"Digging for the Truth" : Stellar Photon Archaeology with γ-rays

F.W. Stecker (NASA/GSFC)

Collaborators: M.A. Malkan (UCLA),
S.T. Scully (JMU)

The Era of Deep Astronomical Galaxy Surveys

- *Spitzer (IR)*
- *Hubble (optical, Near IR)*
- *GALEX (UV)*

Intergalactic Photon Fields

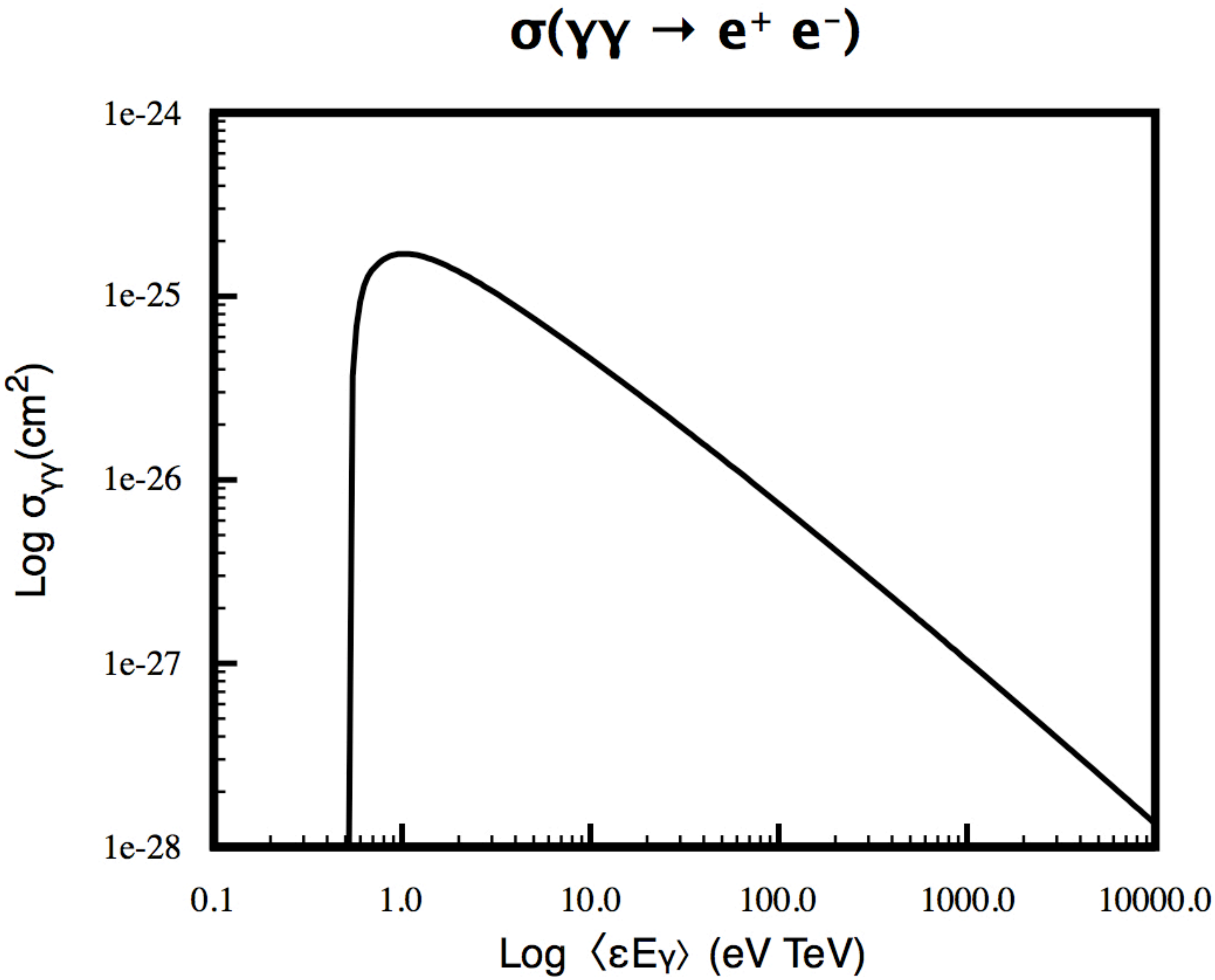
- Emission from stars and dust reradiation of starlight in galaxies produces IR, optical and UV photons
- These low energy photons escape into intergalactic space
- If we know enough about galaxy evolution from deep astronomical surveys, we can calculate the intergalactic photon densities from these processes

The Connection between Low Energy Photons and Gamma-Rays

The Key Relationship is through their mutual annihilation *via* e^+e^-pair production interactions in interglactic space

$$\gamma + \gamma \longrightarrow e^+ + e^-$$

Pair Production Cross Section



γ-ray Annihilation by Pair Production

Determining the energy and redshift dependence of the extinction of high energy γ-rays from distant extragalactic sources through intergalactic annihilation with low energy photons requires the determination of photon densities

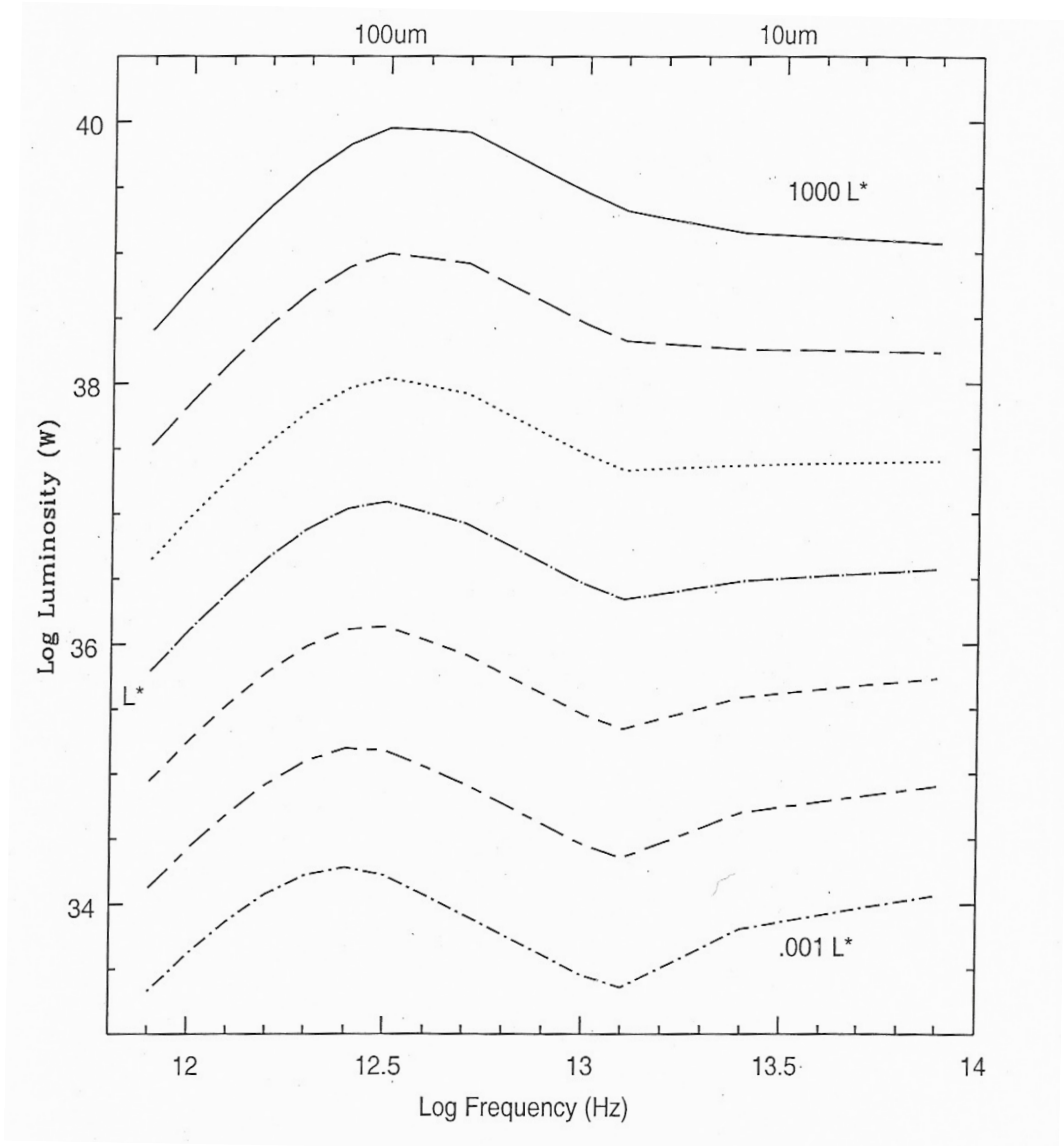
Input for Theoretical Calculations of Intergalactic Photon Fields and γ-Ray Absorption:

