Constraining ALPs with the diffuse γ-ray flux measured by the Large High Altitude Air Shower Observatory

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Based L. M., P. Carenza, M. Chianese, D. F.G. Fiorillo, G. Miele, A. Mirizzi, D. Montanino ArXiv:2206.08945

OUTLINE

- Introduction
- Axions and photons production in host Galaxies
- Conversion probability
- Bounds on axions parameter space
- Conclusions

WORK'S AIMS

- In this work we focused on obtaining:
  - a precise calculation of the axion production from far galaxies;
  - bounds on the axion parameters from the LHAASO measurement.
- The existence of ALPS emerges naturally in extensions of the Standard Model, like Peccei-Quinn theory or string theory [Peter Svrcek, Edward Witten *arXiv:hep-th/0605206*]

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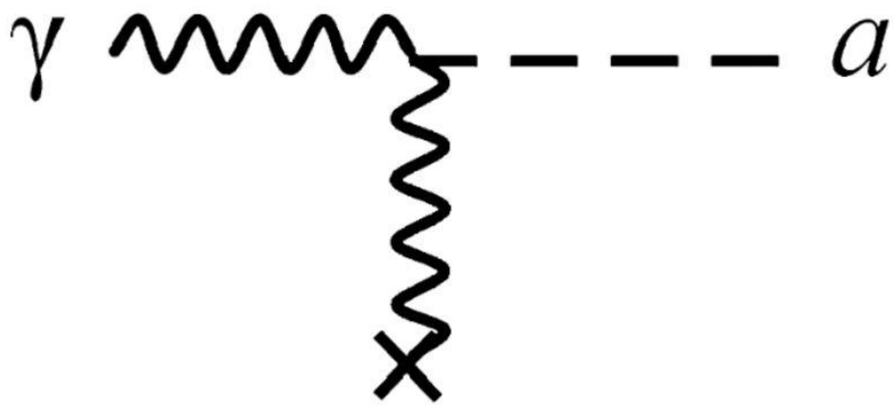
Interest in investigating their parameter space $(m_s, g_{a\gamma})$

- Axions existence affects the photon flux on Earth.

AXIONS

- Axion-like particles (ALPs) are pseudoscalar particles introduced in UV completions of the SM
- Possible interactions with SM particles

$$L_{int} = \sum_{\psi=e,p,n} \frac{g_{a\psi}}{2m_{\psi}} (\bar{\psi}\gamma^{\mu}\gamma^{5}\psi)\partial_{\mu}a - \frac{1}{4} g_{a\gamma} \widetilde{F^{\mu\nu}} F_{\mu\nu} a$$

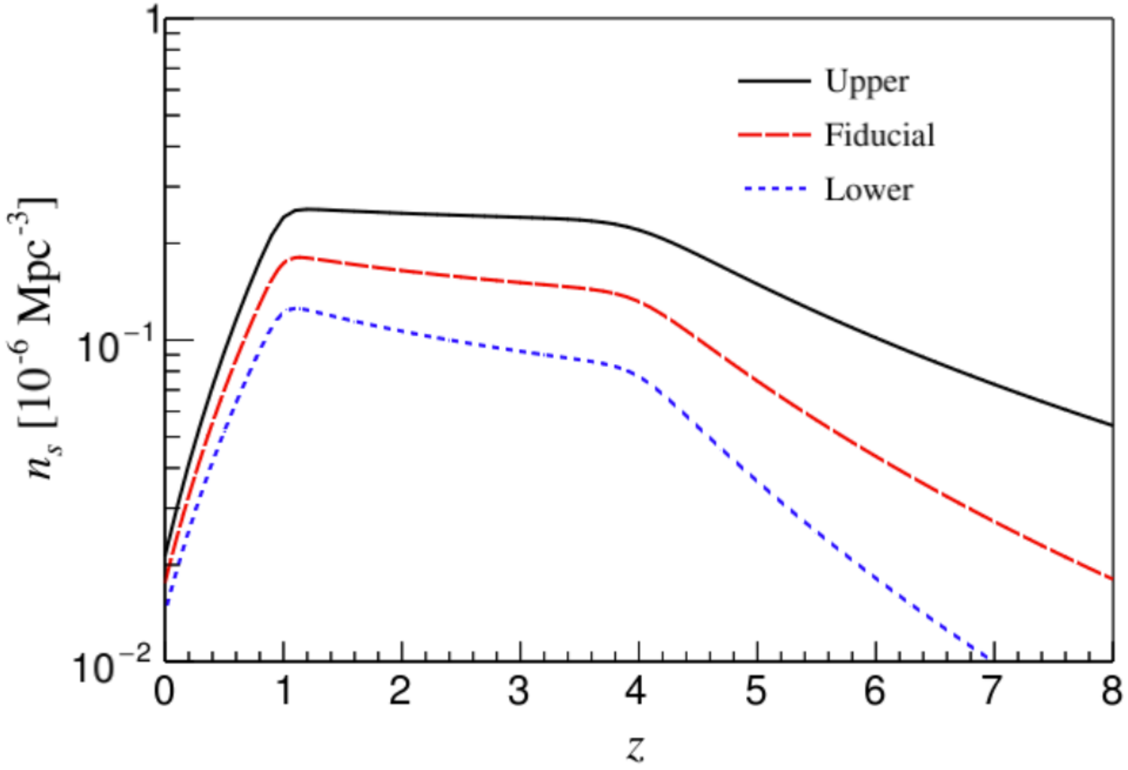


Photon-ALP conversion in an external magnetic field

NEUTRINO FLUX

- We will consider the neutrino host galaxy: different IceCube models (HESE, TG$-\mu$, Cascades).
- Different star formation rate model $n_s(z)$

$$\frac{d\phi_\nu}{dE} = \int_0^\infty [(1+z)Q_\nu(E(1+z))]n_s(z)\left|\frac{cdt}{dz}\right|$$

