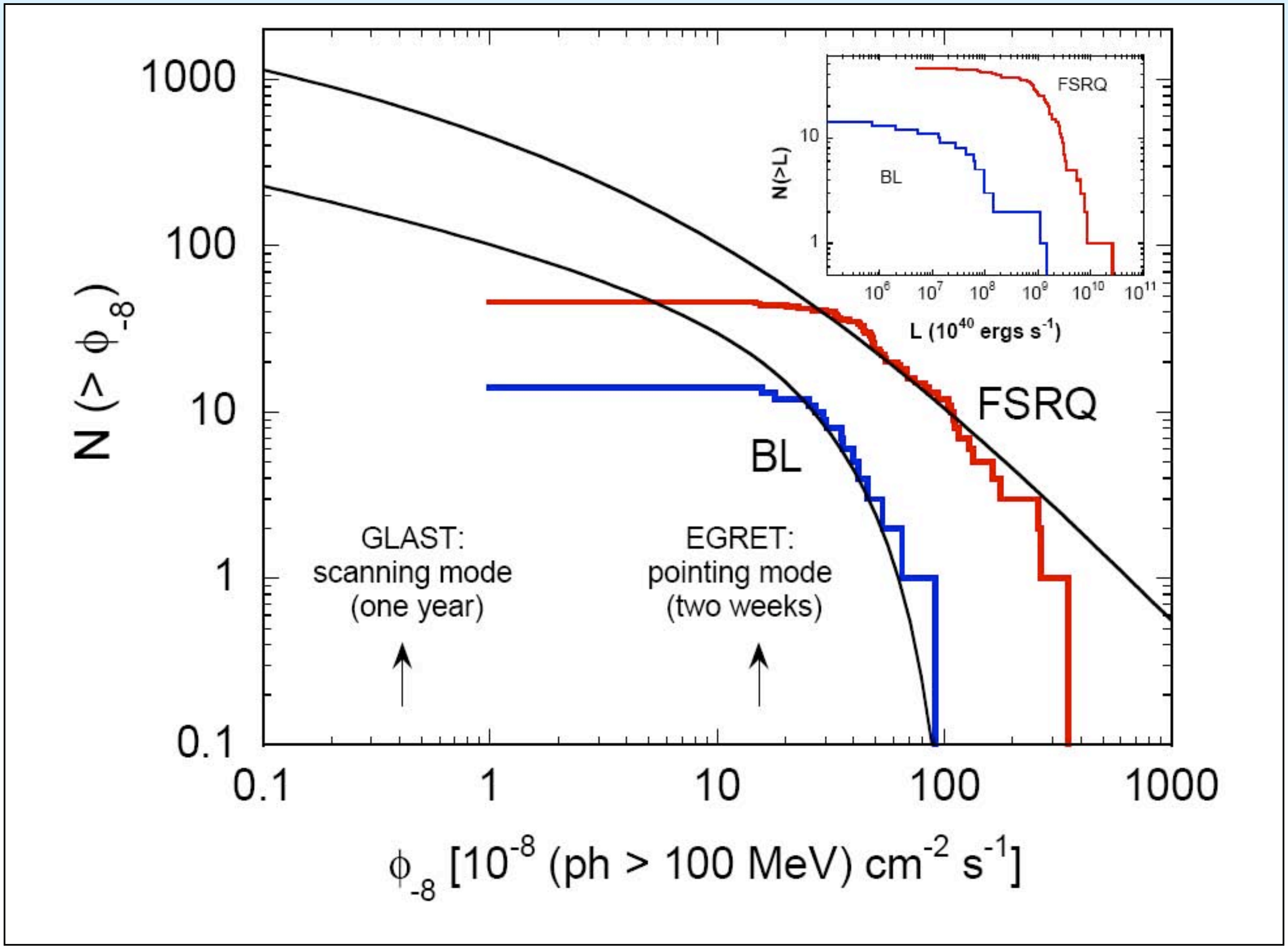
Redshift Predictions for GLAST γ-Ray Blazars



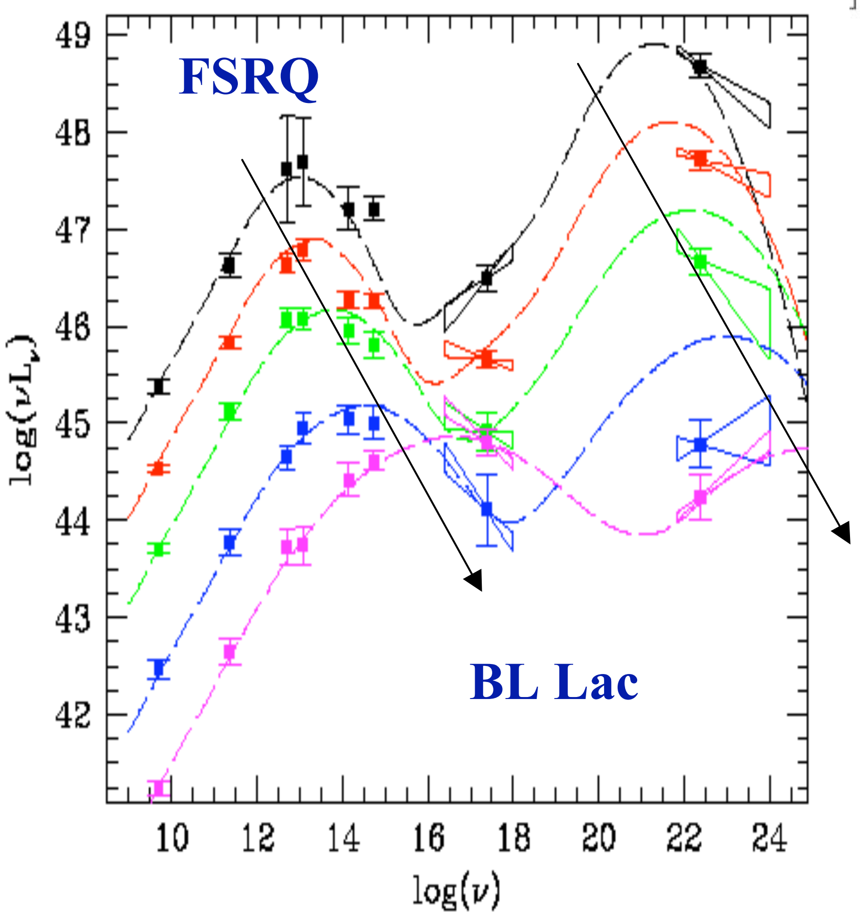
Predicted Number of Blazars with GLAST

GLAST reaches sensitivity of $0.4x10^{-8}$ ph(>100 MeV)/cm^2 s in one year

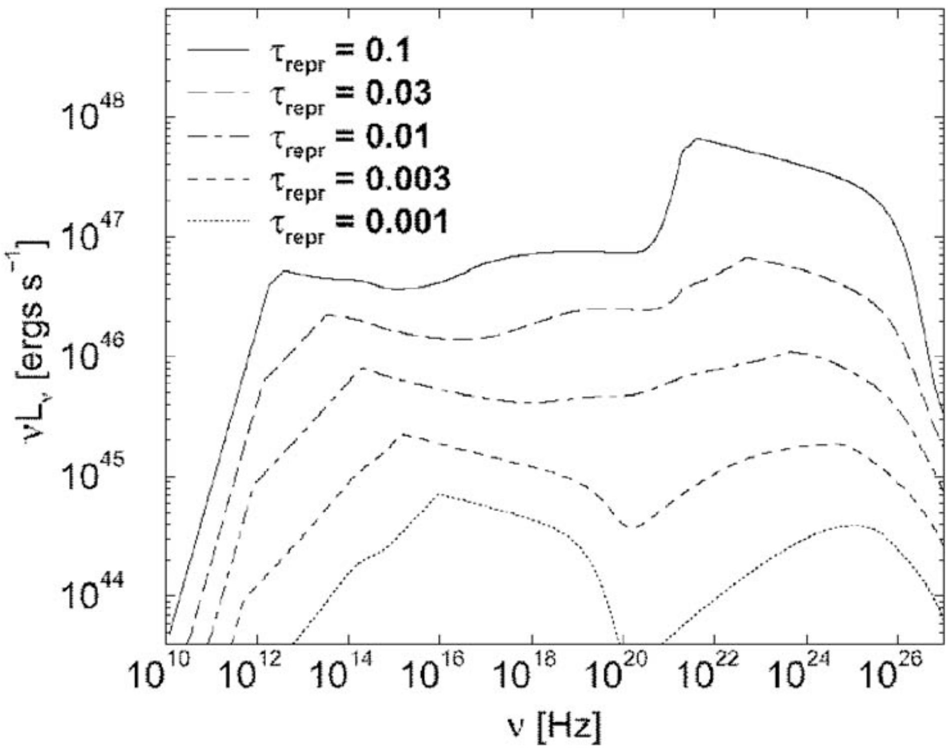
~700 FSRQs and ~150 BLs by end of first year of operation



