Detecting the EBL Attenuation of Blazars with GLAST

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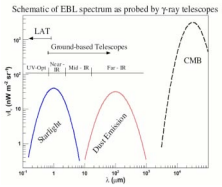
Abstract The Large Area Telescope (LAT) on board GLAST (Gamma-ray Large Area Space Telescope) due for launch in Fall 2007 will study the gamma-ray sky in the energy range 20 MeV to >300 GeV. GLAST-LAT's improved sensitivity with respect to previous missions will increase the number of known blazars from about 100 to thousands, with redshifts up to z~5. Since gamma rays with energy above 10 GeV interact via pair-production with photons from the Extragalactic Background Light (EBL), the systematic attenuation of GLAST-detected blazars as a function of redshift would constitute and effective and unique probe to the optical-UV EBL density and its evolution over cosmic history. Based on the GLAST-LAT instrument performance, detailed simulations of expected blazar populations attenuated by EBL have been performed. In this poster we present an analysis of such simulations in order to measure the EBL attenuation, ensuing a clear distinction between competing EBL models.

1. Introduction

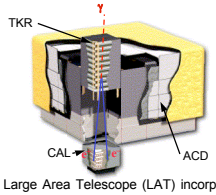
The Extragalactic Background Light (EBL) is the accumulated electromagnetic radiation resulting from the formation and evolution of structure in the universe since the Big Bang [1,2]. The main contributors to the EBL are starlight at UV-optical wavelengths, and infrared radiation resulting from the absorption and re-emission of starlight by the inter-stellar medium.

Measurement of the EBL provides a fundamental insight into the history of the universe. In particular, the UV-optical EBL flux contains information about the star formation rate and dust-extinction process at high redshifts. Unfortunately, direct measurements of the EBL intensity are extremely difficult due to the bright foreground from nearby sources (interplanetary dust, stars and gas in the Milky Way, etc.)



Ground-based γ-ray telescopes have measured the attenuation of several sources by the near- and mid-infrared part of the EBL [3,4,5]. However, the strong opacity experienced by very high energy photons due to infrared radiation limits TeV probes of the EBL to low redshifts. GLAST, on the other hand, will measure the less drastic attenuation of multi-GeV photons by the optical-UV part of the EBL and is expected to observe thousands of sources up to high redshifts. The energy range and capabilities of GLAST are thus ideal for probing the EBL to cosmological distances. This poster presents modeling and simulations of the ability of GLAST-LAT to measure the EBL attenuation.

2. The Capabilities of GLAST-LAT



Subsystems work together to identify and measure the flux of cosmic γ-rays:

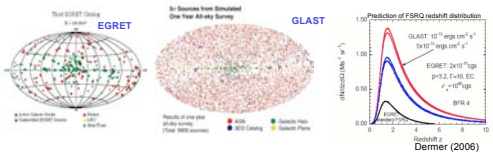
Silicon Microstrip Tracker (TKR)
Measures γ direction
γ identification

Calorimeter (CAL)
Measures γ energy
Shower imaging

Anti-Coincidence Detector (ACD)
Rejects background of charged cosmic rays

The Large Area Telescope (LAT) incorporates modern technology and lessons learned from previous pair-conversion telescopes resulting in a state-of-the-art instrument performance[6].

Although the luminosity function of blazars at GeV energies is unknown (this is something that GLAST itself will measure), it is expected that LAT's improved source sensitivity ($< 6 \times 10^{-9}$ cm^{-2} s^{-1} @ E > 100 MeV) will increase the number of known blazars from about 100 to thousands, with redshifts up to z~5 [7,8,9] (as illustrated below). This will allow for a systematic study of energy cut-offs as a function of redshift and to address the question of whether the measured steepening in blazar spectra is due to intrinsic peculiarities in the sources, or the result of intergalactic absorption by the EBL.



Dermer (2006)

3. Flux-Ratio Method

One method to measure the EBL attenuation of blazars consists of measuring the ratio of the observed fluxes at E > 10 GeV and E > 1 GeV [10]:

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

This ratio is simple, robust and insensitive to rolloffs above ~50 GeV for most EBL models (details in [10]).

Using the blazar luminosity function by Salamon & Stecker [7], our simulation assigns to each blazar:

- Redshift
- Luminosity
- Position in the sky
- Power law spectrum with spectral index distributed as gaussian (-2.15 ± 0.04)
- 2-year integrated flux modified by EBL attenuation models, and extragalactic, galactic backgrounds.

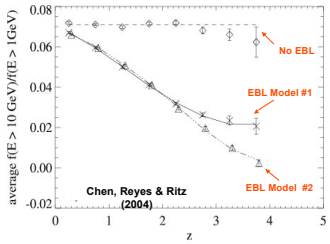
The plot below shows the weighted mean ratio with statistical error bars in each redshift bin calculated for three different scenarios:

(i) No EBL attenuation (diamonds)

(ii) With EBL attenuation according to Stecker & Salamon (1998) [11] (crosses)

(iii) With EBL attenuation according to Primack et al (1999) [12] (triangles)

Note that these EBL models are not used here as predictions to be validated, but rather as a set of reasonable values to illustrate the discriminating power of the technique.



