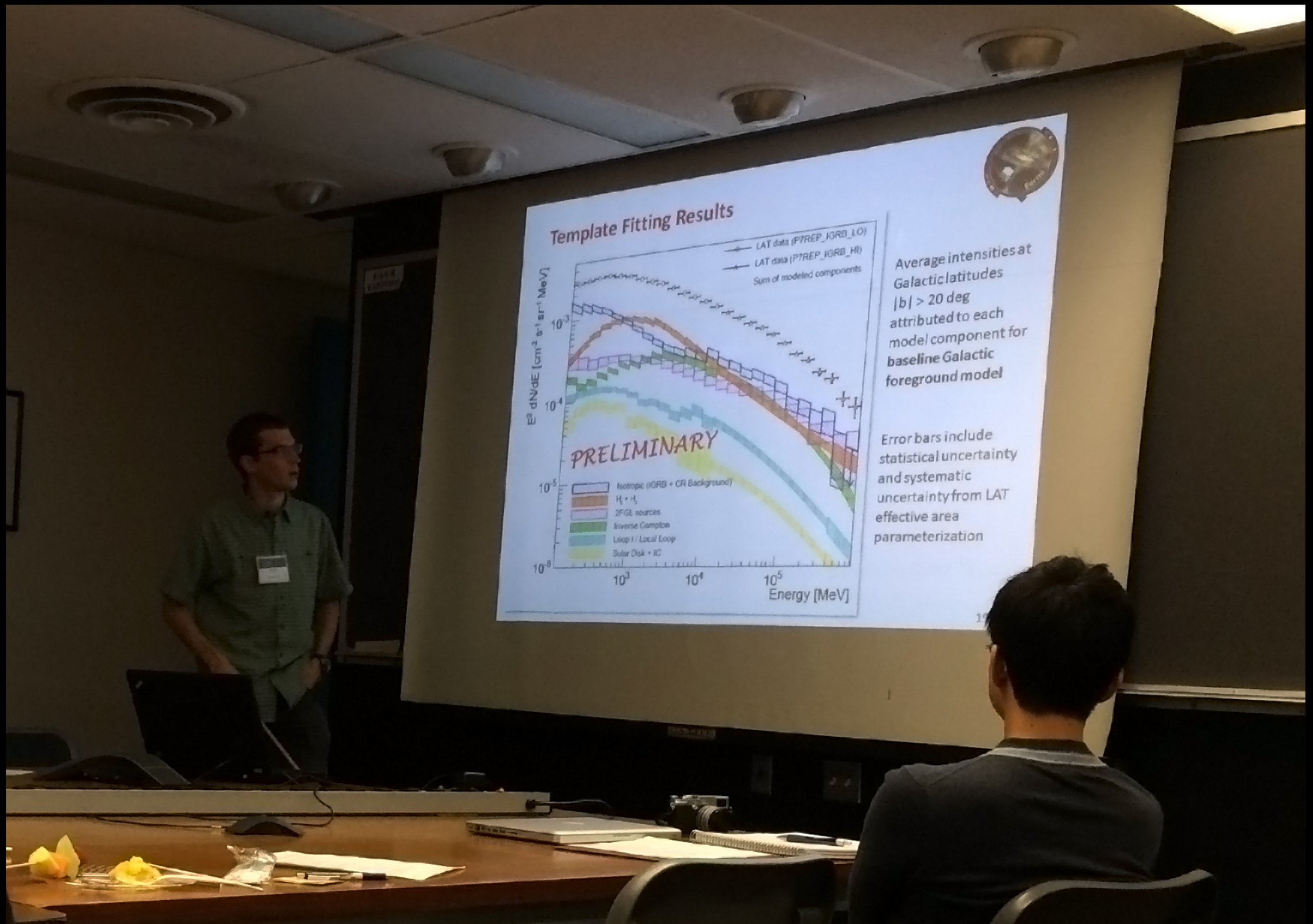
Constraints and Signals from the Diffuse Gamma Ray and X-ray Backgrounds

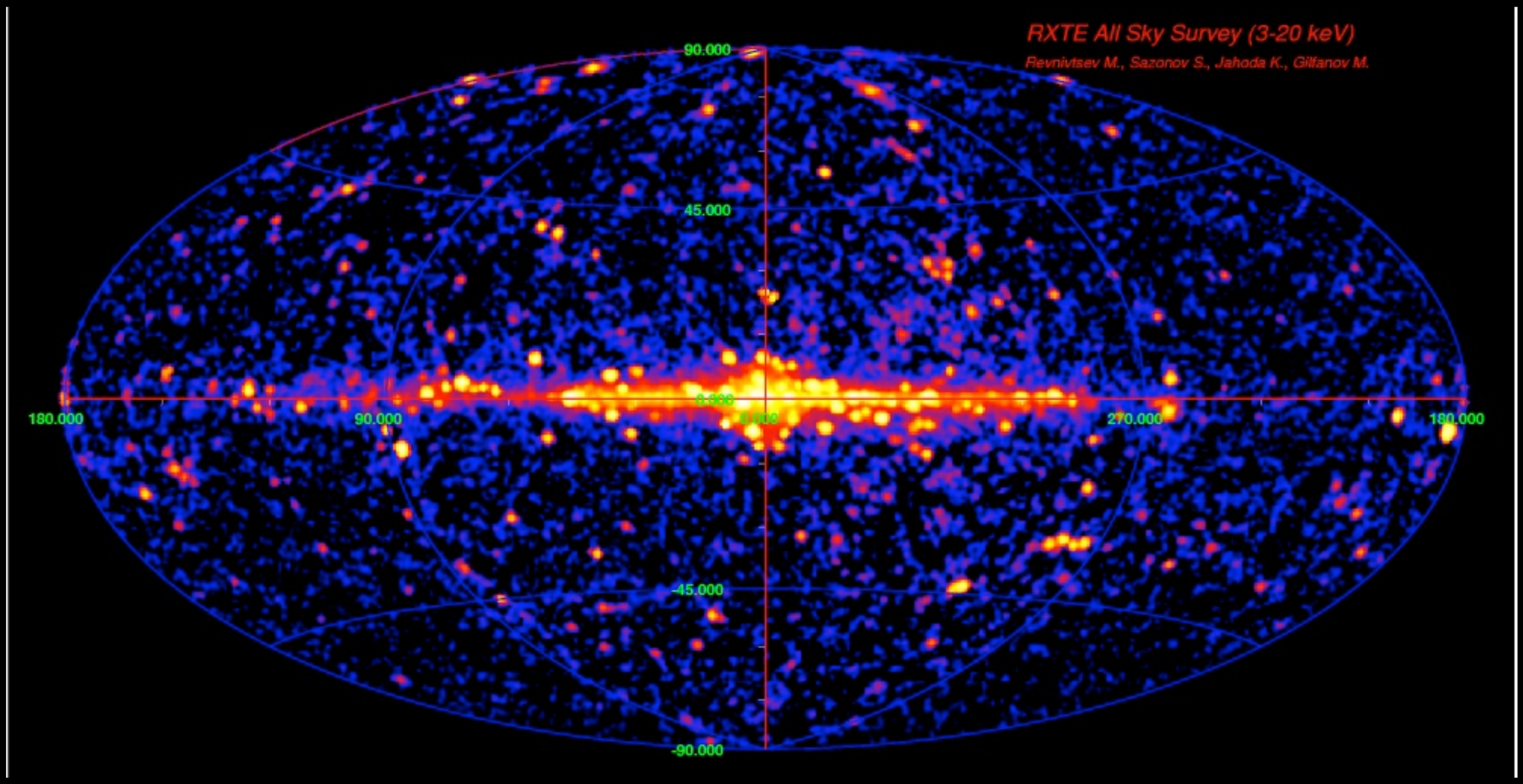
Kevork Abazajian
University of California, Irvine