Blazar Main Sequence



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



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

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

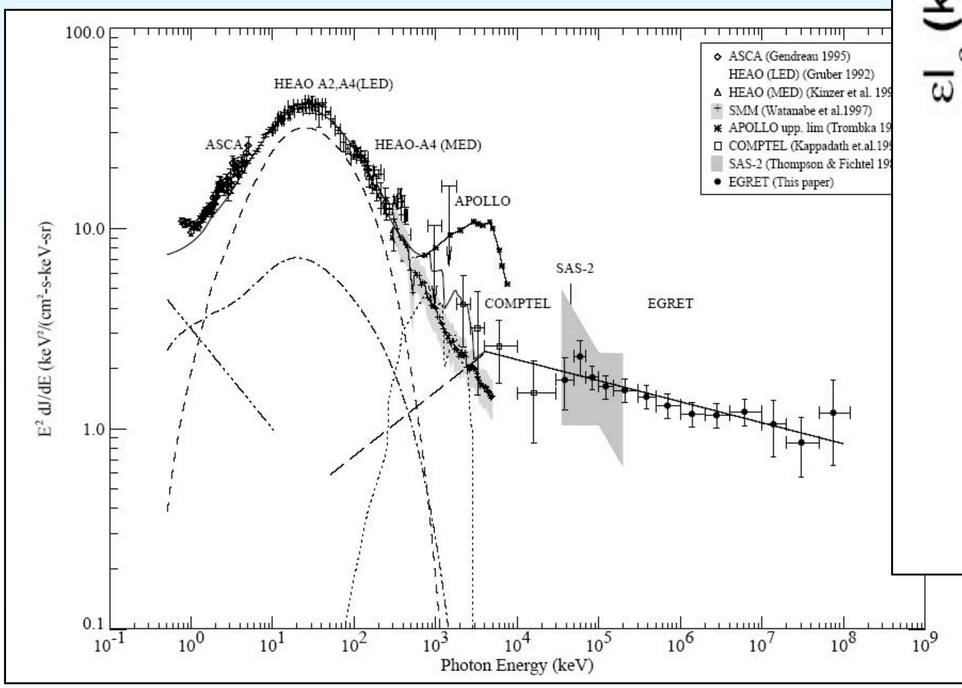
BL Lac objects are late stages of FSRQs: in accord with analysis of EGRET data

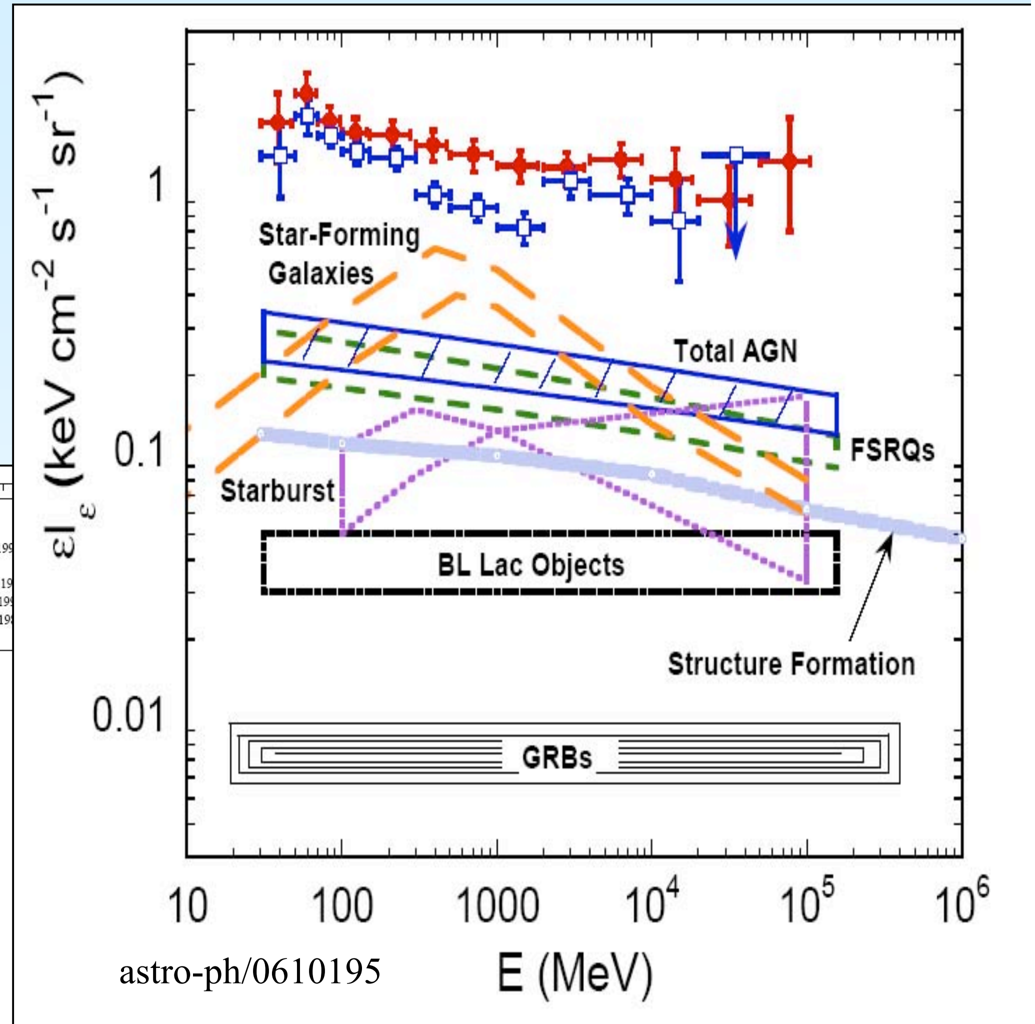
(1) Blazar main sequence valid? (2) BL Lac BH Masses > FSRQ BH masses?

Unresolved γ-Ray Background

BL Lacs: ~2 - 4% (at 1 GeV)
FSRQs: ~ 10 - 15%
Star-forming galaxies: Pavlidou & Fields (2002)
Clusters of galaxies: Keshet et al. (2003)

