Fermi Large Area Telescope results from the evaluation of the Gamma-Ray Opacity of the Universe

Silvia Rainò, Dipartimento di Fisica, Università degli Studi di Bari and INFN-Bari
with Aurelien Bouvier, Andrew Chen, Soebur Razzaque, Anita Reimer and Luis Reyes
on behalf of the Fermi Large Area Telescope Collaboration

Abstract

The Fermi Large Area Telescope (LAT) has provided us with a rich sample of extra-galactic sources, gamma-ray blazars with redshift up to z~3 and GRBs with redshift up to z~4.3, 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. In this contribution I report the methods applied to evaluate gamma-ray flux attenuation by comparing the measured energy spectrum of the source and the unabsorbed spectrum above 10 GeV. We place upper limits on the gamma-ray opacity of the Universe at various energies and redshifts, and compare this with predictions from well-known EBL models. We find that an EBL intensity in the optical-ultraviolet wavelengths as great as predicted by the "baseline" model of Stecker et al. (2006) can be ruled out with high confidence. The results of the analysis in the determination of opacity upper limits are presented.

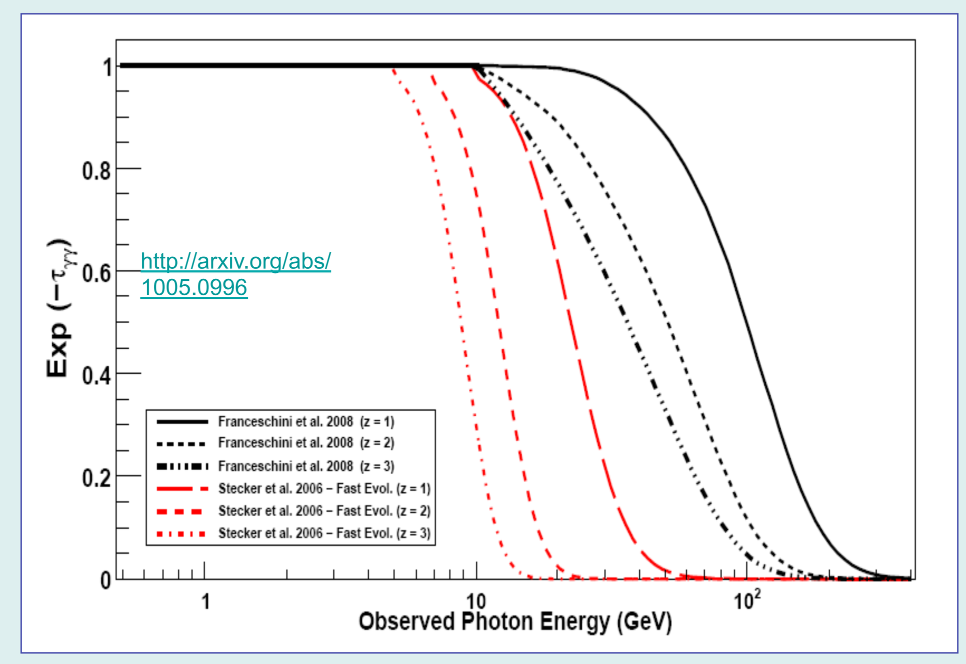
1. The Extragalactic Background Light

The Extragalactic Background Light (EBL) includes photons with wavelenghts from UV through optical wavelenghts, 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.