KICP High-Energy Messengers Workshop
June 10, 2014

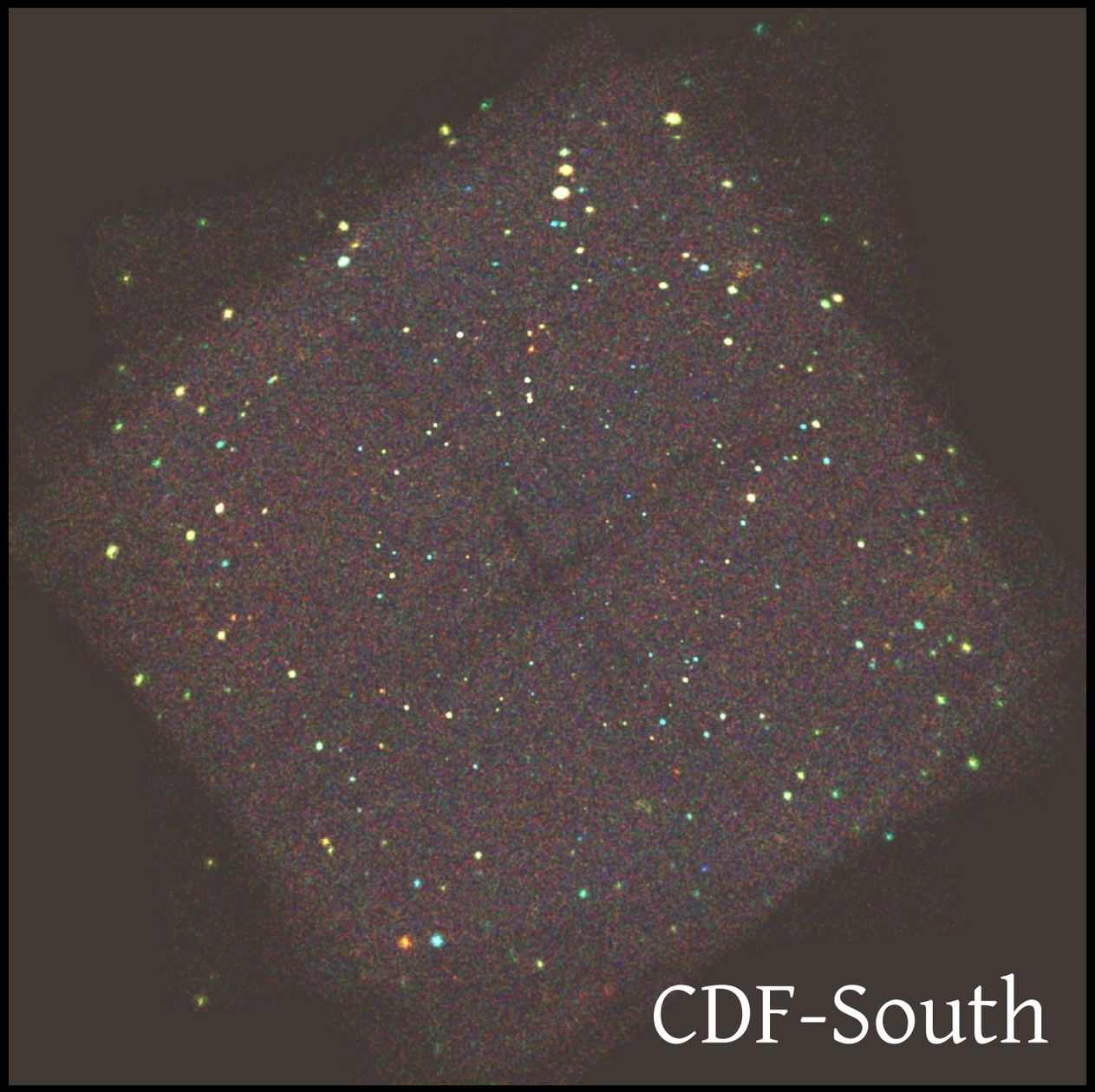
The Diffuse Gamma Ray Background

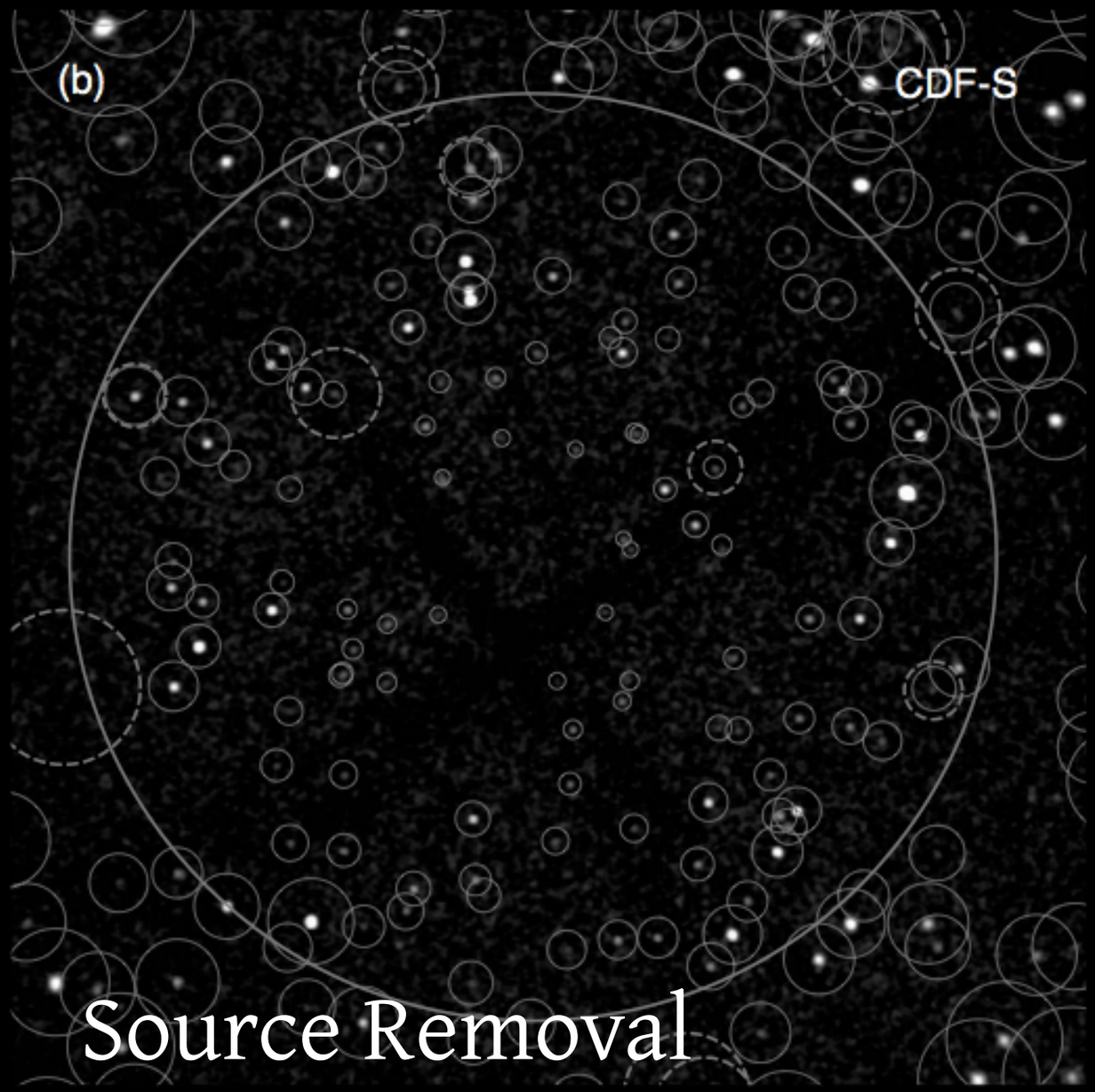


Lessons from the Cosmic X-ray Background



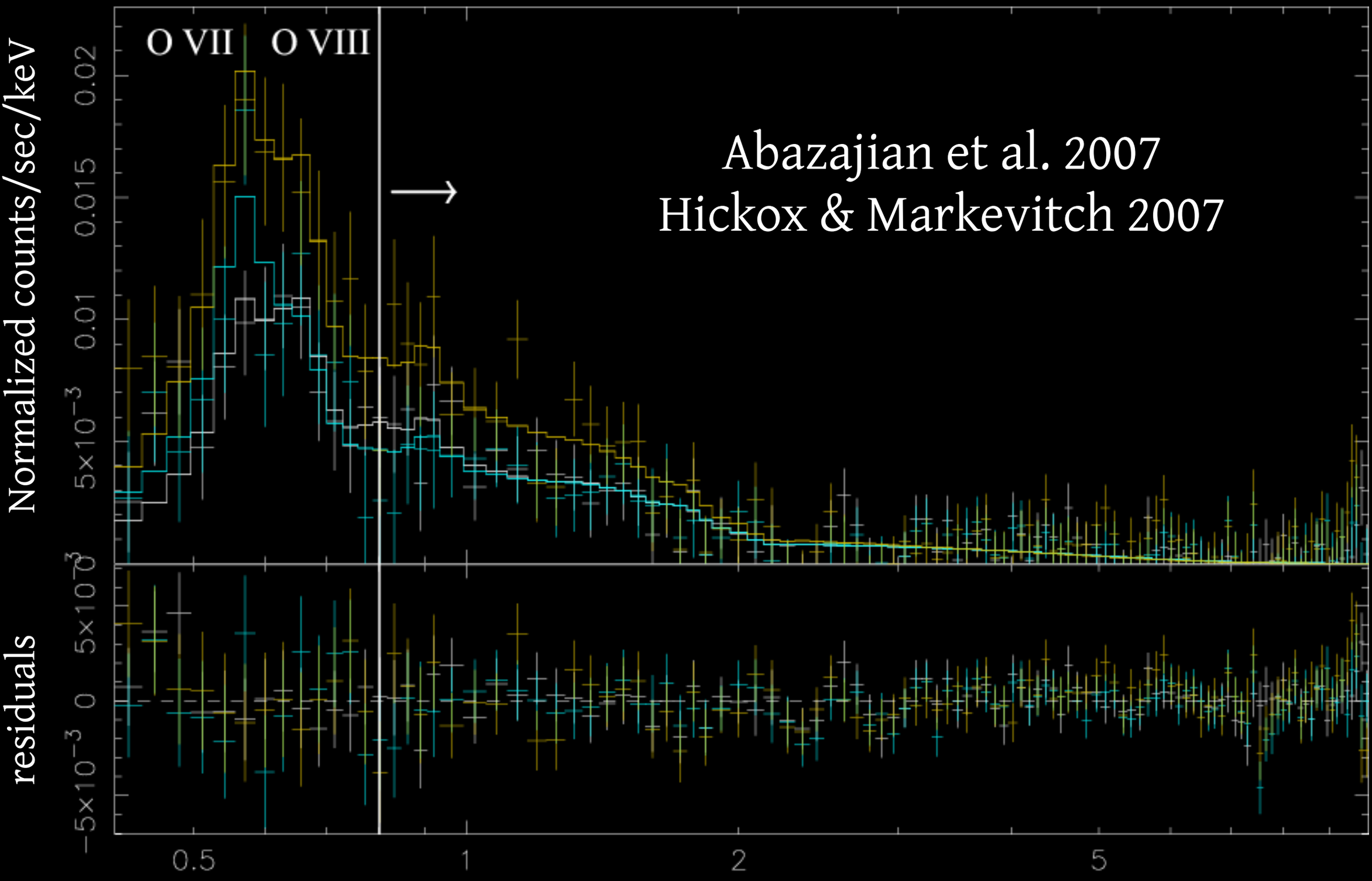
Chandra Deep Field: the *resolved X-ray* Background





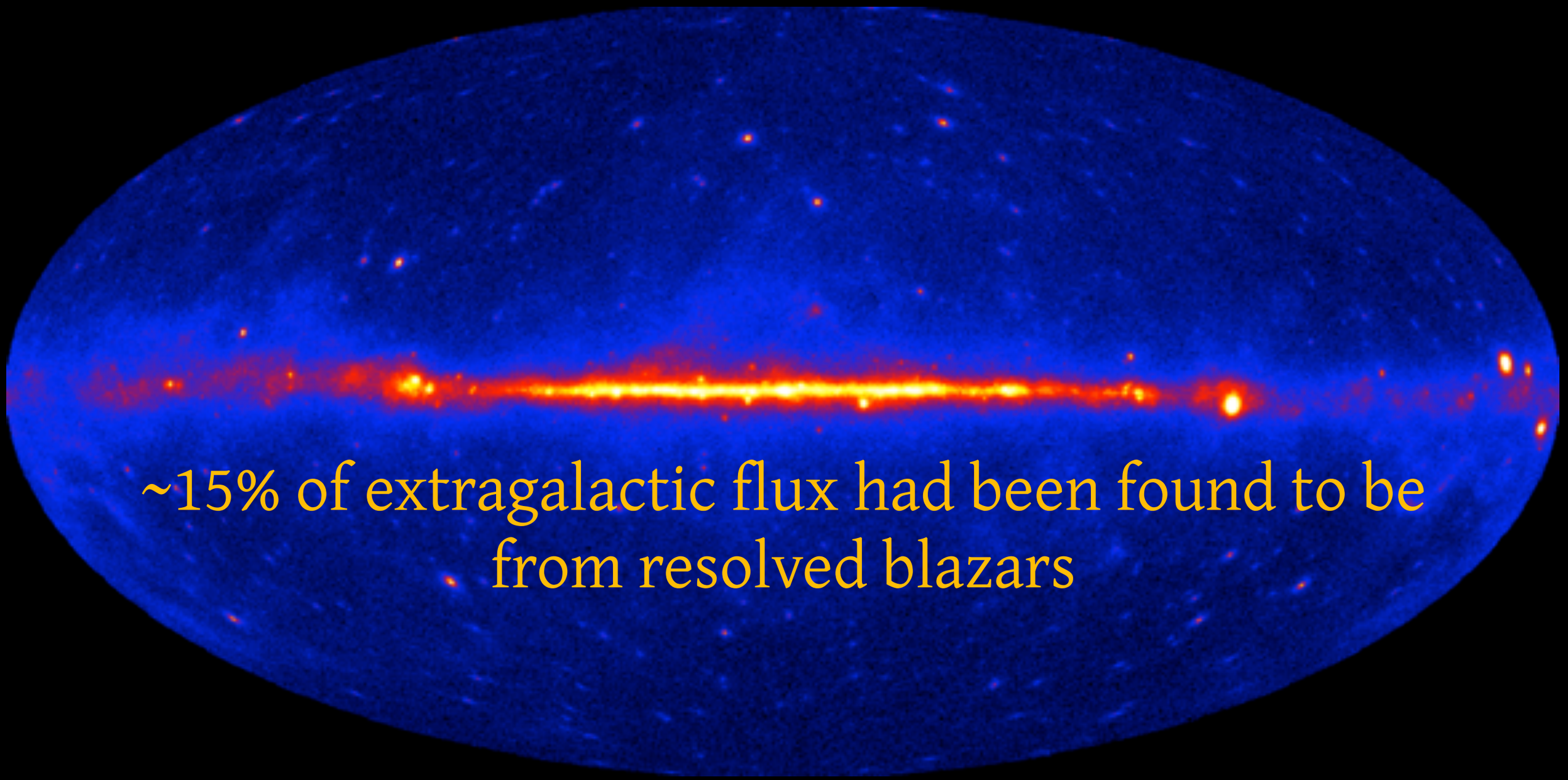
Hickox & Markevitch 2006, 2007

The (Unresolved) Cosmic X-ray Background



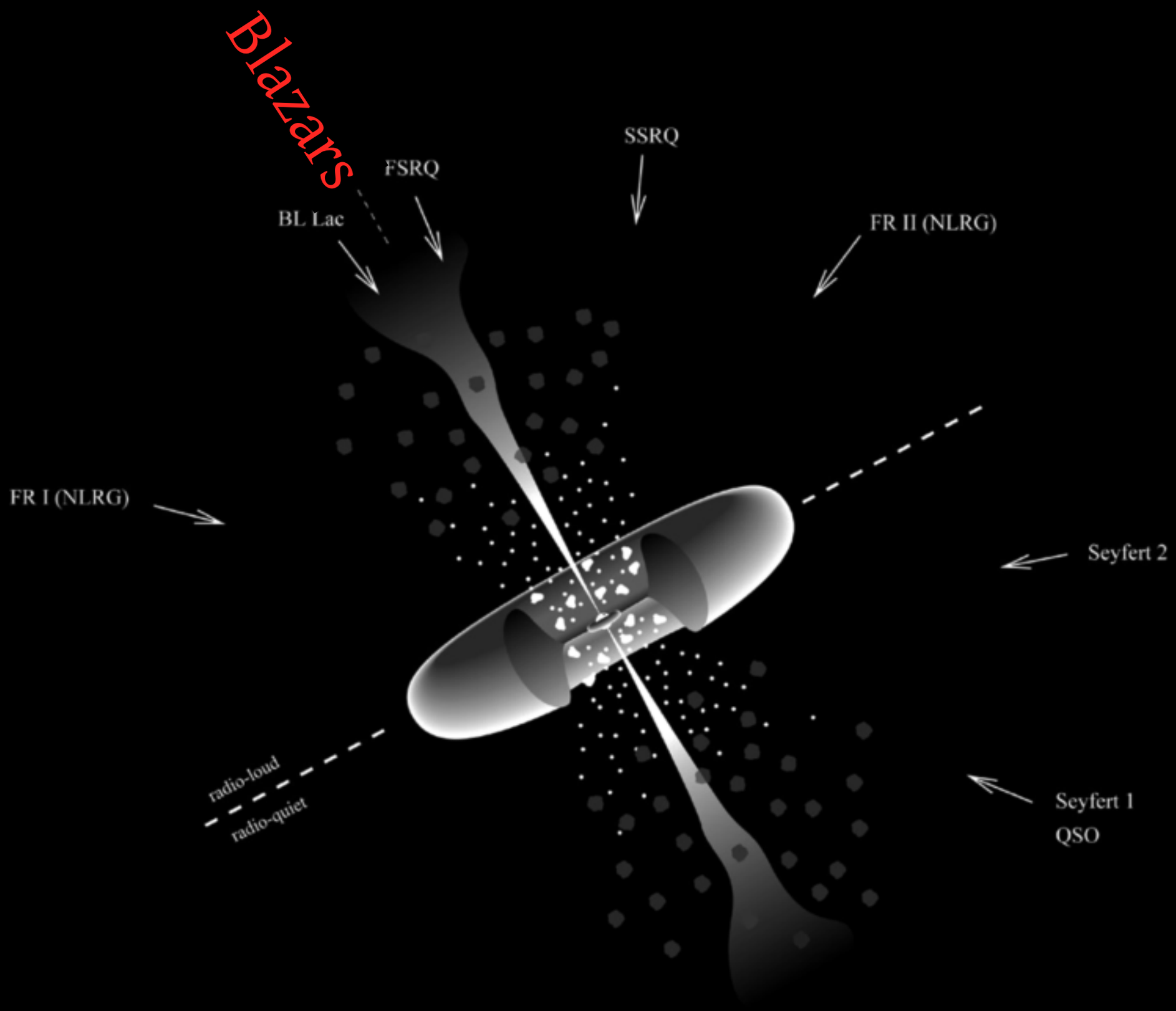
Abazajian et al. 2007
Hickox & Markevitch 2007