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



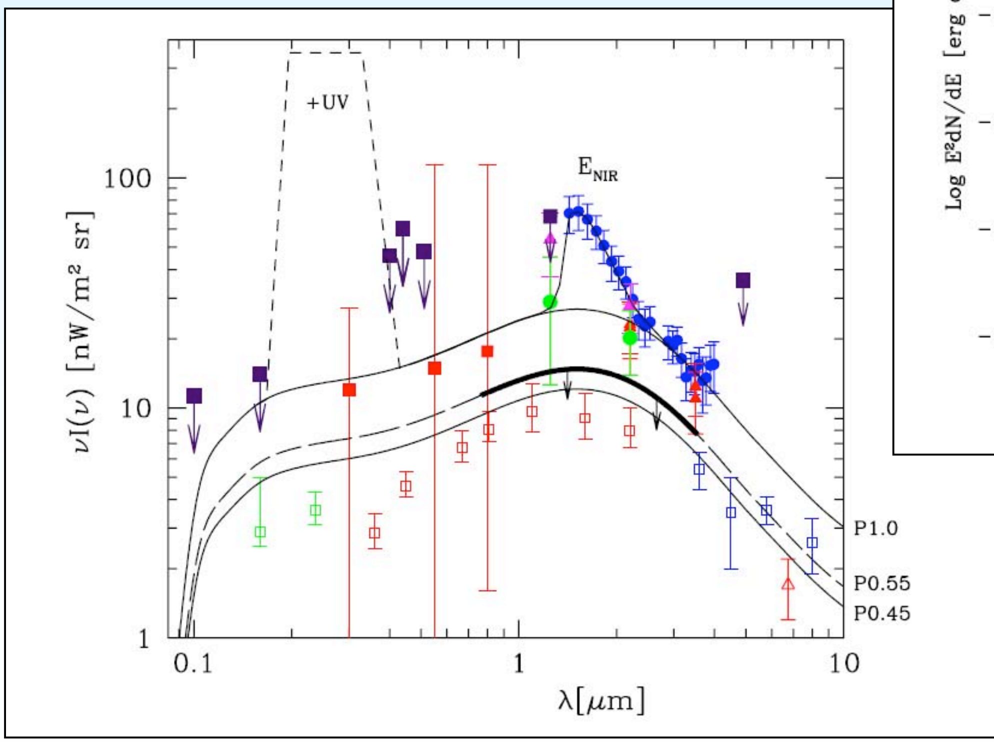


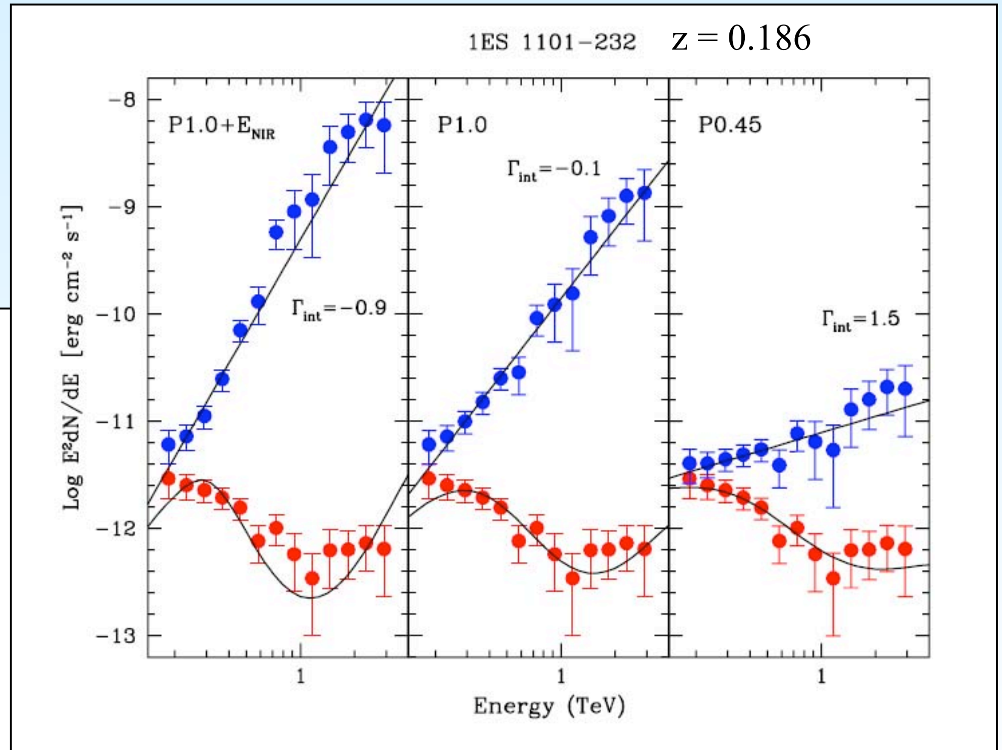
Data: Sreekumar et al. (1998)
Strong, Moskalenko, & Reimer (2000)

Evidence for unknown high-energy (>> 1 GeV) sources or components

Other Evidence for High Energy γ-Ray Components in Blazars

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





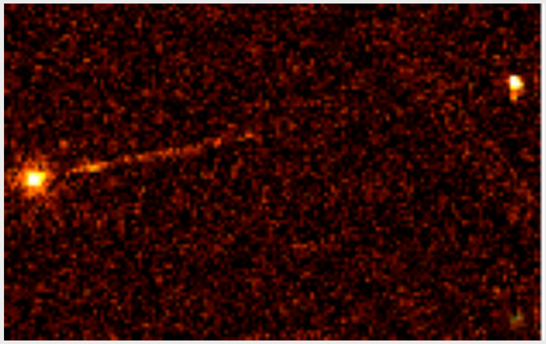
HESS Collaboration, Nature, 2005

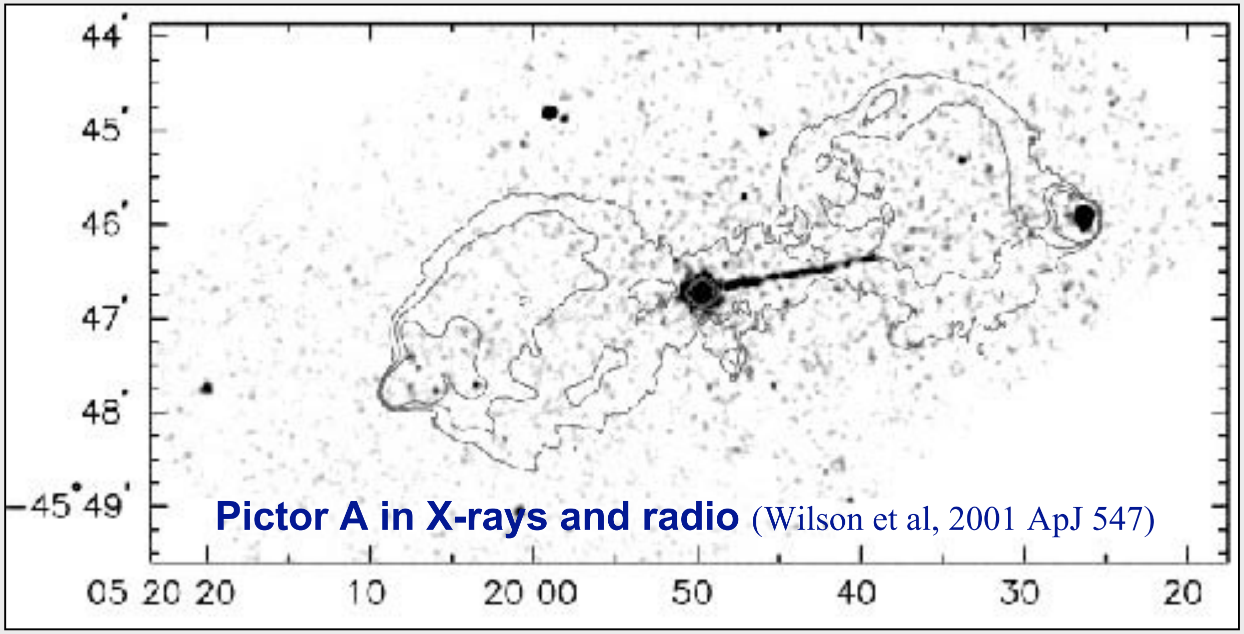
Pictor A

d ~ 200 Mpc

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

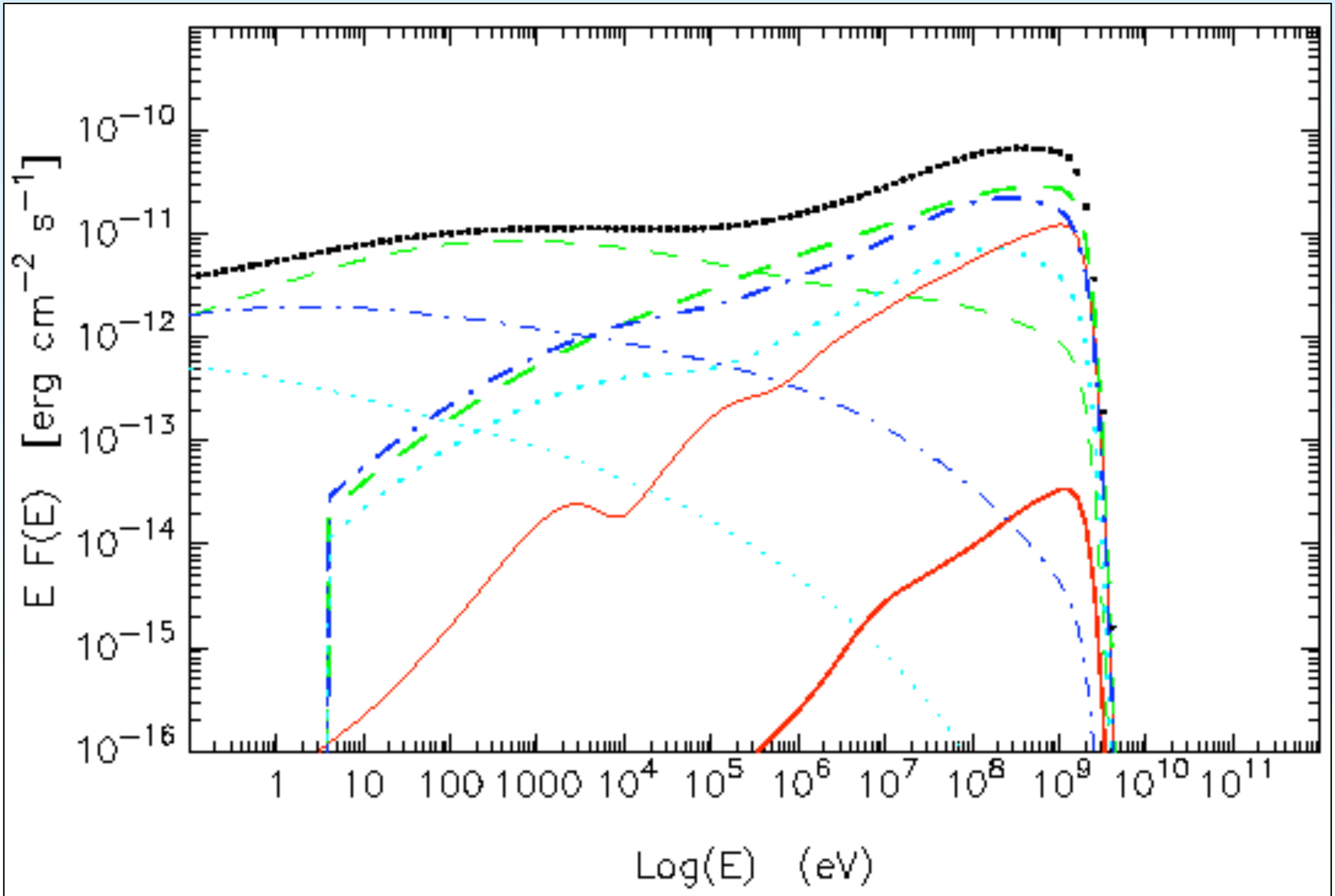
Deposition of energy through ultra-high energy neutral beams **(Atoyan and CD 2003)**