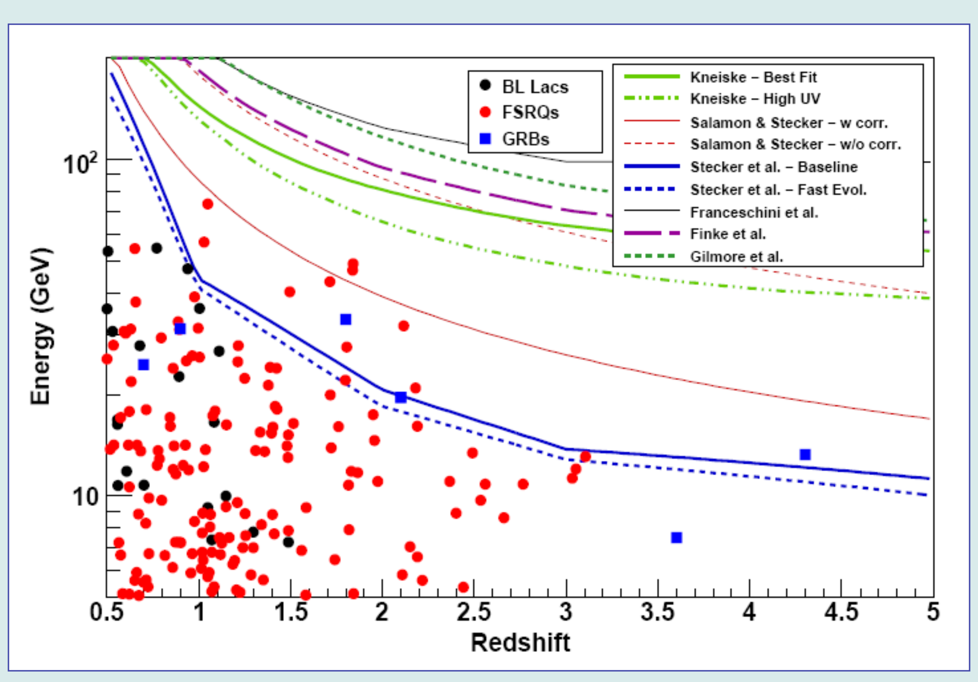
The plot on the side shows the optical depth as a function of observed gamma-ray energy for the EBL models of (Franceschini et al. 2008, A&A, 487, 837) and (Stecker et al. 2006, ApJ, 648, 774). These models predict the minimum and maximum absorption of all models in the literature, and thus illustrate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



2. 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 that include LAT events collected between 2008 Aug 4th and 2009 July 4th; with 100MeV < E < 100 GeV.
✓ LAT-detected GRBs up to 2009 September 30th .
The details are explained in Luis' presentation.

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



3. Analysis of γ-ray flux attenuation – Determination of Opacity upper limits

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 (F_{obs} and F_{unabs}) at the observed energy E can be related by the opacity, $\tau(E, z)$, as

$$F_{obs}(E) = \exp[-\tau(E, z)]F_{unabs}(E). \qquad (1)$$

This is the primary expression that we use to:
(i) explore γ-ray flux attenuation in the EBL from AGNs by means of a redshift-dependent flux ratio between a low- and a high- energy band;
(ii) constrain EBL models which predict $\tau(E, z)$ values much higher than the opacity that would give the observed fluxes from individual blazars and GRBs; and
(iii) put upper limits on the γ-ray opacity calculated from the observed flux of individual blazars and GRBs, and the extrapolation of the unabsorbed flux to high energies.
Refer to Luis' presentation and to http://arxiv.org/abs/1005.0996 for details on all the methods.
This poster concentrates on one of the methods used to evaluate opacity upper limits. Upper limits on the γ-ray optical depth have been evaluated with a method based on the comparison between the measured energy spectrum of the source and the unabsorbed spectrum above 10 GeV.
Starting from eq. (1), since the unabsorbed spectrum is evaluated assuming no EBL attenuation, the opacity already gives a maximum value for the flux. 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:

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

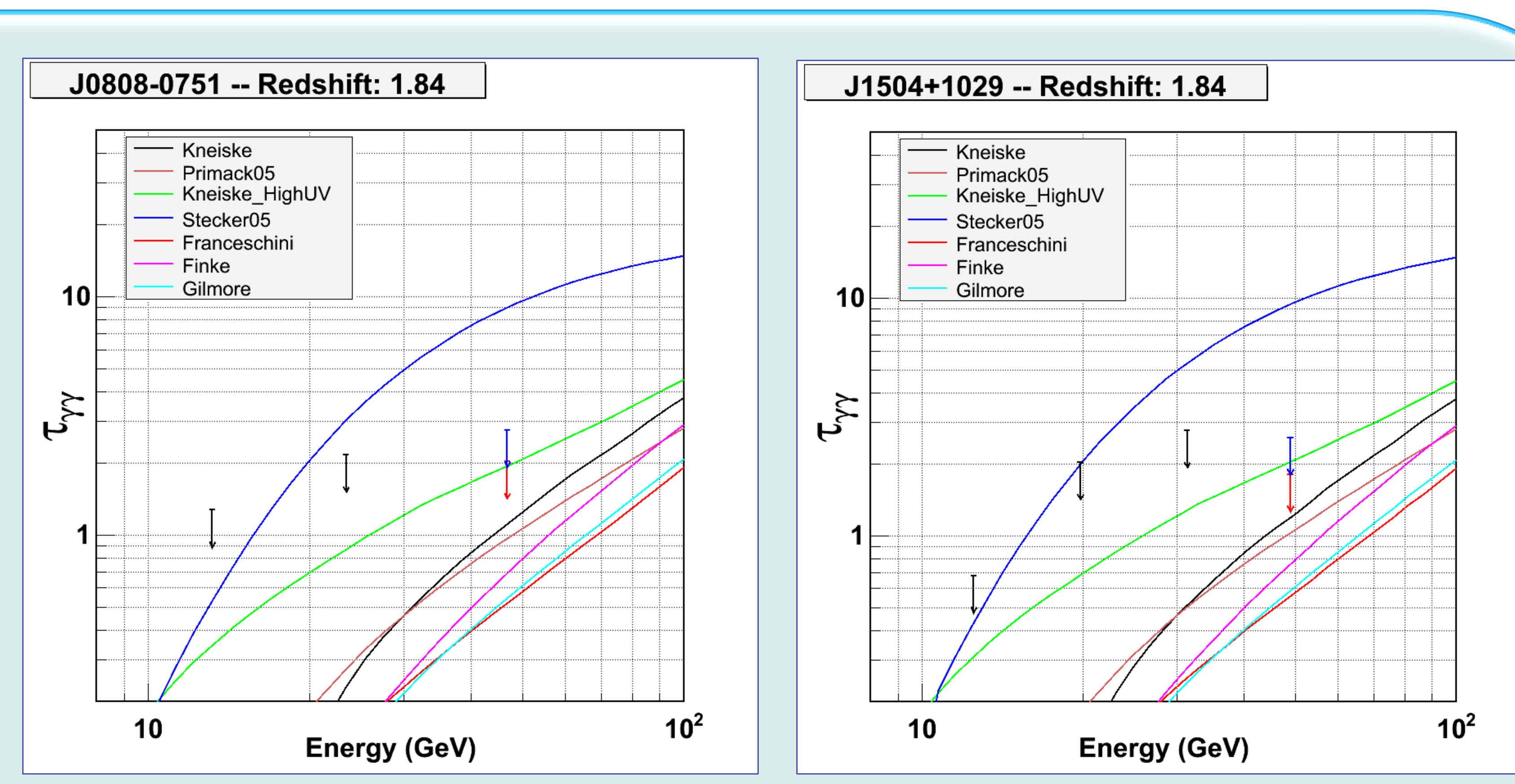
We compare these opacity limits with the ones predicted by known EBL models.

3. Determination of Opacity Upper Limits - Results

In order to determine the flux below 10 GeV, the source under study has been fitted with a power-law or a log-parabola, choosing the one with the best TS value. From the fit results of the flux below 10 GeV we have extrapolated the spectral shape to obtain the unabsorbed flux above 10 GeV, F_{unabs}.
A different method has been used to derive the measured flux F_{obs} in selected energy bins. The whole energy range from 100 MeV to 100 GeV is divided in equal logarithmically spaced bins requiring in each energy bin a TS value greater than 10. In each energy bin the standard gtlike tool has been applied assuming for all the point-like sources a simple Power Law spectrum with photon index fixed to -2.0.
Once both F_{unabs} and F_{obs} are determined, an upper limit on $\tau(\langle E\rangle, z)$ with 95% CL in a constraining energy bin with mean energy <E> can be estimated from Eq. (2).

Source	z	E_{max}	$\tau_{UL}(z, E_{max})$
J1147-3812	1.05	73.7	1.33
J1504+1029	1.84	48.9	1.82
J0808-0751	1.84	46.8	2.03
J1016+0513	1.71	43.3	0.83
J0229-3643	2.11	31.9	0.97
J1012+2439	1.81	27.6	2.41

The table shows the upper limits on the γ-ray optical depth for the analyzed AGN. The first and second column report the name of the sources and their redshift, the third column the maximum photon energy and the fourth column the optical depth upper limits evaluated at 95% c.l. as for Eq (2).



The two plots above show the derived upper limits for the optical depth of γ-rays emitted by the sources J0808-0751 and J1504+1029 at z=1.84.
The black arrows represent upper limits at 95% c.l. in all energy bins used to determine the observed flux above 10 GeV. The red arrow shows the upper limits at 95% c.l. for the highest energy photon. Finally, the blue arrow reports upper limit at 99% c.l. for the highest energy photon.
The upper limits determined with this method are inconsistent with the EBL models that predict the strongest opacity.