Searching for effects of axion-like particles on the γ-ray transparency of the universe with the Fermi LAT

TeVPA 2018 Berlin, Germany

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HELMHOLTZ ASSOCIATION

Fermi Gamma-ray Space Telescope

HUMBOLDT-UNIVERSITÄT ZU BERLIN

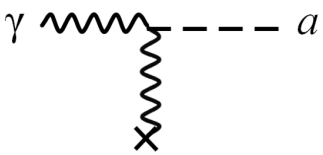
DESY

AXION-LIKE PARTICLES

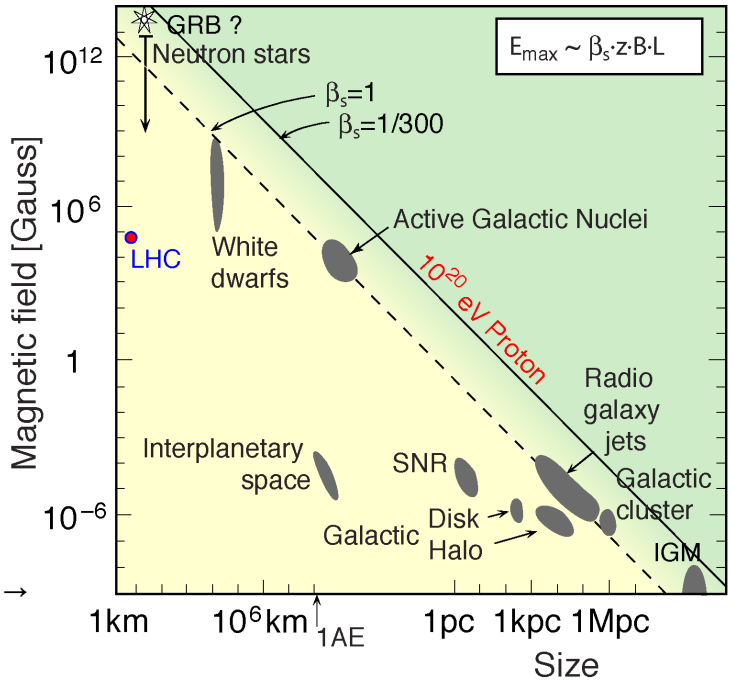
- Axions → Strong CP problem.
  Peccei & Quinn 1977, Weinberg (1978), Wilczek (1978).
- Beyond the Standard Model: axion-like particles.

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

- Oscillation under cosmic magnetic fields.
  Raffelt & Stodolsky (1988).



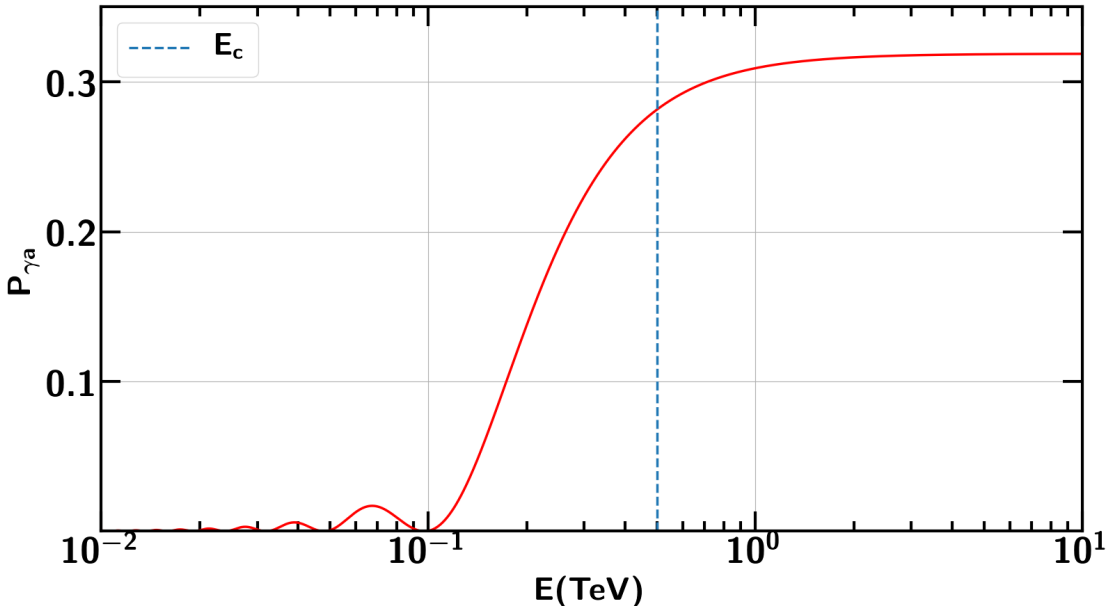
- Different cosmic magnetic fields scenarios
  Possibility of measuring axions in different energy ranges → γ-ray telescopes.



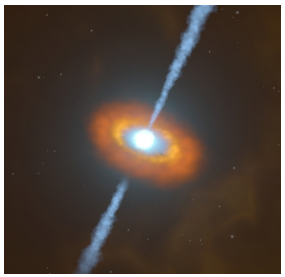
Hillas plot: original by Hillas (1984) → Hooper & Serpico (2007).

PHOTON-ALPS OSCILLATIONS

- Conversion probability for a **polarized state** and a **homogeneous field**.



- **General case**: unpolarized beams with different magnetic field morphologies.



