Sub Gev polarimetric signatures of $\phi\gamma\gamma$ interaction from compact stars.

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Introduction

Interaction of photon (γ) with scalar (ϕ), through dimension-5 operators originates in many physical situations, ranging from medium energy nuclear physics to models for unification of forces. In nuclear physics, a composite scalar meson field (σ alias f_0, $J^P = 0^+$) interacts with two photons through loop effects.

In the field theoretic models, the scalar (termed ϕ) appear in theories where the classical scale invariance is broken through quantum effects as a compensator and is termed as dilaton. In the unified theories of electromagnetism and gravity they appear [1]. In extended supergravity models, they appear as the scalar component of the gravitational graviton multiplet [2, 3]. The interaction term has an universal feature, $\frac{1}{4M}\phi F^{\mu\nu}F_{\mu\nu}$, where, $M = \frac{1}{g_{\phi\gamma\gamma}}$, is the symmetry breaking scale, that varies from theory to theory. The scalar ϕ considered here, belongs to the class of field theoretic models, because of their possible role in solving dark matter dark energy problems [4].

As a scalar, ϕ would couple to all matter fields [5] generating a detectable finite range force. However, the experiments [6], dedicated for this purpose had put an upper bound on its range that in turn provides a lower bound on it's mass, i.e., 10^{-2} eV; the upper limit however is yet to be fixed.

In this work we outline a possible way to estimate scalar field mass m and coupling strength $g_{\phi\gamma\gamma}$ through detection of polarization signatures from the high energy (MeV - sub GeV range) electromagnetic signals coming from compact objects. The particular energy range is chosen to minimize the effect of Stellar, galactic and inter-galactic plasma. In order to perform the same, we evaluate the stokes parameters using standard procedure , followed by their estimation for a typical compact star environment parameters [4].

Equations of Motion

Action for the coupled photon-scalar system in flat four dimensional space-time is given by:

$$S=\int d^4x[\frac{1}{2}(\partial_\mu)\phi(\partial^\mu\phi)-\frac{1}{2}m^2\phi^2-\frac{1}{4}g_{\phi\gamma\gamma}\phi F_{\mu\nu}F^{\mu\nu} -\frac{1}{4}F_{\mu\nu}F^{\mu\nu}]. \quad (1)$$

Here m is the mass of scalar particle. The equations of motion (EOM) are written in matrix form as:

$$\begin{bmatrix} k^2 & 0 & 0 \\ 0 & k^2 & -g_{\phi\gamma\gamma}(\omega\mathcal{B}_\perp) \\ 0 & -g_{\phi\gamma\gamma}(\omega\mathcal{B}_\perp) & k^2-m^2 \end{bmatrix}\begin{bmatrix}\tilde{\psi}\\ \psi \\ \Phi\end{bmatrix}=0 \quad (2)$$

where $\mathcal{B}_\perp = \mathcal{B}sin\Theta$ and Θ is the angle between propagation vector and magnetic field $\mathcal{B}$. We can diagonalize the matrix, (given in Eq. (2)) and find the dispersion relations for $\tilde{\psi}$, $(\Phi sin\theta+\psi cos\theta)$ and $(\Phi cos\theta-\psi sin\theta)$, where $\theta = \frac{1}{2}tan^{-1}\left[\frac{2g_{\phi\gamma\gamma}B_T\omega}{m^2}\right]$. The dispersion relations are given as

$$\begin{aligned}\omega &= K \\ \omega_+ &= \pm\sqrt{K^2+\frac{m^2}{2}+\left(\frac{m^4}{4}+g^2_{\phi\gamma\gamma}\mathcal{B}^2_\perp\omega^2\right)^{\frac{1}{2}}}, \\ \omega_- &= \pm\sqrt{K^2+\frac{m^2}{2}-\left(\frac{m^4}{4}+g^2_{\phi\gamma\gamma}\mathcal{B}^2_\perp\omega^2\right)^{\frac{1}{2}}},\end{aligned} \quad (3)$$

