EBL :

1. Models
2. Detecting the attenuation of Blazars by EBL

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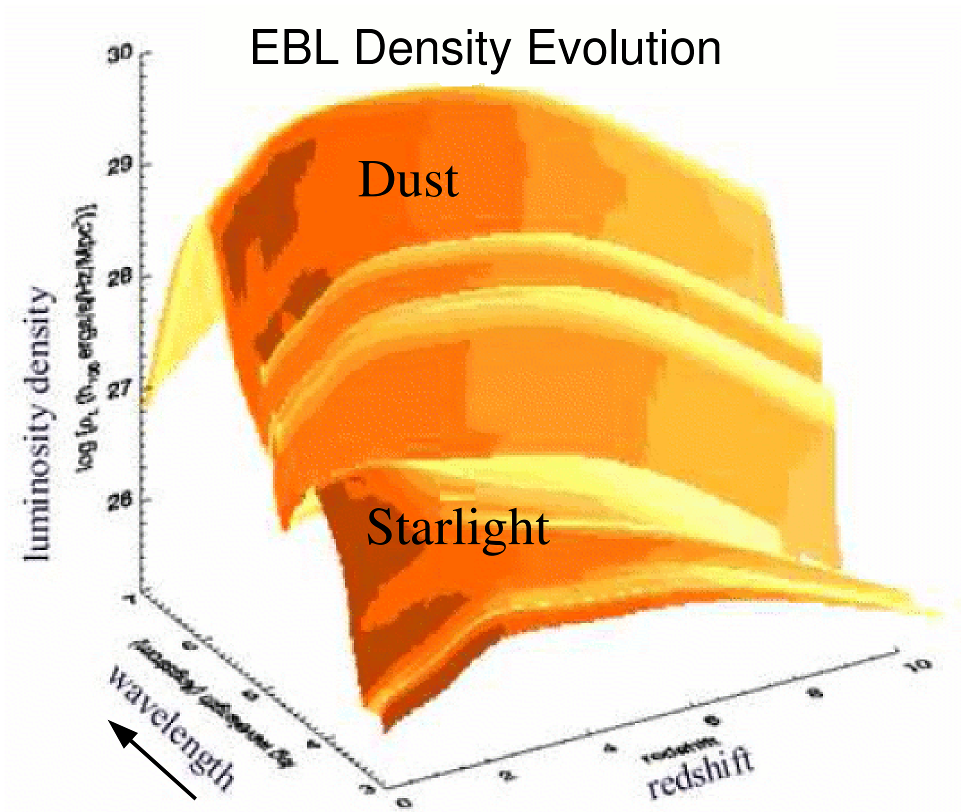
EBL Attenuation

For a given source at redshift z:

$$F_{observed} = e^{-\tau(E,z)} F_{intrinsic}$$

$\tau \sim 0$ for $E < \sim 10$ GeV

with
$$\tau_{\gamma\gamma}(E_\gamma, z_q) = c \int_0^{z_q} \int_0^2 \int_{\epsilon_{gr}}^{\infty} \frac{dl}{dz'} \frac{\mu}{2} \cdot \underbrace{n(z,\epsilon)}_{\text{only unknown quantity}} \cdot \sigma_{\gamma\gamma}(E_\gamma, \epsilon, \mu, z')\, d\epsilon\, d\mu\, dz'$$

