



Researches on axion-like particles with gamma-ray observations

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2021.10.27@TeVPA 2021

What is axion/ALP?

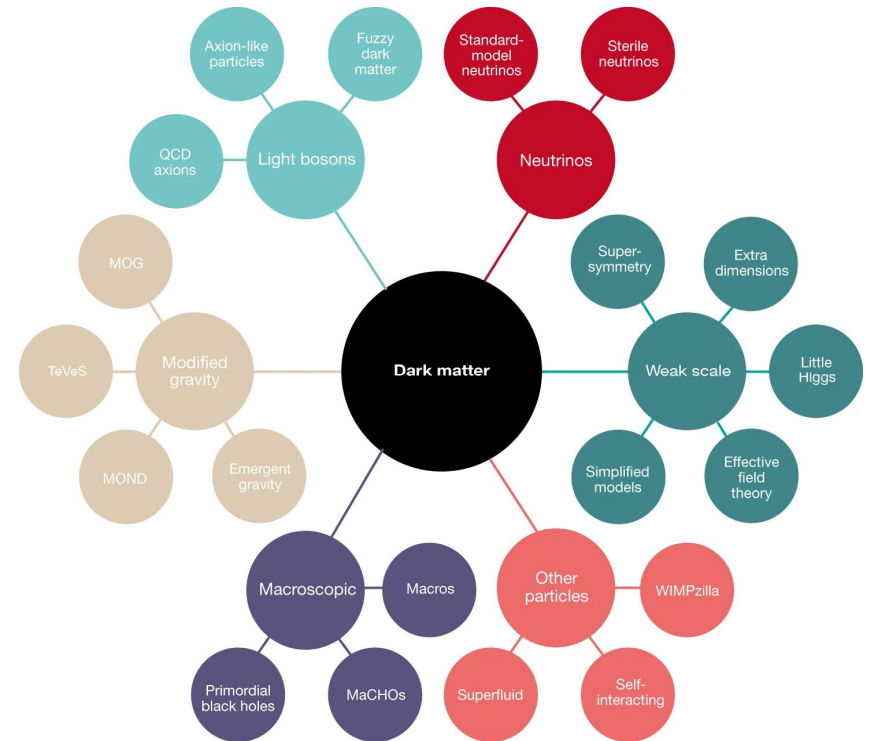
Possible DM candidates

axion/Axion-Like Particle

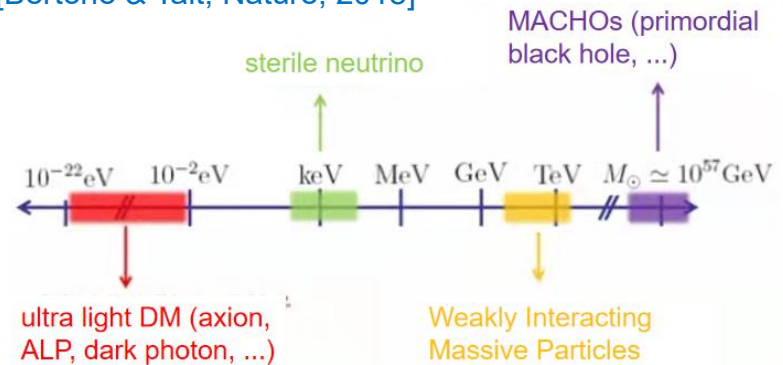
- hypothetical particles
- strong CP problem
- very light

$$(10^{-22} \text{eV} \lesssim m \lesssim 10^3 \text{eV})$$

- DM candidate
- Axion-like particles



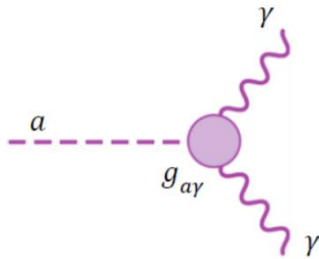
[Bertone & Tait, Nature, 2018]



ALP effect in astro observations

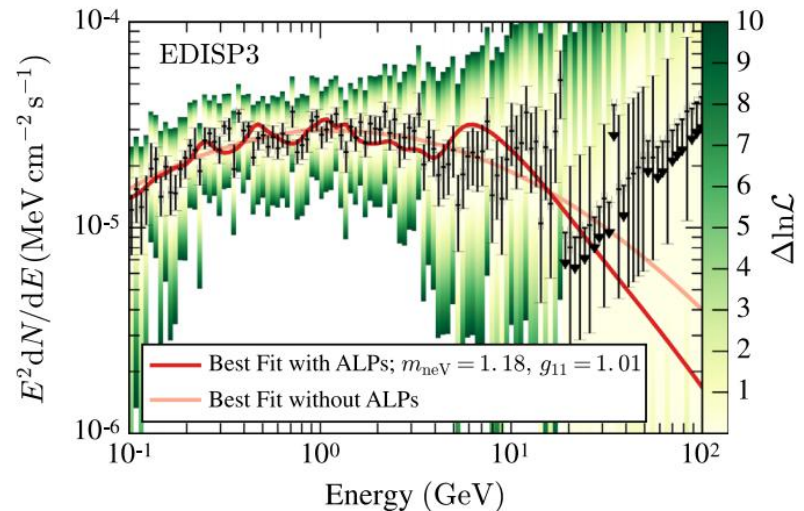
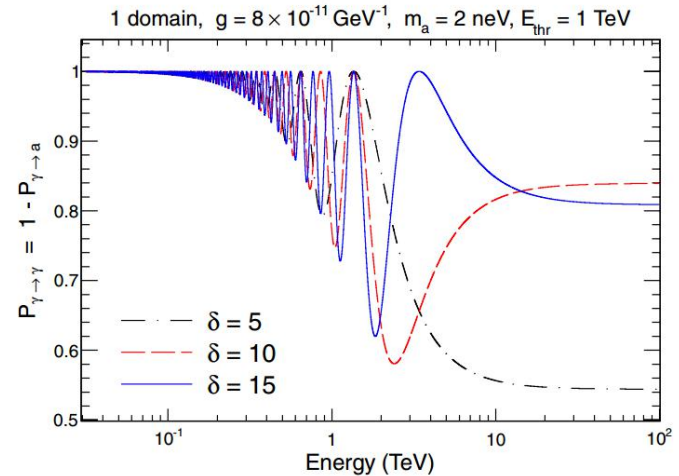
Primakoff process: Photon-ALP conversions in external E or B field

