Spectral modulation of Galactic Gamma-ray sources due to photon-ALPs mixing in Galactic magnetic field.

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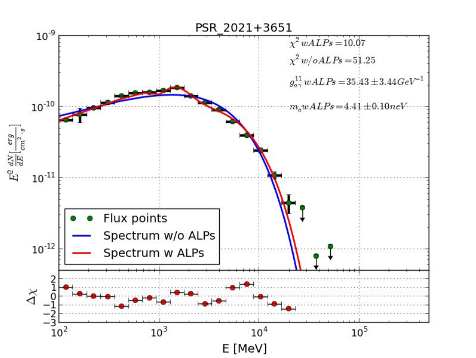
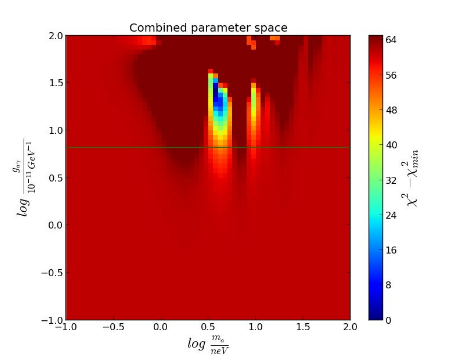
Abstract: Axion like particles (ALPs) are fundamental pseudo scalar particles with properties similar to Axions that have been invoked to solve the strong CP problem in Quantum Chromodynamics. ALPs can oscillate into photons and vice versa in the presence of an external magnetic field. This oscillation of Photon and ALPs could have important implications for astronomical observations, i.e. a characteristic energy dependent attenuation in Gamma ray spectra for astrophysical sources. Here we have revisited the opportunity to search Photon-ALPs coupling in the disappearance channel. We use nine years of Fermi Pass 8 data of a selection of Galactic Gamma-ray source candidates and study the modulation in the spectra in accordance with Photon-ALPs mixing and estimate best fit values of the parameters i.e. Photon-ALPs coupling constant ($g_{\alpha\gamma\gamma}$) and ALPs mass (m_{α}). For the magnetic field we assume large scale galactic magnetic field models based on Faraday rotation measurements. We find consistent evidence for a modulation of the spectra investigated at the level of 5.3 standard deviations. In the framework of ALPS/photon oscillation, the resulting parameters strongly depend upon the chosen magnetic field model, but seem to be within reach of new experiments (e.g. IAXO).

Analysis details:

- We have chosen 5 bright pulsar candidates for the analysis.
- Nine years of Fermi-LAT [1] Pass 8 data of the pulsars has been used.
- For spectral modelling Enrico binned likelihood optimization technique is performed for 25 energy bins.
- Pulsar spectrum is modelled by a power law with exponential cut off parametrization.
- We perform afit to the data minimizing χ^2 function [2] [3].
- Energy dispersion matrix and systematic uncertainties has been taken into account in the analysis.

Results:





Photon-ALPs mixing:

ALPs share same kind of physics to axion: coupling to photon or vice versa in external magnetic field.The equation of the Lagrangian of photon-ALPs coupling describes as:

$$\mathcal{L} = -\frac{1}{4} g_{\alpha\gamma\gamma} F_{\mu\nu} \tilde{F}^{\mu\nu} a = g_{\alpha\gamma\gamma} \vec{E}.\vec{B} a$$

where a is the axion-like field with mass m_a , $F_{\mu\nu}$ is the electromagnetic field-strength tensor and $\tilde{F}^{\mu\nu}$ is its dual field , $g_{\alpha\gamma\gamma}$ is the ALPs-photon coupling. Photons, while travelling across the external magnetic field, oscillate with the ALPs state. If the condition, $g_{\alpha\gamma\gamma} Bd << 1$ holds true, the survival probability of the photons at a distance d is [4] :

$$P_{survival} = \frac{g^2_{\alpha\gamma\gamma}}{8} \left(| \int_0^d dz' e^{2\pi z'/l_0} B_x(x,y,z')|^2 + | \int_0^d dz' e^{2\pi z'/l_0} B_y(x,y,z')|^2 \right) \quad ; g_{\alpha\gamma\gamma} Bd \ll 1$$

where $g_{\alpha\gamma\gamma}$ has the dimension of $(\text{Energy})^{-1}$ and all the parameters in natural units.