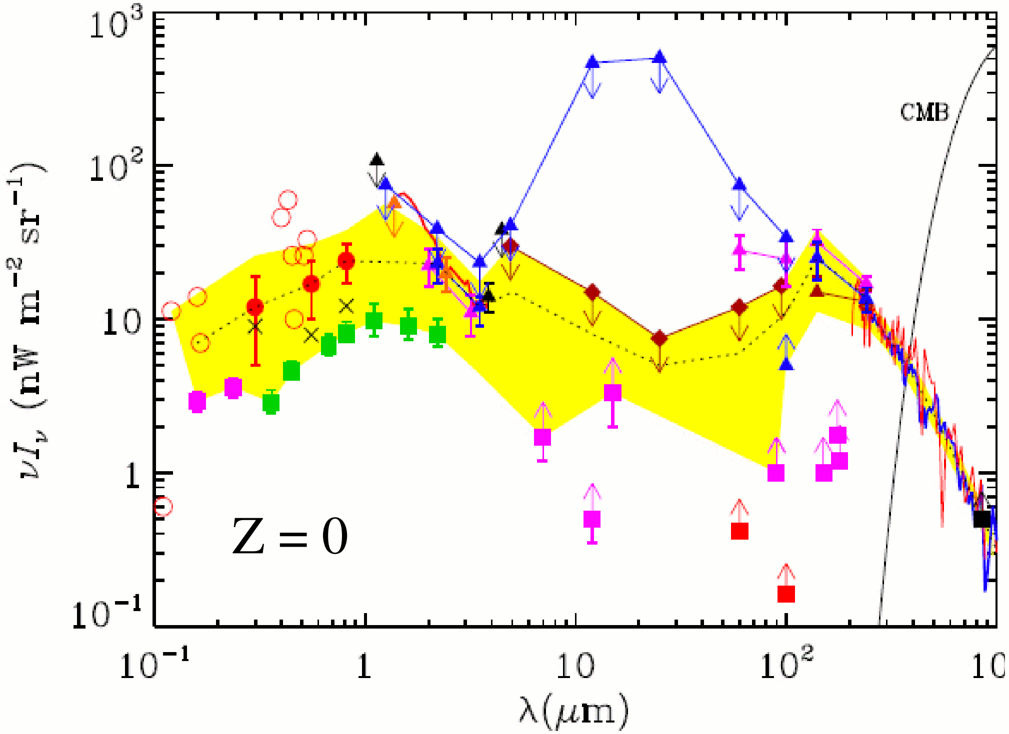


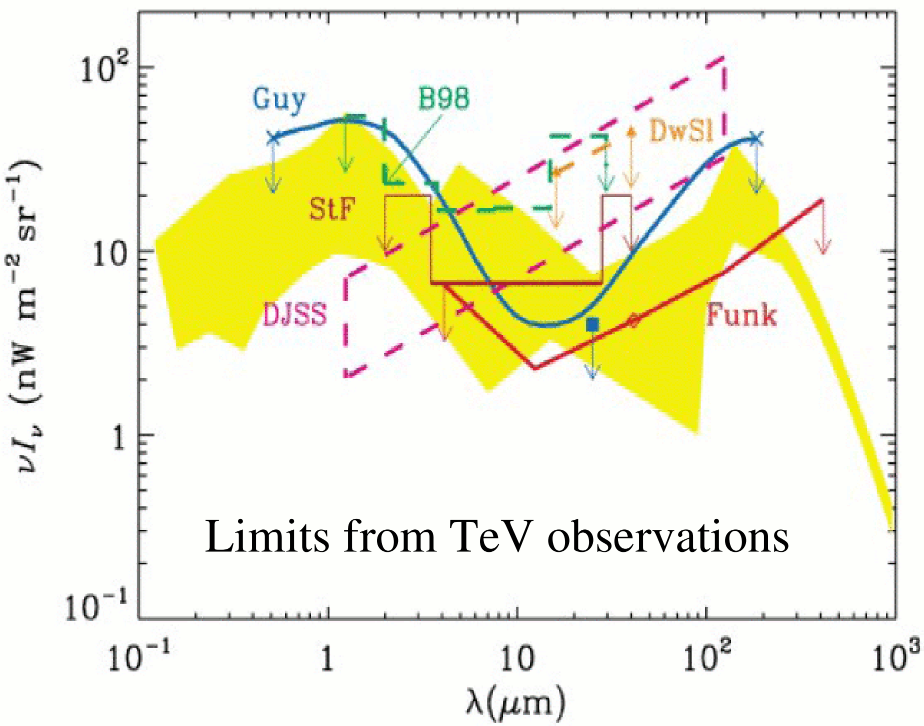
Primack, Bullock, Somerville. AIP Conf. 745, (2005)

- Opacity of the universe to GLAST gamma rays probes the <u>EBL evolution history.</u>
- For TeV blazars, the EBL evolution is usually ignored since all the blazars are nearby. Not the case for GLAST

EBL Data

Hauser & Dwek. Ann Rev Astron. Astrophys. 39, 249, (2001)





- In general, the measurements can be classified as:
  - Absolute lower limits from integrated light from galaxies
  - Claimed detections after foreground subtraction
  - Upper limits from observation of TeV sources

- γ-ray attenuation reported by HESS of distant TeV blazars (z ~ 0.17) suggests an EBL density just above the lower limits in the optical and near-infrared (astro-ph 050873)

