latnewsletter - EBL article

EBL studies with GLAST

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What is the EBL?

The Extragalactic Background Light (EBL) is the electromagnetic radiation accumulated in the universe since the decoupling of matter and radiation following the Big Bang. By definition, the EBL does not include foreground radiation from the Solar System, the Milky Way or other nearby galaxies, nor does it include the Cosmic Microwave Background radiation (CMB).

The EBL spectrum consists of two spectral humps (see fig 1). The left hump, located at UV-Optical-NearInfrared wavelengths, corresponds to the radiated output from stars. The second hump, meanwhile, corresponds to dust emission resulting from the absorption and re-emission of starlight by the interstellar medium within galaxies (other more "exotic" EBL contributors are also possible, see [1] for a review). The EBL is therefore a fosil of the star formation and evolution processes, and its measurement provides a fundamental insight into the history of the universe [2].

Direct measurements of the EBL intensity are very difficult. First, the EBL has no spectral signature to look for, since its spectrum depends in a nontrivial way on the characteristics of the sources, on their cosmic history, and on the process of dust formation around these sources. Second and more important, the EBL flux is excessively weak with respect to the foreground from other celestial sources (such as interplanetary dust, stars and interstellar medium in the galaxy, etc.).

The EBL and GLAST

The EBL is strongly connected to gamma-ray astrophysics because high energy gamma-rays (E > 10 GeV) emitted by extragalactic sources are subject to absorption due to pair-production with EBL photons. One exciting consequence of this effect is that the magnitude of this absorption can then be used to measure (or at least constrain) the column density of background photons between the source and the observer [3]. This principle has been successfully applied by the H.E.S.S. collaboration [13] to constraint the EBL at Near-Infrared wavelengths, revealing at lower EBL flux than previously expected.

Due to the kinematics of pair-production, gamma-rays detected by ground-based telescopes (with energy E >~ 200 GeV) are subject to attenuation by the near- and mid-infrared part of the EBL. Gamma-ray absorption in this energy regime is quite strong, and therefore, probes of the EBL by ground-based instruments is limited to relatively low redshifts (z<~0.2). GLAST, on the other hand, is sensitive to the less drastic attenuation by the UV-optical part of the EBL, with no attenuation expected (at any redshift) for photons with energy below 10 GeV. Thus, EBL attenuation alone will not limit GLAST's ability to detect distant gamma-ray sources.

Studying the EBL with GLAST

GLAST will allow for a completely new approach to EBL studies, namely, study of the effects of EBL attenuation on a large number of blazars as a function of redshift. This is possible thanks to GLAST's sensitivity and wide bandpass, which will allow the number of known blazars to increase from about one hundred [4] to one thousand or more [5, 6, 7], with redshifts up to z > 3-5. Furthermore, because gamma-ray sources to be observed by GLAST are distributed over a wide range of redshifts, EBL studies with GLAST could potentially probe not only the total level of the background radiation (as observed in the present epoch, i.e. z~0), but its evolution as well.

Chen, Reyes & Ritz [8] illustrated the potential of GLAST to probe the optical-UV EBL via the measurement and statistical analysis of the flux-ratio F (E > 10GeV)/F (E > 1GeV) for a large number (>5000) of blazars. An alternate method presented here considers the spectrum steepening of individual blazars by means of a functional form with adjustable parameters that are fitted with gtlikelihood. This analysis in particular provides a measurement of the energy cutoff observed in the source with respect to an assumed intrinsic spectrum. In the absence of information regarding the intrinsic spectrum of the source (from multi-wavelength observations and blazar emission models), a simple power law is used in order to keep the number of free parameters to a minimum. The bias introduced by individual sources given this simplification is expected to become less significant when many sources are considered together as a population.