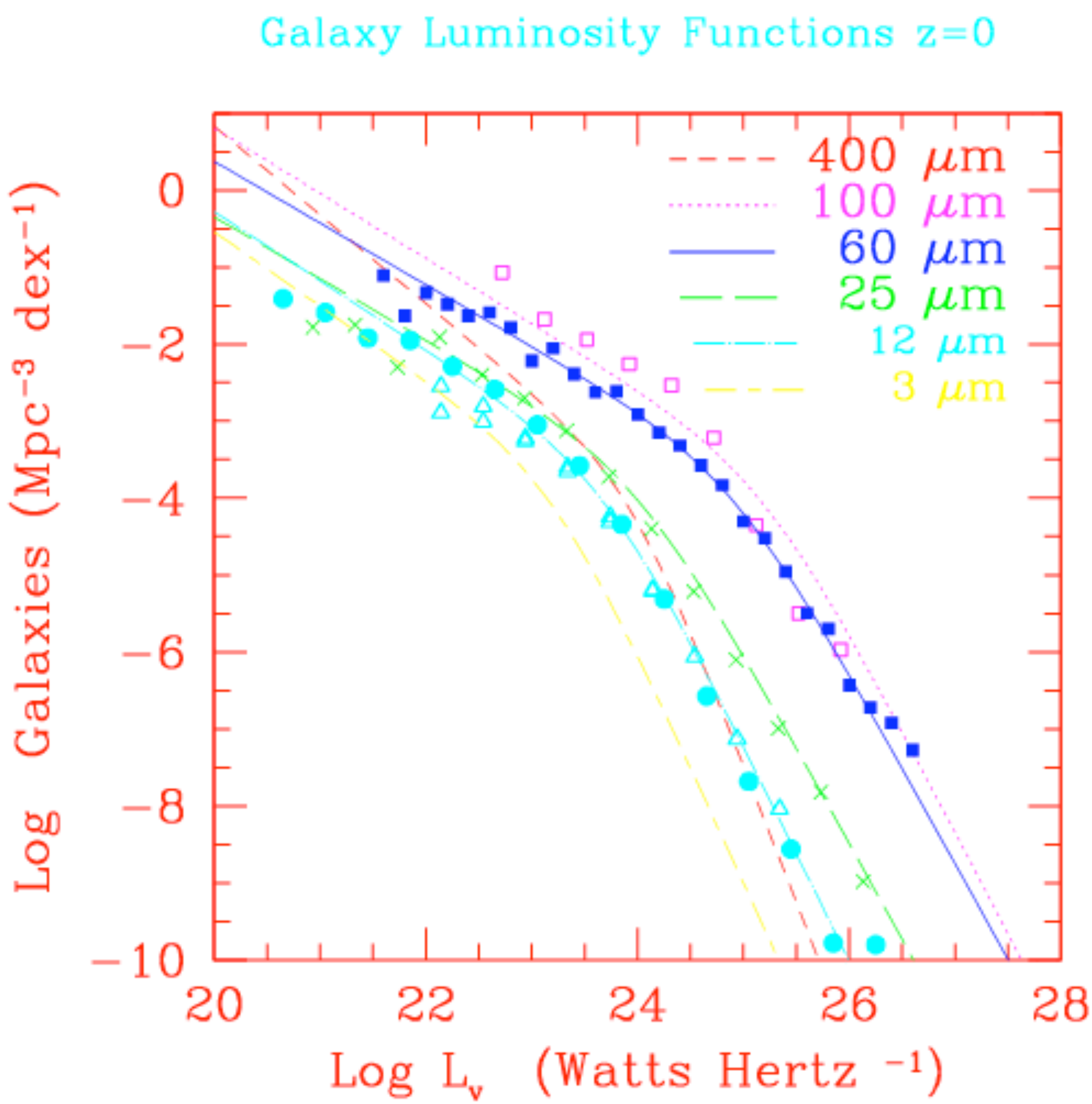
- Galaxy Luminosity Distribution Functions (LF)

- Redshift Dependence of Galaxy LFs

- Spectral Energy Distributions of Galaxies

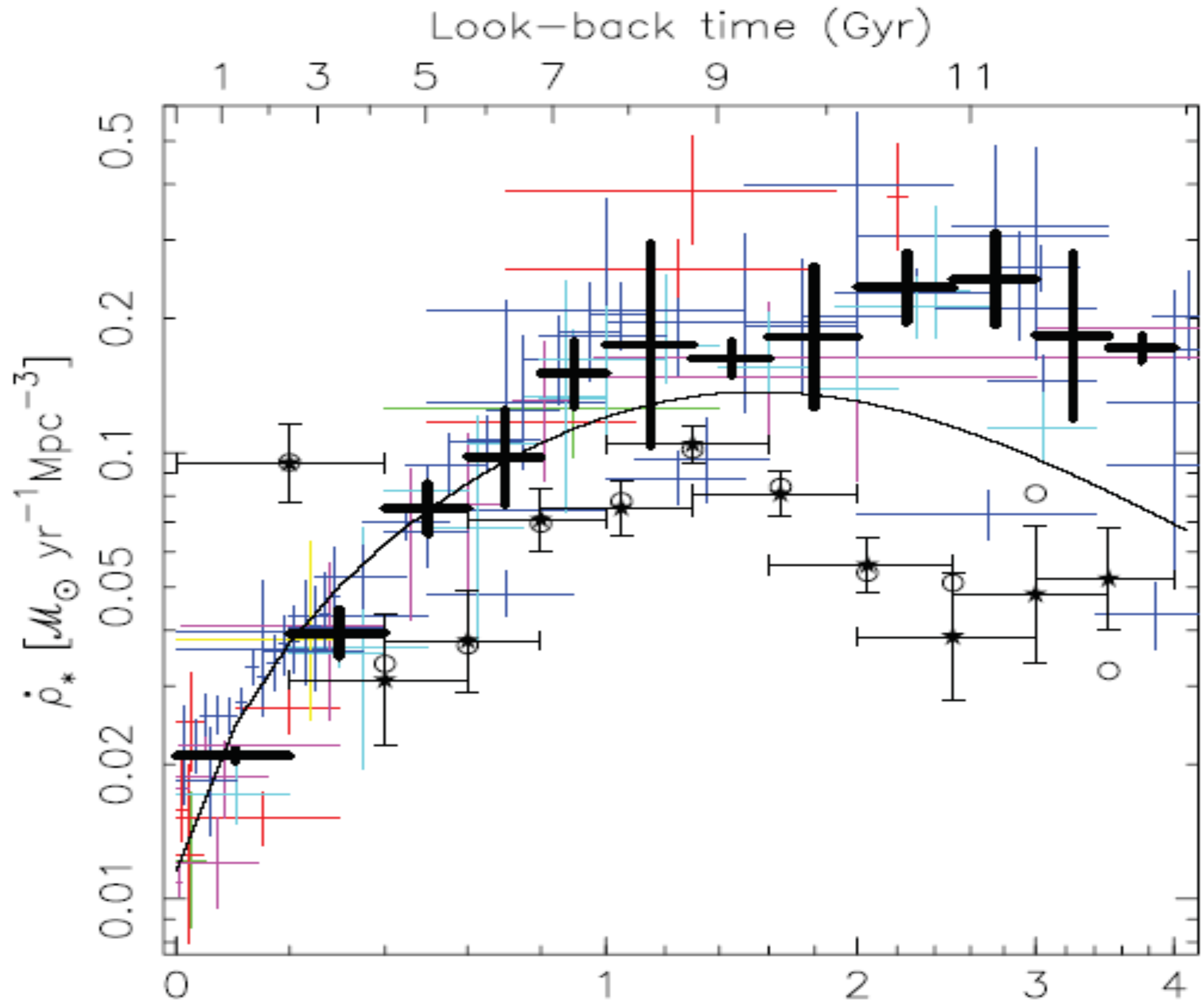
Spectral Energy Distributions vs. Luminosity



