CONSTRAINS ON EXTRAGALACTIC BACKGROUND LIGHT FROM CHERENKOV TELESCOPES

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Very high energy (VHE, E > 30 GeV) γ-rays are absorbed via interaction with low-energy photons from the extragalactic background light (EBL) if the involved photon energies are above the threshold for electron-positron pair creation. The VHE γ-ray absorption, which is energy dependent and increases strongly with redshift, distorts the VHE energy spectra observed from distant objects. The observed energy spectra of the AGNs carry therefore an imprint of the EBL. Recent detections of hard spectra of distant blazars (z = 0.11 – 0.54) by H.E.S.S. and MAGIC put strong constraints on the EBL density in the optical to near infrared waveband. Since the EBL limits depend on model assumptions, it is not yet possible to distinguish between an intrinsic softening of blazar spectra and a softening caused by the interaction with low energy EBL photons. In this paper, we give an overview of the EBL constraints, their limitations and perspectives for the joint efforts of the Fermi Gamma-Ray Space telescope and imaging atmospheric Cherenkov telescopes.

1 Introduction

During the star and galaxy formation history a diffuse extragalactic radiation field has been accumulated in the ultraviolet to far infrared wavelength regimes. This radiation field, commonly referred to as the extragalactic background light (EBL), is the second largest, in terms of the contained energy, background after the Cosmic Microwave Background of 2.7 K (CMB). While the CMB conserves the structure of the universe at the moment of the decoupling of matter and radiation following the Big Bang (at redshift z $\approx$ 1000), the EBL is a calorimetric measure of the entire radiant energy released by processes of structure formation that have occurred since the decoupling (see Hauser&Dwek[1] and Kashlinsky[2] for recent reviews).

The UV – infrared backgrounds is shown in Figure 1, left plot. From right to left, the spectral energy distributions of the three major components are shown: the cosmic microwave background (CMB), and the two components belonging to the EBL: one peaking at around 1 μm is believed to originate directly from stars. The second one, having its peak at $\sim$100 μm, results mostly from starlight that has been absorbed by dust inside galaxies and reemitted at larger wavelengths. Other contributions, like emission from AGN and quasars are expected to produce no more than 5 to 20% of the total EBL density in the mid IR (see e.g. Matute[3] and references therein). The EBL is difficult to measure directly due to strong foregrounds from our solar system and the Galaxy. The observation of distant sources of VHE γ-rays using Imaging Air Cherenkov Telescopes (IACT, such CANGAROO, H.E.S.S., MAGIC or VERITAS) provides a unique indirect measurement of the EBL due to energy dependent γ-ray absorption with the low energy photons of the EBL. The precision of the EBL constraints set by the IACT improved remarkably in the last few years. Contemporaneously with the IACT constraints, there has been rapid progress in resolving a significant fraction of this background with the deep galaxy counts at infrared wavelengths from the Infrared Space Observatory (*ISO*) and from the *Spitzer* satellite as well as at sub-millimeter wavelengths from the Submillimeter Common User Bolometer Array (SCUBA) instrument. The current status of direct and indirect EBL measurements (excluding limits from the IACTs) is shown in Fig. 1, right plot.

