Study of axion-like particles with the Perseus data of MAGIC

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Abstract

- **Axion-like particles** (**ALPs**) - interaction with very high-energy gamma rays in the strong magnetic fields → modifying the SED of the observed target.
- We analyzed **43.2** hours of observational data from the **Perseus Galaxy Cluster**, obtained with **MAGIC** telescopes.
- Two sources located in the **Perseus cluster** – NGC1275 & IC310
- We set the constraints on the **ALPs** mass, around hundreds of neVs and improving the current limits on the strength of their coupling to photons.

Datasets & signal modeling

Dataset	Days	Obs. Time	Zenith range	$S_{Li\&Ma}$
NGC1275 Flare	1 Jan '17	2.5 hrs	12° - 50°	61.3
NGC1275 Post – flare	02-03 Jan '17	2.8 hrs	12° - 38°	37.8
NGC1275 Low – state	Sep '16 – Feb '17	36.0 hrs	12° - 50°	31.8
IC310 – Flare	13 Nov '12	1.9 hrs	12° - 35°	18.0

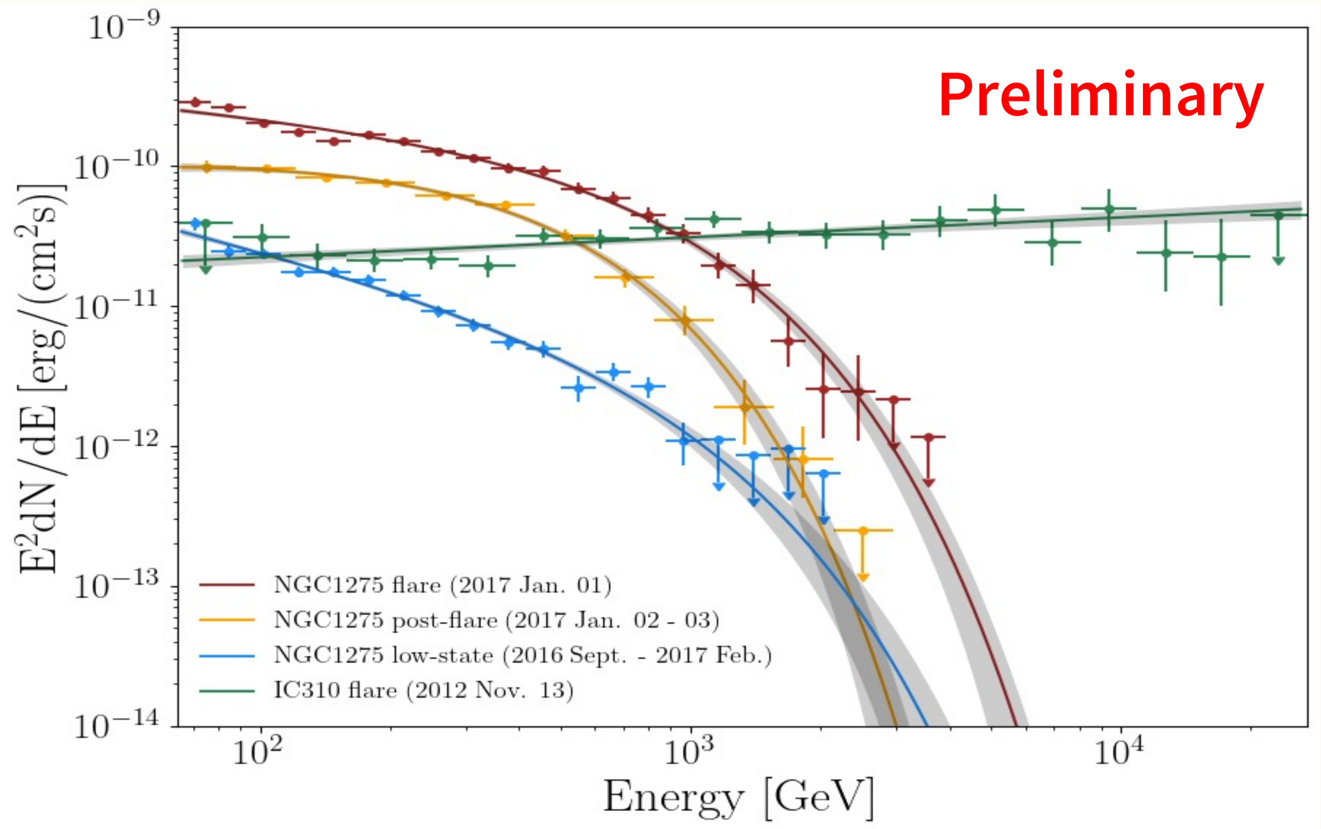

Fig. 1: SED of NGC 1275 (different states) and IC 310.

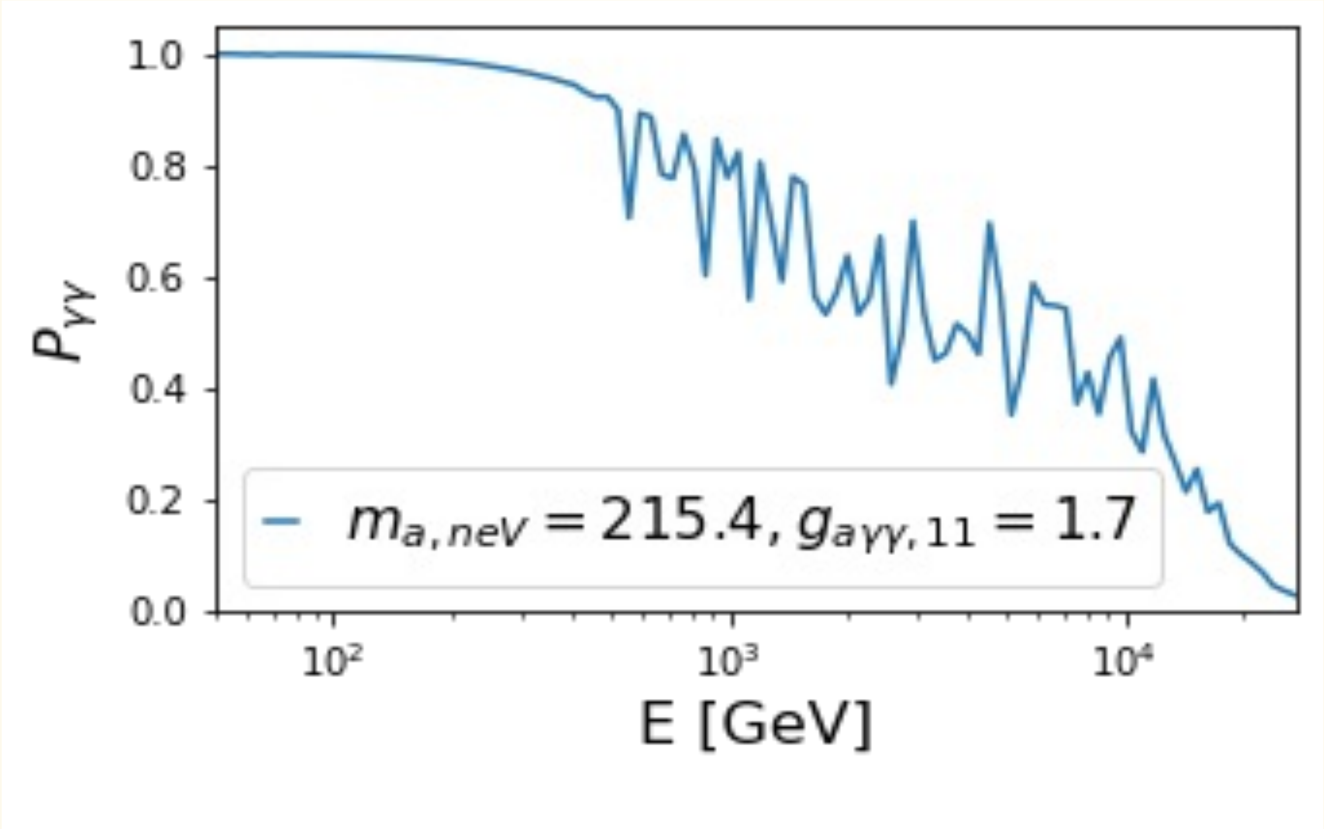

Fig. 2: Photon survival probability $P\gamma\gamma$ for one combination of mass and ALPs coupling.

We analysed 43.2 hours of data of two AGNs in Perseus: NGC1275 and IC310 located on redshift **z ~ 0.017**, observed by the MAGIC telescopes.

- ALPs analysis – gammaALPs code – calculating the photon survival probability taking into account:

1. Magnetic field of the Perseus galaxy cluster
2. Milky Way magnetic field + EBL photon attentuation

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Statistical analysis

- Binned likelihood:

$$\mathcal{L}(m_a, g_{a\gamma}; \mu \,|D) = \prod_{i,k} \mathcal{L}_{i,k}(m_a, g_{a\gamma}; \mu_i \,|D_{i,k})$$

- The spectrum is modified, adding the effect of ALPs (the survival probability):

$$\Phi_{\mathrm{obs}} = \mathrm{dE}\ \Phi_{\mathrm{int}}(\mathrm{E}, \mu_i) P_{\gamma\gamma}(\mathrm{E}') \cdot \mathrm{IRF}(\mathrm{E}|\mathrm{E}')$$

  where $\boldsymbol{\mu_i}$ and $\boldsymbol{D_{i,k}}$ represent nuisance parameters and the observed counts for each of the datasets $\boldsymbol{i}$ per bin $\boldsymbol{k}$, respectively.

- For the case of ALPs, Wilks' theorem cannot be utilized! – we compute 100 realisations of magnetic field and Monte Carlo simulations
- Introducing point-by-point computation to compute the correct coverage using the Monte Carlo simulations

Effects of Systematics

MAGNETIC FIELD MODELING

	B_0[μG]	η	n_0 [cm^{-3}]	n_2 [cm^{-3}]	$\frac{r_{core}}{r_{core2}}$ [kpc]	β/β_2
B	10	0.5	0.039	0.0045	80/280	1.2/0.58
B_{alt}	25	2/3	0.046	0.0036	57/278	1.2/0.71

Tab. 1: The parameters used for the modeling of the Perseus magnetic field B and performing a check of the effects magnetic field modelling has on the constraints by using the B_{alt} as the CTA Coll.

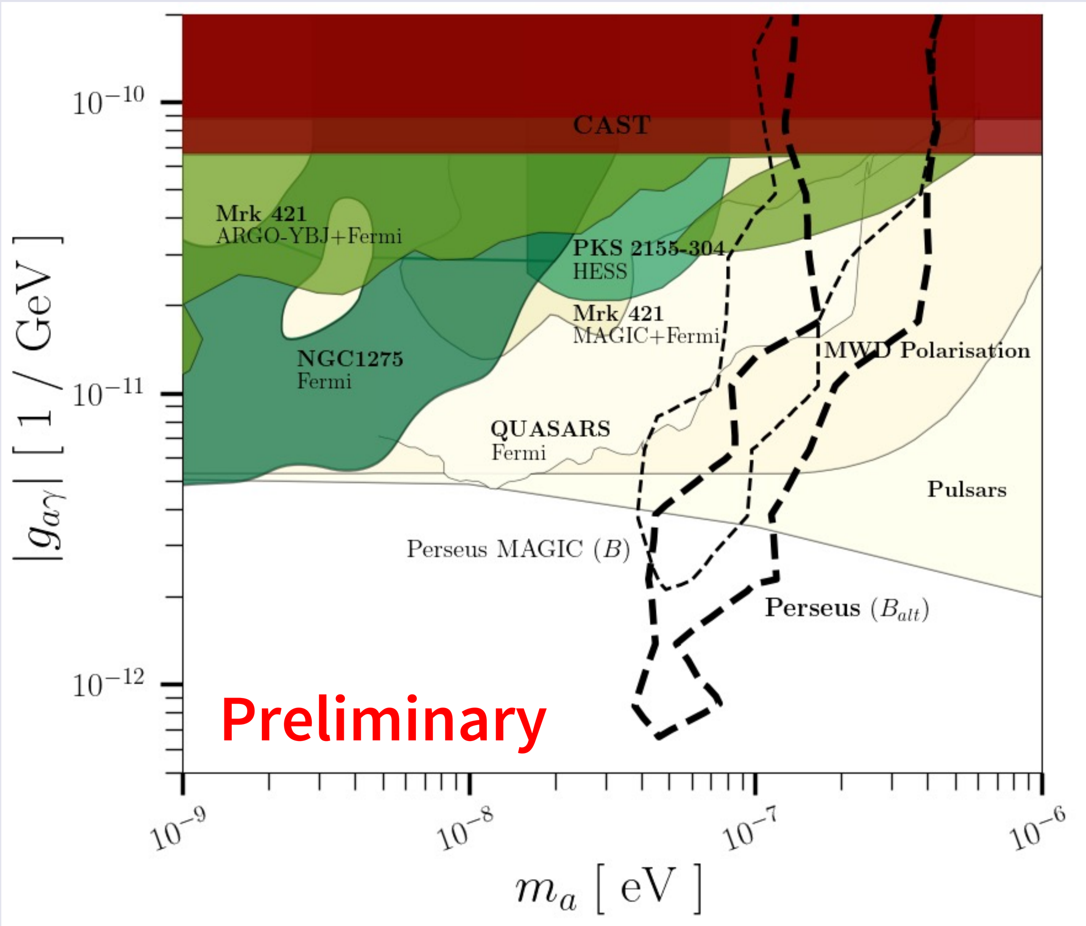

Fig. 3

ENERGY SCALE

To evaluate the effect of energy scale uncertainties coming from the MAGIC telescopes, we artificially scaled the Axion-Like Particle (ALP) energy-dependent signatures in spectra by ±15% and checked the effects on the bounds.

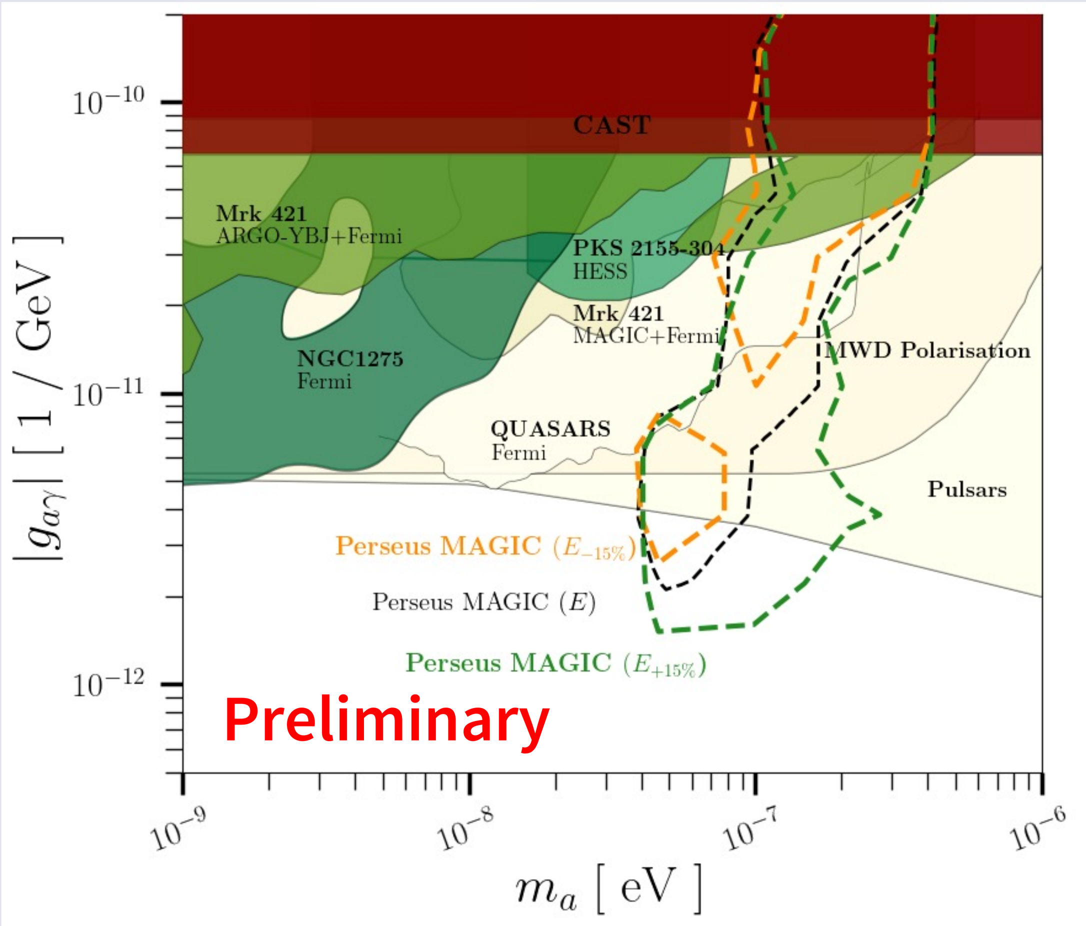

Fig. 4

RESULTS AND CONCLUSIONS

$$S(g_{a\gamma}, m_a) = -2\ ln \frac{\mathcal{L}(g_{a\gamma}, m_a, \hat{\mu}, \hat{B}|D)}{\hat{\mathcal{L}}}$$ - test statistic

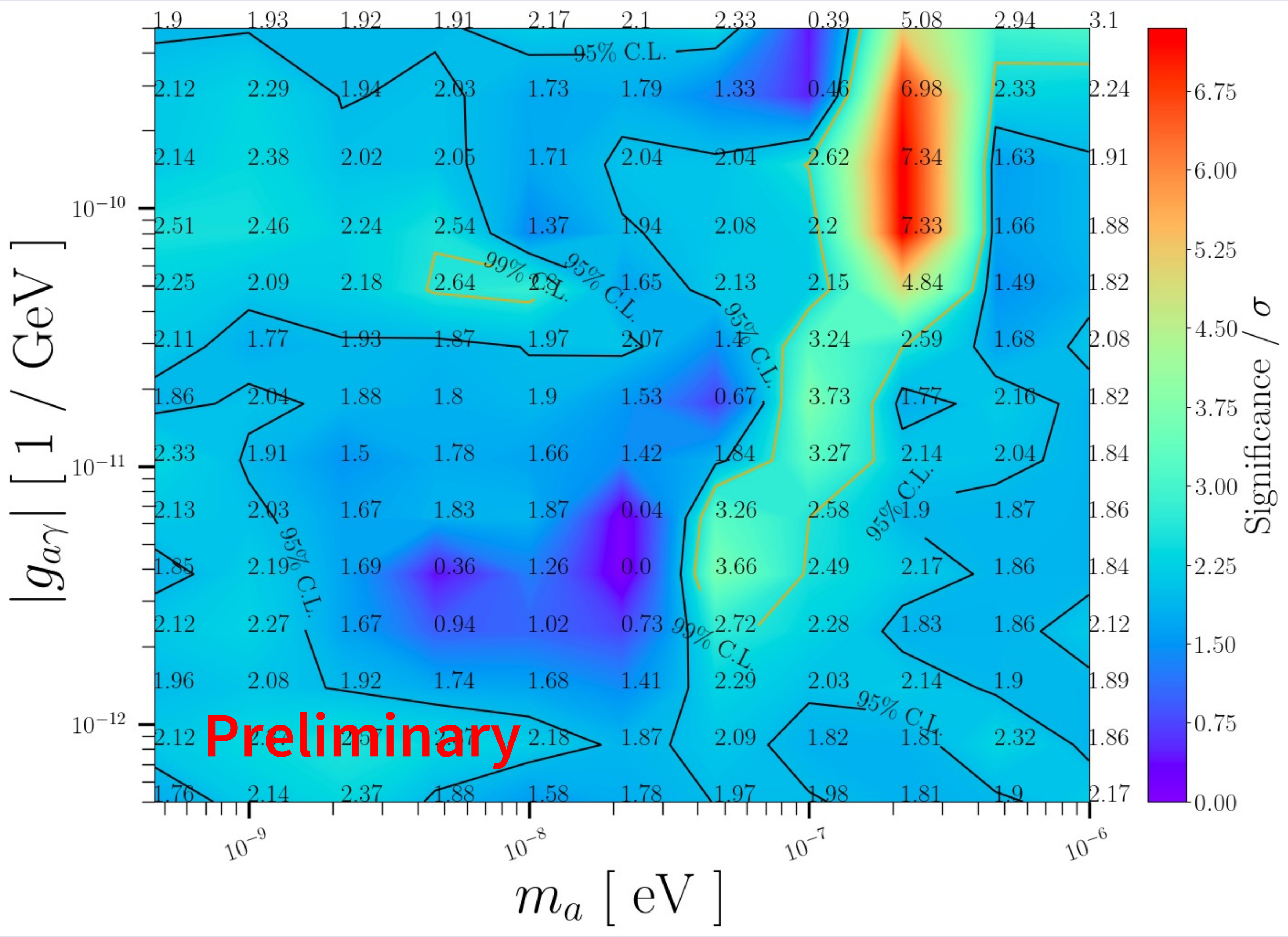

Fig. 5: The likelihood-ratio statistic S computed over 154 ALP points of m_a and $g_{a\gamma}$ using the Perseus data. The black line shows a significance of 1.56 σ and orange one a significance of 2.58 σ (corresponding to a 95% and 99% confidence levels, respectively).

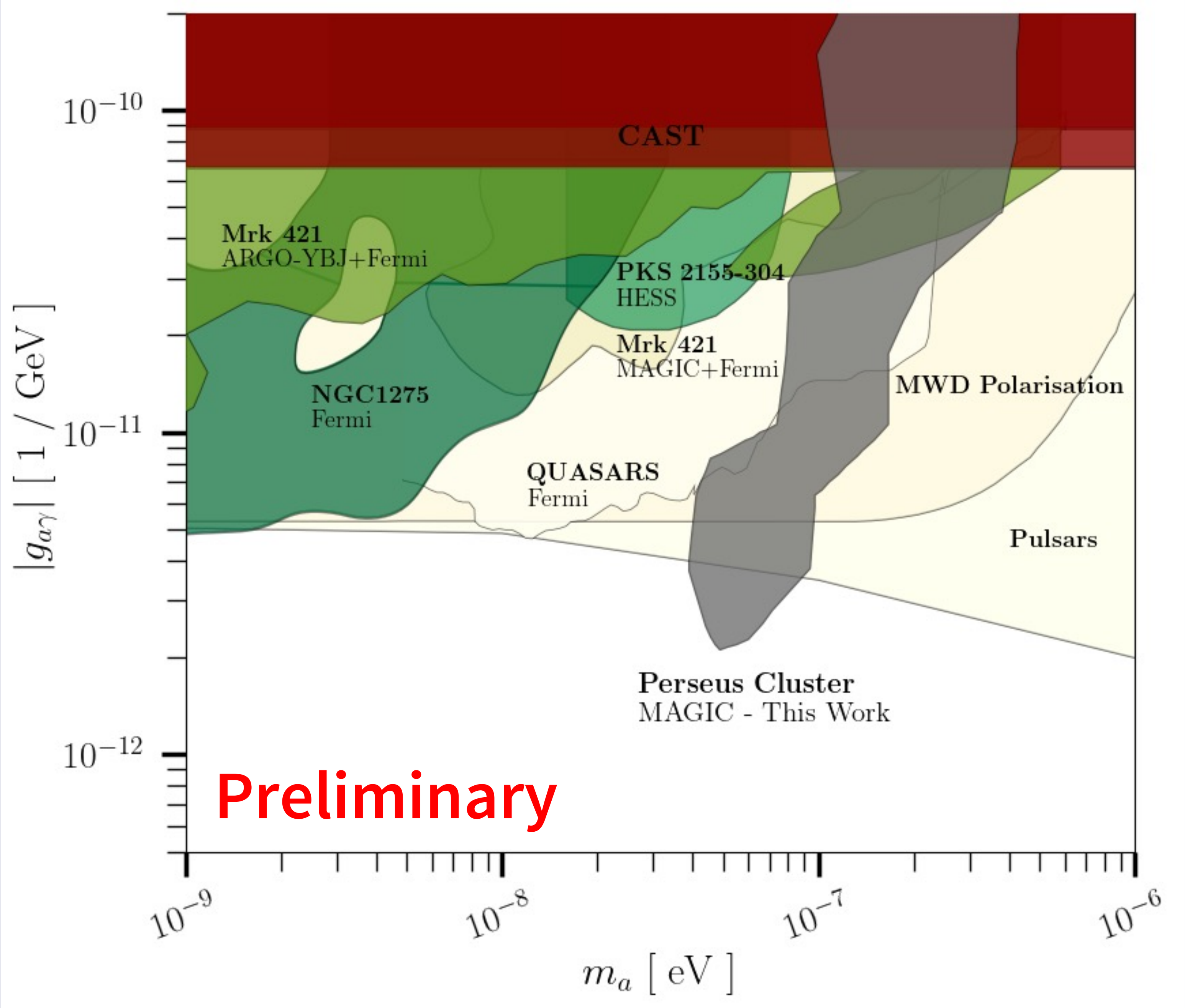

Fig. 6: The limits obtained with this work in comparison with current limits in the same part of the parameter space, gathered in O'Hare, cajohare/axionlimits: Axionlimits, https://cajohare.github.io/AxionLimits/ (2020)

- Confirming the previous constraints on the ALPs coupling to photons set in the range of $40 - 400$ neV.
- Full coverage computation additionally strengthens the
- These results offer the strongest constraints on ALP masses in the range of $40 - 90$ neV, with the greatest sensitivity for ALP masses of $m_a = 50$ neV, reaching the photon-axion coupling down to $g_{a\gamma} = 2.0 \times 10^{-12}$ GeV^{-1}.

This work is currently under review and is soon to be published.