Digging for the Truth: Photon Archeology with GLAST

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Abstract.

Stecker, Malkan and Scully, have shown how ongoing deep surveys of galaxy luminosity functions, spectral energy distributions and backwards evolution models of star formation rates can be used to calculate the past history of intergalactic photon densities for energies from 0.03 eV to the Lyman limit at 13.6 eV and for redshifts out to 6 (called here the intergalactic background light or IBL). From these calculations of the IBL at various redshifts, they predict the present and past optical depth of the universe to high energy γ-rays owing to interactions with photons of the IBL and the 2.7 K CMB. We discuss here how this procedure can be reversed by looking for sharp cutoffs in the spectra of extragalactic γ-ray sources such as blazars at high redshifts in the multi-GeV energy range with GLAST (Gamma-Ray Large Area Space Telescope). By determining the cutoff energies of sources with known redshifts, we can refine our determination of the IBL photon densities in the past, i.e., the archeo-IBL, and therefore get a better measure of the past history of the total star formation rate. Conversely, observations of sharp high energy cutoffs in the γ-ray spectra of sources at unknown redshifts can be used instead of spectral lines to give a measure of their redshifts.

Keywords: gamma-rays, absorption, star formation, background radiation

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INTRODUCTION

The potential importance of the photon-photon pair production process, γγ → e⁺e⁻, in high energy astrophysics has been realized for over 40 years [1]. It was pointed out that owing to interactions with the 2.7 K CMB, the universe would be opaque to γ-rays of energy above 100 TeV at extragalactic distances [2, 3]. If one considers cosmological and redshift effects, it was further shown that photons from a γ-ray source at a redshift z_s would be significantly absorbed by pair production interactions with the CMB above an energy ∼ 100(1 + z_s)⁻² TeV [4, 5].

Following the discovery by the EGRET team of the strongly flaring γ-ray blazar 3C279 at redshift 0.54 [6], Stecker, de Jager and Salamon [7] proposed that one can use the predicted pair production absorption features in blazars to determine the intensity of the infrared portion of the IBL, provided that the intrinsic spectra of blazars extends to TeV energies. It was later shown that the IBL produced by stars in galaxies at redshifts out to ∼ 2 would make the universe opaque to photons above an energy of ∼ 30 GeV emitted by sources at a redshift of ∼ 2, again owing to pair production interactions [8, 9].

In Ref.[10] this approach was expanded by using recent data from the Spitzer infrared observatory the Hubble deep survey and GALEX to determine the photon density of the IBL from 0.03 eV to the Lyman limit at 13.6 eV for redshifts out to 6 (the “archeo-IBL”).[11] The results, giving the IBL photon density as a function of redshift together with the opacity of the CMB as a function of redshift, were then used to calculate the opacity of the universe to γ-rays for energies from 4 GeV to 100 TeV and for redshifts from ∼ 0 to 5. The results of this calculation are shown in Figure 1. They are given for two evolution models, viz., the “baseline” (B) model and the “fast evolution” (FE) model. These two models were chosen to bracket the plausible history of the star formation rates in galaxies which is the input which has the largest uncertainty in the calculation, particularly at the higher redshifts. The FE model is favored by recent Spitzer observations [12, 13]. It also provides a better description of the deep Spitzer number counts at 70 and 160µm than the B model. However, GALEX (Galaxy Evolution Explorer) observations indicate that the redshift evolution of UV radiation may be more consistent with the B model [14]. The Spitzer IRAC (Infrared Array Camera) counts can be best fit with an evolution rate between these two models. One way of understanding the somewhat smaller redshift evolution of the star formation rate implied by the GALEX UV observations vs. that obtained from the Spitzer IR observations is that the effect of dust extinction followed by IR reradiation increases with redshift [15].

