Probing Photon-Axionlike Particle Oscillations from the MAGIC Observations of QSO B1420+326

Bhanu Prakash Pant, Department of Physics, Indian Institute of Technology Jodhpur.
Email: pant.3@iitj.ac.in

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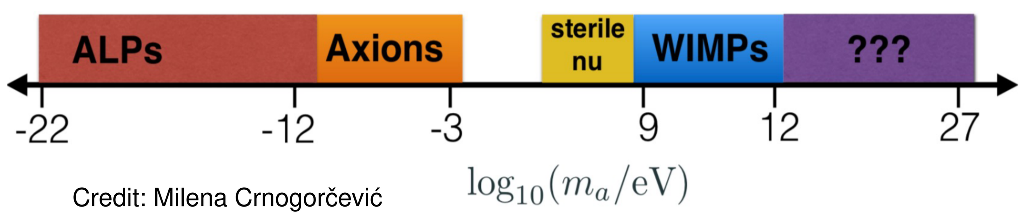
B. P. Pant, Phys. Rev. D 109, 023011 (2024).

I. What are Axion-like Particles (ALPs)?

- Pseudo-scalar bosons.
- Mass range: 10^{-22} eV to 10^{-3} eV.



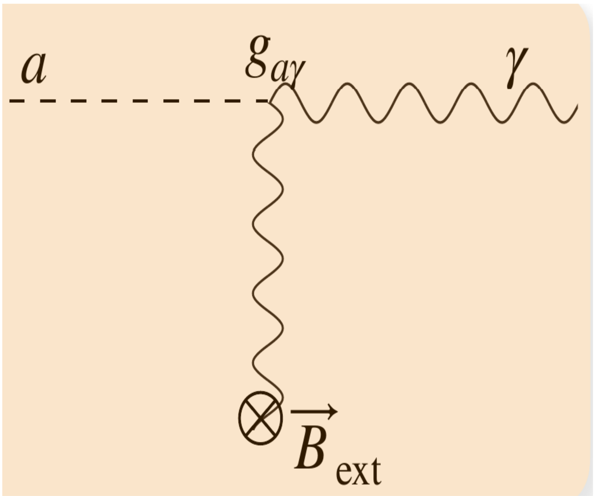
II. Photon-ALP oscillations:

In an external magnetic field, ALPs may convert into gamma-rays:

$$\mathcal{L}_{a\gamma} = -\frac{1}{4} g_{a\gamma\gamma} F_{\mu\nu} \tilde{F}^{\mu\nu} a = g_{a\gamma\gamma} \mathbf{E} \cdot \mathbf{B} a$$