A one-year-long simulation of the ~300 blazars expected to be the brightest in the gamma-ray sky as seen by GLAST was performed. The simulation included galactic and extragalactic gamma-ray backgrounds and a detailed model for the variability of such blazars. To simulate the EBL attenuation the "Best Fit" model from Kneiske et al [9] was used. Figure 2 presents a scatter plot of the energy cutoff vs redshift obtained from the analysis of the Monte Carlo simulation. This relation was first introduced by Fazio & Stecker in 1970 [10] as a way to relate the energy cutoff with the redshift of the source. Kneiske et al 9 have proposed to use the Fazio-Stecker relation (FSR) to compare EBL models with the distribution obtained from observations. This idea is implemented here by considering the FSR obtained after determination of the cutoff energies of the simulated blazars. The black squares in the plot indicate the energy cut-offs as determined from the likelihood fits and can be seen to reproduce very well the EBL model used for the simulation (Kneiske et al's "Best Fit"). Not all the sources considered in the simulation produced meaningful fits: for some blazars the error in the determination of the energy cutoff is greater than the value itself. This is due to the lack of photons at the highest energies for sources with soft intrinsic spectra (index > 2.5). Of the 165 blazars included in the simulation with redshift z > 0.5 (i.e. with EBL energy cut-offs that are in the energy range measured by GLAST) 97 of them yielded meaningful fits.

In the absence of blazar intrinsic absorption and strong blazar spectrum curvature, the data points in the FSR plot will converge (amid statistical fluctuations) to the true curve due to EBL absorption. If it turns out, however, that this is not the case for a few or most blazars, their measured cut-off energies would spread below the EBL-induced value, but never above. This would enable at least and upper limit on EBL attenuation (least-attenuated flux in a particular redshift range).

Caveats

Blazars display strong variability in their intensity and spectra. For the study of EBL attenuation, this constitutes both a nuisance and an opportunity. Variability is a nuisance because measuring the spectral steepening of a source is more difficult when such spectrum is changing constantly. In the case of the LAT, or any other space-based instrument, a precise measurement of the high energy spectrum of a source requires long integration times, and thus, the time-average steepening is what is actually measured. The impact of blazar variability has already been probed with the simulation and analysis described above, and as can be seen, it did not prevent a correct determination of the collective level of EBL attenuation experienced by blazars as a function of redshift. It should be noted however, that blazar variability is not well understood (this is something that GLAST will measure), and that the variability model used in the simulation might differ significantly from reality. Nevertheless, blazar variability could also represent an advantage, since the energy cut-off observed in a given blazar should be the same independently of the flaring state of the source, if due to EBL absorption. This would constitute a powerful check of the effectiveness of individual blazars as probe of the EBL.

An observation of a redshift-dependent effect as the one observed in Fig. 2 does not guarantee actual absorption by EBL background. There would be a possibility that spectral evolution of gamma-ray blazars might coincidentally mimic EBL attenuation. For example, if blazars that formed in the early universe suffered more internal attenuation than younger blazars, a similar effect could be observed. Such possibility has been pointed out by Anita Reimer [11] after modeling the intrinsic absorption of gamma-rays with photons from the accretion disk and broad-line region of blazars during periods of strong accretion. Given the blazar emission model considered in her study, and assuming a correlation between accretion history and black hole mass, Anita found that the intrinsic opacity of blazars is redshift-dependent (through black hole mass evolution), and thus, it mimics EBL attenuation.

If this is the case for the majority of blazars to be observed by GLAST, the intrinsic energy cut-offs are likely to vary significantly blazar-to-blazar, and thus, the data spread in a given redshift bin would have larger scattering with respect to the mean than in EBL-only absorption scenarios. This would allow at least an upper limit on EBL attenuation by looking at the least-attenuated energy-cutoff in a particular redshift bin. Furthermore, intrinsic opacity is likely to change within each blazar during different emission states, allowing thus to constrain over time the nature of the observed energy cutoff.

EBL studies like the one illustrated here will require redshift determinations for a large fraction of GLAST blazars. This is just another example of the importance of cross-wavelength studies: by using optical measurements of blazar redshifts, gamma-ray observations can effectively probe the optical-UV EBL.