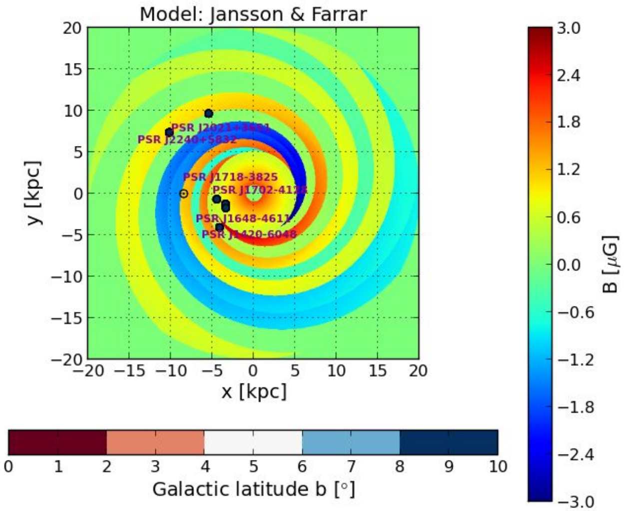
Fermi-LAT data analysis:

Source selection criterion:

- Bright galactic source.
- Sources that are crossing the spiral arms along the line of sight.

Pulsar list:

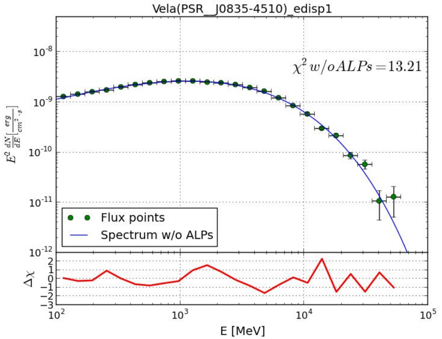
1. J2021+3651
2. J1420-6048
3. J2240+5831
4. J1718-3825
5. J1702-4182

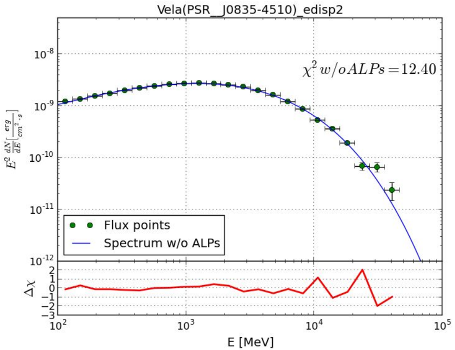


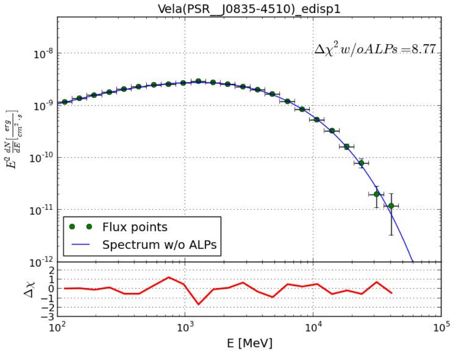
Source positions in the plane of galactic magnetic field (Jansson & Farrar model;Jansson et al. 2012).

Systematic uncertainties derived from Vela:

For P8R2 SOURCE V6 event class, systematic uncertainties in effective area are derived to be about 2.4 %.