Coupling constant — Axion field

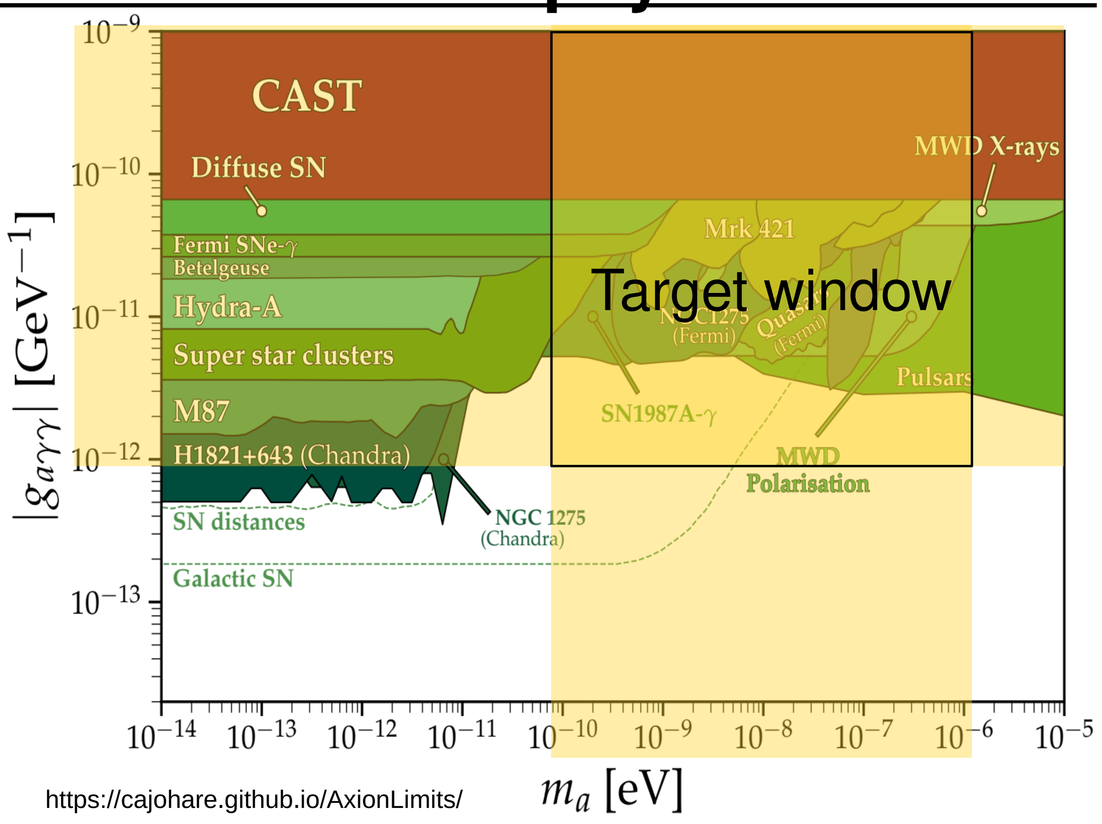
Credit: Christopher Eckner



Implications:

- The sub-PeV range is devoid of extragalactic contributions due to: $\gamma + \gamma_{EBL/CMB} \rightarrow e^+ + e^-$
- ALPs secretly circumvent absorption and reappear in gamma-ray observations.

III. Current Astrophysical Bounds

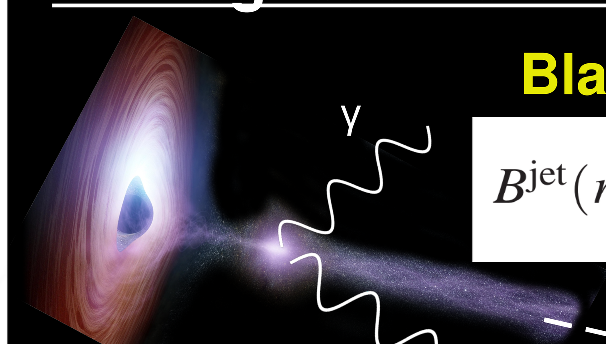


Aim

1) To constrain ALP parameters in the target window

2) Investigate the implications of photon-ALP oscillations on gamma-ray flux at sub-PeV energies.

IV. Magnetic field environments



Blazar jet region

$$B^{\rm jet}(r) = B_0^{\rm jet}\left(\frac{r}{r_{\rm VHE}}\right)^{\eta}$$

Toroidal magnetic field (η = -1)

Galactic region

Consider only large scale regular component.
Magnetic strength is ~O(1) μG
Used magnetic field model by Jansson & Farrar

Intergalactic region

Magnetic strength ~O(1) nG; no oscillations
Only the absorption by EBL/CMB.

