A strict lower-limit EBL
Applications on gamma-ray absorption

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Abstract. A strict lower limit flux for the extragalactic background light from ultraviolet to the far-infrared photon energies is presented. The spectral energy distribution is derived using an established EBL model based on galaxy formation. The model parameters are chosen to fit the lower limit data from number count observations in particular recent results by the SPITZER infrared space telescope. A lower limit EBL model is needed to calculate guaranteed absorption due to pair production in extragalactic gamma-ray sources as in TeV blazars.

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INTRODUCTION

The extragalactic diffuse radiation, also called extragalactic background light (EBL), is the relic emission of galaxy formation and evolution, and is produced by direct star light (UV and visible ranges) and light reprocessed by the interstellar dust (infrared to submillimeter ranges).

The EBL is difficult to measure directly because of strong foreground contamination. Thus, upper limits have been derived by observing the isotropic emission component [1]. Another method consists in using integrated galaxy number counts which has been improved during the last years by sensitive telescopes like Spitzer, to get lower limits. To overcome the poor constraints at far-infrared wavelengths, a stacking analysis of near- and mid-infrared sources is used [2], to significantly resolve the cosmic infrared background, leading to constraining lower limits.

In addition to observational constraints, models are being developed. The main contribution to the infrared diffuse radiation is produced in stars and galaxies too far away for being detected as distinct sources. The physics of stars, the composition and spatial distribution of the interstellar medium can be estimated for close-by galaxies but not easily generalized on global scales. Thus, different formalisms may result in discrepancies of the EBL flux at the order of 5 to 10 at certain wavelengths, despite an overall reasonable shape (for a detailed discussion see [1]). The model used in this paper is an updated version discussed in [3] and [4].

Beside the study of stellar populations on global scales, another effect triggered a great interest in the EBL flux: high-energy gamma rays traveling through intergalactic space can produce electron-positron pairs in collisions with low energy photons from the extragalactic background light [5]. Despite this effect, Cherenkov telescopes have been discovered a great number of extragalactic high energy gamma-ray sources at unexpected large redshift e.g. [6]. The H.E.S.S. collaboration derived an upper limit for the EBL between 1 and 4 micron, which is very close to the optical number counts by the Hubble Space Telescope [7]. The problem is that the so called ”upper limit” strongly depends on the assumption of the intrinsic blazar spectrum. Contrary to this upper limit, a lower limit is derived [8]. Fitting an EBL model to lower limit data from optical to infrared energies leads to a strict lower limit for the extragalactic background light. It will provide a minimum correction for extragalactic gamma-ray sources due to photon photon pair-production. In the next section the EBL model and data are summarized briefly. In the sections to follow the absorption of high energy gamma-rays is studied using the lower limit model. Observed high energy gamma-ray sources are shown with their possible intrinsic GeV spectra. Throughout this paper, we adopt a cosmology with $h = 0.72$, $\Omega_M = 0.3$ and $\Omega_{\Lambda} = 0.7$.

MODEL AND OBSERVATIONS

The review of the lower limits on the Extragalactic Background Light measurements are presented in detail in [8]. Most of them come from the integration of number counts, not from direct measurements of surface brightness, subject to strong foreground emission contamination. This method is based on the simple counting of detected galaxies on a given sky area of a deep survey, a completeness correction, and the integration of the number counts: it is usually robust and gives lower limits;
FIGURE 1. Comoving flux of the extragalactic background light and corresponding extinction of gamma-rays at four different redshifts. The solid line represents the lower-limit EBL introduced here while the dashed line is the old “best-fit” model described in [4]. Meaning of arrows and thin solid lines see text.

The result is shown as solid line in the left panel of Fig.1. The comoving flux of the EBL is shown at four different redshifts (0, 0.2, 0.54 and 1.0). At low redshift the optical and infrared peak are almost on the same level while for higher redshifts the infrared peak dominates. The dashed line is the flux from the "best-fit" model described in [4] which is a factor of about 2 higher.