The Observed Fermi-LAT Gamma-Ray Sky

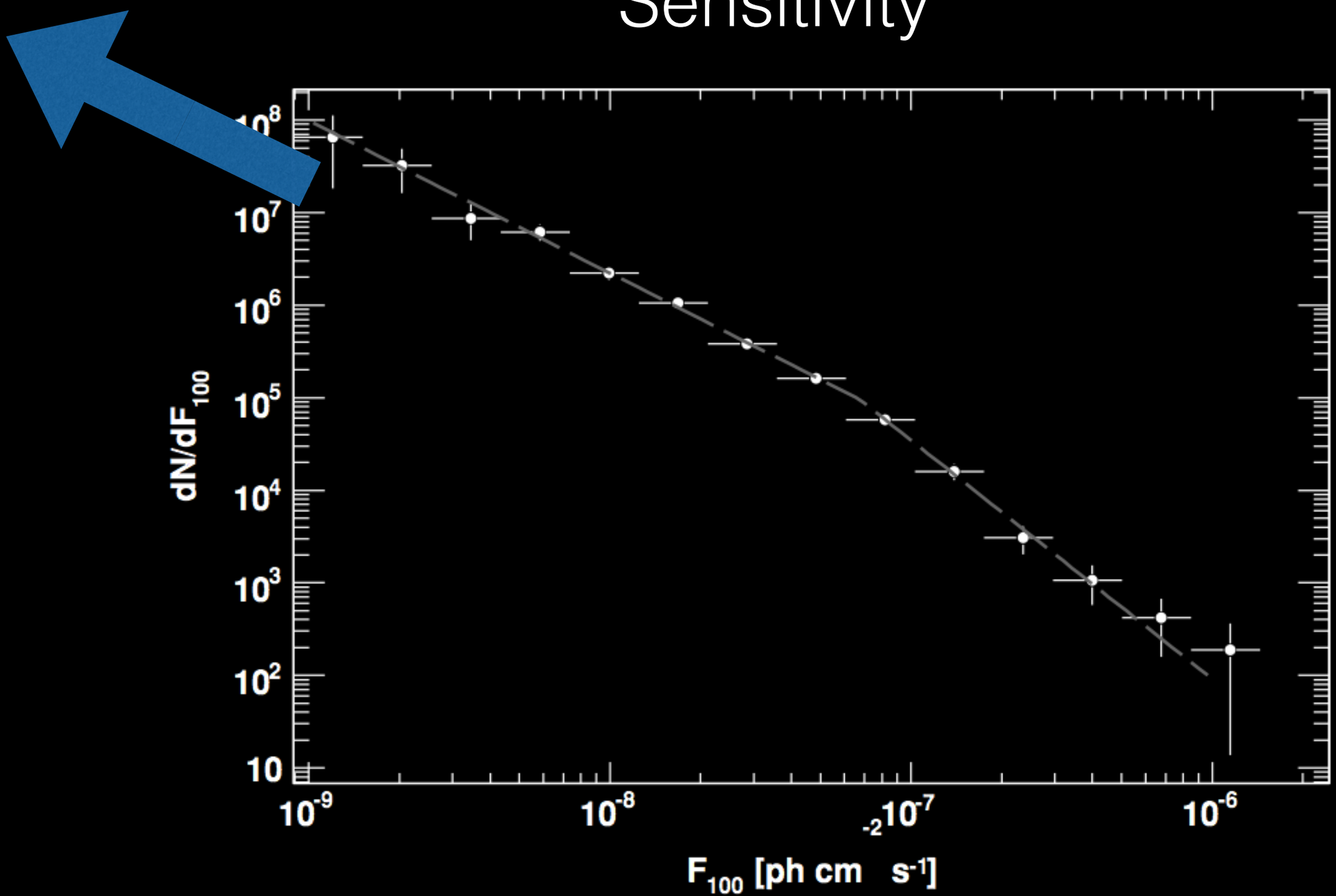


~15% of extragalactic flux had been found to be from resolved blazars

Blazars in the Unified Model of AGN



Simplest Model: Integrate Extrapolations of Source Counts Below the Point Source Sensitivity



Difficulties in Source-Count Extrapolation

- Require a fixed spectrum of all blazars are of their average: often, a power law of two types (BL Lac & FSRQ) with a Gaussian dispersion

- Extrapolated source count distribution is characterized the entire source population of blazars as a broken power-law, which is not necessary nor consistent with population models

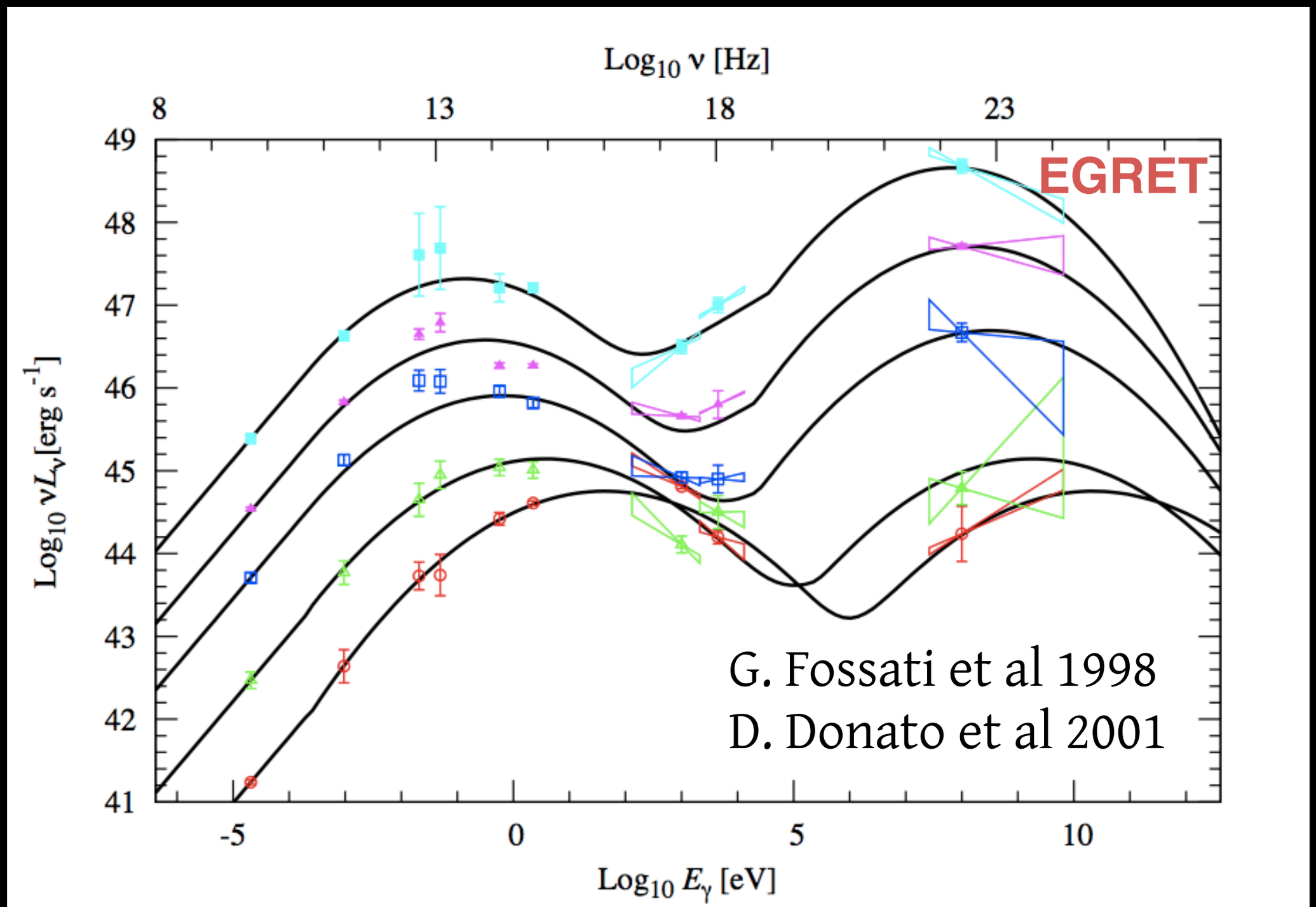
$$\frac{dN}{dSd\Gamma} = f(S) \cdot g(\Gamma)$$

source count as broken power-law ↑ ↑ spectrum as power-law w/ Gaussian distribution

- *Therefore, the DGRB flux calculated from such methods is problematic*

$$F_{\rm diffuse} = \int_{S_{\rm min}}^{S_{\rm max}} dS \int_{\Gamma_{\rm min}}^{\Gamma_{\rm max}} d\Gamma \frac{dN}{dSd\Gamma} S \left(1 - \frac{\Omega(\Gamma, S)}{\Omega_{\rm max}}\right)$$

Blazar SED is Dependent on Luminosity I: c. 2000



Shape of Blazar SEDs: Abdo et al arXiv:0912.2040
Inconsistent with a single-power law model (even with dispersion)

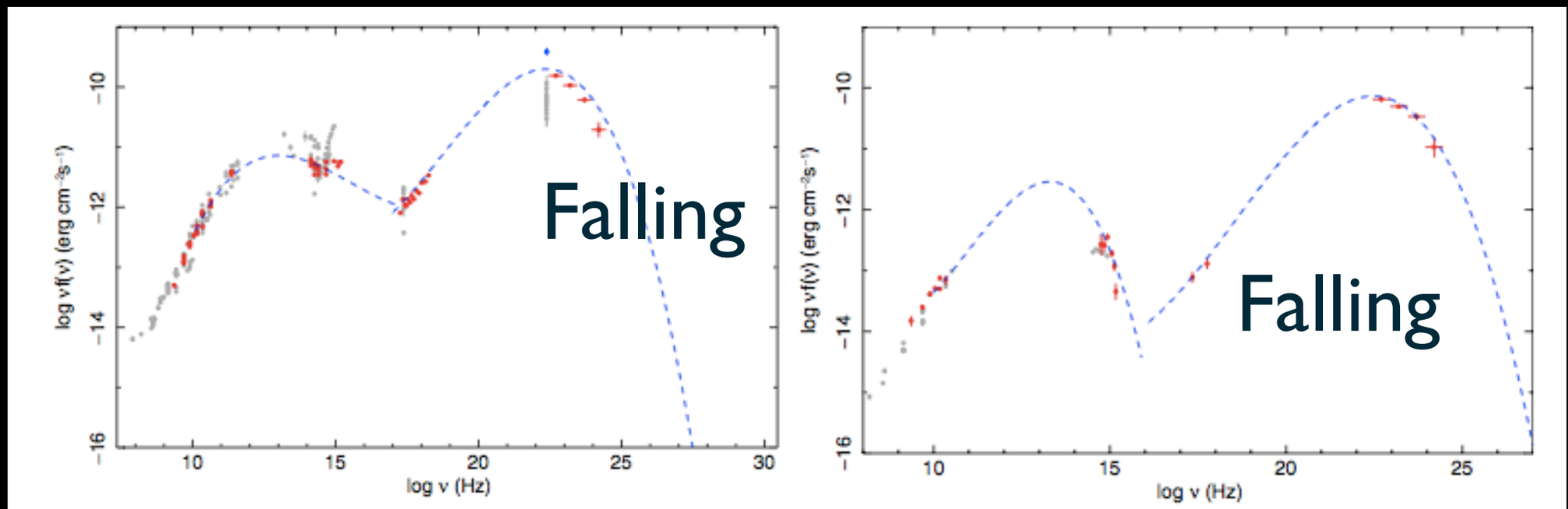
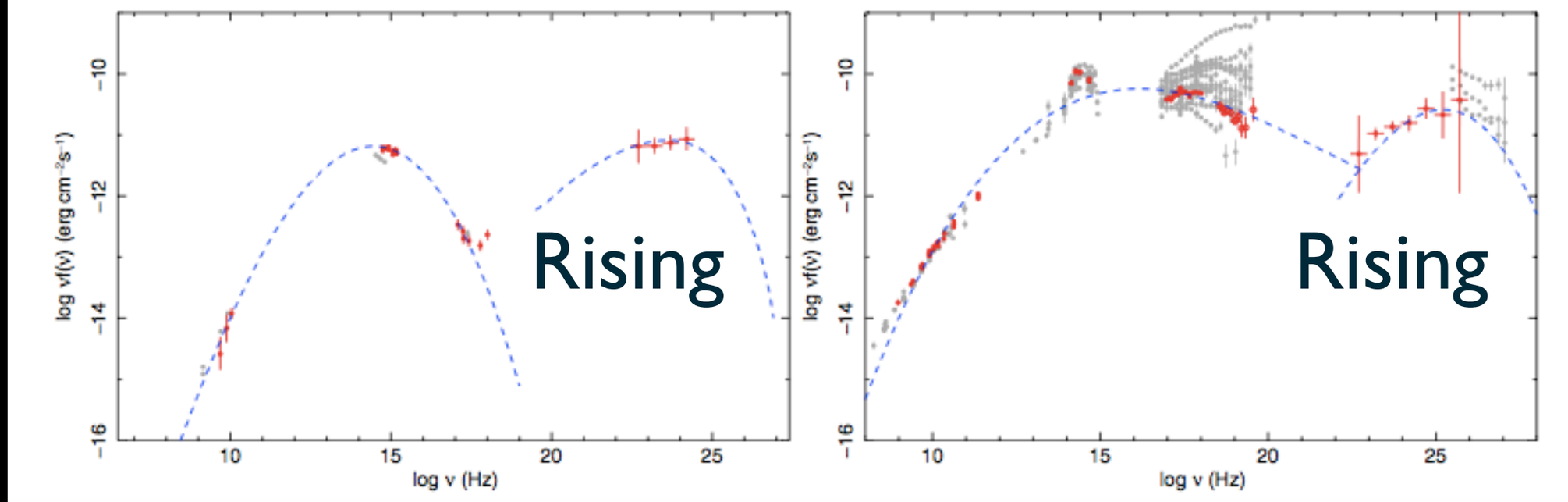
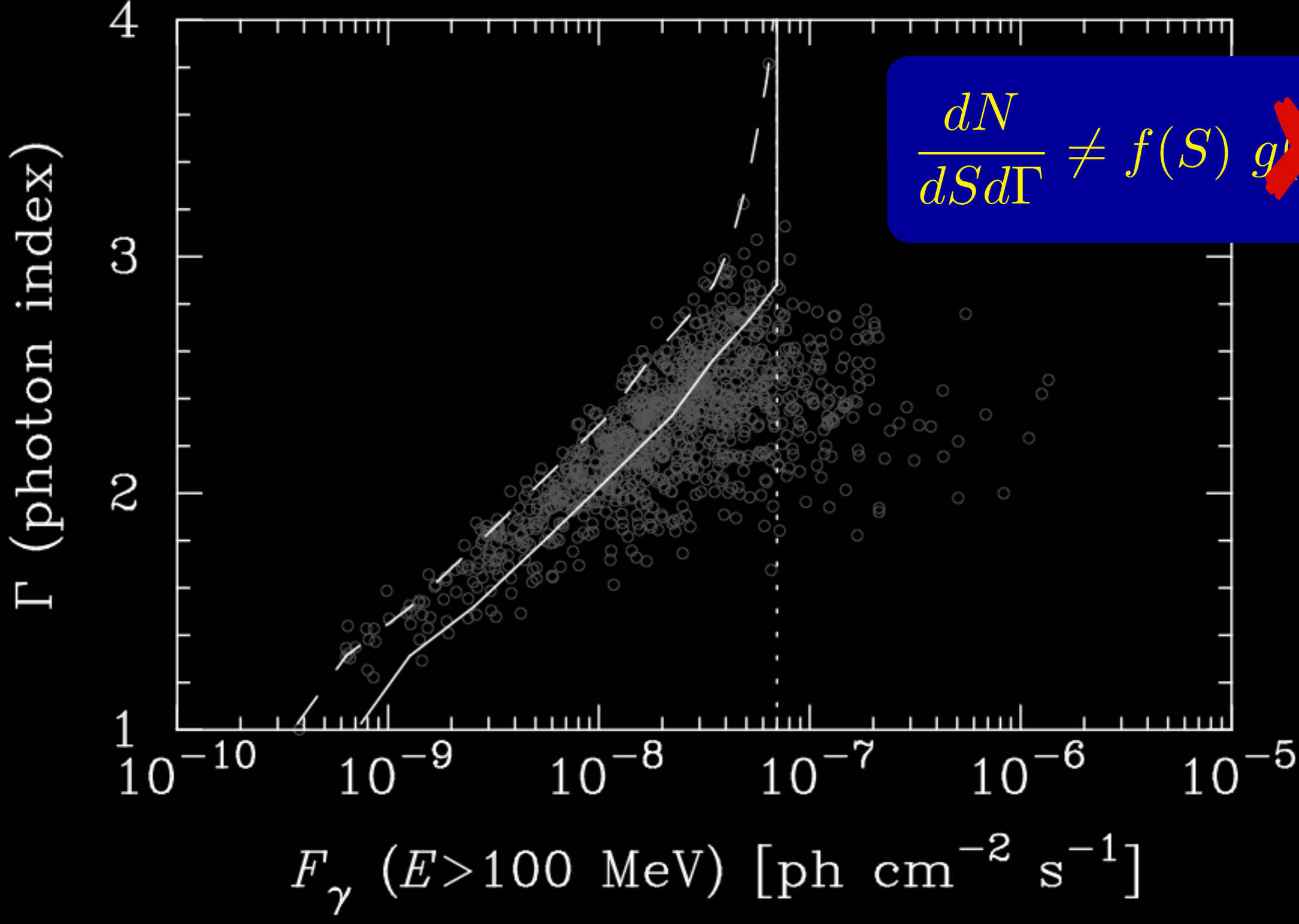