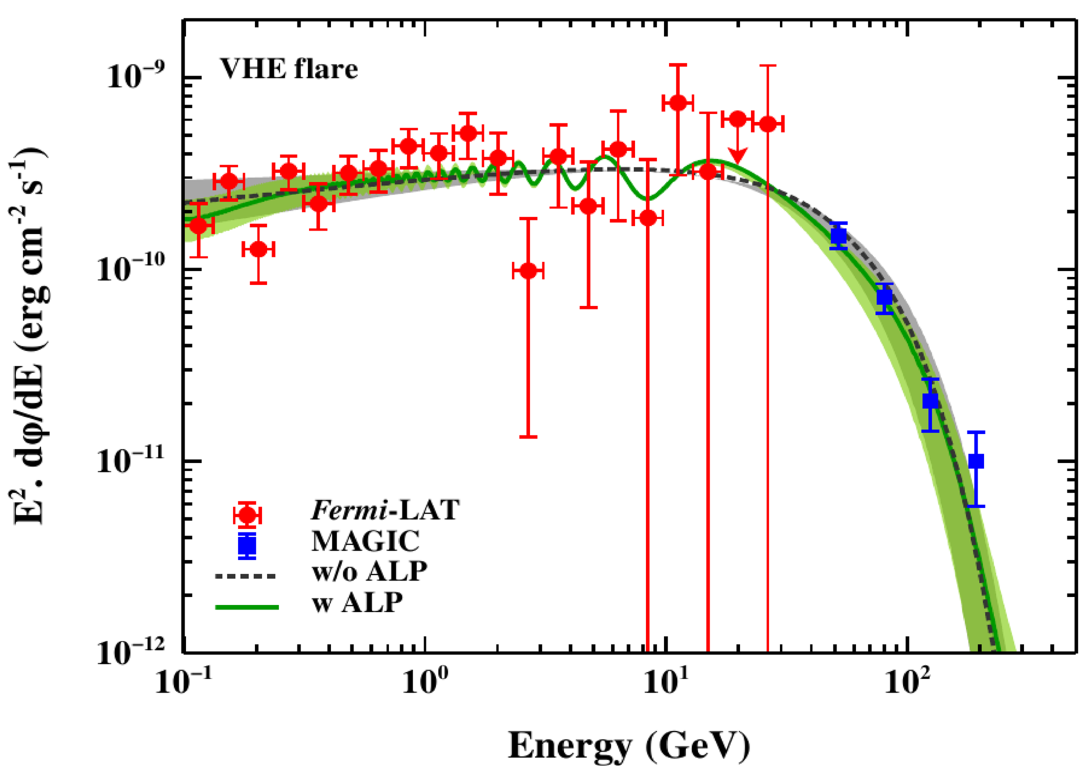
γ, $\gamma_{EBL/CMB}$, a, e^-, e^+

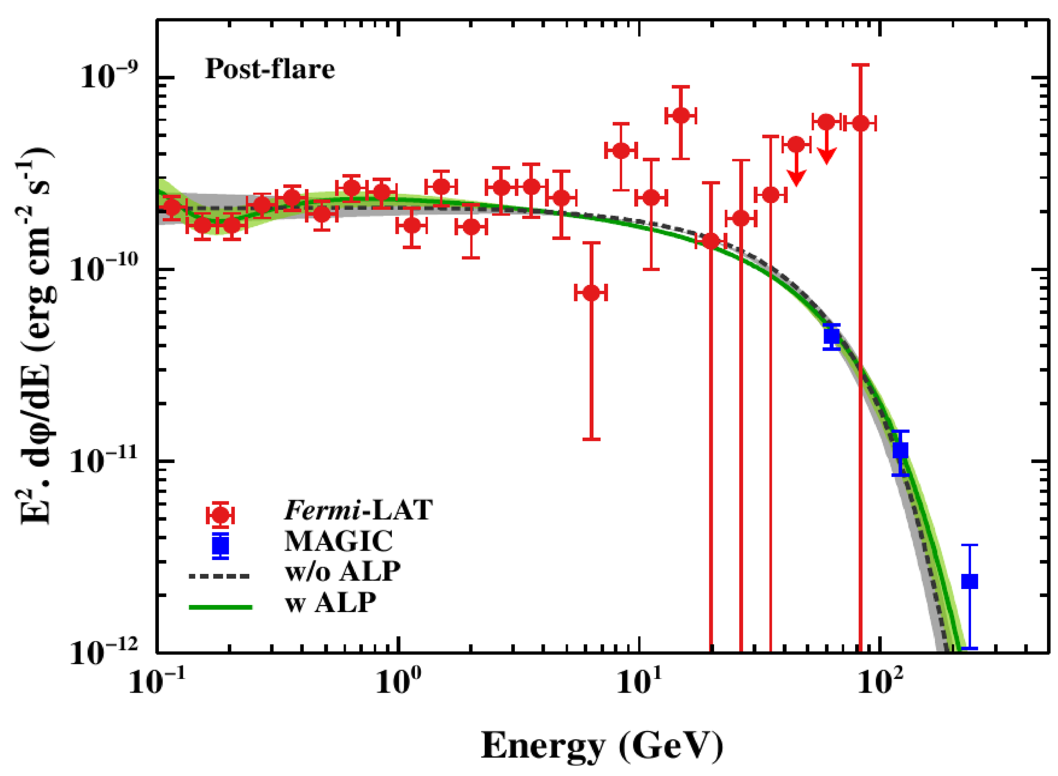
We calculated gamma-ray survival probability using gammaALPs package

M. Meyer, J. Davies, and J. Kuhlmann, Proc. Sci. ICRC2021 (2021) 557

V. Photon-ALP effects in FSRQ QSO B1420+326

- Fourth most distant blazar at 13.6 billion light-years (z = 0.682) with VHE gamma-ray emission
- **VHE flare** (above 100 GeV) seen by MAGIC on **20 January 2020 to 22 January 2020**.
- **Post-flare** in subsequent days, **22 January 2020 to 01 February 2020.**
- **Intrinsic spectrum:** $\Phi_{\rm int}(E) = N_0 \left(\frac{E}{E_0}\right)^{-\alpha} \exp\left(\frac{-E}{E_{\rm cut}}\right),$ E0 = 1 GeV and rest are free parameters
- **Expected spectrum:** $\phi_{\rm alp}(E) = \Phi_{\rm int}(E) \cdot \mathcal{P}_{\rm alp}(E)$

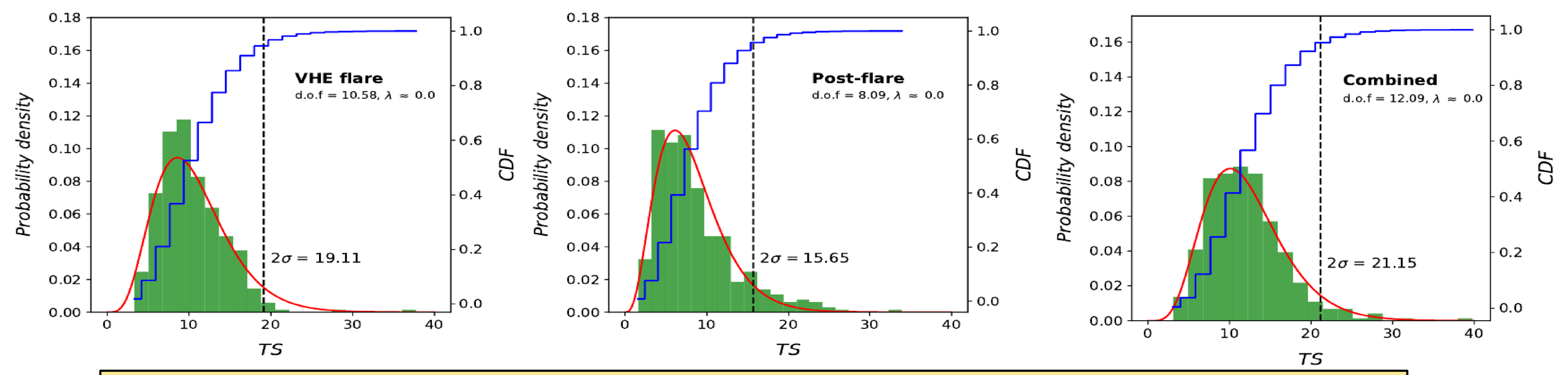




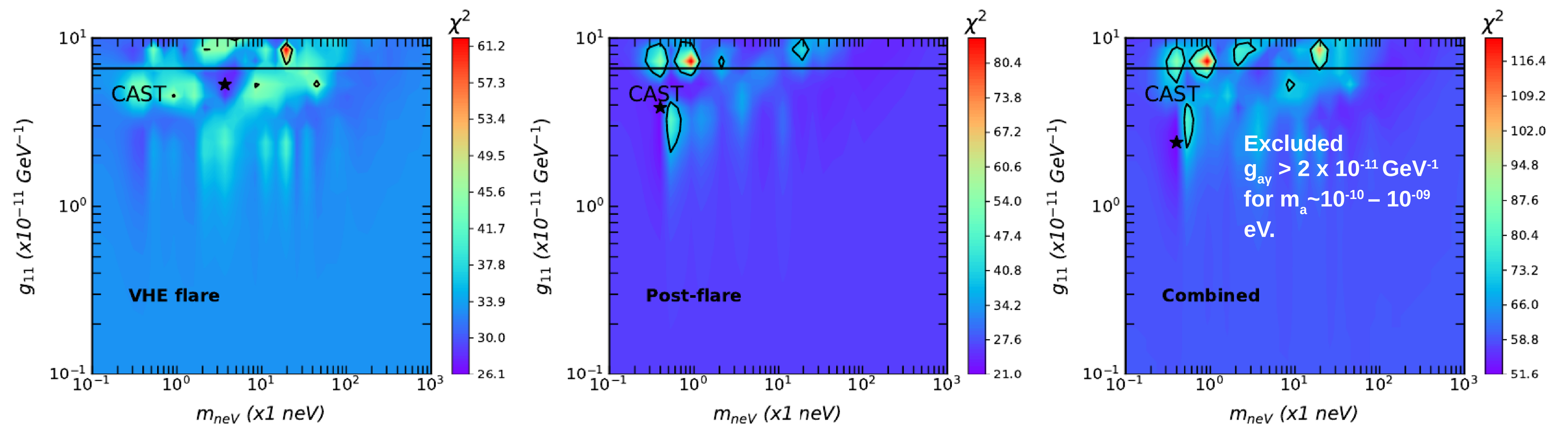
Within uncertainties, NOT much of a difference obtained!

VI. Constraints on ALP parameters

- For each phase, 400 sets of pseudo-data by Gaussian sampling
- For each pseudo-data set, we calculated best-fit chi² under both the null and ALP hypotheses.
- Fitted the TS distribution with the non-central chi² distribution and obtain **Δχ² (2σ value)**



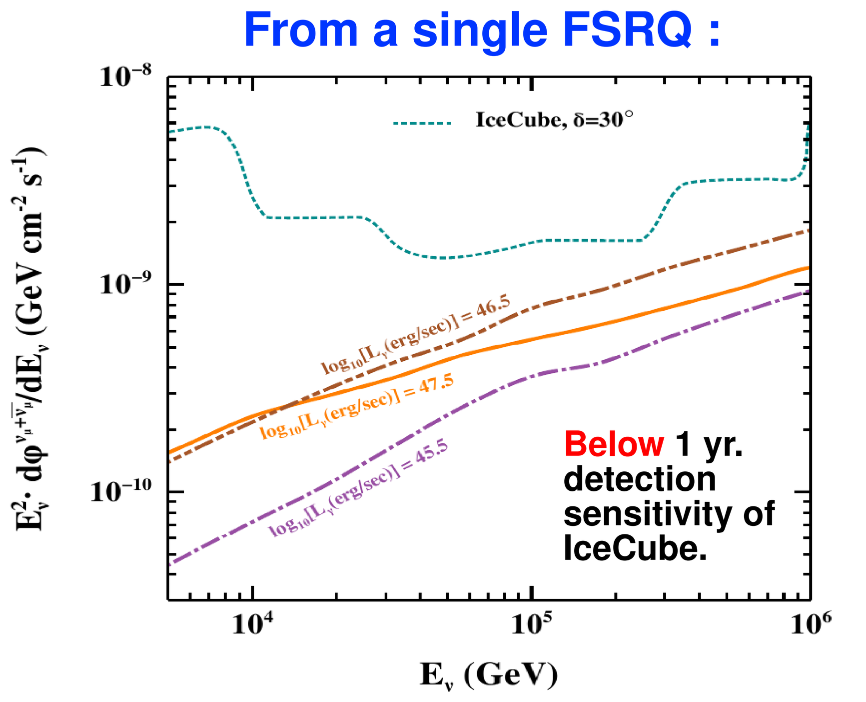
We put 95% C.L. upper limits by requiring $\chi^2_{\rm thr} > \chi^2_{\rm min} + \Delta\chi^2$



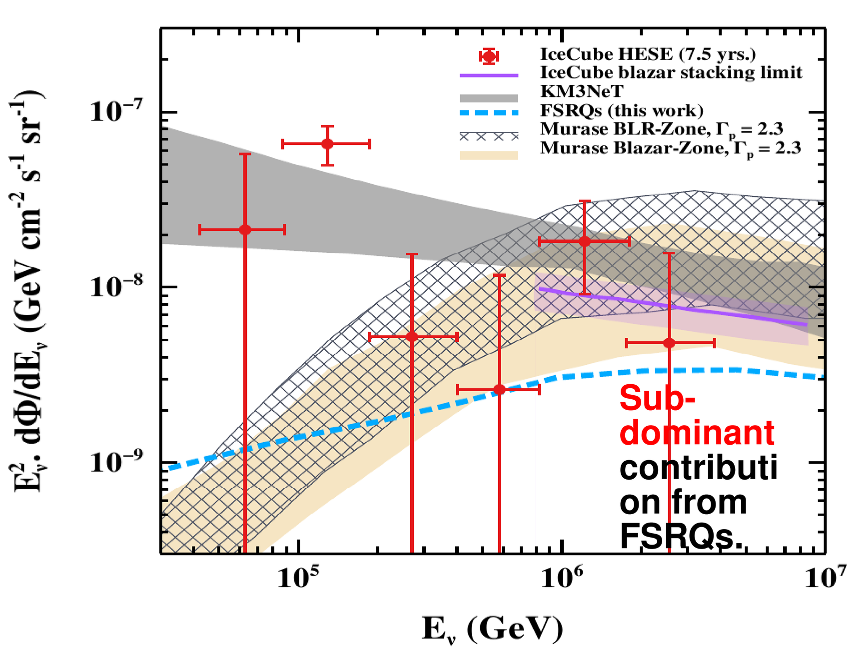
No significant constraint — Weak constraint — Overall weak constraint