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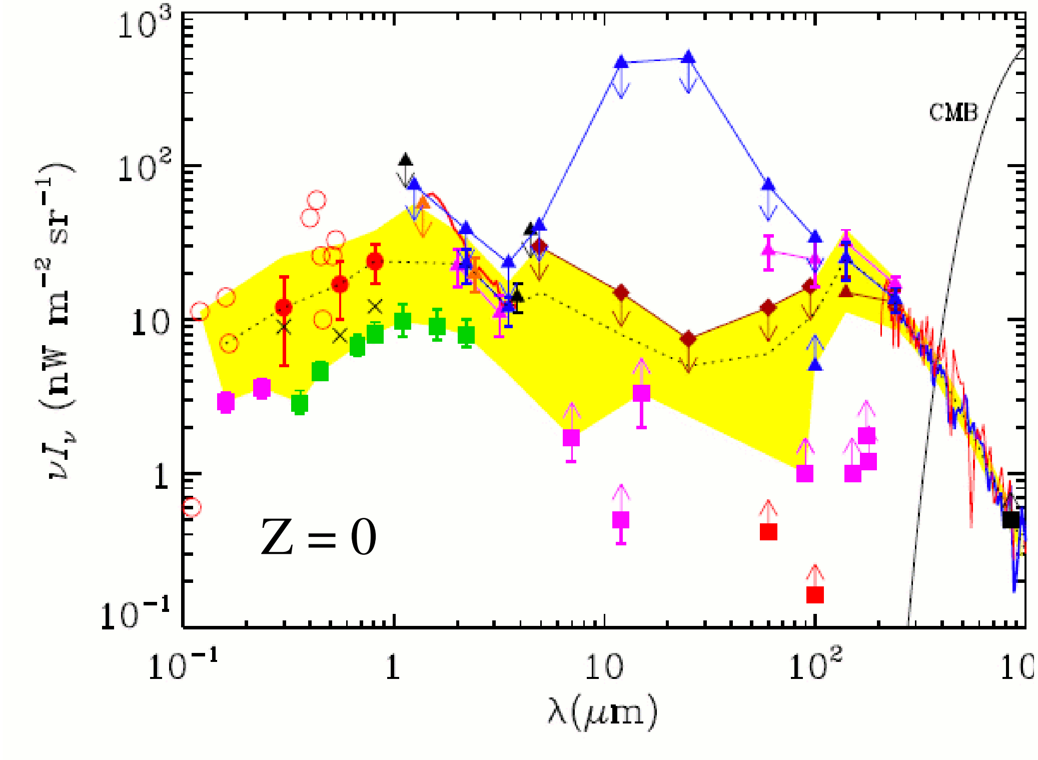
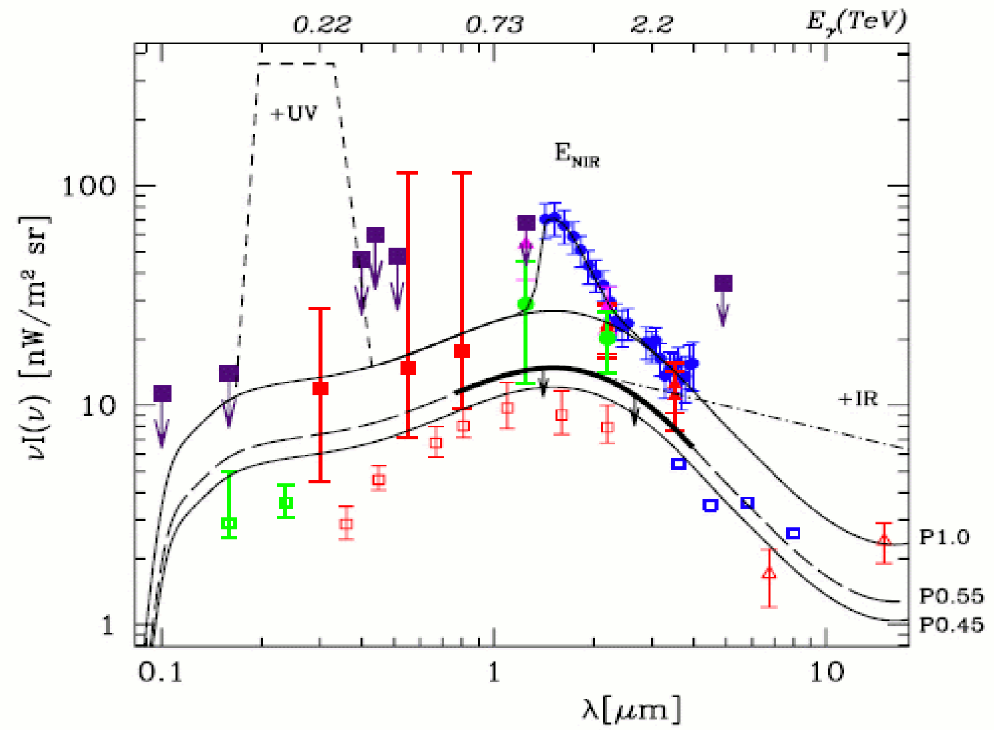


Aharonian et al (astroph 050873)



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EBL models come in flavors...

1a) Backward Evolution Models

- Extrapolate spectral properties of local galaxies back in time (luminosity evolution, density evolution, etc..)

1b) Cosmic Chemical Evolution Models

- Relates the history of averaged properties of the universe to mean density of stars, interstellar gas, metals and ultimately EBL.

2a) Forward Evolution Models

- Follow the evolution of stellar populations and calculates the stellar, gas and chemical composition of a galaxy. Free parameters are constrained to reproduce observed universe

2b) Semi-Analytical Models (SAMs)

- Provide a physical approach to the formation and evolution of galaxies including stochastic processes (galaxy mergers)
- Free parameters to match observed universe

What models are currently available in GLAST software?

1) Kneiske et al "Best fit" model

Kneiske, Bretz, Mannheim, Hartmann A&A 413, 807-815 (2004).

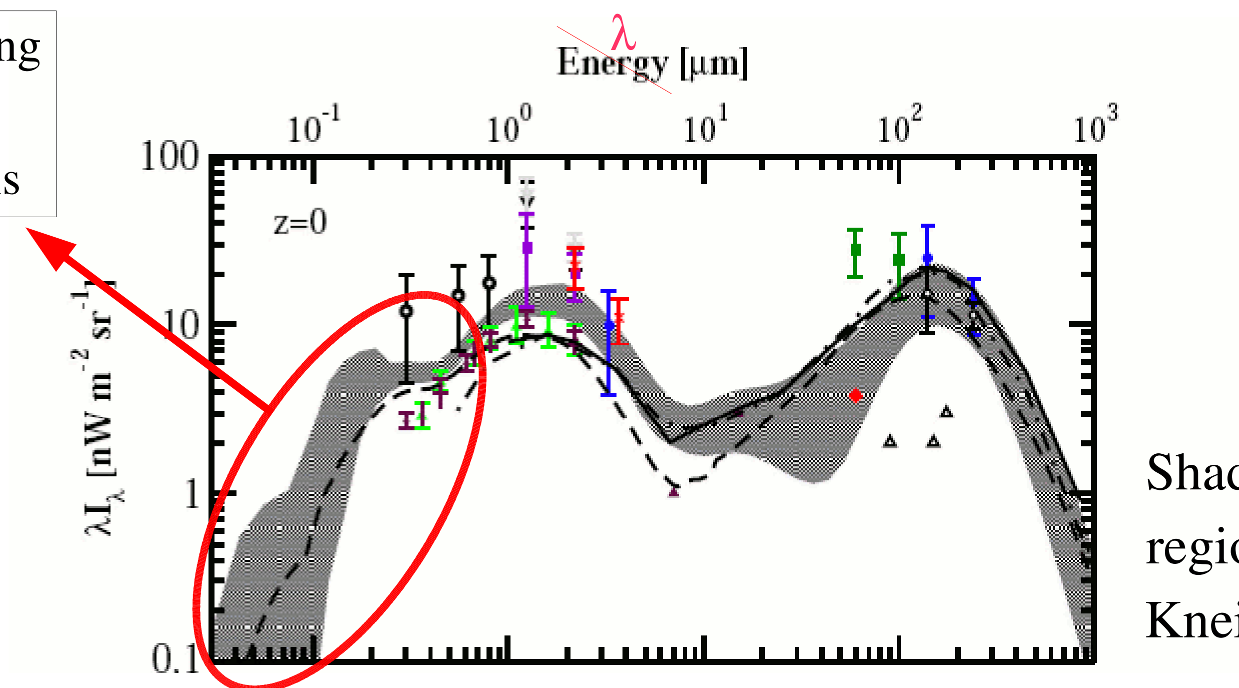
- Semi-empirical, forward-evolution for optical-UV
- Backward evolution for the infrared

