WINDOWS ON THE UNIVERSE, Aug 06-12, 2023

Spectra of axions emitted from main sequence stars

Ngan (Steve) Nguyen

Johns Hopkins University

In collaboration with Marc Kamionkowski and Erwin Tanin

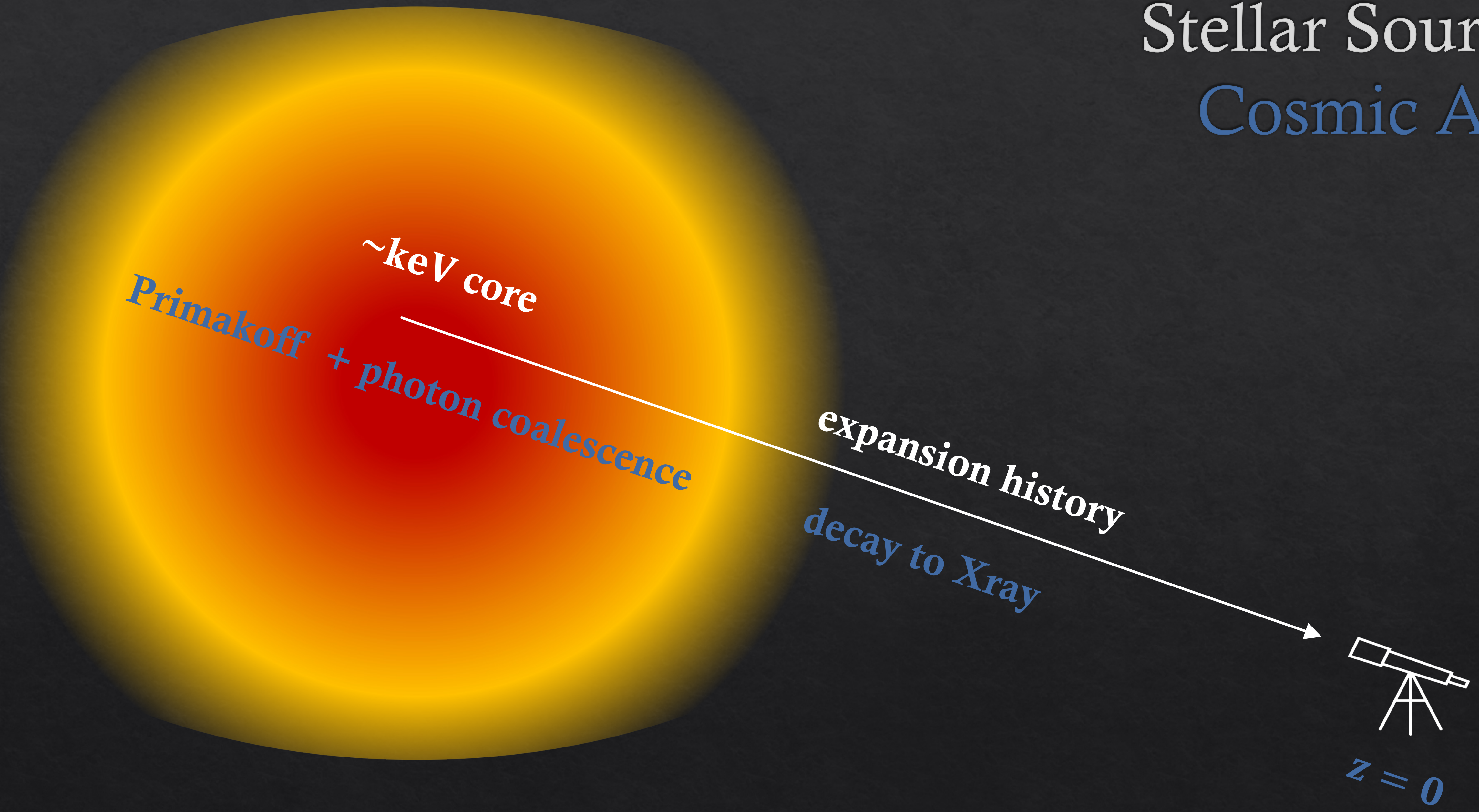
Axion-like particle

$$\mathcal{L} \supset \frac{1}{2}\partial_\mu a \partial^\mu a - \frac{1}{2}m_a^2 a^2 - \frac{g_{a\gamma\gamma}}{4} a F_{\mu\nu}\tilde{F}^{\mu\nu}$$

- The low-mass pseudo-Goldstone bosons, which arise from the breaking of an anomalous (chiral) global symmetry is referred as Axion-Like particles (ALPs).
- ALPs can be found in many models of physics beyond the SM such as supersymmetric theories and string theory.
- ALPs can couple to the gauge fields in a manner proportional to the gauge anomaly.

