Photon Scalar/Pseudoscalar Mixing Dynamics In Magnetized Media

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Abstract

We study the dynamics of photon-scalar interaction (mixing) by operators of mass dimension five (predicted in numerous theories, beyond standard model), in various kinds of media. Our main objectives are to study medium specific modifications to the mixing dynamics of of photons with pseudoscalar (axion a(x)) and scalar e.g., dilaton , moduli etc. (denoted by $\phi(x)$) dark matter candidates. We look into spectro-polarimetric as well as oscillation aspects of the same and their possible astrophysical consequences.

1 Introduction

Scalar or pseudo-scalar bosons like dilaton, $\phi(x)$ [1] or axions $a(x)$, [2–5] arising out of symmetry breaking through quantum effects, have remained possible candidates of dark matter for some time now. Apart from them, scalar (moduli) fields, those appear naturally in string theory also belong to the same class [6] of dark matter candidates. Their interaction dynamics with photons γ is governed by dimension-five operators of the form $g_{\gamma\gamma\phi}\phi F^{\mu\nu}F_{\mu\nu}$ or $g_{\gamma\gamma\phi}\phi\tilde{F}^{\mu\nu}F_{\mu\nu}$, that results in making the vacuum optically active and dichoric–for the photons [7, 8] in a quasi-static or static external magnetic field $\mathcal{B}$. Moreover an additional possibility of subluminal or superluminal motion of the photons with such interaction, in some energy range, have also been reported in the literature [9–12].

In presence of $g_{\gamma\gamma\phi}\phi F^{\mu\nu}F_{\mu\nu}$ (or $\mathrm{g_{\gamma\gamma a}}\phi\mathrm{\tilde{F}^{\mu\nu}F_{\mu\nu}}$) interaction in a *magnetized* vacuum (i.e., in an external magnetic field $\mathcal{B}$), the two transverse degrees of freedom of the photons transform differently under **CP** transformation. One of them (having polarization orthogonal to $\mathcal{B}$ ($|\gamma_{\parallel}>$)) turns out to be **CP** even and the other one (with polarization along $\mathcal{B}$ ($|\gamma_{\perp}>$) **CP** odd respectively. Hence during their space-time evolution only the **CP** even-state gets coupled to **CP** even field $\phi(x)$ (or a(x), as the case may be) and the remaining **CP** odd state propagate freely. In other words, the mixing dynamics between $\phi(x)$ and γ is governed by 2×2 mixing matrix. The role of $|\gamma_{\parallel}>$ gets interchanged with $|\gamma_{\perp}>$ as the interaction vertex changes from $g_{\gamma\gamma\phi}\phi F^{\mu\nu}F_{\mu\nu}$ to $g_{\gamma\gamma a}a\tilde{F}^{\mu\nu}F_{\mu\nu}$. Thus for near degenerate strengths of the coupling constants ($g_{\gamma\gamma\phi}$ and $g_{\gamma\gamma a}$) and masses (m_{ϕ} and m_a) of the respective candidates, proper identification of one from the other may become an arduous task in the astrophysical context, at least.

The basic motivation of behind our investigation is to reduce this uncertainty in (particle) identification, in the spectro polarimetric context through incorporation of other effects. To this end, we would like to note that incorporation of matter effects doesn't change the (mixing) dynamics discussed above. However as the effect of magnetized matter is considered, the situation changes in the following fashion: the axion

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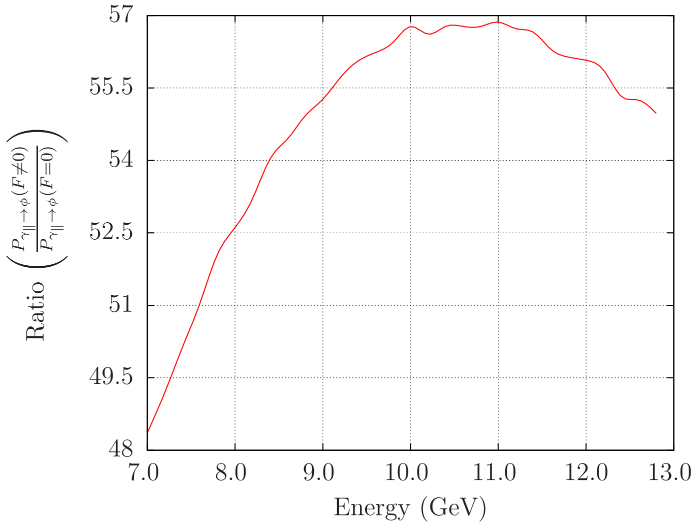

Figure 1: Ratio of oscillation probability ($P_{\gamma_{\|}\to\phi}$, evaluated in a magnetized medium vs the same in an unmagnetized media). Suffix F stands for magnetized contribution. The value of scalar mass: $m_\phi = 10^{-11}$ GeV, magnetic field strength: $\mathbf{B} = 1.0 \times 10^{13}$ Gauss, plasma frequency : $\omega_p = 1.6 \times 10^{-10}$ GeV and $g_{\gamma\gamma\phi} = 10^{-11}$ GeV^{-1}. The x axis has been scaled by a factor of 10^{-5}.

(a(x)) photon (γ) vertex gets augmented by an additional term proportional to $g_{\gamma\gamma a} a \tilde{F}^{\mu\nu} F_{\mu\nu}$, where the proportionality constant depends on temperature, chemical potential and magnetic field strength of the underlying magnetized-medium and the photon energy [13].
Apart from effect stated above incorporation of the effect of magnetized medium also changes the mixing dynamics, that is, the *mixing matrix in this case turns out to be 4×4*, implying, complete mixing of all the three degrees of freedom of photons (in a medium) with the single degree of freedom of the axion [14].

However, incorporation of the same for scalar-photon system, with $g_{\gamma\gamma\phi}\phi F^{\mu\nu}F_{\mu\nu}$) vertex, reduces the *mixing matrix to a 3×3 one [15] that is, there is a mixing between the two transverse polarization states of the photons with the scalar and the longitudinal degree of freedom of the photons get decoupled and propagates freely.*

This note is prepared to highlight this issue. Since the predictions of the spectro-polarimetric signatures from astrophysical objects due scalar and photon oscillation, are dependent on the type (magnetized or unmagnetized) of the underlying media. In order to elucidate upon our observations, a plot of the ratio of the oscillation probabilities $P_{\gamma_{\|}\to\phi}$ estimated in a magnetized vs the same in an unmagnetized media is provided in fig. [1]. The relevant parameters, those considered for the plot– that is the plasma frequency ω_p, the ambient field strength $\mathcal{B}$ and the energy of the emitted photons ω– are typical of a (one to 1.4 solar mass middle aged) compact star environment. The spectral dependence of the ratio of the oscillation probability can be read out from the figure [1]. The implications of this modification to observable physical consequences would be discussed in a separate communication.

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