QCD axion detection from LAD interaction in compact star environment

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Introduction

The zero-spin bosons like pseudoscalar QCD axion have been introduced to resolve the UA(1) anomaly in Quantum field theory. They can interact with the photon via dimension-five coupling and are competitive candidates of dark matter[1]. Their couplings with photons, when considered in presence of magnetized background, may contribute substantially in solving anomalies related with the theoretical estimations and experimentally observed data of the polarimetric observables like ellipticity angle, polarization angle, Luminosity function etc. In order to compare the these observables with experimental data, one has to consider the more realistic model of non-thermal emission of photon by the electrons trapped along the magnetic field of the compact stars like neutron stars. In this paper we tried to do the same and incorporated the effect of radiation reaction over the evolution of Lorentz boost factor Γ of the electrons.

Evolution of Lorentz factor (Γ)

We will consider a simple picture of the non-thermal photon emission from a typical compact object. The basic picture according to these models is, the electric field $\mathbf{E}_{||}$ is produced due to the rotating dipolar magnetic field B of the compact object and is directed parallel to the ambient dipolar field. This field pull the charge particles out of the surface of the star. Their number density is n_{GJ} (where $n_{GJ} = \frac{\Omega B}{2\pi ce}$) [2]. The radiation is emitted from the charged particles, those are accelerated by the electric field $\mathbf{E}_{||}$.

The energy of the emitted photons from the magnetosphere of the compact object can be expressed in terms of the instantaneous Lorentz factor (Γ) of the radiating charged particles. It is given by $\omega = \frac{3}{2}\frac{\Gamma^3}{R_c}$, when R_c is the radius of curvature of the dipolar magnetic field lines.

Evolution of Γ, taking radiation reaction into account and energy gain due to the electric field is described by [3],

$$m\frac{d\Gamma}{dx} = e\mathbf{E}_{||} - \frac{2\mathrm{e}^2\Gamma^4}{3\mathrm{R}_\mathrm{c}^2}. \qquad (1)$$

This equation can be derived from the Lorentz-Abhram-Diraction (LAD) equation. When the energy-gain becomes equal to energy loss in Eqn.(1), a quasi-steady state is reached, that gives the estimate of Γ in terms of electric field. This is given by, $\Gamma = \left(\frac{3\mathbf{E}_{||}\mathrm{R}_\mathrm{c}^2}{2e}\right)^{\frac{1}{4}}$. The electric field, $\mathbf{E}_{||}$ at a position r, $(r > R)$ from the centre of the *compact object* is given by [2] in the space charge limited flow in pulsar emission model. Though in principle one can solve Eqn. (1), to find out position dependence of the Lorentz factor, but solving it analytically is difficult. However it is possible to solve Eqn. (1) numerically. A numerical solution is provided in fig.[1]. The upward turning point (P) corresponds to the quasi static limit in Eqn. (1). The basic motivation for this choice of parameters, was to find out the imprints of $\phi F^{\mu\nu}F_{\mu\nu}$ interaction on the non-thermal spectro-polarimetric signals from the star magnetosphere is realised in nature. In presence of such interaction,

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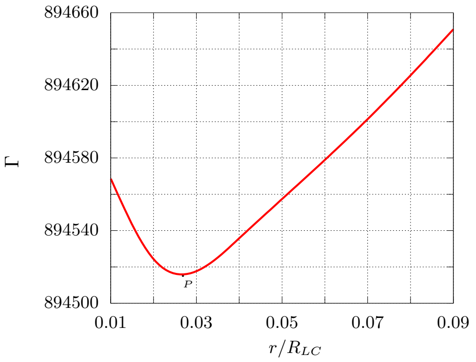

FIG. 1: Numerical evaluation of Γ with respect to the distance r scaled by the factor R_{LC}

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some of these energetic photons may eventually oscillate into QCD axion and go out of the magnetosphere of the compact object, and get detected by oscillating back into photon.

Observables from QCD axion-photon interaction

The QCD axion-photon interaction is governed by the effective Lagrangian given by [4] :

$$L = \left[\frac{1}{2}A^{\nu}\left(-k^2\tilde{g}_{\mu\nu} + \Pi_{\mu\nu} + \Pi^{p}_{\mu\nu}\right)A^{\mu} + ig_{\phi\gamma\gamma}\phi\bar{F}_{\mu\nu}k^{\mu}A^{\nu} + \frac{1}{2}\phi[k^2 - m^2]\phi\right] . \quad (2)$$

Here $\Pi_{\mu\nu}$ is in medium polarization tensor and $\Pi^{p}_{\mu\nu}$ is the correction due to magnetized medium effects. The solutions of the equations of motion corresponding to the system of Lagrangian (eqn. (2)), have been obtained exactly. Using these solutions, the stokes parameters (I, Q, U and V) can be estimated numerically [4].

The ellipticity angle being rotational invariant is suitable observable to look for the signatures of QCD axion. It can be estimate by using the equation: $\tan 2\chi = \frac{V}{\sqrt{Q^2+U^2}}$.

Discussion

The investigation carried out in this text provides a realistic approach to look for the signatures of Axion Like Particles (represented by ϕ') for the given parameter range. It also provides a region of investigation that may be helpful for designing the future detectors to detect very faint signal strength, carrying the imprints of QCD axion-photon interaction. The evolution of the ellipticity angle of the photon (carrying traces of interaction with QCD axion) with respect to energy and path length of the photon evaluated from the solution of the LAD equation in fig. [2]. The plot shows that the ellipticity angle increases with decrease in photon path length and increase in energy of photon with a dip in the curve. This behaviour of ellipticity angle will be explored in other communication.

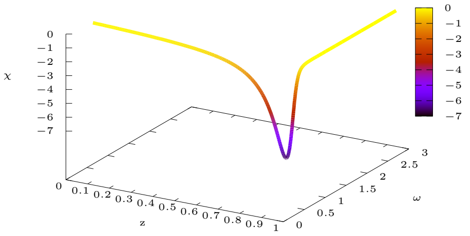

FIG. 2: Plot of ellipticity angle χ vs energy of photon ω and path length of the photon z. Here the magnitude of χ is scaled by the factor 10^{26}, ω is scaled by 10^{6}. The parameters for the plot are: $B \sim 10^{9}$G, $g_{\phi'\gamma\gamma} \sim 10^{-13}$ GeV^{-1}, $\omega_p \sim 10^{-15}$ GeV, $m_{\phi'} \sim 10^{-20}$ GeV.

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