$$L_{a\gamma} = -\frac{1}{4} g_{a\gamma} F_{\mu\nu} \tilde{F}_{\mu\nu} a = g_{a\gamma} \vec{E} \cdot \vec{B} a$$



distant gamma-ray source

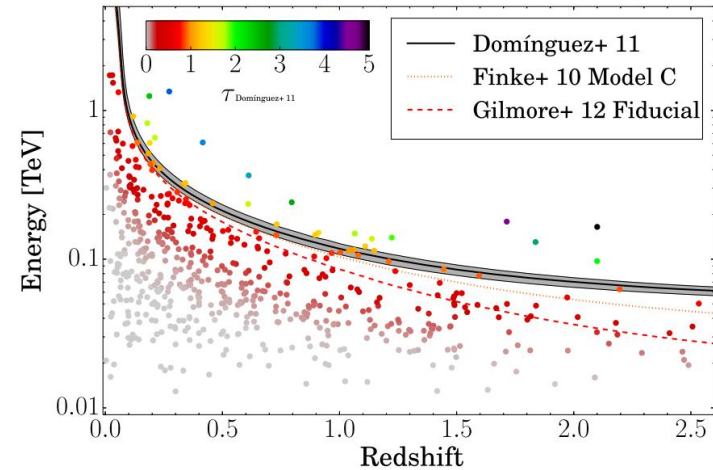
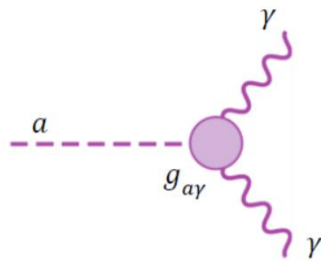
spectral irregularities



ALP effect in astro observations

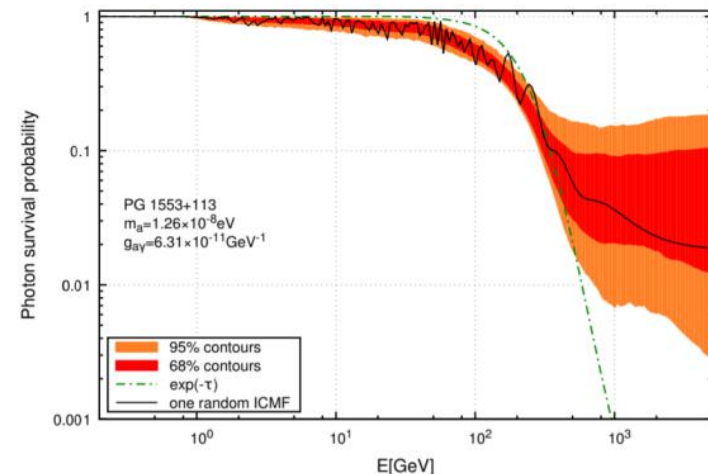
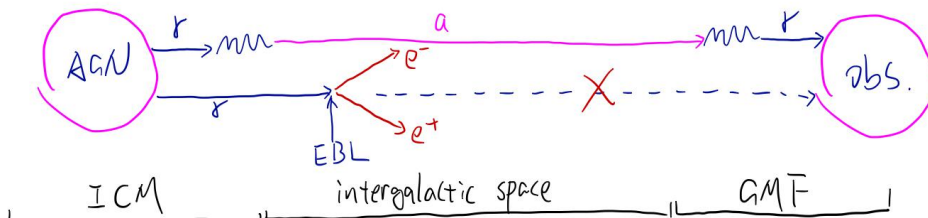
Primakoff process: Photon-ALP conversions in external E or B field

$$L_{a\gamma} = -\frac{1}{4} g_{a\gamma} F_{\mu\nu} \tilde{F}_{\mu\nu} a = g_{a\gamma} \vec{E} \cdot \vec{B} a$$



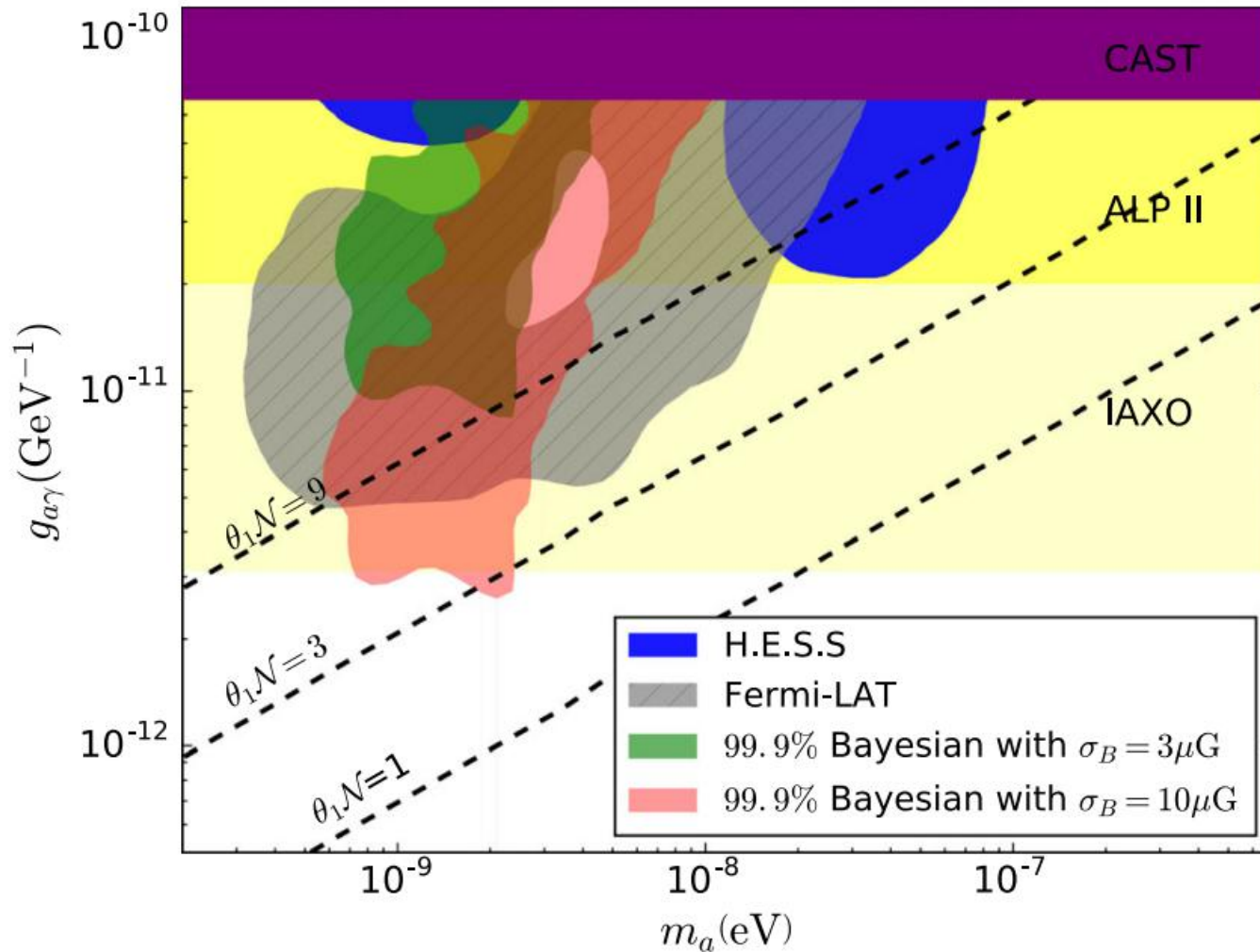
[Fermi 3FHL, 2017, ApJS]