Figure 18. SED of 0FGL J1512.7−0905 = PKS 1510-089 (left) and of 0FGL J1522.2+3143 = B2 1520+31 (right).
(A color version of this figure is available in the online journal.)



Blazar SED Dependence on Luminosity: Fermi-LAT Data

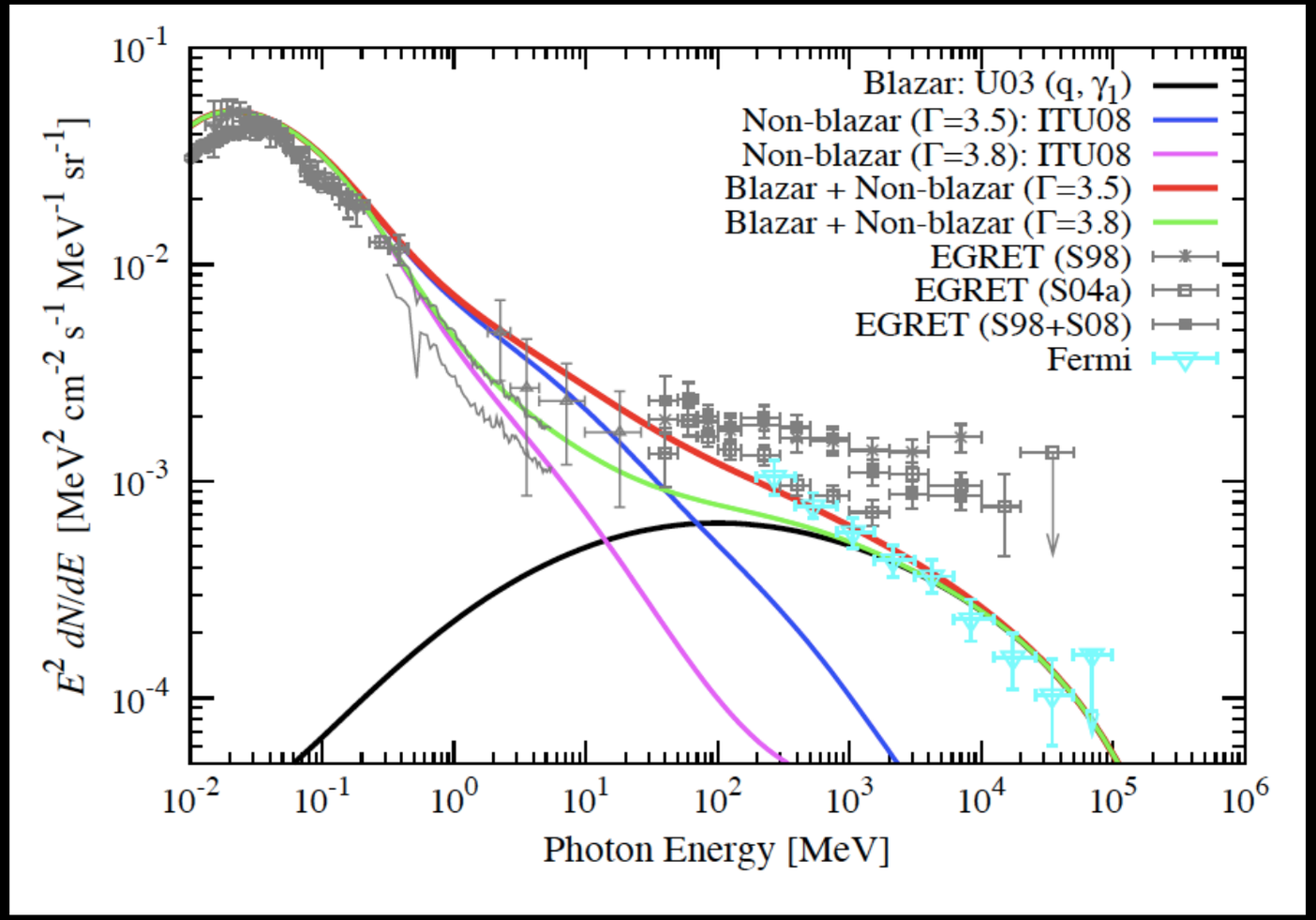


$$\frac{dN}{dS\,d\Gamma} \neq f(S)\ g(\Gamma)$$

Tying the emission with the known X-ray population of AGN: the evolution of the blazar γ-ray luminosity function

$$\frac{dN}{dE_\gamma dA dt d\Omega} = \frac{c}{4\pi}\int_0^{z_{\rm max}} dz \frac{dt_{\rm com}}{dz} e^{-\tau(z,E_\gamma)} \times \int_{L_{\gamma,\rm min}}^{L_\gamma^{\rm lim}(F_\gamma,z)} dL_\gamma \rho_\gamma(L_\gamma,z)\frac{1+z}{h} \times \frac{L_\nu[E_\gamma(1+z)/h, P(L_\gamma)]}{E_\gamma(1+z)}.$$

Inoue & Totani (2008) *predicted* the observed Fermi-LAT DGRB



SED Sequence + GLF(z) Model

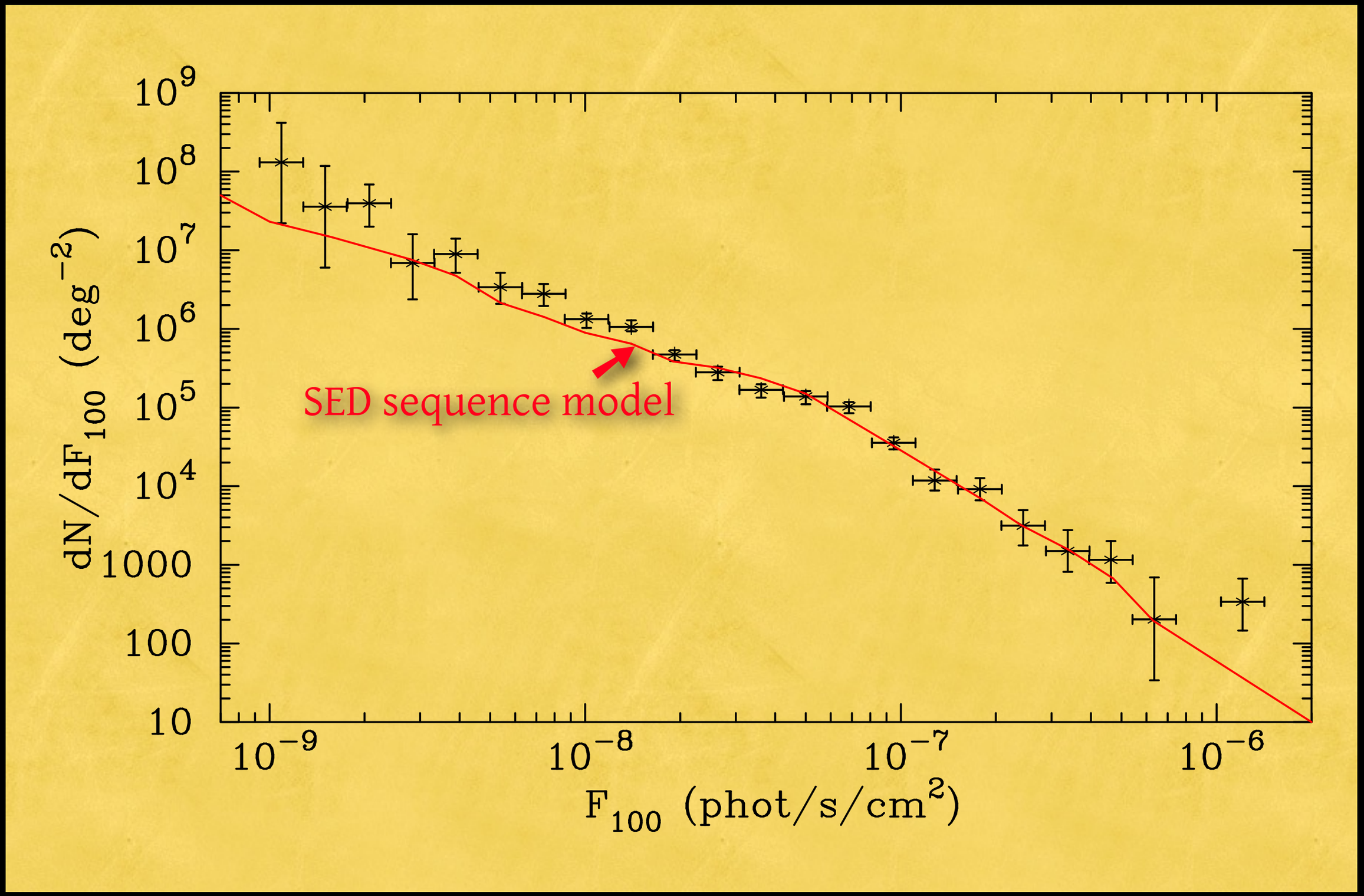
K.A., S. Blanchet, J. P. Harding arXiv:1012.1247

- Blazar population gamma-ray luminosity function (GLF) is dictated as a fraction of X-ray AGN population (XLF)
- DGRB Includes a contribution from non-blazar AGN at low energies (< 200 MeV)
- Three parameter model:
  - γ_1, the faint-end index of the GLF
  - κ, the normalization ratio of blazar GLF to AGN XLF (fraction of AGN as blazars)
  - q, scale of the blazar jet emission to disk X-ray luminosity
- We constrain this model with the observed Fermi-LAT DGRB spectrum and blazar flux source count distribution dN/dF

Results: Resolution of the DGRB?