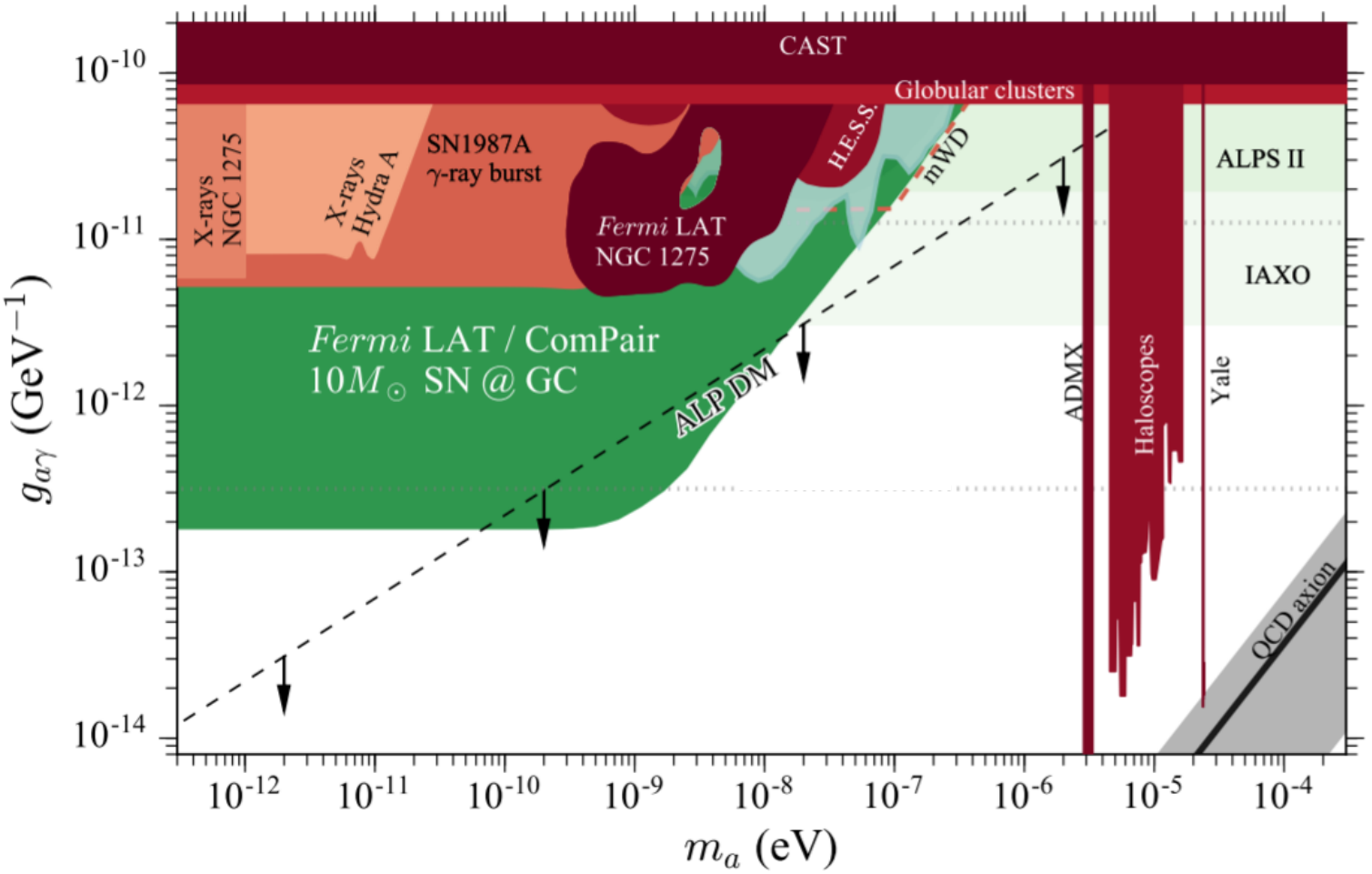
Source

Galaxy cluster

Intergalactic medium

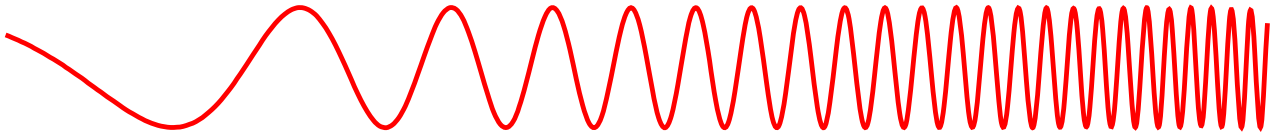
Milky Way

WHERE DO WE STAND NOW?

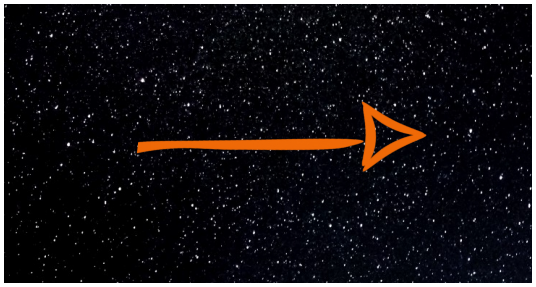


Source: Meyer, M. et al. Phys.Rev.Lett. 118 (2017) no.1.

