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Research Article

Dilaton Detection in Radio Regions

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Abstract. Structure formation is a very important phenomena to follow the cosmological evolution of our universe. The role of ultra-light dark matter in this whole process is substantial. Keeping this point in view one anticipates that the extremely light dilatons can be expected play it's part in this crucial process. The detection of the light dilatons is however not very easy, their cosmological signal may be detected in large radio telescopes. Using radiometer equation we ealborate on the possibility of detecting dilaton signal coming from the dark matter halo of nearby galaxies. Our analysis shows that in some parameter range the possibility of their detection is non-negligible.

Keywords. Dark matter, Dilaton, Photon, Electromgnetic radiation

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1. Introduction

Beyond the Standard Model scalar particles, such as dilatons, are promising candidates for the non-interacting nature of dark matter [4]. 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.

2. 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:

$$P_{\gamma_\parallel\to\phi} = 4\mathbb{A}(\mathbb{A}+\mathbb{C})\sin^2\left(\frac{(\Omega_\perp-\Omega_\parallel)z}{2}\right) + 4\mathbb{B}(\mathbb{B}+\mathbb{A})\sin^2\left(\frac{(\Omega_\phi-\Omega_\perp)z}{2}\right) + 4\mathbb{C}(\mathbb{C}+\mathbb{B})\sin^2\left(\frac{(\Omega_\parallel-\Omega_\phi)z}{2}\right), \tag{2.1}$$

$$\mathbb{A} = \mathcal{N}_{vn}^{2(1)} G(\omega_p^2-\mathbf{E}_1)(\omega_p^2-\mathbf{E}_1)(m_\phi^2-\mathbf{E}_1), \tag{2.2}$$

$$\mathbb{B} = \mathcal{N}_{vn}^{2(2)} G(\omega_p^2-\mathbf{E}_2)(\omega_p^2-\mathbf{E}_2)(m_\phi^2-\mathbf{E}_2), \tag{2.3}$$

$$\mathbb{C} = \mathcal{N}_{vn}^{2(3)} G(\omega_p^2-\mathbf{E}_3)(\omega_p^2-\mathbf{E}_3)(m_\phi^2-\mathbf{E}_3), \tag{2.4}$$

where $\mathcal{N}_{vn}^{(i)}$ 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 [3].

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 $S_\gamma = \frac{\frac{dE}{dt}}{4\pi d^2\Delta\nu}$. 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 eq. (2.1), the signal strength of photon in terms of photon flux density turns out to be:

$$S_\gamma = \frac{12R_o^2}{4\pi d}\left(\frac{\rho}{cm^2}\right)P_{\phi\to\gamma}\tan^{-1}\left(\frac{vT}{d}\right)\frac{1}{\Delta\nu\Delta t}. \tag{3.1}$$

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:

$$S_{\min} = \frac{2k_b S_D T_{sys}}{\eta_s A_{eff}(\eta_{pol}\, t\, \Delta\nu)}. \tag{3.2}$$

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 [1,5]. We have plotted the $S_{\min}$ against the photon frequency in Figure 1 with red curve. The values of parameters have taken from [1].

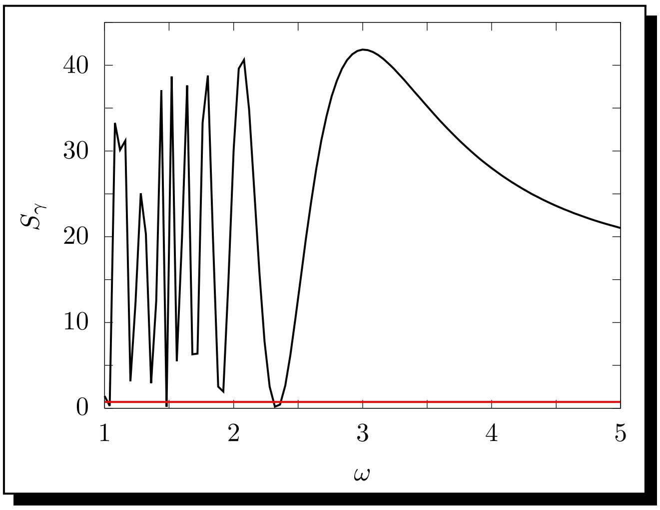

Figure 1. Plot of Photon flux density S_γ (y-axis) received at telescope detector versus Photon energy ω (x-axis; scaled up by the factor 10^{15} in GeV. The parameters choosen are as follows: Dilaton mass $(m_\phi) \sim 10^{-18}$ GeV, Dilaton-Photon coupling constant $(g_{\phi\gamma\gamma}) \sim 10^{-11}$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

4. Discussion

In this article, we have presented the result of the evaluation of photon flux density carrying the imprints of dilaton-photon mixing in the magnetized environment of compact astrophysical systems. Our investigation is based upon the evaluation of the probability of oscillation of parallely polarized photon into dilaton in presence of the magnetized medium. The effect of the inclusion of magnetized medium in our investigation made the mixing of two degrees of photon (parallel and perpendicular) with photon and with each other possible. As a result of this, the magnitude of photon flux density corresponding to the parallely polarized photon in the parameter range we considered, lies above the magnitude of the minimum detectability of the detector. This result open a possibility of investigation to look for the signatures of scalar dark matter from radio telescopes.

Competing Interests

The authors declare that they have no competing interests.

Authors' Contributions

All the authors contributed significantly in writing this article. The authors read and approved the final manuscript.

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