Gamma-ray Spectra of Galactic Pulsars and the Signature of Photon-ALPs Mixing

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In many approaches to describe physics beyond the standard model, light Nambu-Goldstone bosons (named axion-like particles or ALPs) are predicted to exist. For ALPs with a mass of neV, photon-ALPs oscillation takes place in extra-galactic magnetic fields during the propagation of very high energy gamma-ray photons leading to excess radiation observed for optically thick sources. In order to verify this effect,gamma-ray spectra from strong galactic sources can be used. Here the photon-ALPs mixing would lead to an energy dependent suppression of the observed gamma-ray spectra. Here, we have used Fermi-LAT (Fermi-Large Area Telescope) observations of a sample of gamma-ray pulsars located at different line-of-sights to search for spectral signatures and compare the result with the predictions using particular models for the galactic magnetic field.

1 Introduction

Fermi-LAT observations for gamma ray pulsars.- The Fermi-LAT is a pair conversion telescope for gamma rays between 20 MeV to more than 300 GeV. 160 gamma ray pulsars have been discovered by Fermi-LAT. It has a wide field-of-view of 2.4 sr, a peak effective area of $\sim 7000c^2$ at 1 GeV on axis, and a 68 containment radius of 0.6 deg at 1 GeV for events converting in the front section of the LAT. The LAT is ~ 30 times more sensitive than its predecessor, the EGRET telescope.

Galactic magnetic field models.- The magnetic fields in galaxies are believed to be regenerated and maintained by dynamo actions in the interstellar medium. Here we have taken into account two models of magnetic fields: Jansson-Farrar and Pshirkov. Pshirkov's model of galactic magnetic fields consists of two different components: a disk and a halo field. According to directional dependence of this this model, this is categorized in two types: 1) ASS or axisymmetric model (the direction of the field in two different arms is the same) and 2) BSS or bi-symmetric model (the direction of the field in two different arms is opposite). The magnetic field along the line of sight of the pulsar J2021+3651 is shown in Fig. 1.

Axion-like particles.- Axions are considered to be an attractive dark matter candidate and also a solution to the strong CP problem of quantum chromodynamics. The equation of the Lagrangian of ALP-photon is,

$$\pounds = -\frac{1}{4} g_{\alpha\gamma} F_{\mu\nu} F^{\mu\nu} a = g_{\alpha\gamma} E \cdot B a, \tag{1}$$

where a is the axion-like field with mass $m_a, F_{\mu\nu}$ is the electromagnetic field-strength tensor,

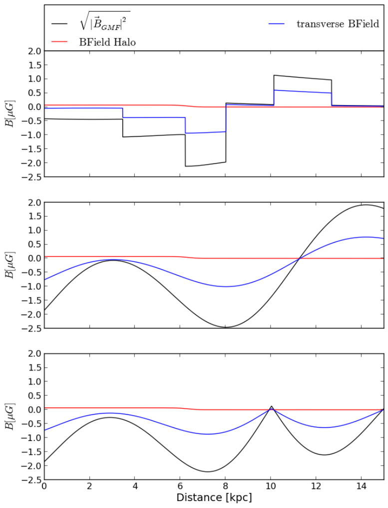

Figure 1: Magnetic field along the line of sight of the pulsar J2021+3651. Top panel for the model of Jansson-Farrar, middle panel for the model of Pshirkov in BSS, down in ASS mode.

and $g_{\alpha\gamma}$ is the ALP-photon coupling. Photons travelling through the external magnetic field couple to ALPs. The probability of the conversion after a distance z is

$$P_{\gamma\to a} = \frac{g_{\alpha\gamma}^2}{8}\left(\left|\int_0^z dz' e^{2\pi i z'/l_0} B_x(x,y,z')\right|^2 + \left|\int_0^z dz' e^{2\pi i z'/l_0} B_y(x,y,z')\right|^2\right) \tag{2}$$

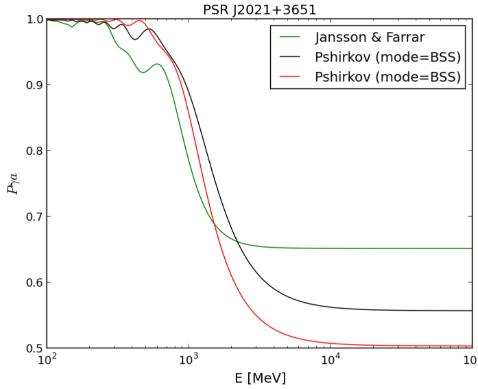

Figure 2: The conversion probability of the photon to axion as a function of energy.

Pulsar Name	χ^2
J2021+3651	139.845
J2021+4026	185.86

Table 1: Minimum value of χ^2 of pulsars as a power law of exponential decay

2 Fermi likelihood analysis

The detection, flux determination and spectral modeling of Fermi-LAT sources likelihood optimization technique is performed for the selected pulsar candidates. The spectrum of a pulsar can be modelled by a power law of exponential decay with the general form:

$$\frac{dN}{dE} = K.\left(\frac{E}{E_0}\right)^{-\tau} \exp\left(\frac{-E}{E_{cut}}\right) \tag{3}$$

We have also performed the same procedure for another pulsar source J2021+4026 as it is close to PSR-J2021+3651. So we can compare the spectra.