TeV transparency



[Guo+, CPC 45 (2021) 2, 025105]

Constraints on ALP parameters



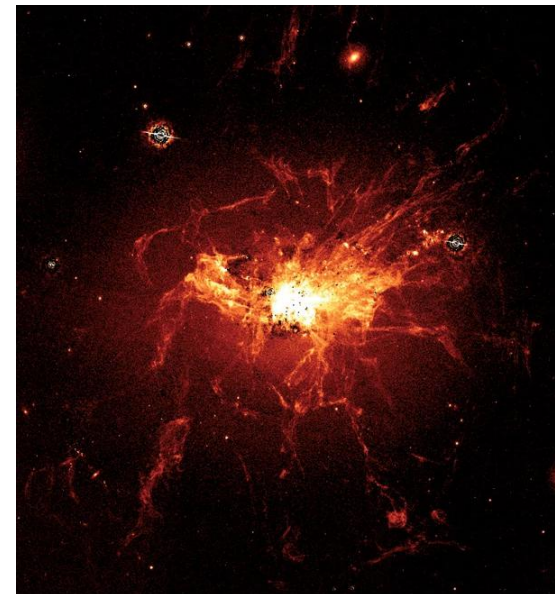
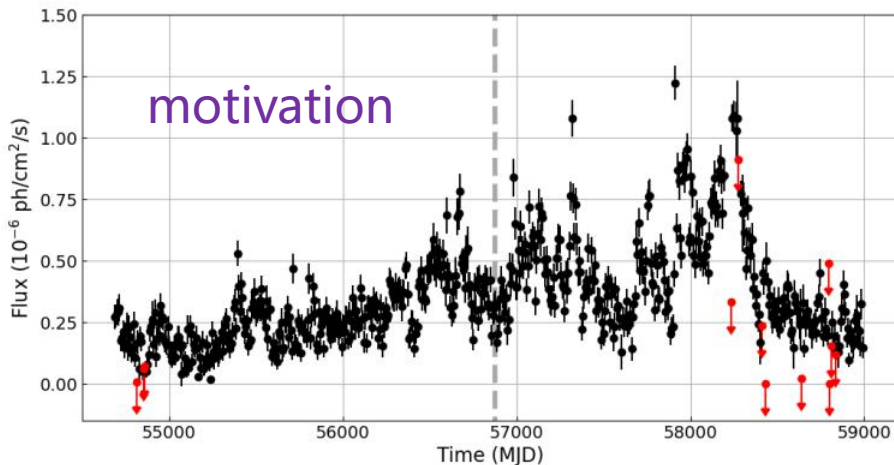
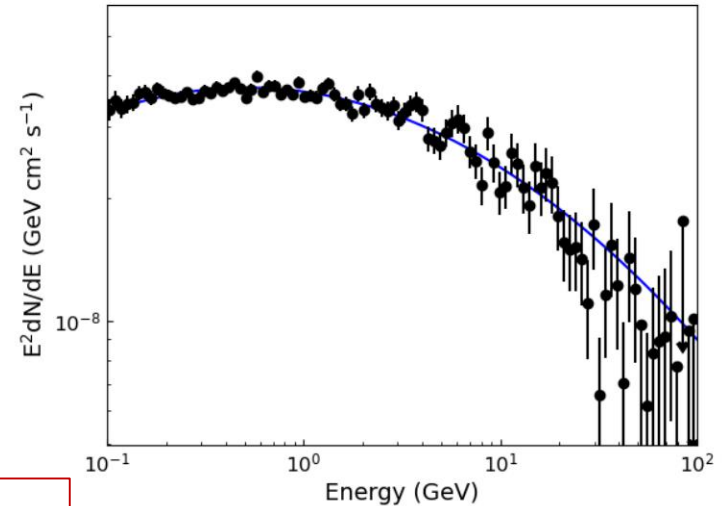
[Zhang, C. et al. 2020, PRD]

(I) ALP results from NGC 1275

NGC 1275

- radio galaxy, $z=0.0176$
- Perseus galaxy cluster
- bright GeV emission
- high central MF
- widely used to study ALPs

Revisiting the analysis of axion-like particles with the Fermi-LAT gamma-ray observation of NGC1275
[Cheng, J.-G. et al. 2021, PLB]