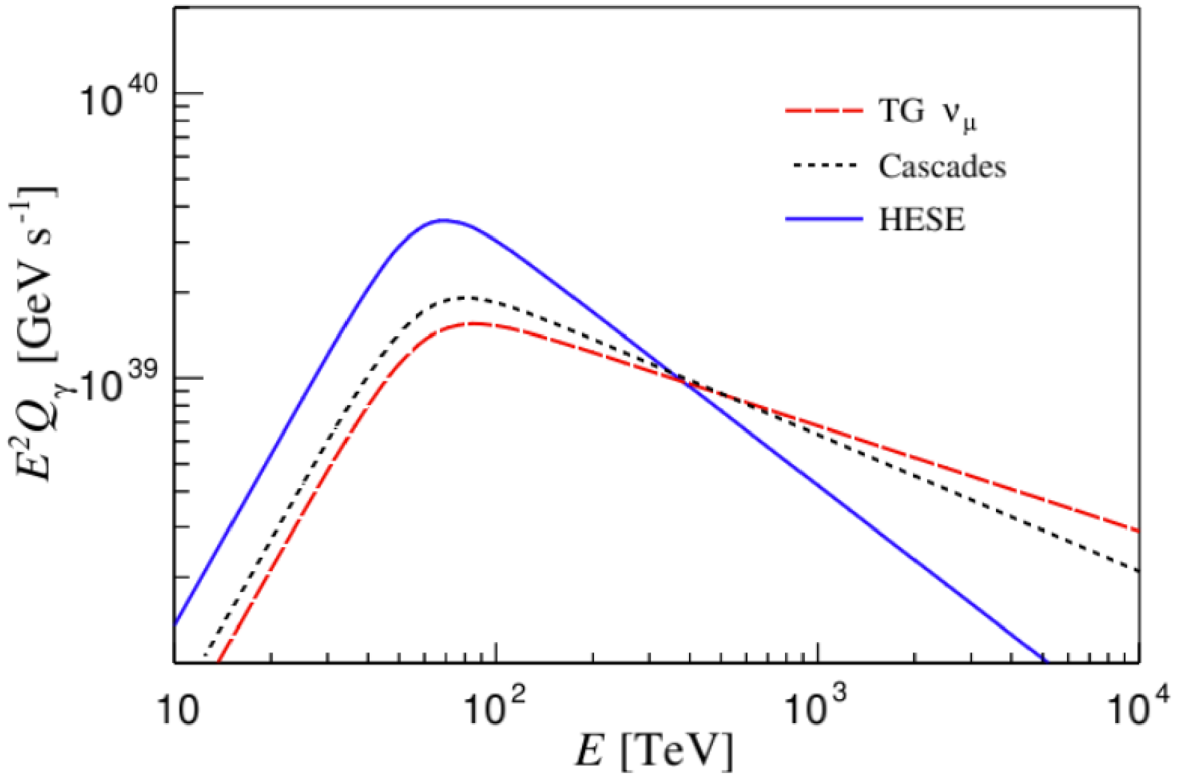


PHOTON FLUX

- We consider the multi-messenger relation for the $p\gamma$ interaction

2 photons for each 3 neutrinos

$$E_\gamma = 2E_\nu$$



ALPs CONVERSION

- The photons travel insider the galactic magnetic field, being converted to ALPs
- We consider a magnetic field with 2 kpc< l < 8 kpc and 2 μG<B < 8 μG
- We consider two models for the galactic magnetic field

$$i \frac{d}{dx_3} \rho = [H_0, \rho] - \frac{i}{2} \{H_{abs}, \rho\}$$

$$\rho = \begin{pmatrix} A_1(x_3) \\ A_2(x_3) \\ a(x_3) \end{pmatrix} \otimes \begin{pmatrix} A_1(x_3) & A_2(x_3) & a(x_3) \end{pmatrix}$$

- The oscillation probability can be written as:

$$P_{\gamma\to a}^{s} = \frac{\left(\Delta_{a\gamma}L\right)^2 \sin^2\left(\frac{\Delta_{\mathrm{osc}}L}{2}\right)}{\left(\frac{\Delta_{\mathrm{osc}}L}{2}\right)^2}$$

