Search for dark matter using SKA

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Introduction

Physics of sigma mesons have similarity with the scalar dark matter candidate like dilatons, are promising candidates for dark matter[1]. Although they do not couple strongly to ordinary matter, their indirect detection is possible through the imprints they leave on electromagnetic (EM) radiation emitted from astrophysical sources and observed by ground- or space-based telescopes.

A major challenge in this line of investigation arises from the extremely weak signal strength of these imprints. If the signal falls below the minimum sensitivity threshold of the detectors within the relevant parameter space, detection becomes unfeasible.

In this paper, we present our recent investigation of dilaton-photon oscillations in the magnetized media of compact astrophysical sources. Our analysis shows that the strength of the EM radiation signal S_γ, which carries the imprint of dilaton-photon mixing, lies within a range suitable for detection by current or upcoming instruments.

The Dilaton-Photon oscillation Probability

The dilaton in presence of magnetic field can oscillate into two degrees of freedom of photon. However participation of the degrees of freedom of photon increases in presence of magnetized medium background. The most favourable environment to facilitate the process of mixing is provided by the magnetosphere of the compact star. The expression of the probability for the oscillation between parallel polarization state of photon to the dilaton in presence of magnetized medium is provided as follows:

$$\begin{aligned} P_{\gamma_\parallel \to \phi} &= 4\mathbb{A}\left(\mathbb{A}+\mathbb{C}\right)\sin^2\left(\frac{\left(\Omega_\perp - \Omega_\parallel\right)z}{2}\right) \\ &+ 4\mathbb{B}\left(\mathbb{B}+\mathbb{A}\right)\sin^2\left(\frac{\left(\Omega_\phi - \Omega_\perp\right)z}{2}\right) \\ &+ 4\mathbb{C}\left(\mathbb{C}+\mathbb{B}\right)\sin^2\left(\frac{\left(\Omega_\parallel - \Omega_\phi\right)z}{2}\right) \end{aligned} \quad (1)$$

$$\mathbb{A} = \mathcal{N}_{\mathrm{vn}}^{2(1)}\mathrm{G}(\omega_{\mathrm{p}}^2 - \mathbf{E}_1)(\omega_{\mathrm{p}}^2 - \mathbf{E}_1)(\mathrm{m}_\phi^2 - \mathbf{E}_1), \quad (2)$$

$$\mathbb{B} = \mathcal{N}_{\mathrm{vn}}^{2(2)}\mathrm{G}(\omega_{\mathrm{p}}^2 - \mathbf{E}_2)(\omega_{\mathrm{p}}^2 - \mathbf{E}_2)(\mathrm{m}_\phi^2 - \mathbf{E}_2), \quad (3)$$

$$\mathbb{C} = \mathcal{N}_{\mathrm{vn}}^{2(3)}\mathrm{G}(\omega_{\mathrm{p}}^2 - \mathbf{E}_3)(\omega_{\mathrm{p}}^2 - \mathbf{E}_3)(\mathrm{m}_\phi^2 - \mathbf{E}_3). \quad (4)$$

Here $\mathcal{N}_{\mathrm{vn}}^{(\mathrm{i})}$ are the normalization constants, $G = (g_{\phi\gamma\gamma} B_\perp \omega)$ $\mathbf{E}_i$ are the Eigen values of the dilaton-photon mixing matrix and the other parameters have their usual meanings that can be found in [2, 3].

Photon flux density and Radiometer Equation

The signal strength of the photon carrying the traces of dilaton-photon mixing in the magnetosphere of the star received by the detector of the telescope can be obtained from the photon flux density $S_\gamma = \frac{dE/dt}{4\pi d^2 \Delta\nu}$. Here $\frac{dE}{dt}$ is the rate of change of conversion of dilaton mass into photon energy i.e., $\frac{dE}{dt} = P_{\phi\to\gamma_\parallel}\frac{dm_\phi}{dt}$. Thus using eqn. (1) the signal strength of photon in terms of photon flux density turns out to be:

$$S_\gamma = \frac{12R_o^2}{4\pi d}\left(\frac{\rho}{cm^2}\right)P_{\phi\to\gamma}\tan^{-1}\left(\frac{vT}{d}\right)\frac{1}{\Delta\nu\Delta t}. \quad (5)$$