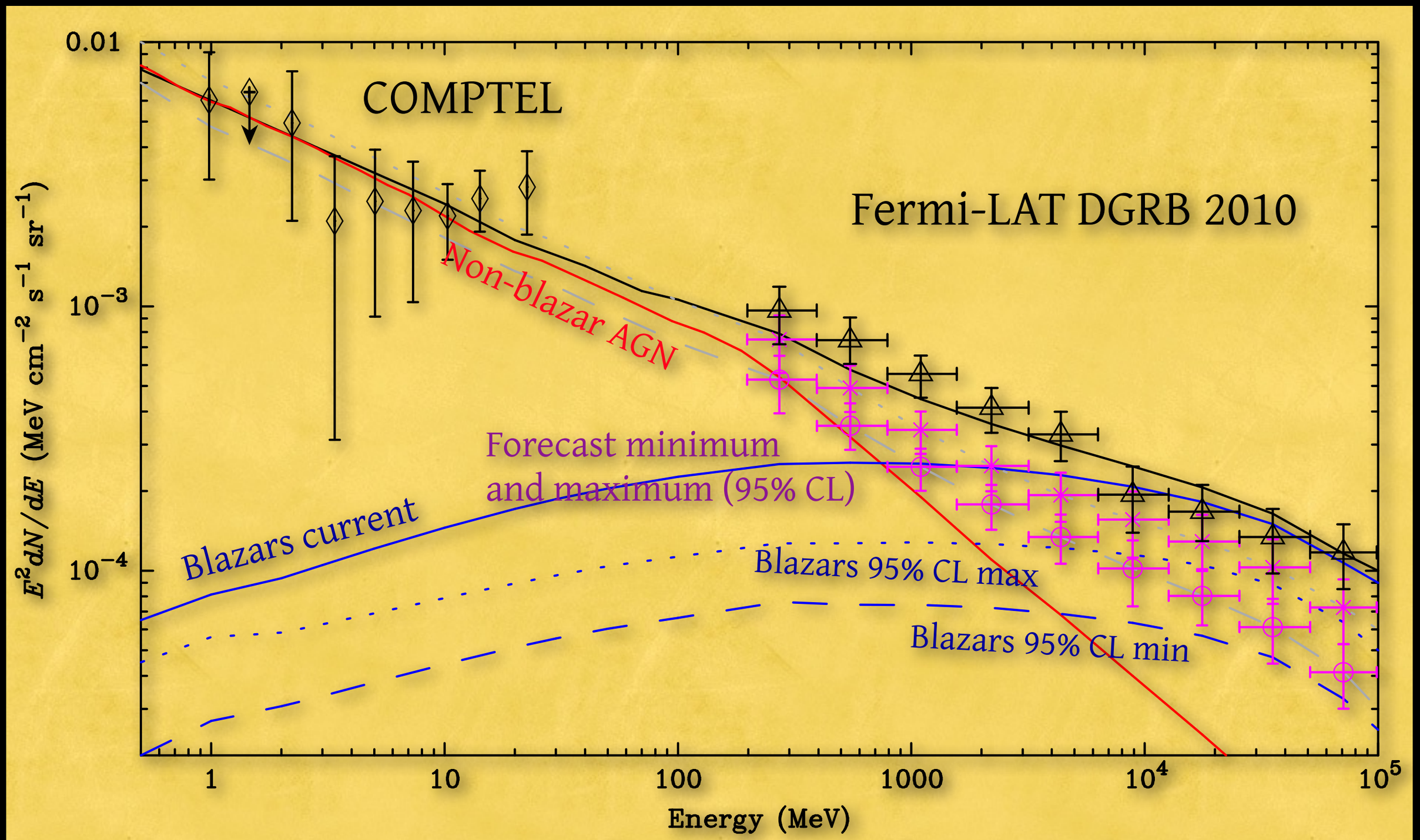
- The Blazar SED sequence LDDE model successfully matches the DGRB as originating from blazars and dN/dF
- > 95% of all blazars will be resolved at the 5-year Fermi-LAT forecast point-source sensitivity of 2×10^{-9} photons cm^{-2} s^{-2}
- Flux in the DGRB will decrease by a factor of 2-3 (95% CL) with the 5 year sensitivity