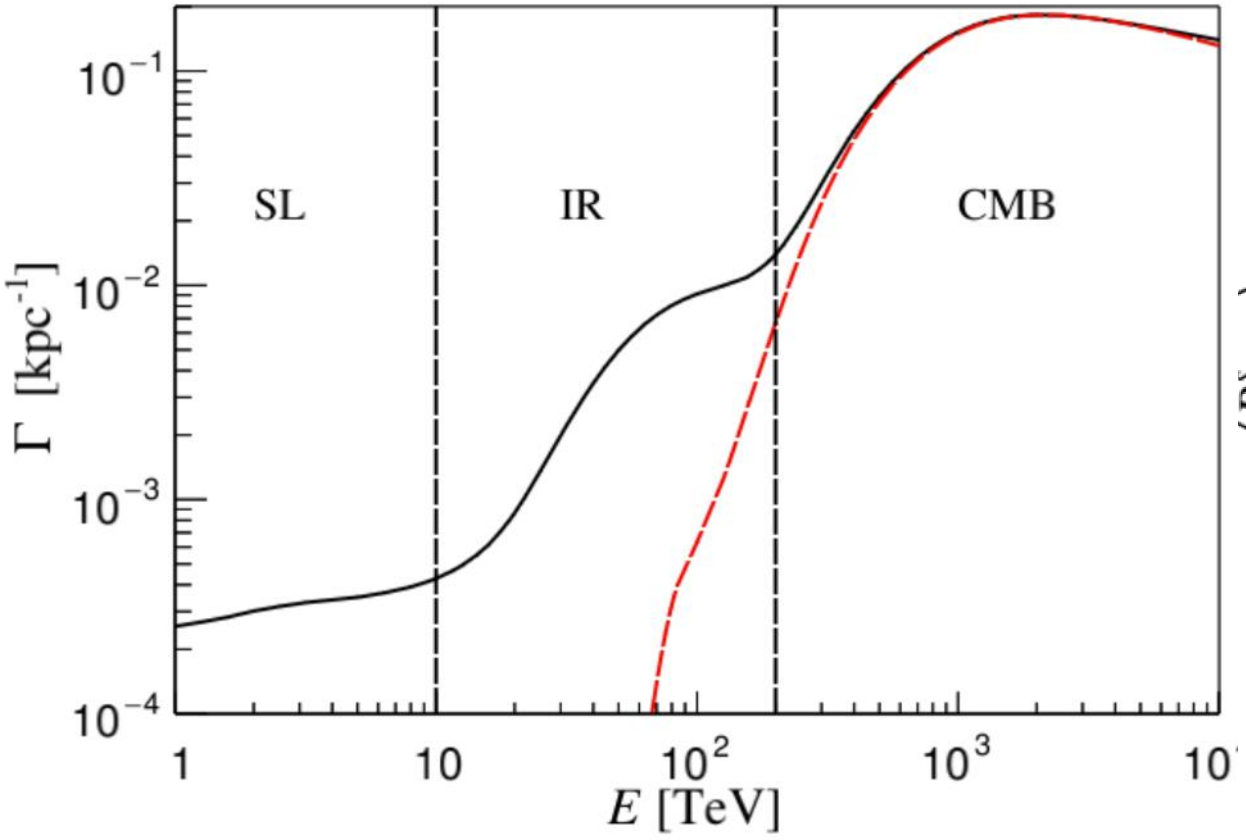
with

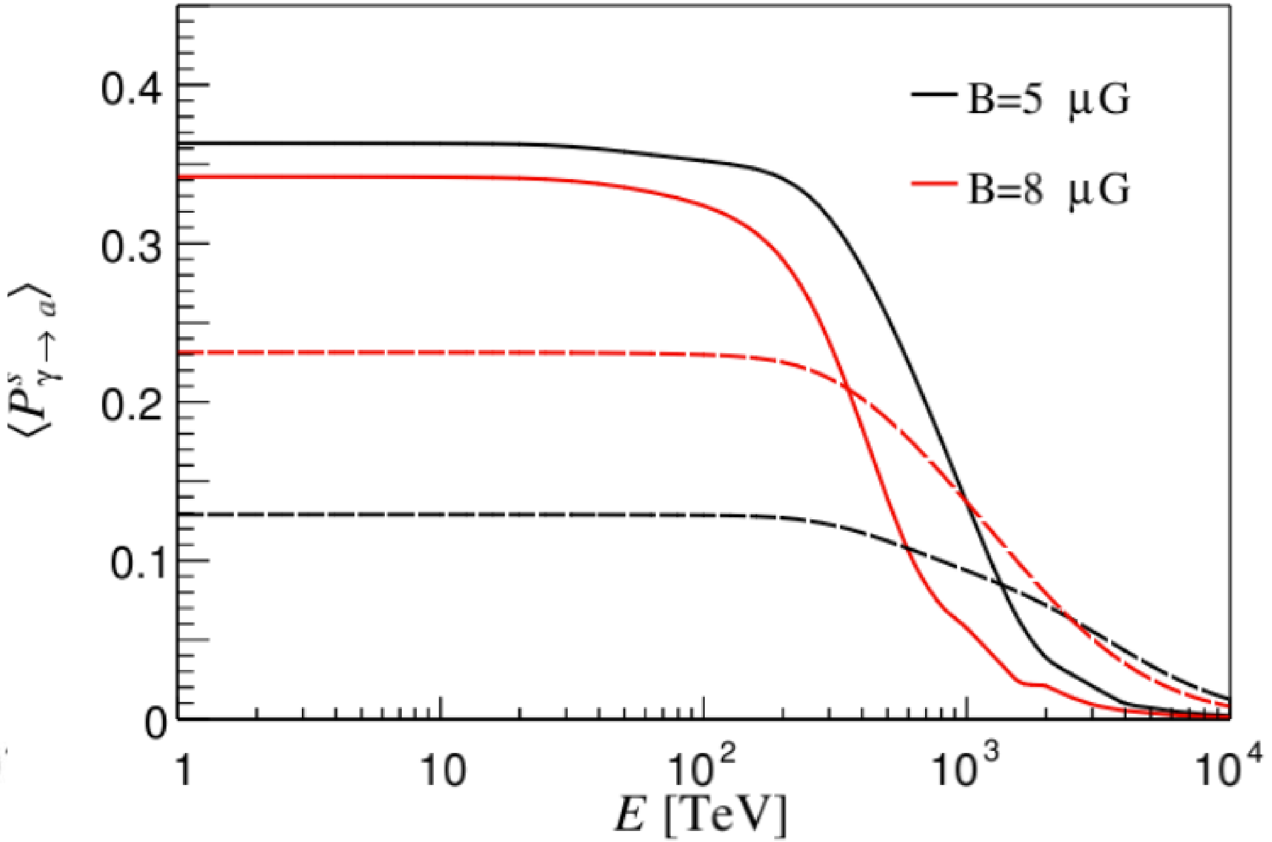
$$\Delta_{a\gamma} \simeq 1.5 \times 10^{-2} \left(\frac{g_{a\gamma}}{10^{-11}\mathrm{GeV}^{-1}}\right)\left(\frac{B_T}{10^{-6}\mathrm{G}}\right)\mathrm{kpc}^{-1}$$

$$\Delta_{\mathrm{osc}} = \sqrt{\left(\Delta_{\parallel} - \Delta_a - \frac{i}{2}\Gamma\right)^2 + 4\Delta_{a\gamma}^2}$$

$$\Delta_{\parallel} = \Delta_{pl} + \frac{7}{2}\Delta_{QED} + \Delta_{\mathrm{CMB}}$$

