# *The Contribution of Astrophysical Sources to the Extragalactic $\gamma$-ray Background*

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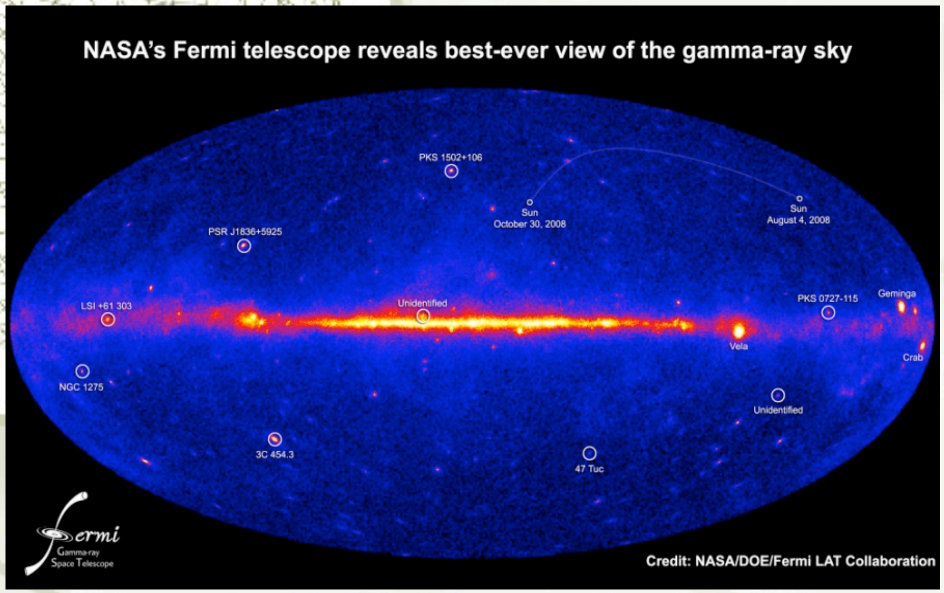
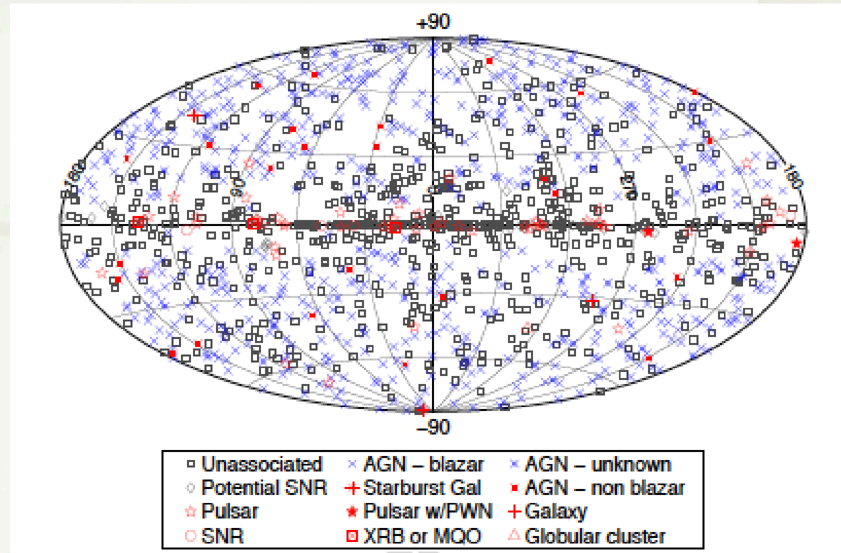
*Based on work in collaboration with F. W. Stecker - arXiv:1012.3678

# *The Gamma-ray Sky ala Fermi LAT*

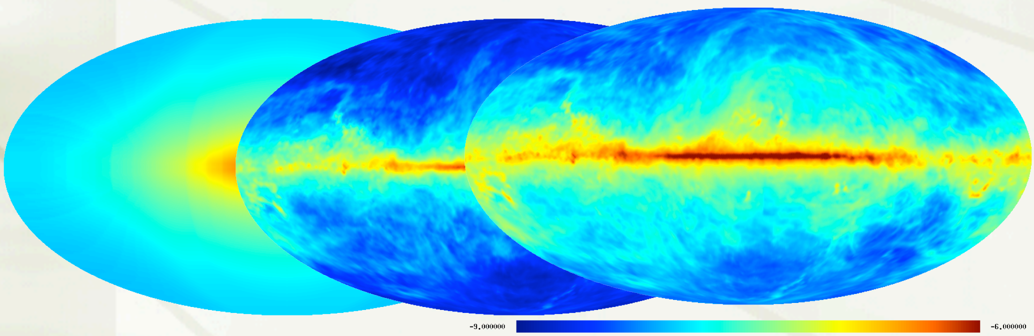



**Resolved Point Sources**




Inverse Compton

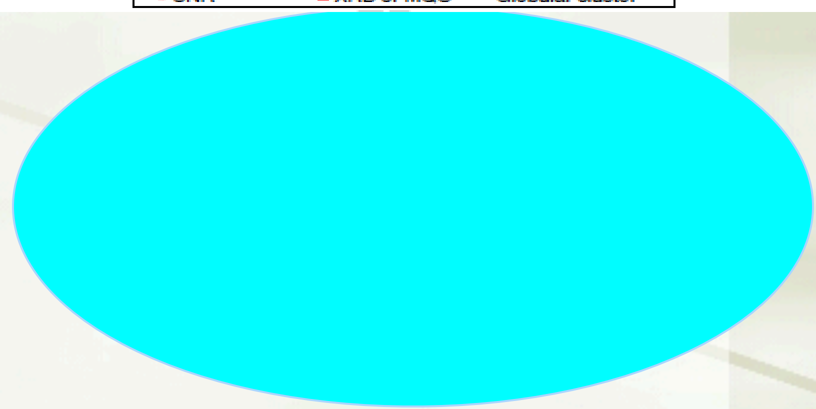
$\pi^0$-decay



Bremsstrahlung

**Galactic diffuse emission**

(CR interactions with the interstellar medium)

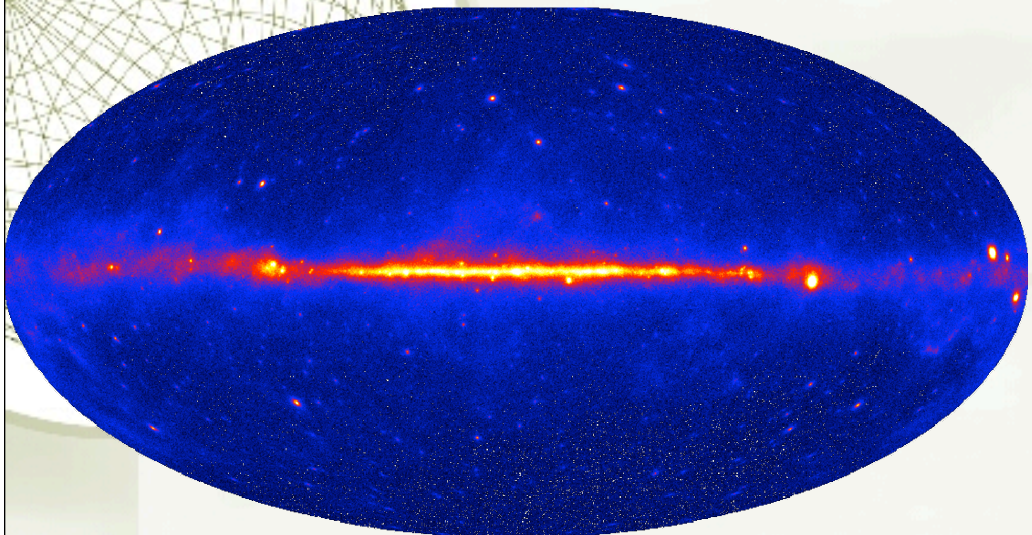


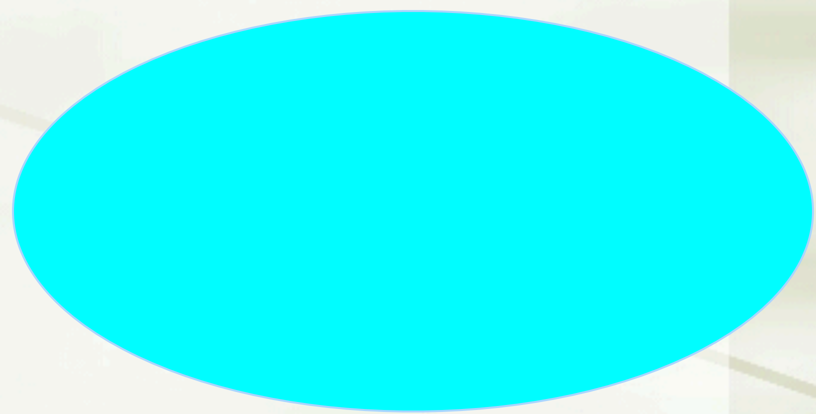
**Isotropic diffuse emission**

(presumably extragalactic)

