Impact of axion decay on the cosmic background

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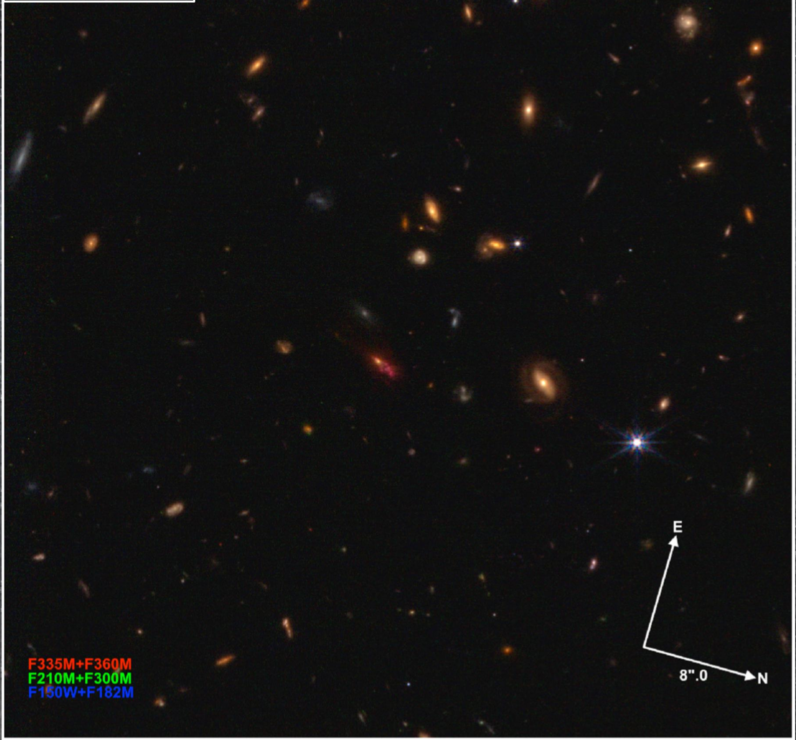
The Cosmic Background (CB)

JWST image



- Homogeneous and isotropic diffuse radiation background, extragalactic origin [1].
- Covers the entire electromagnetic spectrum.
- Focus on the range 10^{-6} – 10 μm or 10^{13} – 10^{20} Hz.

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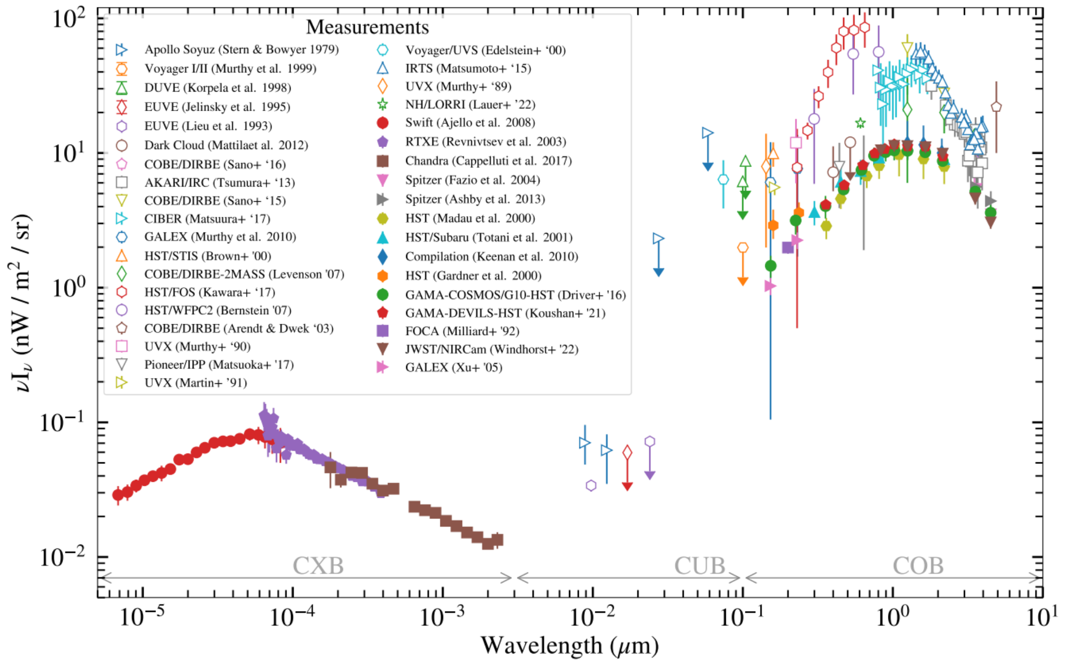

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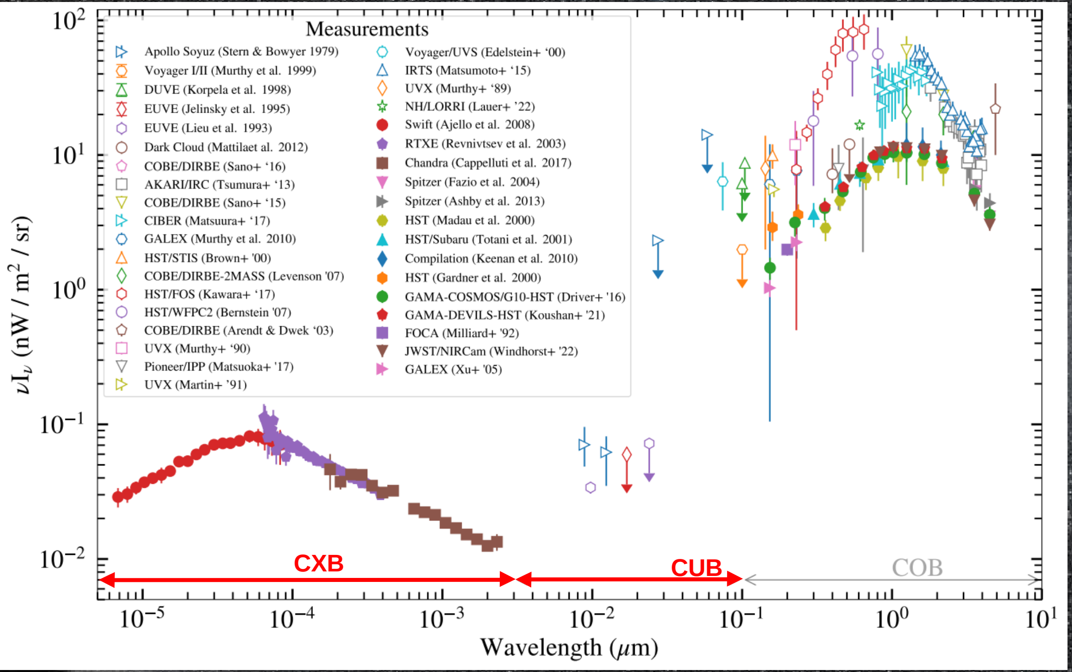
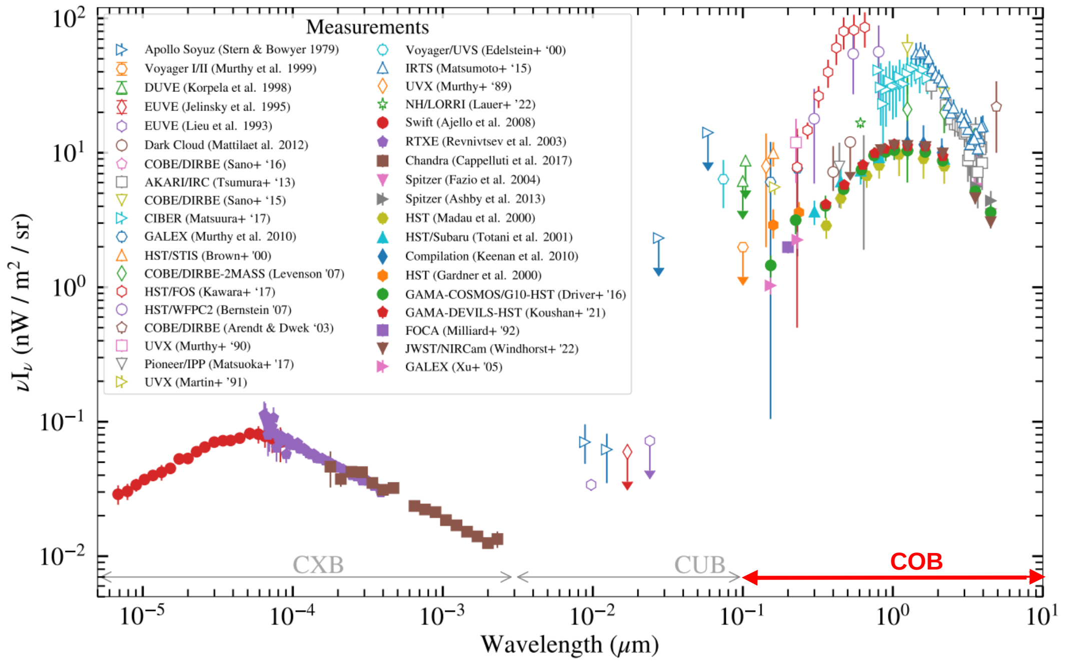
Cosmic X-ray and Ultraviolet Backgrounds (CXB and CUB)



