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Probing photon-axionlike particle oscillations from the MAGIC observations of QSO B1420+326

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We investigate the effect of photon-axionlike particle (ALP) oscillations in the gamma-ray spectra of the fourth most distant blazar QSO B1420+326 measured by Fermi-LAT and MAGIC around the flaring activity in January 2020. We set the 95% CL upper limit on the photon-ALP coupling constant $g_{a\gamma} < 2 \times 10^{-11}$ GeV^{-1} for ALP masses $m_a \sim 10^{-10} - 10^{-9}$ eV. Assuming the hadronic origin of very-high-energy photons, we also estimate the expected neutrino flux and the cumulative flux from QSO B1420+326-like FSRQs at sub-PeV energies. Furthermore, we study the implications of photon-ALP oscillations on the counterpart gamma-rays of the sub-PeV neutrinos. Finally, we investigate a viable scenario of invisible neutrino decay to ALPs on the gamma-ray spectra and diffuse γ-ray flux at sub-PeV energies. Interestingly, we find that for the choice of neutrino lifetime $\tau_2/m_2 = 10^3$ s eV^{-1}, the γ-ray flux has a good observational sensitivity towards LHAASO-KM2A.

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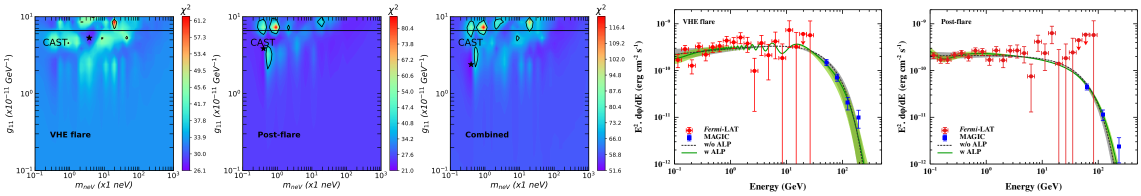

Figure 1: Distribution of χ^2_{ALP} and the best-fit spectra. The "$\star$" symbol in black represents the best-fit parameter point, and the black contours represent the excluded parameter space at 95% CL.

PoS(ICHEP2024)713

1. Introduction

Axionlike particles (ALPs) are ultralight spin 0 bosons proposed as potential dark matter candidates [1]. ALPs can couple to photons via coupling strength $g_{a\gamma}$ in an external electromagnetic field, resulting in photon-ALP oscillations. We focus on the *Fermi*-LAT and MAGIC observations of γ-ray spectra of the fourth most distant FSRQ, QSO B1420+326, around the flaring activity in January 2020 to put constraints on ALP parameters. We also investigate the implications of invisible neutrino decay to ALP on the sub-PeV γ-ray spectrum [2].

2. Methodology

We perform *Fermi*-LAT data analysis for two phases: (i) **VHE flare :** January 20, 2020 (MJD 58868.3) to January 22, 2020 (MJD 58870.3), and (ii) **Post flare :** January 22, 2020 (MJD 58873.5) to February 01, 2020 (MJD 58880.5). The intrinsic spectrum is taken to be an exponential cutoff power law $\Phi_{int}(E) = N_0\,(E/E_0)^{-\alpha}\exp(-E/E_{cut})$, where $E_0 = 1$ GeV and rest are free parameters. The photon survival probability on Earth under the ALP hypothesis is computed using `gammaALPs`[1] [3]. By looping over the ALP parameter space, we calculate the expected γ-ray spectrum on Earth and obtain the parameters minimizing the χ^2 fit. The χ^2_{ALP} distribution and the best-fit γ-ray flux is shown in Fig. 1.

3. Results

3.1 Constraints on ALP parameter space

We determine a threshold value $\chi^2_{thr} = \chi^2_{min} + \Delta\chi^2$ by generating 400 sets of pseudodata for each phase realized by Gaussian samplings. For each pseudodata set, we again calculate the best-fit χ^2 under the null and ALP hypotheses and obtain $\Delta\chi^2$ derived at 95% CL by fitting test statistics (TS) distribution with the noncentral χ^2 distribution. We find weaker constraints than CAST bounds in the case of VHE flare. For the post-flare phase, we can exclude a narrow region with 2×10^{-11} GeV^{-1} $\leq g_{a\gamma} \leq 4\times10^{-11}$ GeV^{-1} for $\sim 10^{-10}$ eV $\leq m_a \leq 10^{-9}$ eV as shown in Fig. 1.