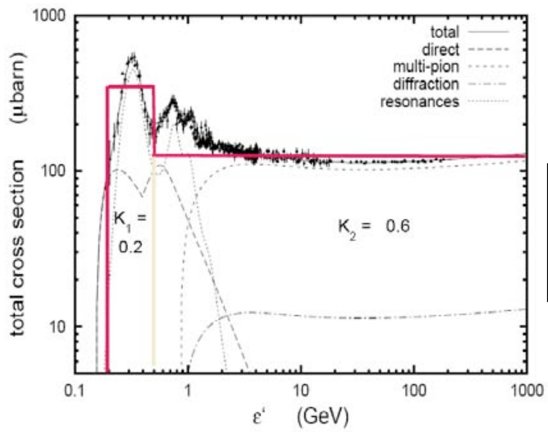


Blazars as High Energy Hadron Accelerators

w/ Armen Atoyan **(UdeM)**



Guaranteed Strong Photohadronic Losses



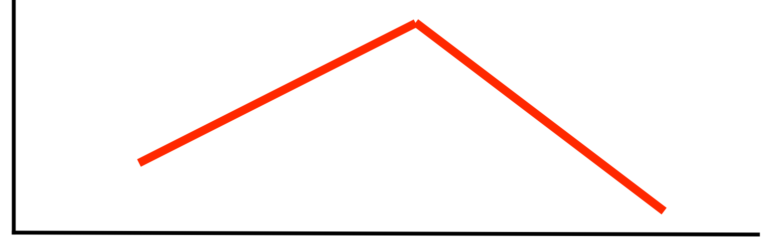
$$\rho_{\phi\pi} > (1+z)/\delta_{\rm D} t_v$$

Do blazars have hard photohadronic tails?

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

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

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



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

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

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

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

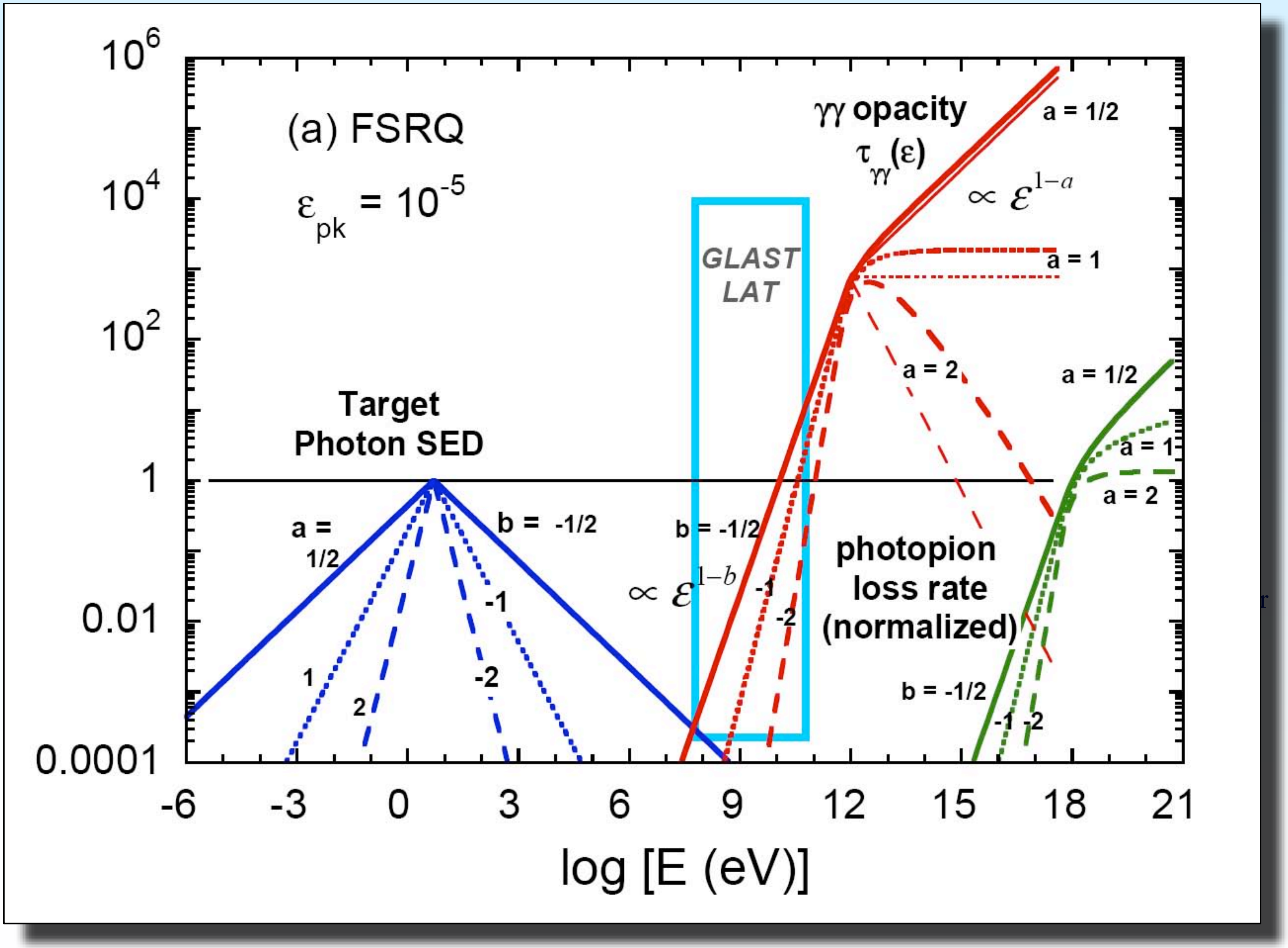
w/ Truong Le **(NRL),**
Enrico Ramirez-Ruiz **(IAS)**