And Match to the Source Count Distribution



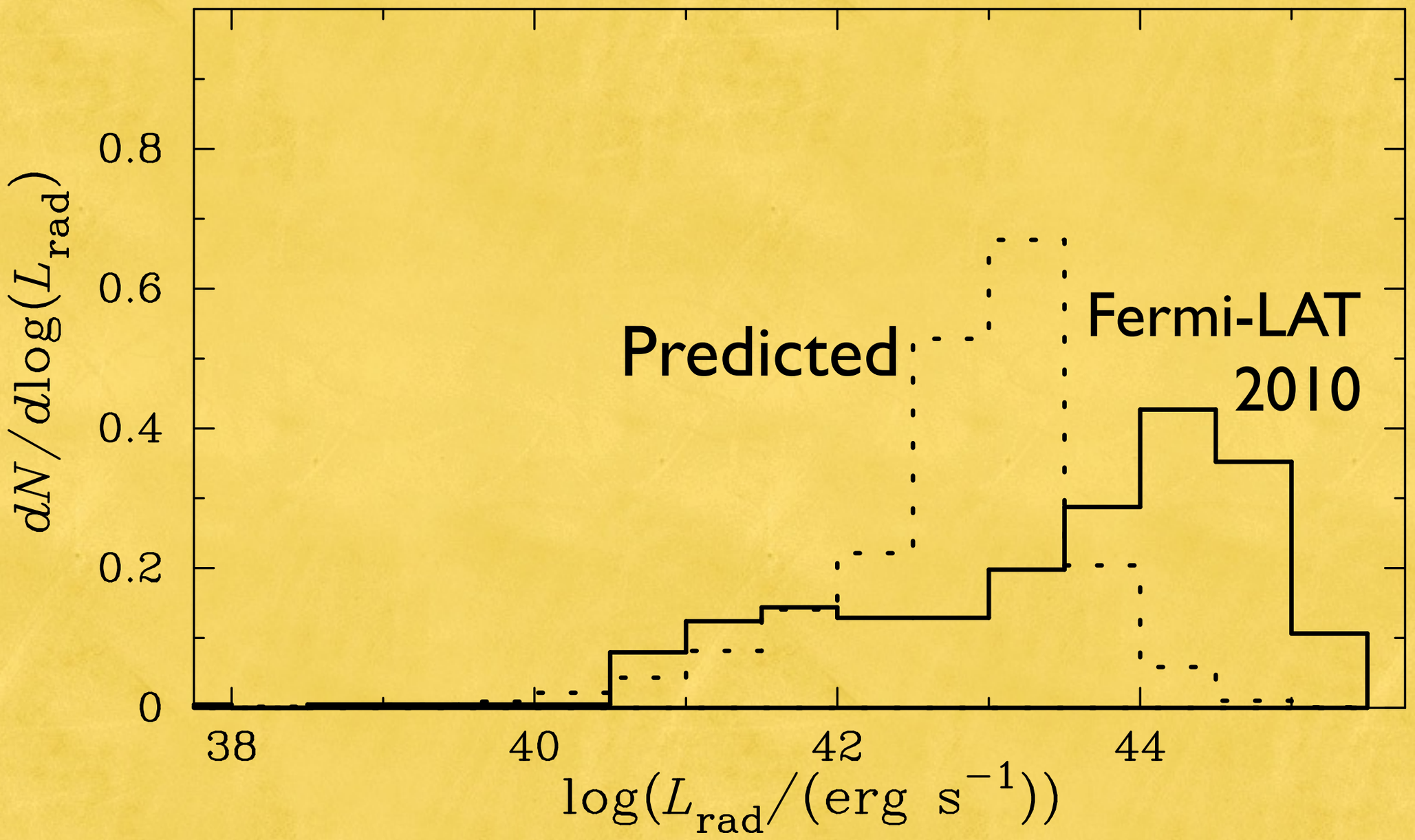
Abazajian, Blanchet & Harding 2011

Fits & Forecasts for Fermi-LAT's DGRB

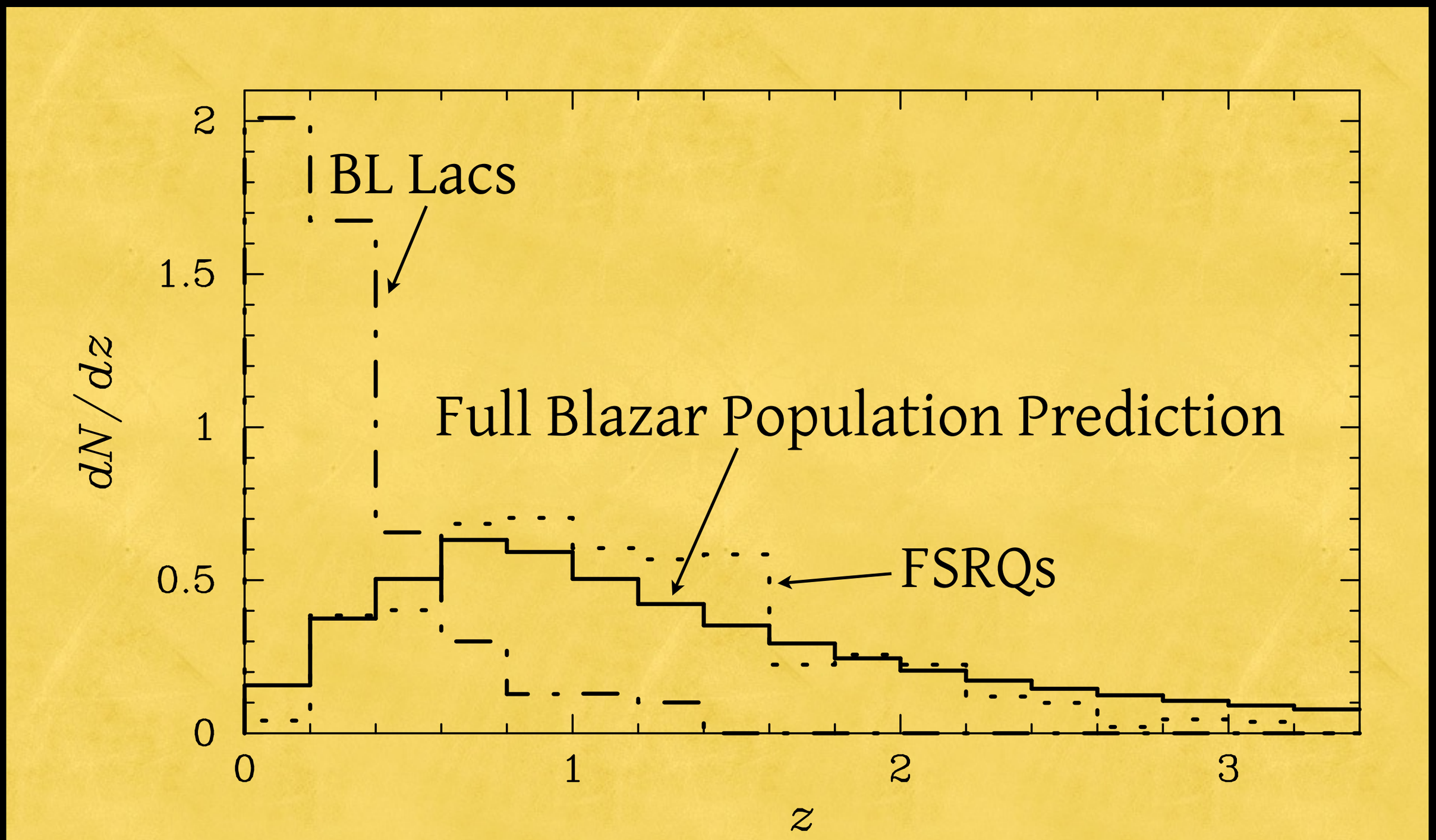


Abazajian, Blanchet & Harding, 1012.1247

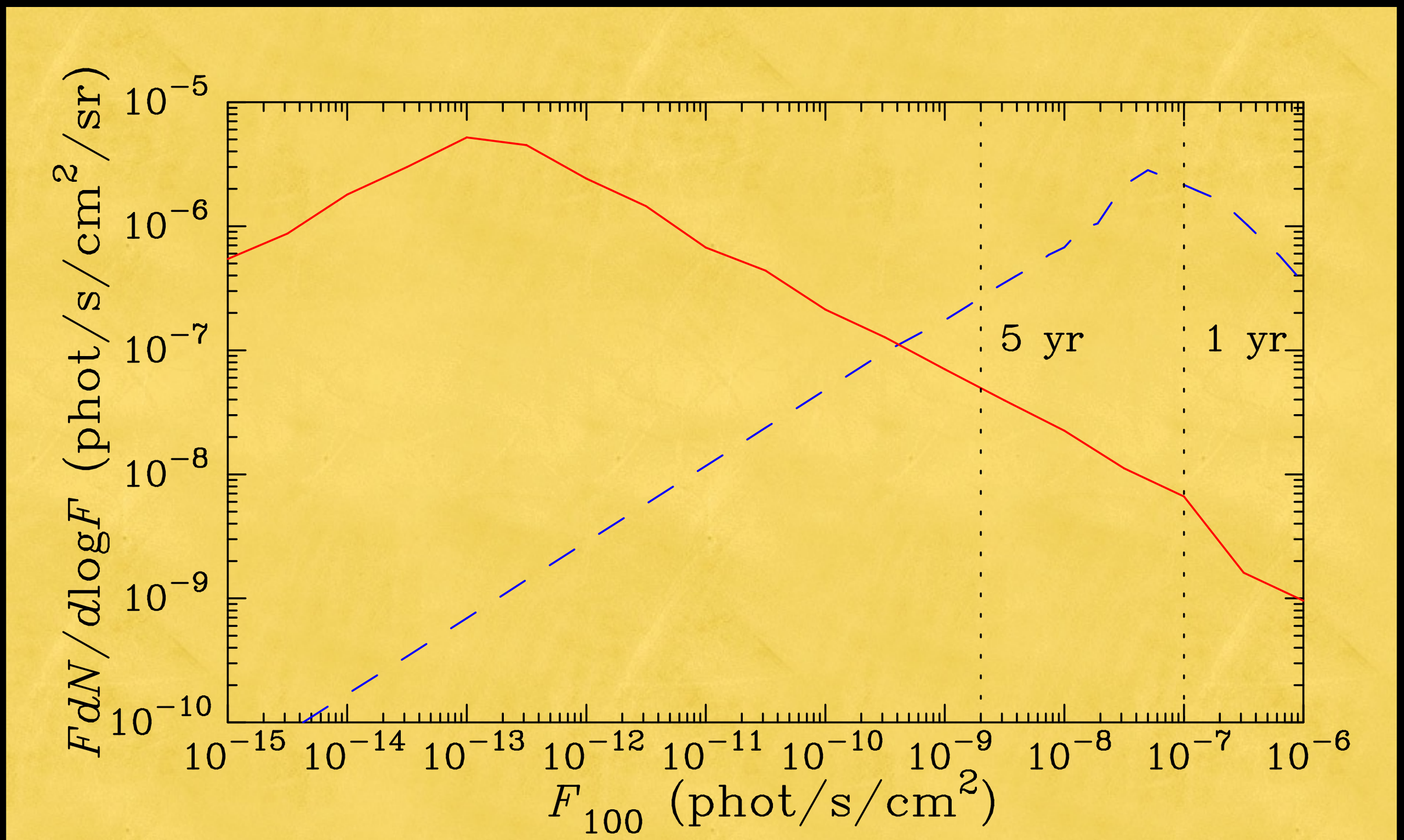
Luminosity Distribution of Blazars



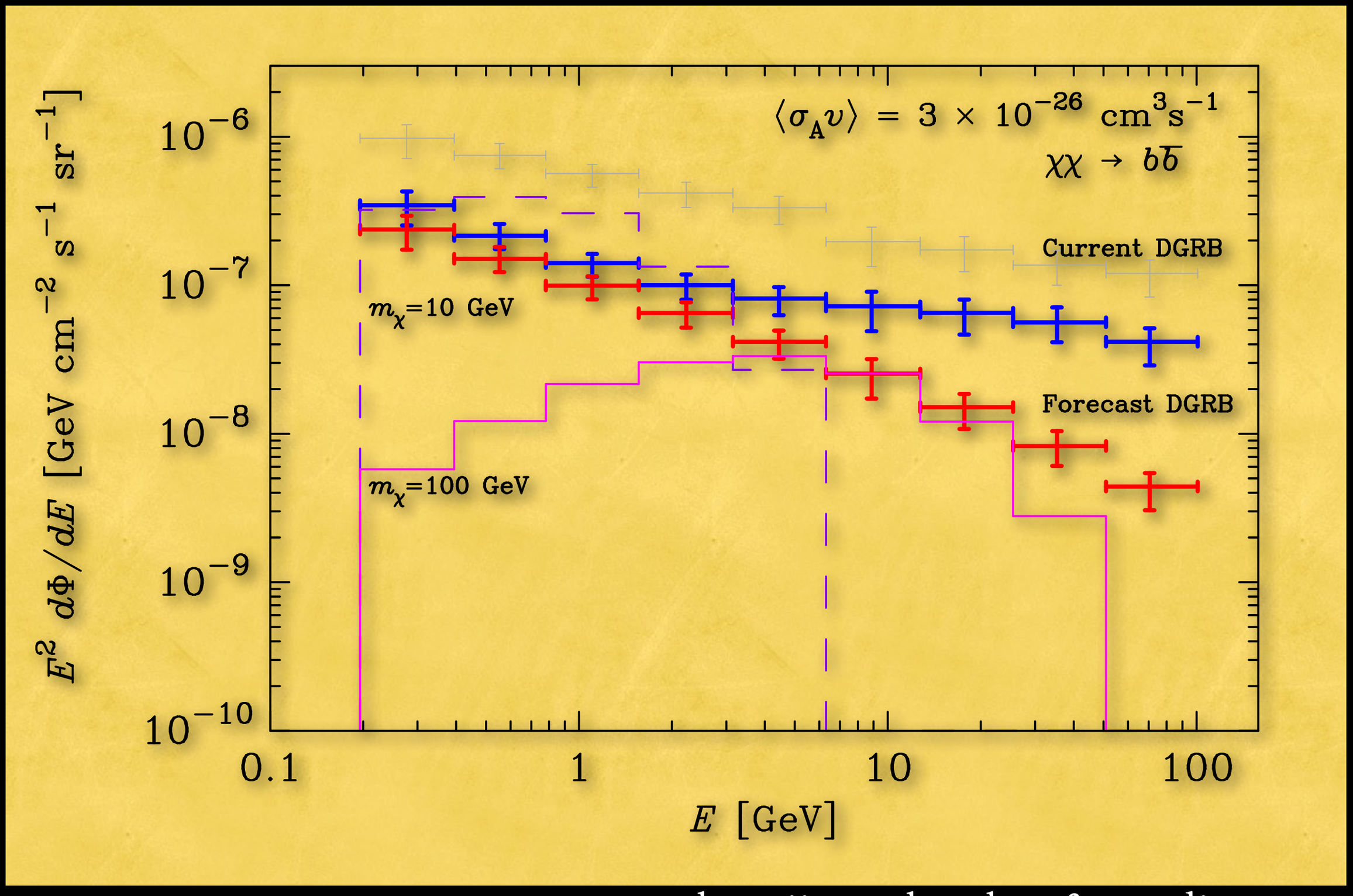
Redshift Distribution of Blazars



Flux Sensitivity Distribution

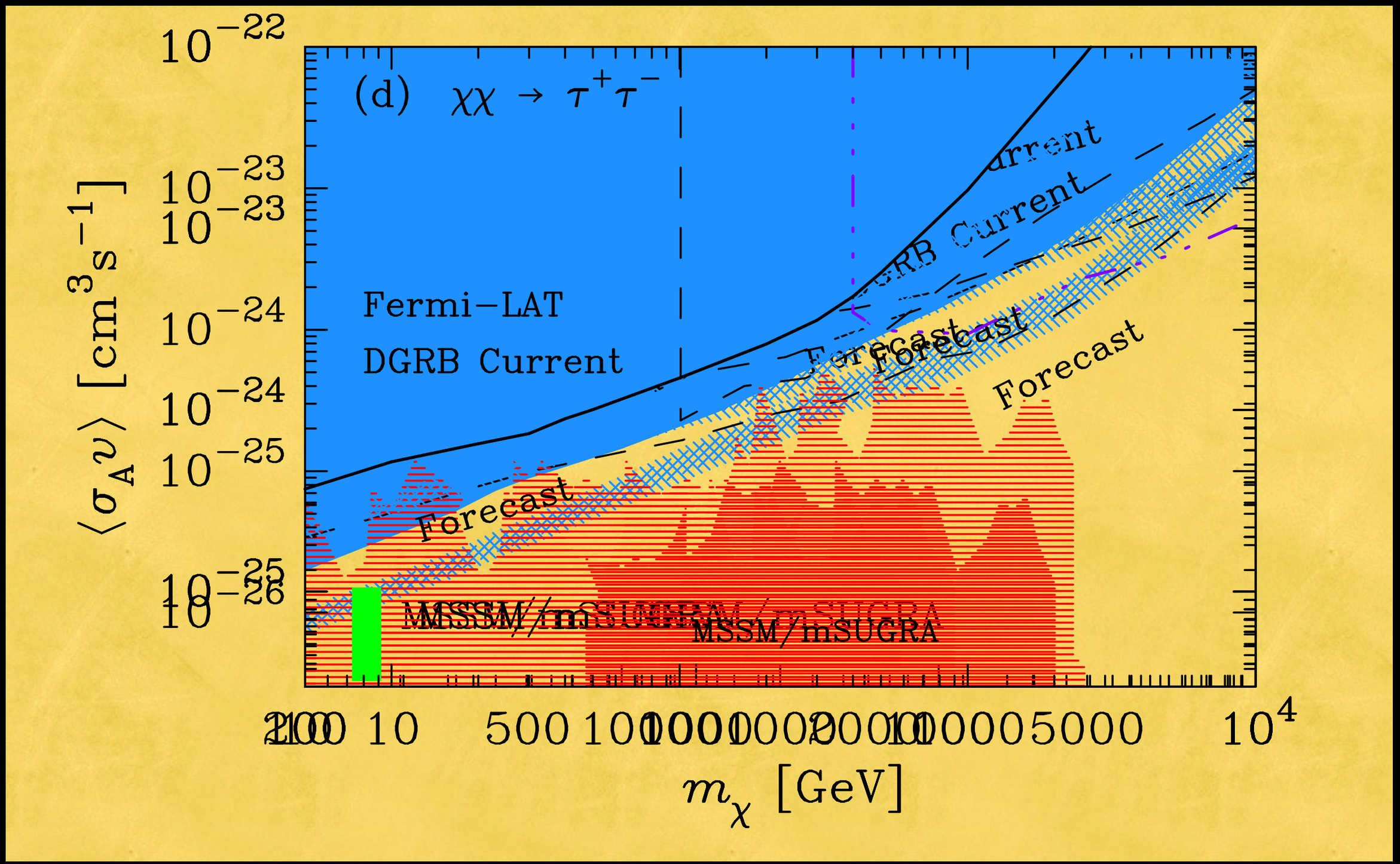


Dark Matter Search Implications



Abazajian, Blanchet & Harding 2010

Annihilation Channel Forecasts

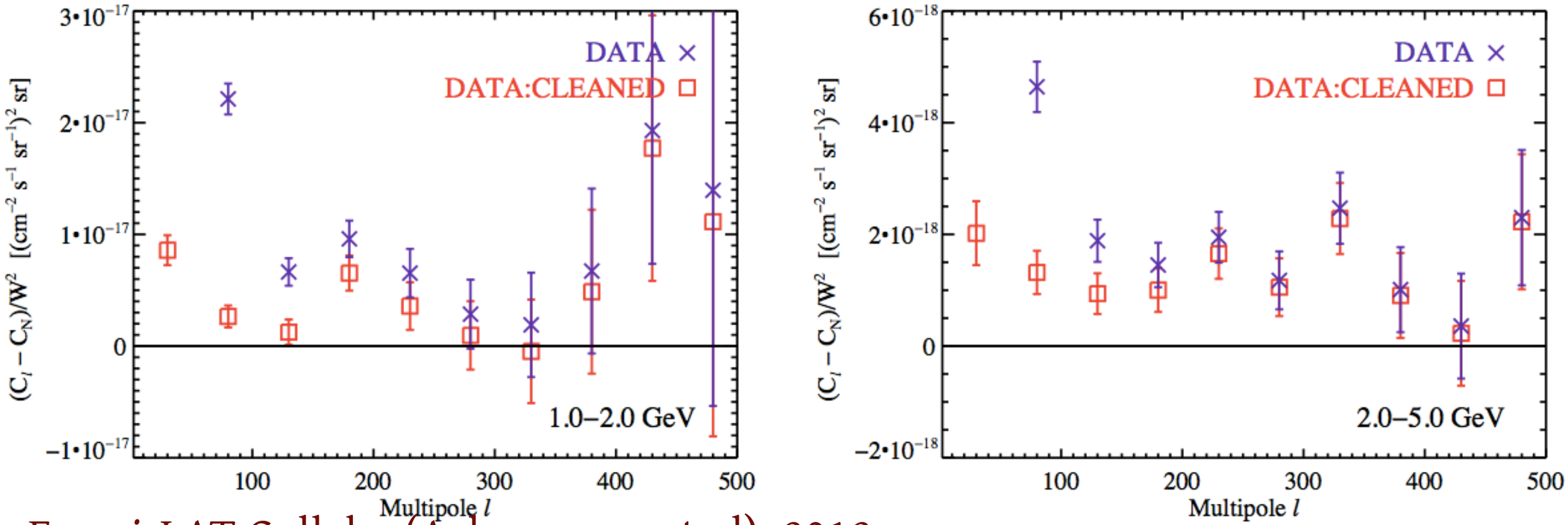


Abazajian, Blanchet & Harding 2010

Anisotropy in the "Isotropic" Diffuse γ-ray background

Fermi-LAT Collab. (Ackermann et al), 2012

Nonzero but small anisoptropy

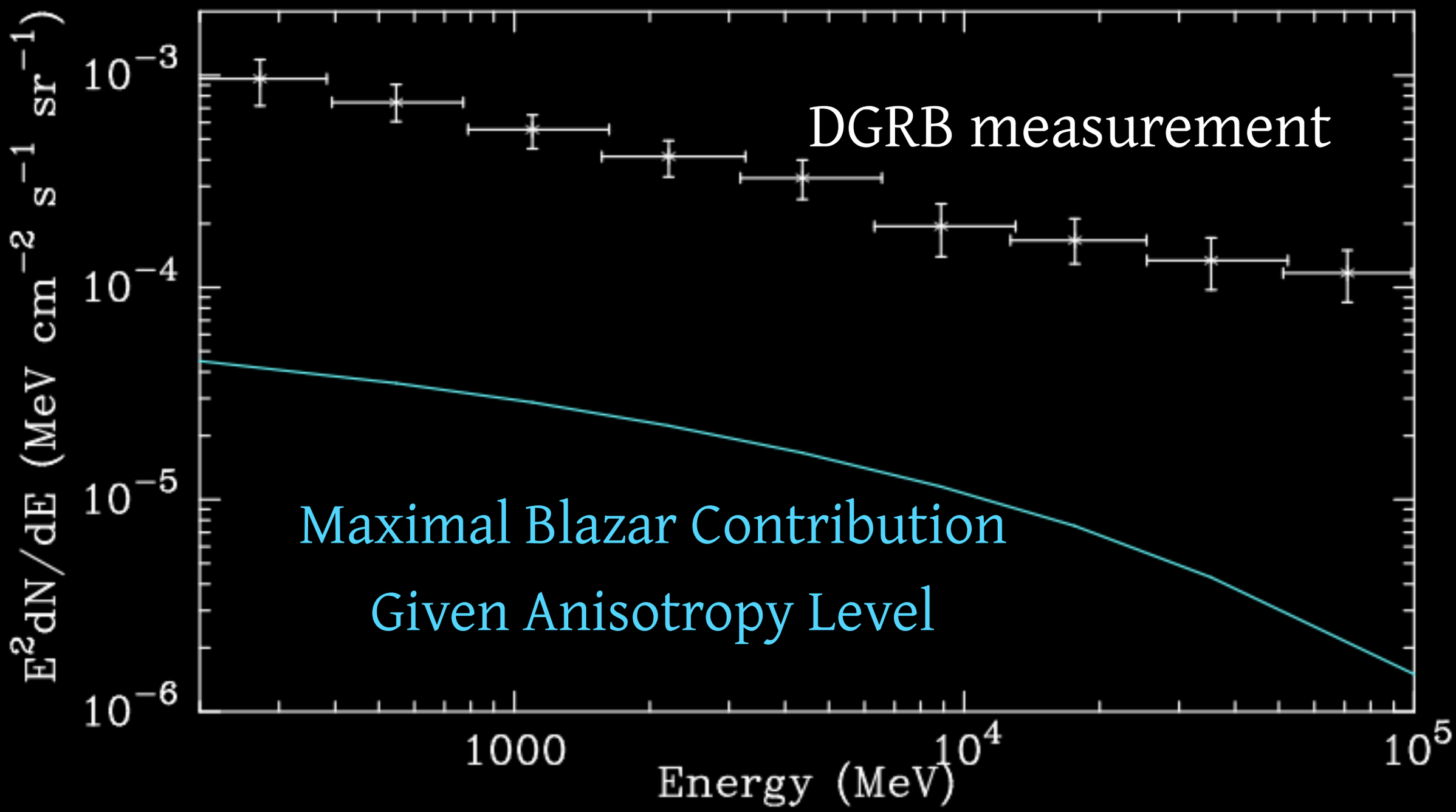