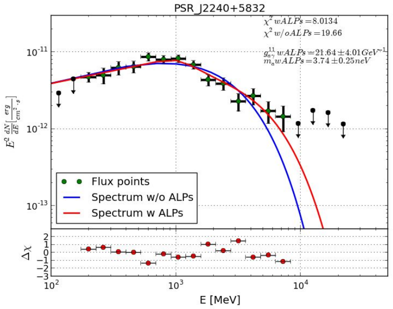


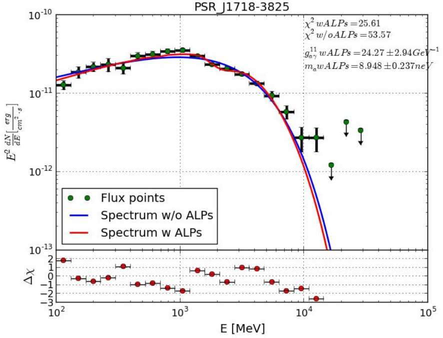


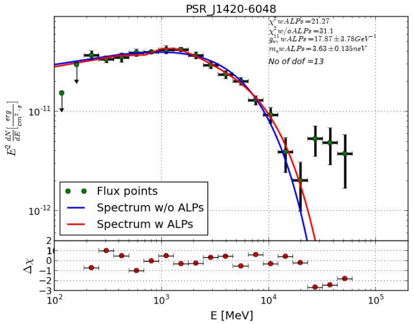


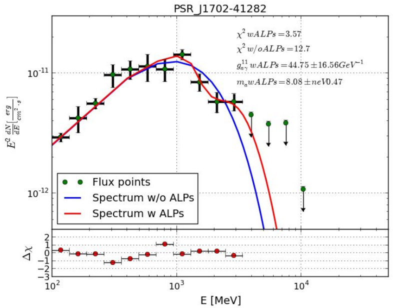
Results:

signature of photon-ALPs oscillations, including the effect of oscillations in the predicted spectra: $\left(\frac{dN}{dE}\right)_{fit} = P_{survival}\left(E, g_{a\gamma\gamma}, m_a\right) \cdot \left(\frac{dN}{dE}\right)$

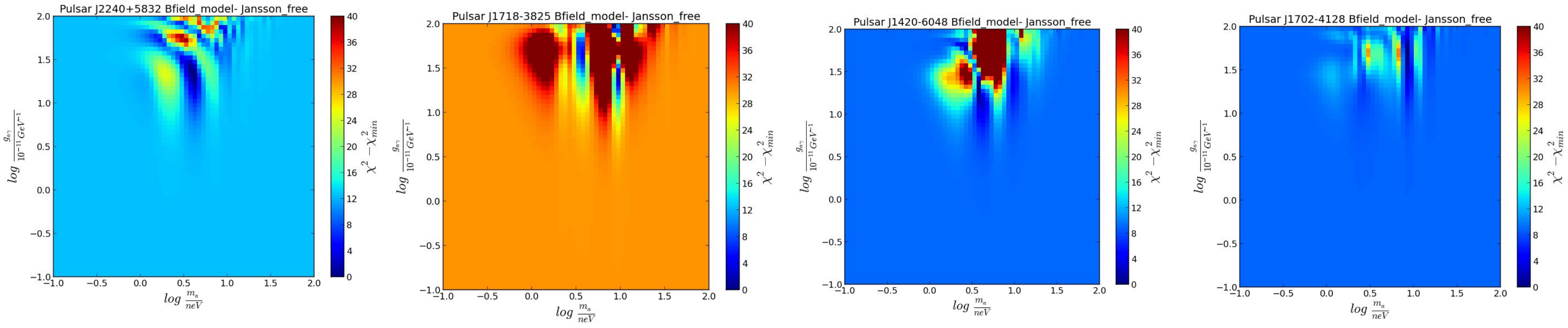








ALPs parameter space for individual pulsar:



Summary:

- Indications for ALPs in case of Fermi LAT data of Galactic pulsar candidate.
- Photon-ALPs mixing is nonlinear in the spiral arms and in the large scale field of the inner Galaxy.
- ALPs mass bounds: 1 neV≤ m a ≤ 4 neV .
- Photon-ALPs coupling bound: 15 - 30 $\times 10^{-11}$ GeV $^{-1}$.
- Significance level calculated by F-test: 6.43 σ.
- The main challenge of this work is to choose the magnetic field model as the resulting mixing parameters are quite model dependent.

References:

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