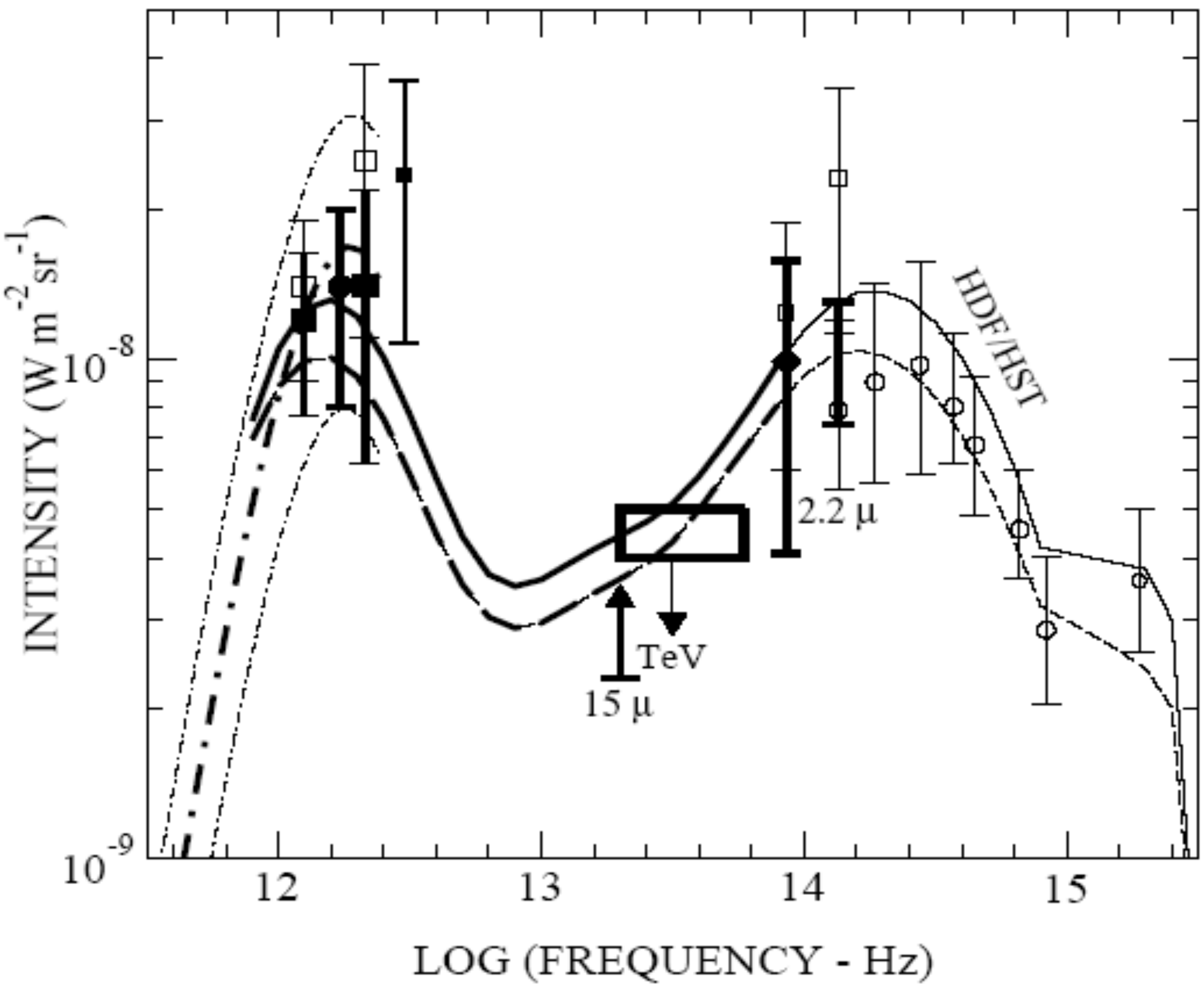

Galaxy Luminosity Functions z=0
400 μm
100 μm
60 μm
25 μm
12 μm
3 μm
0
−2
−4
−6
−8
−10
20
22
24
26
28
Log Galaxies (Mpc⁻³ dex⁻¹)
Log L_ν (Watts Hertz ⁻¹)

Star Formation *v*. Redshift

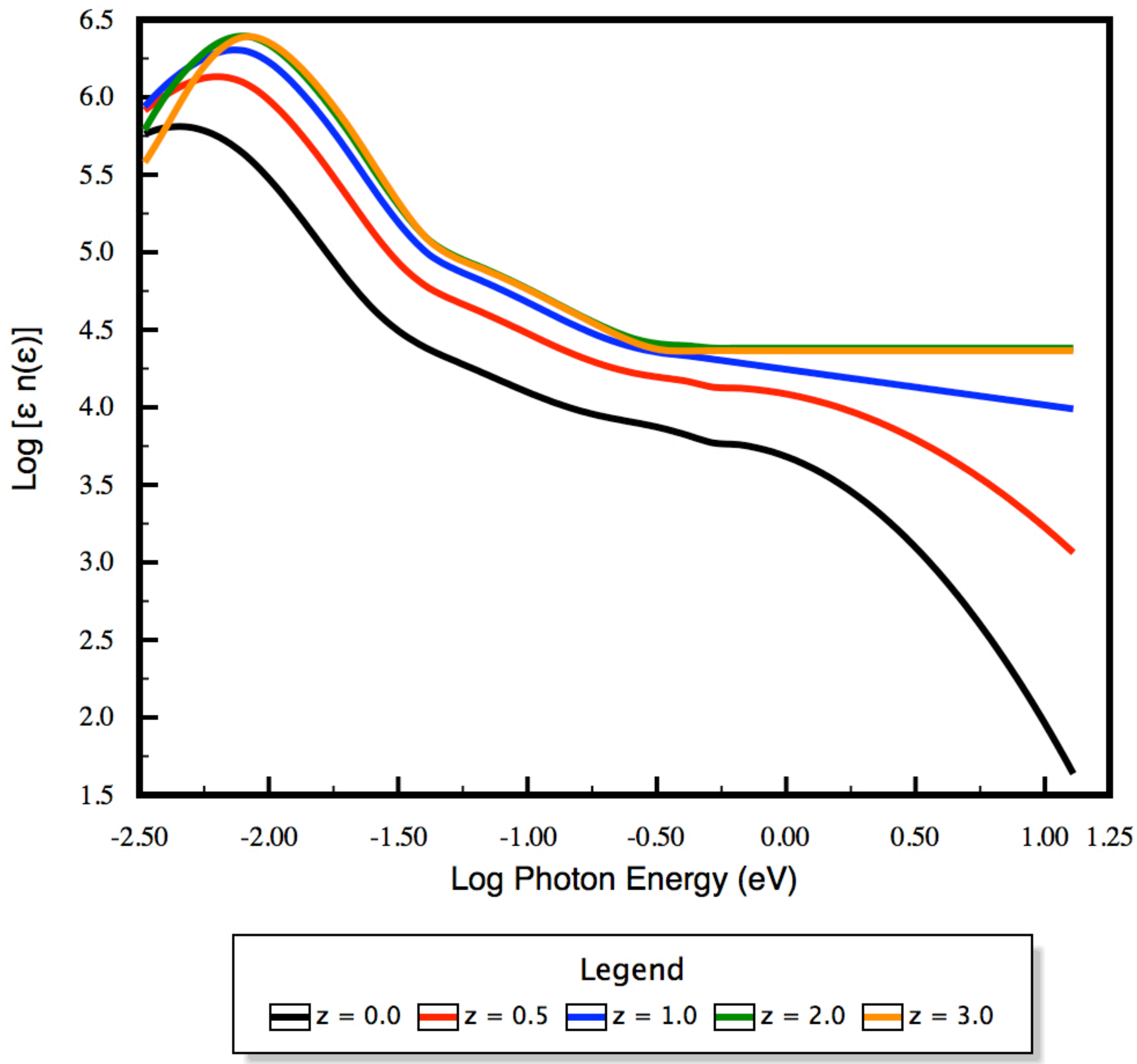
(Perez-Gonzalez *et al.* 2008)