ASTRONOMY IN THE HIGH-ENERGY RANGE



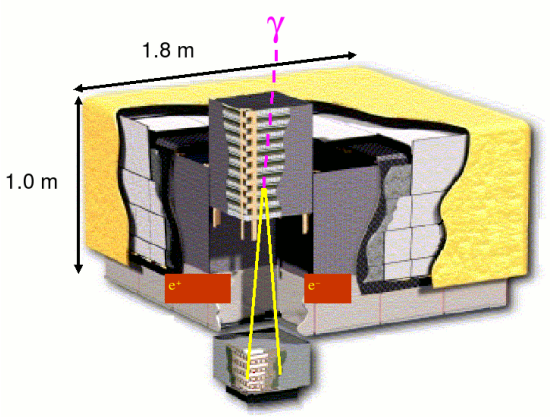
Radio	Microwave	Infrared	Visible	Ultraviolet	X-ray	Gamma ray
10^{3}	10^{-2}	10^{-5}	0.5×10^{-6}	10^{-8}	10^{-10}	10^{-12}



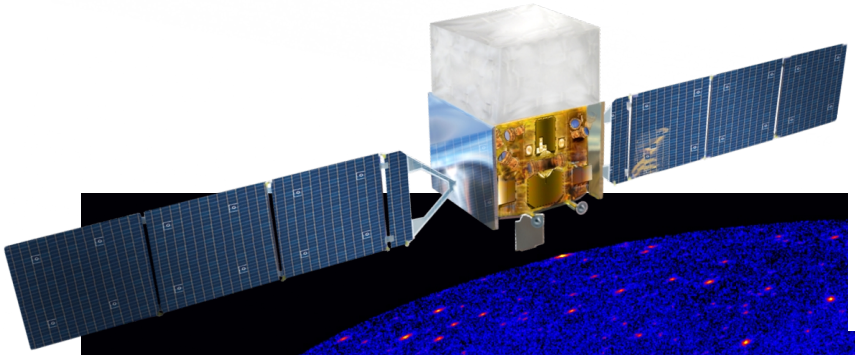
Space

Ground

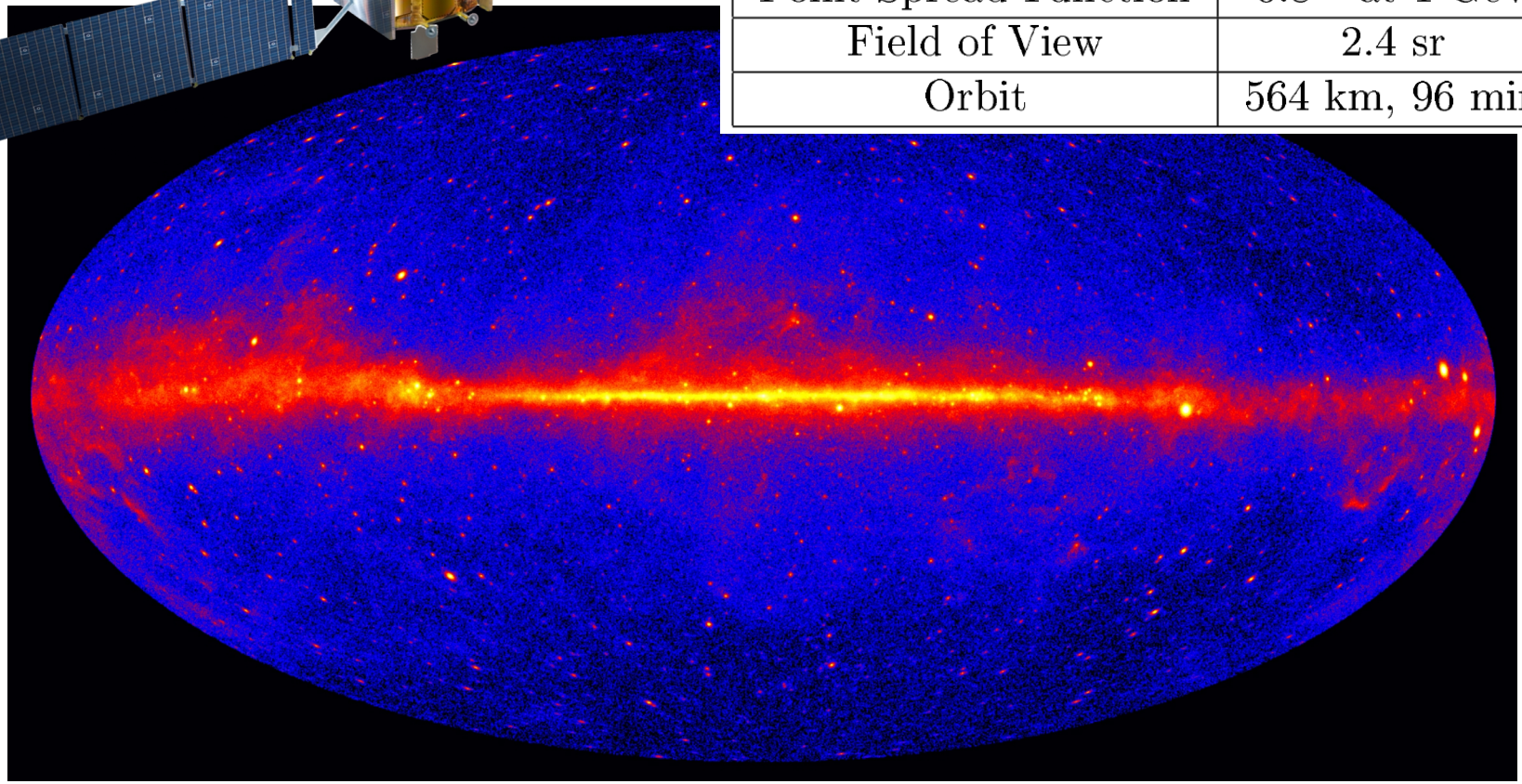