The scattering of flux-ratios within every redshift bin is due (amid statistical fluctuations in the source fluxes) to the differences in the intrinsic spectra of the blazars. The mean ratio, however, reflects the common level of EBL attenuation experienced by sources at the same redshift.

The following conclusions can be drawn from the plot:

- EBL attenuation produces a clear signature in the flux-ratio as a function of redshift.
- The technique can distinguish between different EBL models

The statistical analysis of a large sample of blazars is a powerful tool to study EBL absorption and GLAST will be the first mission to observe a large sample of high-redshift blazars with sufficient statistics to separate intrinsic differences between blazars from redshift-dependent EBL absorption.

4. Spectral Analysis of a collection of blazars and Fazio-Stecker Plot

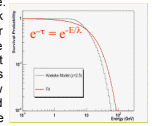
An alternate method presented here measures the spectrum steepening of individual γ-ray sources by means of a functional form with adjustable parameters that are fitted by the method of maximum likelihood.

By studying the collective steepening (via fitted parameters) of the sources as a function of redshift it is possible to measure or at least constraint the effects of intergalactic absorption by the EBL.

The flux attenuation of extragalactic sources is generally expressed in terms of the optical depth τ: $F_{observed} = \exp(-\tau)\, F_{intrinsic}$, where τ itself is a function of the photon's observed energy E_γ and the redshift z of the source $\tau=\tau(E_\gamma,z)$.

The functional form used to describe the attenuated spectrum of a source at a given redshift should thus be able to account for different possible realizations of τ while restricted to the minimum possible number of free parameters.

EBL attenuation is sometimes characterized as $F_{observed}=F_{intrinsic}\, e^{-E/\lambda}$ (ie. $\tau \propto E$), which doesn't work well when trying to fit over the LAT energy range because it doesn't account for the fact that τ is effectively zero at low energies (E ~ 1 GeV) and then "turns on" at some particular energy above 10 GeV (right plot).

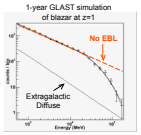


By using one additional degree of freedom (2 in total) we propose the following functional form that has proven useful for the level of EBL absorption that γ-ray sources observed by GLAST are expected to experience:

$$\tau = \begin{cases} 0 & ;\ \text{if} \quad E < E_b \\ \dfrac{(E - E_b)}{P_1} & ;\ \text{if} \quad E > E_b \end{cases}$$

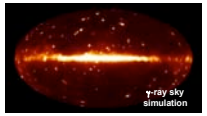
Note that τ(E,z) is a complex function of the EBL density as a function of redshift, and the parameterization in terms of E_b and P_1 presented above is just an approximation, valid only in terms of its utility to describe the observed spectrum of a source within experimental uncertainty. For a source with a very high number of statistics one could add more degrees of freedom to characterize τ more accurately.

The plot in the right shows the spectral fit of a simulated blazar observed by GLAST. A power-law function for the intrinsic spectrum times $e^{-\tau}$ (as defined above) provides a good fit to the data.

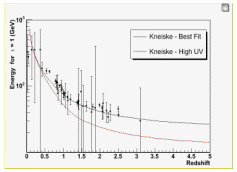


Assuming a power-law for the intrinsic spectrum of a blazar is simplistic, since radiation fields within the source could lead to energy cut-offs below the EBL-originated ones. In the case of GLAST, however, the large number of sources to be studied will allow for a systematic study of energy cut-offs as a function of redshift, permitting then a discrimination of the mean attenuation due (at least in part) to EBL absorption.

Simulation: A one year simulation of the 100+ blazars expected to be bright in the γ-ray sky as seen by GLAST was performed. The simulation included galactic and extragalactic γ-ray backgrounds and a realistic model for the variability and spectrum of the blazars. To simulate the EBL attenuation we use the "Best-Fit" model by Kneiske et al (2004) [13].



The plot below is known as the Fazio-Stecker relation [13,14] and serves to relate the energy cut-off with the redshift of the source. The black squares indicate the energy cut-offs as determined from the fits (observations) and can be seen to reproduce very well the EBL model used for the simulation (Kneiske et al – "Best Fit"). Also shown is a different EBL model ("High UV") to illustrate the discriminating power of the technique.



5. Summary

- Due to its improved sensitivity with respect to previous missions, GLAST is expected to observe for the first time thousands of blazars with redshifts up to z~5. By measuring the attenuation of these sources, GLAST will probe the UV-optical EBL density and its evolution over cosmic time. Indeed, if enough sources are observationally available at the relevant redshifts, GLAST could also probe the early history of structure formation.
- Statistical analyses which involve a large number of sources, as those presented in this poster, are a powerful tool to distinguish intrinsic peculiarities of blazar spectra from redshift-dependent EBL attenuation.
- The effects of EBL absorption can also be measured by using emission models to predict the intrinsic spectrum of blazars through fitting of multi-wavelength data. This constitutes and independent type of analysis with respect to the one illustrated here and when considered together they will validate and complement each other.
- Even after observation of a redshift-dependent effect, the possibility would remain that the spectral evolution or observational selection of γ-ray blazars mimic redshift-dependent EBL absorption. Future analyses will have to address the likelihood of such scenarios. GLAST observations, in any case, will provide an important constraint.
- EBL analyses in general will require redshift determination for a large fraction of GLAST blazars, just another example of the importance of multi-wavelength observations.

Acknowledgements

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