*Ackermann 2009*

# *The EGRB (after subtraction)*

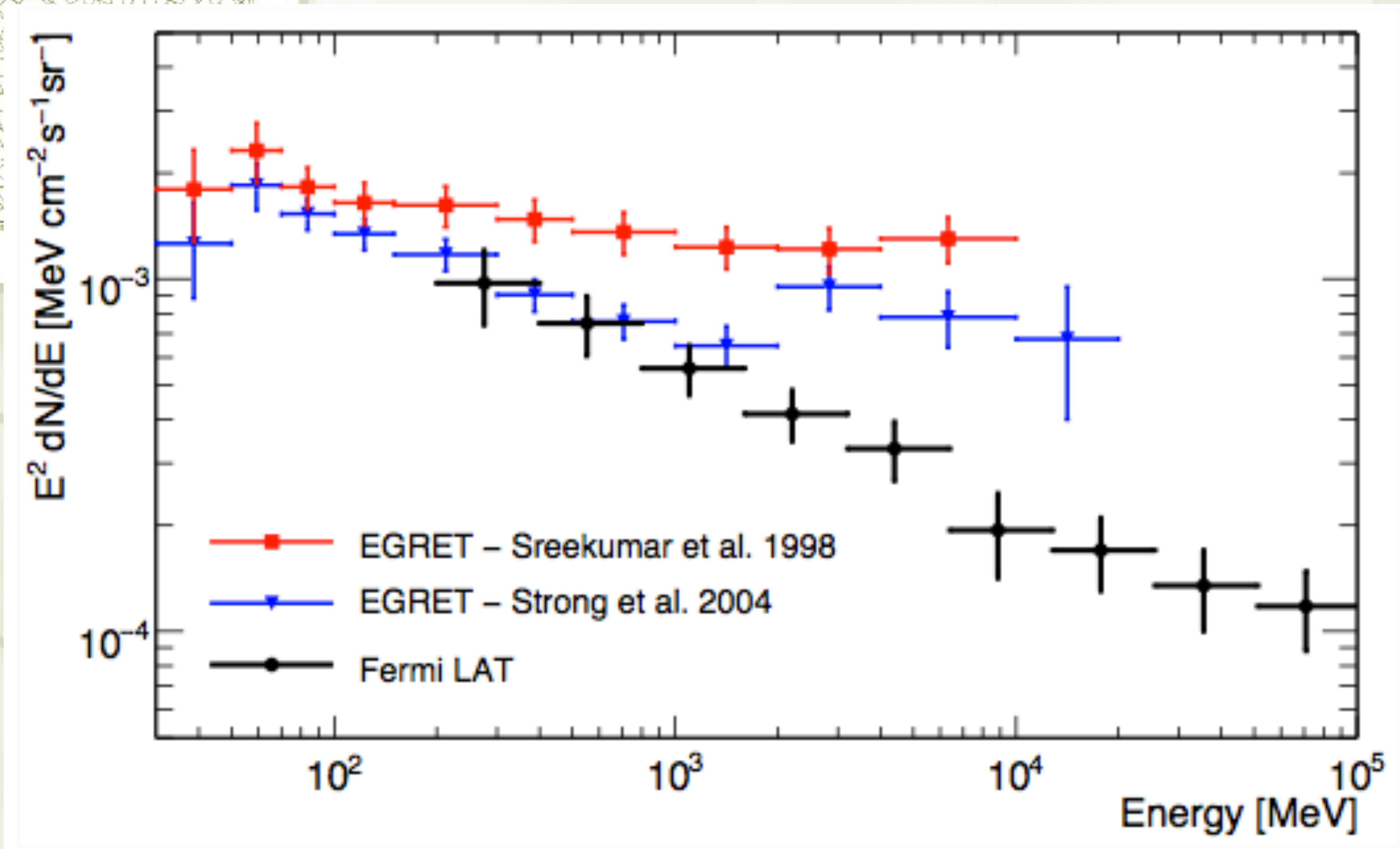




**Isotropic diffuse emission**
(presumably extragalactic)

*Ackermann 2009*

# The Spectrum of the EGRB



# *Contributions to the EGRB*

Guaranteed gamma-ray emission from:

- Star-forming galaxies
- Active galactic nuclei (blazars, maybe some from other types of radio galaxies)
- Unidentified gamma-ray sources

Possible gamma-ray emission from:

- Diffuse emission (e.g. VHE photon propagation? cosmic ray propagation?)
- Exotic physics (e.g. dark matter annihilation?)

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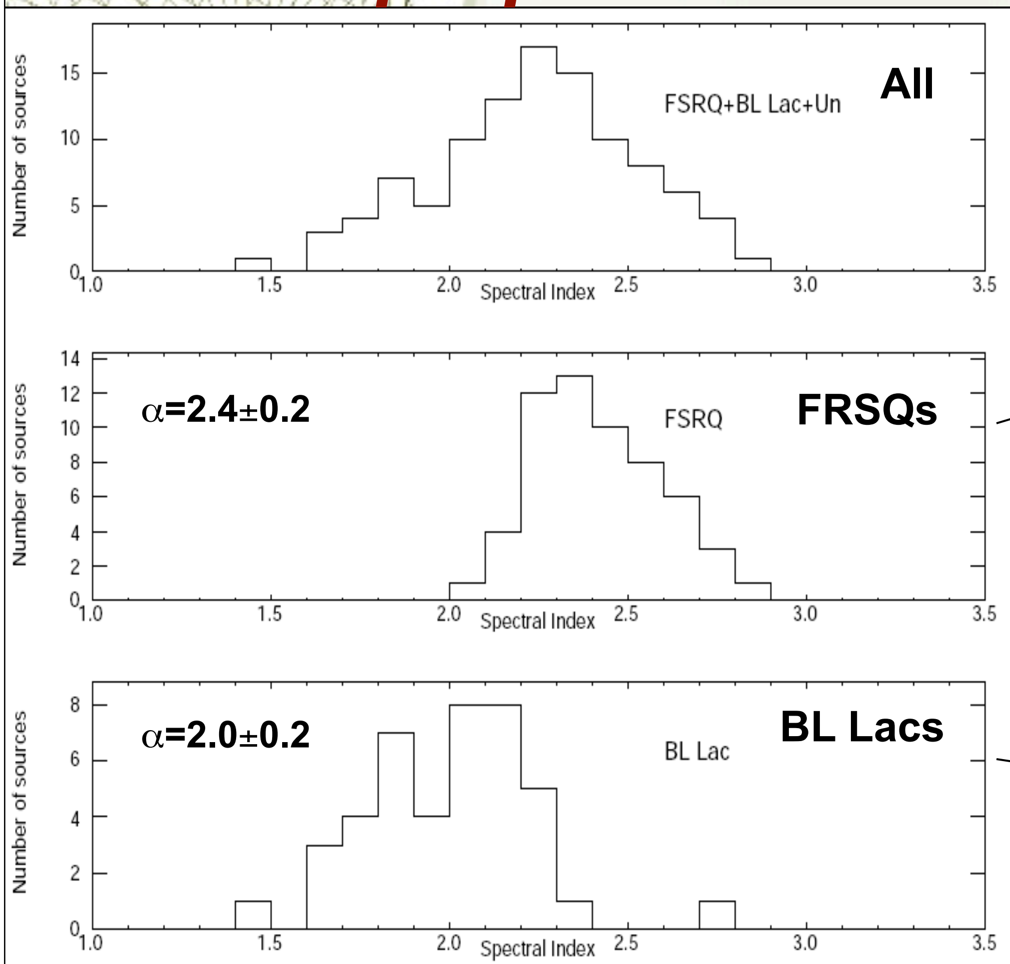
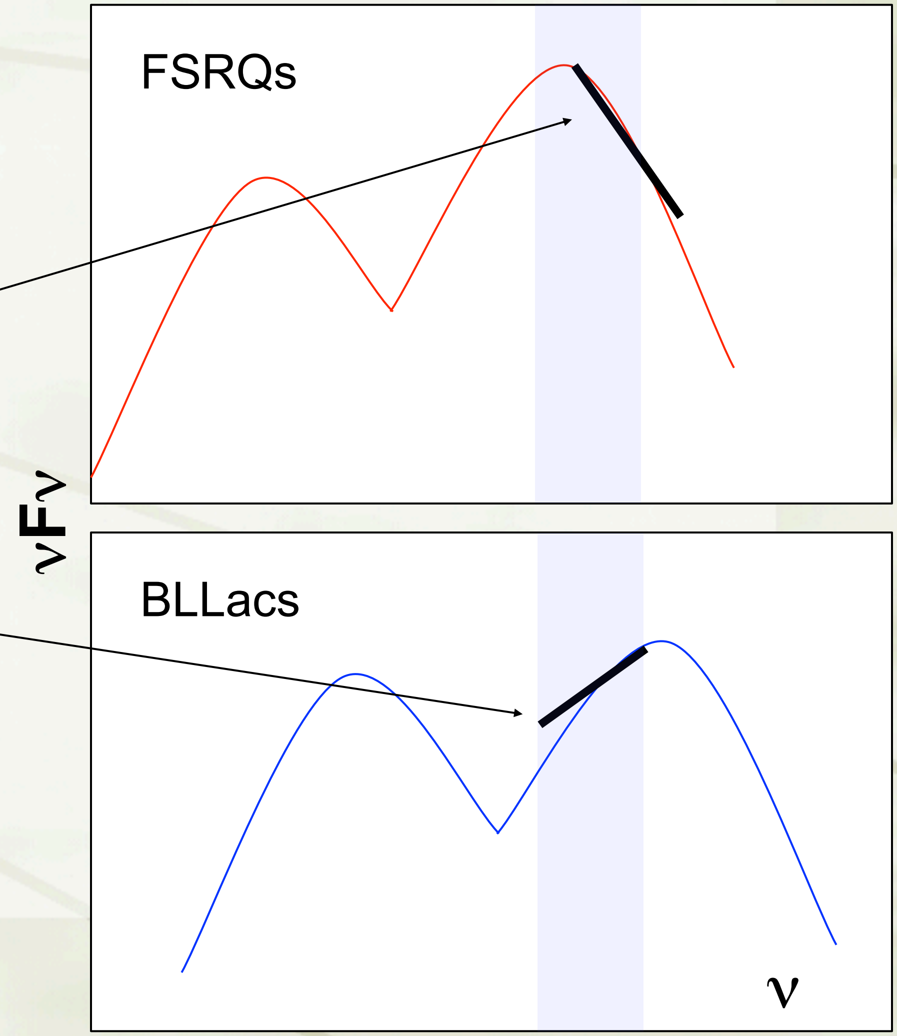
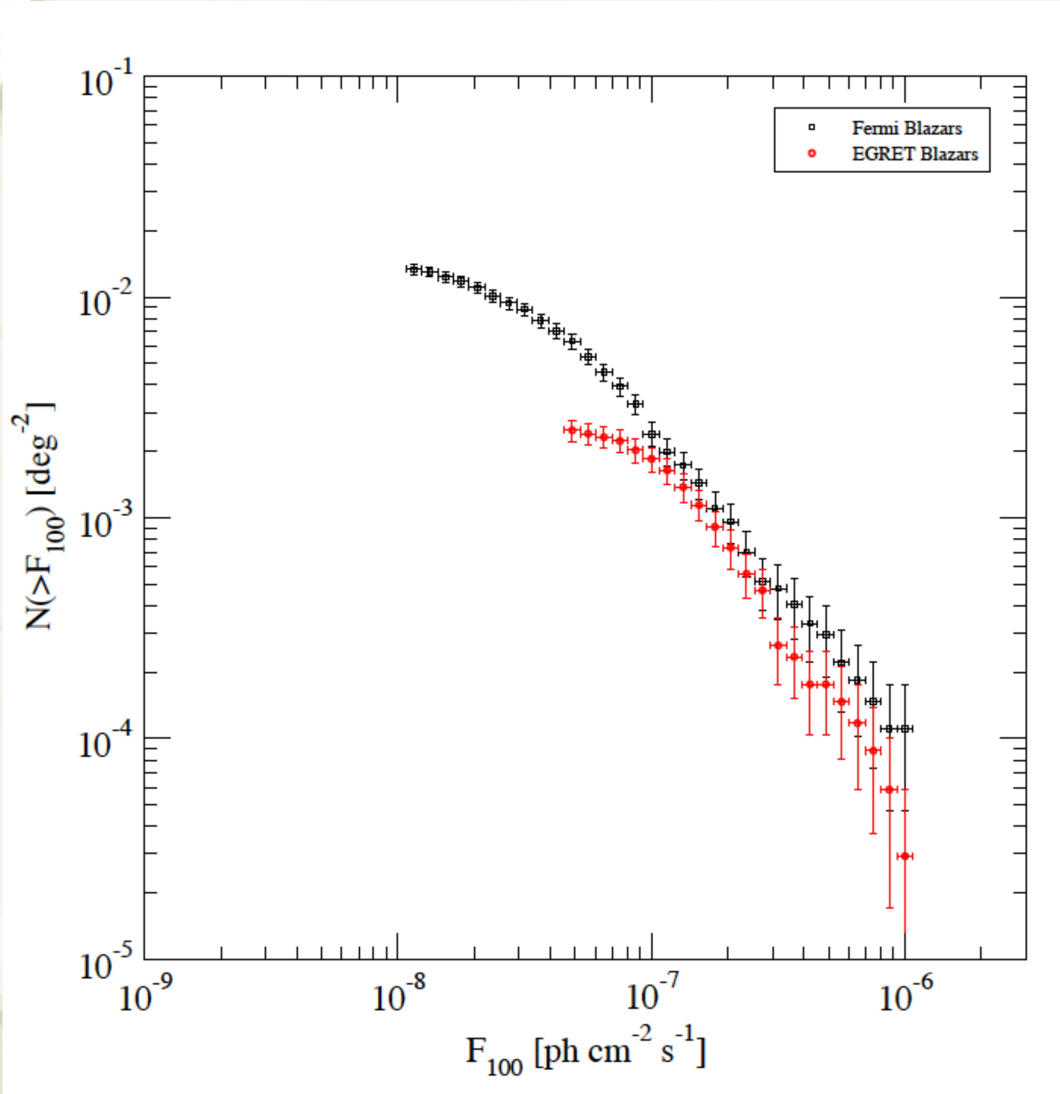
# *Gamma-ray Spectra of Sub-populations of Blazars*