Creation → Propagation → Detection



THE FERMI LARGE AREA TELESCOPE

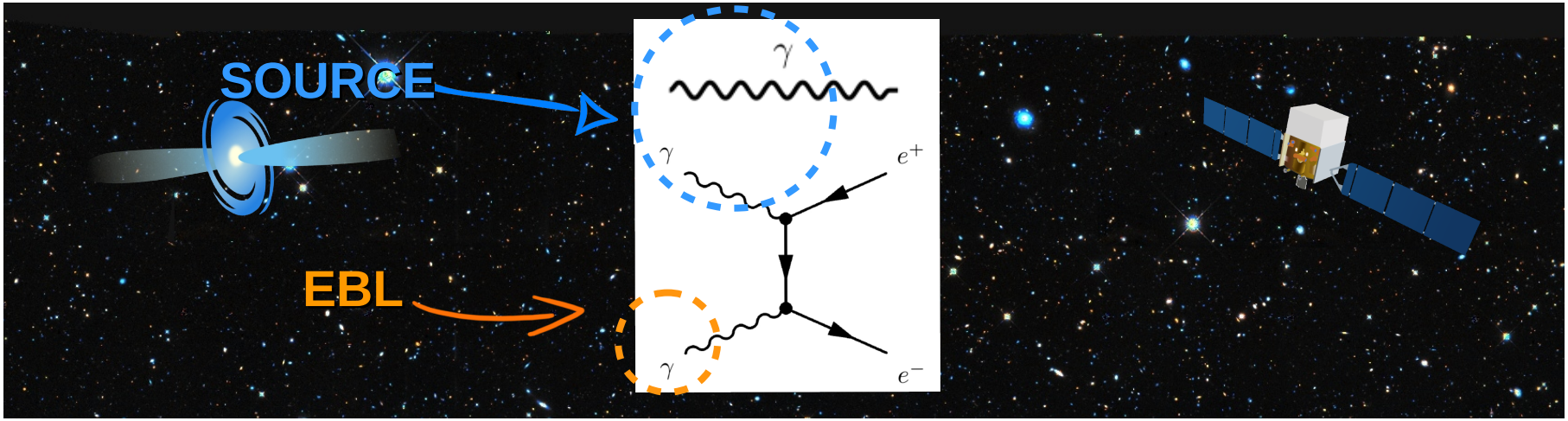


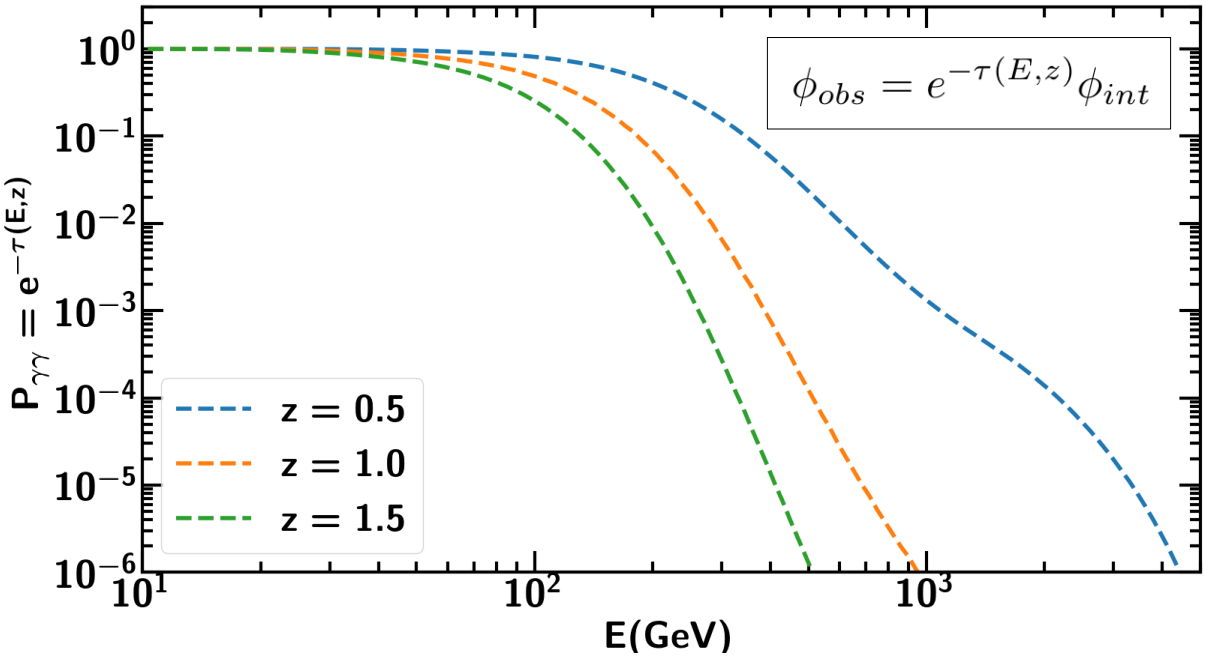
Energy	30MeV-800GeV
Effective Area	$1m^2$
Point Spread Function	0.8° at 1 GeV
Field of View	2.4 sr
Orbit	564 km, 96 min



