Kavli Institute
for Cosmological Physics
AT THE UNIVERSITY OF CHICAGO

Fermi
Gamma-ray
Space Telescope

EBL Studies with the Fermi Gamma-ray Space Telescope

Luis C. Reyes
KICP

The Extragalactic Background Light (EBL)

- *What is it?*

➢Accumulation of all energy releases in the form of electromagnetic radiation. It includes everything but CMB and the foreground emission from anything local (Milky Way, Solar System, etc.)

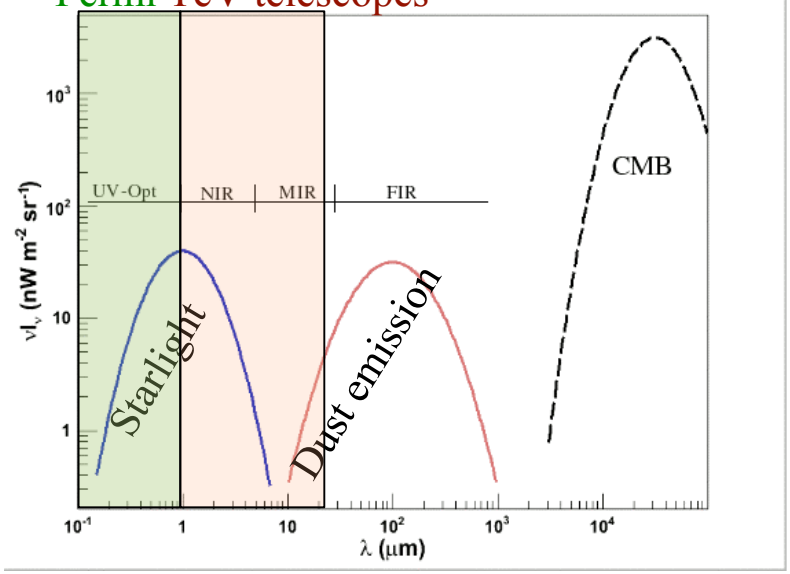
- *Why is it important?*

➢Contains information about the evolution of matter in the universe: star formation history, dust extinction, light absorption and re-emission by dust, etc.

➢Knowledge of the EBL is necessary to infer the actual spectra of extragalactic gamma-ray sources.

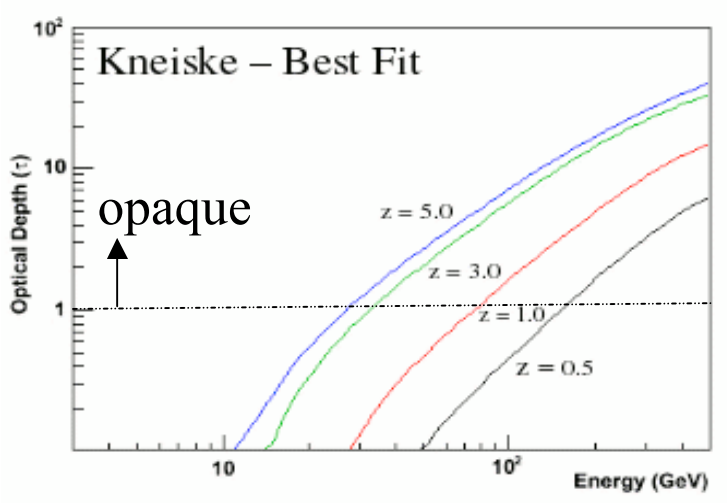
- Direct measurements of the EBL are very difficult because of foreground subtraction
- EBL **evolves** due to star formation, absorption and re-emission of light by dust