*Abdo et al. 2009*

# log N – log S for Fermi and EGRET Blazars



# *Fermi Source Detection Efficiency from Monte Carlo Simulation*

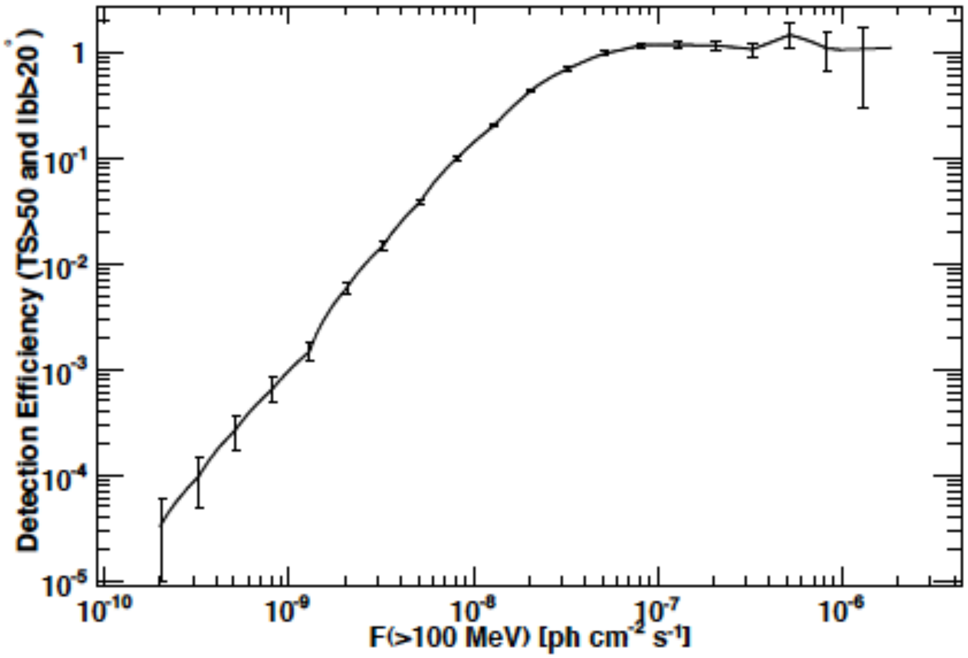
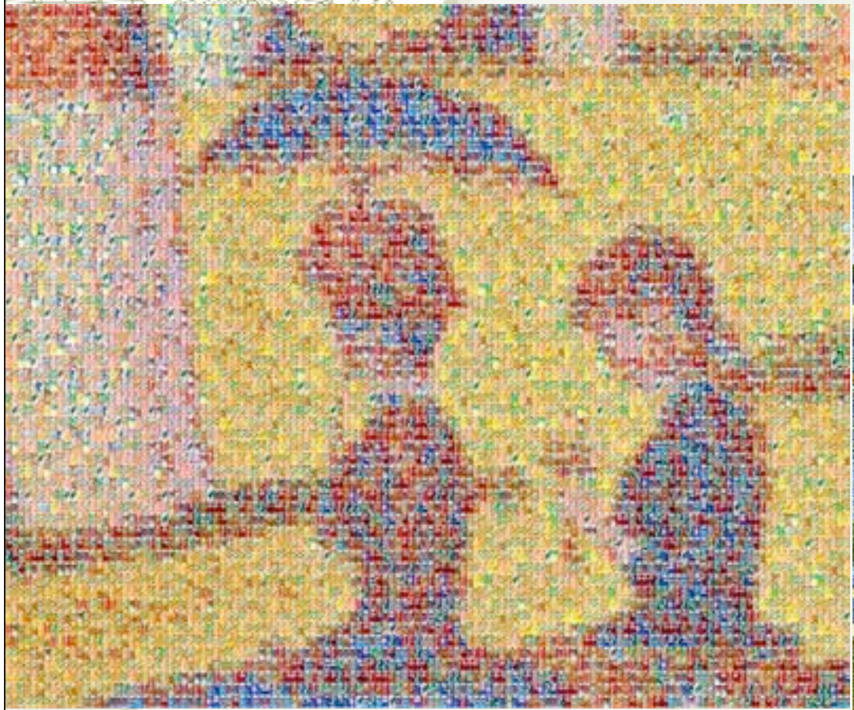



Fig. 7.— Detection efficiency as a function of measured source flux for $|b| \geq 20°$, TS$\geq$ 50 and for a sample of sources with a mean photon index of 2.40 and dispersion of 0.28. The error bars represent statistical uncertainties from the counting statistic of our Monte Carlo simulations.