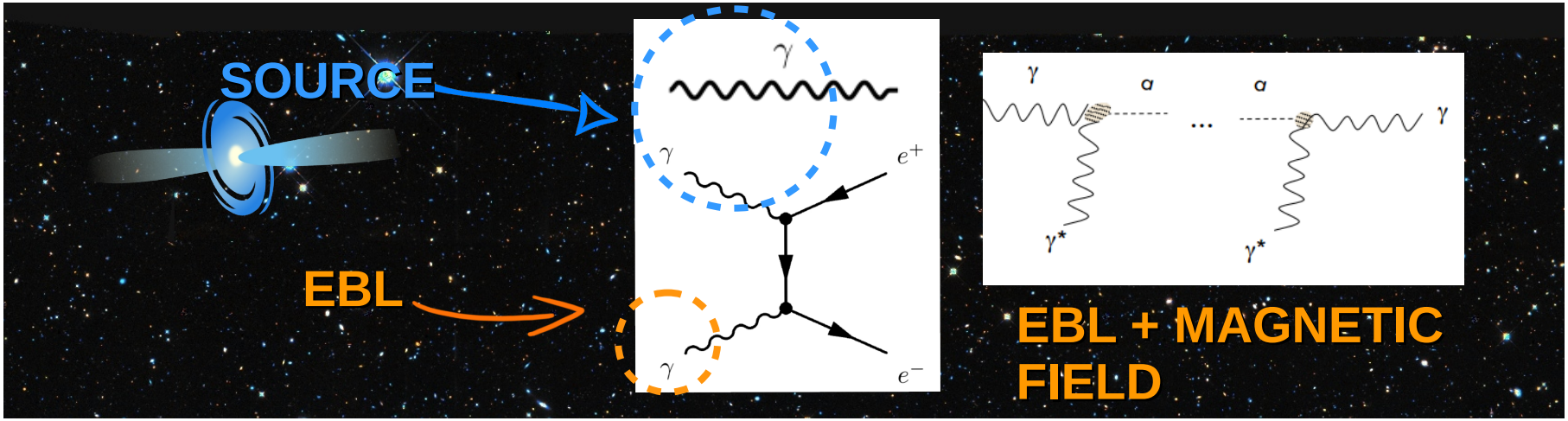
Credit: NASA/DOE/Fermi LAT Collaboration