VII. Expected neutrino flux from QSO B1420+326

From a single FSRQ :



Diffuse flux of neutrinos:



VIII. Photon-ALP oscillation effect at sub-PeV

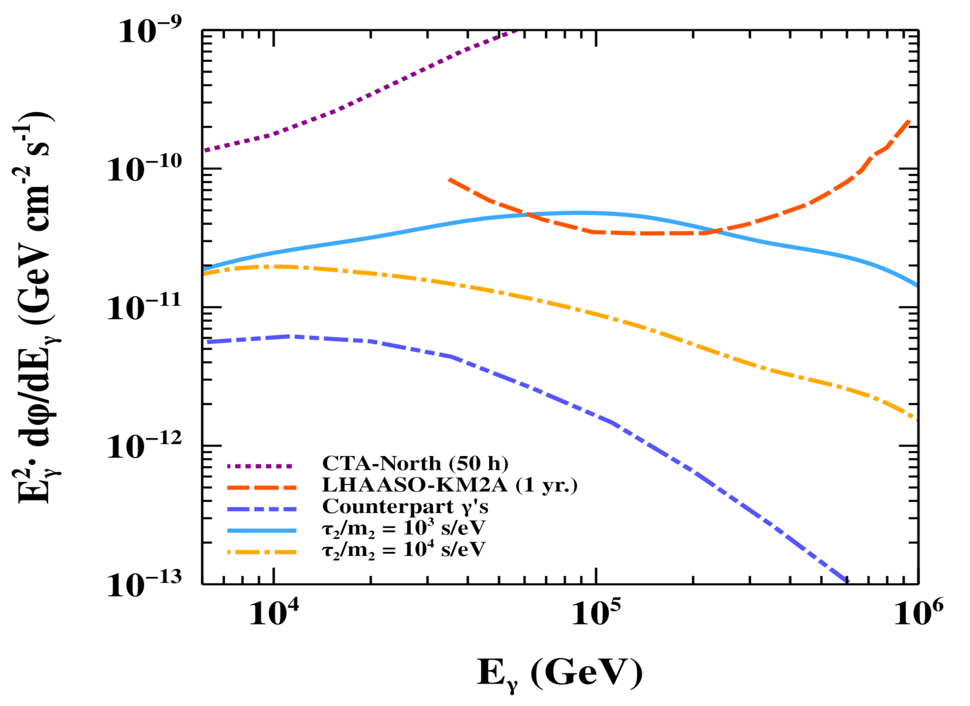
- **ALP-induced gamma rays:**

$$E_\gamma^2 \cdot \frac{dN_\gamma}{dE_\gamma} \mathcal{F}^{\rm esc}_{\gamma\gamma} . e^{-\tau^{\rm ALP}_{\gamma\gamma}(E,z)}$$

Below detection sensitivity of LHAASO and CTA-North.

- **Invisible neutrino decay:**

For $\tau_2/m_2 = 10^3$ s eV^{-1} and $\tau_2/m_2 = 10^4$ s eV^{-1}, & $\tau_3/m_3 = 10^7$ s eV^{-1}.



For $\tau_2/m_2 = 10^3$ s eV^{-1}, ALP-induced gamma rays may show above the detection sensitivity of LHAASO.

IX. Diffuse gamma rays at sub-PeV energies

$$\Phi_{\rm diff}(E_\gamma) = \int_{\Gamma_{\rm min}}^{\Gamma_{\rm max}} \frac{dN}{d\Gamma} d\Gamma \int_{z_{\rm min}}^{z_{\rm max}} \frac{d^2V}{dzd\Omega} dz \int_{L_\gamma^{\rm min}}^{L_\gamma^{\rm max}} dL_\gamma \, \rho(L_\gamma, z). \frac{dF_\gamma^{\rm int}}{dE} . e^{-\tau^{\rm ALP}_{\gamma\gamma}(E,z)}$$