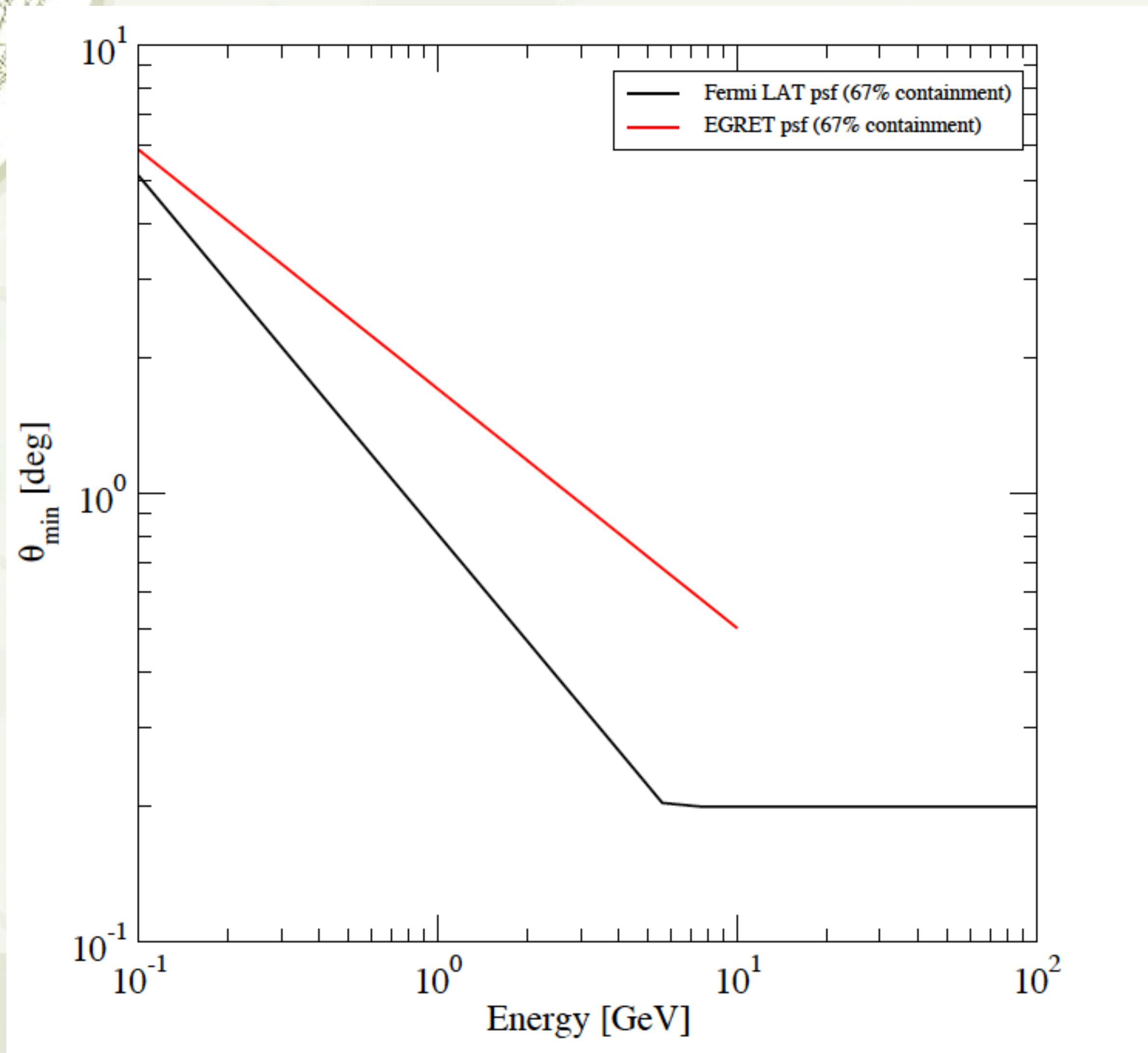
*Abdo et al. (2010)*

# Source Confusion

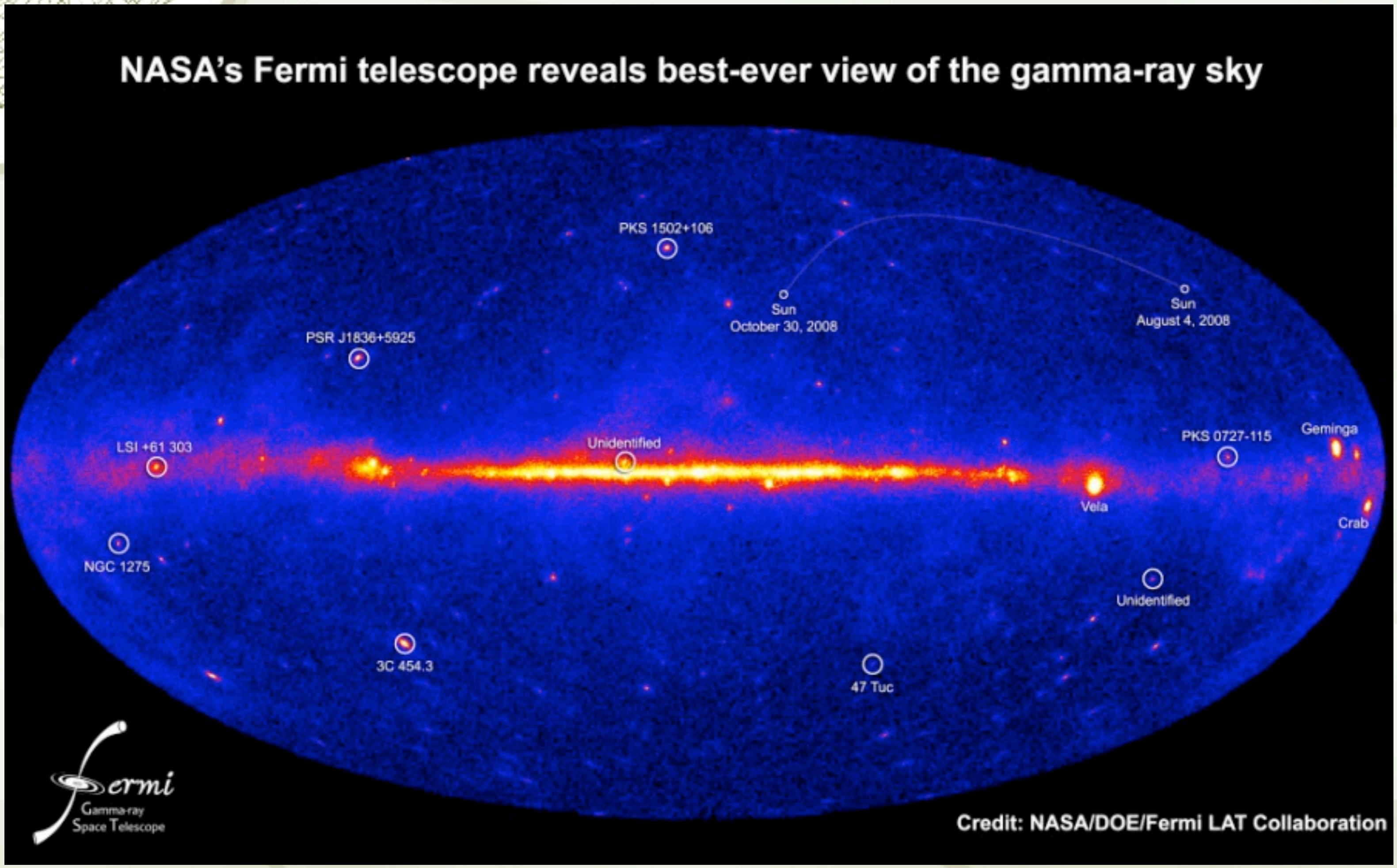


*Georges Seurat*

# *Angular Resolution for Fermi and EGRET*



# *The Effect of Source Confusion at 100 MeV*



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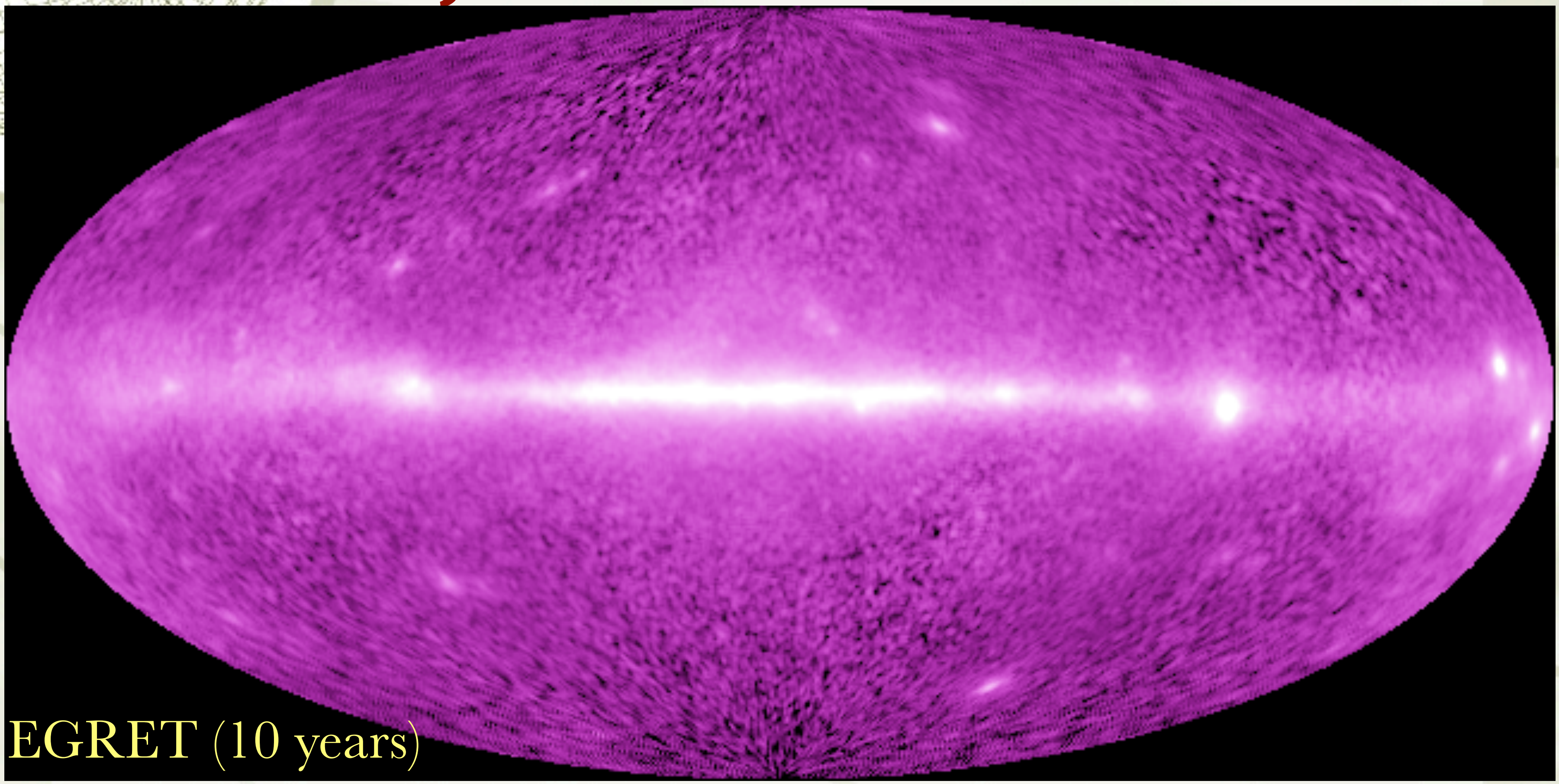
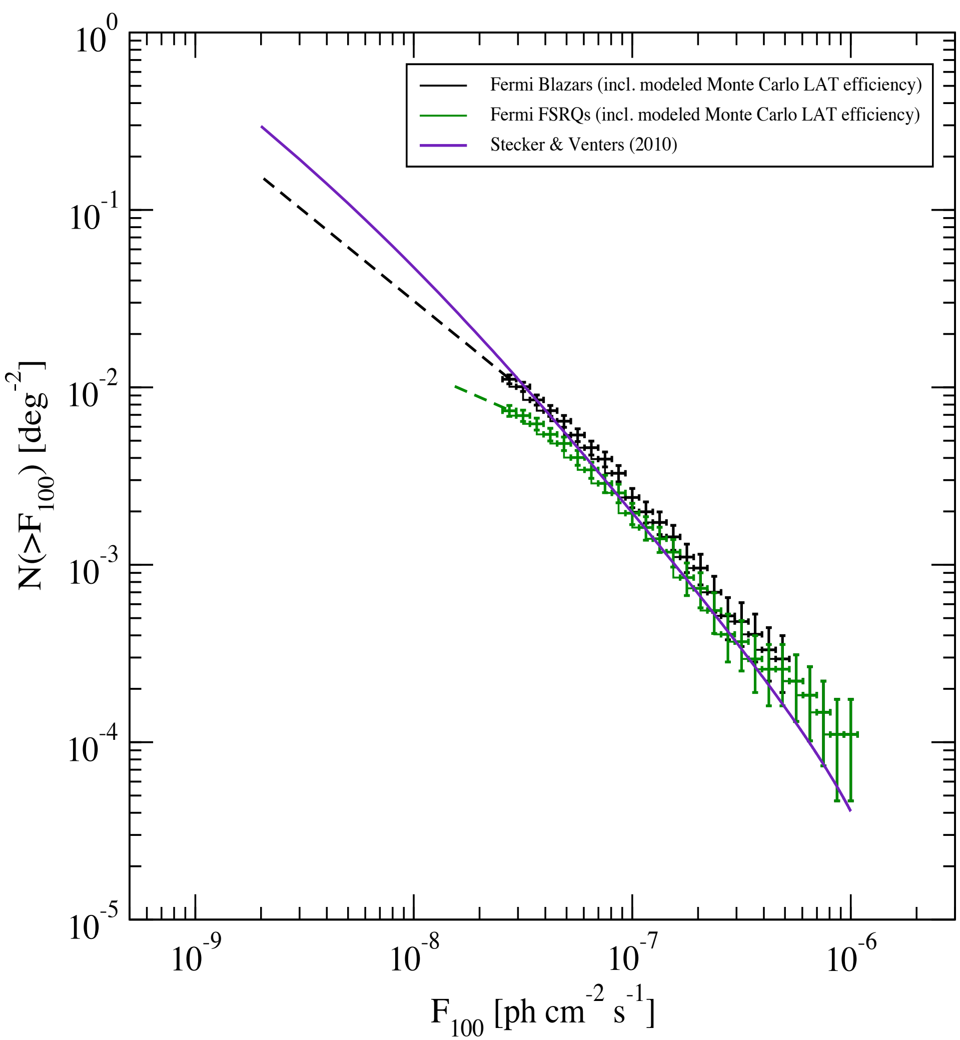
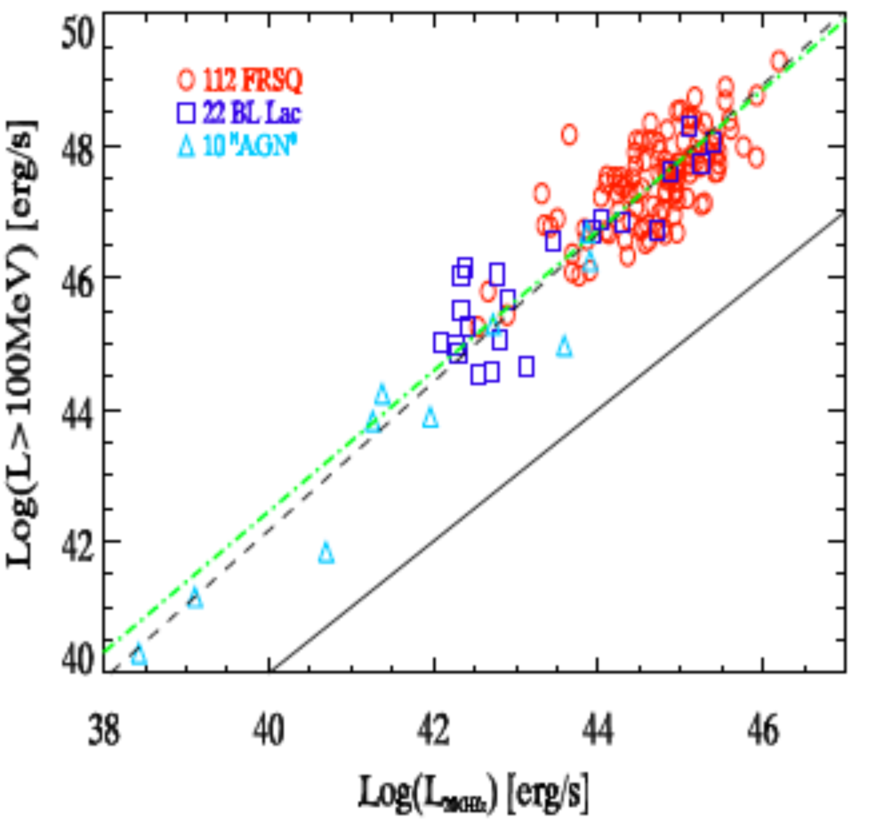