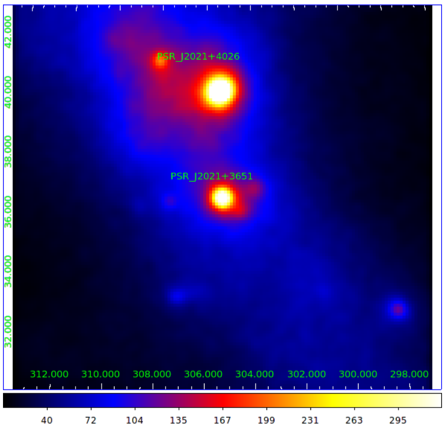

Figure 3: Event map of the PSRJ2021+3651 with color coding of photon events.

3 Pulsar spectrum

Determination of spectrum from the pulsar candidates.- We have adopted the energy range for the pulsar candidates from 100 MeV to 300 GeV and divided the entire range in 30 energy bins. The spectrum is derived for the data sets of front region of the tracking detector. The pulsar spectrum is determined for both sources PSR J2021+3651 and PSR J2021+4026 (Figure 4).

Best fit model of the pulsar - spectrum.-To investigate the signatures of the photon ALPs oscillations, a combination of power law with exponential cut-off energy and the survival probability to be adapted to the data points. For the fitting of the spectral data points, a χ^2 method is applied with the adjustment of free parameters like $g_{a\gamma}$ and m_a.

It can be said that the value of χ^2 decreases in adapting to the data points, taking into consideration larger distances.

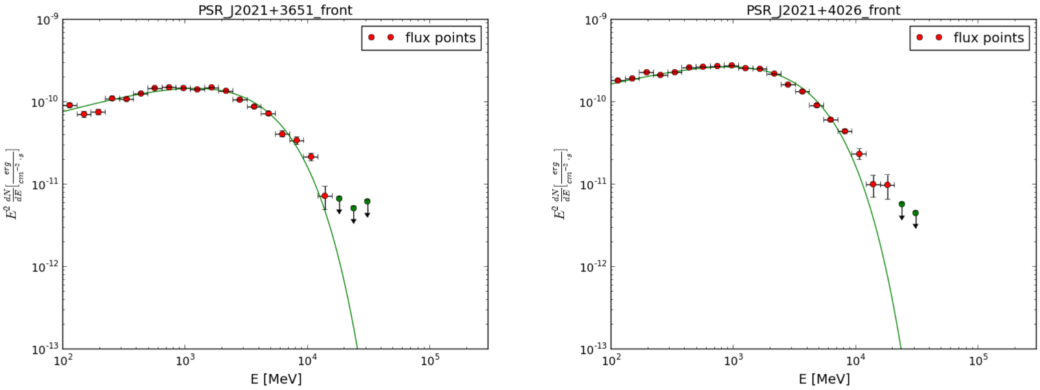

Figure 4: Model of the spectrum of PSR J2021+3651 (left) and PSR J2021+4026 (right) as a power law of exponential decay in accordance with the spectral data points

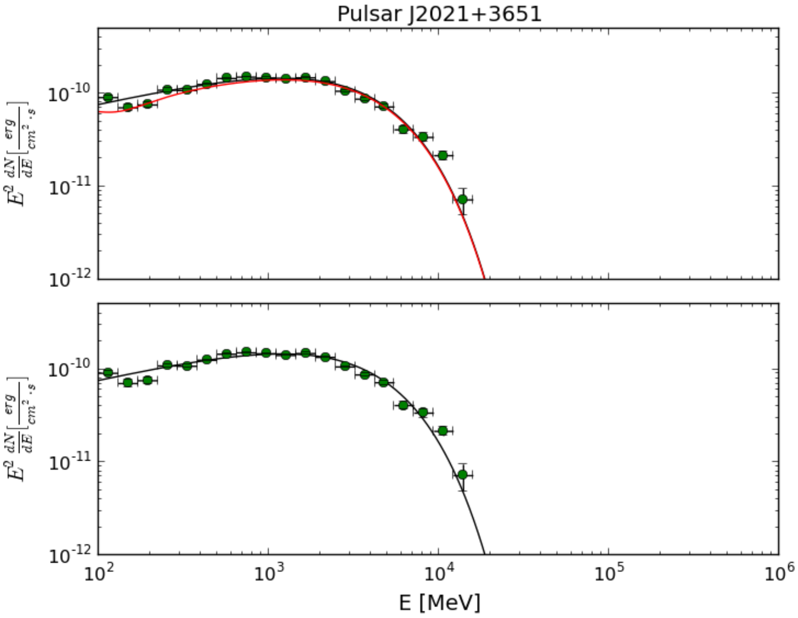

Figure 5: Best fitting model to the data points of the PSR J2021+3651.

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Bfield-model	χ^2	$g_{a\gamma}$ $[10^{-11}\text{GeV}^{-1}]$	m_a [neV]
Jansson.Farrar	126.015	5.36939	3.27676
Pshirkov(BSS)	103.727	5.28798	4.74197
Pshirkov(ASS)	133.417	4.70924	3.7189

Table 2: Minimum value of χ^2 in accordance with the value of $g_{a\gamma}$ and m_a.

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