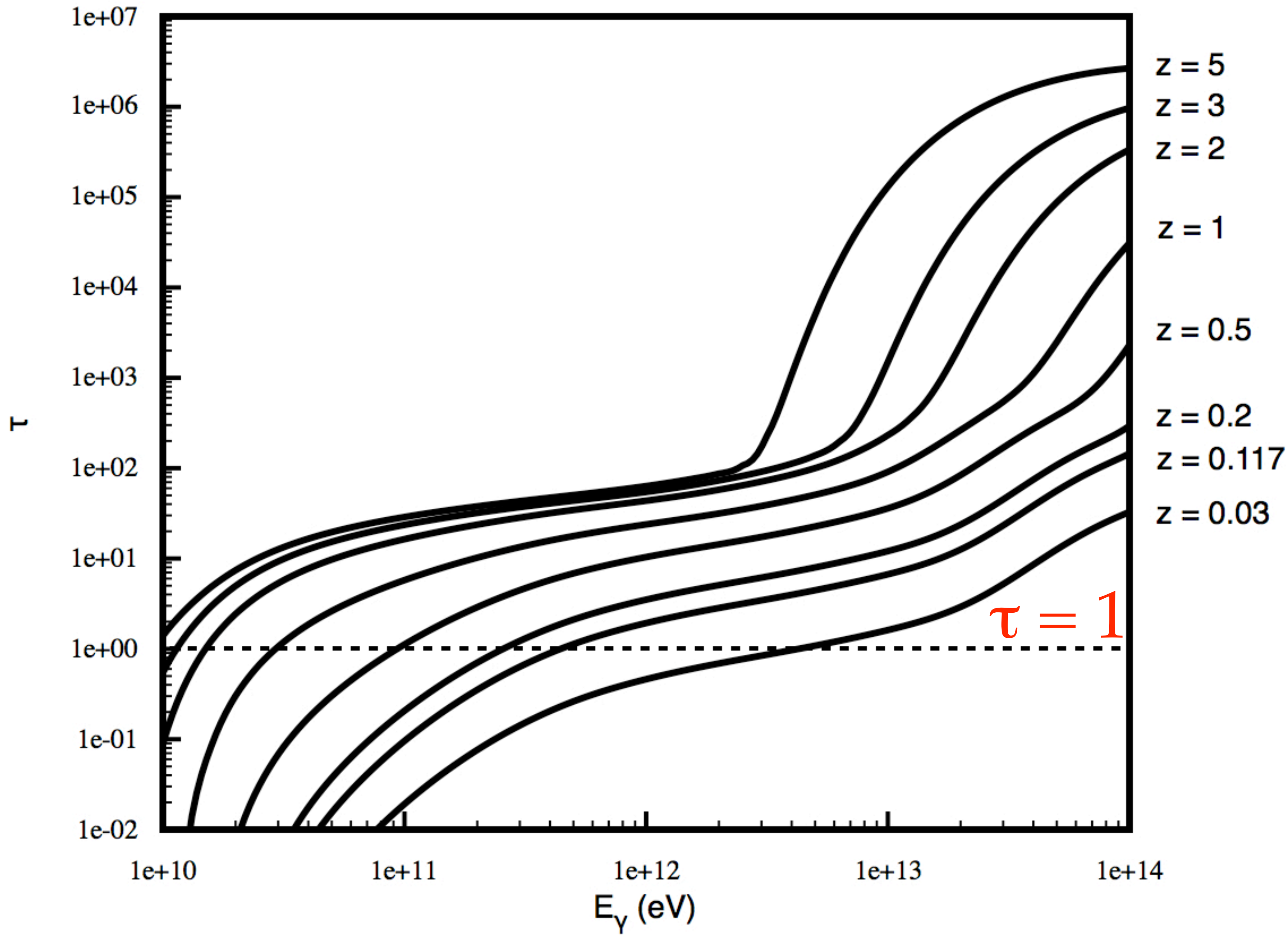
Predicted Extragalactic Background Fluxes (z=0) with Data



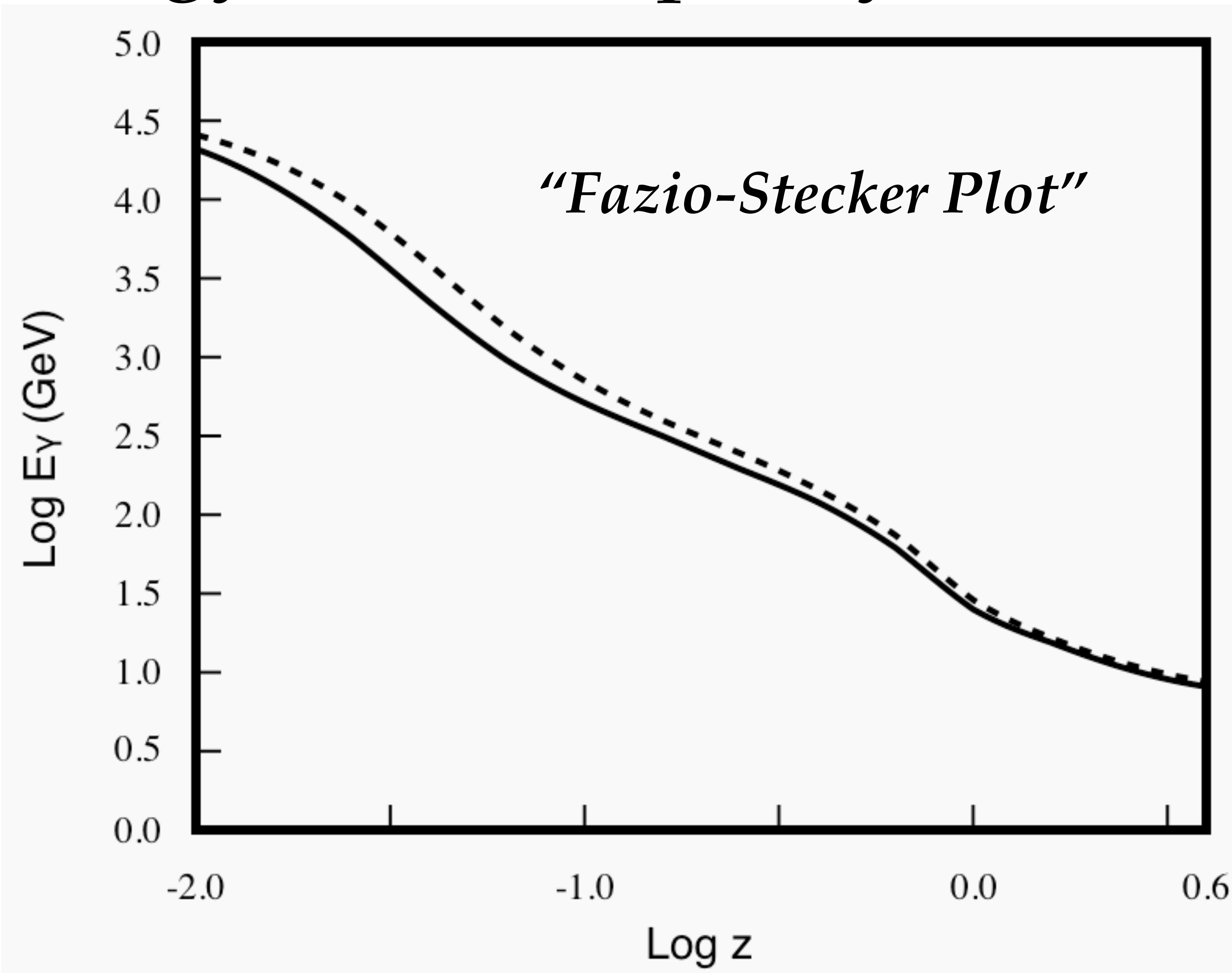
Predicted Photon Density Spectra
(Higher *z* Spectra TBD by Observation)