- CXB - created mainly by accretion disks around active galactic nuclei (AGNs).
- CUB - young stars and interstellar nebulae, scattering by gas and hot intercluster gas.
  - Measurements (filled symbols) and upper limits (open symbols).

The Cosmic Optical Background (COB)



- Dominated by stellar emission.
  - Direct measurements: difficult due to foreground emission → treated as upper limits (open symbols).
  - Lower limits from galaxy number counts (filled symbols).
  - New Horizons probe (NH): measurement at 51 AU [4], should not be affected by foreground emission (green star).

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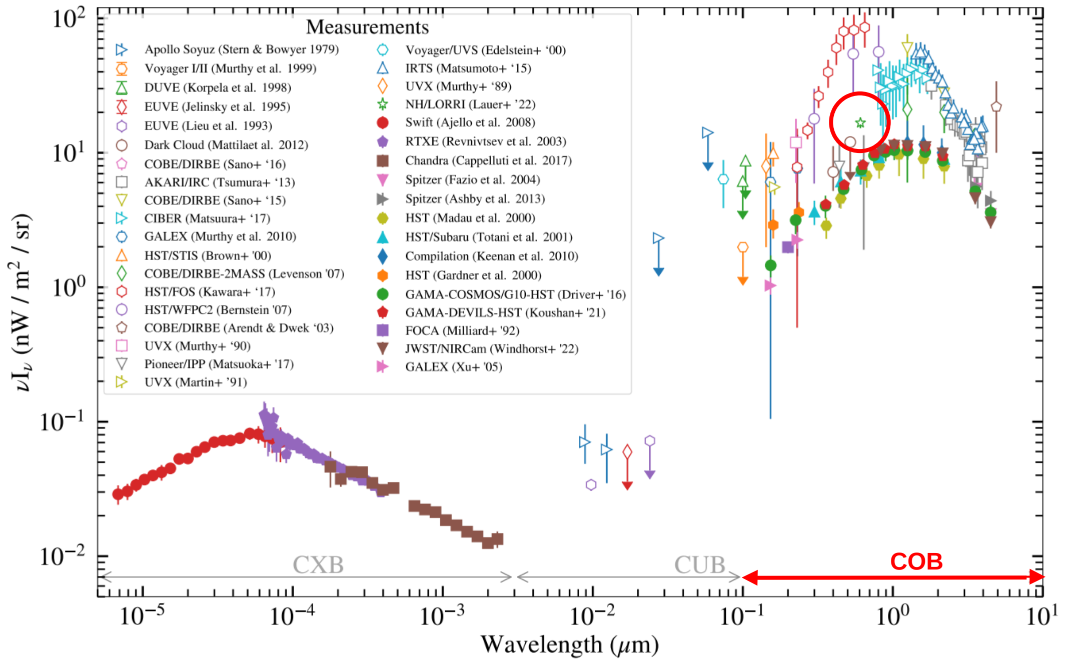

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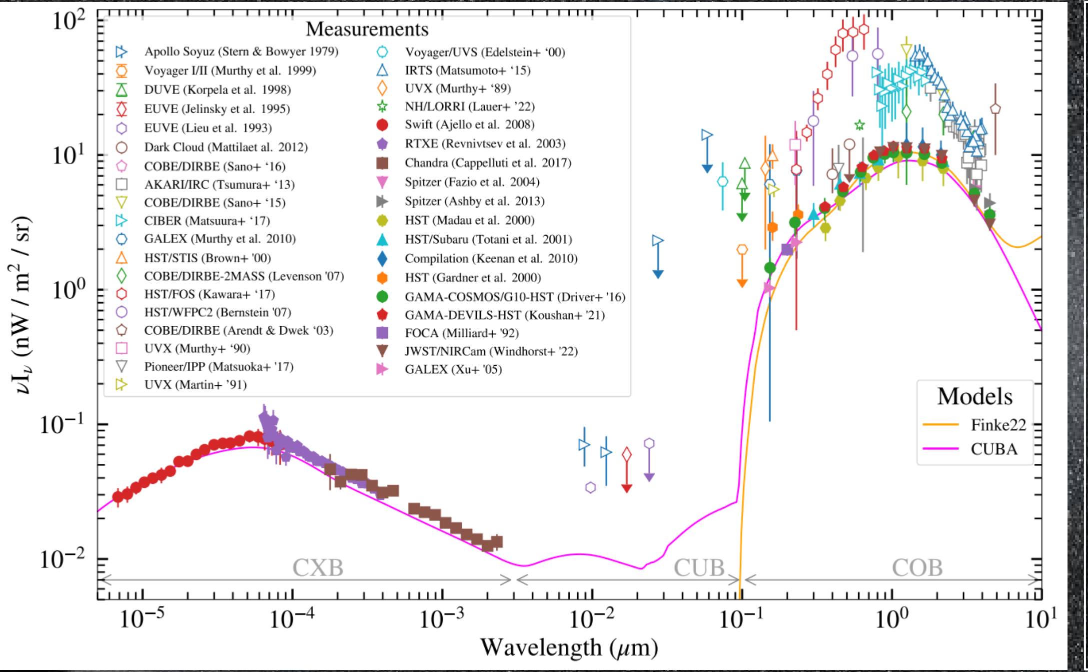
How to model the CB



Previous attempts in literature

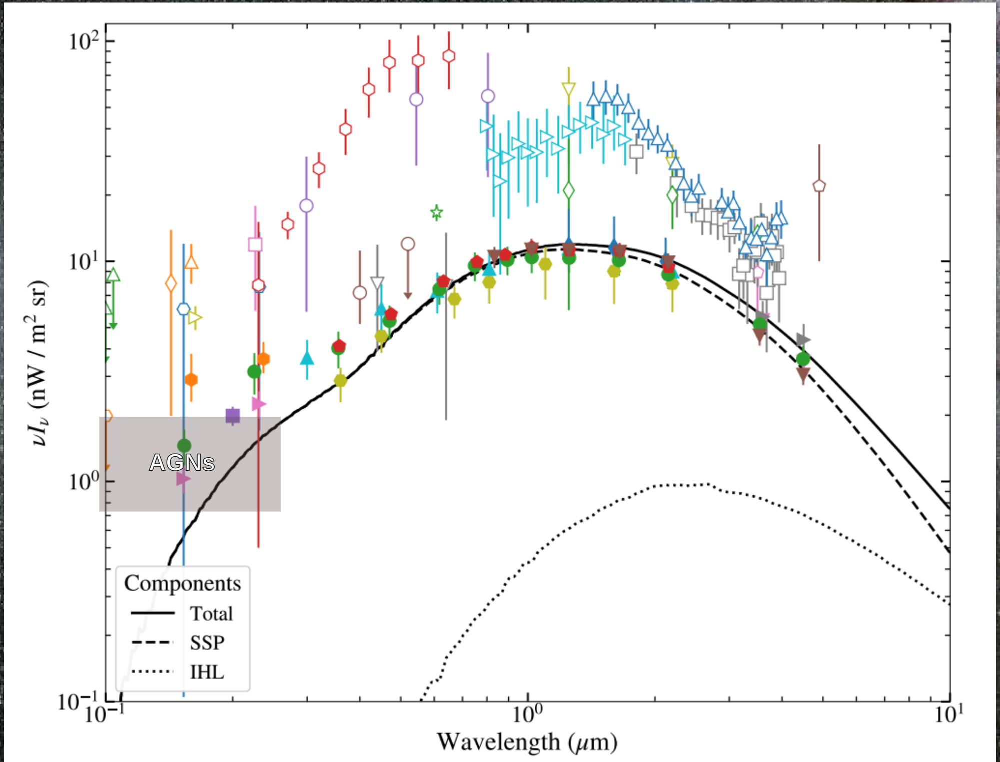
- CUBA model [2] (CXB - COB)
  - Model from first principles, not fitted to CUB.
- Finke22 model [3] (COB – further)
  - Fitted to COB lower limits.