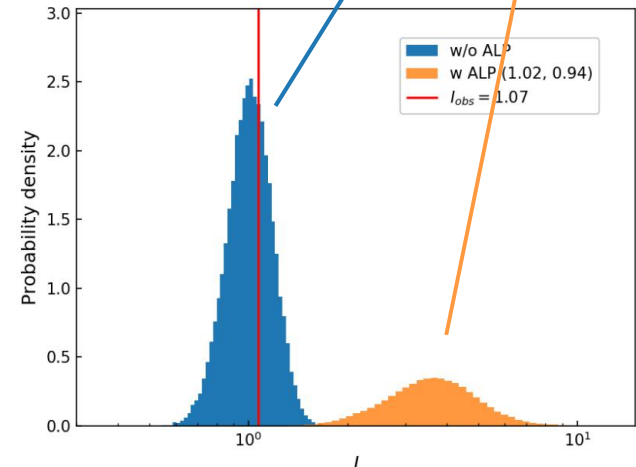
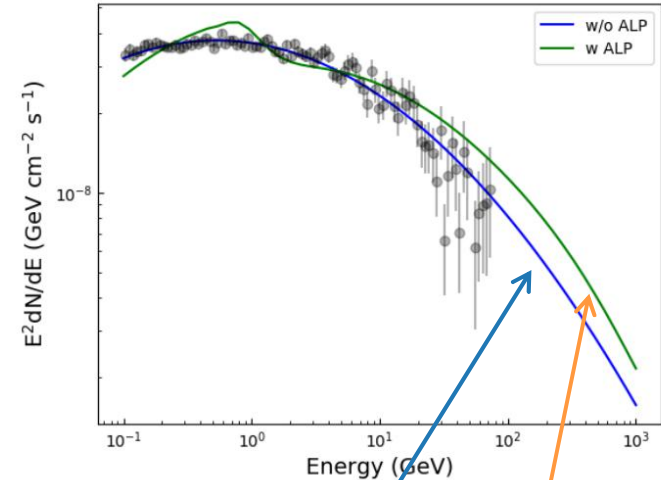
(I) ALP results from NGC 1275

12 years of Fermi-LAT data (0.1-500 GeV)

Method

$$I = \frac{1}{d} \sum_k^N \frac{(\phi_{\text{w/oALP}}(\vec{\theta}) - \phi_k)^2}{\sigma_k^2} = \chi^2/d$$

- irregularity estimator I
- I distribution under ALP models
- 20x20 $(m_a, g_{a\gamma})$
- 500x100 pseudo spectra



$$I_{\text{obs}} = 1.07$$

(I) ALP results from NGC 1275

propagation equation of ALP-photon beam

$$\left(i \frac{d}{dx_3} + E + \mathcal{M}_0 \right) \Psi(x_3) = 0 \quad \mathcal{M}_0 = \begin{pmatrix} \Delta_{\perp} - \frac{i}{2}\Gamma & 0 & 0 \\ 0 & \Delta_{\parallel} - \frac{i}{2}\Gamma & \Delta_{a\gamma} \\ 0 & \Delta_{a\gamma} & \Delta_a \end{pmatrix}$$

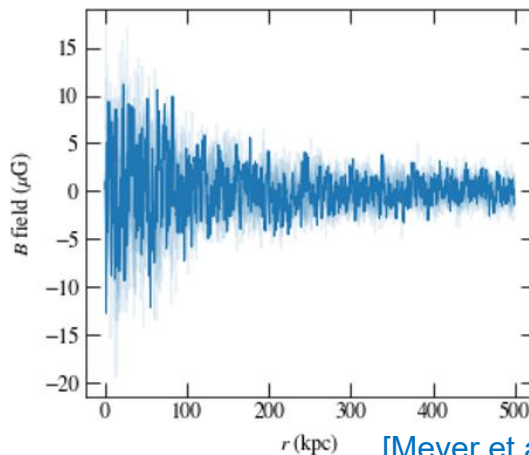
$g_{\alpha\gamma}, m_a, B_T, E, n_e$

For constant and homogeneous MF and initially polarized photon

$$P_{\text{ALP}} = 1 - P_{\gamma \rightarrow a} = 1 - \frac{1}{1 + E_c^2/E_\gamma^2} \sin^2 \left[\frac{g_{a\gamma} B_T l}{2} \sqrt{1 + \frac{E_c^2}{E_\gamma^2}} \right]$$

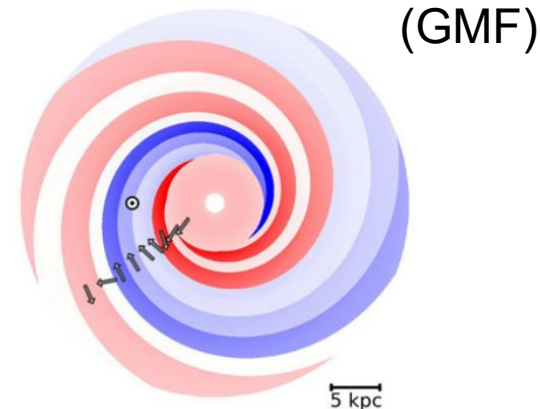
- gammaALPs: <https://gammaalps.readthedocs.io/en/latest/index.html>
- <https://github.com/lyf222/alpconv>

Magnetic field scenarios



[Meyer et al. 2014, JCAP]

+



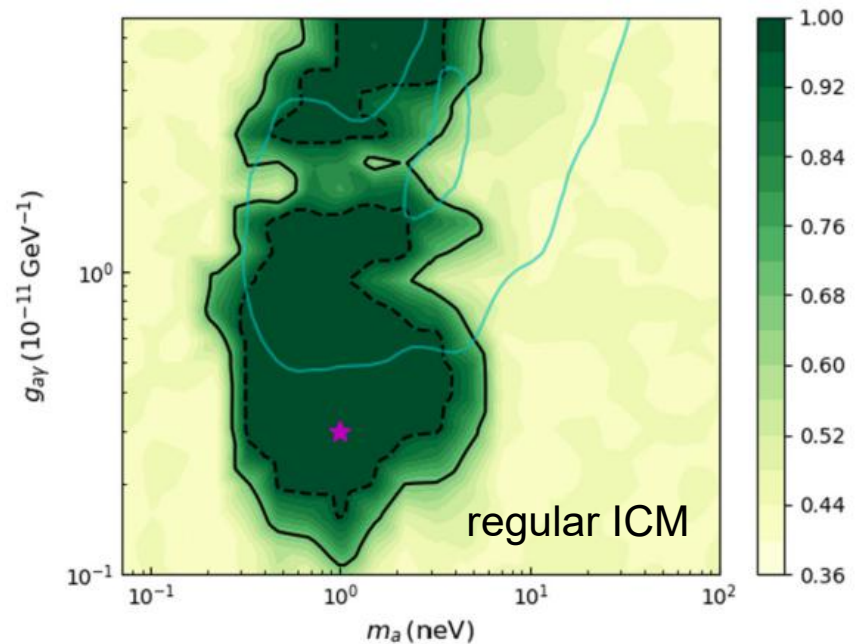
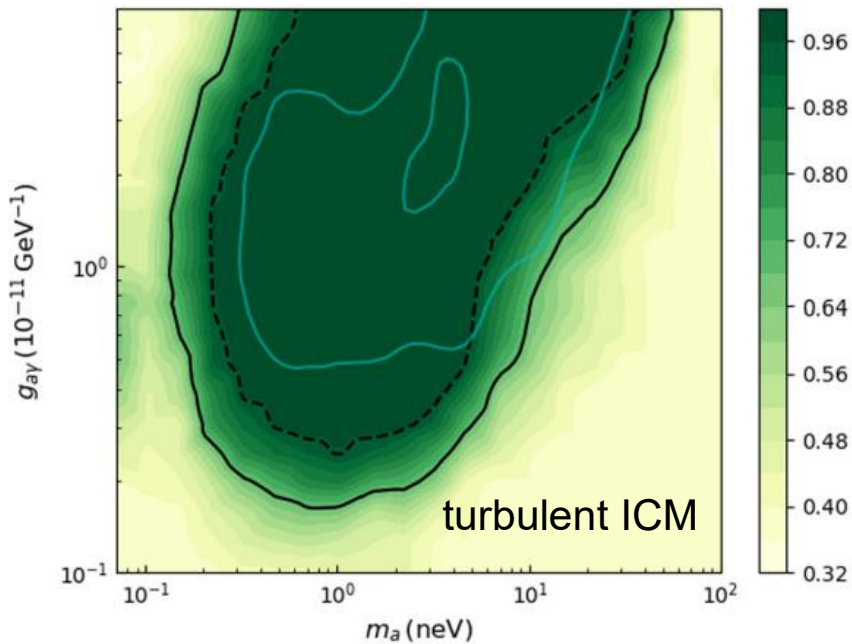
[Jansson & Farrar 2012, ApJ]

