Blazar variability affecting the gamma-ray opacity calculation of the universe

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Abstract

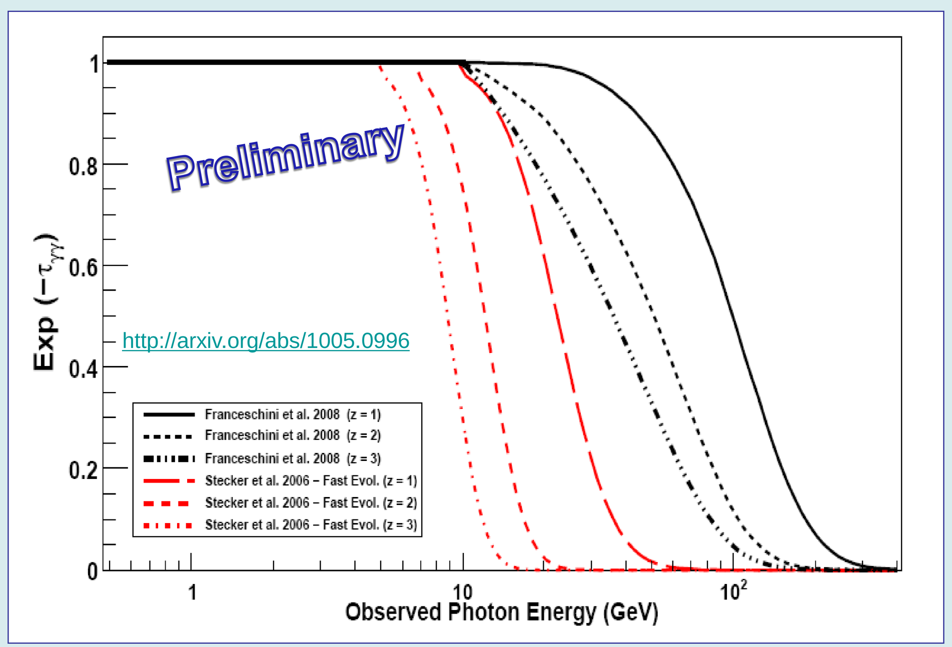
The Fermi Large Area Telescope (LAT) has provided us with a rich sample of extra-galactic sources with redshifts up to z~3 that we have used to probe the interaction via pair production of gamma-ray photons above 10 GeV with low-energy photons from the Extragalactic Background Light (EBL). The EBL from the infrared to the ultraviolet is difficult to measure directly, but can be constrained with a variety of methods. The EBL photons absorb gamma-rays from distant extra-galactic sources like blazars, resulting in a red-shift and energy dependent attenuation of their gamma-ray flux and allowing one to use blazar spectra to put upper limits on the opacity of the universe. Since blazars are known to be extremely variable sources we have also studied if the opacity limits derived from the flux attenuation due to EBL absorption could be affected by their intrinsic time variability and the results of this analysis are here presented.

1. The Extragalactic Background Light

The Extragalactic Background Light (EBL) includes photons with wavelenghts from UV through optical wavelengths, which constitute the main source of opacity for γ-rays from extragalactic sources, such as blazars and GRBs in the Fermi LAT energy range.

Measurement of the EBL provides a fundamental insight into galaxy and star formation, but direct measurements of its intensity are extremely difficult, due to the bright foreground from nearby sources.

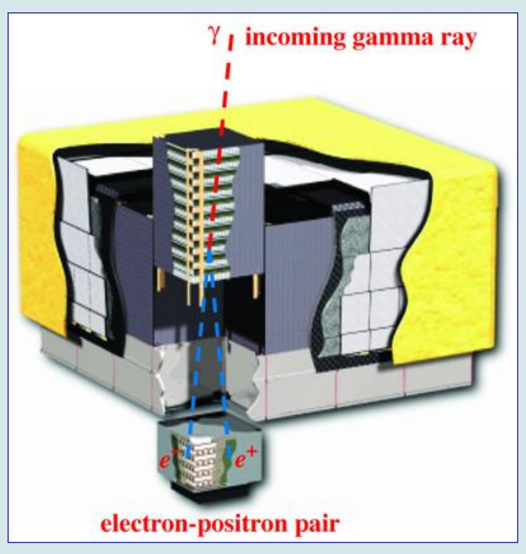
The effect of absorption of HE γ-rays is reflected in an energy and redshift dependent softening of the observed spectrum from a distant γ-ray source.
The observation, or absence, of such spectral features at HEs, for a source at redshift z can be used to constrain the $\gamma\gamma \rightarrow e^+e^-$ pair production opacity, $\tau(E, z)$.
A major science goal of Fermi is to probe the opacity of the universe to high-energy (HE) γ-rays as they propagate from their sources to the Earth.



The plot above shows the optical depth as a function of observed gamma-ray energy for the EBL models of (Franceschini et al. 2008, A&A, 487, 837 (F08)) and (Stecker et al. 2006, ApJ, 648, 774). These models predict the minimum and maximum absorption of all models in the literature, and thus illustrate the range of optical depths predicted in the Fermi-LAT energy range.