CONVERSION PROBABILITY

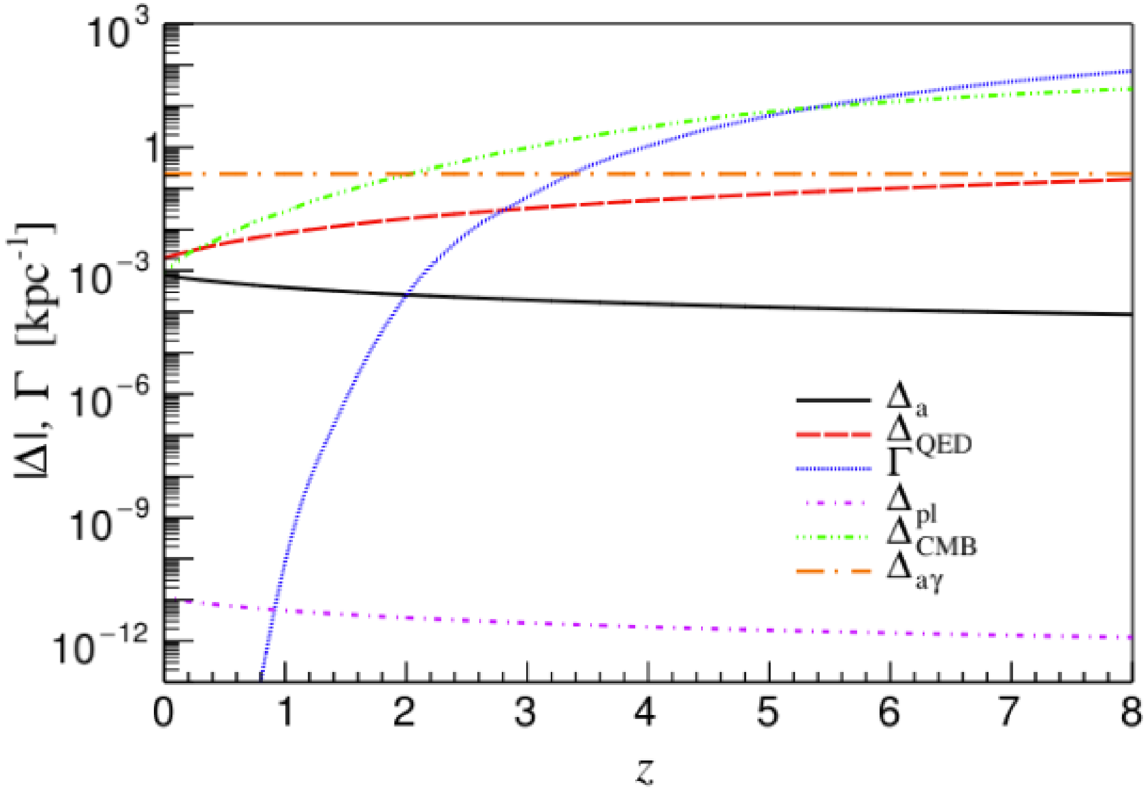


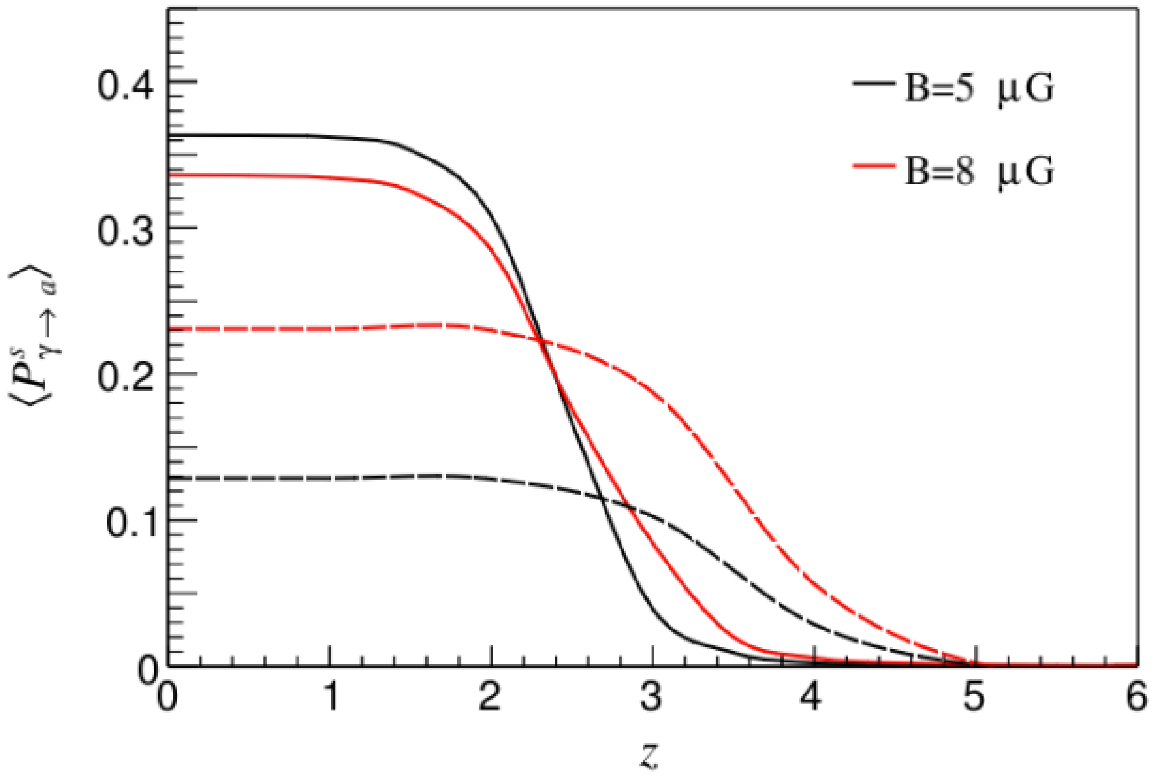


$$\langle P^{S}_{\gamma\to a}\rangle = \frac{1}{2\Delta L}\int_{2}^{8} dL\, P^{S}_{\gamma\to a}$$

EVOLUTION IN z

- The quantities inside $\langle P^{s}_{a\to\gamma}\rangle$ evolve with the redshift.
- The probability is zero for very far galaxies





ALPs FLUX

- With the $\langle P^{s}_{a\to\gamma}\rangle$ function in z and E, we can determine the ALPs flux

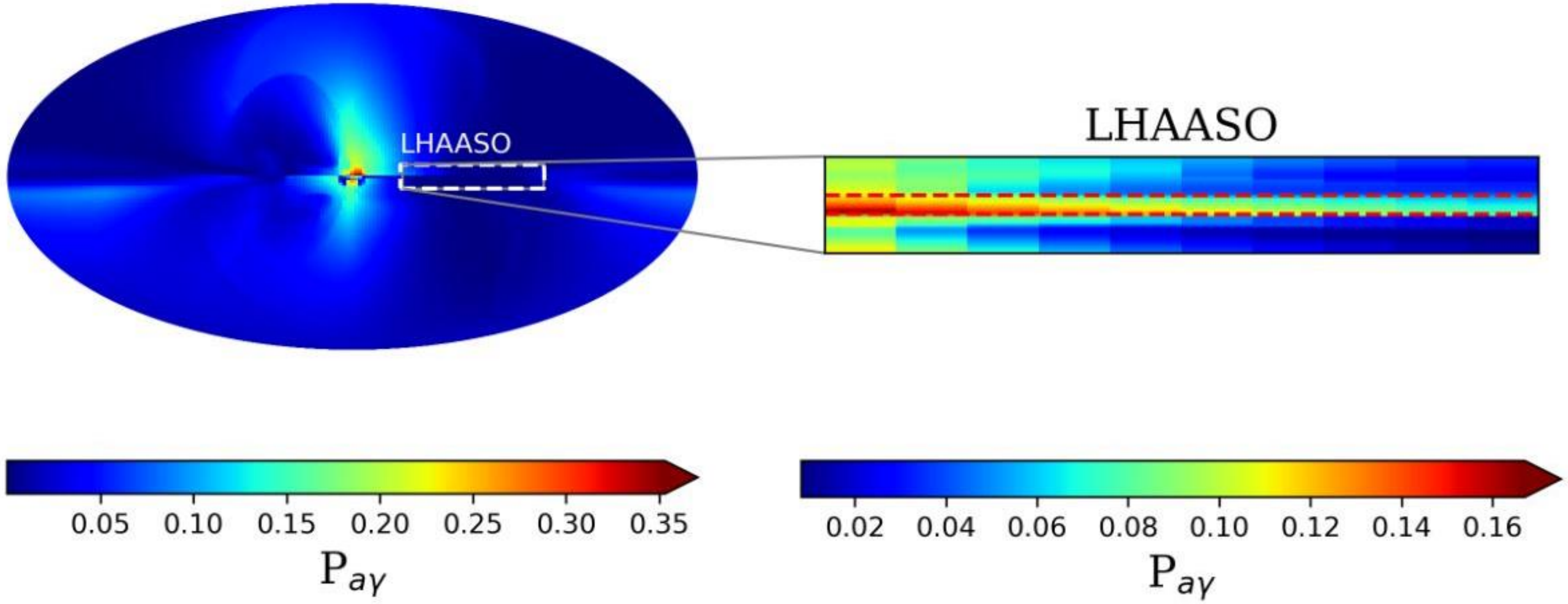
$$\frac{d\phi_a}{dE} = \int_0^\infty dz \left|\frac{cdt}{dz}\right| (1+z) Q_\gamma\big(E(1+z)\big)\big\langle P_{a\to\gamma}(E(1+z),z)\big\rangle n_s(z)$$

- The ALPs travel to Earth without being absorbed. We assume no photons in the same energy range.

- Once in the Milky-Way they are back-converted into photons.

ALPs BACKCONVERSION

- For the magnetic field in the MW, we have adopted the Jansson-Farrar model. [Ronnie Jansson, Glennys R. Farrar, *arXiv:1204.3662*]
- We have followed the techniques in [Dieter Horns et al, *arXiv:1207.0776*] to solve the 3D model.
- In Figure the probability for $g_{a\gamma} = 3 \times 10^{-11}\mathrm{GeV}^{-1}$ and $m_a \ll 10^{-7}\mathrm{eV}$

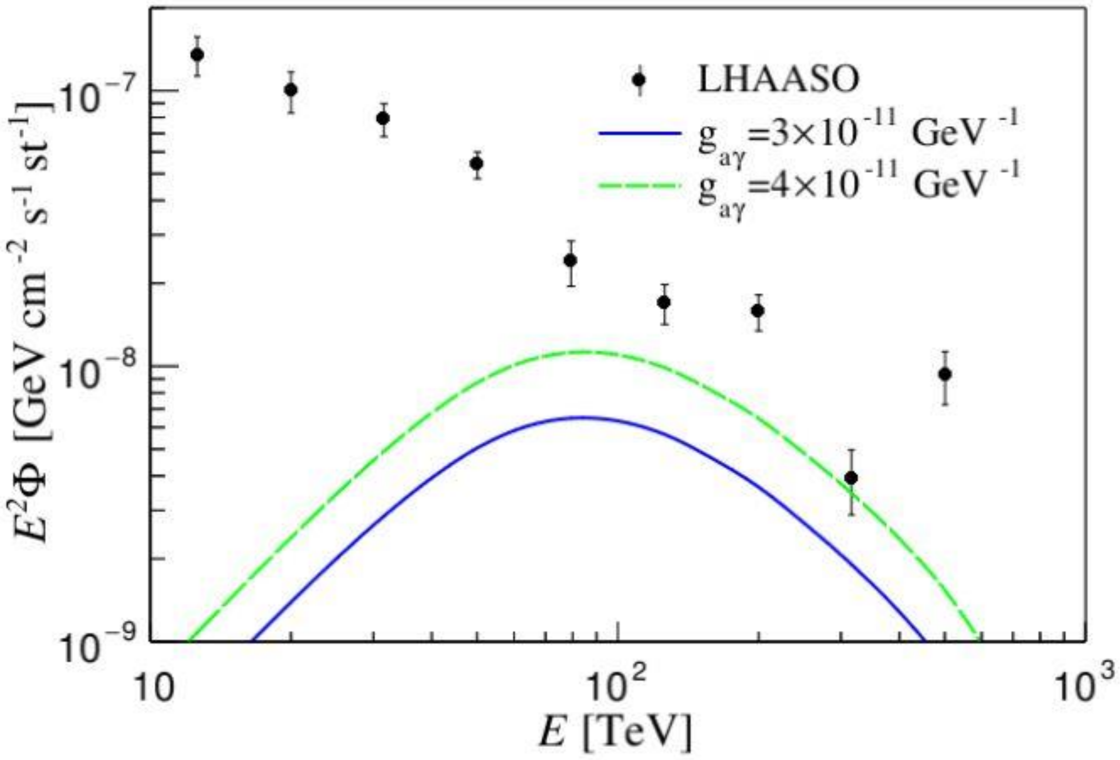


PHOTON FLUX FROM ALPs

- We obtained the photon flux as

$$\frac{d\phi_\gamma}{dE} = P_{a\gamma}^{MW} \frac{d\phi_a}{dE}$$

- Left part follow the neutrino spectra
- Right part due to $\langle P_{a\gamma} \rangle$ shape
- We compare with LHAASO data



ANALYSIS

- We have performed a half-χ^2 analysis

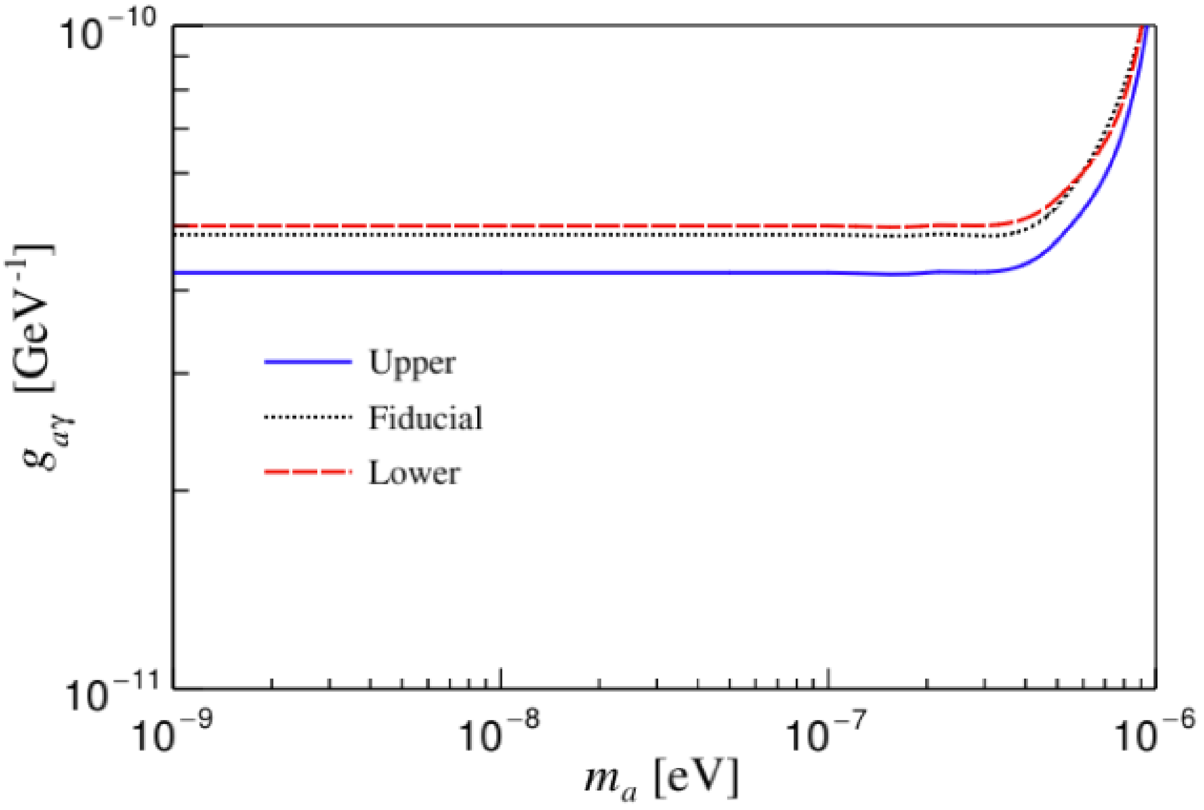
$$\chi^2 = \sum_i^N \begin{cases} \left(\dfrac{\dfrac{d\phi_\gamma^i}{dE_i} E_i^2 - \dfrac{d\phi_{\gamma,\mathrm{exp}}^i}{dE_i} E_i^2}{\sigma(E_i)} \right)^2 & \left(\text{if} \dfrac{d\phi_\gamma^i}{dE_i} E_i^2 > \dfrac{d\phi_{\gamma,\mathrm{exp}}^i}{dE_i} E_i^2 \right) \\ 0 & (\text{otherwise}) \end{cases}$$

where N is the number of LHAASO points

- We exclude values for which $\chi^2 > 2.71$
- Fiducial case: box model, $B_T = 5\,\mu G$, no photon background, fiducial $n_s(z)$ and Cascades data-set

IMPACT OF THE ν FLUX MODEL

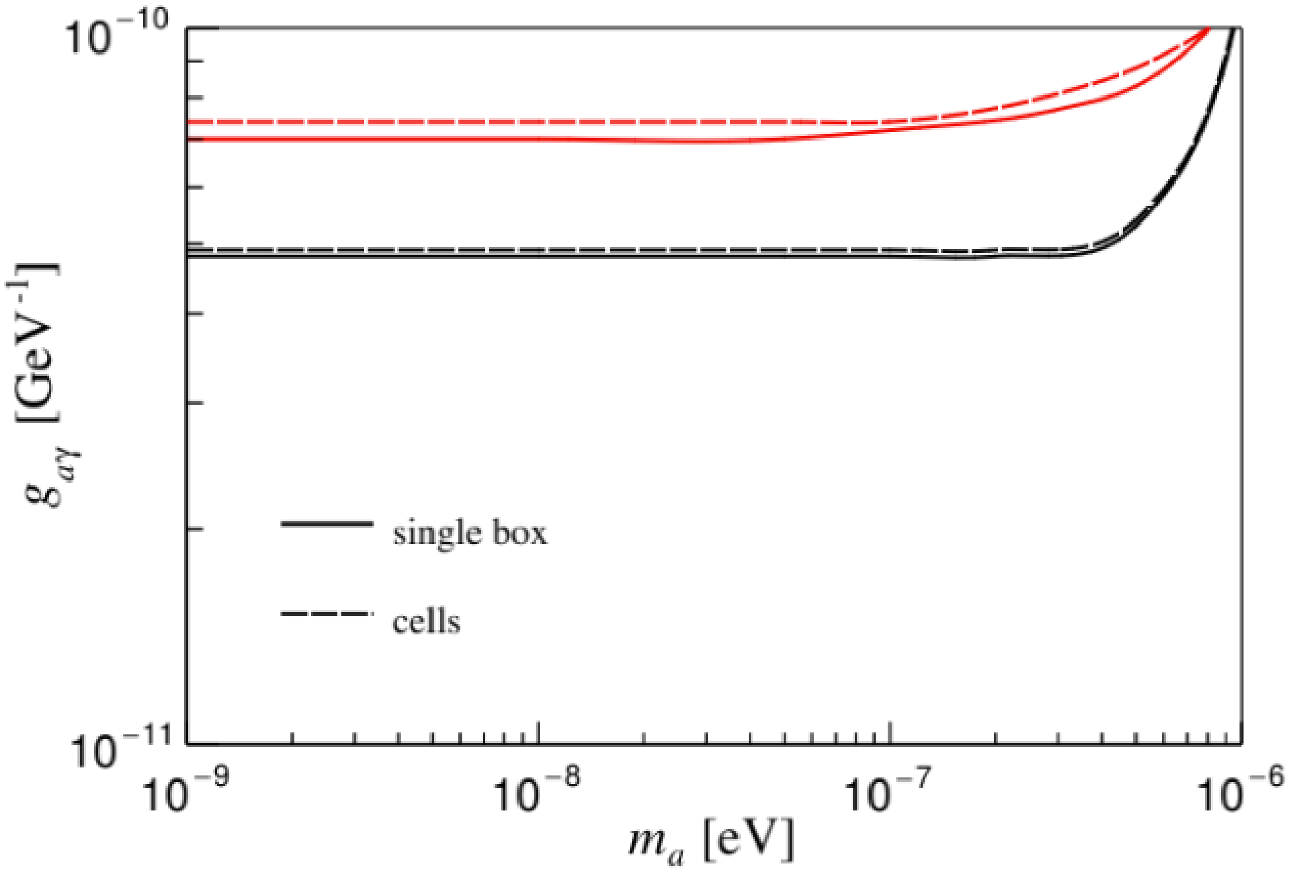
- We have chosen to take into account three different high energy ν flux model: Cascades, TG-μ and HESE



Analytic fits	$n_s(0)$	α	β	γ	z_1	z_2	Q_ν
Upper	0.0213	3.6	-0.1	-2.5	1	4	HESE
Fiducial	0.0178	3.4	-0.3	-3.5	1	4	Cascades
Lower	0.0142	3.2	-0.5	-4.5	1	4	TG ν_μ

IMPACT OF THE B_T MODEL

- We have considered a single box model and a cells model of $l = 1$ kpc. Moreover $|\vec{B}_T| \in [2\,, 8]\ \mu G$
- Main source of uncertainties



BACKGROUND ANALYSIS

- Partial incompatibility between LHAASO and Tibet data

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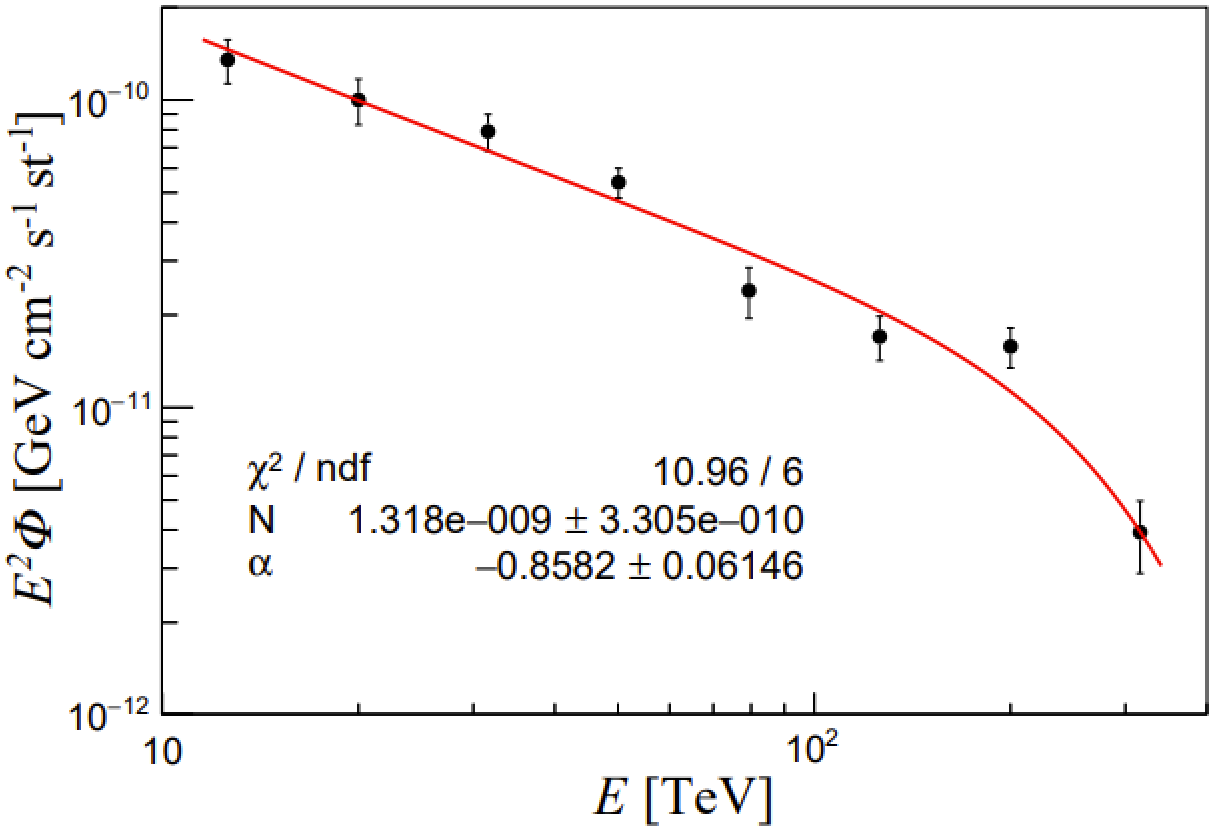
No univocal photon background fit [Pedro De la Torre Luqueet al, *arXiv:2203.15759*]

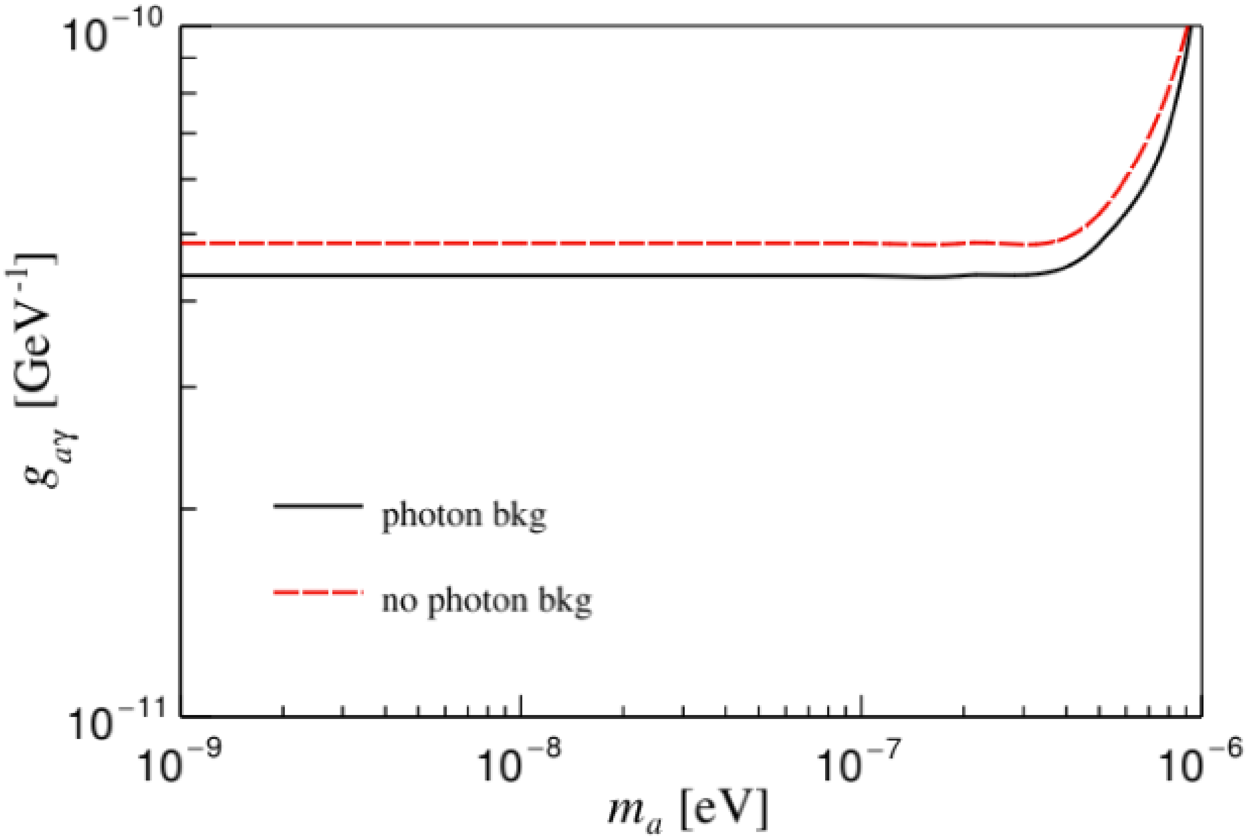
- We have therefore tried to simulate the existence of a background with a power-law fit

$$\frac{d\phi_\gamma^{bkg}}{dE} = NE^\alpha \times F(E)$$

where $F(E)$ is a reduction factor caused bu the CMB and SL+Infrared absorption

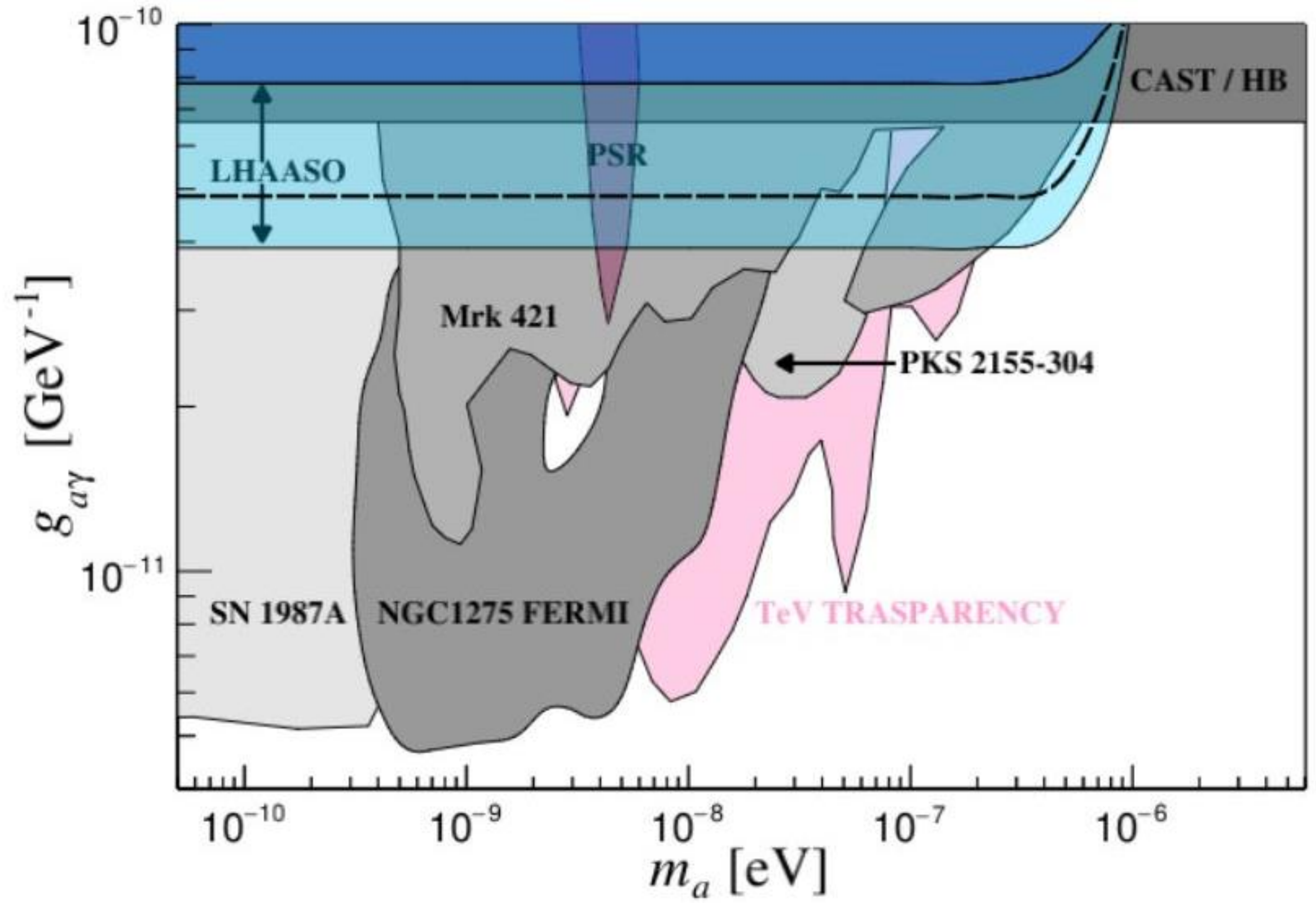
- Background fit in absence of photons and variation of the fiducial case bound





RESULTS

- ALPs constraint in the $(m_a, g_{a\gamma})$ parameter space. The black dashed line is our fiducial bound. The blue contours are the variation with the $|\vec{B}|$ model and intensity and on the background analysis.



CONCLUSIONS

- We analyzed the phenomenology of the diffuse flux of high energy ALPs with $\mathrm{E} > O(1)$ TeV
- We characterize the photon production, conversion and diffusion until Earth.
- Using the LHAASO data we have obtained the most conservative constrain for the ALPs parameters $(m_s, \sin^2\theta)$
- Finally, these results can be improved with future LHAASO data.

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Thanks for the attention

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