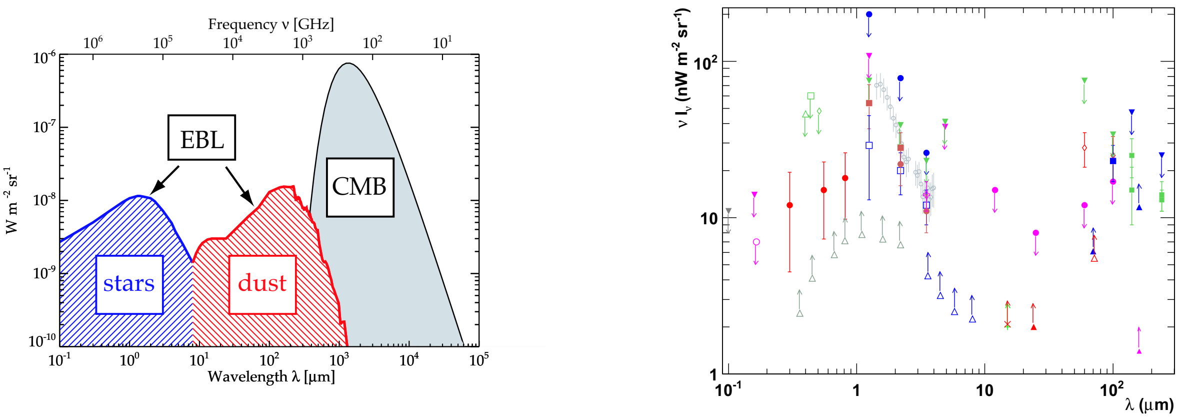

Figure 1: *Left:* Schematic Spectral Energy Distributions (SED) of the most important (by intensity) backgrounds in the universe. CMB and EBL are shown. Plot adopted from Dole et al.[4]. *Right:* EBL measurements and limits (status end 2006). Symbols see in Mazin&Raue[5].

There is fundamental entangled problem for the EBL and intrinsic blazar spectra: to study intrinsic blazar physics one needs to understand the EBL and vice versa. Therefore, one may concern that from a single observed energy spectrum of a distant VHE γ-ray source, it is rather difficult if not impossible to uniquely distinguish between the imprint of the EBL and intrinsic features of the source. Observed features can be source inherent due to an internal absorption inside the source or due to a source, which does not provide necessary conditions for acceleration of charged particles to high enough energy. However, there are many ideas how to overcome this duality: e.g., population studies of many extragalactic sources (whereas the intrinsic features might be different, the imprint of the EBL at a given redshift is the same) or/and variability of the spectra (variability is intrinsic, whereas the EBL imprint is always the same). With the current population of VHE γ-ray sources, it is only possible to set limits on the EBL, arguing that the observed spectra contain at least the imprint of the EBL.

2 Status of the EBL limits set by Cherenkov telescopes

Assuming a certain EBL density and the measured blazar spectrum, the intrinsic spectrum at the source can be calculated. By comparing the intrinsic spectra with blazar model predictions, limits on the EBL density can be derived.

The H.E.S.S. collaboration reported the detection of two intermediate redshift blazars 1ES 1101-232 (z = 0.186) and H 2356-309 (z = 0.165) [6]. Both observed spectra (measured in the range 150 GeV – 3 TeV) show a relatively hard spectral index of 2.9 and 3.1, respectively. Using the criterion that the intrinsic blazar spectrum cannot be harder than $\Gamma_{\mathrm{int}} = 1.5$, the authors derived a stringent upper limit on the EBL density in the region between 0.8 and 4 μm (see Fig. 2, left plot). The derived upper limits imply a low level EBL density in agreement with the expectations from standard galaxy evolution models. Later, the limits were confirmed using the blazar 1ES 0347-121 (Aharonian et al.[7]). The limits, in turn, rule out a cosmological origin of the near infrared excess (e.g. Matsumoto et al.[8]).

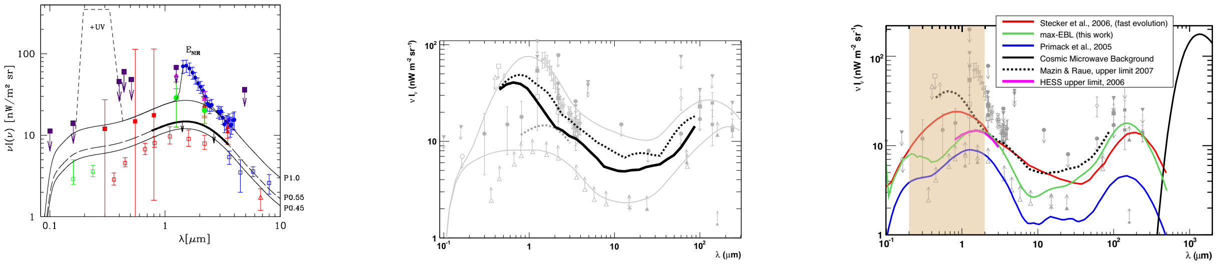

Figure 2: *Left:* Limits set by H.E.S.S. The thick black line between 0.8 and 4 μm shows the H.E.S.S. limit. *Middle:* Combined results from Mazin&Raue: the *extreme* scan (dashed black line) in comparison to the result from the *realistic* scan (solid black line). *Right:* Limits set by MAGIC using the 3C 279 spectrum. The green line inside the shadowed region corresponds to the EBL upper limit.