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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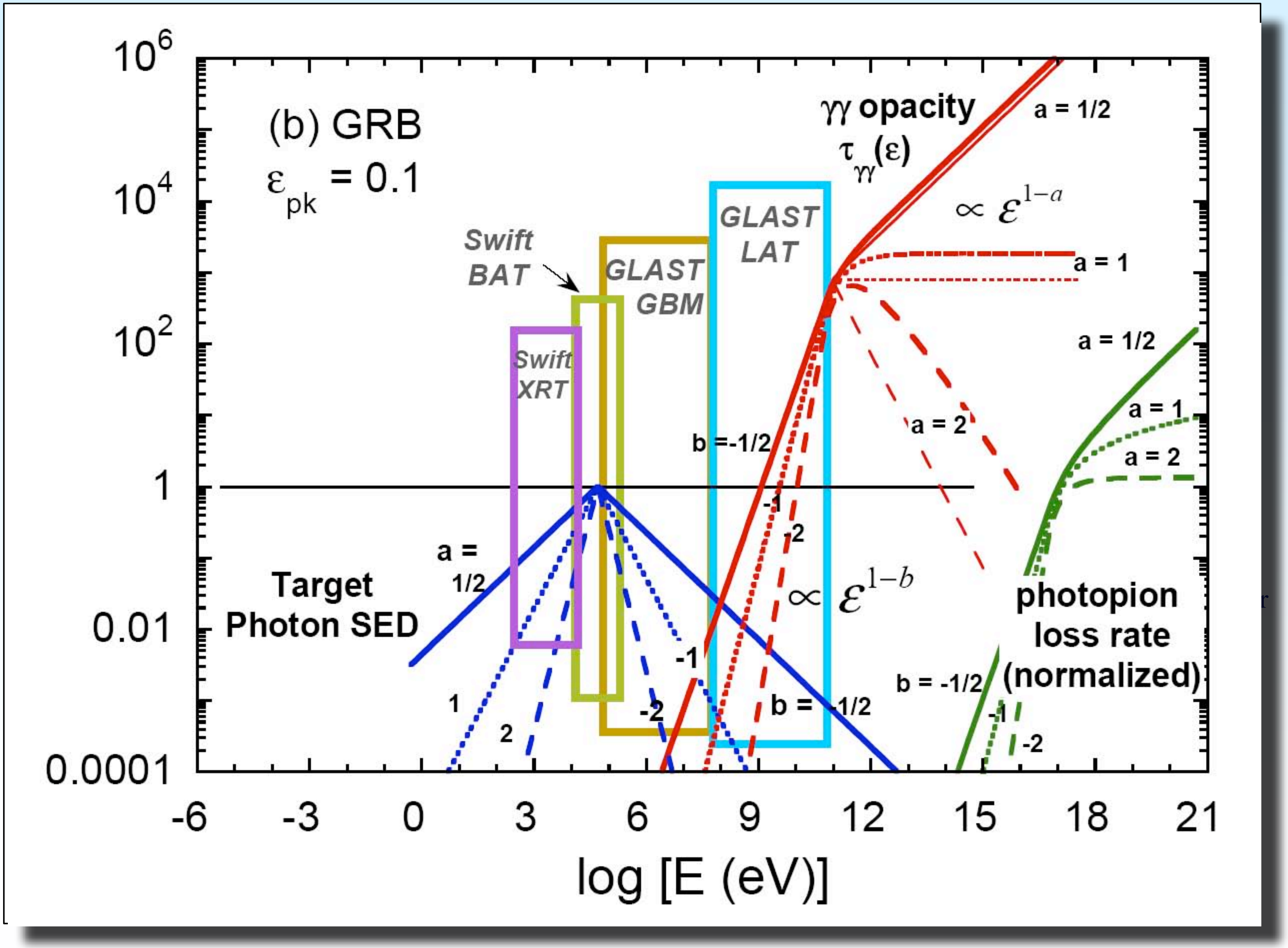
γ ray				-1 (51 keV)	280	92	5×10^{16}
X–ray flare		-9	2	-3 (0.5 keV)	50	290	1.6×10^{17}

Correlation of Fluxes for GRBs



Neutrino Detection from GRBs with Large Baryon-Loading

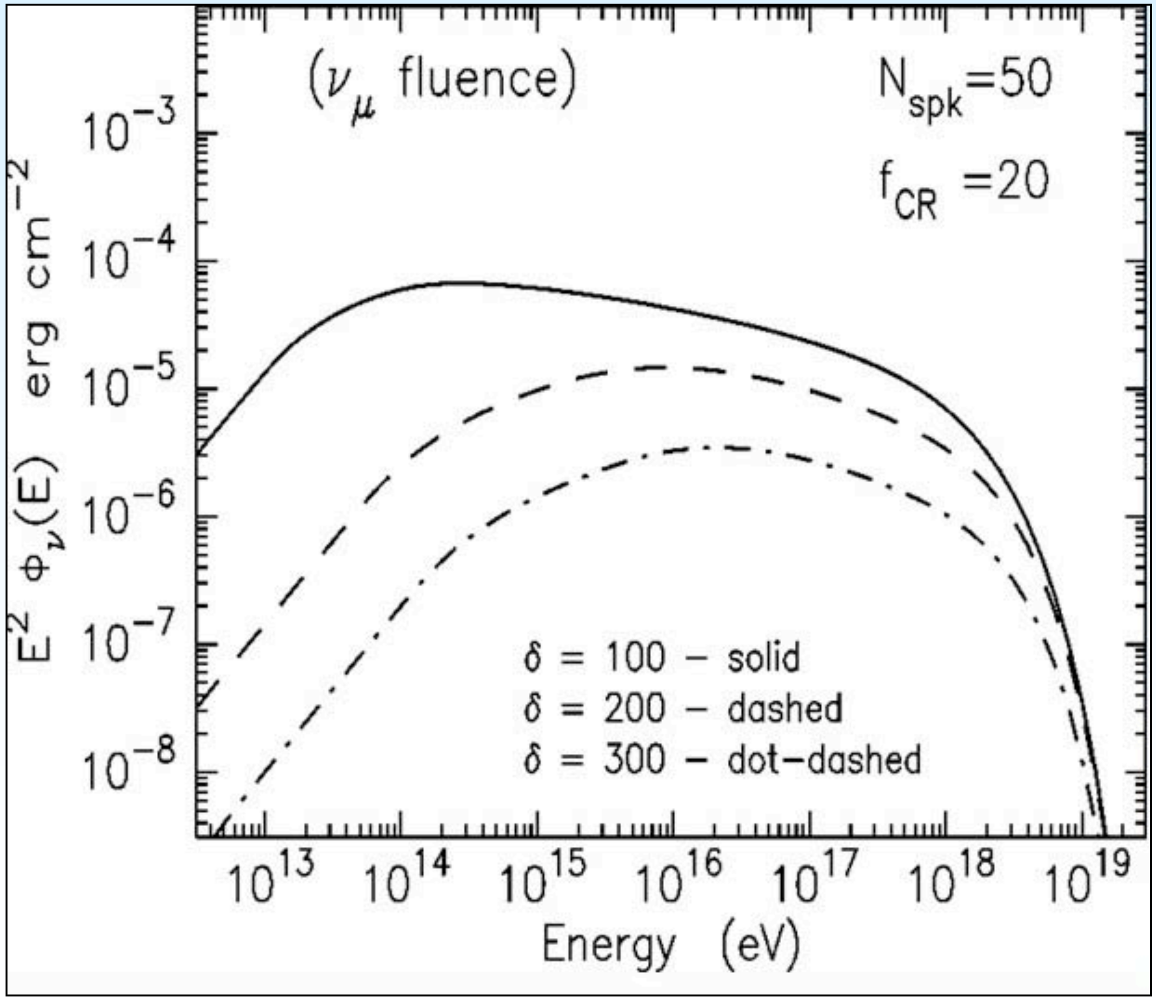
For a fluence of $3x10^{-4}$ ergs/cm^2, (~2/yr)

N_ν predicted by IceCube:

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

Dermer and Atoyan (PRL, 2003)

Nonthermal Baryon Loading Factor f_b = 20



Summary

- GLAST will test microquasar models

- GLAST predictions of number and evolution of blazars

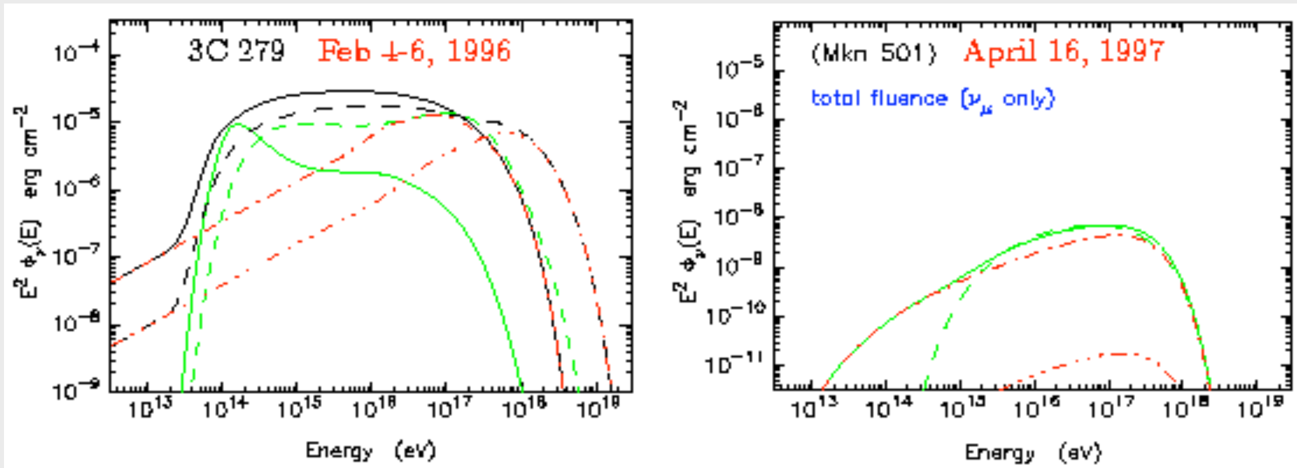
- Do hard blazar emission components, or new population of γ-ray sources, make "diffuse" extragalactic γ-ray background?