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We have estimated S_γ numerically against the photon frequency ω and plotted in figure [1] represented by black colour. The detectability of the this photon flux S_γ carrying the imprints of dilaton-photon conversion in the radio range by the radio telescope depends upon the sensitivity of the implanted detector on the telescope. This sensitivity can be estimated by using the Radiometer Equation that tells the minimum detectable signal and is given by:

$$S_{min} = \frac{2k_B T_{sys} S_D}{\eta_s A_{eff} (\eta_{pol} t \Delta\nu)^{\frac{1}{2}}}. \quad (6)$$

Here T_{sys} is the system temperature in K, t integration time in seconds, A_{eff} is the effective collective area of the telescope, η_s is system efficiency and η_{pol} is the number of polarization states of photon. Rest other parameters have their usual meanings that can be found in [4, 5]. We have plotted the S_{min} against the photon frequency in figure[1] with red curve. The values of parameters have taken from [4].

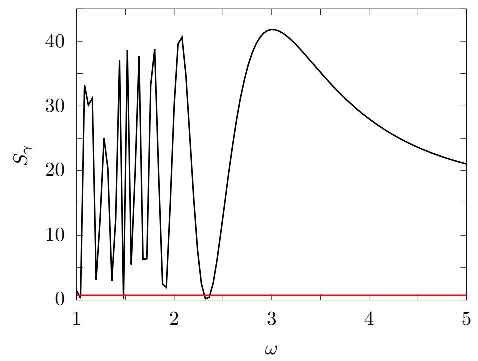

FIG. 1: Plot of Photon flux density S_γ (y-axis) received at telescope detector versus Photon energy ω (x-axis; scaled up by the factor 10^{15} in GeV. The parameters choosen are as follows: Dilaton mass (m_ϕ) $\sim 10^{-18}$ GeV, Dilaton-Photon coupling constant ($g_{\phi\gamma\gamma}$) $\sim 10^{-11} GeV^{-1}$, magnetic field of compact star (B) $\sim 10^{12}$ Gauss, plasma frequency (ω_p) $\sim 10^{-22}$ GeV, photon pathlength (z) $\sim 4R_0$, where R_0 is the radius of star, distance from the source to the detector (d) $\sim$ 1Kpc, the dark matter density (ρ) $\sim$ 3 GeV cm^{-3}, spectral line broadening around peak frequency ν_p due to dispersion of dark matter velocity v_d is $(\Delta\nu) \sim \nu_p \nu_d$, time of observation $\Delta t \sim 100$ Hours.

Discussion

In this article we have presented the result of the evaluation of photon flux density carrying the imprints of cosmological dark matter clump found close to the galactic centre. The dilaton-photon mixing in the magnetized environment of compact astrophysical systems generates the signal.

Our investigation is based upon the evaluation of the probability of conversion of clumped dilaton into parallely polarized photon in presence of the magnetized medium. Due to inclusion of a parity violating piece coming from the magnetized medium in the effective Lagrangian makes the mixing of three degrees of freedom of the system, two degrees of photon (parallel and perpendicular) with the dilaton. As a consequence, the magnitude of photon flux density of the parallely polarized photon (in the parameter range we considered, the details are in Figure [1] caption), lies above the magnitude of the minimum detectability of the SKA1-Low array detector. We considered fuzzy dilaton for this analysis keeping the simulation results for structure formation. This result opens a possibility of investigation to look for the signatures of scalar dark matter using radio telescopes.

References

[1] G. Raffelt, and L. Stodolsky, Phys. Rev. D **37**, 1237-1249 (1988).

[2] Ankur Chaubey, Manoj K. Jaiswal, Damini Singh, Venktesh Singh, Avijit K. Ganguly, Eur. Phys. J. C **84** 627 (2024).

[3] Ankur Chaubey, Manoj K. Jaiswal, and Avijit K. Ganguly, Phys. Rev. D**102**, 123029 (2020).

[4] Robert Braun, Anna Bonaldi, Tyler Bourke, Evan Keane, Jeff Wagg, arXiv 1912.12699.

[5] Guan-Sen Wang, Zhan-Fang Chen, Lei Zu, Hao Gong, Lei Feng and Yi-Zhong Fan, arXiv 2303.14117v4 (2024).