# log N – log S Data vs. Models



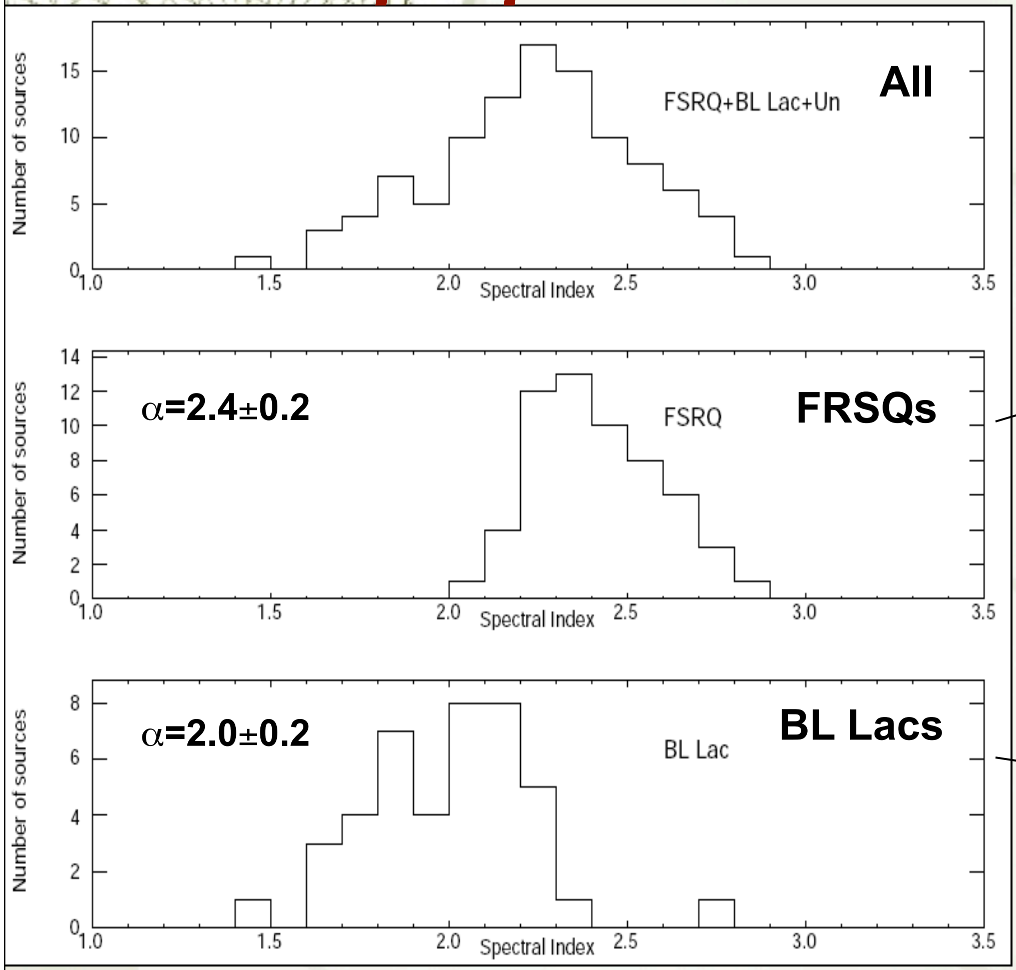
# Radio/γ-ray Correlation

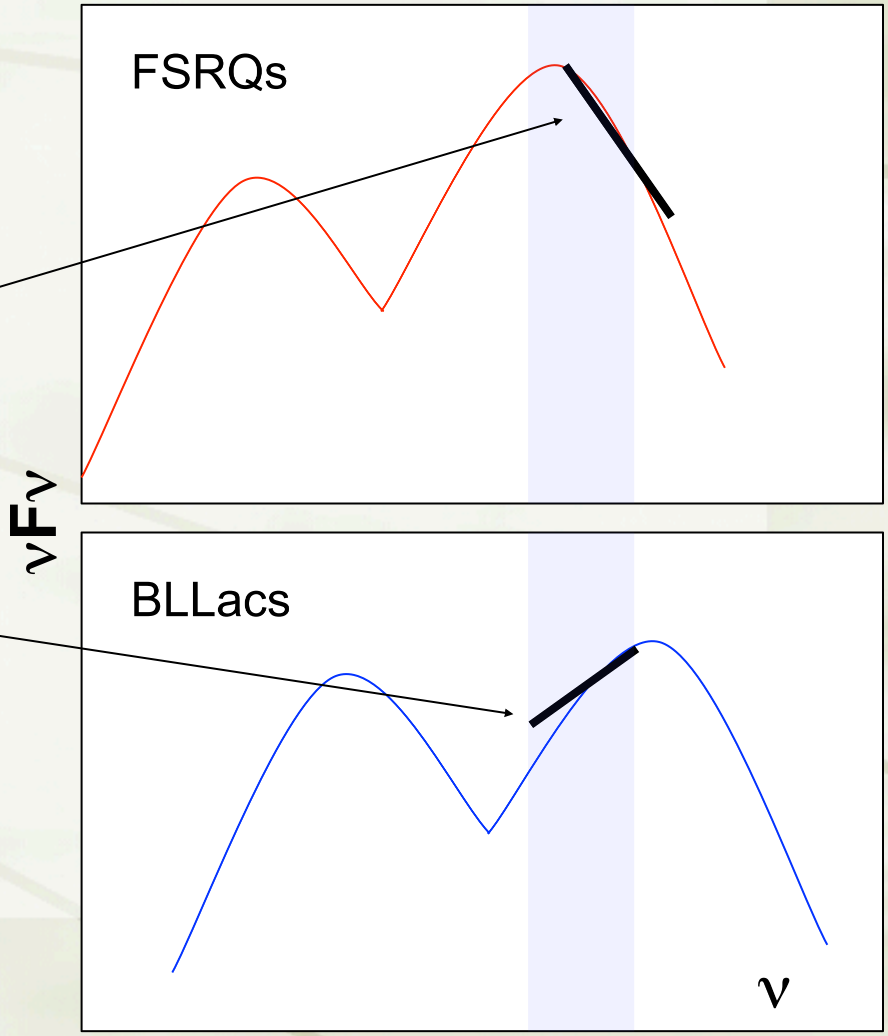



*The shape of the blazar contribution depends on the spread in the distribution of spectral indices: little spread ⇨ little curvature; large spread ⇨ large curvature*