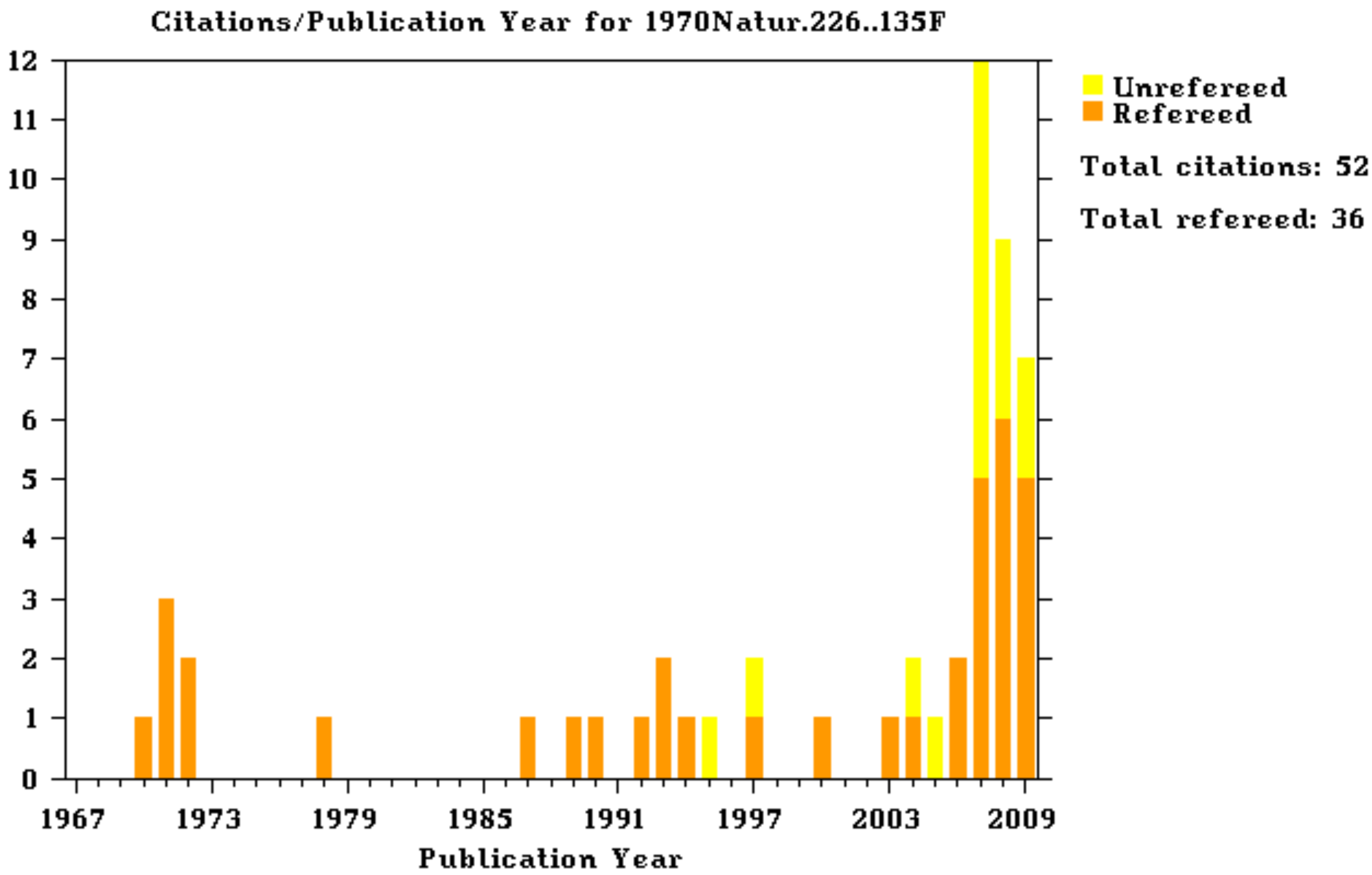
Predicted γ-Ray Optical Depth



Energy Where Opacity $\tau = 1$ *v. z*



Citations to Fazio-Stecker paper



Power-Law to Power-Law Steepening by Absorption*

If the spectrum at the source has the form

$$\Phi_s(E_\gamma) = K\, E_\gamma^{\,-\Gamma_s}$$

the observed spectrum after intergalactic absorption will then have the form

$$\Phi_o(E_\gamma) = K e^{-(A+Bz)}\, E_\gamma^{\,-(\Gamma_s + C + Dz)}$$

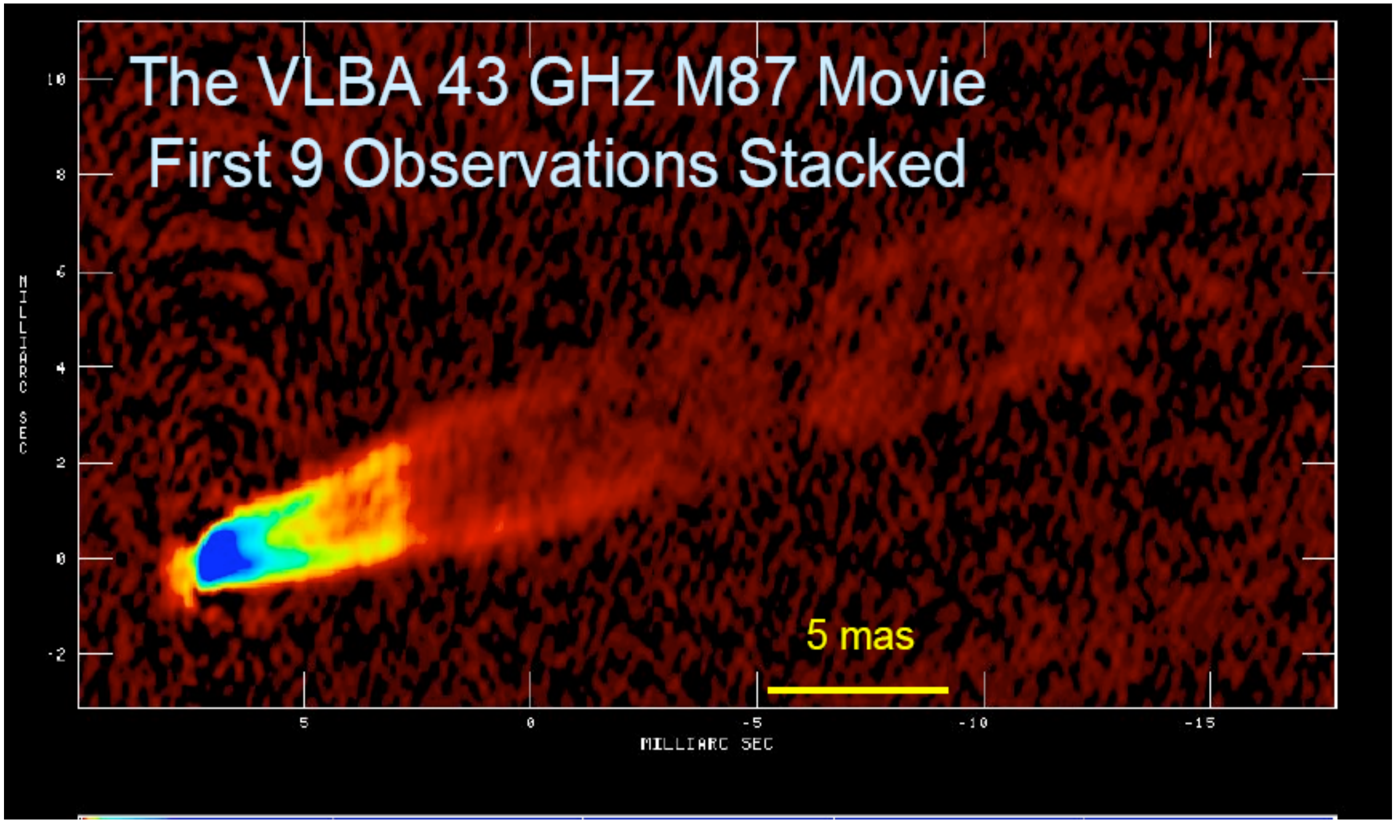
Thus, the spectral index is increased by an amount