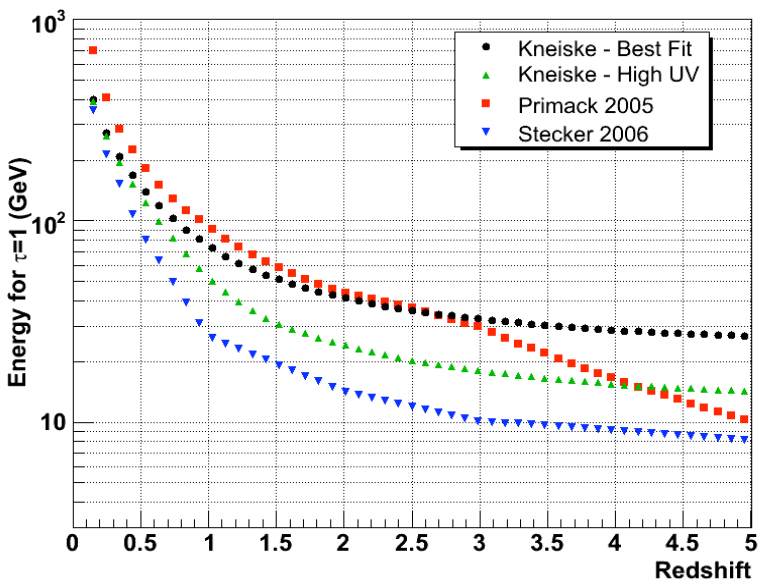
Fermi TeV telescopes



Primack, Bullock, Somerville (2005)

Optical Depth Predictions From Different EBL Models





- Models make very distinguishable predictions
- The universe is "optically thin" to γ-rays with energy below 10 GeV
- At moderate to high redshifts (z~1-5) the optical depth is dominated by the UV part of the EBL (i.e. it depends on the star formation rate and the effects of dust extinction), which is not well constrained. Measurement of the EBL at these redshifts is needed.
- Gamma-ray instruments with a threshold much lower than ~100 GeV are required to probe the EBL at cosmological distances (z >~ 1).