COB → possible to model, uncertainties in the stellar component.

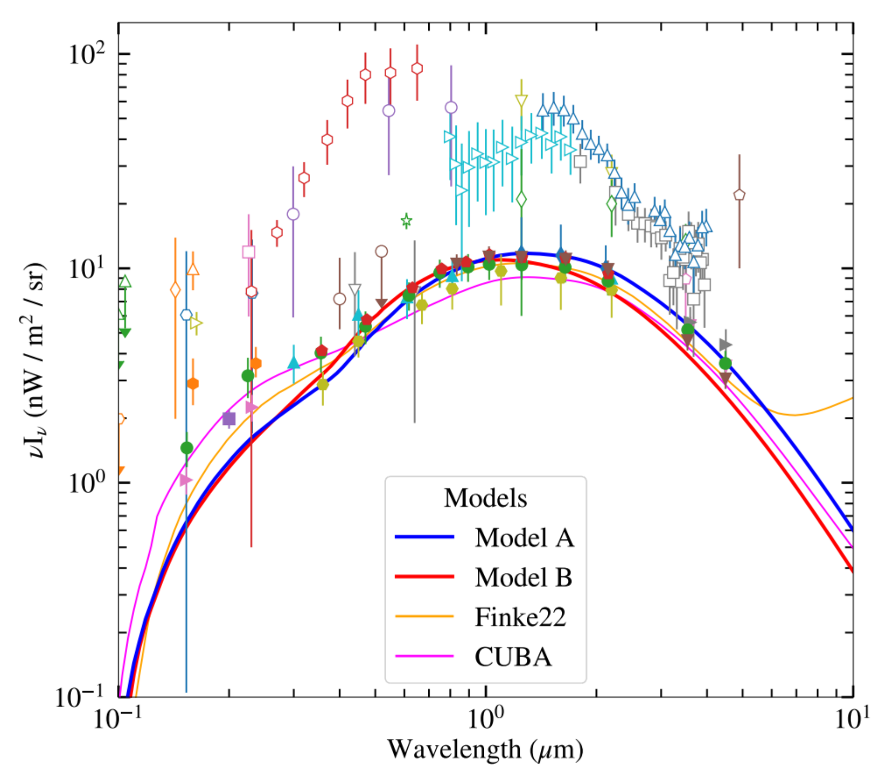
COB model → what to model

Different COB components:

- Stars
- Active Galactic Nuclei (AGNs)
  - → ≤ 10% intensity of stars in COB
- Intra-Halo Light (IHL)
- Possible Dark Matter (DM) decay
- …



COB model → fittings to data



We propose two cases to study:

- Model A → calibrated to starburst galaxies [9].
- Model B → general stellar evolution [3].

Freeing the stellar formation rate parameters, fit to observational data.

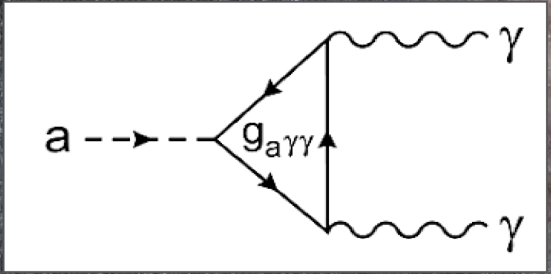
Axions and Axion-Like Particles

- Pseudo-Nambu–Goldstone boson.
- Arises from the Peccei–Quinn solution to the strong CP problem [5].
- Relaxing m_a - $g_{a\gamma}$ relation, we have Axion-Like Particles (ALPs).

➔ One of the preferred DM candidates.

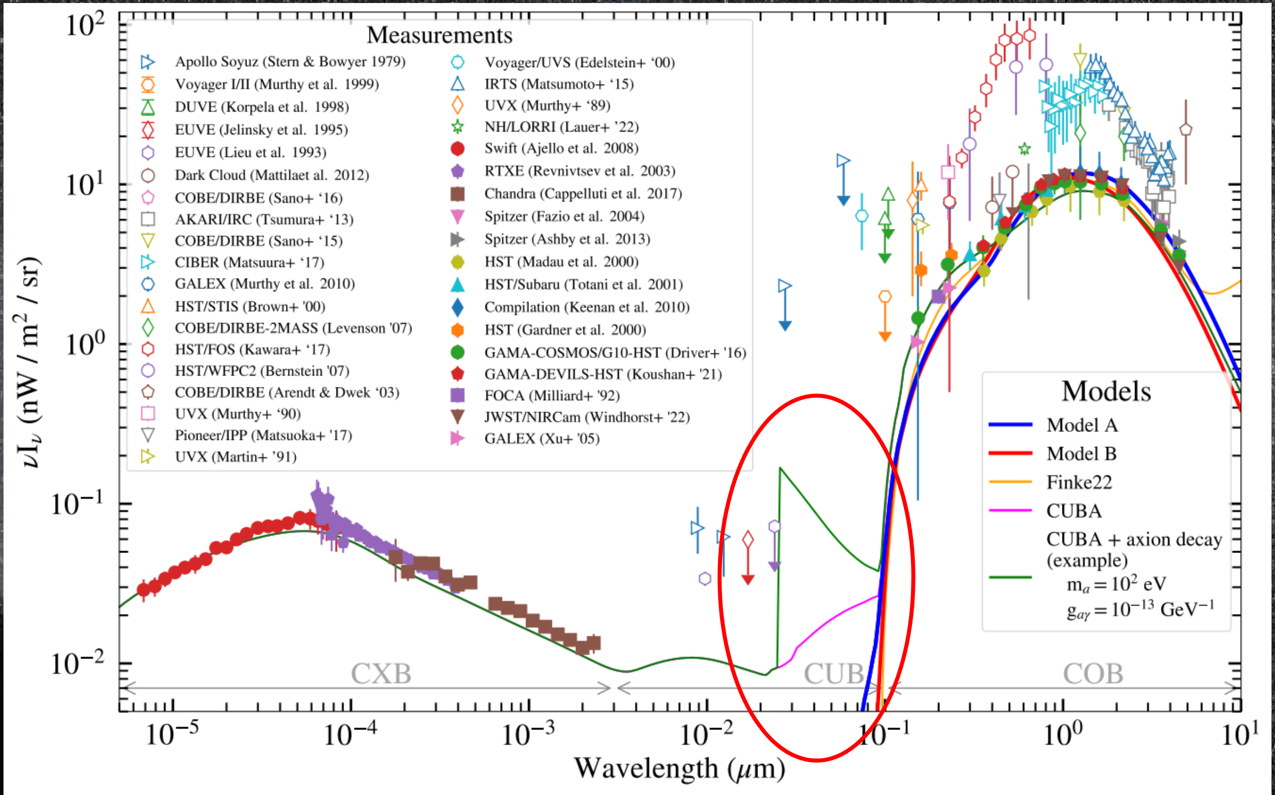
➔ $m_a \geq O(\mathrm{eV})$ we expect to observe decay into two photons.

➔ Minimum mean life $\tau_{a,\,min} \approx 10^{17}$ s (age of the Universe).