$$\Delta\Gamma = C + Dz$$

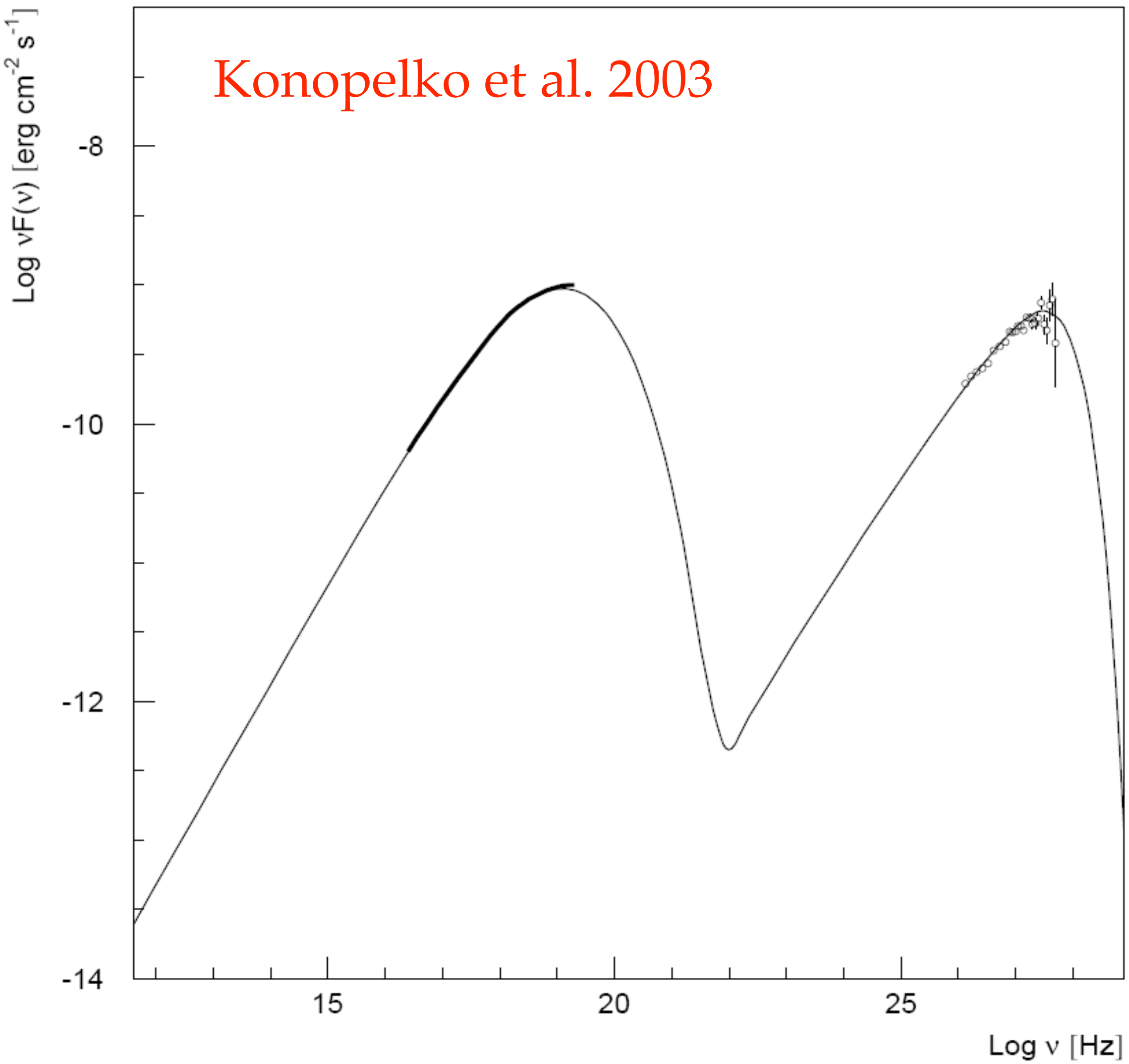
*In the limited energy range 0.2 TeV < E_γ < 2 TeV and the redshift range 0.05 < z < 0.4

Blazars

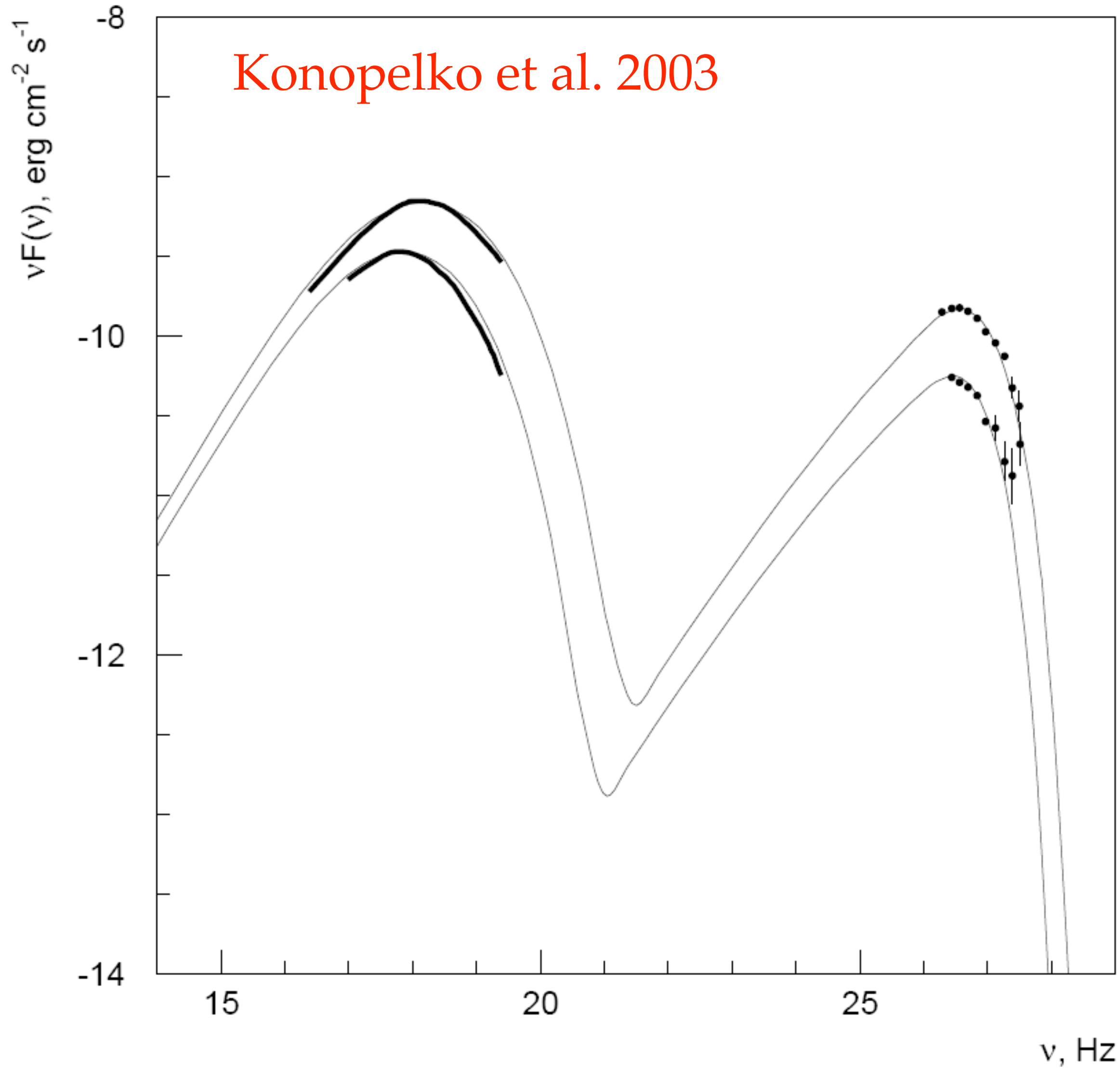
Almost all known extragalactic γ-ray sources are active galactic nuclei called blazars which have their jets pointing towards us