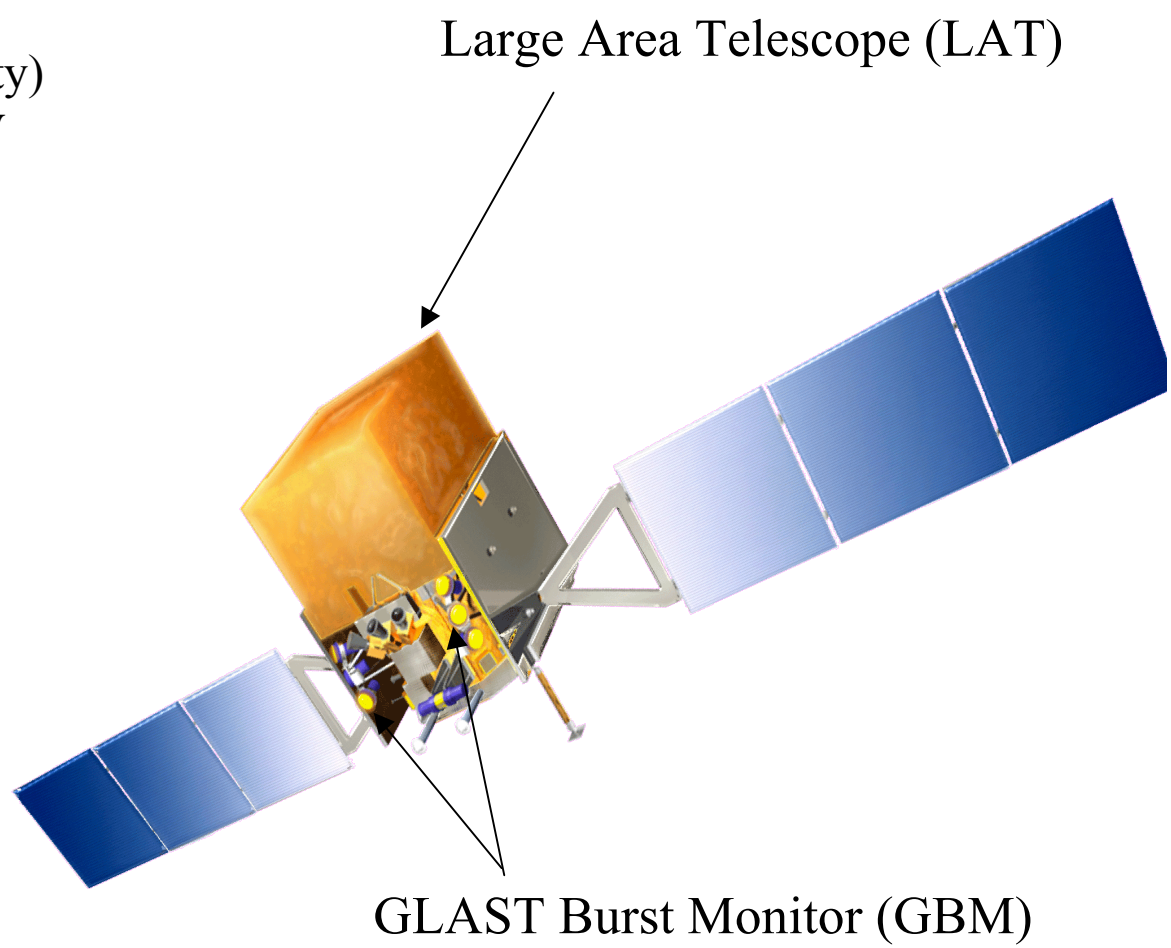
The Fermi Gamma-ray Space Telescope

Two Instruments:

Large Area Telescope (LAT)
PI: P. Michelson (Stanford University)
Energy range: 20 MeV - >300 GeV
Field of view: > 2 sr

GLAST Burst Monitor (GBM)
PI: C. Meegan (NASA/MSFC)
Co-PI: G Lichti (MPE)
Energy range: 8 keV – 30 MeV
Field of view: > 8 sr

Launch: June 11th, 2008
Lifetime: 5 years (req)
10 years (goal)

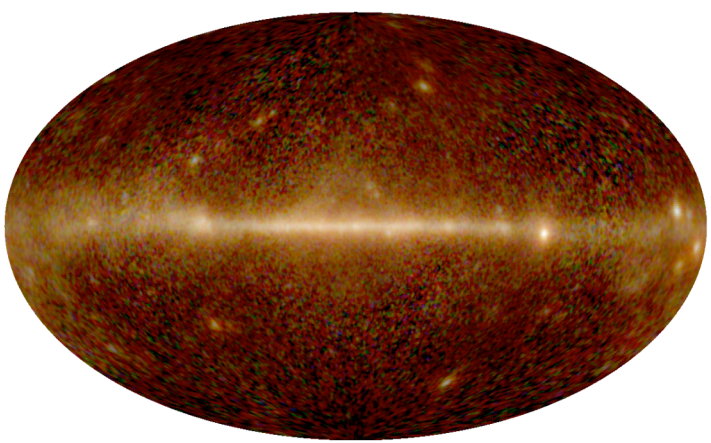


Fermi LAT Performance

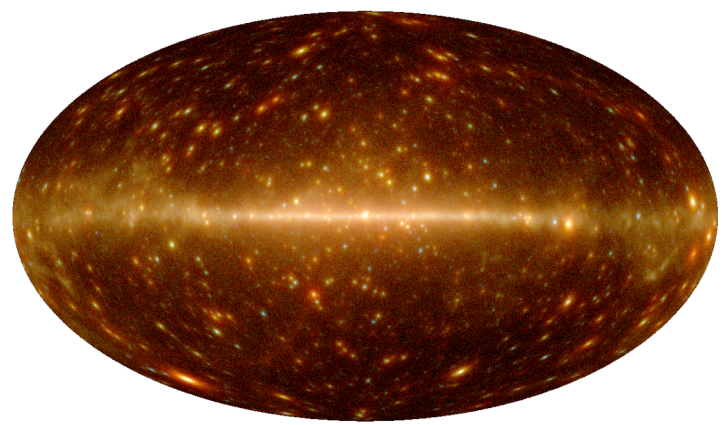
Background rejection and event selection cuts can be optimized for specific science goals.

	Fermi LAT	EGRET
Energy Range	20 MeV - >300 GeV	30 MeV – 10 GeV
Energy Resolution	10 %	10 %
Peak Effective Area	~10000 cm^2	1500 cm^2
Field of View	>~2 sr.	0.5 sr.
Angular Resolution	3.5°@100MeV 0.1°@10 GeV	5.8°@100 MeV 0.5°@10 GeV
Sensitivity >100 MeV	4×10^{-9} cm^{-2} s^{-1}	~10^{-7} cm^{-2} s^{-1}
Deadtime per event	27 µs	100ms

EGRET (~9 years):



Fermi (1 year):