Fermi-LAT Collab. (Ackermann et al), 2012

Blazar SED + GLF(z) model prediction:

$$C_P = \int_0^{z_{\max}} dz \frac{d\chi}{dz} \int_{L_{\gamma,\min}}^{L_\gamma^{\lim}(F_\gamma,z)} dL_\gamma \frac{\rho_\gamma}{d_L^2} \left[\int_{(E_0^{\min})(1+z)/h}^{(E_0^{\max})(1+z)/h} \times \frac{d\nu}{\nu} \frac{L_\nu(\nu, P) \exp\left[-\tau\left(z, h\nu/(1+z)\right)\right]}{4\pi h} \right]^2$$

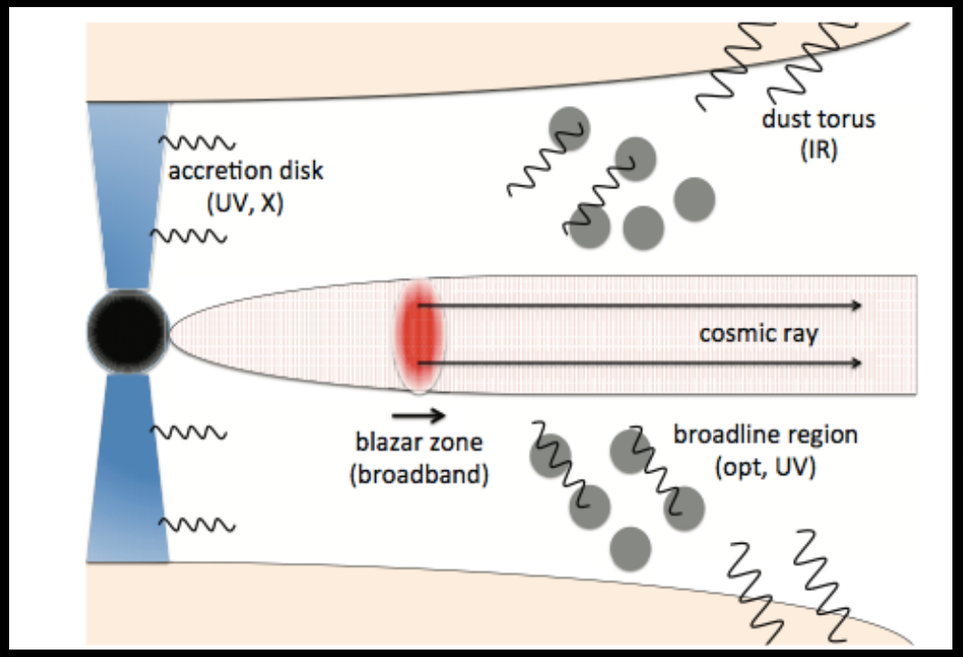
Diffuse γ-ray background from Blazars Limited by Anisotropy

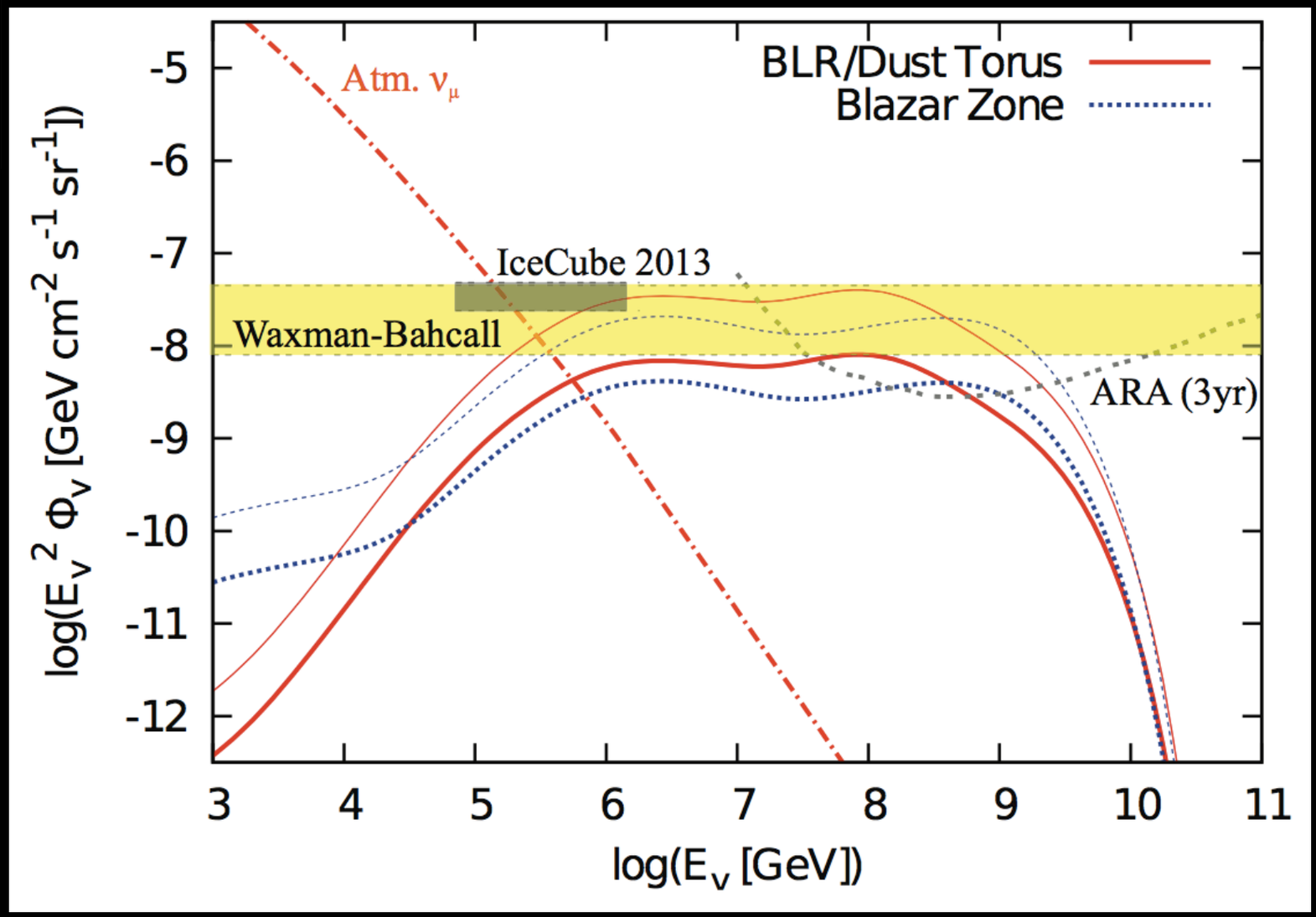


Harding & Abazajian, 2012

similar results using source count extrap: Cuoco, Siegal-Gaskins, Komatsu 2012

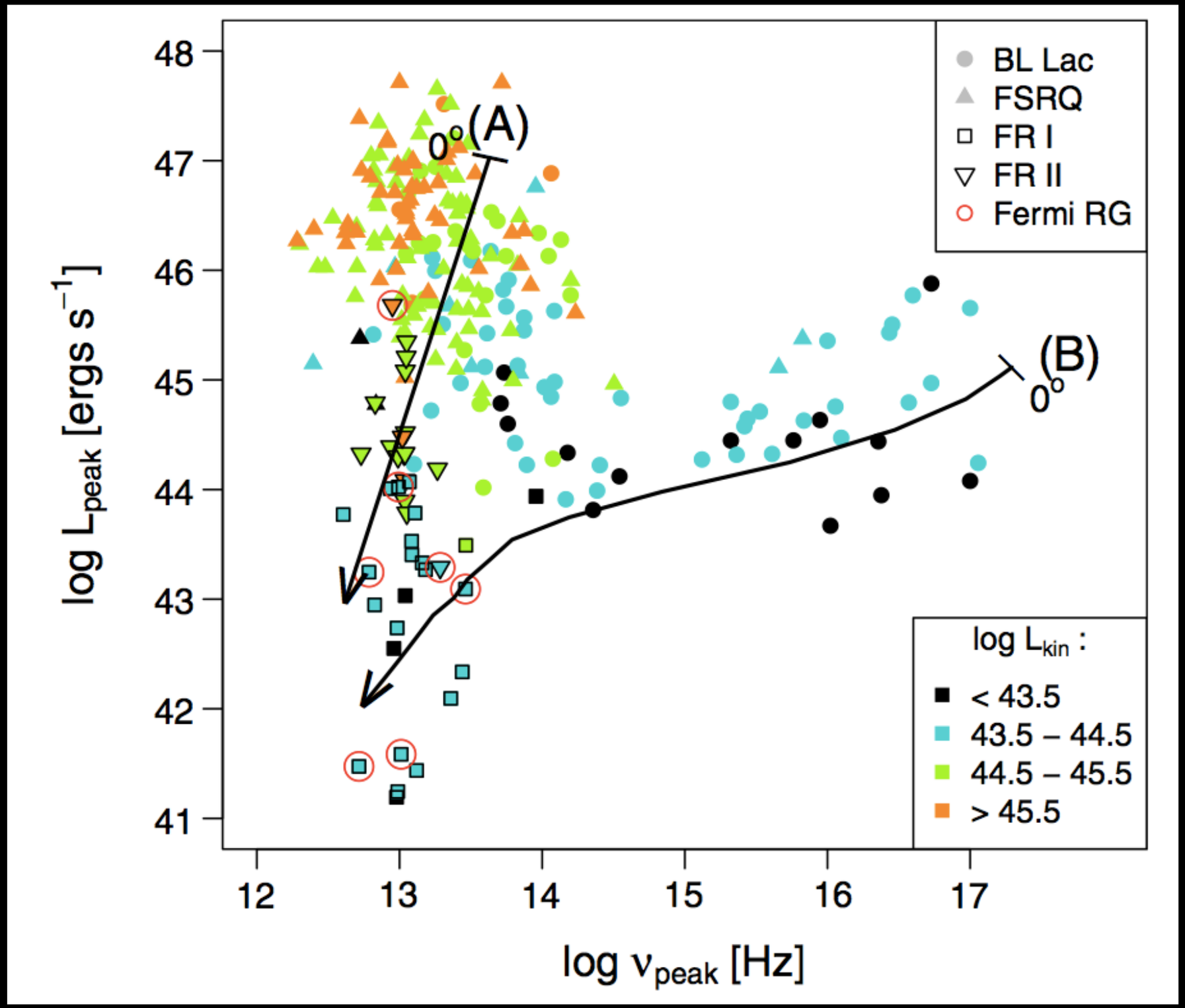
Further Applications of the GLF(z) + SED Sequence Model





Murase et al 2014

The GLF(z) + SED sequence is Far from Complete...