Deabsorbed Mrk 501 Spectrum and Theoretical SSC Model Predictions



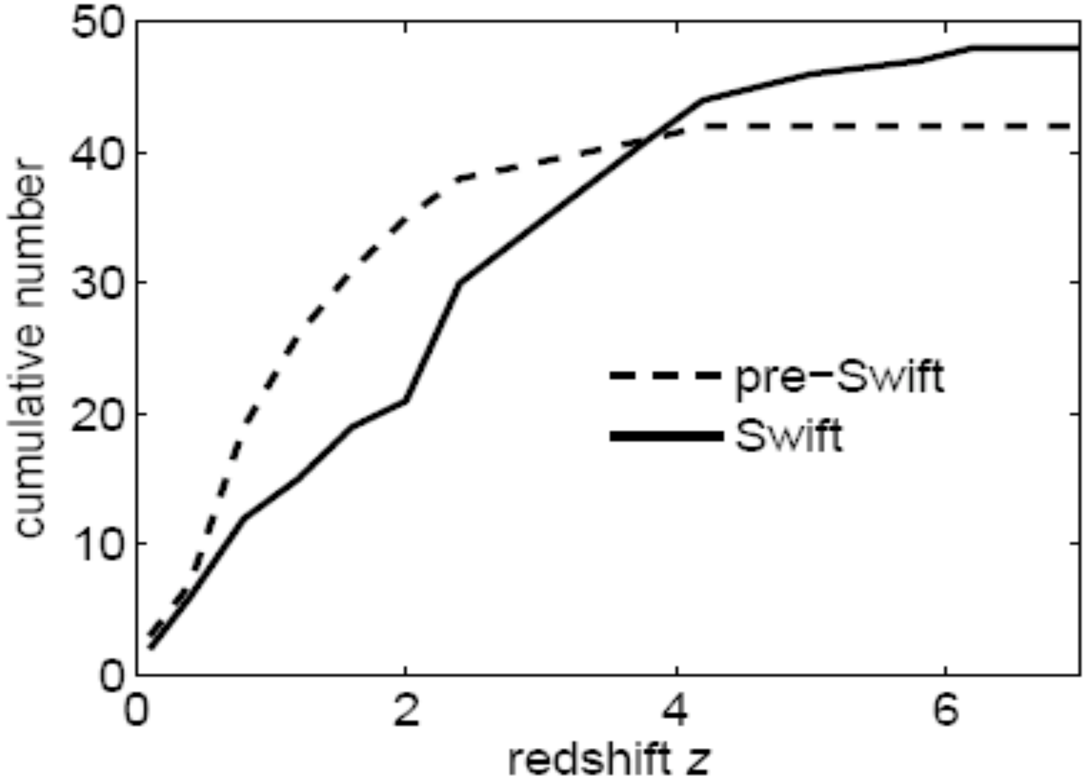
Deabsorbed Mrk 421 Spectra and Theoretical SSC Model Predictions



Questions: What Lurks at the Higher Redshifts?:

- Faint Galaxies
- Protogalaxies (Stellar “Blobs”)

Redshift Distribution of GRBs: More Star Formation at Higher *z*?



Fermi γ-ray Space Telescope

Launch: June, 2008

The *Fermi* Mission

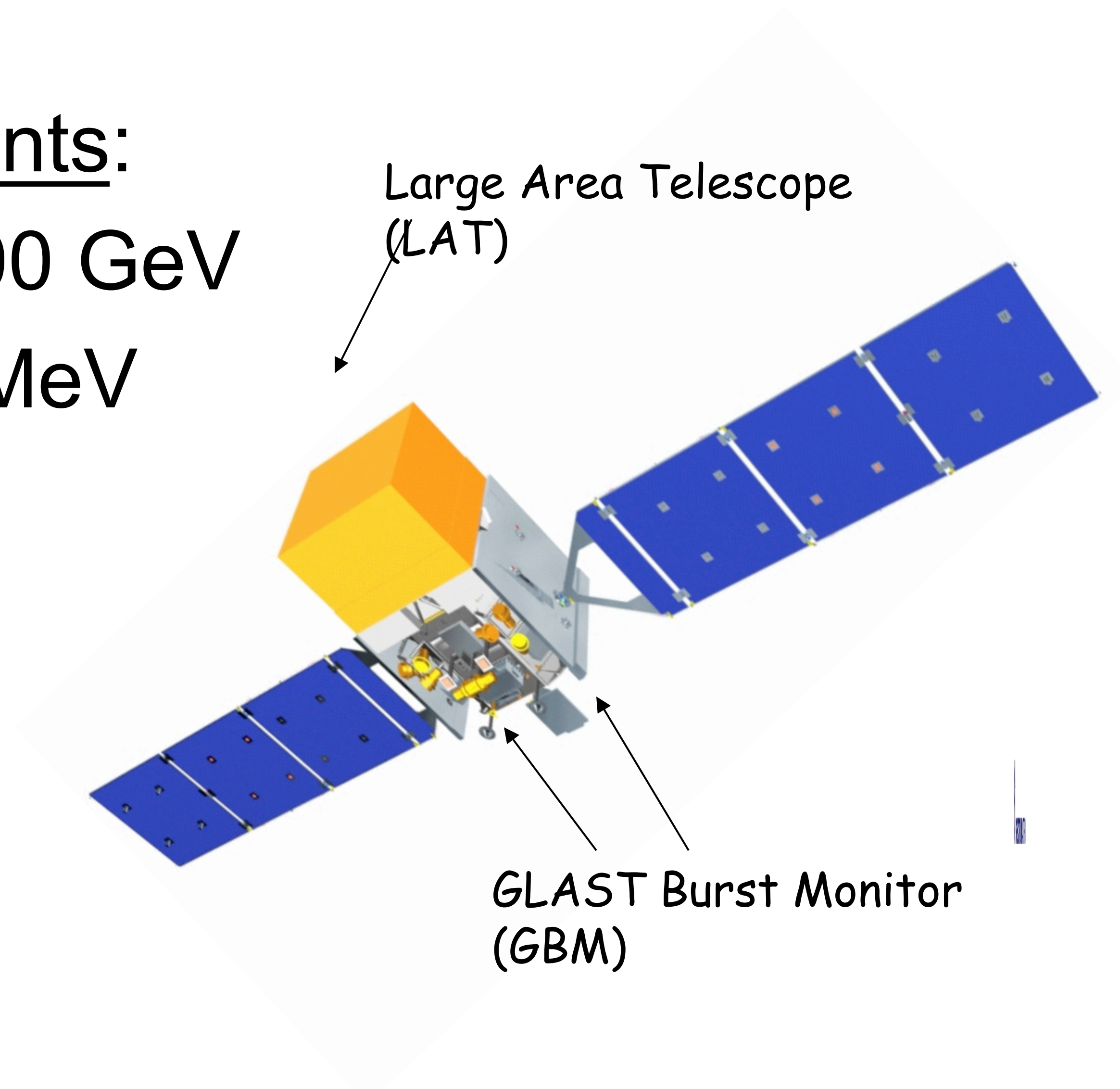
Two *Fermi* instruments:

LAT: 20 MeV – >300 GeV

GBM: 10 keV – 25 MeV

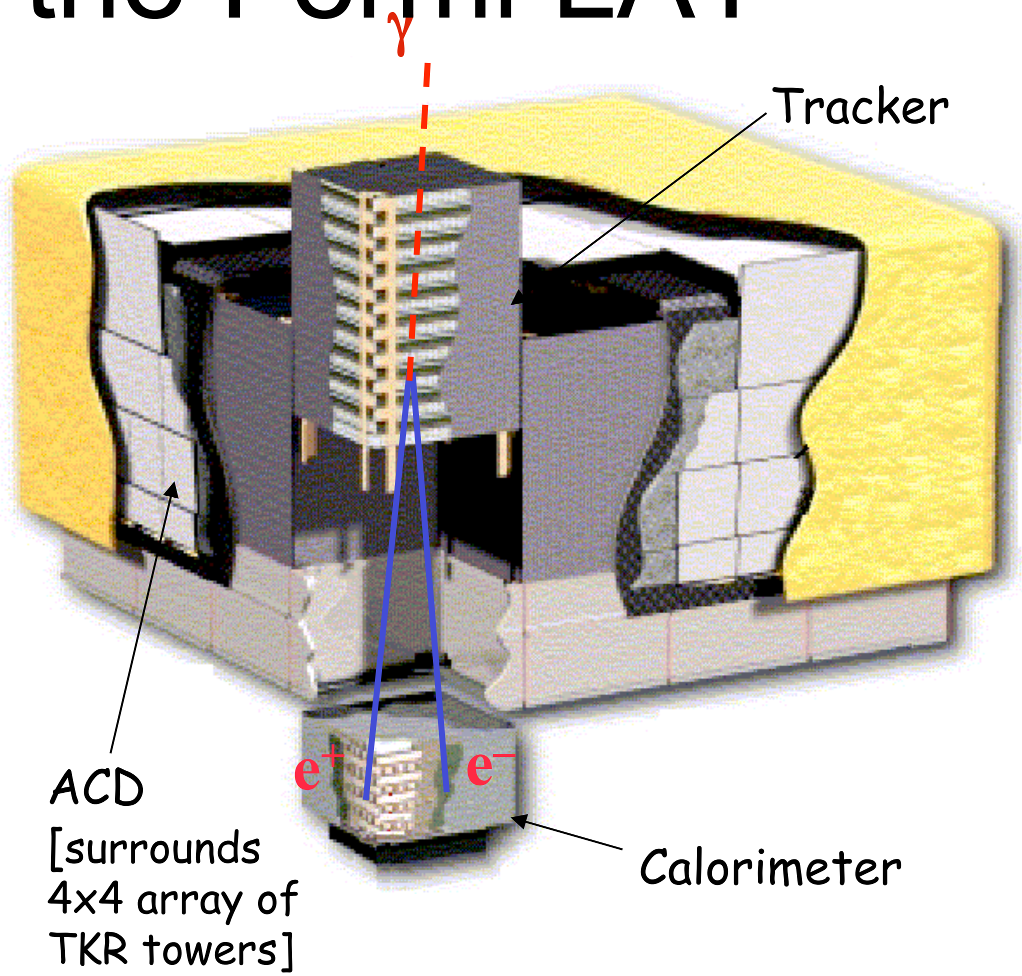
Launch: June 2008

5-10 year mission



Overview of the Fermi LAT

- <u>Si-strip Tracker</u> 18 XY tracking planes. Single-sided silicon strip detectors measure the photon direction
- <u>Hodoscopic CsI Calorimeter(CAL)</u> Array of 1536 CsI(Tl) crystals in 8 layers. Measure the photon energy; image the shower.
- <u>Segmented Anticoincidence Detector (ACD)</u> 89 plastic scintillator tiles.



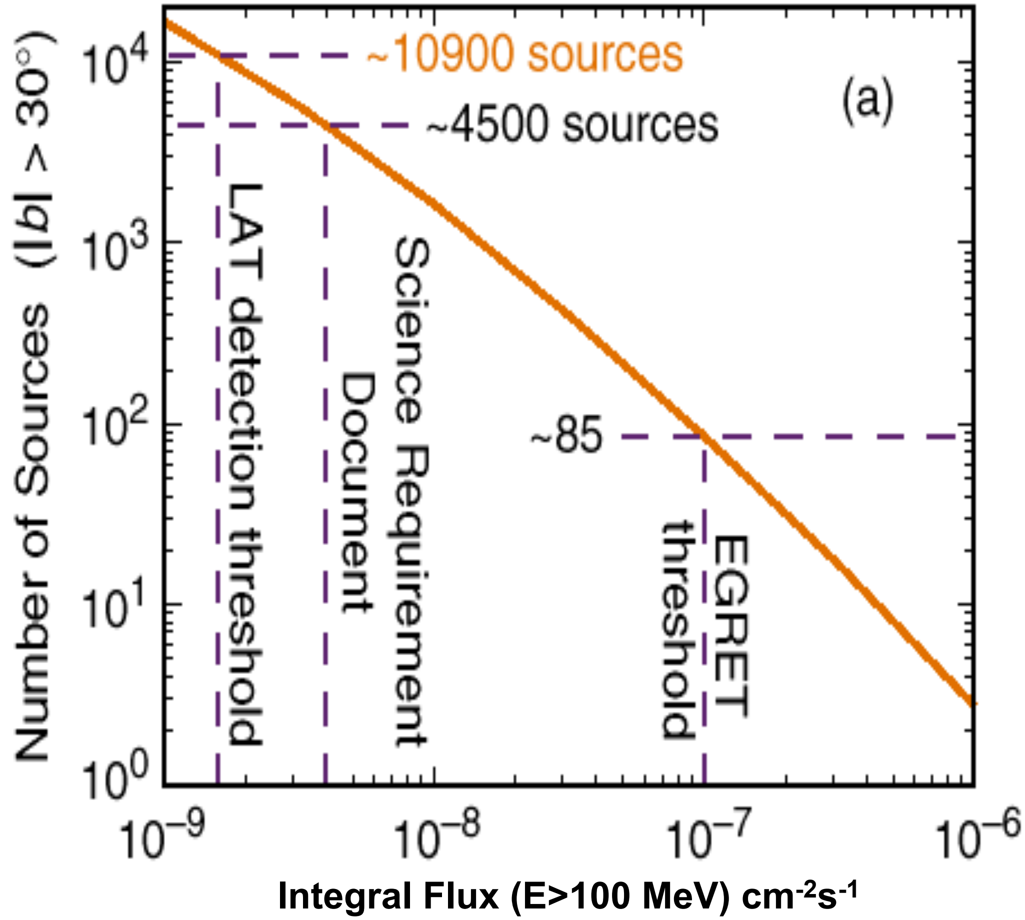
<u>Systems work together to identify and measure the flux of cosmic gamma rays with energy 20 MeV - >300 GeV.</u>

AGN: What *Fermi* will do

EGRET has detected ~ 90 AGN --

GLAST should expect to see dramatically more– in fact, THOUSANDS :

(Stecker & Salamon 1996, ApJ 464, 600)



Archaeological Goals for *Fermi*

- Look for sharp cutoffs in the Energy Range above ~10 GeV in High-Redshift Blazar Spectra to Probe Fossil Intergalactic Background Radiation from Early Galaxies (both seen and unseen).

- Use Cutoffs in Unidentified Source Spectra to Determine Redshifts of High-Redshift Sources