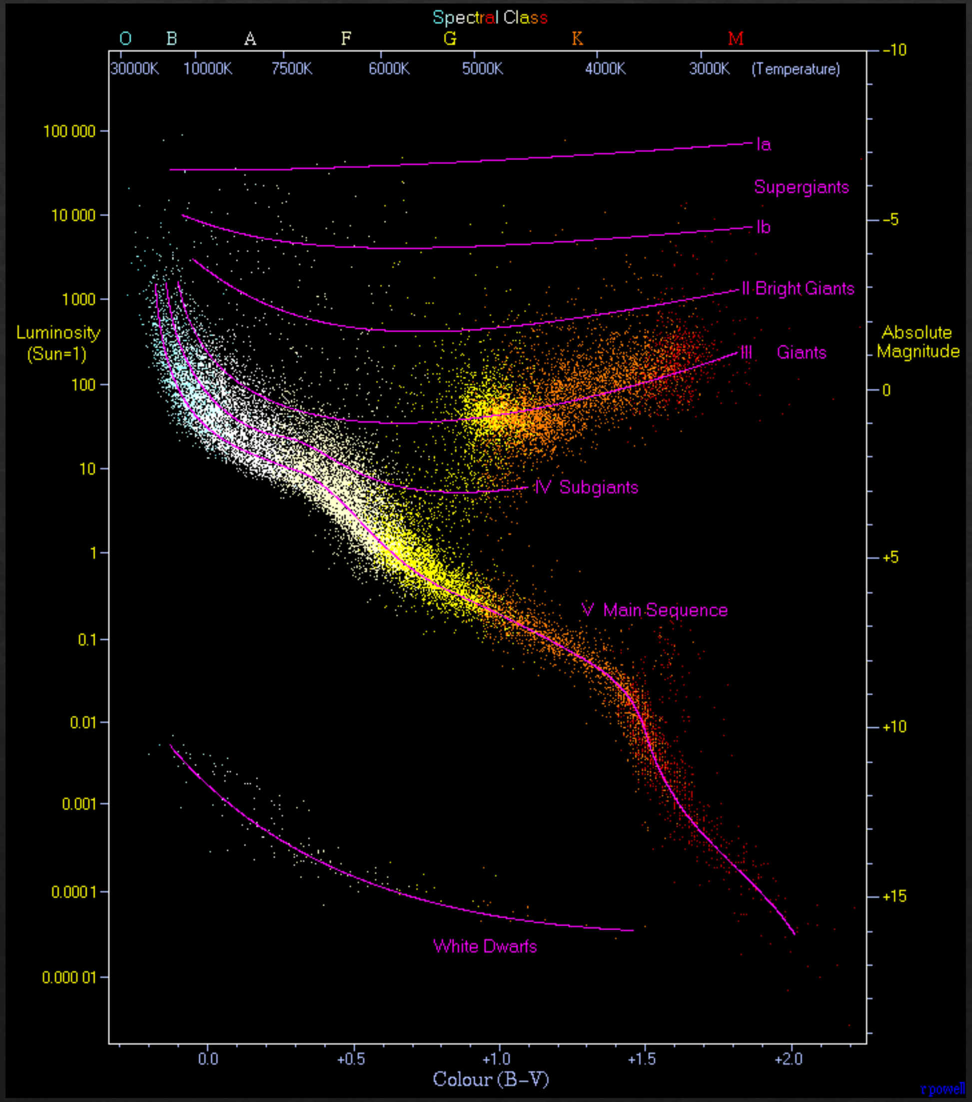
R. Peccei, H. Quinn, PRL 38 (1977); S. Weinberg, PRL 40 (1978); F. Wilczek, PRL 40 (1978); P. Graham, D. Kaplan, S. Rajendran, PRL 115 (2015)