- Photohadronic cascades make ultra-high energy γ-ray emission component (without lower energy emission) from FSRQs, not BL Lac objects

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

- Implication for black-hole demographics, cosmic-ray origin

Neutrinos: expected fluences/numbers



Expected ν - fluences calculated for 2 flares, in 3C 279 and Mkn 501; red curves - contribution due to 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 $\delta = 6$ (solid curve) and $N_\nu = 0.18$ for $\delta = 10$ (dashed)

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

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

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

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

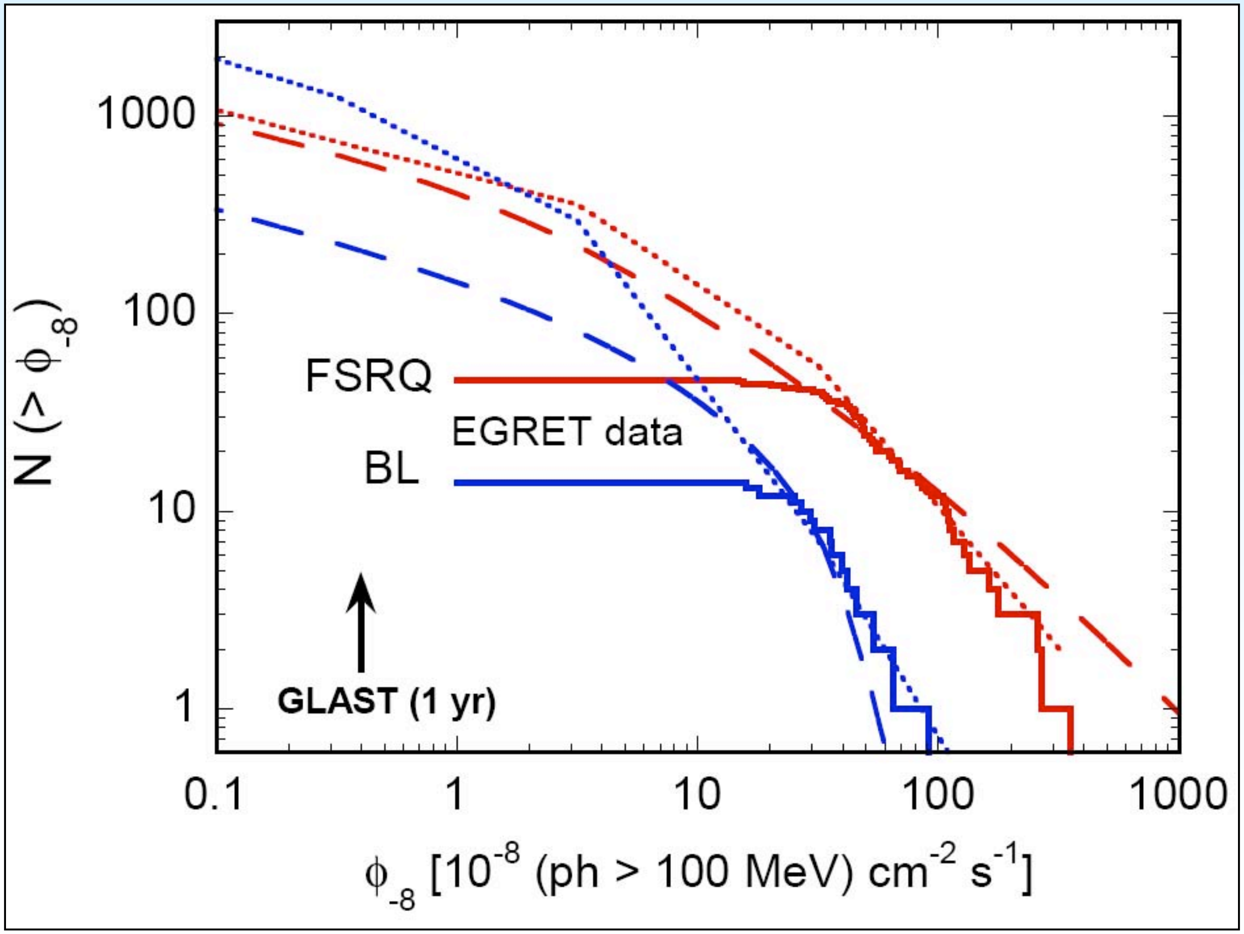
Detection of one ν implies large energy in neutrals

Predicted Number of Blazars with GLAST

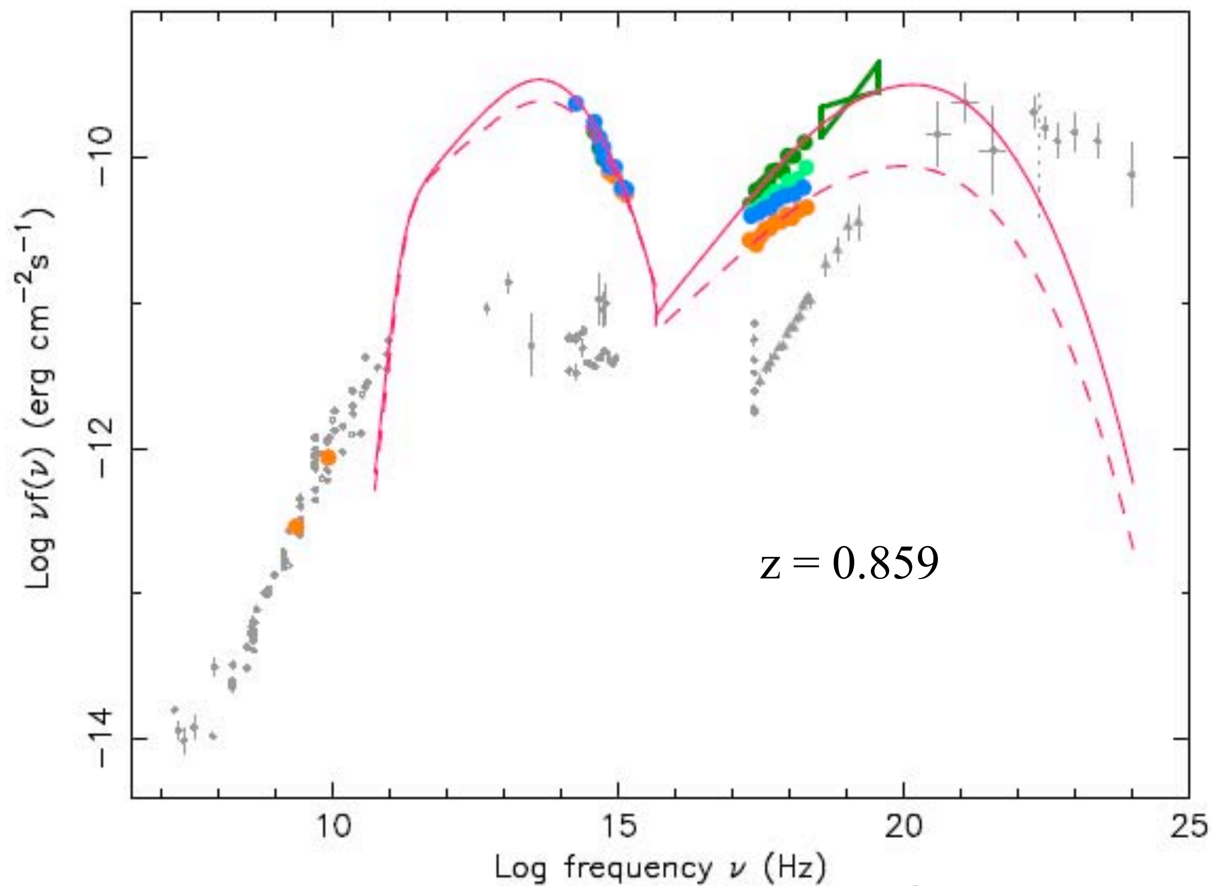
- Peak flux size distribution of EGRET blazars for two-week pointings during the all-sky survey