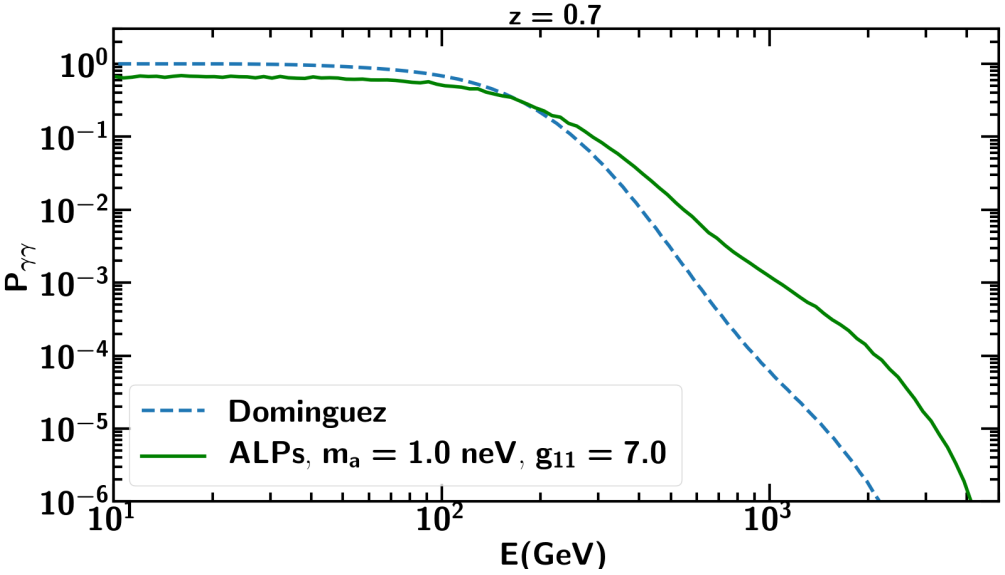
TRANSPARENCY OF THE UNIVERSE TO γ RAYS

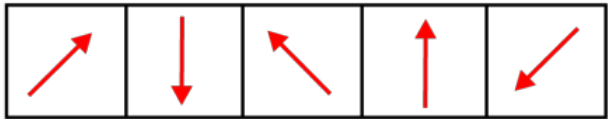




MIXING IN THE INTERGALACTIC MEDIUM

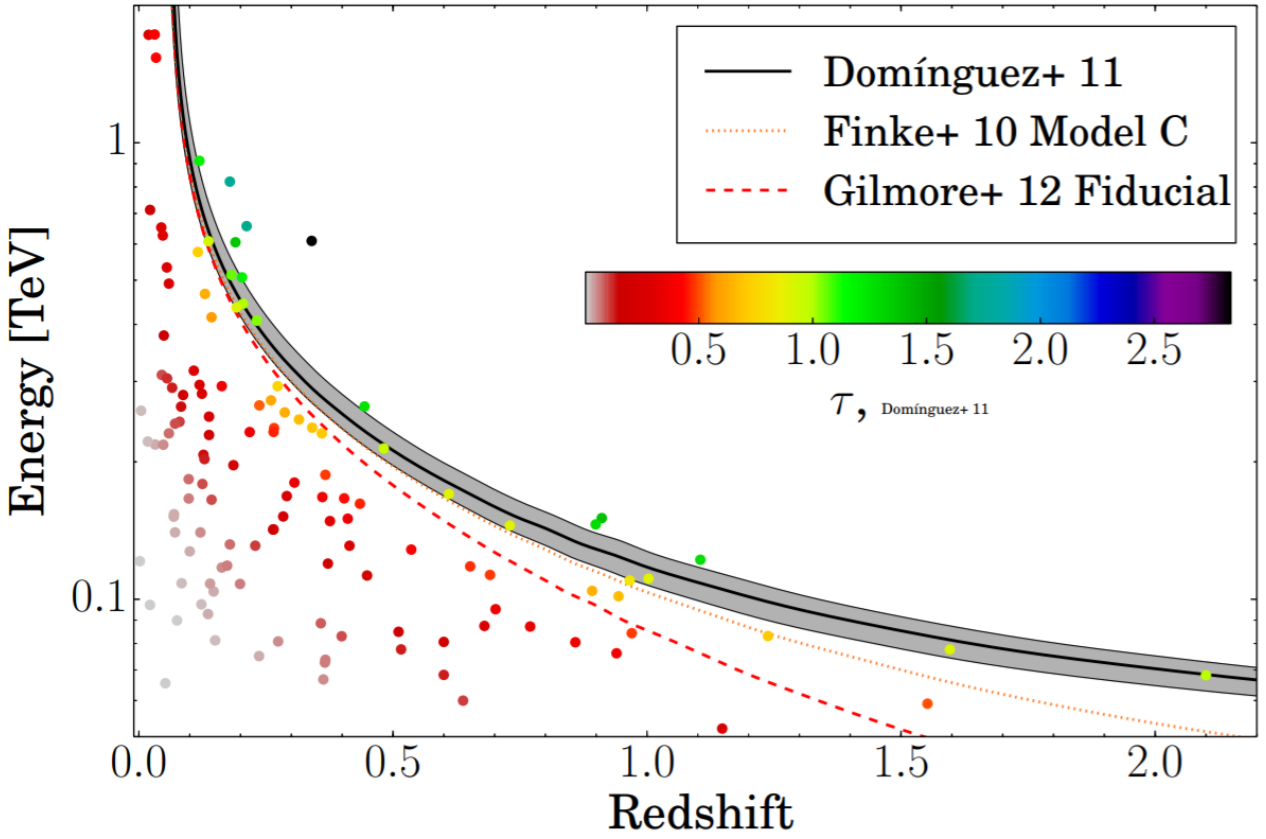






Parameter	Value
B_T	≤ 1 nG
s	1 Mpc
n_e	10^{-7} cm^{-3}
ω_{pl}	$1.17 \cdot 10^{-14}$ eV

THE COSMIC γ-RAY HORIZON



Source: Fermi-LAT Collaboration, Astrophys.J.Suppl. 222 (2016) no.1, 5.

- Are the events consistent with current EBL models?
- Use these highest-energy photon events to compare between EBL and ALPs models.
- 96 sources of the 2FHL catalog with redshifts above z = 0.1. Most of them are AGN.

THE SIMULATION

1. Compute the expected number of events per energy bin and per source:

$$N_{E_1 E_2} = \int_{E_1}^{E^2} \exp\left(-\tau(E, z, \theta)\right) \phi(E) \epsilon(E) dE$$

- EBL + ALPS → Dominguez et al. + IGM mixing (GammaALPs by M. Meyer: https://github.com/me-manu/gammaALPs.)

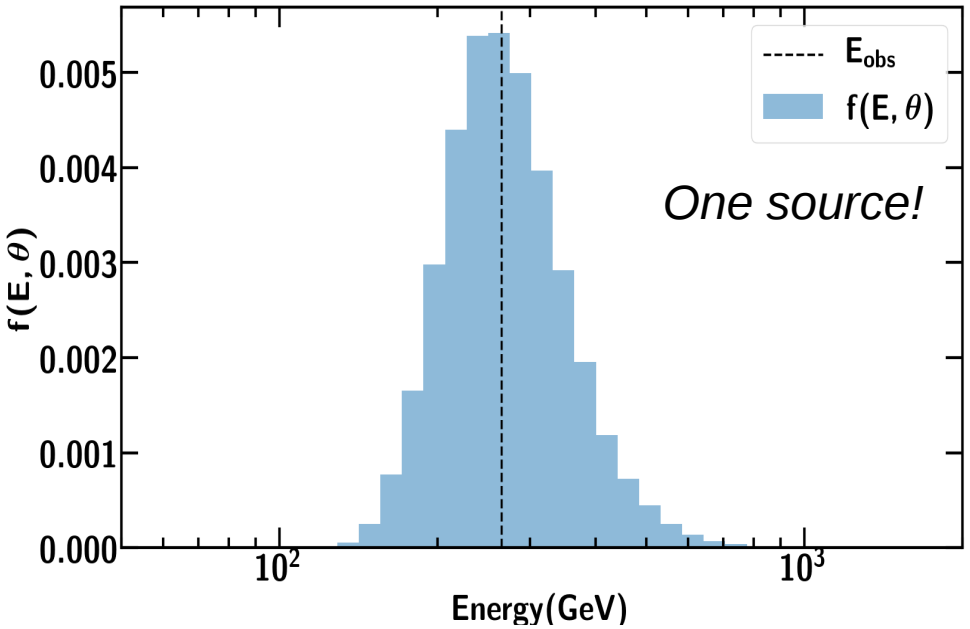
- Intrinsic spectra: 2FHL re-analysis with Pass 8 (van den Berg, J. P. et al.)

- Exposure map.