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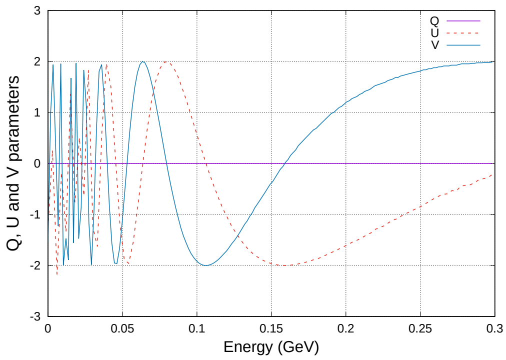

FIG. 1: Plot for Q, U and V vs energy. Here parameters are $g_{\phi\gamma\gamma} = 10^{-11} GeV^{-1}$,mass of scalar $m = 10^{-9} GeV$, magnetic field is $\mathcal{B} = 10^{12}$ Gauss and distance is taken 5 KM.

Solutions of Wave Equations

The solutions for inhomogeneous wave equations are given as:

$$\tilde{\psi}(t, x) = A_0 \; e^{i(\omega t - k.x)},$$
$$\psi(t, x) = A_1 \, cos\theta \, e^{i\left(\omega_+ t - k.x\right)} - A_2 \, sin\theta \, e^{i\left(\omega_- t - k.x\right)},$$
$$\Phi(t, x) = A_1 \, sin\theta \, e^{i\left(\omega_+ t - k.x\right)} + A_2 \, cos\theta \, e^{i\left(\omega_- t - k.x\right)}.$$

Here we consider the boundary conditions, $\Phi(0, 0) = 0$ and $\psi(0, 0) = 1$, according to the physics of curvature radiation. With this condition we have $A_0 = 1$, $A_1 = cos\theta$, $A_2 = -sin\theta$. With these conditions the solution for ψ turns out to be

$$\psi(t, x) = \left[cos^2\theta \, e^{i(\omega_+ t - k.x)} + sin^2\theta \, e^{i(\omega_- t - k.x)} \right].$$

Stokes Parameters for Coupled ($\gamma\phi$) System

We can evaluate stokes parameters by using the solutions $\psi(t, x)$ and $\tilde{\psi}(t, x)$

$$\begin{aligned} \mathrm{I} &= < \tilde{\psi}^*(x)\tilde{\psi}(x) > + < \psi^*(x)\psi(x) >, \\ \mathrm{Q} &= < \tilde{\psi}^*(x)\tilde{\psi}(x) > - < \psi^*(x)\psi(x) >, \\ \mathrm{U} &= 2\mathrm{Re} < \tilde{\psi}^*(\mathrm{x})\psi(\mathrm{x}) >, \\ \mathrm{V} &= 2\,\mathrm{Im} < \tilde{\psi}^*(\mathrm{x})\psi(\mathrm{x}) > . \end{aligned} \tag{4}$$

We can find polarization angle (Ψ)and ellipticity angle (χ), by these parameters, given as

$$\tan(2\chi) = \frac{V}{\sqrt{Q^2 + U^2}} \; \& \; \tan(2\Psi) = \frac{U}{Q}. \tag{5}$$

Conclusions

High energy electromagnetic (EM) emission in compact stars originate through synchro-curvature radiation in different energy ranges, due to presence of external magnetic field $\mathcal{B}$. These radiation is plane polarized.

These EM-radiation beams travel different path lengths in this field ($\mathcal{B}$), inside the stellar environment– till they come out of the light cylinder. Assuming the path-lengths to be same in our chosen energy interval, we have plotted the multi-energy-band stokes parameters in Fig.[1].From the multi-energy-band plot, the distinct energy dependent behavior of the stokes parameters can easily be identified.

The nonzero value of V shows the possibility of generation of circular polarization from initially plane polarized beams through $\phi\gamma$ induced mixing. This could be a possible signature of the existence of ϕ. Further more, one can estimate the polarization angle and ellipticity parameter using eq. [5] and compare them with the same obtained from the satellite based experiments to draw bound on the mass of ϕ and $g_{\phi\gamma\gamma}$.

Work in this direction is currently under progress; some details presented here can be found in [4]; and the further developments will be communicated elsewhere.

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