Searching for ALPs from CCSNe with *Fermi* LAT's low-energy technique

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AXIONLIKE PARTICLES

and where to find them

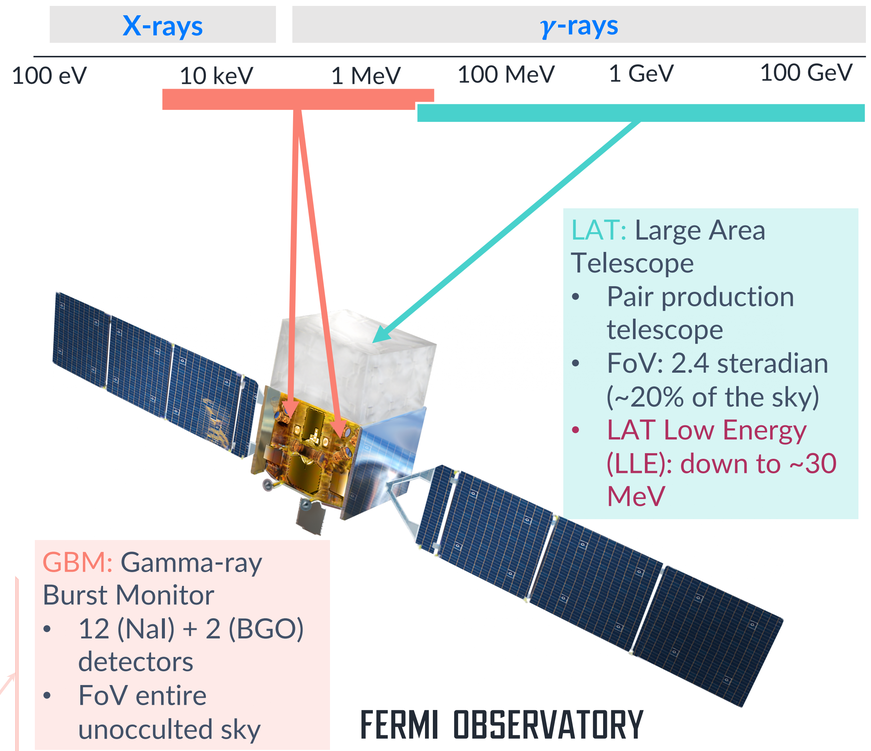
MOTIVATION

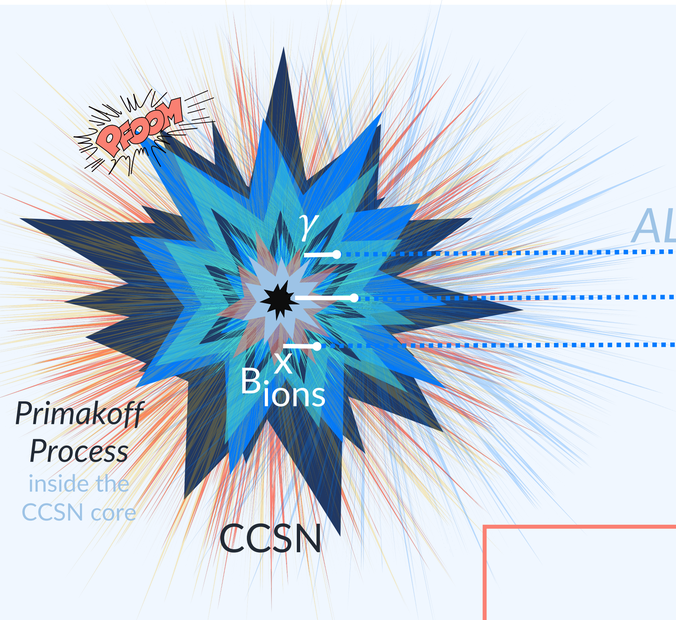
1. Axion-like particles (ALPs) could have a **unique** spectral signature in the gamma-ray spectrum of a core-collapse supernova (CCSN)
2. The **progenitor** of a long gamma-ray burst (LGRB) is a CCSN

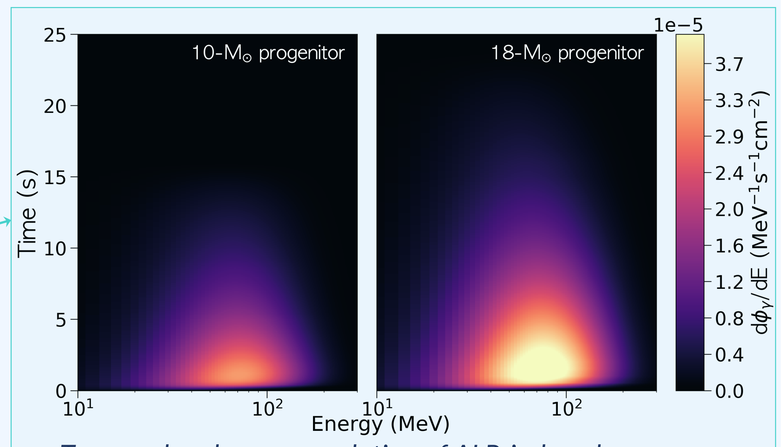
→ Observations of LGRBs with gamma-ray observatories (e.g., *Fermi)* provide us with insights about the ALP parameter space (ALP mass, ALP-photon coupling), i.e., $(m_a, g_{a\gamma})$