2. The Fermi Gamma-Ray Space Telescope

The Fermi LAT is a pair-conversion detector sensitive to γ -rays with 20 MeV< E < 300GeV with highly improved sensitivity over its predecessor EGRET (Atwood et al. 2009, ApJS).
The 3 subsystems of the Fermi-LAT 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 the charged
cosmic rays background

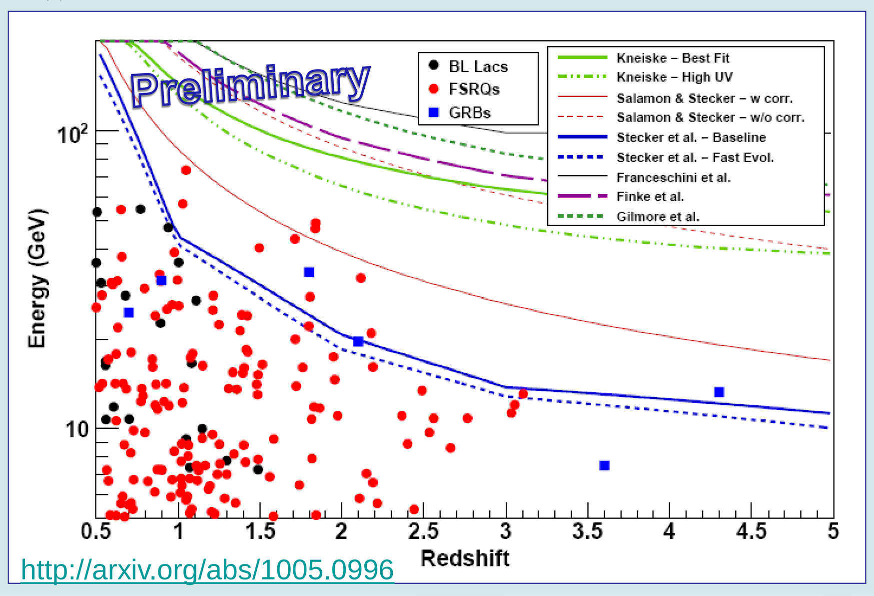
3. Observations and Data Selection

The sources we have analyzed to probe the UV through optical EBL are:
✓ blazars extracted from the 1st LAT AGN Catalog
✓ LAT-detected GRBs up to 2009 September 30th .
This poster presents the results obtained in the analysis of the AGN sample.
The data set used includes LAT events collected between 2008 Aug 4th and 2009 July 4th; with 100MeV < E < 100 GeV.

Due to the large background domination, only continuous observations of blazars over long time scales allow the detection of the underlying emission. The LAT detects a sample of γ-ray blazars with redshift up to z~3.

Using photons >10 GeV collected by Fermi for these sources, we investigate the effect of attenuation by EBL on the γ-ray flux.

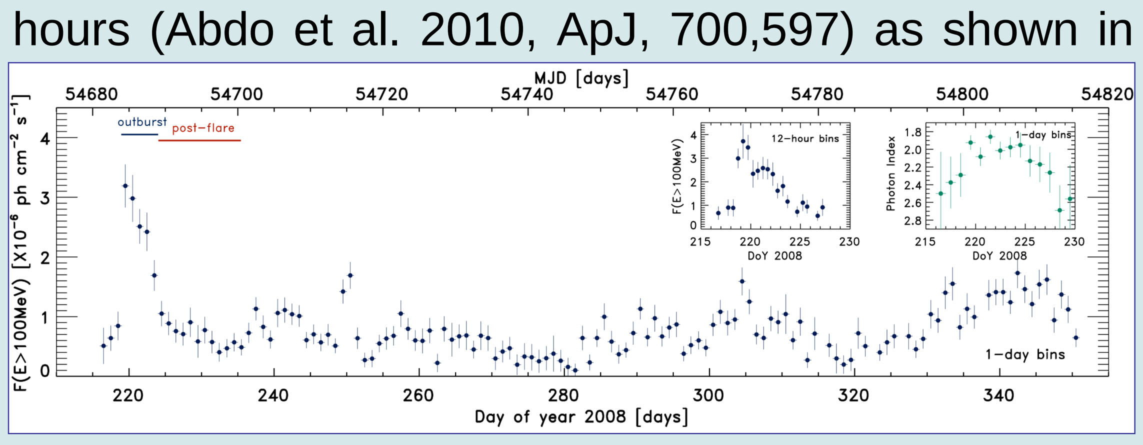
Below the highest energy photons from blazars and GRBs from different z compared with predictions of $\gamma\gamma$ opacity $\tau_{\gamma\gamma}$=3 from various EBL models.



4. Time variability and analysis of opacity upper limits

To detect absorption features in the HE spectra of Fermi blazars, a thorough understanding of their intrinsic spectra, including variability, and source internal spectral features is required.