(I) ALP results from NGC 1275

main results

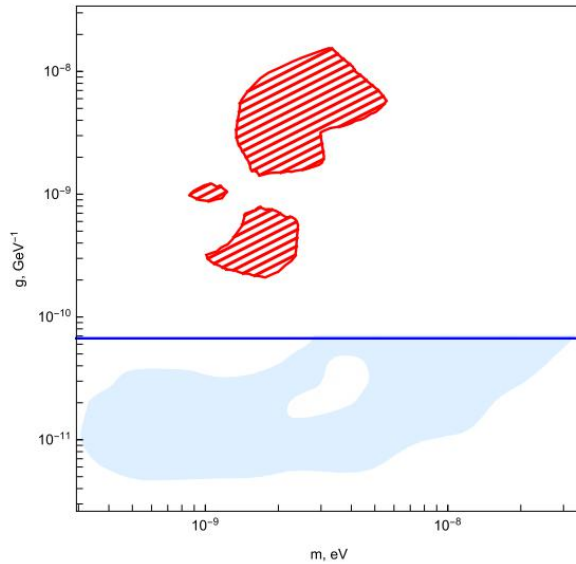
$$I_{\text{obs}} = 1.07$$

No ALP signal is found in our analysis.

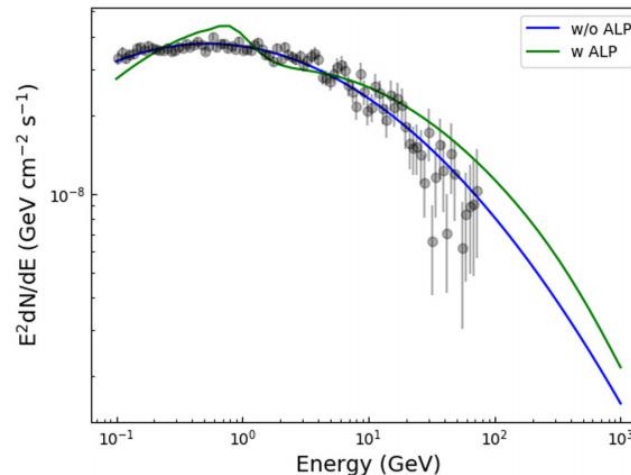
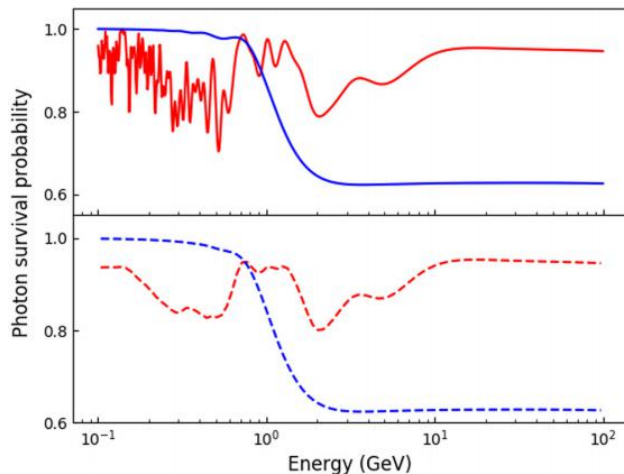
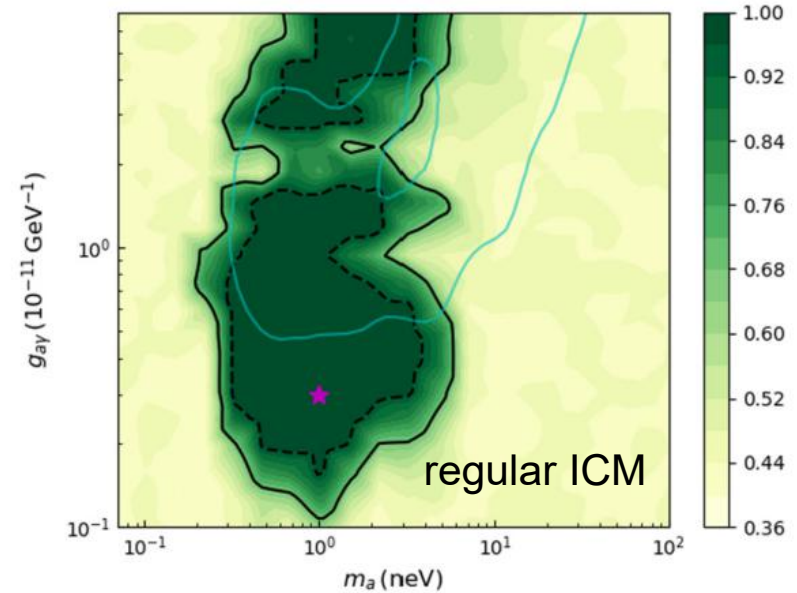