A common criticism of the EBL limits derived as shown above is that they use only few blazars (therefore not providing consistency with other sources) and that the limits are obtained by assuming a certain EBL model and e.g. scaling it, or by exploring just a few details, i.e. the derived limits become very model-dependent. In order to avoid this dependency Mazin&Raue[5] performed a scan over many hypothetical EBL realizations (over 8 million different ones). The authors also tested all available blazar spectra (until 2006) to generalize the EBL limits. The derived upper limits on the EBL density are shown in the middle plot of Fig. 2. Two limits are shown: the solid line represents the upper limit assuming that the intrinsic blazar spectrum cannot be harder than $\Gamma_{\rm int} = 1.5$, whereas the dashed line shows the limit for $\Gamma_{\rm int} = 2/3$. The latter one can be understood as the most conservative one as it is derived for monoenergetic electrons, which are responsible for the inverse Compton scattering of ambient photons. One can see that the derived limits favor a low EBL level and are in good agreement with galaxy counts from the optical to the mid infrared regimes. Again, the cosmological origin of the near infrared excess (e.g. Matsumoto et al.[8]) can be ruled out even for the extreme case of $\Gamma_{\rm int} = 2/3$. Using these EBL limits, constraints on the physical parameters of the early stars (z>5) were explored by Raue et al.[9].

In 2007, the MAGIC collaboration reported a detection of a very distant (z = 0.536) radio quasar 3C 279 at energies above 80 GeV [10]. The measured energy spectrum of 3C 279 extends up to ≈500 GeV, which implies a very low EBL level. In order to derive an EBL limit, the MAGIC collaboration used the EBL model of [13]. The authors [10] fine-tuned physical parameters of the EBL model in order to comply with the requirement that the intrinsic spectrum of 3C 279 cannot be harder than $\Gamma_{\rm int} = 1.5$. The resulting maximum allowed EBL model is shown by the green line in Fig. 2, right plot. The EBL limit derived by MAGIC [10] is on a similar level as limits derived earlier (H.E.S.S.[6] and Mazin&Raue[5]) and for the first time the EBL was probed at higher redshifts $0.2 < z < 0.5$. Moreover, the MAGIC limit extends into the ultraviolet regime (0.2μm to 0.8μm).[a] Tavecchio&Mazin[11] tested the effect of internal absorption on the intrinsic spectrum for several realistic scenarios and confirmed limits derived by MAGIC.

Summarizing the status of the EBL constraints obtained by the IACTs, the following can be stated:

- robust EBL upper limits are derived by different groups extending from ultraviolet through mid infrared regimes;
- the limits are close (at most factor of 2 higher) to the EBL low level inferred from the resolved galaxies by *HST*, *ISOCAM* and *Spitzer*;

[a] See Stecker&Sculy[12] for an alternative interpretation.

- this implies that instruments like *HST*, *ISOCAM* and *Spitzer* resolved most of the EBL sources;
- the resulting γ-ray horizon can be determined to lie within a narrow band between the upper limits from the IACTs and the low limits from the galaxy counts;
- the limits disfavor several EBL models which imply a late peak in the star formation history;
- the limits rule out a cosmological origin of the near infrared excess.

Even for an EBL model tuned to the level of the resolved galaxies [14], the intrinsic spectra of several TeV blazars show the maximum realistic hardness of 1.5 or close to it (e.g. Krennrich et al.[15]). This can be related to the selection effect: only blazars with extremely hard spectra can be detected because the flux of blazars with softer spectra falls below the current sensitivity limit of the IACTs. Harder than expected intrinsic spectra of VHE γ-ray sources would imply either an unnatural fine-tuning of low energy radiation fields inside the sources (e.g., Aharonian et al.[16]), different acceleration mechanisms of charged particles responsible for VHE γ-ray emission or even new physics (e.g. violation of Lorentz invariance [17] or new particles [18]). Future observations with the *Fermi* Gamma-ray observatory and new generation of IACTs such as H.E.S.S. II and MAGIC II will clarify the issue of hard intrinsic spectra due to a higher sensitivity of the instruments.

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