Meyer, Fossati et al 2011

Gamma-ray Spectra of Blazars: (Abdo et al ApJ 710:1271, 2010)

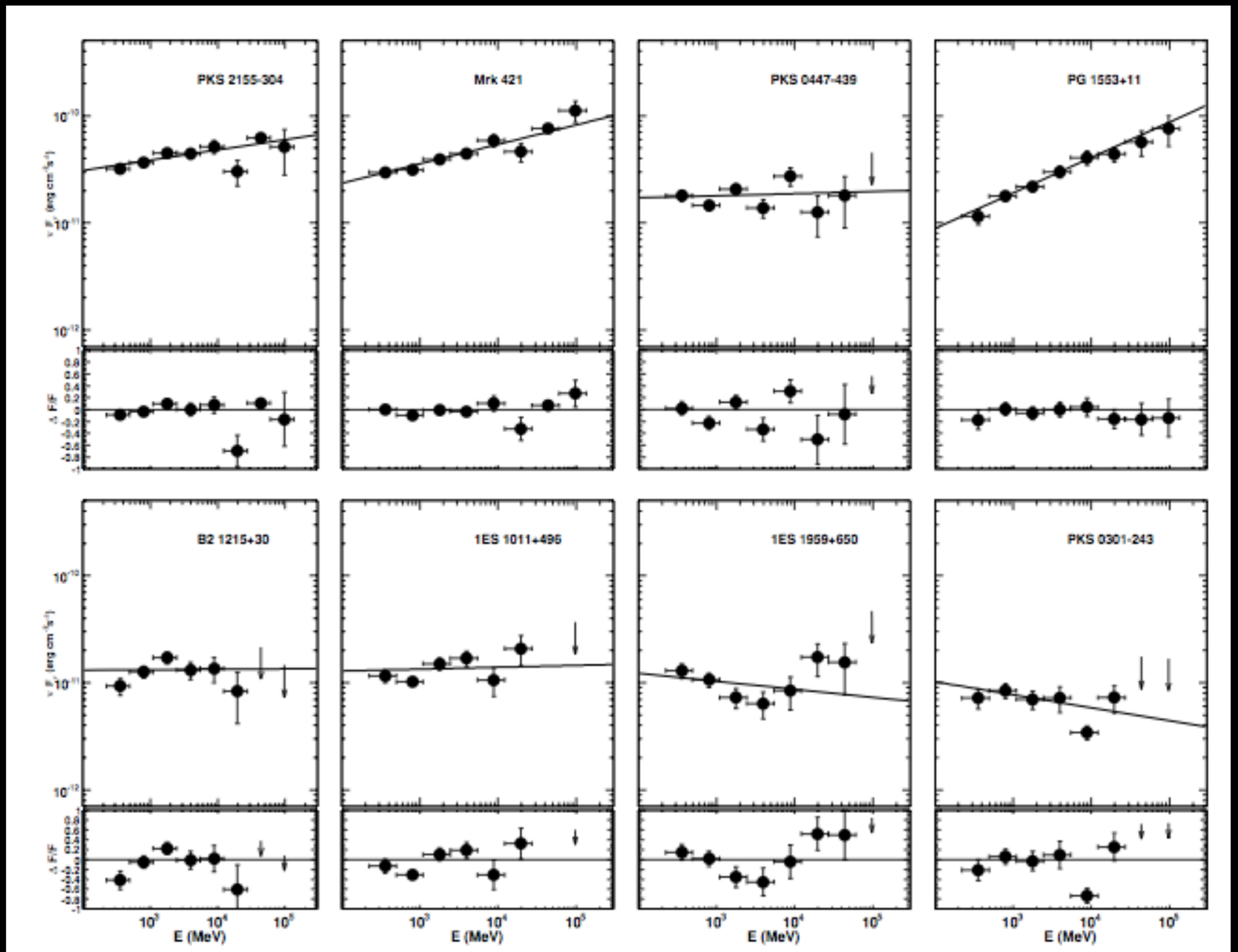
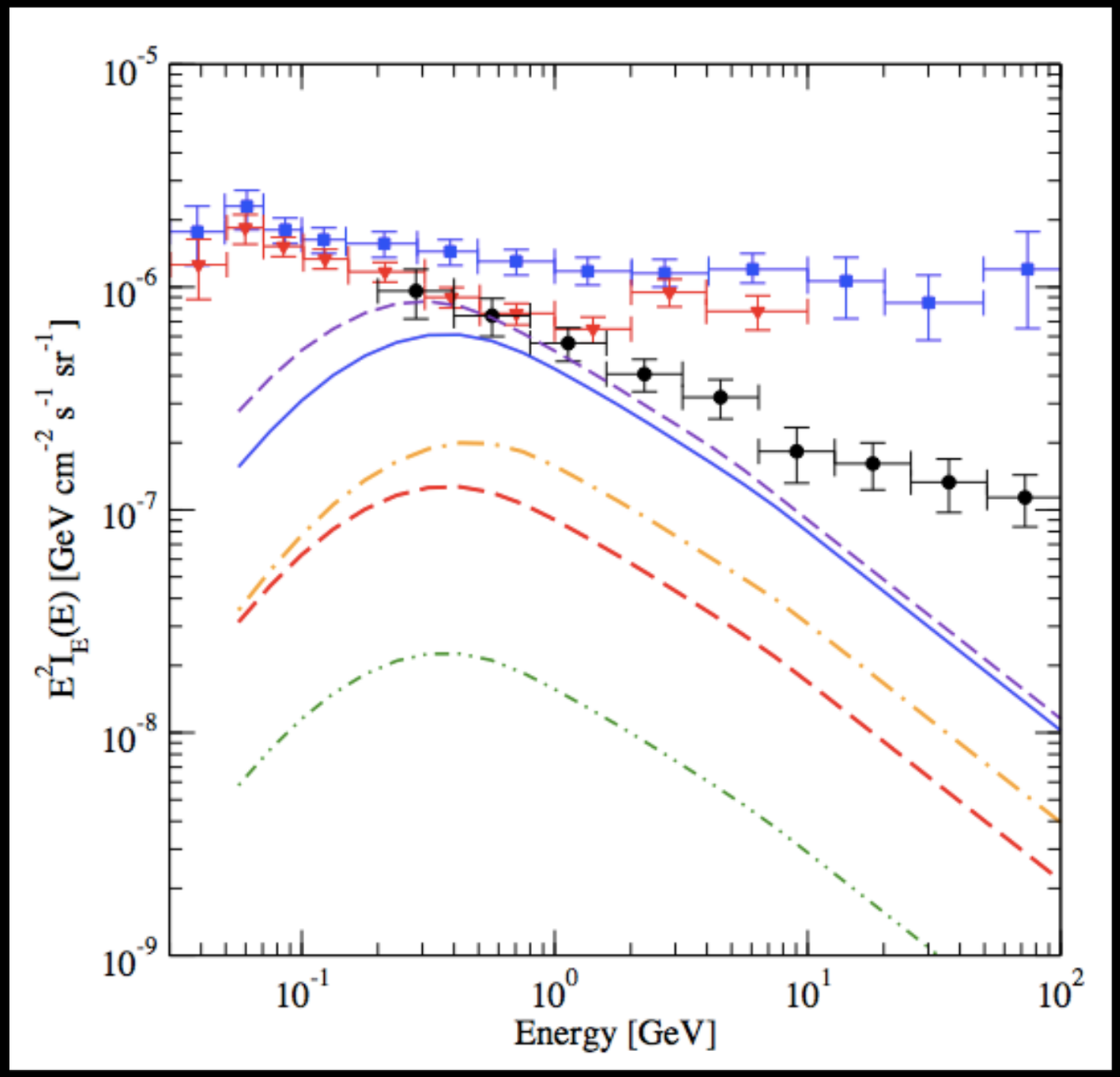


Figure 9. Same as Figure 6, but for the eight brightest HSP-BLLacs in the LBAS sample.

Summary

- Extrapolating source count distribution functions beyond point source thresholds is problematic...
- Cosmological evolution models with SED dependence on luminosity are physically well motivated.
- The *intensity* of the DGRB is *consistent* with being produced by blazars with an evolving SED sequence + GLF (z) model
- The *anisotropy* of the DGRB is *inconsistent* with being produced by blazars with an evolving SED sequence + GLF (z) model
- Resolution of the DGRB into blazars with further exposure in Fermi-LAT test evolution models for the blazar population, their GLF(z)
- The blazar SED sequence plus GLF(z) is a very rich model compared to source count extrapolation models yet remains quite simplistic: the dependence of spectrum on luminosity is not singularly parametric (e.g., Meyer & Fossati 2011)

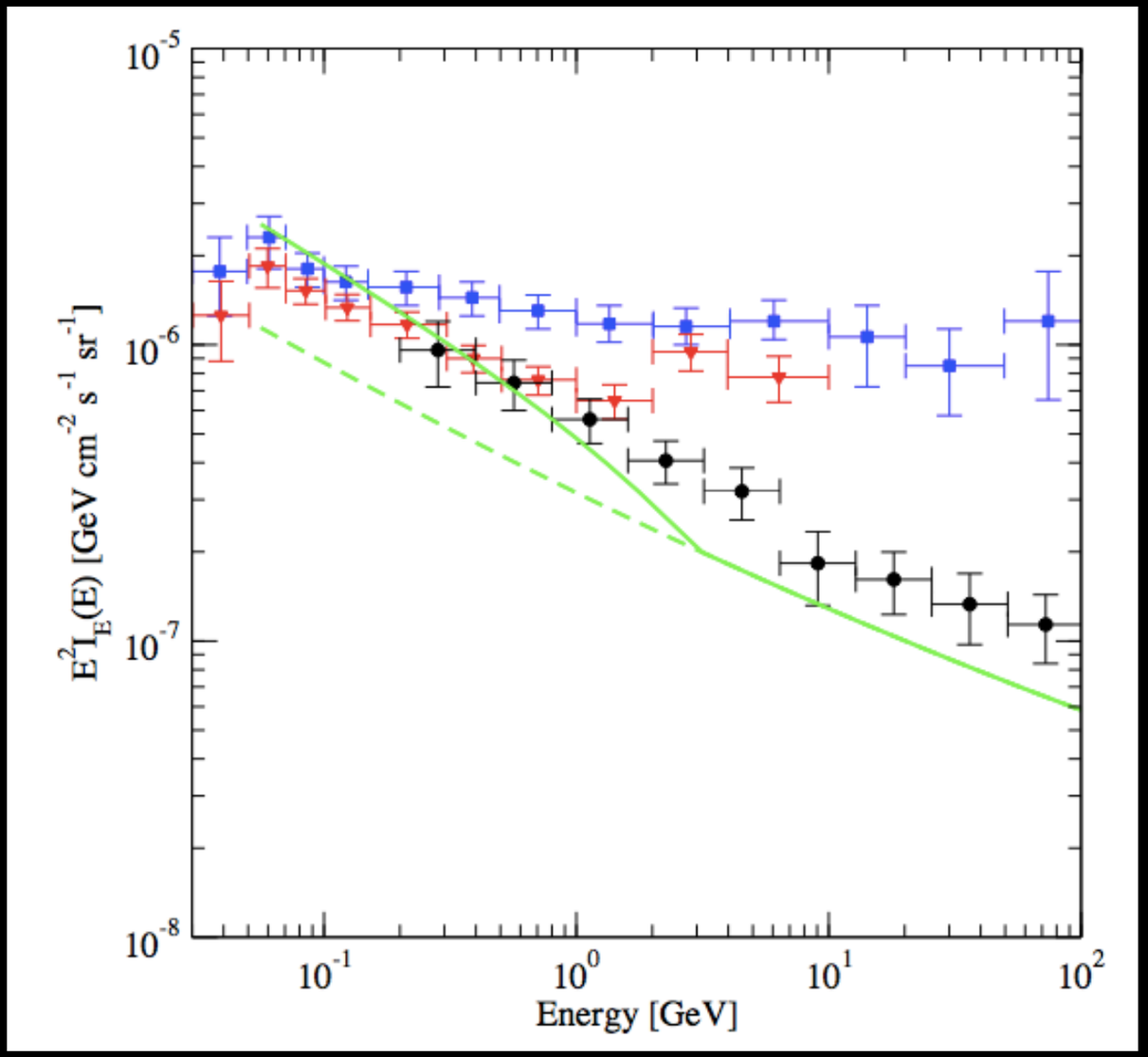
DGRB from Star Forming Galaxies?



- Potentially matches a portion of the DGRB at low energies as seen by Fermi-LAT for models at the edge of the star forming galaxy predictions (Fields et al. 2010)
- Mikaya et al. (2010) find a contribution of likely 4% to 7% of the DGRB from star forming galaxies
- Stecker & Venter (2010) showed that the spectrum generally underpredicts the DGRB, and does not match the shape measured by EGRET at low energy

Stecker & Venter 2010

A Different Model for the Blazars as the DGRB?



- Stecker & Venter (2010) used a different model, correlating the gamma-ray luminosity to the radio luminosity for the FSRQs and ignoring the BL-Lac contribution
- SV 10 also used a power-law spectral distribution that omitted spectral curvature in the spectrum and the hardness-luminosity relation seen in the Blazar SED sequence