Dotted curves: Mücke and Pohl (2000)

see Dermer (2006), ApJ, submitted (see astro-ph) for blazar statistics

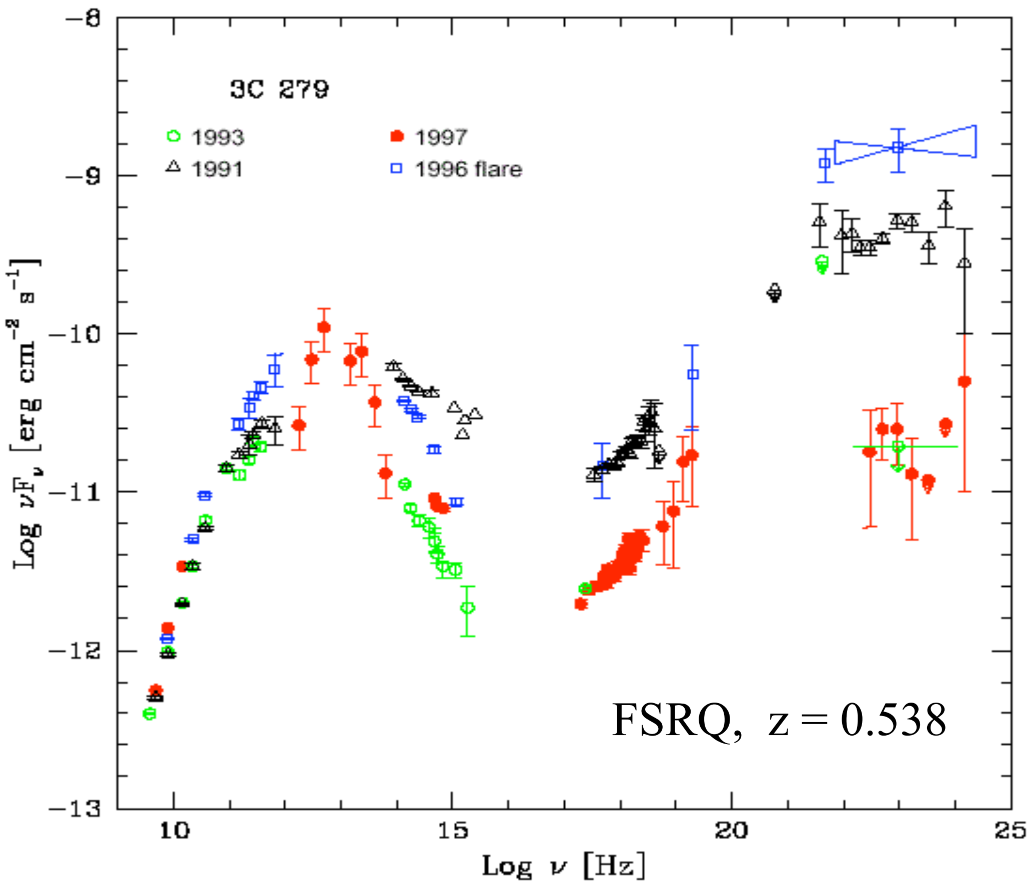


3C 454.3



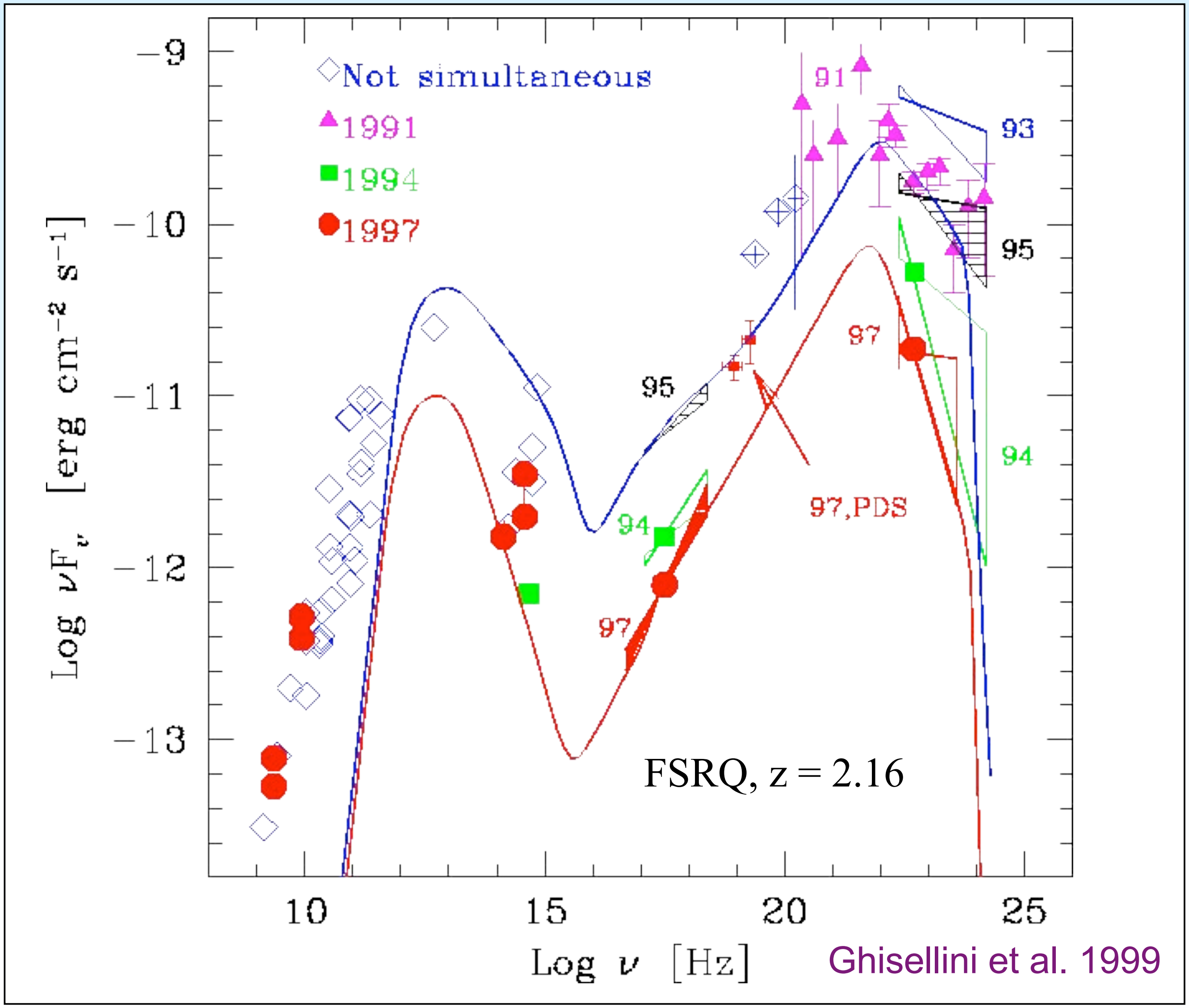
Giommi et al. 2006

3C 279



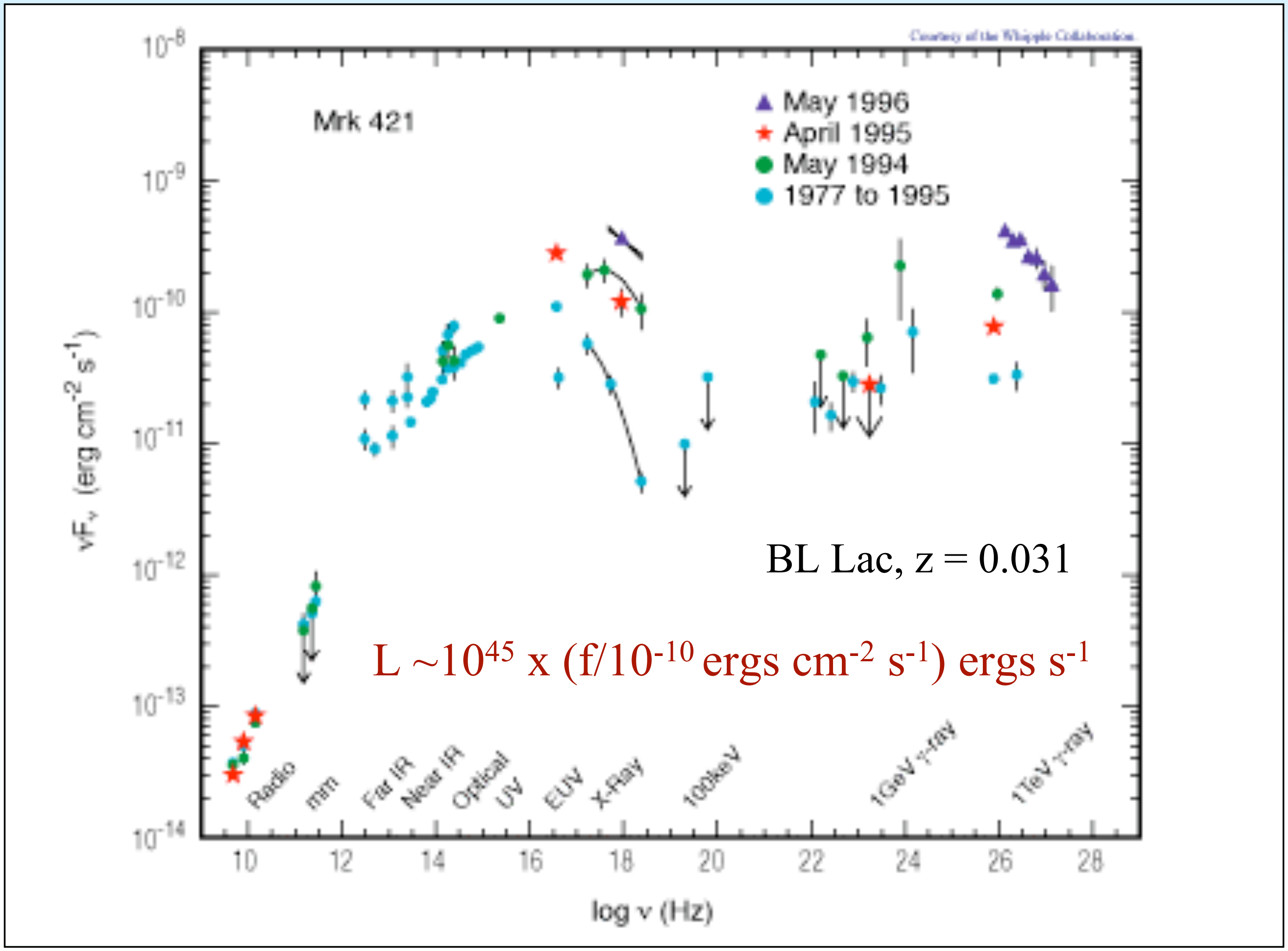
$L \sim 5 \times 10^{48} \times (f/10^{-9}\ \mathrm{ergs\ cm^{-2}\ s^{-1}})\ \mathrm{ergs\ s^{-1}}$

PKS 0528+134



Ghisellini et al. 1999