Feynman diagram of axion decay into two photons

Axions and ALPs: decay and analysis

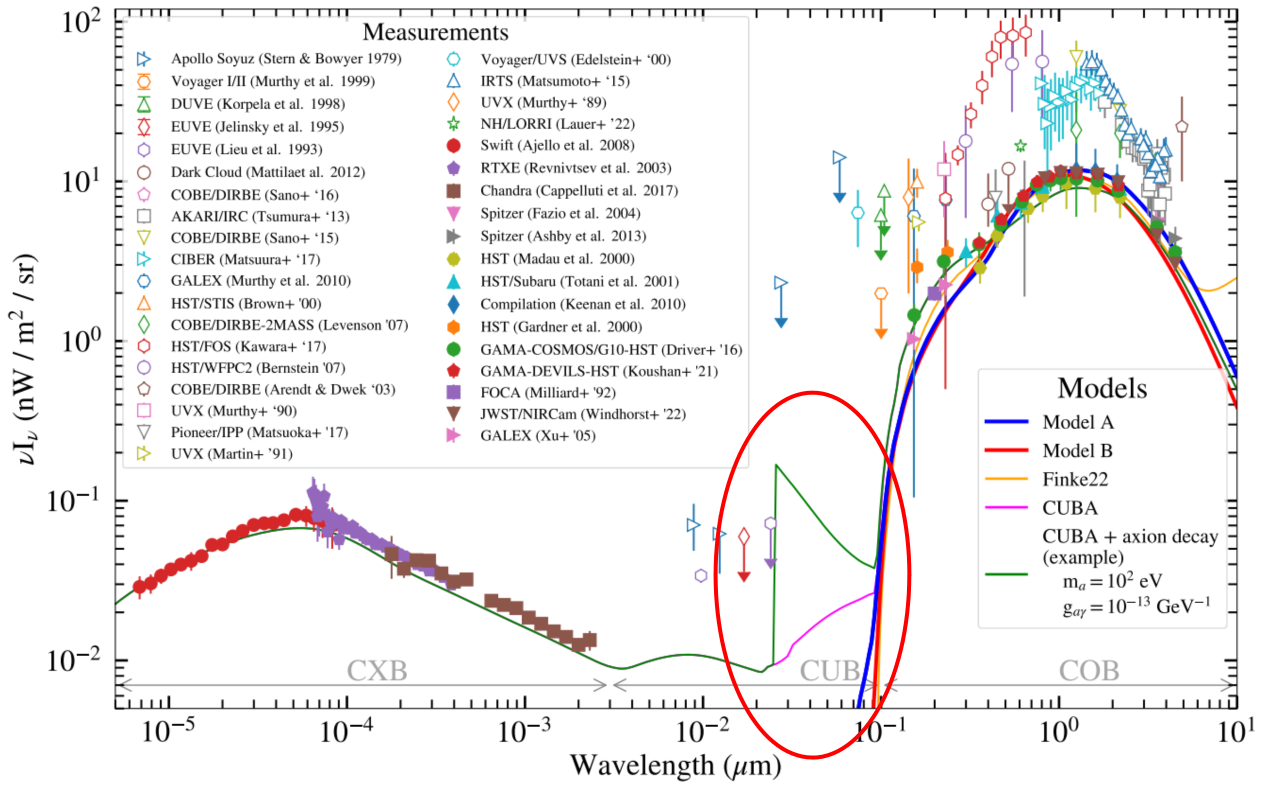


Decay of an ALP

Analytical formula:

$$\nu I_\nu \propto m_a^2 \cdot g_{a,\gamma}^2$$

Axions and ALPs: decay and analysis



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Likelihood analysis

NH datapoint:

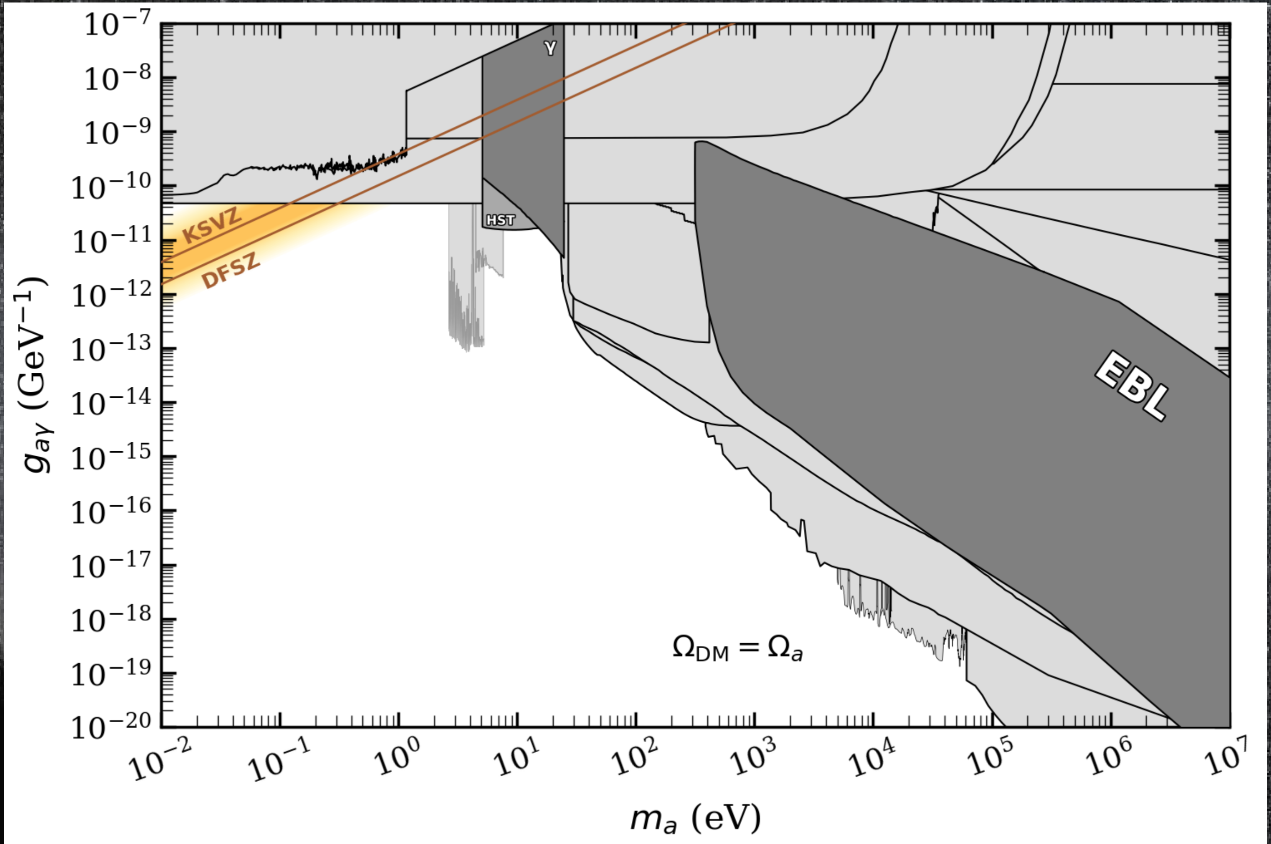
- As a measurement, so the decay contribution has to strictly fit to it.

$$\chi^2 = \left(\frac{\nu I_{\nu,model}(\lambda_{NH}) - \nu I_{\nu,NH}}{\sigma_{NH}} \right)^2$$

- As an upper limit. Used alongside the other upper limits from CB.

$$\chi^2 = 2 \cdot \sum \left(\frac{\nu I_{\nu,model}(\lambda) - \nu I_{\nu,data}}{\sigma_{data}} \right)^2$$

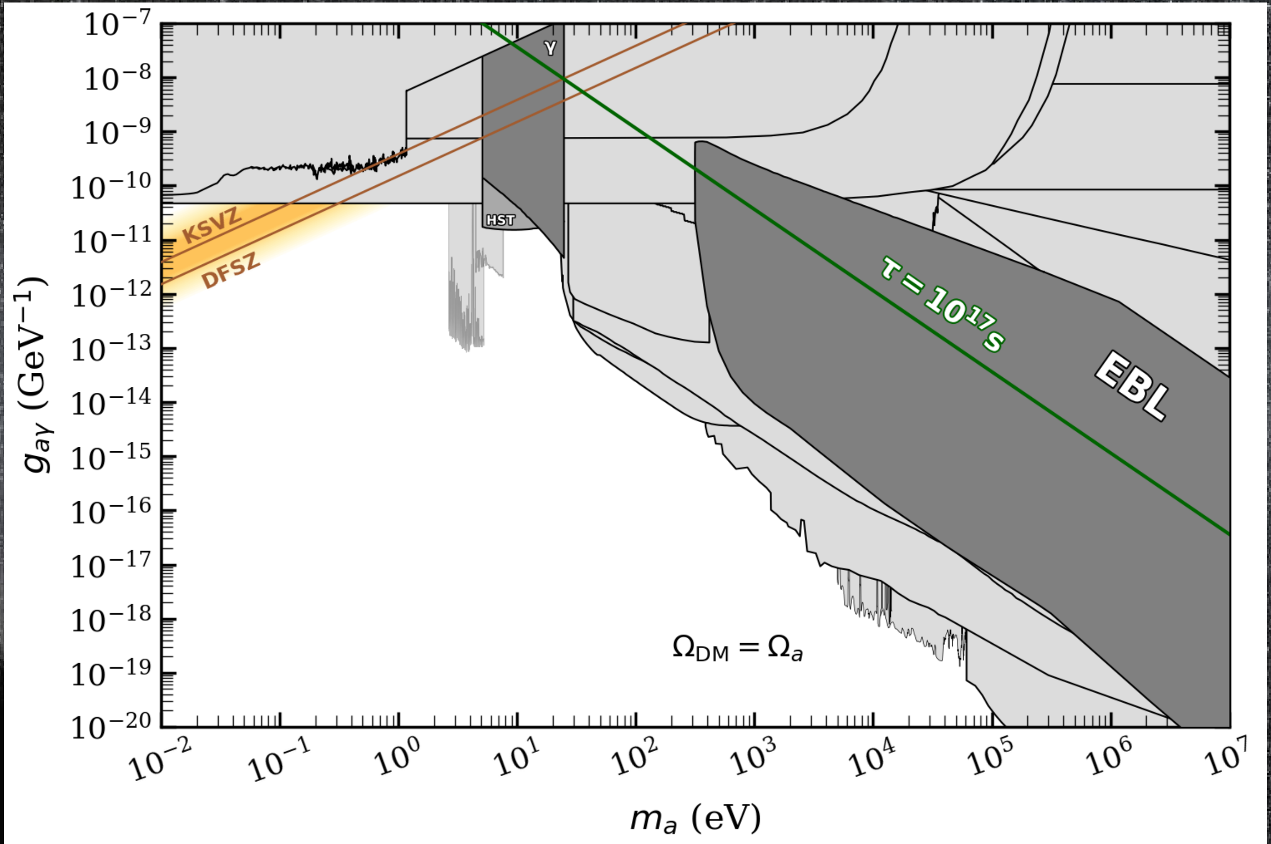
Axions and ALPs: parameter space



Previous constraints from literature.

Limits from [6].

Axions and ALPs: parameter space



Only exclude below the green line.

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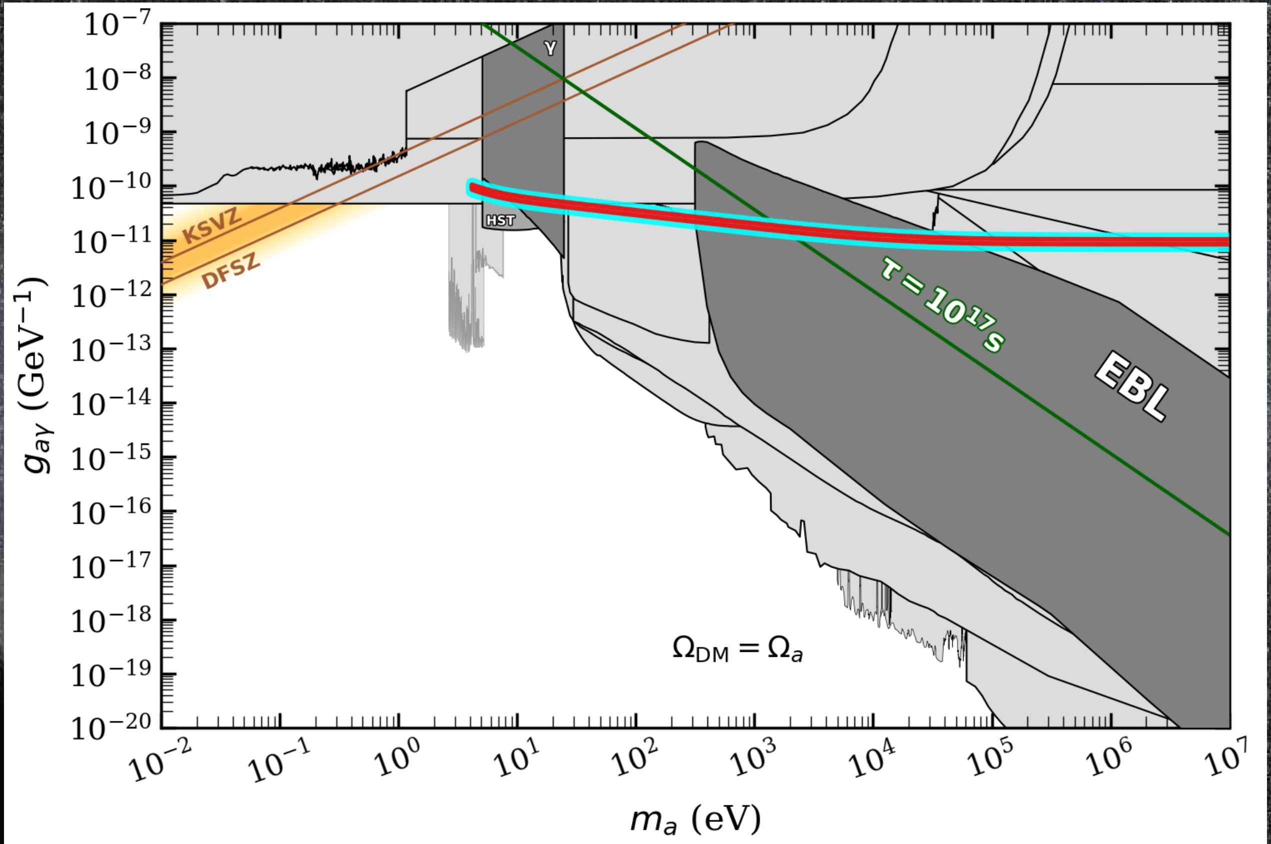

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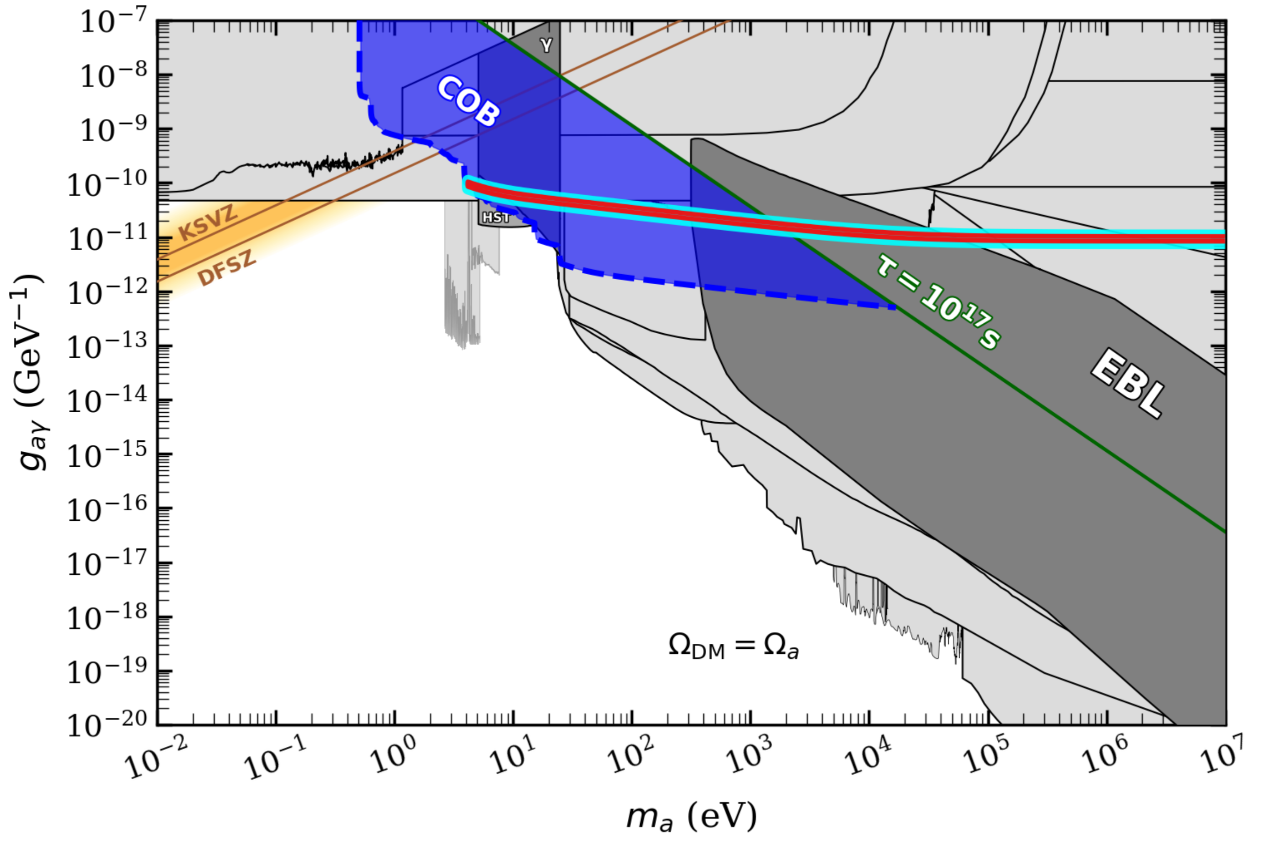

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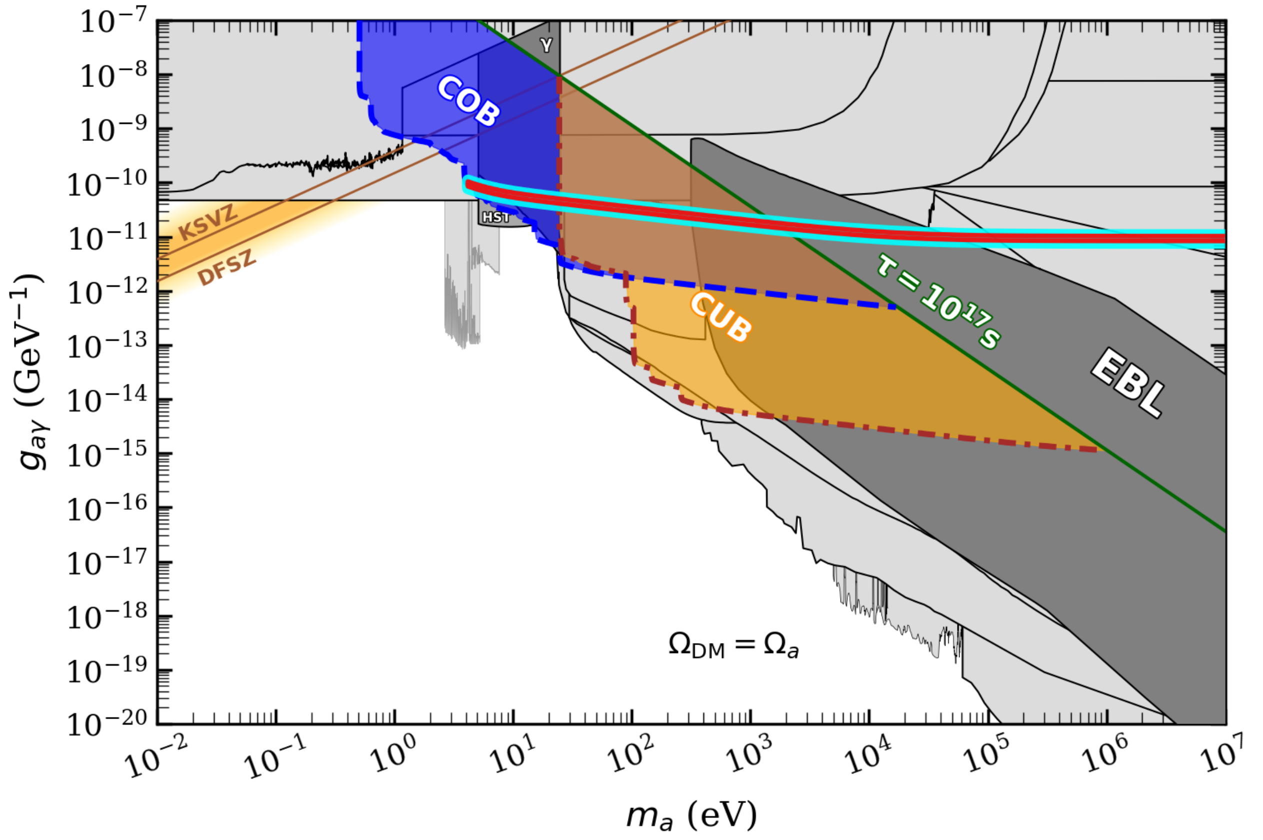

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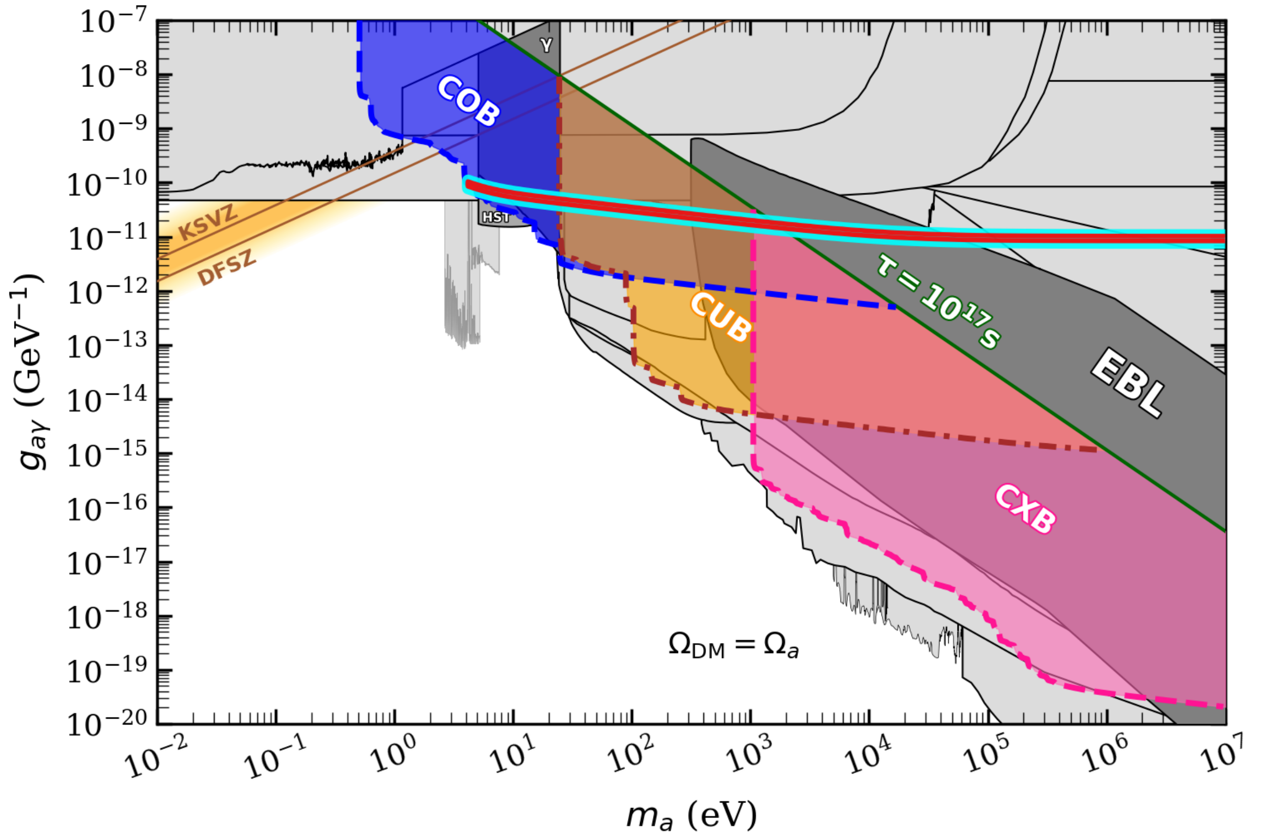

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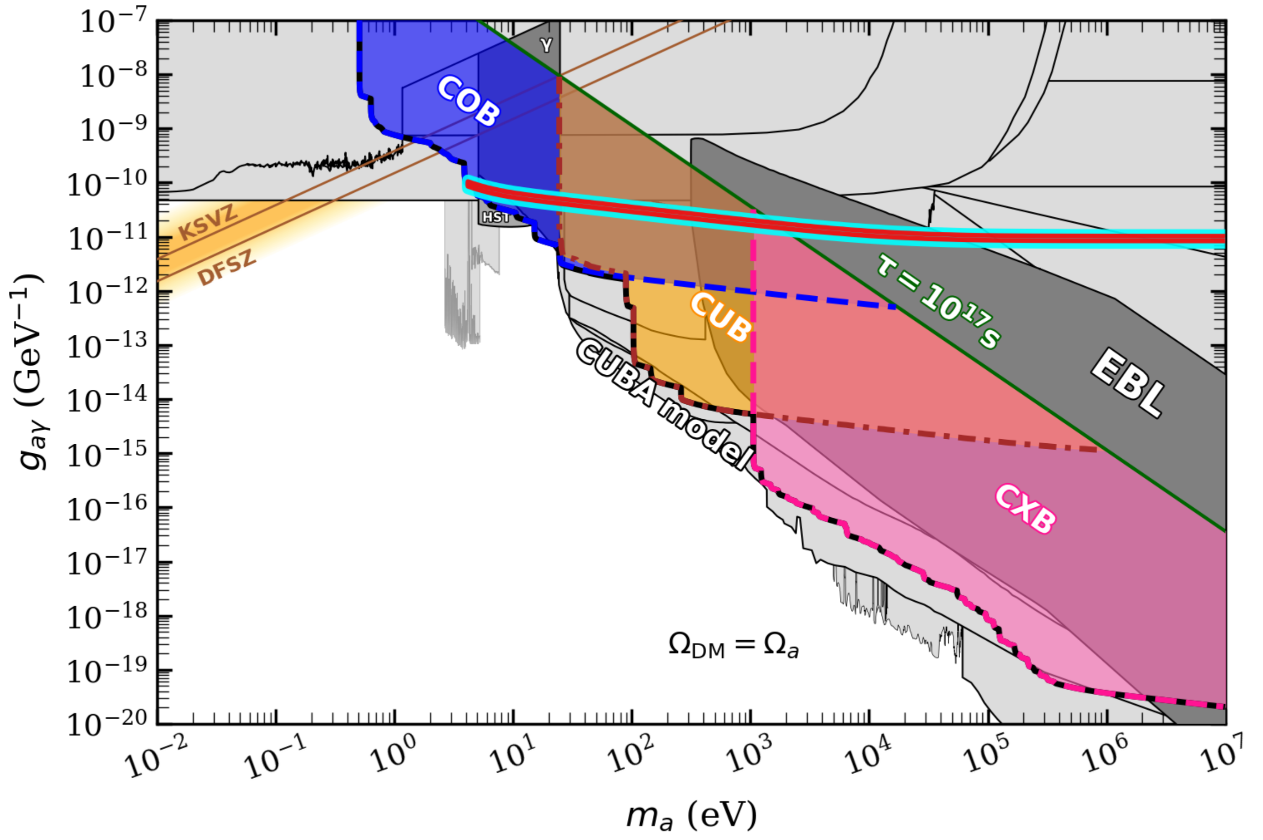

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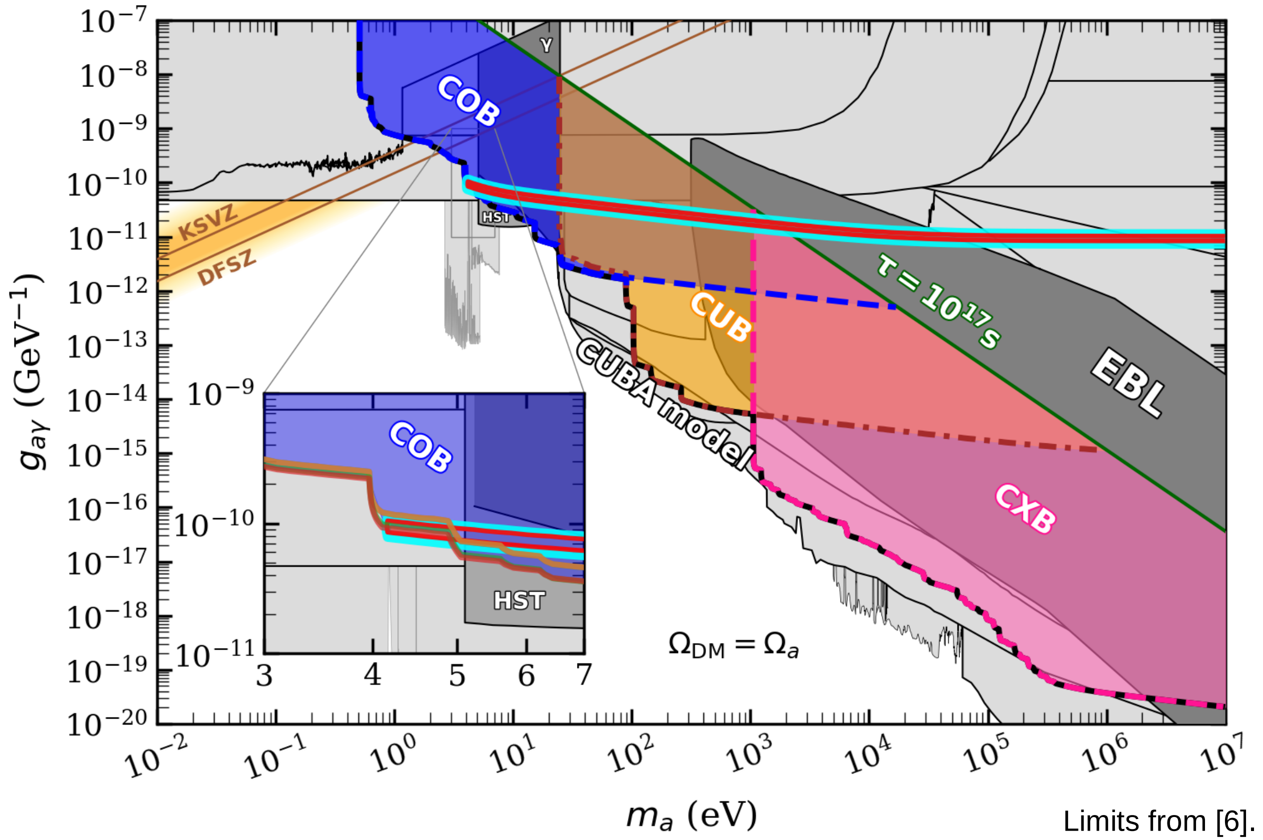

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The choice of COB model (inset brown lines) does not greatly affect the constraints.

Only small region fits the NH point and is accepted by upper limits. Ruled out by other experiments.

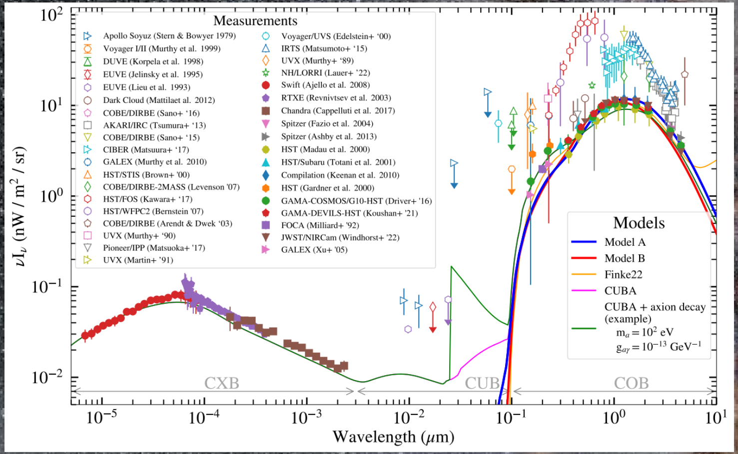
Conclusions and outlook

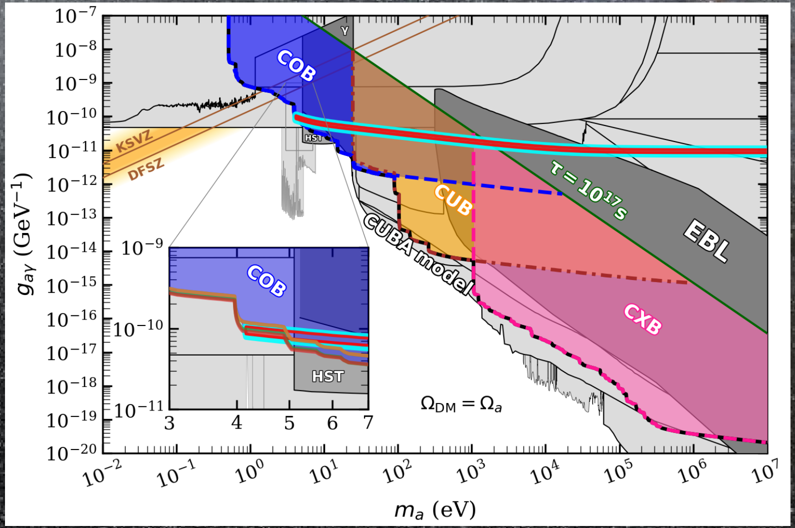
Conclusions

- Modular code to calculate different COB contributions.
- We model CXB-COB adding an axion decay contribution to the astrophysical model.
- Axion parameter space with new constraints.

Outlook

- ➔ New measurements (JWST)
- ➔ Unknown CB sources – Pop III stars, primordial black holes, dark stars...





Thank you for your attention

References

[1] R. Hill, K. W. Masui, and D. Scott, The Spectrum of the Universe, Appl Spectrosc 72, 663 (2018).

[2] F. Haardt and P. Madau, Radiative Transfer in a Clumpy Universe. IV. New Synthesis Models of the Cosmic UV/X-Ray Background, The Astrophysical Journal 746, 125 (2012).

[3] J. D. Finke, M. Ajello, A. Dominguez, A. Desai, D. H. Hartmann, V. S. Paliya, and A. Saldana-Lopez, Modeling the Extragalactic Background Light and the Cosmic Star Formation History (Data), https://doi.org/10.5281/zenodo.7023073.

[4] T. R. Lauer et al., Anomalous Flux in the Cosmic Optical Background Detected with New Horizons Observations, ApJL 927, L8 (2022).

[5] Peccei R. D. and Quinn H. R., 1977, Phys. Rev. Lett., 38, 1440

[6] C. O’Hare, cajohare/axionlimits: Axionlimits, https://cajohare.github.io/AxionLimits/ (2020).

[7] Claus Leitherer et al., “ Starburst99 v7.0.1: Space Telescope Science Institute ”.

[8] M. Fioc and B. Rocca-Volmerange, PÉGASE.3: A Code for Modeling the UV-to-IR/Submm Spectral and Chemical Evolution of Galaxies with Dust, A&A 623, A143 (2019).

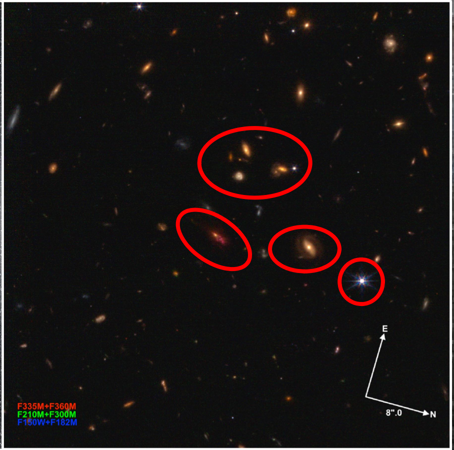
[9] T. M. Kneiske, K. Mannheim, and D. H. Hartmann, Implications of Cosmological Gamma-Ray Absorption - I.Evolution of the Metagalactic Radiation Field, A&A 386, 1 (2002).

COB: sources of foreground light

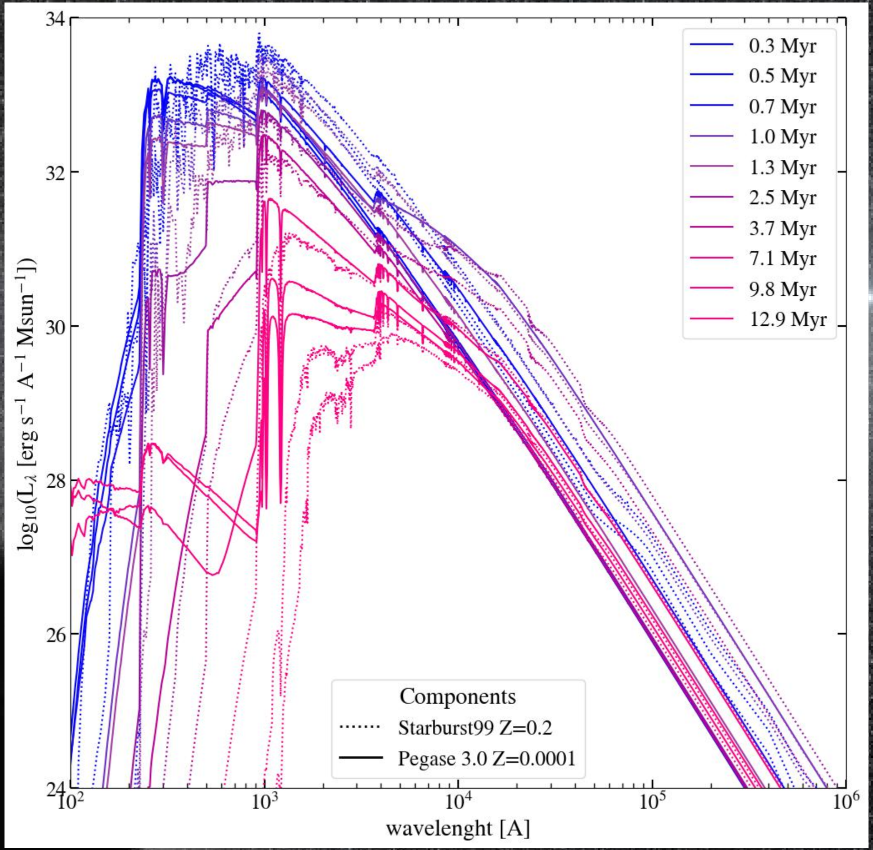
Individual sources (stars and galaxies present in observations) ⇨ Resolve their contributions

Terrestrial emission (atmosphere) ⇨ Measurements from outside the atmosphere

Zodiacal light (diffuse sunlight scattered by interplanetary dust) ⇨ Measurements from outside the Solar System
or
Subtraction of dust component with theoretical models derived from observations

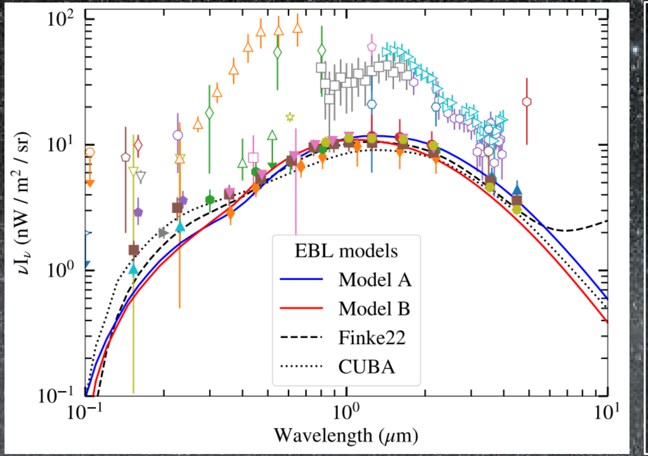


COB model → fittings to data



- We use synthetic stellar spectra to simulate the luminosities of stellar populations [7, 8] .
- We propose two cases to study:
  - Model A → calibrated to starburst galaxies [9].
  - Model B → general stellar evolution [3].
- They differ in stellar spectra, metallicity and dust treatment.

COB model → fittings to data



Freeing the stellar formation rate (sfr) parameters, combined fit of COB lower limits, emissivities and sfr to observational data.