GAMMA-RAY ABSORPTION

The optical depth $\tau_{\gamma\gamma}$ for gamma-rays in the universe can now be calculated following the equation in [4]. The effect of absorption for sources at different redshifts $z$ is shown in the right panel of Fig. 1. Here the extinction $\exp(-\tau_{\gamma\gamma})$ is plotted as a function of gamma-ray energy. A value of one means that the photons can pass unaffected through extragalactic space. A smaller value leads to higher absorption effects. The effect is often described in terms of the so called “cut-off energy” $E_c$ which is defined as $\tau_{\gamma\gamma}(E_c) = 1$. Photons with energies $E > E_c$ are absorbed by more than a factor of $1/e$. For those pho-
tons the universe is optically thick. The cut-off energy depends on the redshift of the source and is about 12 TeV, 500 GeV, 185 GeV and 100 GeV for $z = 0.03, 0.2, 0.54$ and 1.0 respectively. Due to the peaked cross section for this process the absorption mainly takes place between EBL photons with energy $\epsilon_{BL}$ and gamma-ray photons with energies $E_\gamma$ if $\epsilon_{BL} E_\gamma < 2m_c c^2 \approx 1.2$ TeV$^2$. The thin solid lines and arrows in Fig.1 are bracketing the corresponding gamma-ray and EBL energies depending on redshift. For example at a redshift of 0.03 the absorption effects mainly the photons with energies $100 \text{ TeV} > E_\gamma > 10 \text{ TeV}$ while interacting with EBL photons with $10 > \lambda > 100 \mu m$.

As an example for photon-photon pair production a sample of blazars have been studied. In Fig.2 the flux of sixteen blazars observed with different Cherenkov Telescopes like (Whipple, Hegra, MAGIC and H.E.S.S.) is plotted at GeV energies. The spectra have been scaled by numbers between $10^{10}$ and $10^{25}$. The lower limit EBL model has been used to correct the intrinsic spectra which can now be compared with the observed data (solid lines in Fig.2). An intrinsic power-law spectrum has been assumed for each detected source. The spectral indices $\alpha$ are shown in Fig.2 as first number in the legend. The second number is the redshift $z_s$ of the source. The following relation has been used

$$\frac{dN}{dE} \propto E^\alpha \exp(-\tau_{\gamma\gamma}(E_\gamma, z_s, E_{BL})) \quad (1)$$

Note that the power-law index has been chosen without looking into statistical details. They are not representing best-fit values but are rather crude estimates to show the absorption effect with the lower limit EBL. The spectral indices and therefore the intrinsic blazar properties are quite different. A more detailed analysis is only useful if the results can be compared with a detailed theoretical model for each blazar separately.

**CONCLUSIONS**

In this proceeding we have discussed the effect of pair production on extragalactic gamma-ray sources using a lower limit EBL model based on strict lower limit coming from infrared number counts. The lower-limit EBL is still in agreement with upper limits derived so far from the process of pair production with very high energy gamma-ray emission by BL Lacs.

The intrinsic power-law spectra derived with the lower-limit EBL are still in agreement with standard acceleration mechanisms proposed for relativistic jets in blazars. We find, however, that using a simple power-law to fit the observed spectra corrected for absorption is not optimal, and intrinsic spectra exhibit large variations between sources. For example Mkn501 and Mkn421 would be better fit by a power-law with exponential cut-off. Furthermore, low photon statistics limits the accuracy at which individual intrinsic spectra can be recovered; Gamma-ray spectra with higher statistics, like we were able to observe from PKS2155-304 in its extraordinary flair [9], are needed for a detailed studied of each single blazar. Finally, there might be a selection effect with redshift towards lower spectral indices, that is so far not estimated.

Despite the use of the power-law approximation for the intrinsic spectra, the modeled spectra corrected for EBL absorption using our lower-limit EBL reproduce qualitatively well the observations (Fig. 2). This was not particularity expected, given for instance the unrealistically low cosmic star formation rate that our lower-limit EBL implies [8].

Another hint towards more complex blazar models would be if future EBL limits from GeV/TeV observations become lower. If they drop below the strict lower-limit EBL presented here, observations of galaxies and star formation are violated and the standard assumptions on blazar physics have to be revised. Attempts have already been made like more detailed SSC simulations [10] which are only leading to very small changes of the photon index in BL Lacs. Other solution might be intrinsic absorption [11], [12] or even exotic particle processes which prevent the gamma-ray photons from being absorbed [13].

Lower limits measurements and the lower-limit EBL model are available online.1

REFERENCES


1 in Orsay: http://www.ias.u-psud.fr/irgalaxies/ and in Hamburg: http://www.desy.de/kneiske
FIGURE 2. Observed spectral energy distributions for blazars indicated in the figure. The sources are ordered by their redshift, from high (top) to low redshift (bottom). The total flux is normalized for a better visualization. The lines are model spectra corrected for minimum EBL absorption, described in the text. Numbers on the right indicate the spectra index $\alpha$ and the redshift of the source.