Once the additional "Low SFR(Star formation rate)" and the "High-Stellar-UV" models from this paper are implemented, we will bracket two main observational uncertainties:

i) Redshift dependence of the star formation rate

ii) Fraction of UV radiation released from star forming regions

GLAST is going to be really sensitive to this



Shaded area denotes the regions bounded by Kneiske's models.

2) Primack et al model (1999)

Primack, Bullock, Somerville, McMinn, Astropart. Phys., 11, 93 (1999).

- Semi-Analytical Model (SAM)
- The most recent version (2005) of the model from the same authors finds a lower EBL density.

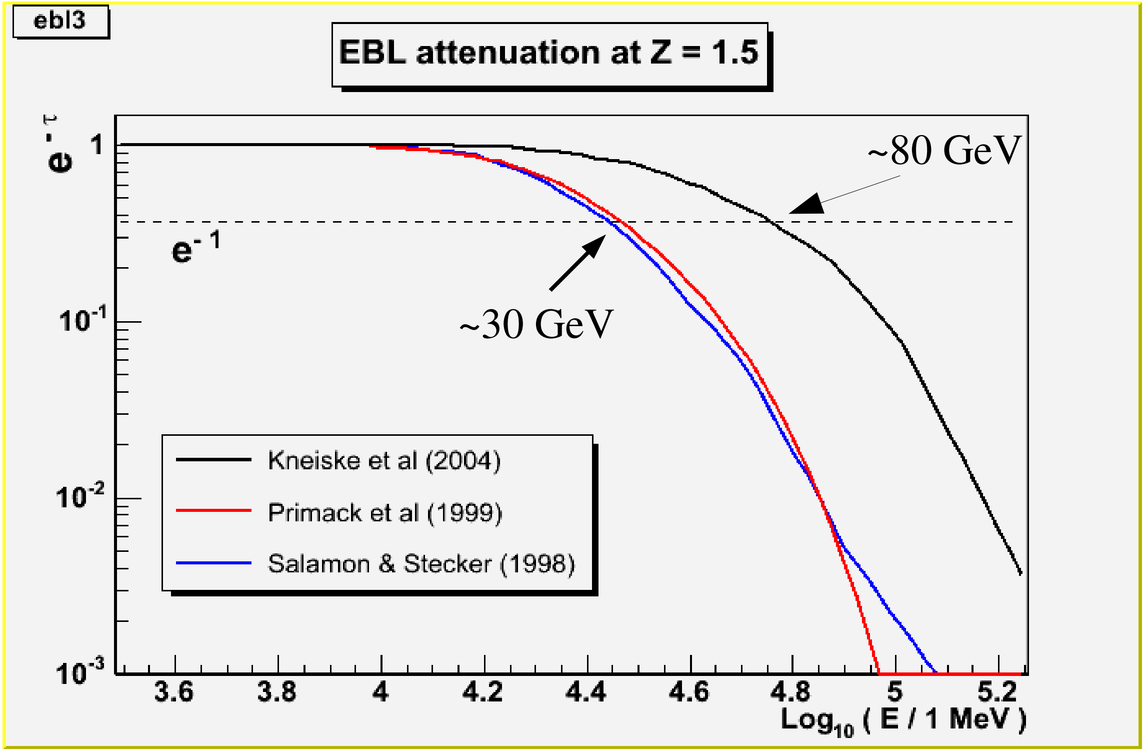
3) Salamon & Stecker model (1998)

Salamon, Stecker. ApJ 493, 547 (1998)

- Based on the cosmic chemical evolution model by Fall et al (1996)

4-7) Other models are available from Stecker & de Jager (2002) and Primack et al (1999, 2004). They are not really suitable for GLAST since they are valid only for z < 0.3 or E > 100 GeV.

Ebl attenuation for a source at z = 1.5 according to the currently implemented models:



What models are next?

- “Low SFR” and “High-UV” models from Kneiske et al.
- Primack et al (2005). James Bullock just provided us with the data, expect the model to be available very soon.
- Contributions to the EBL from population III stars? (Astroph. 0508089, 0508133, 0508262)

What is next for the simulation tools?

- The EBL model to be used in a given simulation should be a parameter given by the user, instead of being hardwired to the code as it is now.
- GRBs and other sources (apart from blazars) are encouraged to “talk” to the EBL routines in cvs:celestialSources/eblAtten and get attenuated.