GOALS

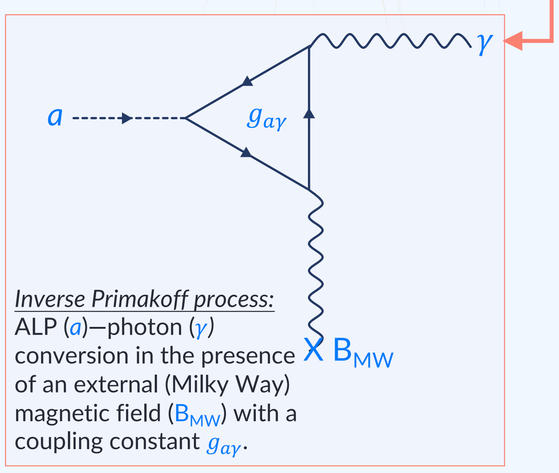
1. Determining the sensitivity of *Fermi*-LAT low-energy to detecting an ALP signal for a given mass & coupling
2. Comparing LGRB spectra: ALPs or no ALPs?



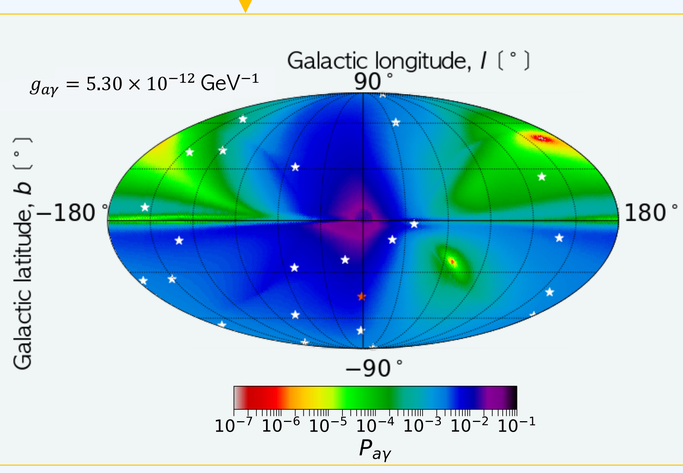




Temporal and energy evolution of ALP-induced gamma-ray emission produced inside a CCSN core, following the time of core-collapse, $t = 0$ s, for a 10- and 18-solar-mass progenitor



Inverse Primakoff process: ALP (a)—photon (γ) conversion in the presence of an external (Milky Way) magnetic field (B_{MW}) with a coupling constant $g_{a\gamma}$.

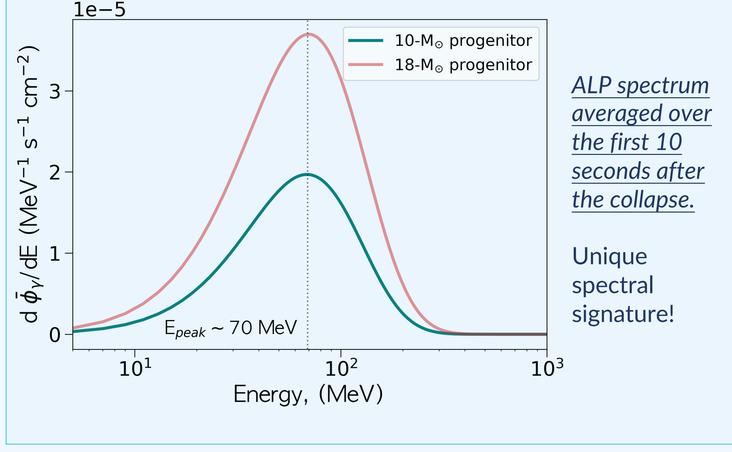


ALP-photon conversion probability as a function of source position in the sky.

- ALP convert into γ rays within the Milky Way's coherent magnetic field component.
- ALP mass $m_a = 10^{-10}$ eV, covering energies $10 < E < 300$ MeV

☆ : *no-redshift*, LLE-observed LGRBs

★ : GRB 101123A



ALP spectrum averaged over the first 10 seconds after the collapse.

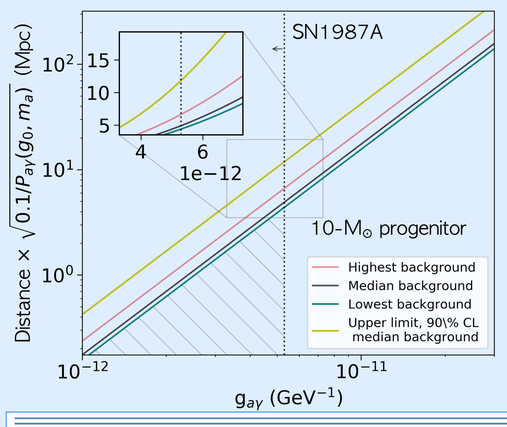
Unique spectral signature!

