Probing the existence of Axion Like Particles using observations of very high energy γ–rays from distant blazars

K. K. Singh,* S. Bhattacharyya, A. K. Tickoo, and N. Bhatt
Astrophysical Sciences Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA

Introduction

The propagation of very high energy (VHE, 100GeV–100TeV) γ–rays emitted from extragalactic sources like blazars is suppressed due to their interaction with soft photons of extragalactic background light (EBL). The energy and distance dependent EBL absorption leads to the optical depth > 1 when VHE γ–rays emitted from a distant source propagate towards the Earth. However, observations from current generation ground based imaging atmospheric Cherenkov telescopes (IACTs) indicate enhanced transparency of intergalactic space to VHE γ–rays. A possible explanation of the observed enhanced transparency of the Universe has been proposed by various authors in the literature and is attributed to the oscillation of VHE photons into hypothetical axion-like-particles (ALPs) in ambient magnetic field of intergalactic space [1].

EBL Absorption and γ–ray horizon

VHE γ–rays emitted by distant sources are not able to propagate large distances because of the absorption by low energy EBL photons. These low energy optical/IR photons in the wavelength band 0.1-1000μm originate from the starlight integrated over all epochs and the starlight absorbed and re-emitted by dust in galaxies in the course of cosmic history. The pair production interaction process for absorption of VHE photons can be expressed as

$$\gamma_{VHE} + \gamma_{EBL} \rightarrow e^- + e^+ \qquad (1)$$

*Electronic address: kksastro@barc.gov.in

This process causes energy (E) and distance (redshift, z) dependent absorption of VHE γ–rays propagating in the extragalactic space. This opacity is characterized by the optical depth τ(E,z) which also depends on the number density of EBL photons. As a result of EBL absorption, the intrinsic or emitted VHE γ–ray spectrum of distant sources (F_{em}(E,z)) is exponentially suppressed and is related to the observed spectrum (F_{obs}(E_0,z)) as

$$F_{obs}(E_0, z) = F_{em}(E, z) \times e^{-\tau(E,z)} \qquad (2)$$

where E_0 is the observed photon energy. Therefore, the Universe should be opaque to VHE γ–rays coming from the sources at cosmological distances. For a given distance and energy of VHE γ–ray photon, $\tau(E, z) = 1$ is referred to as *gamma-ray horizon* and $\tau(E, z) > 1$ corresponds to *opaque Universe*. The *gamma-ray horizon* represents the boundary beyond which the emission of VHE γ–ray sources is strongly attenuated in the extragalactic space. Although, several models have been proposed for the intensity and spectral energy distribution of EBL at $z = 0$, all of them yield nearly similar results in the local Universe (z<1) [2]. Some recent analysis of the observed VHE spectra of a few distant blazars indicates that the EBL absorption predicted by current models is very strong especially at higher energies. Therefore, it has become necessary to invoke other alternate possibilities which can explain the enhanced transparency of intergalactic space to VHE γ–rays coming from distant sources so that the measured flux points would be interpreted adequately.

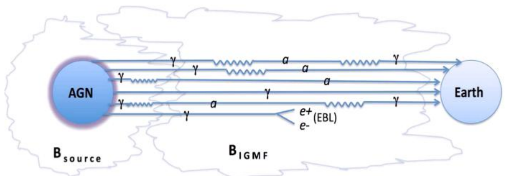

FIG. 1: Conceptual sketch for photon-axion like particle oscillations and EBL absorption during the propagation of VHE γ–rays from source to the Earth [4].

Photon-ALP oscillation and Summary of the present work

The existence of axions (pseudo-scalar bosons) is predicted by different Standard Model Extensions to solve the *Charge-Parity (CP)* problem in Quantum Chromodynamics [3]. Axions are defined by a generic property of two-photon interaction (a$\gamma\gamma$) with coupling strength inverse of their masses. However, there exist other predicted states with same phenomenology but mass and coupling constant not inversely related to each other. Such states are referred to as ALPs. A possible explanation for the observed transparency of the Universe to VHE γ–rays is proposed to be the oscillations of photons to ALPs and vice versa owing to a$\gamma\gamma$ coupling in the presence of external magnetic field as shown in Figure 1 [4]. If mixing between photons and ALPs occur, a fraction of VHE photons would travel in the form of ALPs over a large cosmological distance without interacting with EBL photons, since the process a$\gamma \rightarrow \gamma$ is kinematically forbidden and a$\gamma \rightarrow e^- e^+$ scattering has negligibly small cross section. ALPs are reconverted to photons before reaching the Earth and lead to a more tranparent Universe. This oscillation mechanism would increase the transparency of the Universe as ALPs are expected to propagate unimpeded over cosmological distances.

In this work, we use an EBL model which gives minimal attenuation (and hence high degree of transparency of Universe to VHE γ–rays) to obtain the emitted spectra from the observed spectra of a few distant blazars using observations with IACTs. The emitted spectra show flatness or turn up at higher energies, which can not be explained by the standard frame work of blazar emission. We study the effect of photon-ALP oscillations on the VHE γ–ray spectra of distant blazars (upto redshift z$\leq$1) at optical depth τ $\geq$1 due to EBL absorption in different intergalactic magnetic fields over the range 0.01–1 nG. We find that the effect of photon-ALP oscillations is significant particularly at higher energies and large redshifts for intergalatic magnetic field above 0.1 nG and ALP mass $m_a \geq 10^{-10}$ eV.

More specifically, under the frame work of conventional physics for VHE γ–ray emission from a blazar at redshift z = 0.287, the photon-ALP conversion probability is found to be between 3-10% and for z = 0.034 the probability is estimated between 1-10% in the strong mixing regime [5]. Detection of this signature with ground based IACTs allows to infer the existence of ultra-light ALPs with mass $m_a \leq 10^{-8}$ eV and photon-ALP coupling constant $\leq 10^{-10}$ GeV^{-1}. It is expected that such signatures would start to emerge at energies above 1 TeV which can be clearly tested with the highly sensitive next generation ground based facilities like Cherenkov Telescope Array (CTA). An independent laboratory check of the existence of ALPs is also proposed by various authors with photon regeneration experiments ALPS at DESY and solar axion detector at International Axion Observatory (IAXO).

References

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