An example of how to define a source with EBL attenuation

Jim Chiang brought to life the EBL attenuation by implementing it in the source class "Spectral Transient": http://confluence.slac.stanford.edu/display/ST/Sources+available+to+obsSim

```
<source_library>
 <source name="blazar_0">
  <spectrum escale="MeV">
  <SpectrumClass name="SpectralTransient" params="1e-1,0, 3.154e7, template.dat,20.,3e5,0,3., 0."/>
  <celestial_dir dec="45." ra="45."/>
  </spectrum>
 </source>
</source_library>
```

Parameters: mean flux = 0.1 (1e4 photons/m^2/s) integrated over [emin,emax], start time (seconds), stop time (seconds), template file name, emin, emax, light curve # (if using fits template file), redshift, useLogParabola.

The file template.dat allows the user to define variability and spectral shape. In this case we just want a simple power law that is constant in time:

```
# template.dat
# @Used by SpectralTransient class
# tstart tstop  flux gamma1 gamma2 ebreak/MeV
    0.    1.0       1.      1.7          1.7         1000.
```

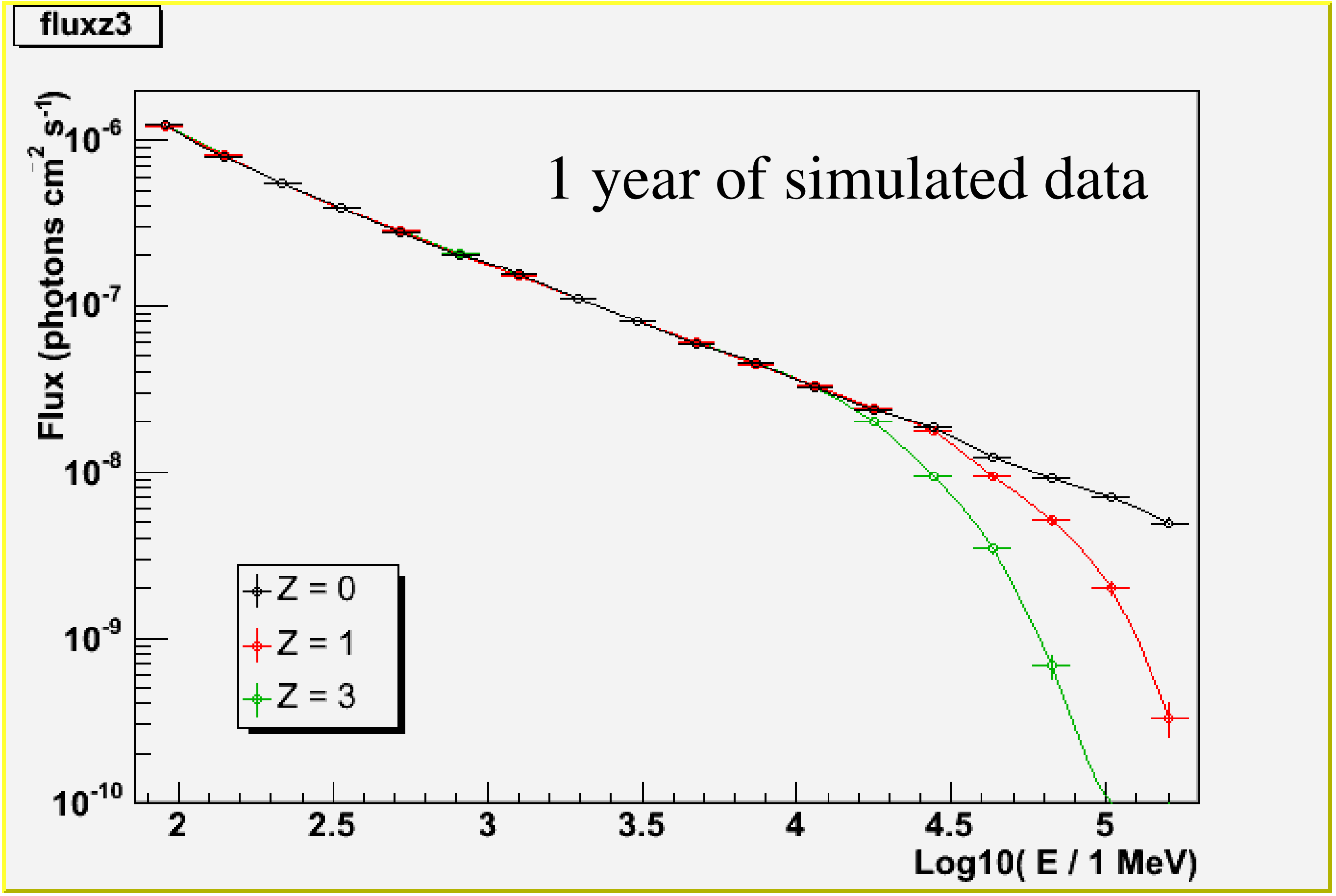
tstart, tstop, and flux are normalized with respect to the source definition of blazar_0 above.

Simulated Blazar

The simulated spectra below corresponds to a very bright blazar with a very hard spectra (α = -1.7) at 3 different redshifts, using the "best fit" ebl model from Kneiske et al :

Science tools used:

- gtobssim (photons)
- gtlivetimecube
- gtexpmap (exposure)



Detecting the EBL attenuation of Blazars

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

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

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

- 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.
- Still useful with rolloffs above 50 GeV at the source.