[Cheng, J.-G. et al. 2021, PLB]

(I) ALP results from NGC 1275



[Libanov & Troitsky, PLB, 2020]



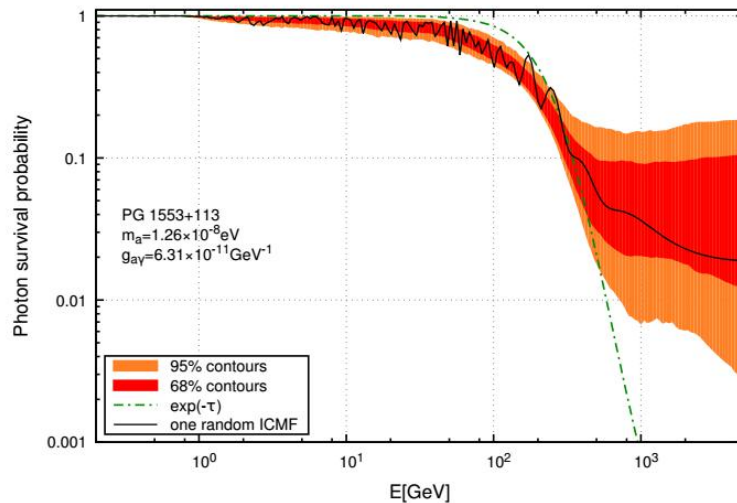
The changes of ICM model affect the ALP- γ conversion greatly, for this source we can still place strong limits on ALP coupling with the pure regular ICM model.

[Cheng, J.-G. et al. 2021, PLB]

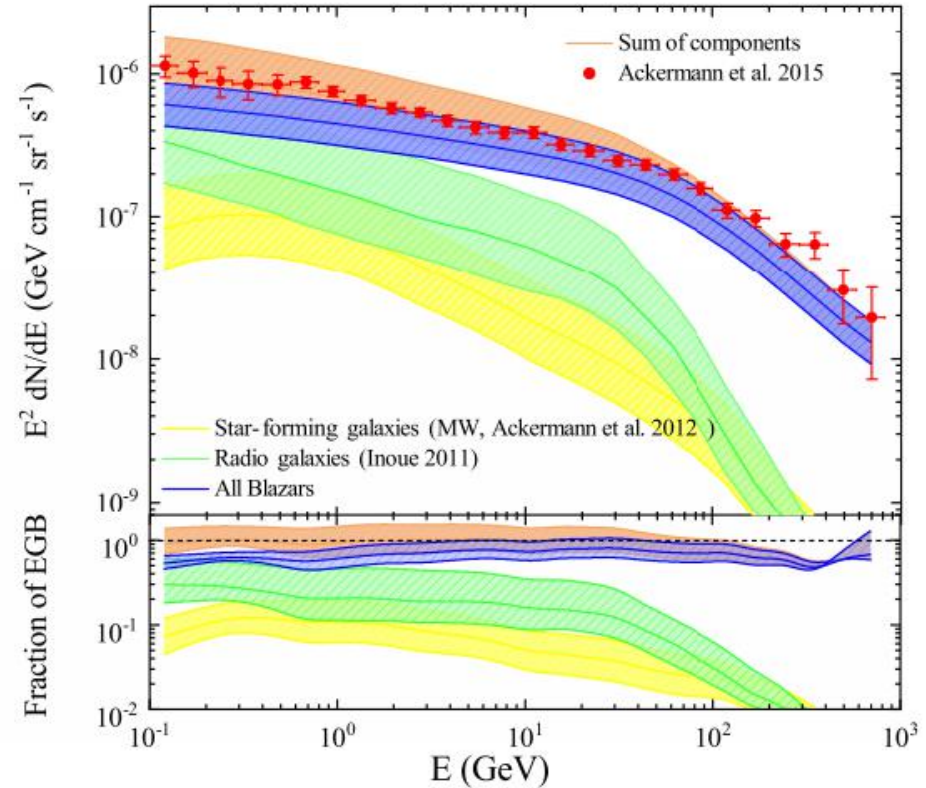
(II) ALP effect in the EGB

About EGB

- extragalactic γ -ray background
- from all extragalactic sources
- Blazars, radio galaxies, SF galaxies
- at VHE mainly from Blazars



Motivations



For individual sources:

- poor statistics
- unknown intrinsic spectrum
- randomness of the MFs

(II) ALP effect in the EGB

Model expected EGB spectrum

$$F_{\text{EGB}}(E_\gamma) = \int_{\Gamma_{\min}=1.0}^{\Gamma_{\max}=3.5} d\Gamma \int_{z_{\min}=10^{-3}}^{z_{\max}=6} dz$$

$$\times \int_{L_\gamma^{\min}=10^{43}}^{L_\gamma^{\max}=10^{52}} dL_\gamma \cdot \Phi(L_\gamma, z, \Gamma) \cdot \frac{dN_\gamma}{dE} \cdot \frac{dV}{dzd\Omega}$$

Luminosity function

[Ajello et al. 2015, ApJL]

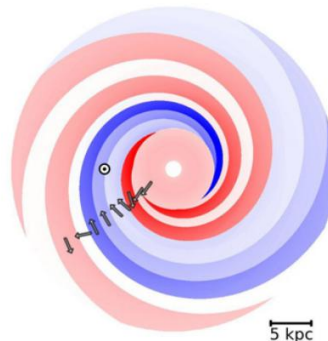
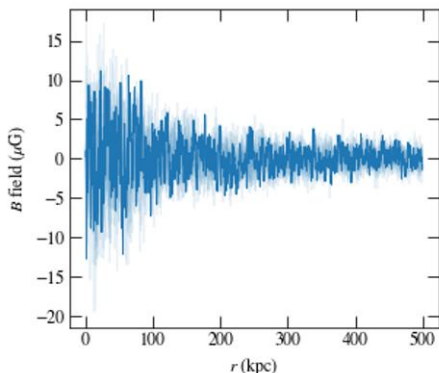
$$\frac{dN_\gamma}{dE} = K \left[\left(\frac{E}{E_b} \right)^{\gamma_a} + \left(\frac{E}{E_b} \right)^{\gamma_b} \right]^{-1} \cdot P_{\gamma\gamma}(E, z)$$

$$P_{\gamma\gamma} = e^{-\tau(E, z)} \quad (\text{pure EBL})$$

$$P_{\text{ALP}} = 1 - \frac{1}{1 + E_c^2/E_\gamma^2} \sin^2 \left[\frac{g_{a\gamma} B_\Gamma l}{2} \sqrt{1 + \frac{E_c^2}{E_\gamma^2}} \right]$$