2. Simulate photons per energy bin following N.

3. Take the simulated highest-energy photon from each pseudo-experiement.

$$\dashrightarrow \quad f(E, \theta)$$



THE LIKELIHOOD ANALYSIS

- Since observations are independent, the combined likelihood is:

$$L(E_1, E_2, ...E_N|\theta) = \prod_{i=1}^{N} f_i(E_i, \theta)$$

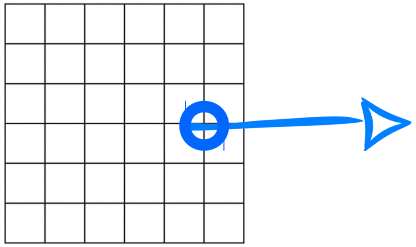
- And the test-statistic:

$$\Lambda = 2\log\left(\frac{L(E_1, E_2, ..., E_N|\max\theta_1)}{L(E_1, E_2, ..., E_N|\max\theta_0)}\right)$$

$$H_1 \rightarrow \theta_1 = (m_a, g_{a\gamma})$$

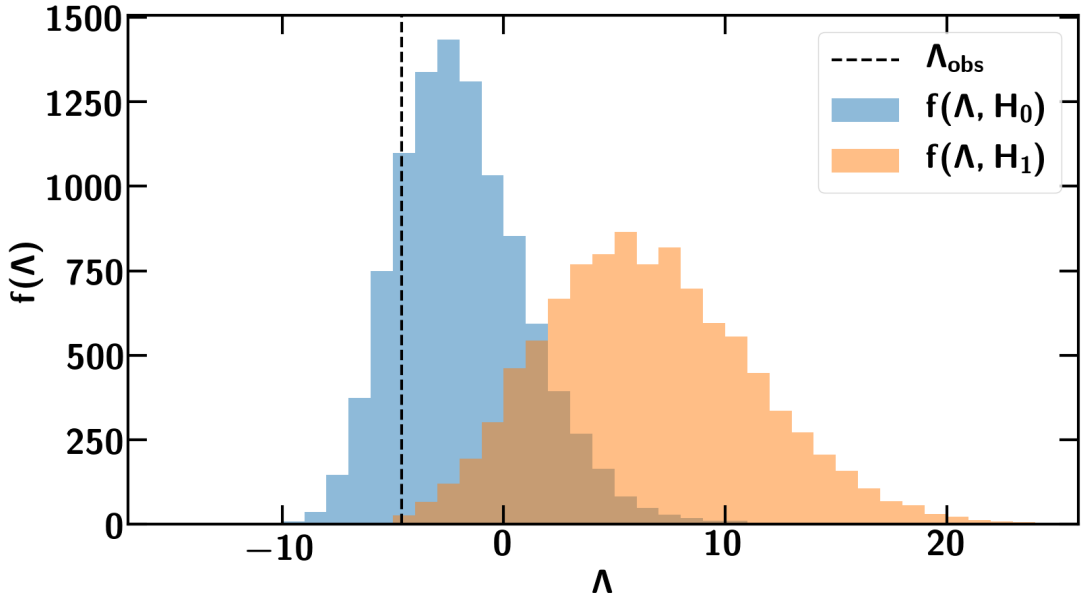
$$H_0 \rightarrow \theta_0 = (0, 0)$$

- Simulate the null and alternative test-statistic distributions for each point in the ALPs parameter space:



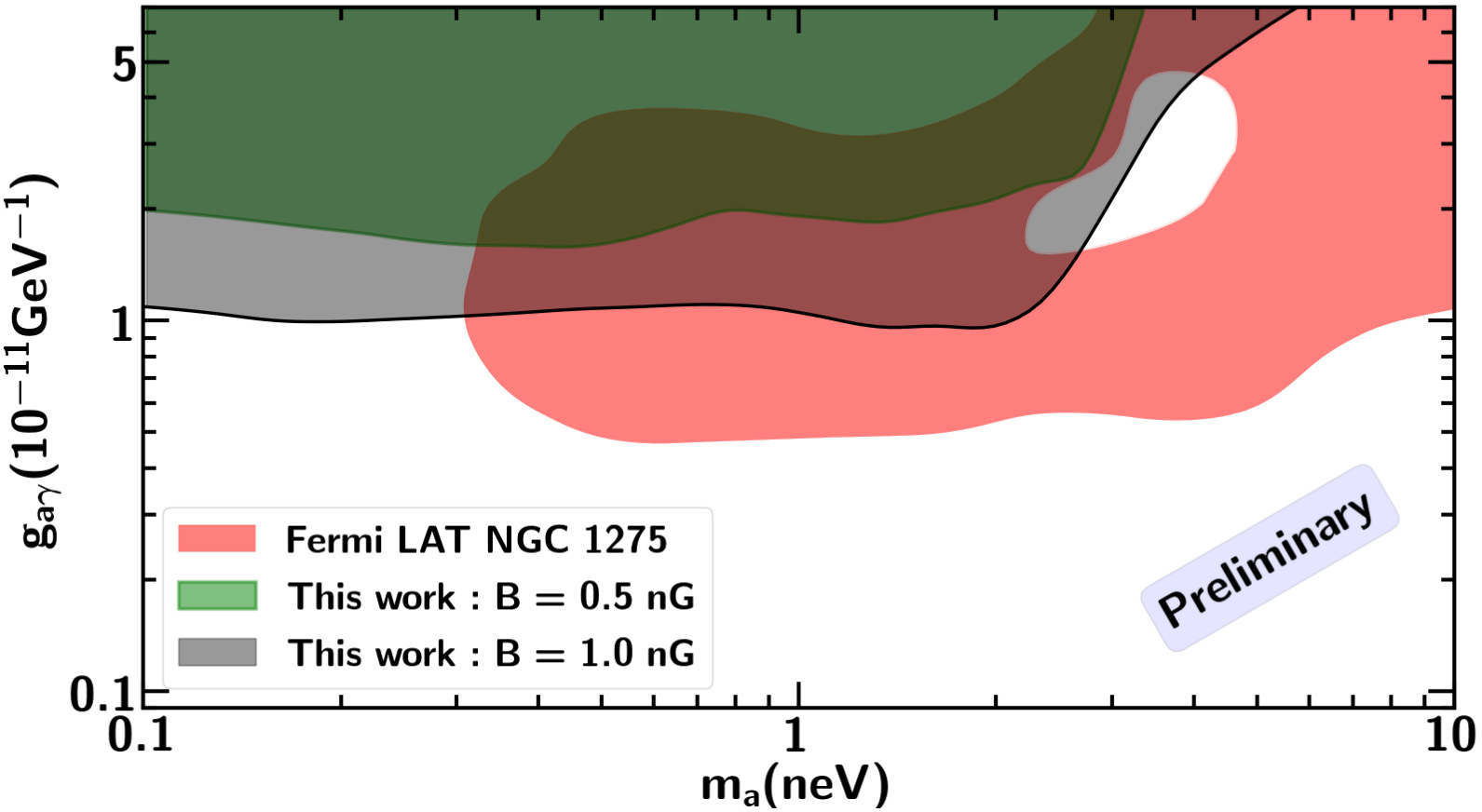
$$m_a(neV) : 0.1 - 10$$

$$g_{a\gamma}(10^{-11}GeV^{-1}) : 0.5 - 7.0$$

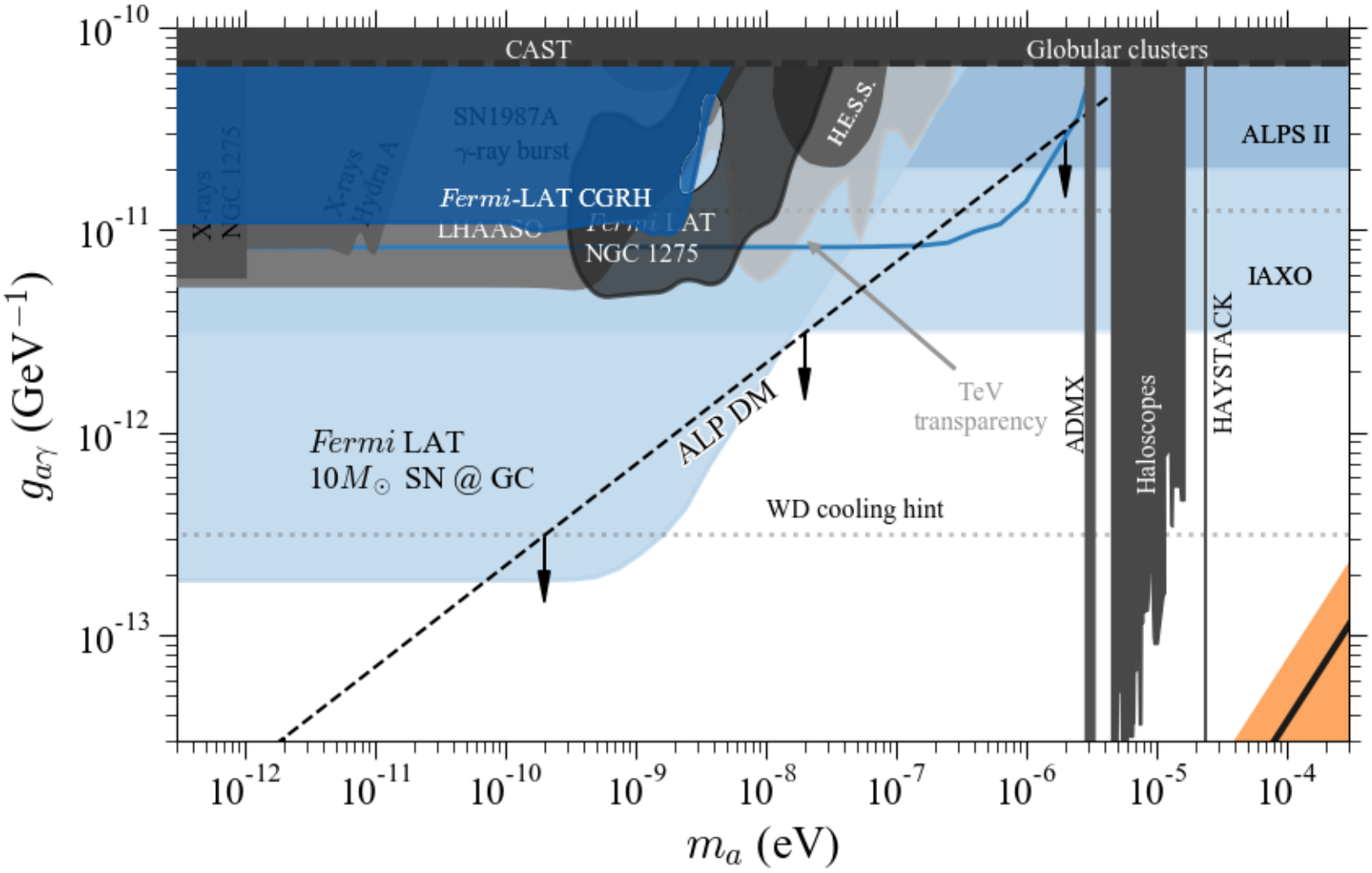


RESULTS

- No evidence for ALPs is found within the tested parameter space.
- We reject the alternative hypothesis (set limits) per point if Λ_{obs} is smaller than the 95% exclusion threshold from the alternative f(Λ) distribution.



LIMITS COMPARISON



SUMMARY

- The extragalactic background light adds opacity to the universe that increases with redshift and energy.
- Photons can oscillate into axion-like particles under the presence of cosmic magnetic fields and thus the photon survival probabilities change.
- We used the HEP from 96 2FHL sources to study ALPs effects on the transparency of the universe to γ rays.
- Sadly, no ALPs. But the results are consistent with current EBL models and the limits are compatible with other experiments!

THANKS FOR YOUR ATTENTION!