Statistical error given by:

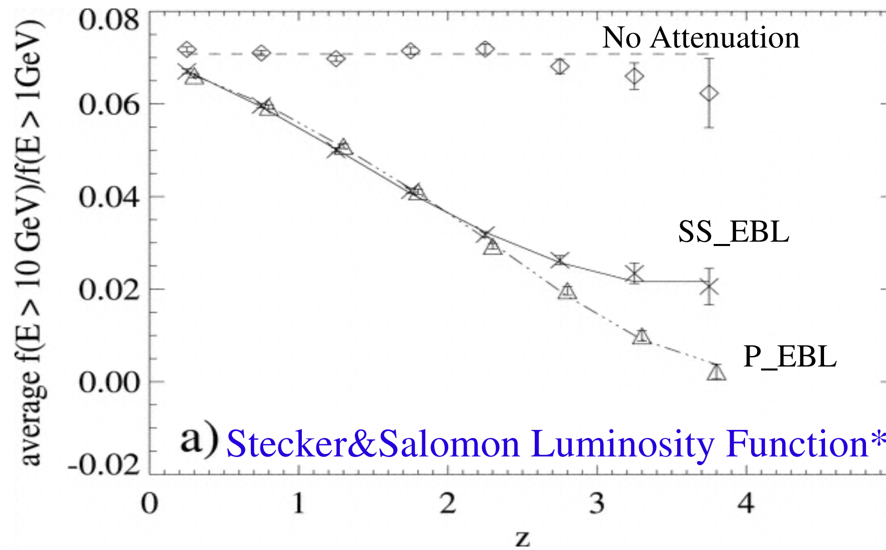
$$\sigma_{ratio} = \frac{1}{F\,(E > 1\,GeV)} \times \sqrt{\sigma^2_{F(E>10\,GeV)} + \left[\frac{F\,(E > 10\,GeV)}{F\,(E > 1\,GeV)}\sigma_{F(E>1\,GeV)}\right]^2}$$

A statistical treatment of the spectra from a large number of blazars washes out the intrinsic peculiarities of the individual sources and leaves behind the EBL attenuation.

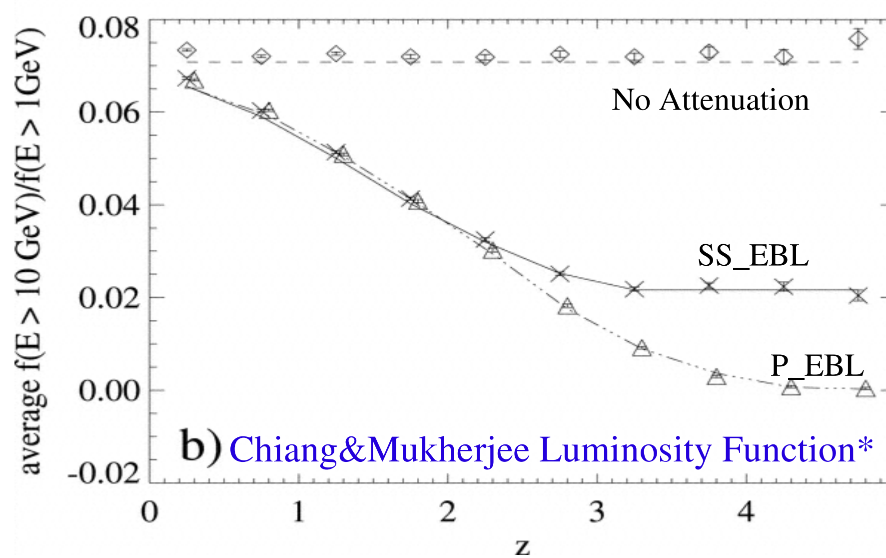
MC Simulation

We simulate for each blazar:

- Redshift
- Luminosity
- Position in the sky
- Power law spectrum – Spectral index is distributed as gaussian (-2.15 + 0.04)
- Flux modified by EBL attenuation model, and galactic/extragalactic backgrounds.



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



SS_EBL = Salamon & Stecker (1998) EBL model

P_EBL = Primack et al (1999) EBL model

*Luminosity functions are used to illustrate the technique, we are not trying to predict how many blazars GLAST is going to detect.

