EBL data and limits: Implications for Axion Search

Tanja M. Kneiske
Experimentalphysik, University of Hamburg, Luruper Chaussee 148, Hamburg, Germany

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One way to search for axion like particle (ALP) is to study the absorption in extragalactic gamma-ray sources. The change of a high-energy photon to an ALP could prevent the absorption due to pair production with ambient infrared photons. The knowledge of these diffuse low energy photon fields are therefore one of the key elements in such a search. In the following the different methods are explained to get limits and data for the extragalactic background light (EBL) to show the current status in this field. The purpose of this article is to show that up to now there is no disagreement between observations of the EBL flux and absorption of gamma-ray photons from extragalactic sources. Only future detections of high redshifted gamma-ray sources could lead to non-standard physics.

1 Data & limits

The extragalactic background light is the optical to infrared part of the local component of the cosmic radiation fields (for a review see [1]). Direct emission from stars and reprocessed light by the interstellar medium can explain most of the observed flux, but there are still uncertainties, which give room for other contributions [2]. There are basically two types of observations constraining the EBL flux, direct observations (Figure 1; green symbols) and galaxy number counts (Figure 1; blue symbols).

1.1 Galaxy number counts

Galaxy counts are a good method to estimate a strict lower limit for the EBL flux from galaxies. The idea is to count in a deep field the observed galaxies according to their luminosity. The integrated light of all counted galaxies is a certain contribution to the EBL. Most of the data derived in this way are much smaller than the direct observations and model predictions since the samples are flux limited and they have been derived only from a small part of the sky. A better estimate is if the results are extrapolated for the whole sky. This can only be done if the deep field represents an average and cosmological representative part of the universe. Therefore recent observations and number counts are not based on one deep field but on two or more. The choice of the deep fields and their dimensions are also very important. The deep fields are chosen to lie in a direction without bright foreground galaxies, stars and clusters. The line of sight includes also only low cirrus infrared emission, low extinction and low hydrogen column densities. To avoid an over- or underprediction due to the large-scale structure a combination with wide fields are important. They are not as deep but cover a larger area at the sky averaging voids and filaments of the cosmic web. Lower limits shown Figure 1 using this method are from the Hubble Space Telescope (HST) (solid blue squares) [3], the SPITZER data in the near IR (open blue triangles) [4], the lower limits in the far infrared derived from Herschel (filled blue circles) [5] and by AKARI (blue X) [6]. A technique to get even deeper galaxy count images is to use galaxy cluster lenses as has been done with ISO (cyan filled triangles) [7], [8] and Herschel (Cyan filled circles) [9]. Another way of deriving good lower limits is the stacking analysis of deep fields. Using a source catalogue of observed galaxies at 24 microns [10] has looked for a combined signal from all sourced at 70 and 160 microns where the galaxies were not observable as single sources. This has been updated in [11] (open blue triangles). All the derived data, even if they are not published as that, are to be handled as lower limits, due to the detection technique. It is always possible that the surveys are missing faint galaxies or stars and galaxies at higher redshift. As a result it seems that the far infrared background is close to being resolved by recent observatories, since the number counts are on the same flux level as the direct observations.

1.2 Direct observations

A different way of observing the EBL flux is the direct observations. Here the sky is searched for a radiation component, which is independent of direction and place of observation. The biggest problem with this method is that the EBL flux is very small compared to the dominating foreground emission like the zodiacal light. It is reflected sunlight by a ring of dust particles around the sun. Venus and the earth are inside the ring and so also inside the dust emission. Although the zodiacal light is not completely isotropic detailed models of the location and type of dust is needed to estimate this component (see [1] and refs. therein). In the far infrared the interstellar medium can also play a role and DIRBE data have been analyzed by different authors to estimate its influence (open green circles) [12]. So despite great efforts to study the foreground emission contamination of data from IRTS (Infrared Telescope in Space [13] and DIRBE (Diffuse infrared Background Explorer, [14] are still under discussion. More recent data from AKARI [6] show a good agreement with the older observations. Since it is not clear if all foreground emission have been removed all the direct observations have to be seen as upper limits.

1.3 EBL limits from AGN observations

Besides the direct ways of detecting the EBL flux there is the method of using the effect of EBL photons on the high-energy spectra of extragalactic gamma-ray sources. This indirect method is based on the pair-production process, which takes place between the ambient infrared photons and the relativistic gamma-rays. The search for absorption features in AGN at GeV and TeV energies is a possibility to study the EBL flux avoiding the problems stated above. But here another uncertainty comes into play. To calculate from the observed AGN spectra the EBL density the physics of the AGN needs to be known. Right now there are several theories, which could explain the multi-wavelength behavior of AGN spectra. But since AGN are complex objects where hadrons and electrons accelerated to relativistic energies meet thermal emission from the interstellar medium of the host galaxies and the gas and dust close to their cores, it is very hard to develop a model which can describe AGN completely. Each AGN also needs to be treated on its own, since even belonging to the same class of objects like blazars they can look quite differently. Making only very general and almost model independent assumptions about the gamma-ray spectrum upper limits on the EBL flux can be derived by Cherenkov telescope observations of blazars[15] (dashed red line), [16] (solid red line), [17] (solid red line), [18](short dashed line)). Using observed gamma-ray spectra by FERMI more optical limits could be derived [19] (red triangles down). Interestingly the limits from AGN observations came close to the lower limits from number counts. But right now the upper limits are within the errors about a factor of two above the lower limits and are therefore still in agreement. Only if the AGN upper limits fall below the lower limits from number counts, one has to re-think about the assumptions going into the limits. There awould be basically two possibilities then; AGN are different from the model predictions used or some process prevent the high energy photons from being absorbed.

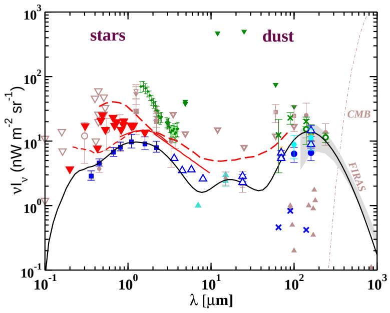

Figure 1: Extragalactic background light flux: data and limits (description and refs. see text). The black line is the lower limit EBL model [23] which gives a physically correct description of the lower limit data, including redshift evolution.

2 Implications for axions and axion like particles

Assuming that the EBL lower limit flux has been measured correctly and that the AGN physics is understood there are several theoretical ideas, which could alter the pair production process on large scales in the universe. One is the conversion of photons into axions or ALPs. If such a particle is converted back to a gamma-ray photon before it reaches earth is would be detected together with the unabsorbed emission. The gamma-ray spectrum would look less absorbed than it should be and the resulting upper limit on the EBL flux could be below the number counts [20], [21]. However all the absorption features including high 3C279, can be explained by standard physics in the photon-photon pair production framework. But there are some discrepancies, which are so small that they can still be explained by observational and theoretical uncertainties, but could also hint towards some disagreement in the standard picture. To model the lower limit number counts a very low cosmic star formation rate (CSFR) needed. Data of the CSRF are highly model dependent and scatter almost within one order of magnitude. Since the star formation cannot be observed directly the data are calculated from galaxy number counts, the same that are used to derive the EBL data. To infer the CSFR a conversion factor is needed [22]. The CSFR, which is used to fit the EBL lower limit data, lies below the average data. So the lower-limit EBL star formation is already underestimating the amount of stars observed in the universe. A factor of two more star formation in the universe would describe the CSFR data much better, but it also leads to an EBL flux on the same level as the AGN upper limits.

Only a slight change of the limits could lead to question standard physics.

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