(EBL+ALP)

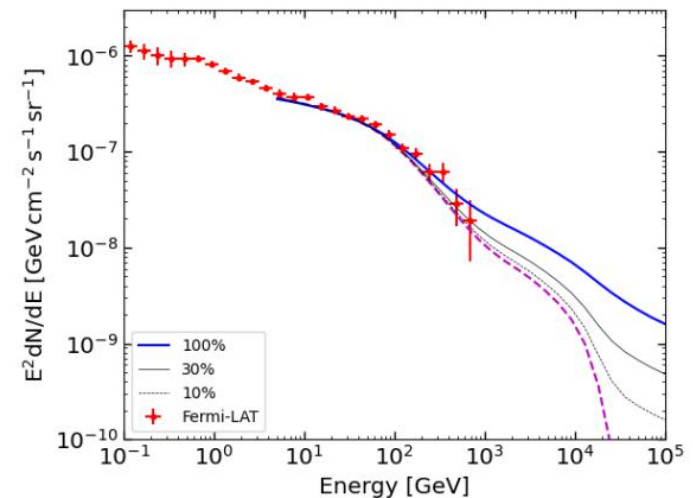
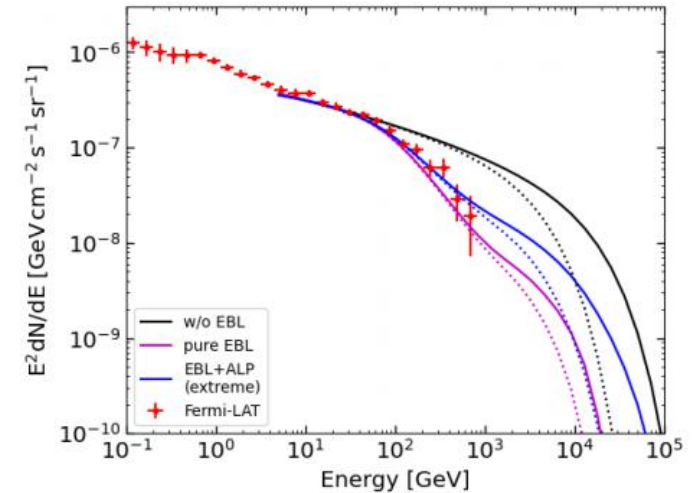
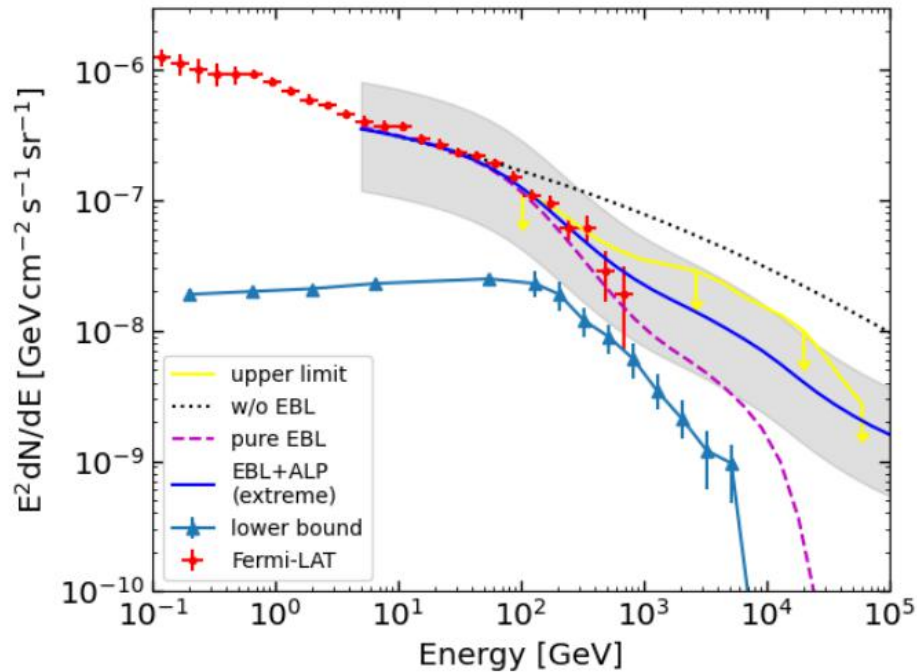
MF configurations



- ICM+GMF
- NGC 1275 ($B_0=3 \mu\text{G}$)
- optimistic

(II) ALP effect in the EGB

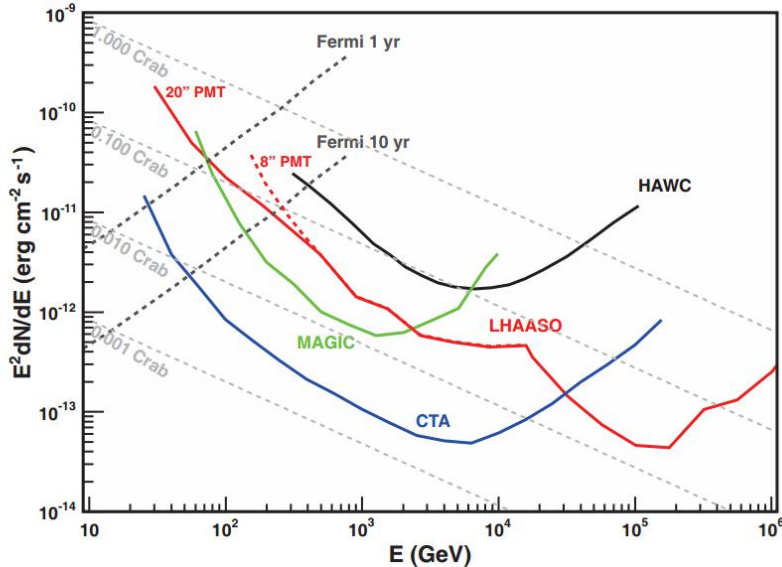
main results



The effect of axion-like particles on the spectrum of the extragalactic gamma-ray background