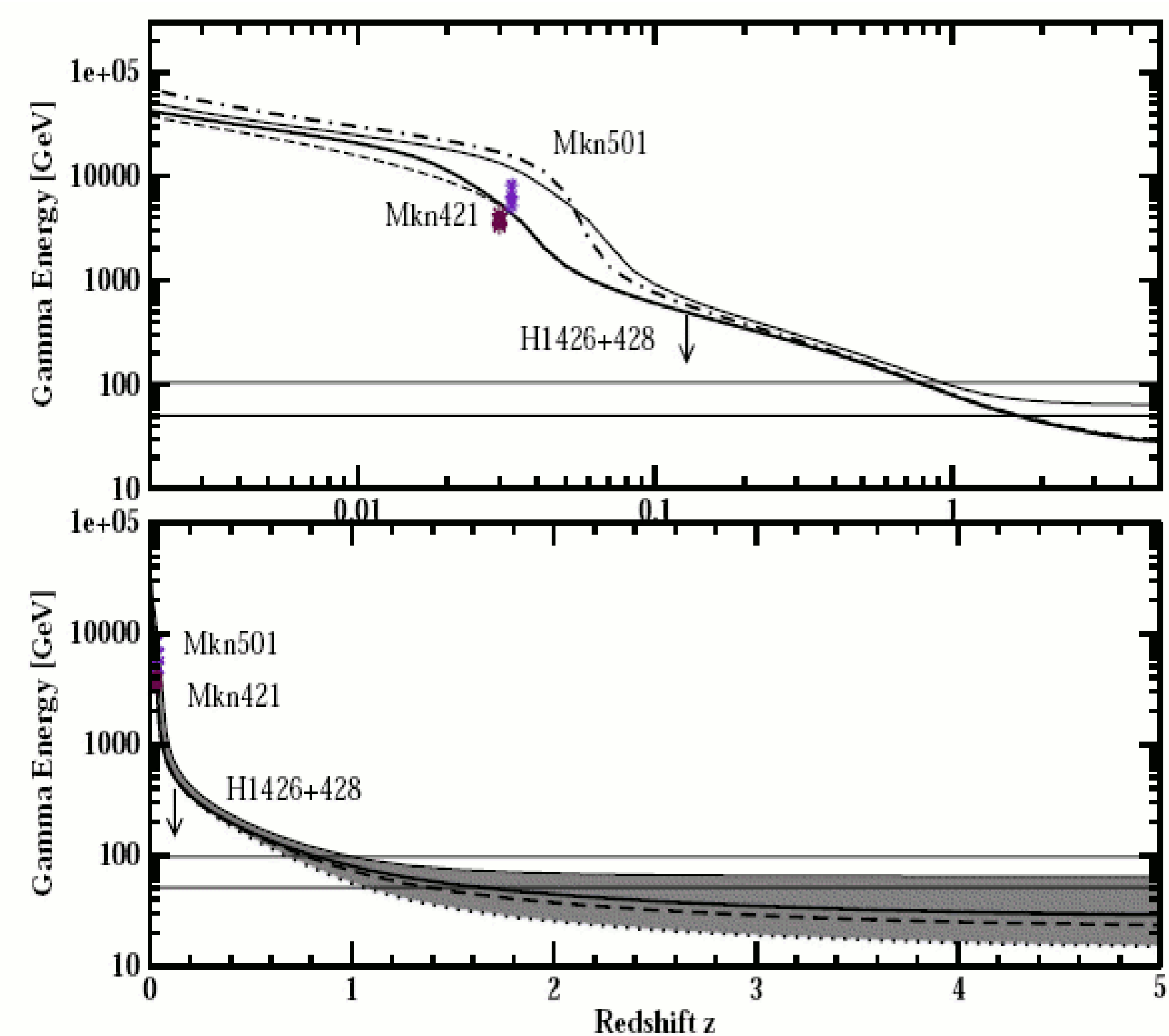
Caveats

- Selection Effects and biases:
  - Dim sources will have poorly measured flux ratios
  - Dim sources are more likely to be misidentified
  - Availability of optical telescopes at a given latitude
  - Source clustering
- Measuring the redshift of thousands of blazars is a formidable task
- Small but not vanishing possibility that spectral evolution of blazars mimics EBL attenuation (cosmic conspiracy). How can you tell?

Next Steps...

- To move ahead with the idea of using GLAST's large number of blazars to filtrate the EBL attenuation (redshift dependent) from the individual peculiarities of blazars:
  - Attenuation parametrization
  - Flux ratios at different energies vs redshift
  - Fazio-Stecker relation
- Implement more realistic blazar intrinsic flux models (not just power laws) in order to study our ability to separate the EBL attenuation from individual blazar characteristics

The Fazio-Stecker Relation



Kneiske et al (2004)

Points in the plot satisfy:

$$\tau(E,z) = 1$$

- Convergence of theoretical and observed FSR will validate the EBL models.
- The presence of energy cut-offs intrinsic to the sources will result in points moving down from the expected FSR,
- but with a large number of sources the “cosmological” FSR will appear naturally as the upper boundary of the data points.

BACKUP SLIDES

MonteCarlo Analysis

SS_LF

CM_LF

- Number of Blazars GLAST will observe

For each blazar:

- Redshift
- Luminosity
- Position in the sky
- Spectral index

SS_EBL

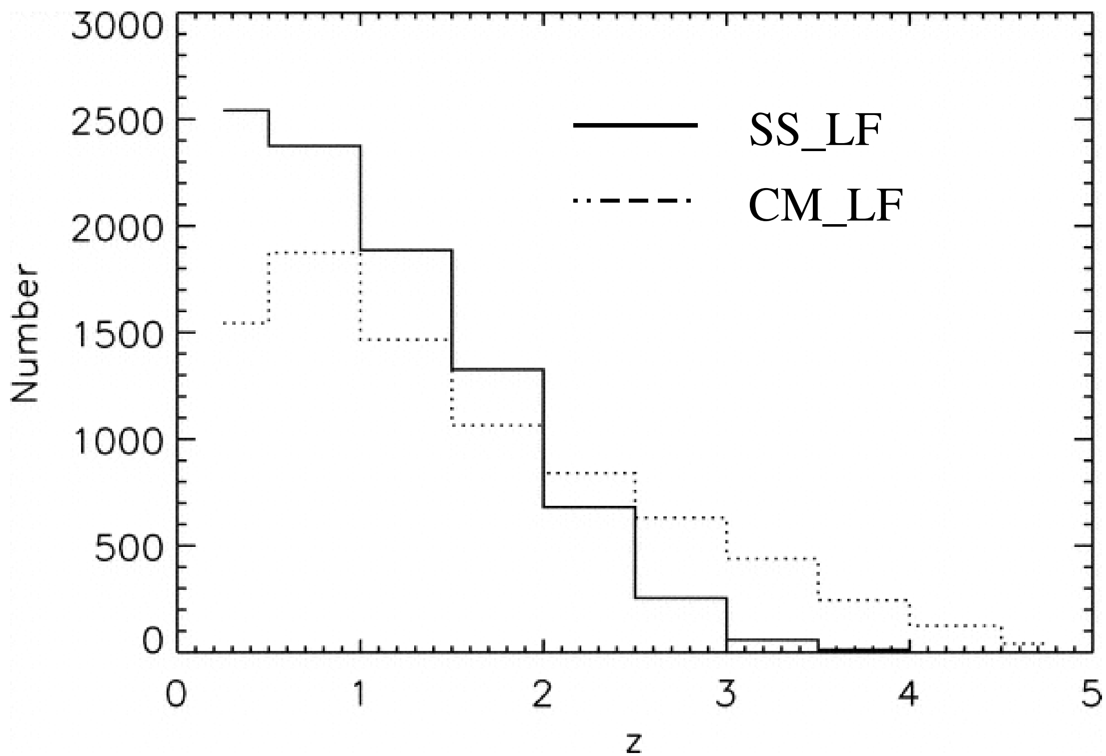
P_EBL

- Flux with:
  - Attenuation by EBL absorption
  - Galactic and Extragalactic background
- Error in the flux by Poisson statistics

Observational Selections:

- $|b| > 10°$
- Flux $> 5\sigma$ above background at 1 GeV

MonteCarlo Analysis



SS_LF ⇒ ~9100 blazars

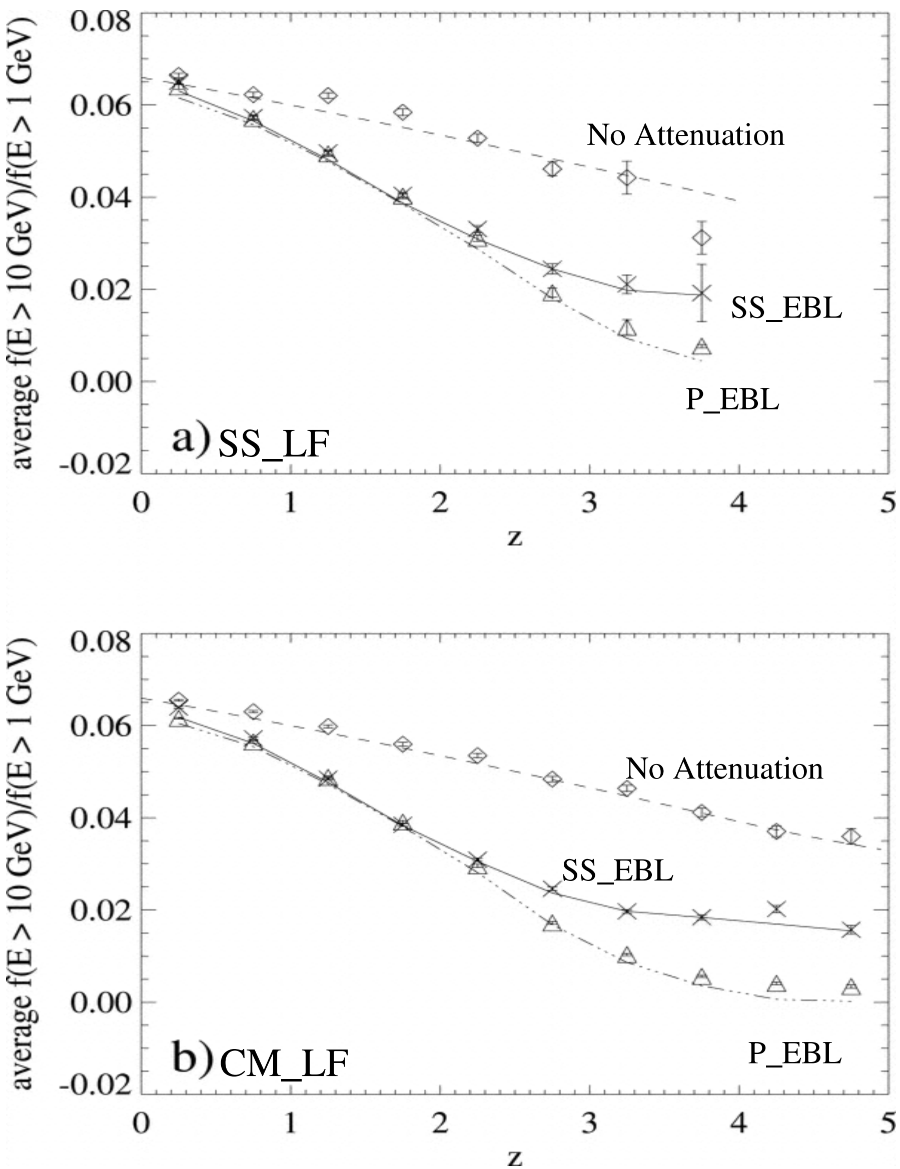
~60 blazars with z>3

CM_LF ⇒ ~ 8200 blazars

~700 blazars with z>3

Caveat Emptor II : The LFs are used here just for illustrative purposes, all this data will be replaced for the data GLAST itself provides.

EBL Attenuation – Broken Power Law Blazar Spectra



- The ratio obtained without EBL absorption depends upon redshift.
- EBL absorption is still evident

Ebl attenuation for a source at z = 3.5 according to the currently implemented models: