GEORG-AUGUST-UNIVERSITÄT
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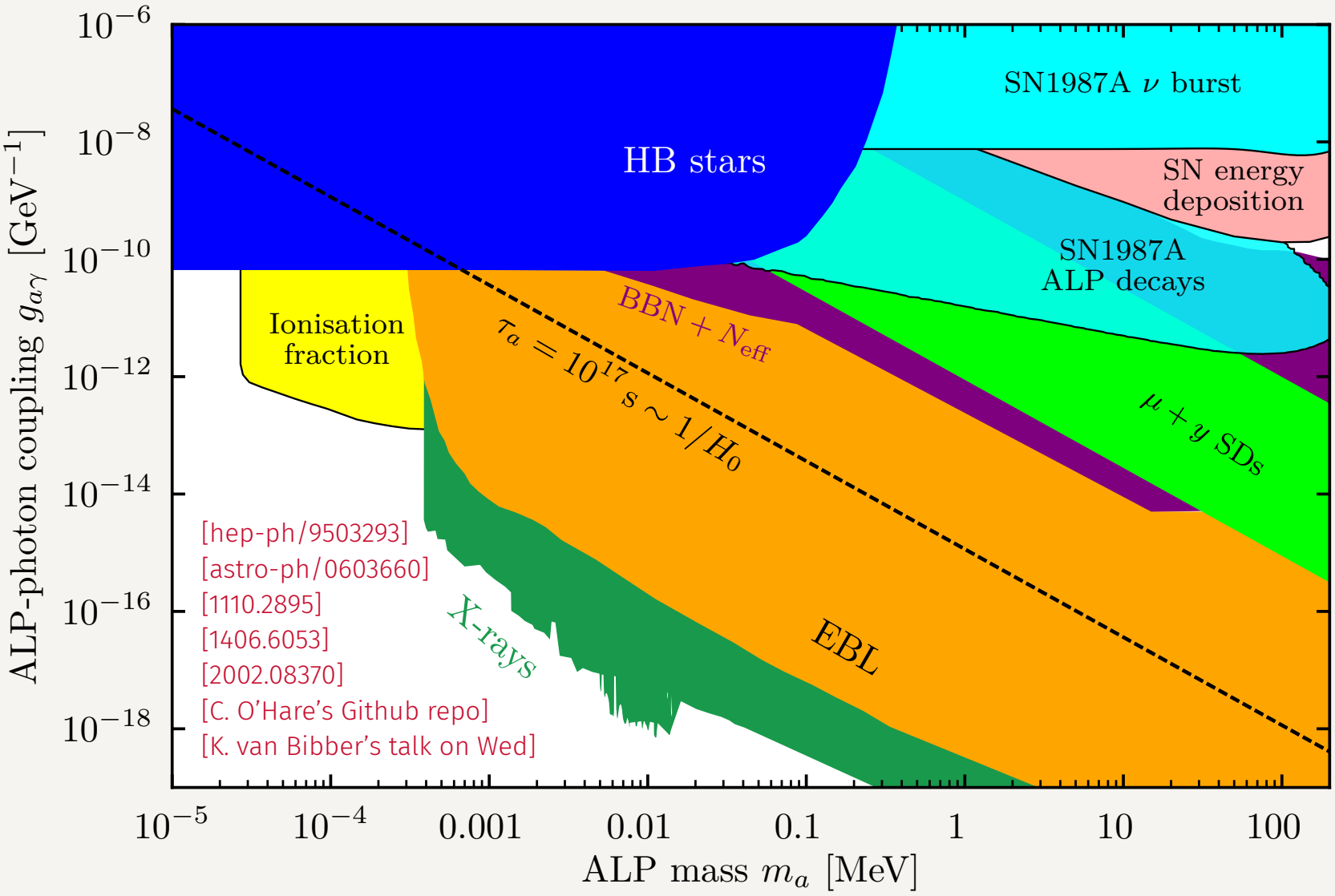
Cosmological constraints on decaying axion-like particles: a global analysis

C. Balázs, S. Bloor, T. E. Gonzalo, W. Handley, **Sebastian Hoof**, F. Kahlhoefer,
M. Lecroq, D. J. E. 'Doddy' Marsh, J. J. Renk, P. Scott, P. Stöcker; submitted to JCAP

[arXiv:2205.13549]

14th Conference on the Identification of Dark Matter
Vienna, Austria
21 July 2022

High-mass ALPs – cosmologically excluded?



Interpretation of overplotted limits may be inconsistent/suboptimal[2012.09874]

Global fits of high-mass ALPs

- Several constraints from astro & cosmo (also accelerators)
- Possible future additions: CMB-S4, Galactic core-collapse SN, spectral distortion missions (e.g. PIXIE), ...
- Not just m_a-$g_{a\gamma}$ space: consistency conditions, cosmo models, exp. nuisance parameters, various axion interactions, ...

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↣ Calls for a global-fitting framework!

↣ Extend previous axion global fit[1810.07192] and "CosmoBit" extension[2009.03286, 2009.03287] from GAMBIT software[1705.07908]

The GAMBIT framework

- Easily extendable, modular software framework to confront combined models with joint likelihood from many experiments A. Beniwal's talk on Mon
- Studies on SUSY, scalar singlet, Higgs portal, RHN, axion models, ... GAMBIT publication list

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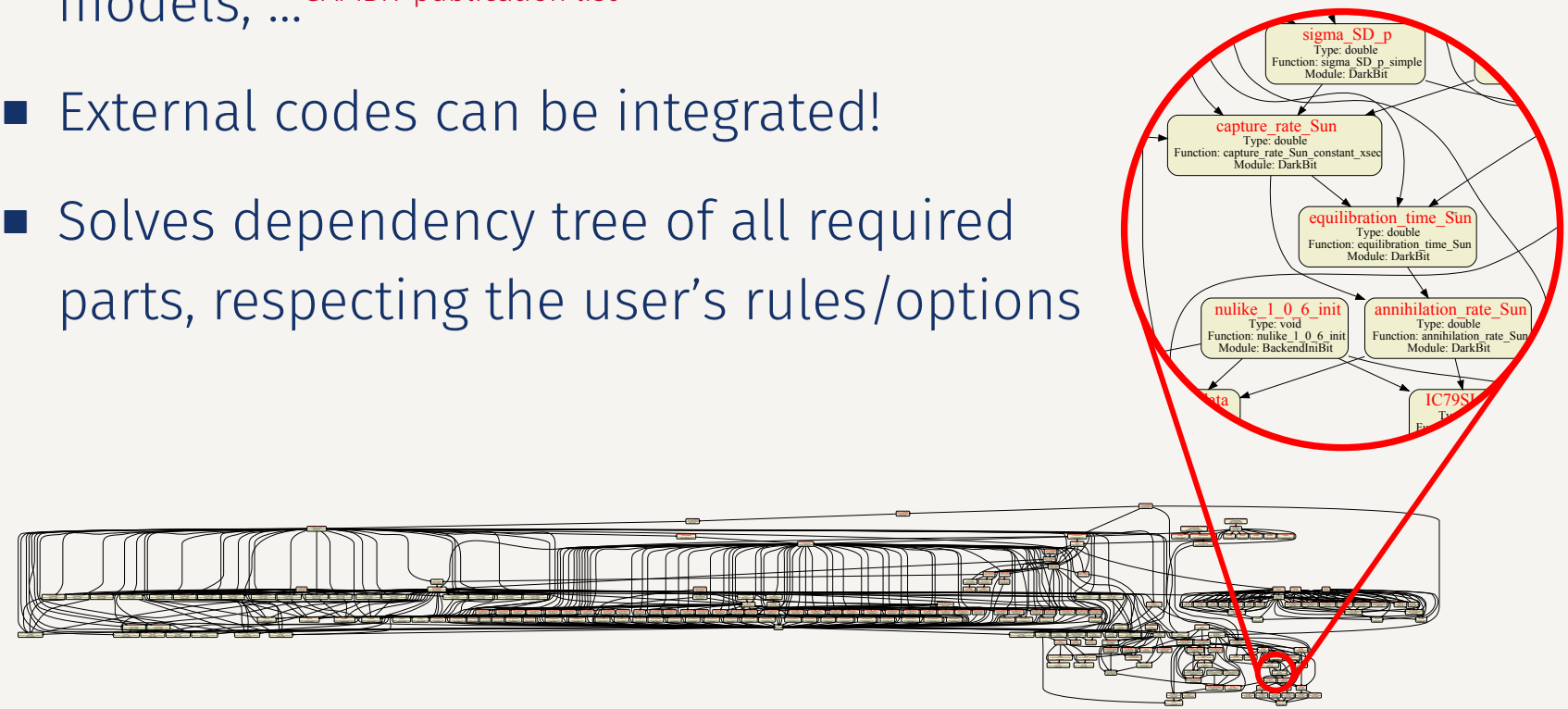
- External codes can be integrated!
- Solves dependency tree of all required parts, respecting the user's rules/options



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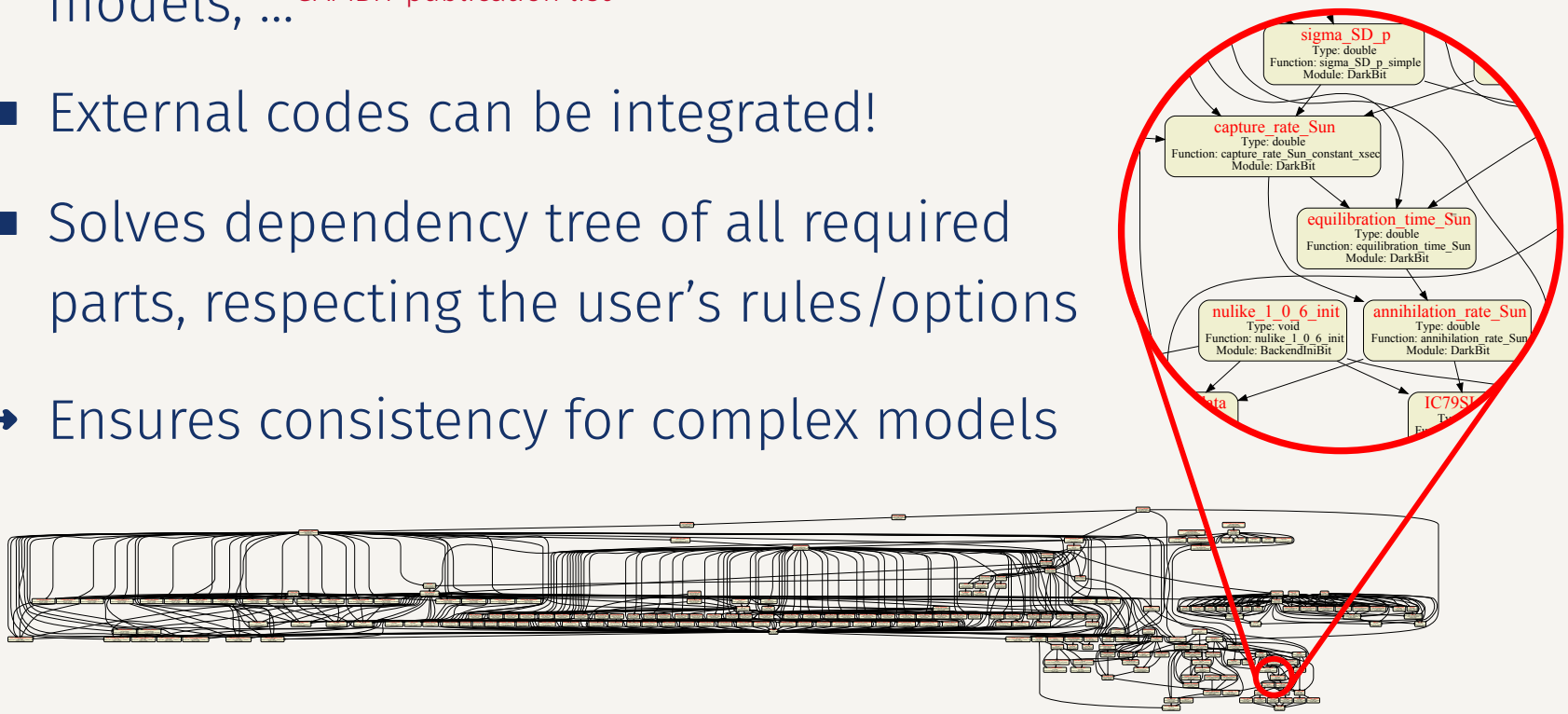
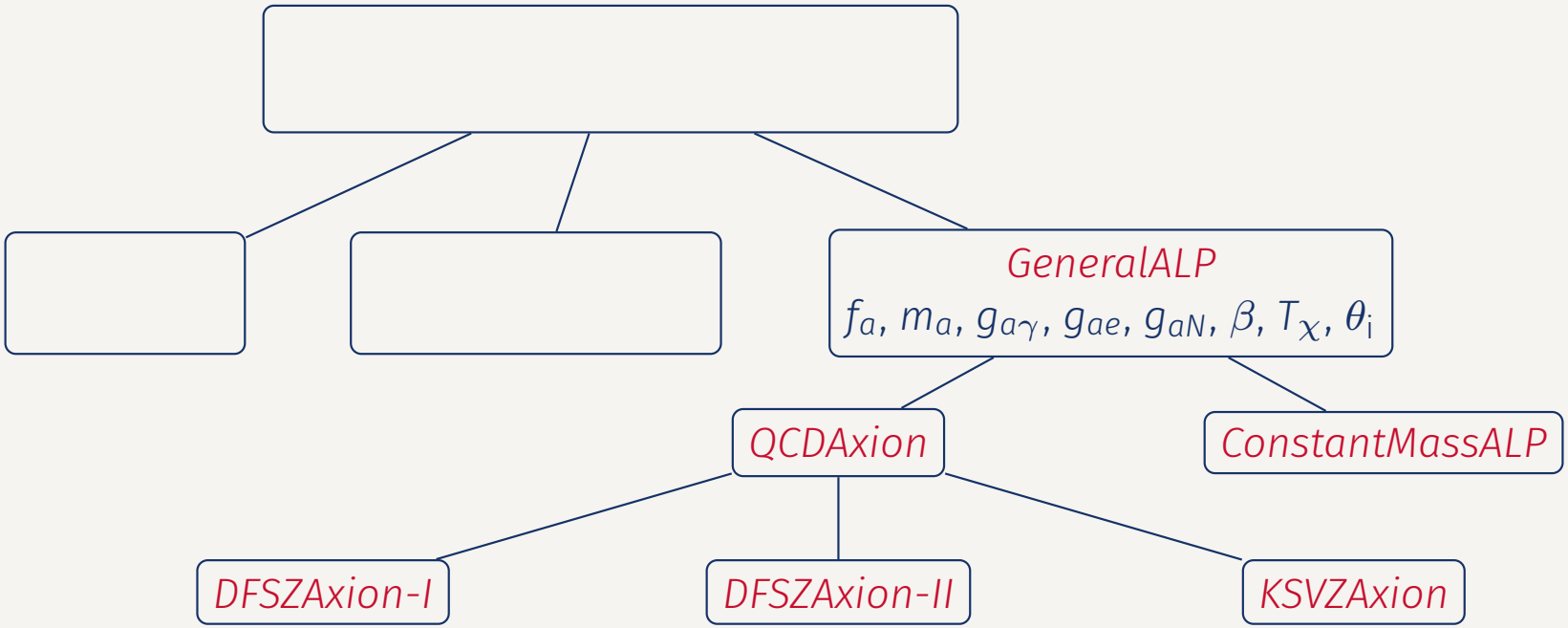
- ➳ Ensures consistency for complex models



The GAMBIT framework – models

Build on “family tree” of ALP models from previous study[1810.07192]



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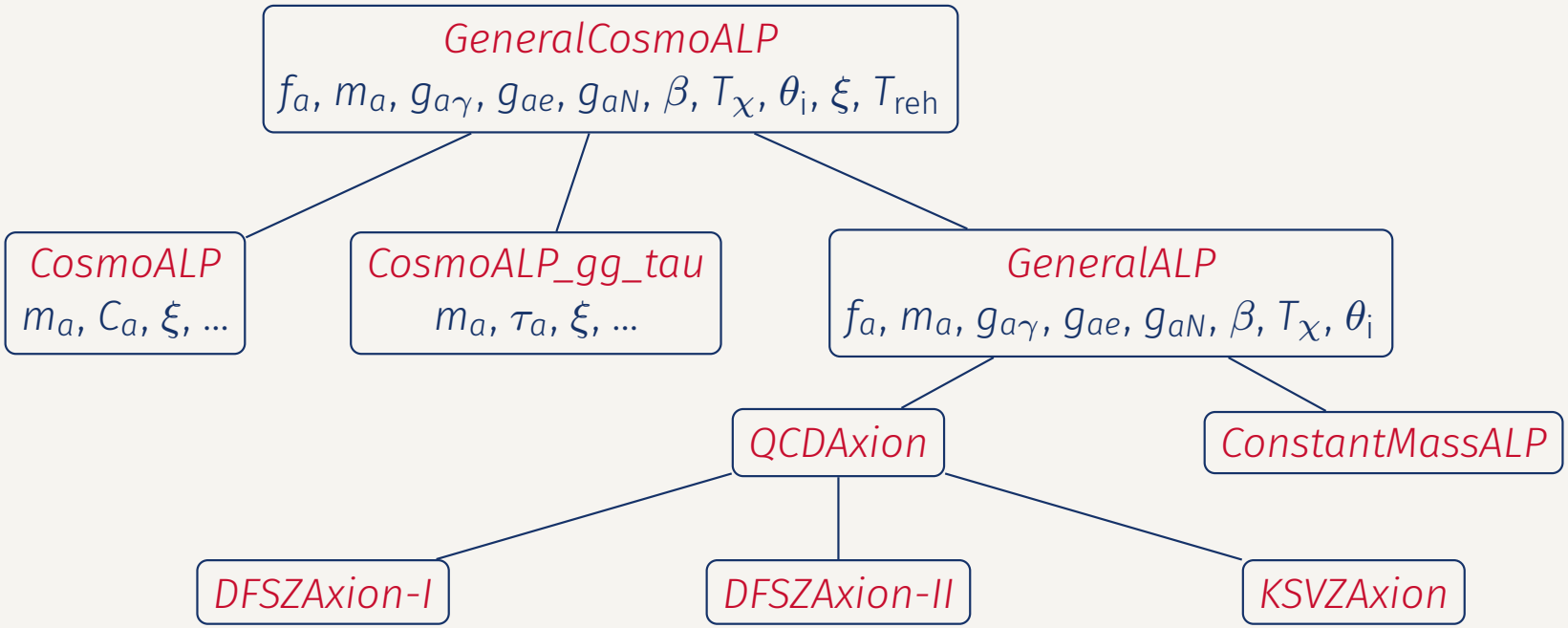

- New params: abundance ξ and reheating temperature T_{reh}
- Automatic parameter translation: can use pre-existing axion likelihoods out of the box

The ALP model

GeneralCosmoALP

8 model parameters:

f_a, m_a, $g_{a\gamma}$, g_{ae}, g_{aN}, β, T_χ, θ_i, ξ, T_reh

- Only interaction: coupling to photons via $\mathcal{L} \propto g_{a\gamma}\, \vec{E} \cdot \vec{B}$

The ALP model

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6 model parameters:
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- Simple ALP: m_a const.

The ALP model

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4 model parameters:
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- Thermal and realignment contributions to ξ but we focus on irreducible freeze-in mechanism[0911.1120]

$$\xi_{\rm FI} \sim \left(\frac{m_a}{50\,\text{MeV}}\right)\left(\frac{T_{\rm reh}}{5\,\text{MeV}}\right)\left(\frac{g_{a\gamma}}{10^{-10}\,\text{GeV}^{-1}}\right)^2 \mathrm{e}^{-m_a/T_{\rm reh}}$$

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GeneralCosmoALP
3 model parameters:
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The ALP model

CosmoALP_gg_tau
3 model parameters:
f_a, m_a, τ_a, g_{ae}, g_{aN}, β, T_χ, θ_i, ξ, T_{reh}

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➳ Parameters: mass m_a, lifetime $\tau_a \leftrightarrow g_{a\gamma}$, abundance ξ

The cosmological model

- 6-parameter ΛCDM model: ω_b, ω_c, H_0, z_{re}, A_s, n_s
- **In total 12 parameters**: 3 ALP, 6 LCDM, 2 experimental parameters, neutron lifetime

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- Can the ^{7}Li problem[1203.3551] be improved by ALPs?[2011.06519]
- ROI: $0.01\,\mathrm{MeV} < m_a < 200\,\mathrm{MeV}$; $10^4\,\mathrm{s} < \tau_a < 10^{13}\,\mathrm{s}$, i.e. decays between BBN and CMB formation

Constraints & likelihoods in target region

Cosmology

- CMB anisotropies (modification of recombination history)
- CMB spectral distortions (SDs; energy injection from ALPs)
- BBN element abundances (photodisintegration)
- ΔN_{eff}, η_{b} (photon injection/higher T_γ)
- BAO (structure formation)

Astrophysics

- SN1987A missing gamma-ray burst (ALP decays), based on our own update of [1702.02964]
- HB vs RGB star counts (stellar evolution, cooling)
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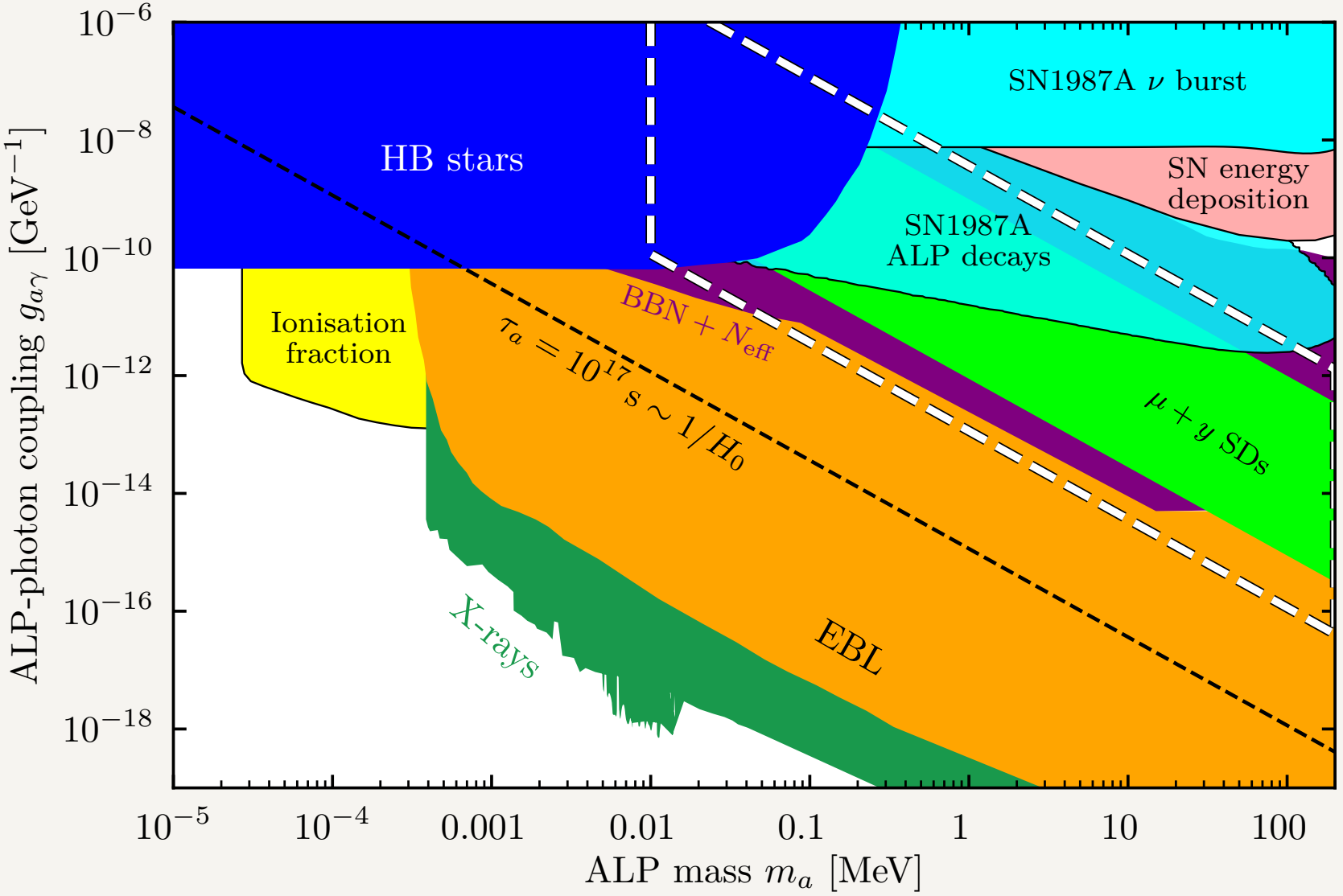
➽ Not all constraints are equally relevant in this study

Results – ALP limits



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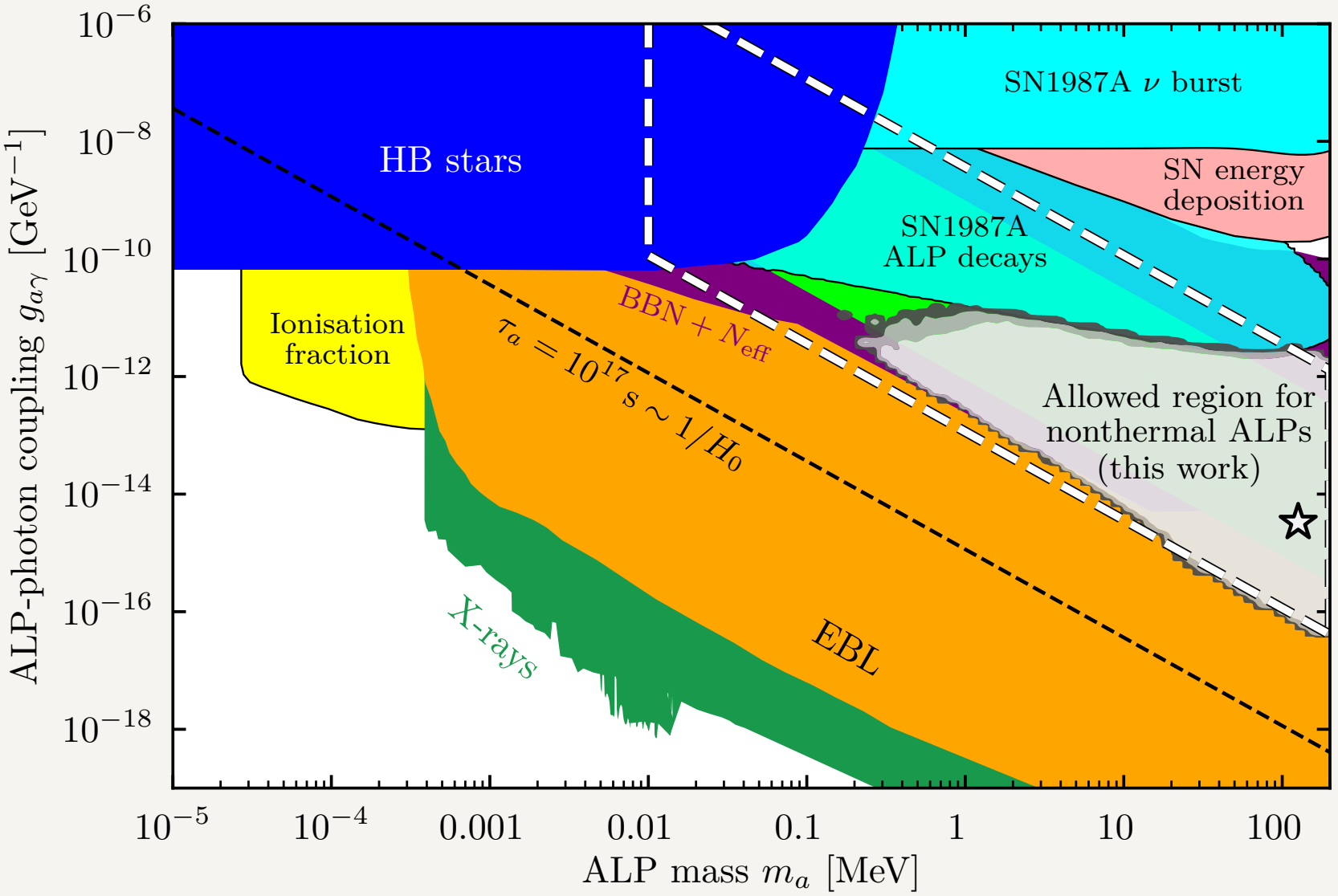
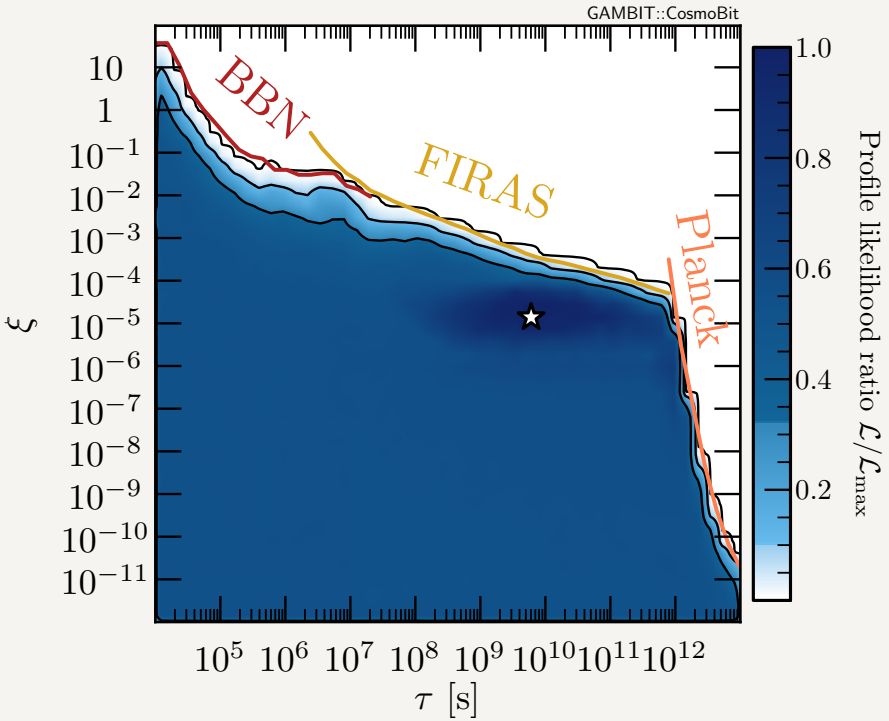
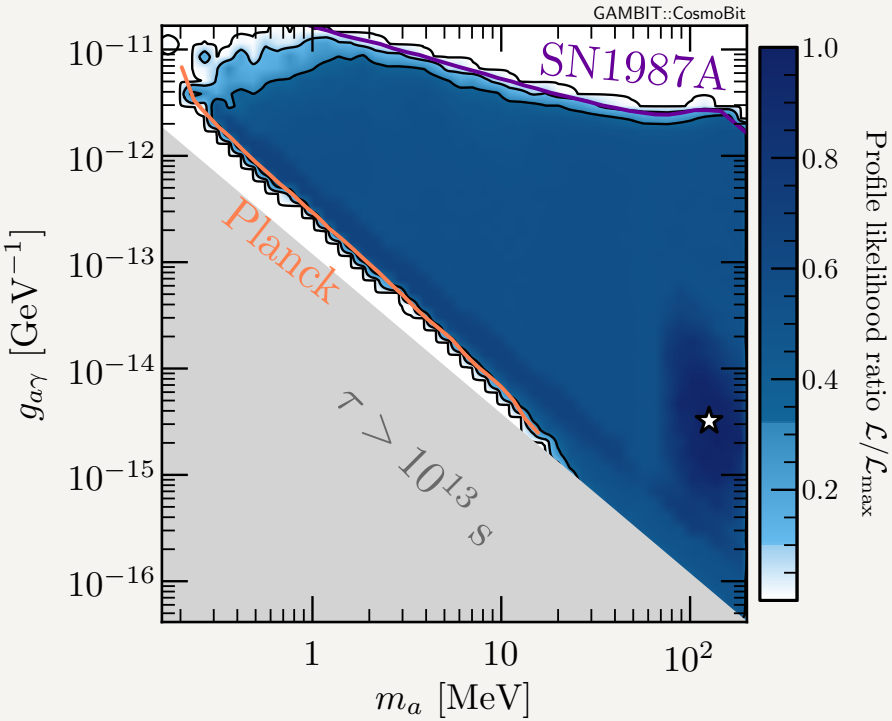


Results – projected ALP limits





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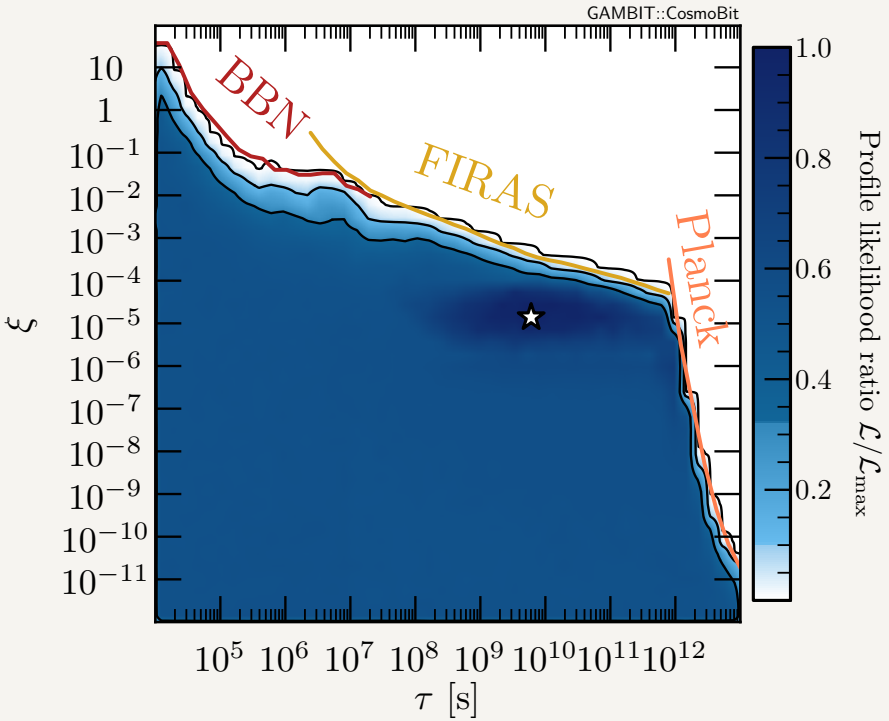
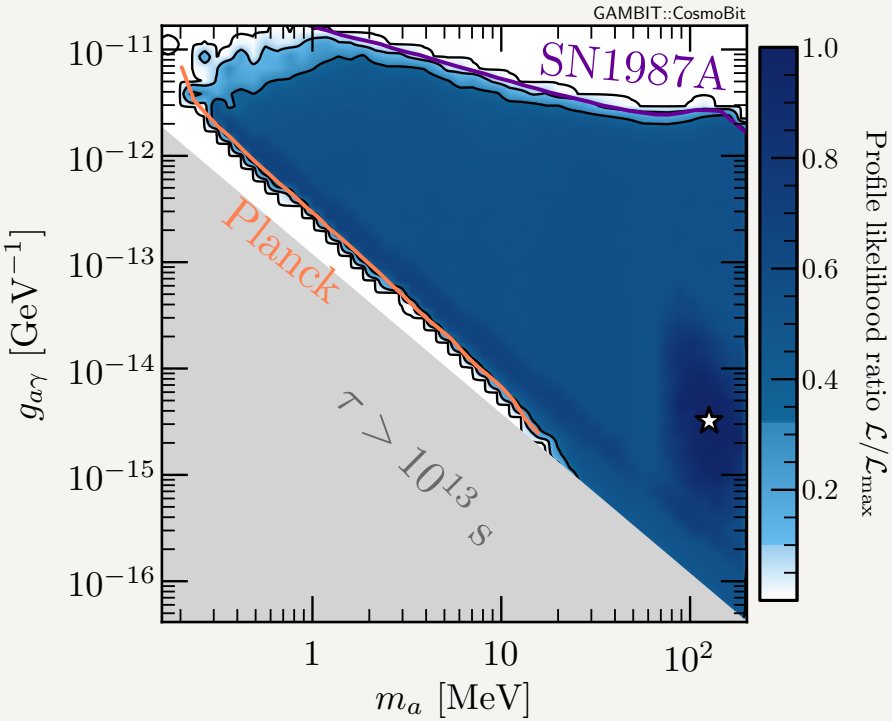


Mostly cosmo constraints



No loopholes (ξ) for astro constraints

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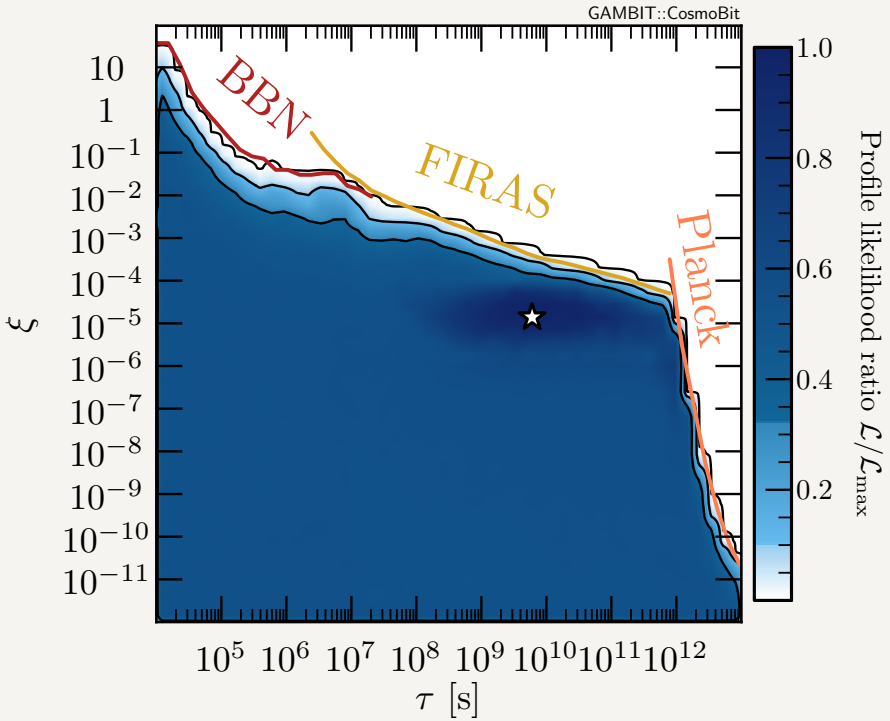

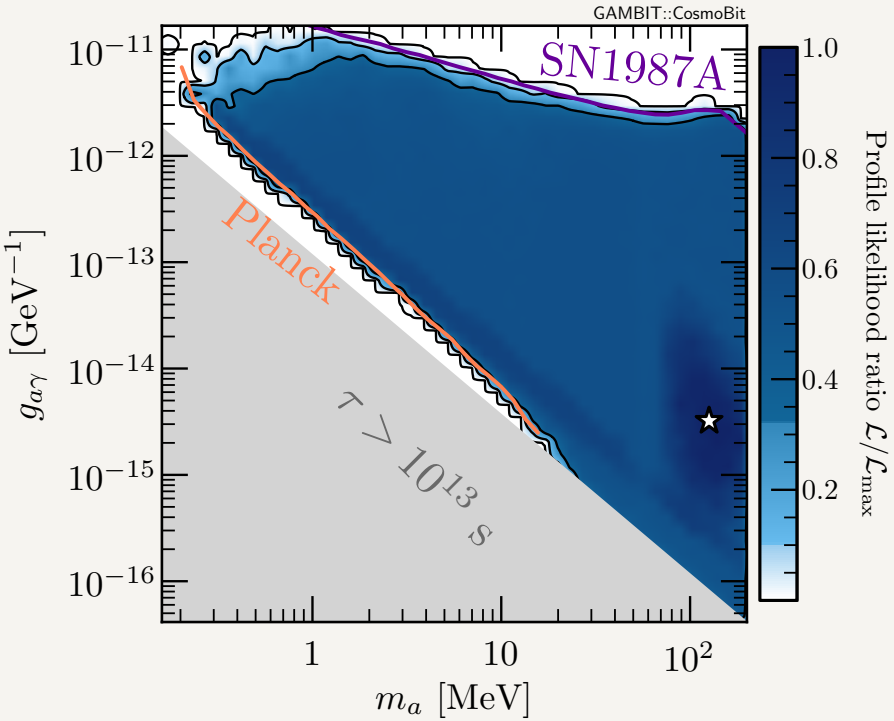

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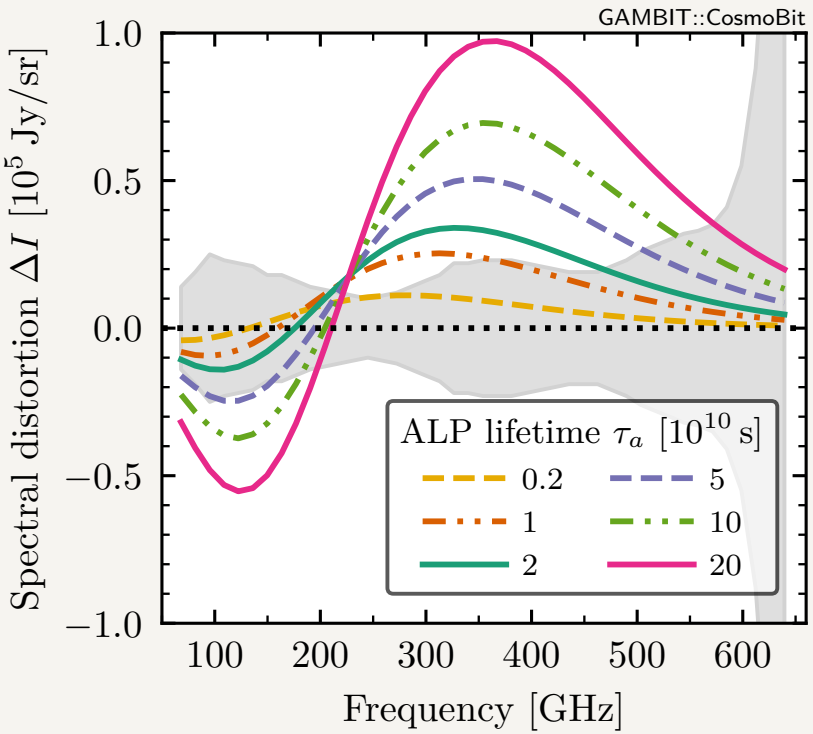
Also: Bayesian analysis with two prior choices: ΛCDM+ALP best-fitting point (☆) *not* preferred over ΛCDM

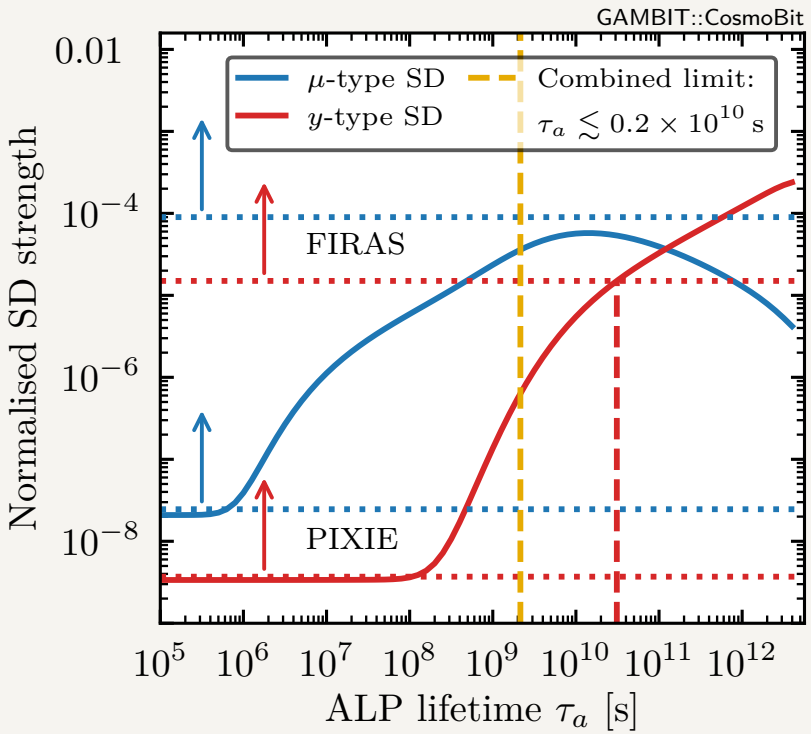
Summary

- Global-fitting frameworks (GAMBIT) can perform powerful analyses in many parameter dimensions consistently by including complementary constraints
- Heavy ALPs are still viable in cosmology ...
- ... but cannot solve ^{7}Li problem due to SD constraints
- Look forward to future CMB missions, studying ALPs with ALP-electron interactions, etc.
- Future SD missions can exclude our best-fitting region around $m_a \sim 130\,\text{MeV}$, $g_{a\gamma} \sim 3 \times 10^{-15}\,\text{GeV}^{-1}$

Backup slides

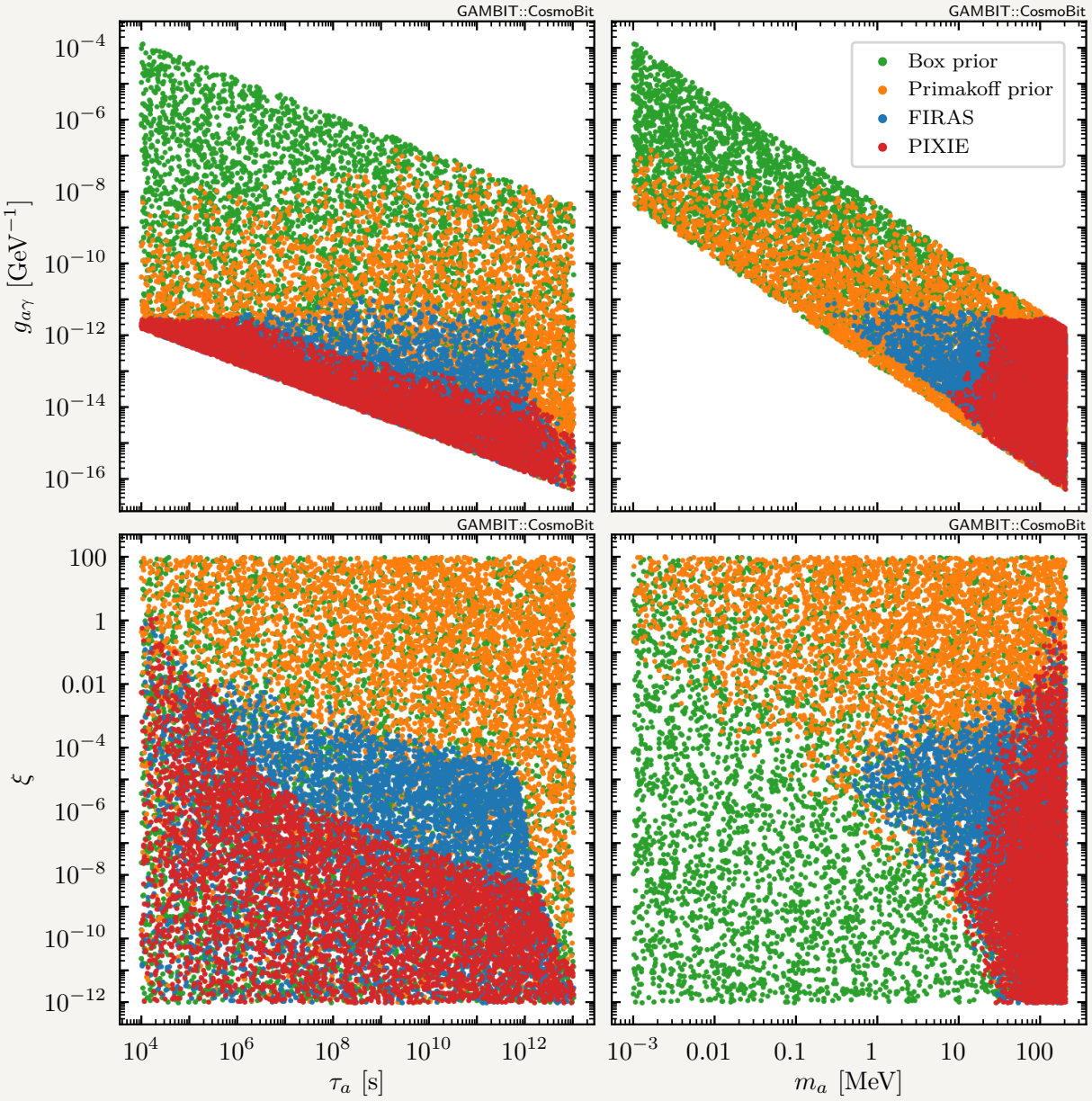
ALP constraints from spectral distortions (SDs)





- ALPs with $\tau_a \lesssim 10^{10}$ s induce larger-than-observed SDs
- Total SD shape is significantly more constraining than μ-type or y-type SDs individually
- Proposed future CMB missions (e.g. PIXIE) would give orders of magnitude stronger constraints

Bayesian results



Nested sampling runs (with Polychord)