*Ghirlanda et al. 2010*

# Gamma-ray Spectra of Sub-populations of Blazars

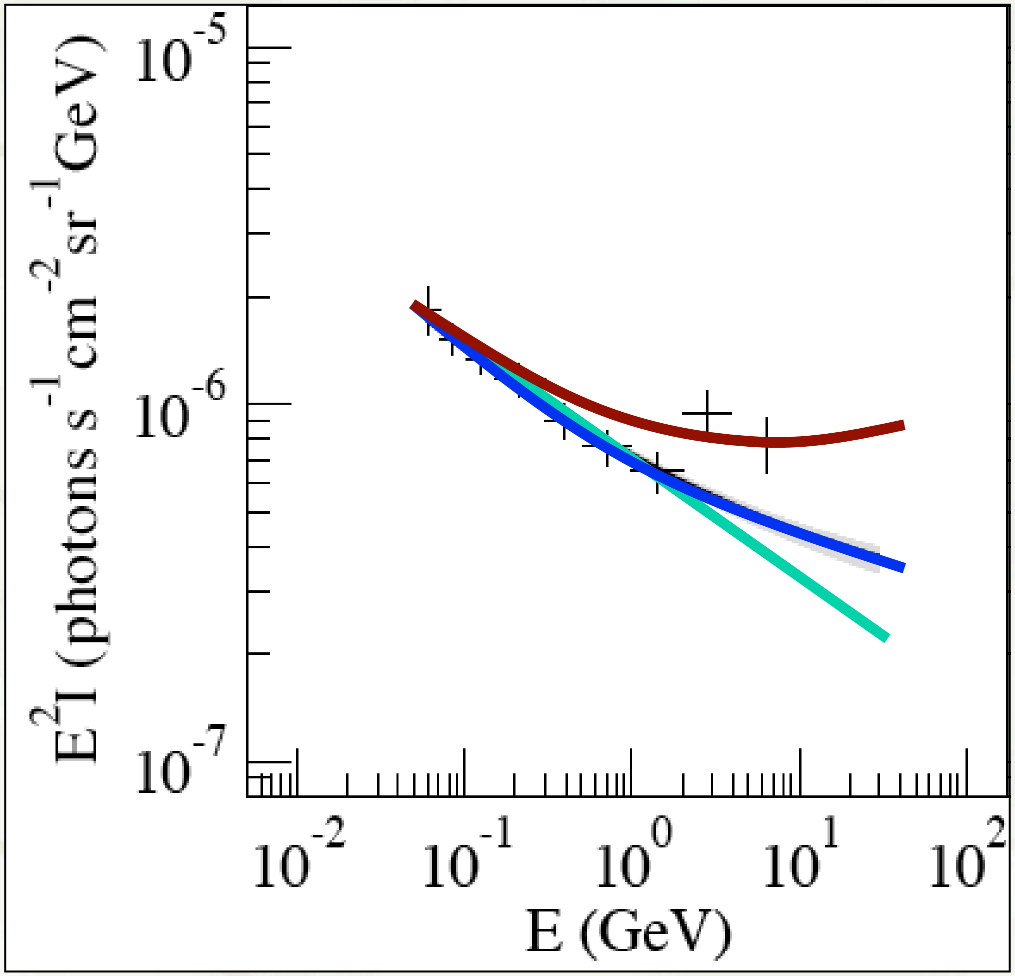


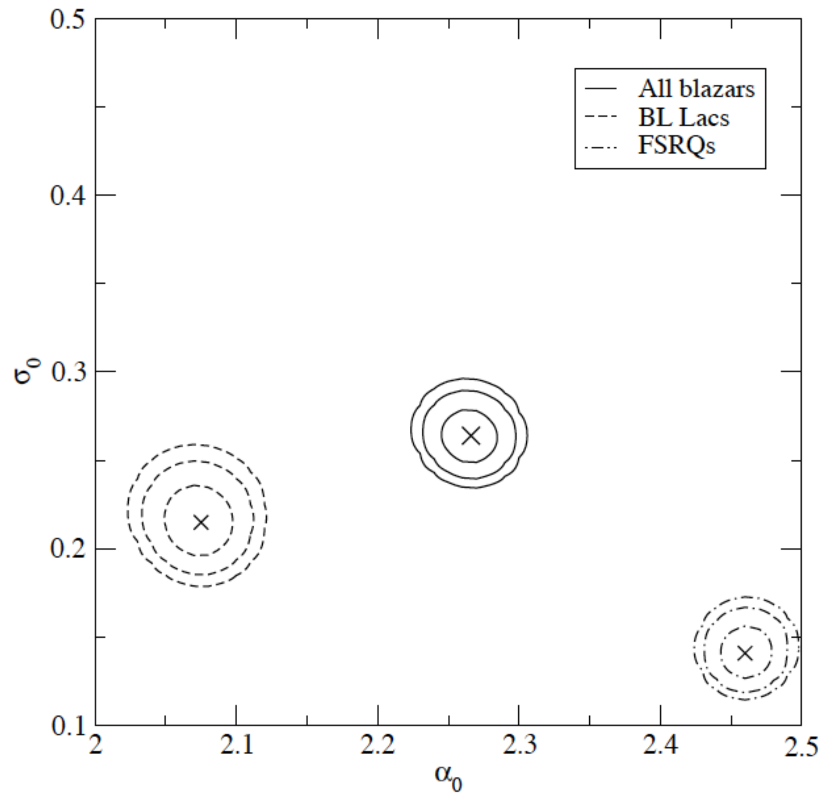




*Abdo et al. 2009*

# The SID and the Spectral Shape

*The shape of the blazar contribution depends on the spread in the distribution of spectral indices: little spread ⇨ little curvature; large spread ⇨ large curvature*






# The Likelihood Approach

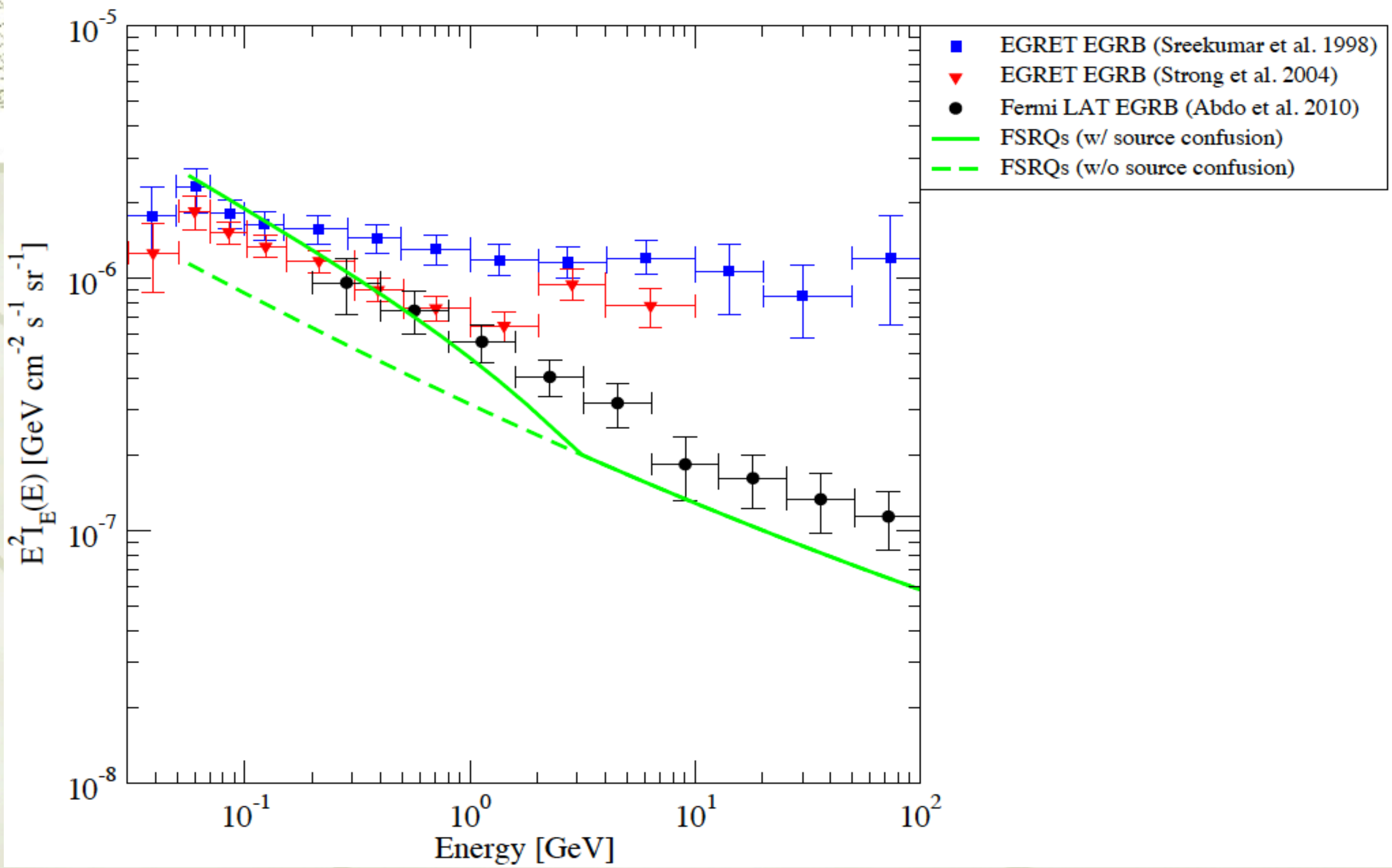
$$P(x_i \mid y_j) \propto P(x_i) \times \mathcal{L}(y_j \mid x_i)$$

$$\mathcal{L} = \prod_{j=1}^{N} l_j$$

$$l_j = \int d\alpha \, \frac{\exp[-(\alpha - \alpha_j)^2 / (2\sigma_j^{\,2})]}{\sqrt{2\pi}\,\sigma_j} \, \frac{\exp[-(\alpha - \alpha_0)^2 / (2\sigma_0^{\,2})]}{\sqrt{2\pi}\,\sigma_0}$$

$$\mathcal{L} = \left( \prod_{j=1}^{N} \frac{1}{\sqrt{\sigma_0^{\,2} + \sigma_j^{\,2}}} \right) \exp\left[ -\frac{1}{2} \sum_{j=1}^{N} \frac{(\alpha_j - \alpha_0)^2}{\sigma_0^{\,2} + \sigma_j^{\,2}} \right]$$

# Background from Unresolved Blazars and Data



LAT collaboration: *Fermi*/LAT observations of Local Group galaxies: detection of M 31 and search for M 33

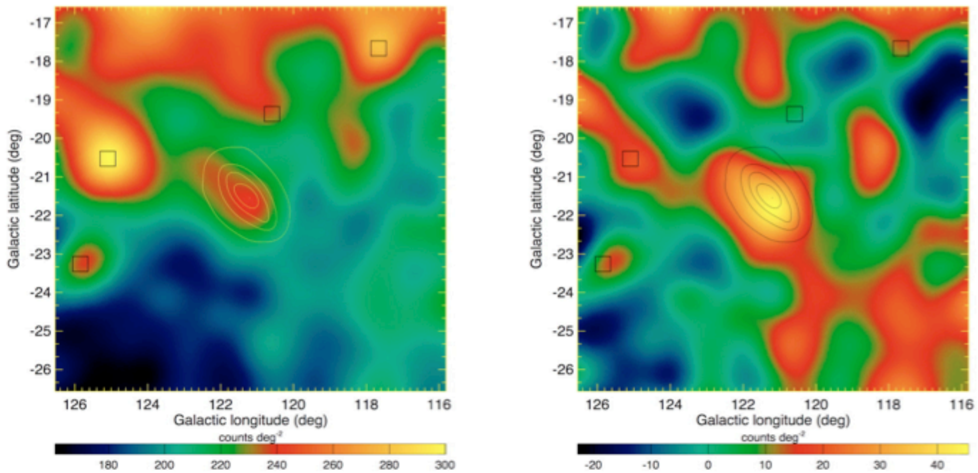



**Fig. 1.** Gaussian kernel ($\sigma = 0.5°$) smoothed counts maps of the region of interest (ROI) in a true local projection before (*left*) and after subtraction of the background model (*right*) for the energy range 200 MeV–20 GeV and for a pixel size of $0.05° \times 0.05°$. Overlaid are IRIS 100 $\mu$m contours of M 31 convolved with the LAT point spread function to indicate the extent and shape of the galaxy. The boxes show the locations of the 4 point sources that have been included in the background model.