Sensitivity Analysis & Results

Analysis Steps

1. Model backgrounds from the considered LLE-detected GRB sample
2. Compute the extreme background levels
3. Produce a grid of scaled ALP signals for two different progenitors.
4. Produce 2000 realizations of the background + ALP spectrum and their corresponding (GRB) response functions (`XSPEC fakeit`)
5. Fit the ALP and the "background-only" models
6. Apply Wilks' Theorem and LLR test to find for which normalization ALP model is preferred

→ **Find the coupling-distance parameter space for that normalization.**



Distance limits for a LAT-LLE ALP 5-sigma detection for a 10-solar-mass progenitor for different background levels.

Conversion probability	Distance limit (Mpc)		
	Background level:		
$P_\gamma(g_0)$	Low	Median	High
0.1	4.4 (6.5)	4.9 (7.1)	6.6 (9.7)
0.05	3.1 (4.6)	3.5 (5.0)	4.7 (6.9)
0.01	1.4 (2.1)	1.5 (2.3)	2.1 (3.1)
0.001	0.4 (0.7)	0.5 (0.7)	0.7 (1.0)

Analogous to above, (including 18-solar-mass progenitor) for different background levels and conversion probabilities.

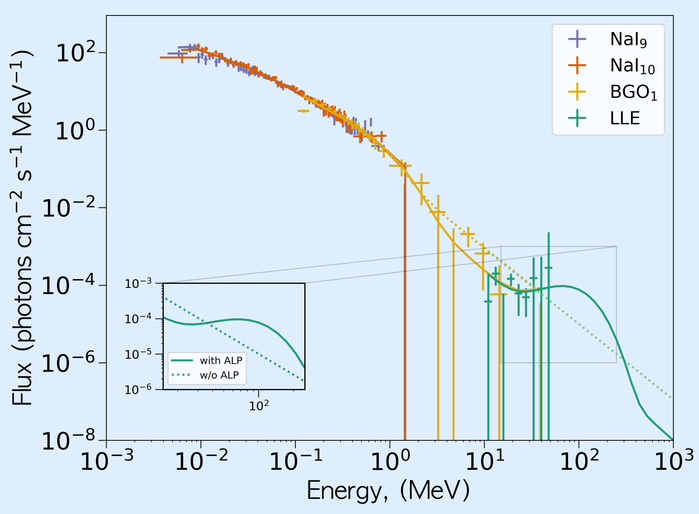
ALP Searches

Analysis Steps

1. Data selection: 186 LAT-detected GRBs → final sample of 24 LGRBs

Property	Selection Criterion
Distance	unassociated (no redshift)
Detection significance	$\geq 5\sigma$ in LAT-LLE ($\gtrsim 30$ MeV)
Observed time interval	$\geq$ duration of the burst
Burst duration	long GRBs ($T_{95} \gtrsim 2$ seconds)

2. Model comparison (null model: w/o ALP, alternative: w/ ALP)



An example of a spectral fit for GRB 101123A with and without the ALP component. The corresponding pre-trial LLR value is 5.8, or ~2.4 σ. The corresponding post-trials value is p~0.3.

3. **We report no statistically significant detections.**

Conclusions & Current Work

- *Novel method and results: using a transient data class as observed by Fermi to probe its sensitivity. Results are consistent with the analysis using the standard LAT data [Meyer et al. 2020]*
- *Sensitivity analysis pipeline: adaptable for calculating distance limits for the current and future gamma-ray instruments for the given ALP mass and coupling*
- *Good scientific case for the future instruments: they need more sensitivity in the MeV region in order to be able to increase the statistics of sources considered (see AMEGO-X posters!)*

Current work: Comprehensive search for precursor emission in LGRBs, computing competitive limits on $(m_a, g_{a\gamma})$

Read our paper! arXiv:2109.05790

References

• *M. Crnogorčević et al., Phys. Rev. D 104, 103001 (2021)* • *M. Meyer et al., Phys. Rev. Lett. 124, 231101 (2020); Erratum, Phys. Rev. Lett. 125, 119901 (2020).* • *A. Payez et al., J. Cosmol. Astropart. Phys. 02 (2015) 006.* • *M. Meyer et al., Phys. Rev. Lett. 118, 011103 (2017).* • *G. Raffelt et al., Phys. Rev. D 37, 1237 (1988).* •

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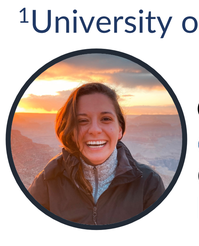

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