3.2 Expected neutrino flux and counterpart γ-rays at sub-PeV energies

Assuming hadronic interactions, the flux of astrophysical neutrinos, ϕ_{src}, at Earth from a single FSRQ can be estimated as [4] $d\phi_{src}/dE_\nu = (1/4\pi d(z)^2)\times(dL_\nu/E_\nu dE_\nu)\times\eta(L_\gamma)$, where $d(z)$ is

[1] https://gammaalps.readthedocs.io/en/latest/index.html

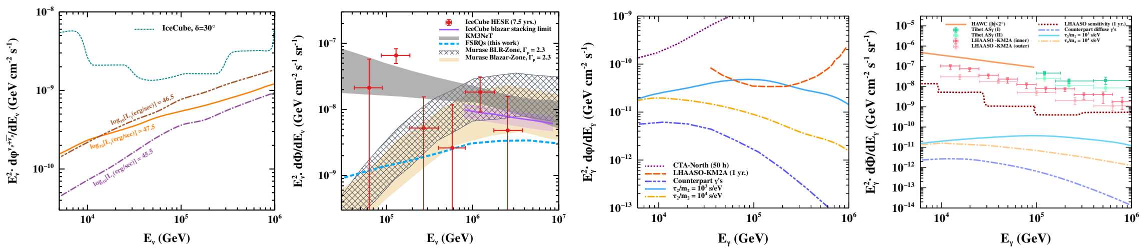

Figure 2: (a) Expected $\nu_\mu + \bar{\nu}_\mu$ flux. (b) Diffuse neutrino flux. (c) Counterpart γ-ray flux for $L_\gamma = 10^{47.5}$ erg/sec. (d) Counterpart diffuse γ-ray flux from FSRQs. The solid blue and dot-dash yellow lines in (c) and (d) correspond to γ-ray flux from invisible neutrino decay for two benchmark values of τ_2/m_2.

the comoving distance, $dL_\nu/E_\nu dE_\nu$ is the neutrino spectra, and $\eta(L_\gamma) = L_{CR}/L_\gamma$ is the baryonic loading. We calculate the neutrino flux for three benchmark values of L_γ: $10^{45.5}$ erg/sec, $10^{46.5}$ erg/sec, and $10^{47.5}$ erg/sec, and find weak observational sensitivity as shown in panel (a) of Fig. 2.

Next, we estimate the diffuse neutrino flux from FSRQs by convolving the obtained flux for $L_\gamma = 10^{47.5}$ erg/sec, as shown in panel (b). We find that FSRQs can provide a sub-dominant contribution to the extragalactic diffuse neutrino flux at sub-PeV energies. The corresponding counterpart γ-rays and diffuse γ-ray flux are also shown in panels (c) and (d).

3.3 Implications of invisible neutrino decay on the sub-PeV γ-ray spectra

We also study the implications of invisible neutrino decay to ALPs $\nu_i \longrightarrow \nu_j + a$ on the γ-ray flux at sub-PeV energies. Here, ν_i's are the mass eigenstates with masses m_i's. We assume normal mass ordering, $m_1 = 0$, $m_2 \approx 8.61$ meV and $m_3 \approx 50.1$ meV. The ALP flux at the detector is $\phi_a = \sum_\alpha \mathcal{P}_{\nu_\alpha a}\,\phi_{\nu_\alpha}$, with $\mathcal{P}_{\nu_\alpha a}(E_\nu) = \sum_{i=2,3}\left[1 - \exp\left(\frac{-m_i\, l_{eff}(0)}{\tau_i E_\nu}\right)\right]|U_{\alpha i}|^2$, where E_ν is the neutrino energy at $z = 0$, τ_i is the decay lifetime, $l_{eff}(0)$ is the source distance from the Earth, ϕ_{ν_α} is the neutrino flux of ν_α at the source, and $U_{\alpha i}$ denotes the leptonic flavor mixing matrix. As shown in panel (c) of Fig. 2, we find that for neutrino lifetime $\tau_2/m_2 = 10^3$ s eV^{-1}, LHAASO-KM2A provides a good observational sensitivity. We also estimate the diffuse γ-ray flux as shown in panel (d) and find that it is still negligible to provide any contribution to diffuse γ flux from the Galactic plane.

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