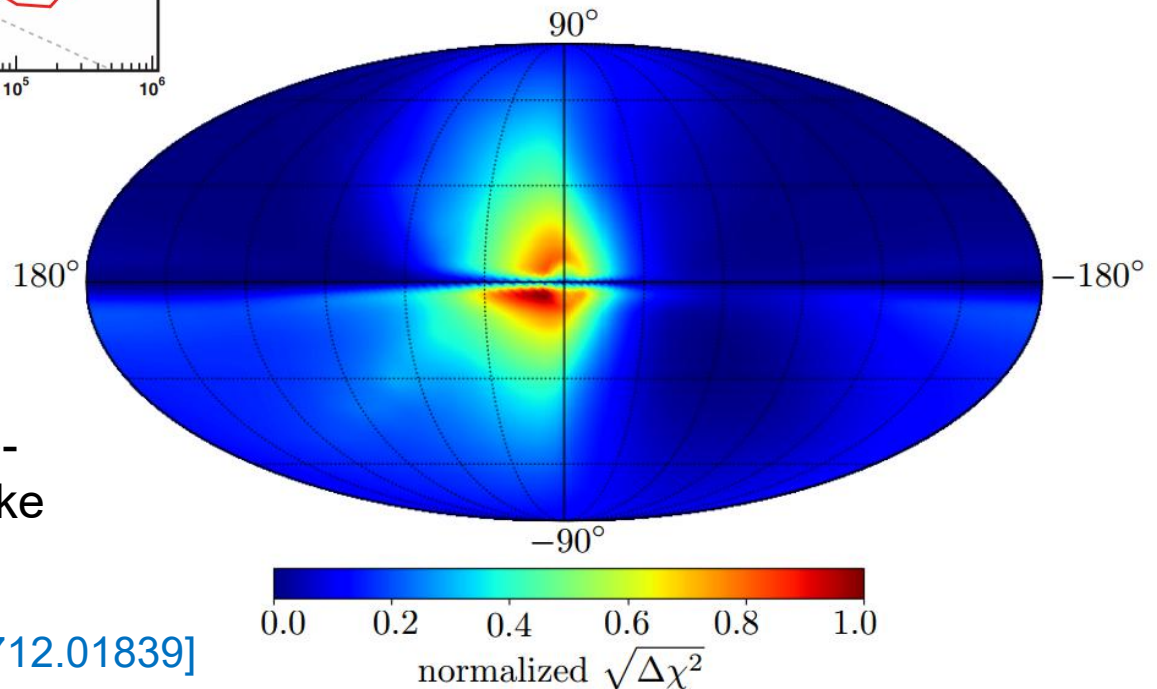
[Liang, Y.-F. et al. 2021, JCAP accepted]

(II) ALP effect in the EGB



← LHAASO sensitivity

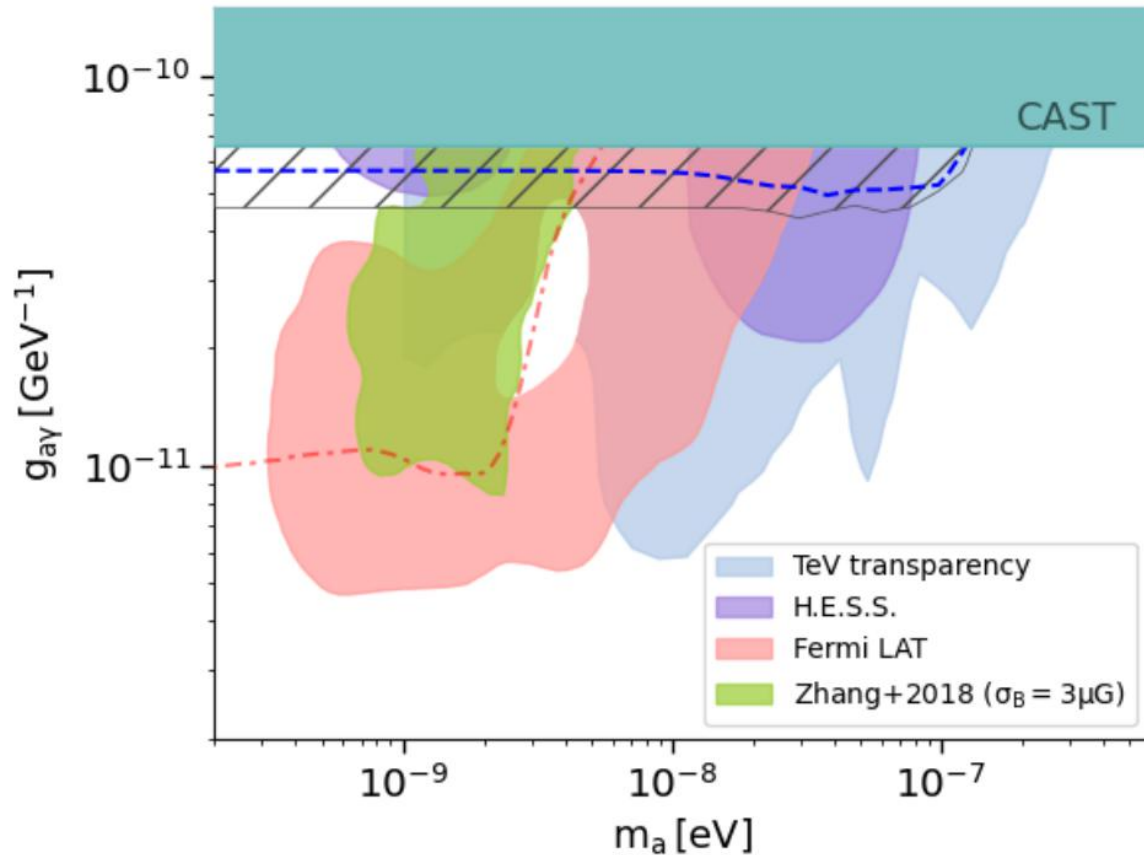
[LHAASO science white paper]



Relative sensitivity to the photon-flux from a diffuse-ALP flux for a LHAASO-like experiment.

[Vogel et al., arXiv: 1712.01839]

(II) ALP effect in the EGB



Less encouraging
but a first attempt.

[Liang, Y.-F. et al. 2021, JCAP accepted]



Summary

- Revisit the analysis of axion-like particles with the Fermi-LAT gamma-ray observation of **NGC1275**
- Study the effect of axion-like particles on the spectrum of the **extragalactic gamma-ray background**

Thanks!