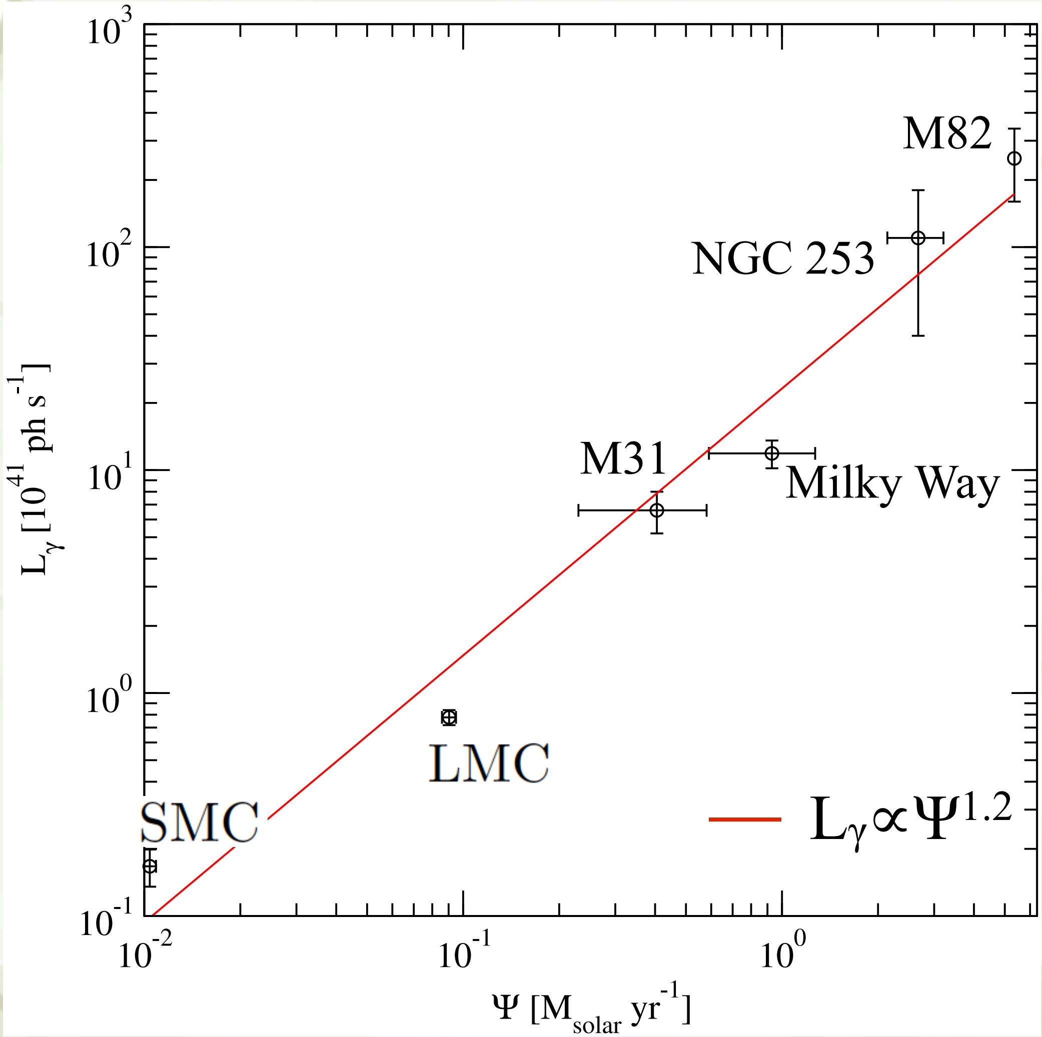
# *γ-ray Production in Star-Forming Galaxies*

- A Galaxy's γ-ray flux is mainly from $\pi^0$ production in CR-gas interactions followed by $\pi^0$ decay.
- ∴ γ-ray flux ∝ (CR flux) x (gas density).
- CR flux ∝ supernova rate ∝ star formation rate (SFR).

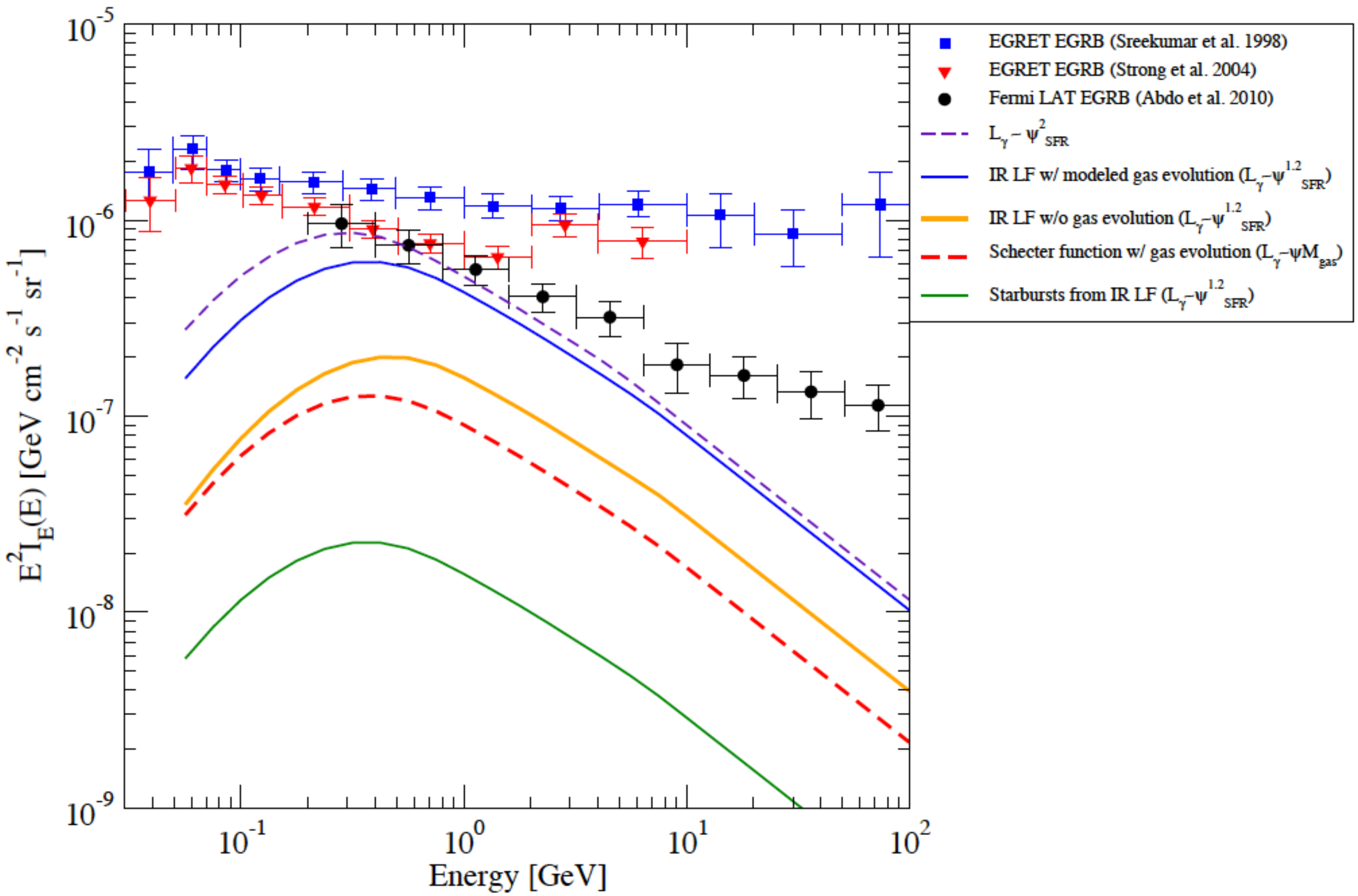
# *Three Strategies for Estimating γ-Ray Luminosity in Star Forming Galaxies:*

- Relate the galaxy γ-ray luminosity to its SFR, which, in turn, is related to an observable for which there is a redshift distribution (e.g., IR luminosity).
- Relate the galaxy gas mass to its stellar mass assuming a gas fraction that evolves with redshift.
- Relate the cosmic density of gas in star forming galaxies to the star formation rate density.

