Observed signals from axion to photon conversion for the strongly magnetized neutron stars

Shubham Yadav,* M. Mishra, and Tapomoy Guha Sarkar
Department of Physics, Birla Institute of Technology and Sciences Pilani, Pilani Campus, Rajasthan - 333031, INDIA

Introduction

Recent developments in astrophysical observatories have played a vital role in studying compact objects such as Neutron Stars (NSs). The massive stars ($\geq$ 8-10$M_{\odot}$) in the final stages of their life spans undergo violent transitions to form NSs. These are incredibly dense objects with high central densities and robust field gravity. According to the virial theorem, the magnetic fields in the interiors of NSs could be as high as 10^{18} Gauss, also called magnetars. The existence of such fields affects the charged particle's energy and have imprints on the star's global structure and transport properties. The fundamental cooling mechanism for the NSs is based on the neutrino and photon emissions. For the initial thousand years, cooling as a neutrino emission prevails, and then photon emission as a cooling surpasses neutrinos. The theories related to NSs cooling and corresponding equation of states (EoS) are paramount for exploring the properties of the interiors of the superdense matter. Various dark matter particles such as WIMPs, Axions, and MACHOs have been proposed in the literature. The axions may be generated in the NSs cores along with the photons and neutrinos. Axions are hypothetical, weakly interacting particles that may solve the mystery of dark matter. As the axions pass through NSs magnetospheres, they get subsequently convert into photons. Their interaction with photons is given by the Lagrangian:

$$\mathcal{L} = -\frac{1}{4} g_{a\gamma\gamma} a F \widetilde{F} \qquad (1)$$

We examine the impact of the intense magnetic field on the energy spectrum of axions and axions-converted-photon flux for APR EoS.

Formalism

We solved the Tolman-Oppenheimer-Volkoff (TOV) system of equations in the presence of a magnetic field to obtain the profiles by employing the APR EoS. We have used the NSCool Code, which solves the heat transport and energy balance equations given by [1]:

$$C_v \; dT_b^{\infty}/dt = -L_{\nu}^{\infty} - L_{\gamma}^{\infty}(T_s) - L_a^{\infty} \qquad (2)$$

The energy spectrum of the axions follows the modified thermal distribution expressed as:

$$\frac{dF}{dE} \propto \frac{(E/T)^3 \; (E/T)^2 + 4\pi^2}{e^{E/T} - 1}, \qquad (3)$$

The detailed description of the energy spectrum of axions due to the spin-0 s-wave and spin-1 p-wave for Cooper pair Breaking and Formation process (PBF) and the Bremsstrahlung process are mentioned in our previous work [2].
The expression for the conversion probability is given as:

$$P_{a\to\gamma} \approx 1.5 \times 10^{-4} \left(\frac{g_{a\gamma\gamma}}{10^{-11}\, GeV^{-1}}\right)^2 \left(\frac{1\, keV}{\omega}\right)^{0.8} \times \left(\frac{B_0}{10^{13}\, G}\right)^{0.4} \left(\frac{R_{NS}}{10\, km}\right)^{1.2} \sin^{0.4}\theta, \qquad (4)$$

*Electronic address: shubhamphy28@gmail.com

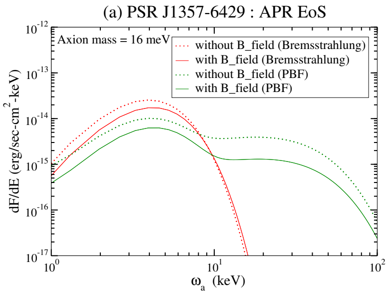

FIG. 1: The variation of the energy spectrum of axions with axion energies in the presence/absence of a magnetic field.

Results

In the present work, we have investigated the energy spectrum of axions and axion-converted-photon flux as a function of axion energies in the presence/absence of the magnetic field for the APR EoS from PSR J1357-6429. Fig. 1 shows the energy spectrum of axions as a function of axion energies at axion mass 16 meV for APR EoS. At the lesser values of the axion energies, the energy spectrum of axions from the Bremsstrahlung process remains higher than the energy spectrum of axions from the PBF process. For the Bremsstrahlung process, the curve separation between with/without magnetic fields decreases as the axion energies increases before the curves overlap between the axion energies 10 keV-20 keV. For only PBF process, the separation between the curves with/without a magnetic field remains almost similar for all values of axion energies. Fig. 2 depicts the axion-converted-photon flux versus time at axion mass 16 meV for APR EoS. At lesser energies, the energy spectrum of axions from the Bremsstrahlung process remains higher than the PBF process. A significant difference is found in the axion-converted-photon flux for the PBF process for all values of axion energies. However, the magnetic fields do not change the qualitative behavior.

Conclusions

The axions' energy spectrum and axion-converted-photon flux are quite axions mass-sensitive. A significant departure in the observables is seen in the presence of a magnetic field, although the overall qualitative features remain the same.

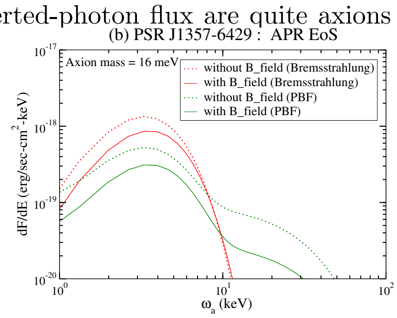

FIG. 2: The variation of axion-converted-photon flux with axion energies in the presence/absence of a magnetic field.

Acknowledgments

The author acknowledges Birla Institute of Technology and Sciences, Pilani, Pilani Campus for providing the financial support.

References

[1] Yadav S., Mishra M., Sarkar T. G., and Singh C. R., Thermal evolution and axion emission properties of strongly magnetized neutron stars. 2024. The European Physical Journal C **84** (3), 225.

[2] Yadav S., Mishra M., Sarkar T. G., X-ray emission spectrum for axion-photon conversion in magnetospheres of strongly magnetized neutron stars. 2024. The European Physical Journal C **84**, 687.