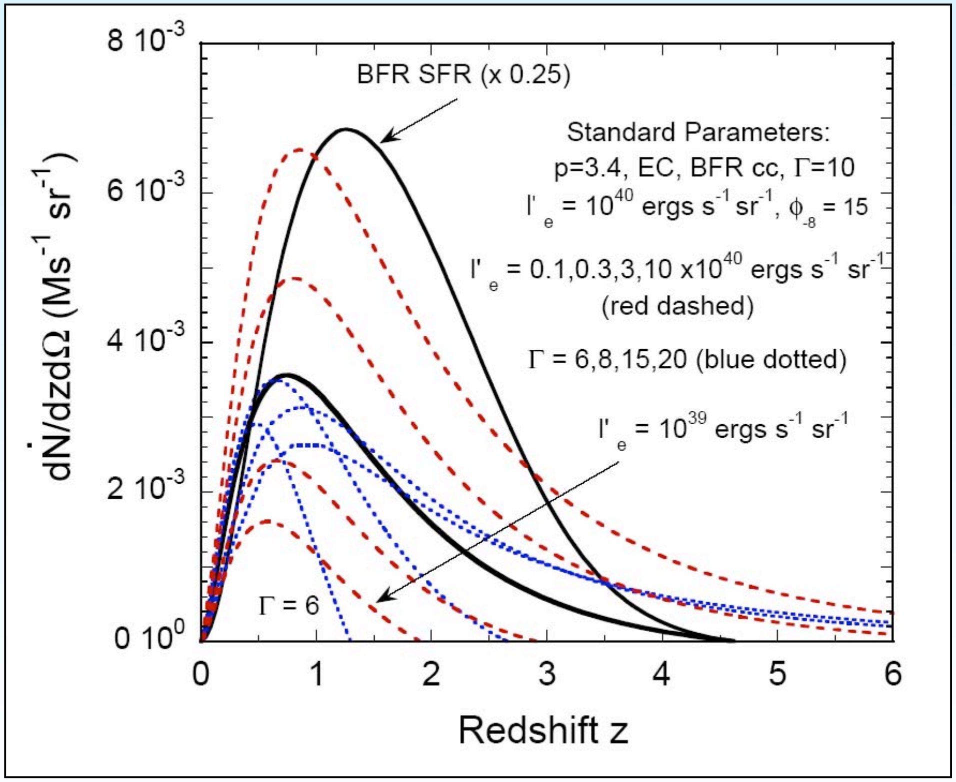
Mrk 421

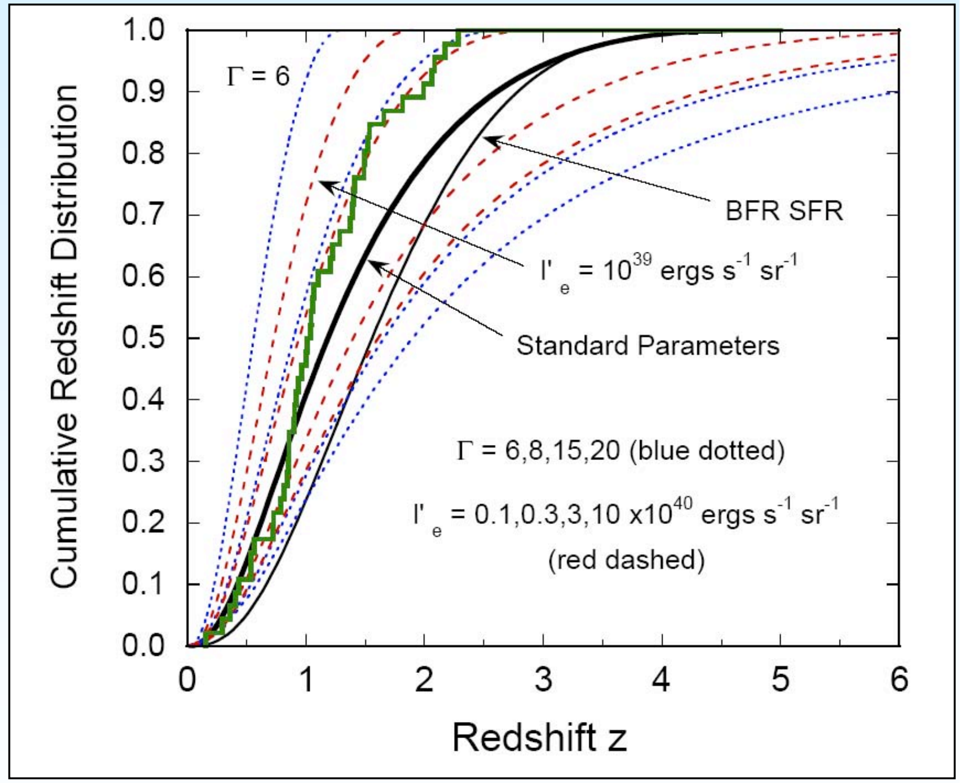


Macomb et al. 1995

Model FSRQ Parameter Study

Model redshift distributions of EGRET FSRQ blazars





Vary bulk Lorentz factor Γ, comoving directional luminosity $l'_e\ (ergs\ s^{-1}\ sr^{-1})$

One parameter family of solutions + SFH: find simplest model that fits (compare approach of Mücke and Pohl 2000)