# γ-ray Luminosity vs. Star Formation Rate for Star-forming Galaxies



# Background From Unresolved Galaxies and Data

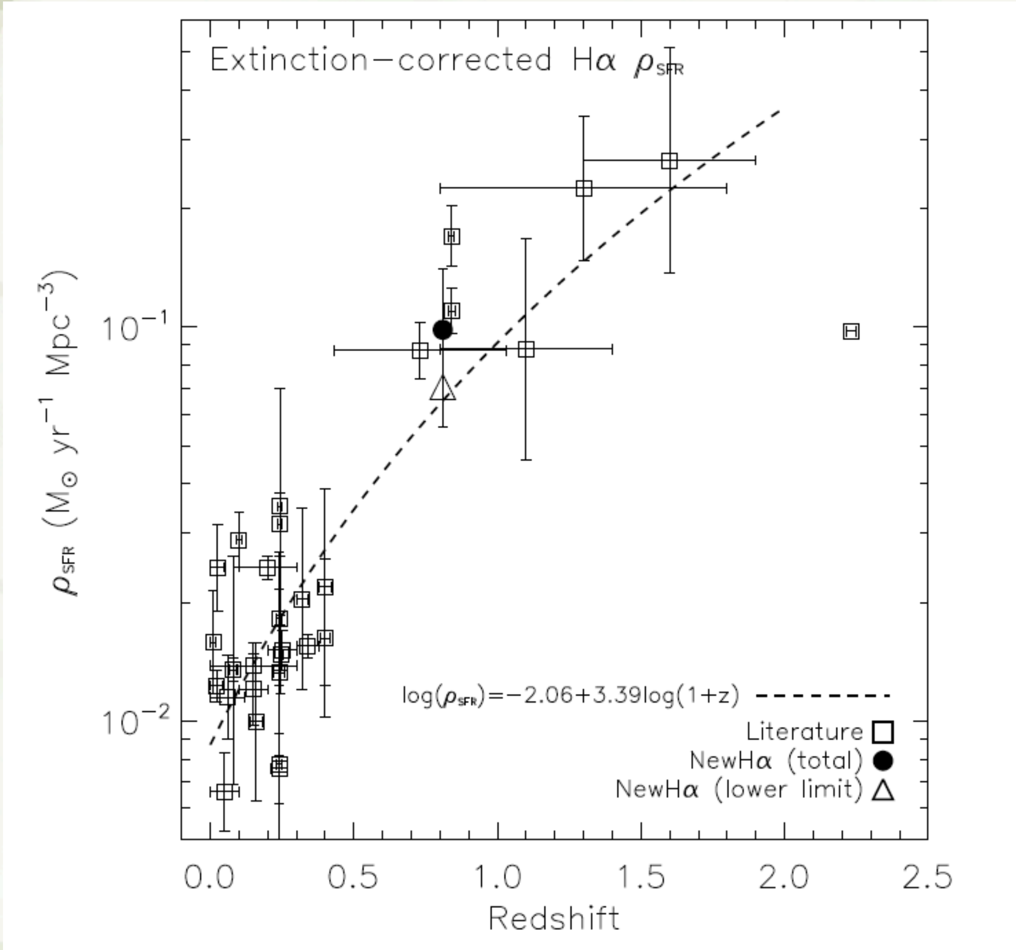


# Conclusions

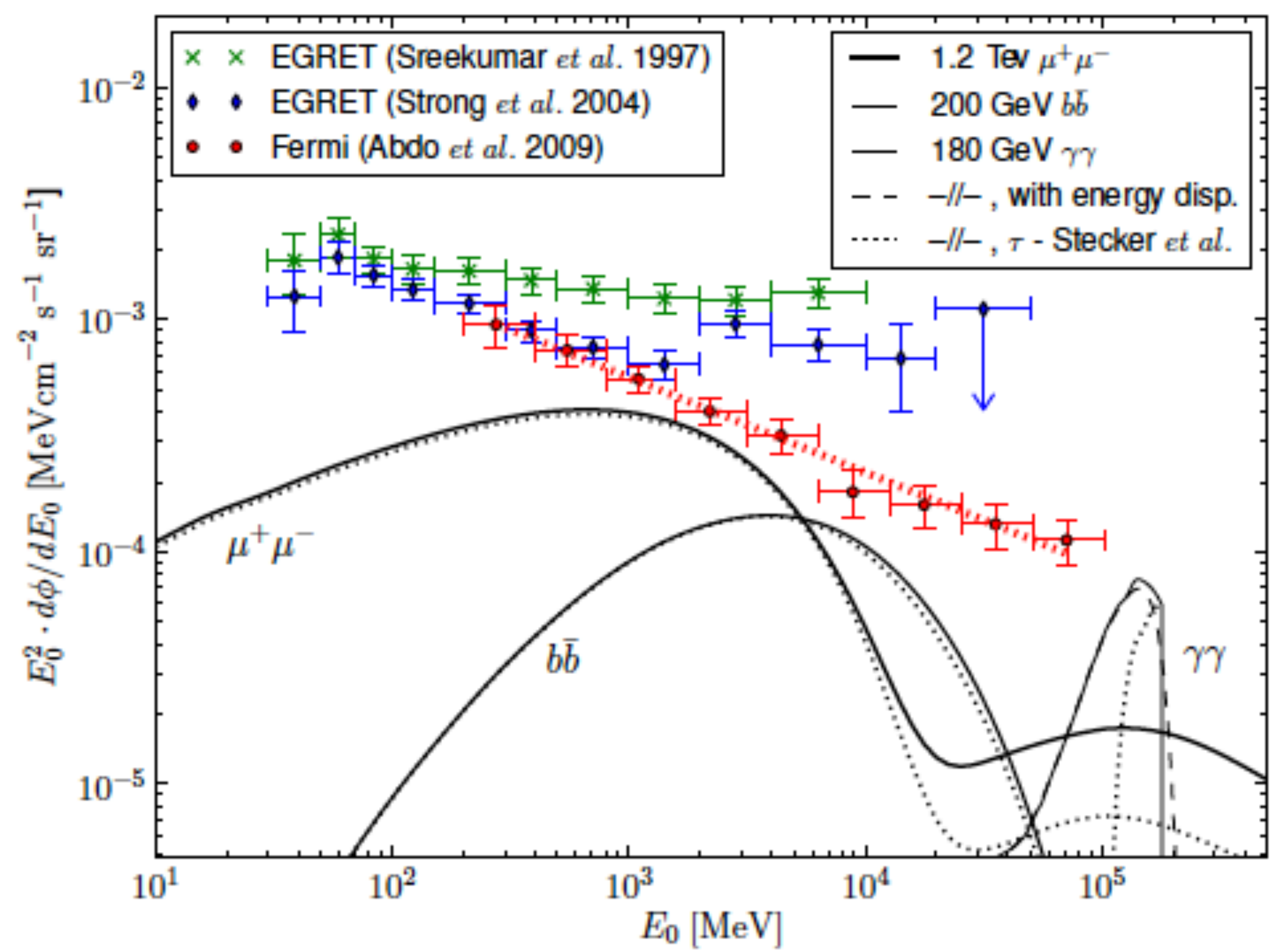
- The EGRET and *Fermi* γ-ray data do not, as yet, rule out a scenario in which the background is dominated by γ-rays from unresolved blazars.
- γ-rays from unresolved star forming galaxies may or may not contribute significantly to the background (see also, Fields & Pavlidou 2010; Makiya et al. 2010). Starburst galaxies make a negligible contribution to the background (see also, Stecker 2007, Makiya et al. 2010).
- *Fermi* will be taking data for a few more years, so there'll be plenty of time to keep arguing about this issue.

# *Extra Slides*

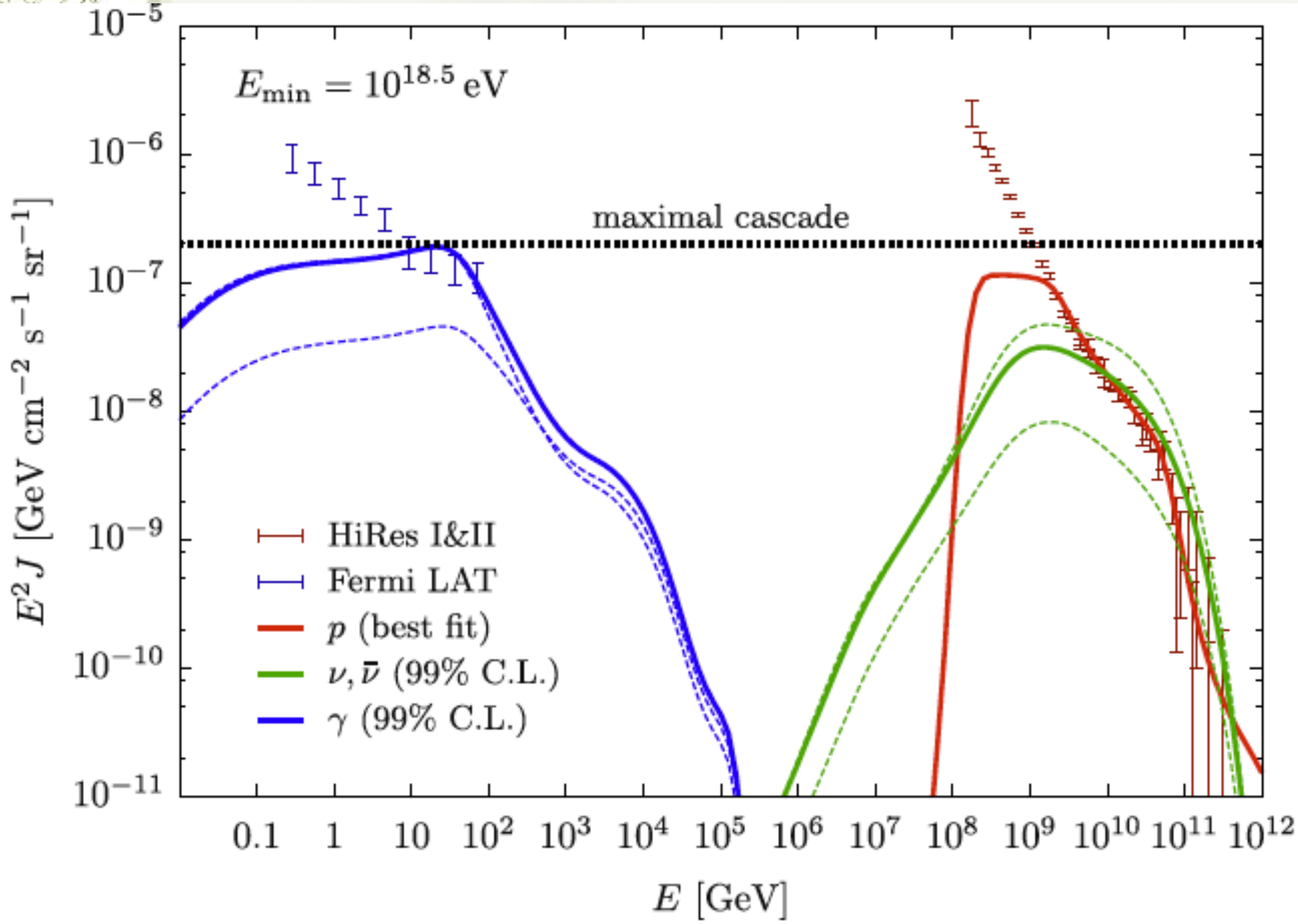
# SFR Density vs. z  (Ly 2010)



# Spectral Features of a Background from Dark Matter Annihilation



# Maximum Background from EM Cascades of UHE Electrons from



# *Efficiency of a $\gamma$-ray telescope for detecting extragalactic sources determined by:*

- The flux of the source
- The spectral index of the source
- The intrinsic detector background from cosmic-ray induced events
- The foreground from the Milky Way
- The extragalactic background