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1 See also Refs. [11, 12, 13] and the paper of D. H. Hartmann, these proceedings.
FIGURE 1. Optical depth of the universe to $\gamma$-rays from interactions with photons from the EBL and 2.7K CMB for various redshifts, $z$. The solid lines are for the FE model and the dashed lines are for the B model. The curves shown are for (from top to bottom) $z = 5.0, 3.0, 2.0, 1.0, 0.5, 0.2, 0.117, 0.03$.[10]

It has been argued that TeV $\gamma$-ray observations of the blazars 1ES1101-232 and H 2356-309 place an upper limit on the present IBL of $14 \pm 4$ nW m$^{-2}$sr$^{-1}$ in the wavelength range 1–2 $\mu$m [18], based on the assumption that the intrinsic photon spectra of these sources in the energy range of observation cannot have a spectral index which is flatter than 1.5. Should this assumption be true, it would tend to favor model B [19].

The results of Ref. [10] predict that the universe will become opaque to $\gamma$-rays for sources at the higher redshifts at somewhat lower $\gamma$-ray energies than those given in Ref. [9]. This is because the newer deep surveys have shown that there is significant star formation out to redshifts $z \geq 6$ [20, 21], greater than the value of $z_{\text{max}} = 4$ assumed in Ref. [9]. This conclusion is also supported by recent Swift observations of the redshift distribution of GRBs [22].

Stecker, Malkan and Scully [10] found that the function $	au(E_\gamma, z)$ shown in Fig. 1 can be very well approximated by the analytic form

$$ \log \tau = Ax^4 + Bx^3 + Cx^2 + Dx + E $$

over the range $0.01 < \tau < 100$ where $x \equiv \log E_\gamma$ (eV). The coefficients A through E are given in Table 1 for various redshifts [23]. (This is the corrected form of the original table given in Ref. [10].)

## WHAT GLAST CAN DO

It can be seen from Figure 1 that for $\gamma$-ray sources at the higher redshifts there is a steeper energy dependence of the optical depth $\tau(E_\gamma)$ near the energy where $\tau = 1$. There will thus be a sharper absorption cutoff for sources at high redshifts. It can easily be seen that this effect is caused by the sharp drop in the UV photon density at the Lyman limit.

It is expected that GLAST will be able to resolve out thousands of blazars [24]. Because of the strong energy dependence of absorption in blazar spectra at the higher redshifts in the multi-GeV range, GLAST will be able to probe the archeo-IBL and thereby probe the early star formation rate. GLAST should be able to detect blazars at known redshifts $z \sim 2$ at multi-GeV energies and determine their critical cutoff energy. A simple observational technique for probing the archeo-IBL has been proposed in Ref. [25]. In such ways, GLAST observations at redshifts $z \geq 2$ and $E_\gamma \sim 10$ GeV may complement the deep galaxy surveys by probing the total star formation rate, even that from galaxies too faint to be detected in the deep surveys. Future GLAST observations in the 5 to 20 GeV energy range may also help to pin down the amount of dust extinction in high-redshift galaxies by determining the mean density of UV photons at the higher redshifts through their absorption effect on the $\gamma$-ray spectra of high redshift sources. If the diffuse $\gamma$-ray background radiation is from unresolved blazars [24], a hypothesis which can be independently tested...
TABLE 1. Coefficients for Parametric Fit to $\tau(E_\gamma, z)$ for various redshifts for the baseline model (upper row) and fast evolution (lower row) for each individual redshift. The parametric approximation holds for $10^{-2} < \tau < 10^2$ and $E_\gamma < \sim 2$ TeV for all redshifts but also up to $\sim 10$ TeV for redshifts, $z \leq 1$ [23].

<table>
<thead>
<tr>
<th>$z$</th>
<th>$A$</th>
<th>$B$</th>
<th>$C$</th>
<th>$D$</th>
<th>$E$</th>
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<td>285.131</td>
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</table>

by GLAST [26], absorption will steepen the spectrum of this radiation at $\gamma$-ray energies above $\sim 10$ GeV [9]. Thus, GLAST can also acquire information about the evolution of the IBL in this way.

Conversely, observations of sharp high energy cutoffs in the $\gamma$-ray spectra of sources at unknown redshifts can be used instead of spectral lines to give a measure of their redshifts.

REFERENCES