Conclusion

Given enough observationally available gamma-ray sources at the relevant redshifts, GLAST observations could become a powerful cosmological probe of the high-redshift universe. Indeed, if enough of these sources are suitable for EBL studies (bright and free of intrinsic energy cutoffs at E<~100 GeV energies) GLAST will probe the UV-optical EBL density and its evolution over cosmic time.

This will not be a simple task. When considering blazars for example, the emission process(es) and intrinsic spectra are not known. Conversely, blazars can not be completely understood if the effects of EBL absorption are not considered. GLAST represents a great opportunity to break this circle by allowing the study of EBL attenuation with a large population of sources that are distributed over a wide range of redshifts. Analysis techniques like the one outlined here attempt to use this advantage by studying the collective behavior of blazars and its correlation with redshift.

This is not the only type of method. EBL absorption can also be measured by using blazar emission models to predict the unattenuated spectrum of a few blazars through fitting of multi-wavelength data. Furthermore, blazars are not the only class of extragalactic gamma-ray sources; GRBs are also located at cosmological distances (observed up to z>~6) and will experience the same kind of EBL attenuation (Nukri Komin, Fred Piron and V. Pelassa [12] were able to measure energy cutoffs in the spectra of a couple of blazars from the Service Challenge simulation). These two possibilities constitute independent types 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 gamma-ray blazars mimic EBL absorption. Detailed analyses will have to address the likelihood and impact of such scenarios. GLAST observations, in any case, will provide an important constraint.

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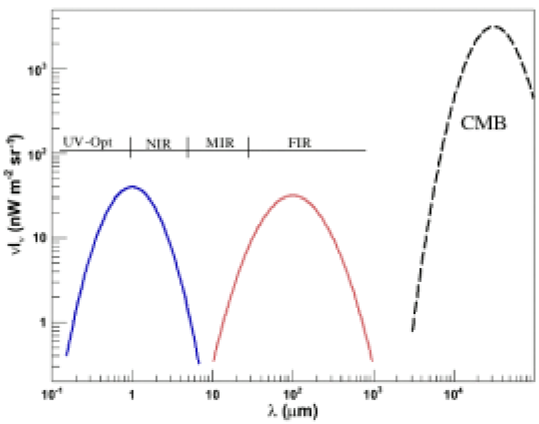

Figure 1. Schematic EBL spectrum as a function of wavelength. The EBL spectrum consists of two spectral humps: The blue hump at UV-Optical-NIR wavelengths is the radiated output from stars. The red hump at MIR (mid-infrared) and FIR (far-infrared) wavelengths results from the absorption and re-emission of starlight by the interstellar medium. The CMB spectrum (dashed black line) is presented here just for comparison purposes (since it is not considered part of the EBL). The location and size of the humps is just approximate, since the precise shape and intensity of the EBL is not completely constrained from observations.

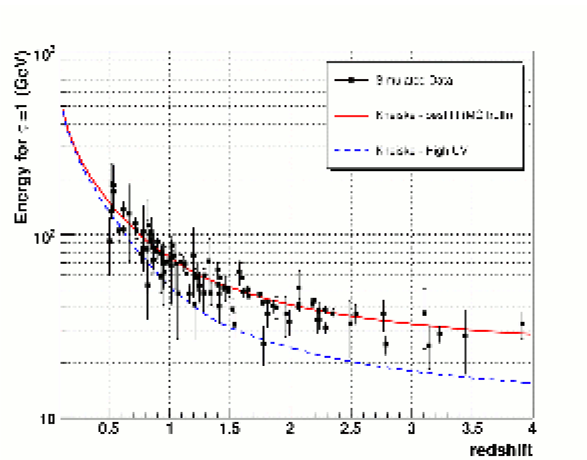

Figure 2. Fazio Stecker Relation for the simulated data. The black squares represent the energy cut-offs determined from the fits and their uncertainties. They converge to the EBL model (Kneiske et al. - best fit) used for the simulation (red line). Also shown is a different EBL model (Kneiske et al. - high-UV ; blue dashed line) used here to illustrate the discriminating power of the analysis.