Most blazars do not show strong spectral variability in the LAT energy range on ≥ week scales (Abdo et al. 2010, ApJ, 710, 1271), despite often strong flux variability (Abdo et al. 2010, ApJ accepted, arXiv:1004.0348).
PKS 1502+106 is one of the most constraining sources for the EBL analysis presented in this poster. It displayed an exceptional flare in August 2008 with a factor ~ 3 increase in flux within ~ 12 hours (Abdo et al. 2010, ApJ, 700,597) as shown in



During this flare a flatter (when brighter) spectral shape was evident. The spectral curvature at the high energy end increased with decreasing flux level. If the high energy (> 10 GeV) photons are emitted during such flare activity, the constraints on the γ-ray opacity would be tighter if only the flare-state spectral data were used.
However, during the flare the photon statistics is limited and the analysis done to constrain the opacity value, that makes use of a time averaged spectrum, does not show significant differences if the flare interval is excluded from the time period of the analysis. Moreover, the highest energy photon for this source at 48.9 GeV was emitted in the post-flare period, in an intermediate level of brightness.

We discuss here only the method and results from the analysis carried out to put upper limits on the γ-ray opacity calculated from the observed flux of individual blazars and the extrapolation of the unabsorbed flux to high energies, reminding to the specific paper (Abdo et al, http://arxiv.org/abs/1005.0996) for a complete explanation of all the methods and results.

Assuming that high-energy photon absorption by the EBL is the sole mechanism that affects the γ-ray flux from a source at redshift z, the observed and unabsorbed fluxes at the observed energy E can be related by the opacity, τ(E, z), as

$$F_{obs}(E) = \exp^{-\tau(E,z)} \cdot F_{unabs}(E)$$

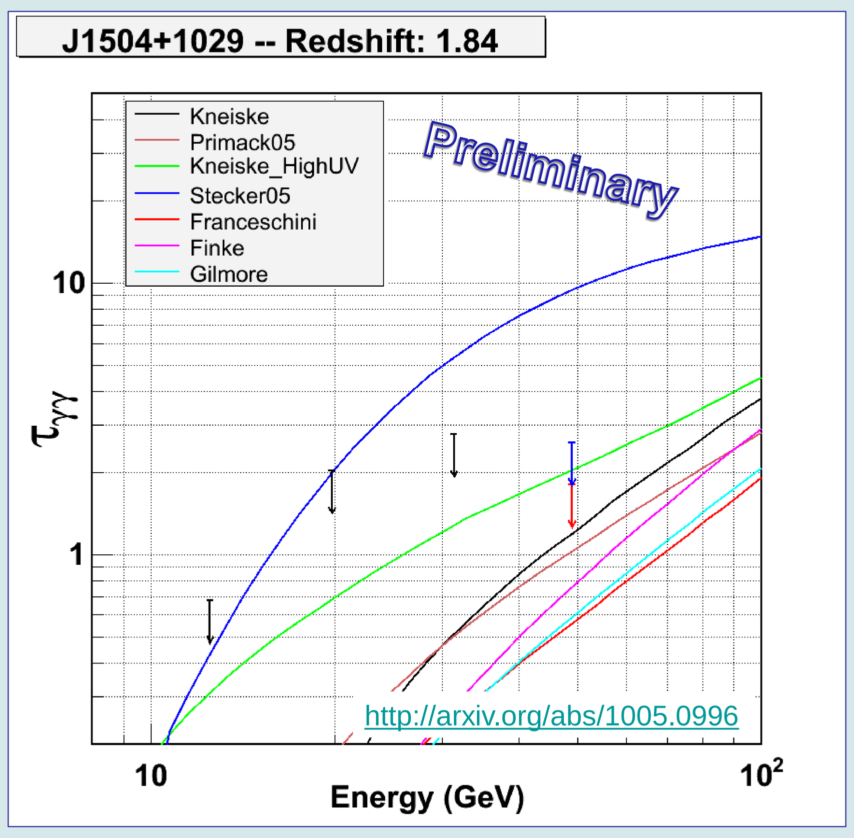
$$\Downarrow$$

$$\tau_{\gamma\gamma}(E, z) = \ln[F_{unabs}(E)/F_{obs}(E)]$$

Since the unabsorbed spectrum is evaluated assuming no EBL attenuation, the opacity already gives a maximum value. For details on the evaluation of F_{unabs} and F_{obs} refer to Abdo et al. http://arxiv.org/abs/1005.0996.
Consequently, an upper limit on $\tau_{\gamma\gamma}(E, z)$ with a 95% c.l. in a constraining energy bin with mean energy <E> is calculated by propagating the parameter uncertainties in the fitted flux:

$$\tau_{\gamma\gamma UL(95\%c.l.)}(<E>,z) = \tau(E,z) + 2\sigma$$

We compare these opacity limits with opacities predicted by various EBL models.



The results for PKS1502+106 above 10 GeV and for the highest energy photon at 95 and 99% c.l. are reported in the plot above. These results are obtained evaluating the average energy spectra in the entire time period, including August 2008 flare.
The same analysis has been also carried out in a time interval excluding the flare and the opacity ULs found are within the errors.
Overall, the results on opacity ULs are not significantly affected by the 5 days flare at the beginning of the observation period.