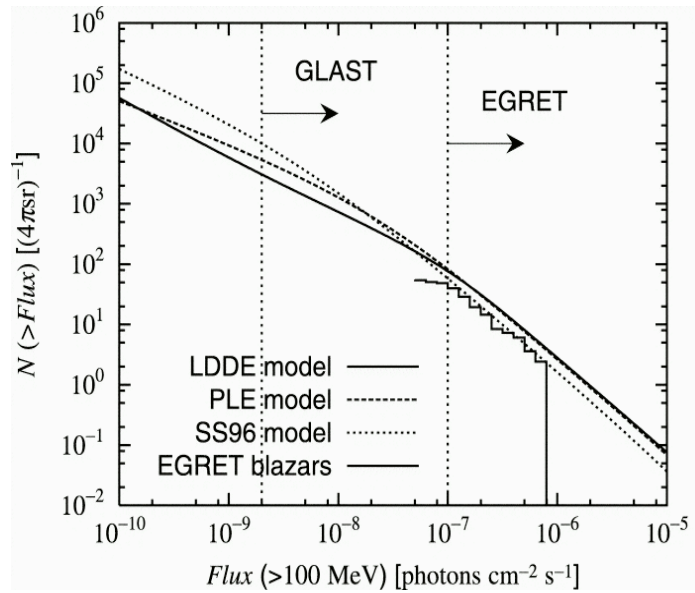


The Impact of Fermi on EBL Studies

In general, Fermi's improved performance with respect to EGRET will lead to:

- Study of the previously unexplored region 10 GeV < E < 300 GeV, where EBL attenuation is relevant
- More detected blazars
- Better understood blazars

Expected number of detected blazars:



Narumoto & Totani (2006)

Relevant to EBL studies:

- No attenuation is expected for γ-rays with energy below 10 GeV, therefore EBL attenuation will not limit GLAST's ability to detect blazars at high redshift.
- GLAST-detected blazars will be distributed over a wide range of redshifts, thus GLAST will probe the evolution of the EBL.
- For the first time: study the systematic effect of EBL attenuation as a function of redshift thanks to the large number of blazars

Method 1: Flux-ratio

Chen, Reyes and Ritz. ApJ, 608, 686 (2004)

To measure the attenuation of γ-ray emission by EBL absorption the following ratio is calculated:

$$\frac{F\,(E\,>\,10\,GeV)}{F\,(E\,>\,1\,GeV)}$$

- Simple to calculate
- F(E>10 GeV) is sensitive to EBL attenuation for 0<z<5 given the expected EBL density.
- The ratio is independent of blazar brightness.
- Without EBL attenuation the flux ratio depends on the spectral index only. Mean ratio = ~0.07
- Still useful with rolloffs above 50 GeV at the source.

A statistical treatment of the spectra from a large number of blazars filters out the intrinsic peculiarities of the individual sources and leaves behind the EBL attenuation (with some caveats addressed later).

MonteCarlo Simulation

- Number of blazars GLAST will observe

  For each blazar:
  - Redshift
  - Luminosity
  - Position in the sky
  - Spectral index(distributed as Gaussian: -2.15±0.04)

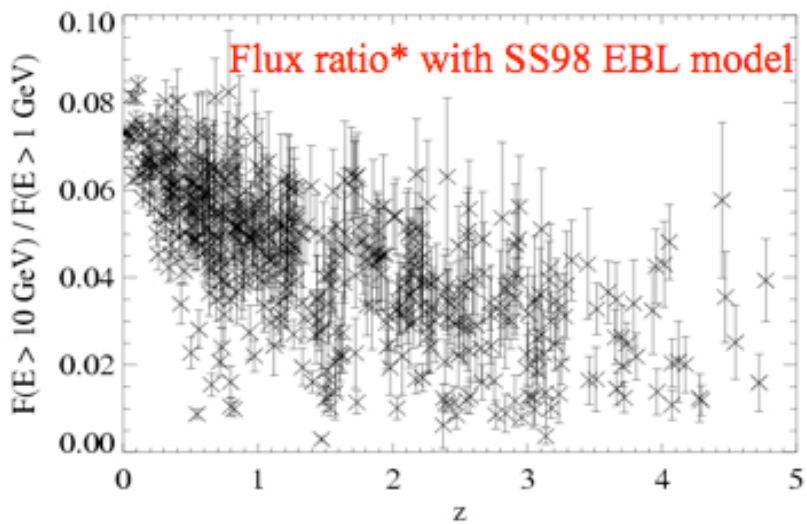
↓

Flux with:
- Attenuation by EBL absorption
- Galactic and Extragalactic background

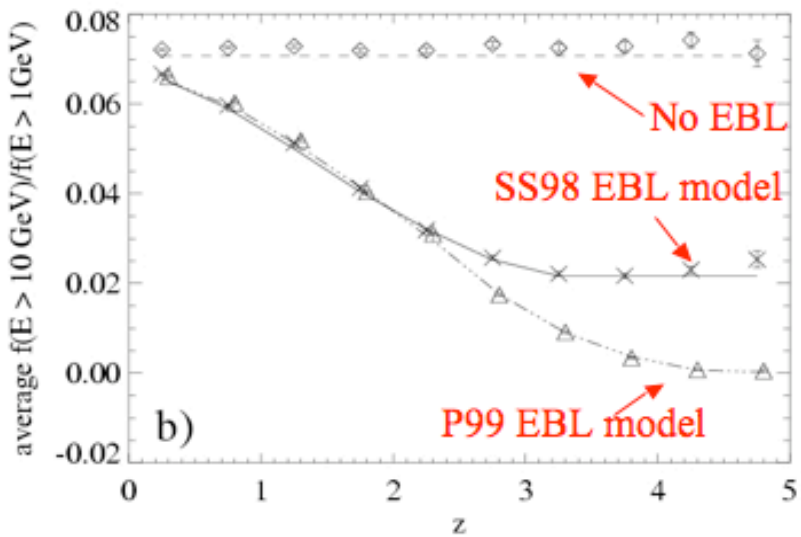
↓

Observational Selections:
- $|b| > 10°$
- Flux > 5σ above background at 1 GeV

Simulation Results



*Only 1/20 of the data points is shown in the top plot for clarity



- EBL attenuation is evident
- The technique can distinguish between different EBL models
- If sources are available, EBL absorption can probe the high-redshift universe.

SS98: Salamon & Stecker (1998)
P99: Primack et al (1999)

Method 2: Spectral Analysis of Bright Blazars

- Measuring the blazar steepening due to EBL absorption through spectral fits of individual sources

- Systematic steepening as a function of redshift provides a signature of the effects of intergalactic absorption by the EBL

- This method has advantages and disadvantages with respect to the flux-ratio method:

Advantages:

- Less sensitive to scattering in the spectral index distribution of blazars
- A smaller number of blazars (the brightest) is required to make a statement about the effects of EBL absorption.

Disadvantages:

- More sensitive to selection effects (discussed later under caveats)
- Lower number of sources available at high redshifts.

Montecarlo Simulation

1 year-long simulation of:

- 105 identified blazars from the 3rd EGRET catalog
- Other bright blazars (~200) from Giommi et al. synthesis code with a γ-ray flux over 1.5×10^{-7} $cm^{-2}s^{-1}$
- Blazar variability (in flux and spectral index)
- Galactic diffuse emission according to the GALPROP model by Moskalenko et al
- Extragalactic diffuse background with intensity 1.55×10^{-5} $cm^{-2}s^{-1}sr^{-1}$ (E > 100 MeV), which is consistent with the EGRET measurement.

Spectral Fit

- ExpCutoff is used to model the point sources (blazars):

$$\frac{dN}{dE} = P \quad \text{x} \quad \begin{cases} \left(\frac{E}{S}\right)^{-\alpha} & ; \quad if \quad E < E_b \\ \left(\frac{E}{S}\right)^{-\alpha} \times \boxed{\exp(-(E-E_b)/P_1)} & ; \quad if \quad E > E_b \end{cases}$$

Parameters:

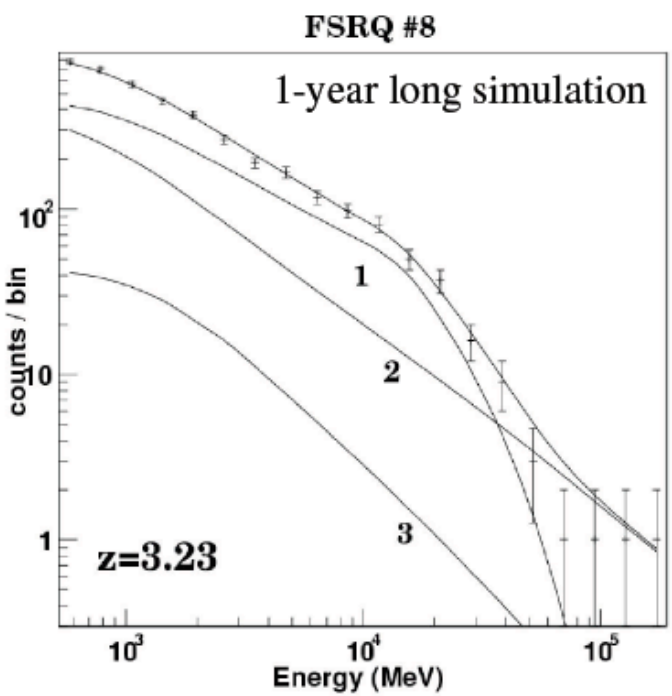
$P \rightarrow$ Prefactor

$S \rightarrow$ Scale factor

$\alpha \rightarrow$ Index

$E_b \rightarrow$ "Break" energy (GeV)

$P_1 \rightarrow$ Attenuation Scale



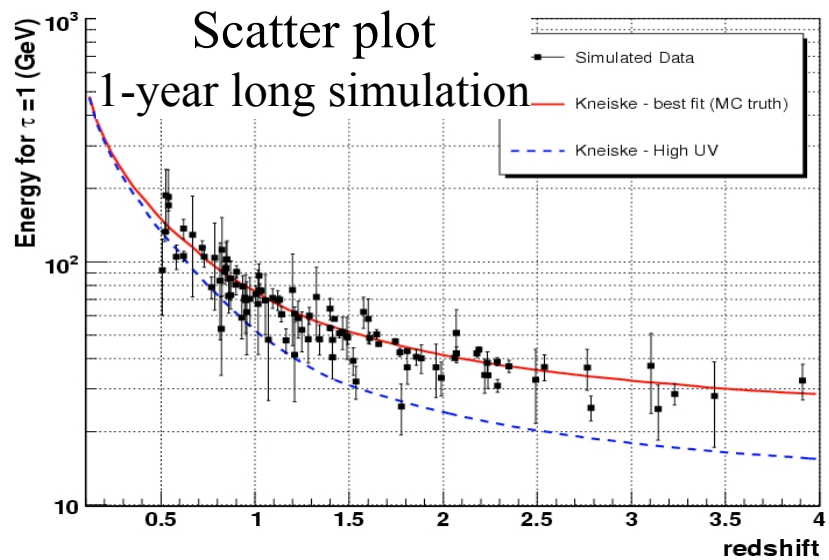
- The unattenuated spectrum of the blazar is assumed to be a simple power law
- It is simple and sensitive to steepening of the spectrum of dim sources.
- Galactic and extragalactic diffuse are considered

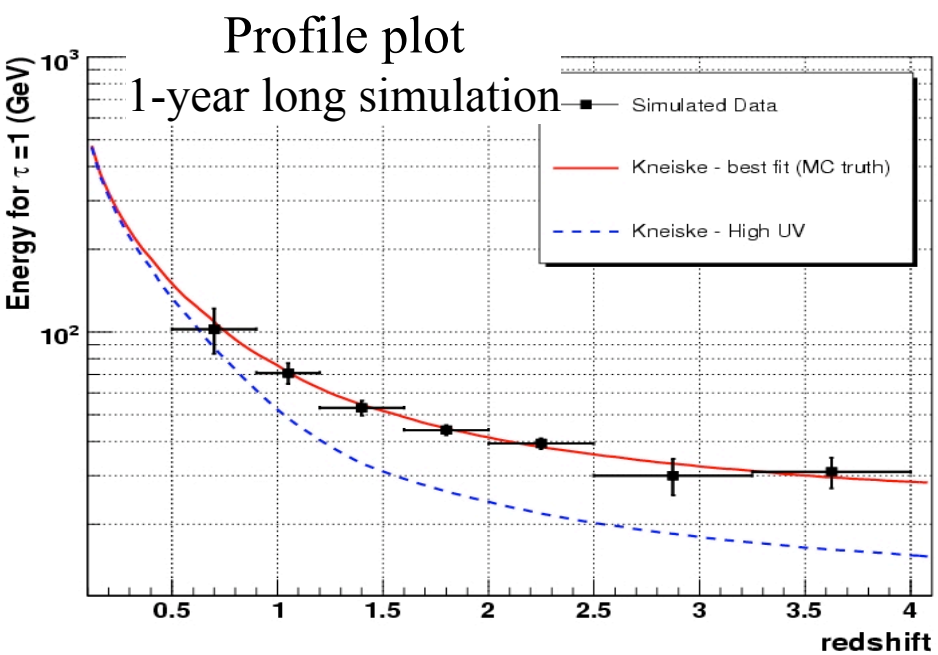
1. Blazar spectrum with exponential cutoff
2. Extragalactic diffuse
3. Galactic diffuse

Fazio-Stecker Relation

The observed spectral steepening (as measured from the maximum likelihood fit) can be used to characterize the optical depth:

- Cutoff energy $\tau(E_o,z) = 1$





The data points in the FSR plot will converge -amid statistical fluctuations- to the true curve $\tau(E, z) = 1$ due to EBL absorption.

Combining the data into redshift bins

Caveats

- Sources of bias:
  - Selection effects:
    - Source misidentification
    - Internal absorption could be more common in high luminosity sources:
    high luminosity = high accretion rate -> strong radiation fields -> intrinsic absorption

- Blazar variability:
  spectral variability could lead to a bias in the energy cutoff determination
  different flaring states of the same blazar -> same cutoff energy? (cross check)

- Blazar evolution could mimic EBL attenuation (Reimer 2007)
  Did blazars in the early universe suffer more internal absorption?

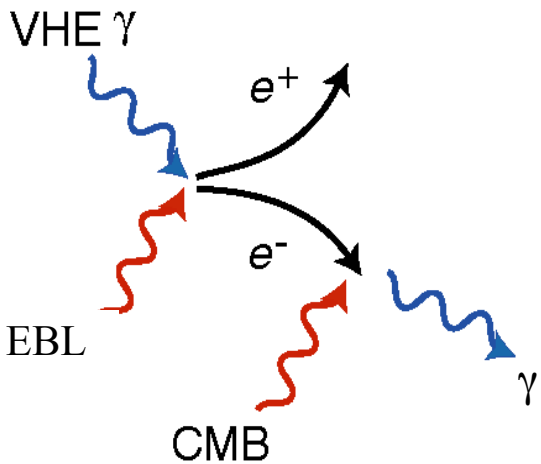
- Redshift determination:
  Measuring the redshift of hundreds (maybe thousands) of new blazars is a formidable task

Related EBL Phenomena

- EBL attenuation of gamma-ray bursts (GRBs)
  (same EBL, but different sources and systematics)

- Effects of the EBL attenuation on the gamma-ray extragalactic diffuse (spectral steepening of the diffuse is expected... how much will tell us about its origin)

- Gamma-ray cascades:
  (Dai et al 2002, Aharonian, Coppi, Volk 1994)
  - could become a probe of the intergalactic magnetic field and UHE gamma-ray universe
  - All of these at the end is dumped into the extragalactic diffuse



Kavli Institute for Cosmological Physics AT THE UNIVERSITY OF CHICAGO

Fermi Gamma-ray Space Telescope

- Relevant physical quantities:
  - gamma-ray spectrum of the source
  - Intergalactic Magnetic Field
  - EBL spectra

- VHE γ rays are absorbed quickly by the EBL and the direction of the resulting pair is randomized by the magnetic field (if strong enough ~10^{-9} G). Compton-upscatter photons are emitted isotropically (Aharonian, Coppi & Volk, 1994)
  - EM halo is formed around the sources
  - Off-axis radio-loud galaxies become candidates for faint γ-ray emission
  - Many halos overlapping will contribute to the ExtraGalactic Diffuse γ emission.

- If the original γ rays are absorbed over cosmological distances (E < 100 GeV) then the observer might be inside the halo, therefore contributing to the ExGal Diffuse)

- γ−rays are absorbed by the EBL but the magnetic field is not strong enough (~10^{-17} G) to randomize the direction of the e-pair. Secondary GeV emission will follow the original TeV emission with some delay due to angular spreading time (Dai et al, 2002)

Conclusions

- Under reasonable assumptions, Fermi will measure the EBL attenuation of blazars and thus, probe the optical-UV EBL

- The large number of Fermi-detected blazars would allow a new approach to EBL studies: systematic attenuation as a function of redshift

- If enough sources are observationally available at high redshifts ($z>3$), EBL attenuation of distant gamma-ray sources could become a cosmological probe of the early processes of star formation

- Blazar evolution could mimic the effect of EBL attenuation and thus, needs to be considered. Fermi observations in any case will provide an important constraint