Stellar Source of Cosmic Axion



Overview

- keV axions sourced by all stars!
  - Dominated by Main-Sequence stars



Hertzsprung-Russell diagram from Powell 2011

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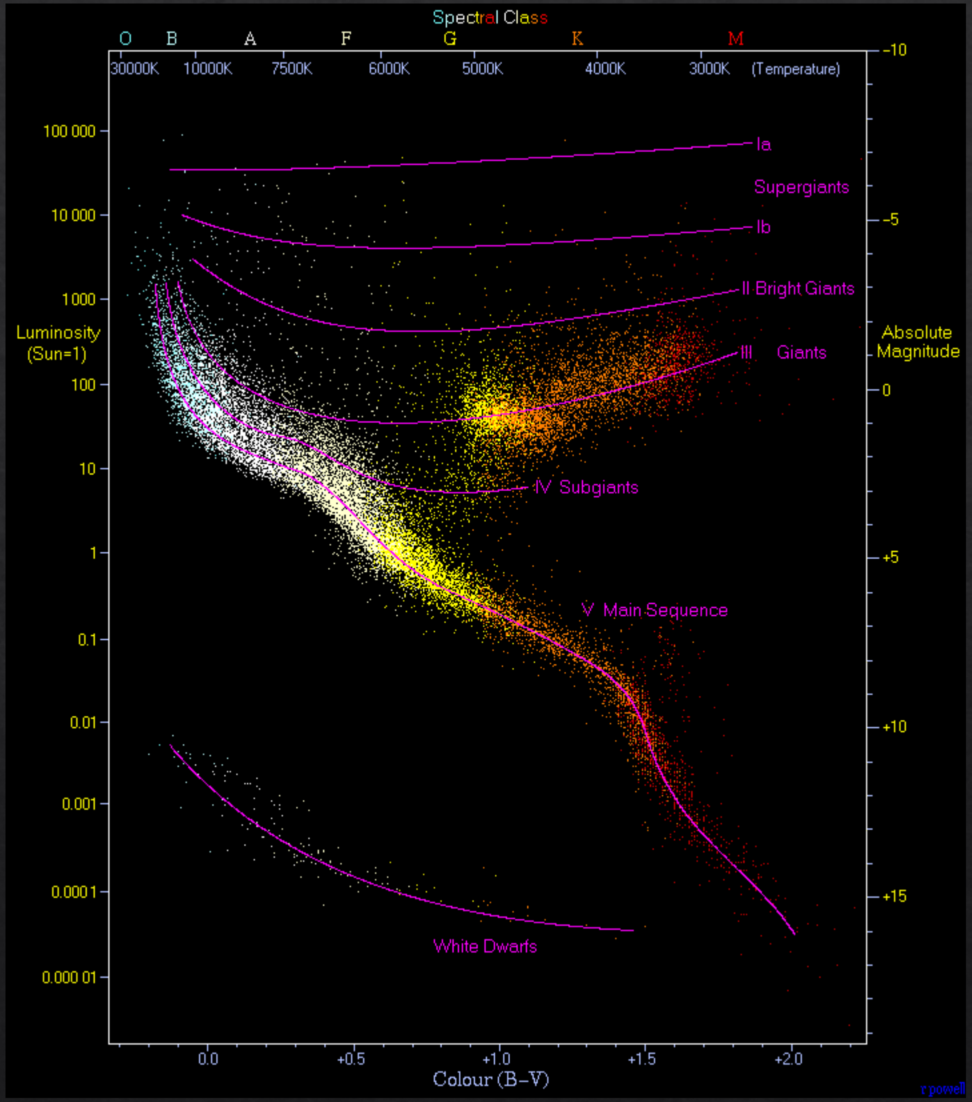
- A triple integral over:
  - Stelar **interior**: MESA + Primakoff and photon coalescence processes
  - Stellar **population**: mass function $\phi(M)$
  - Stellar **formation history**: $H(z) + \psi(z)$



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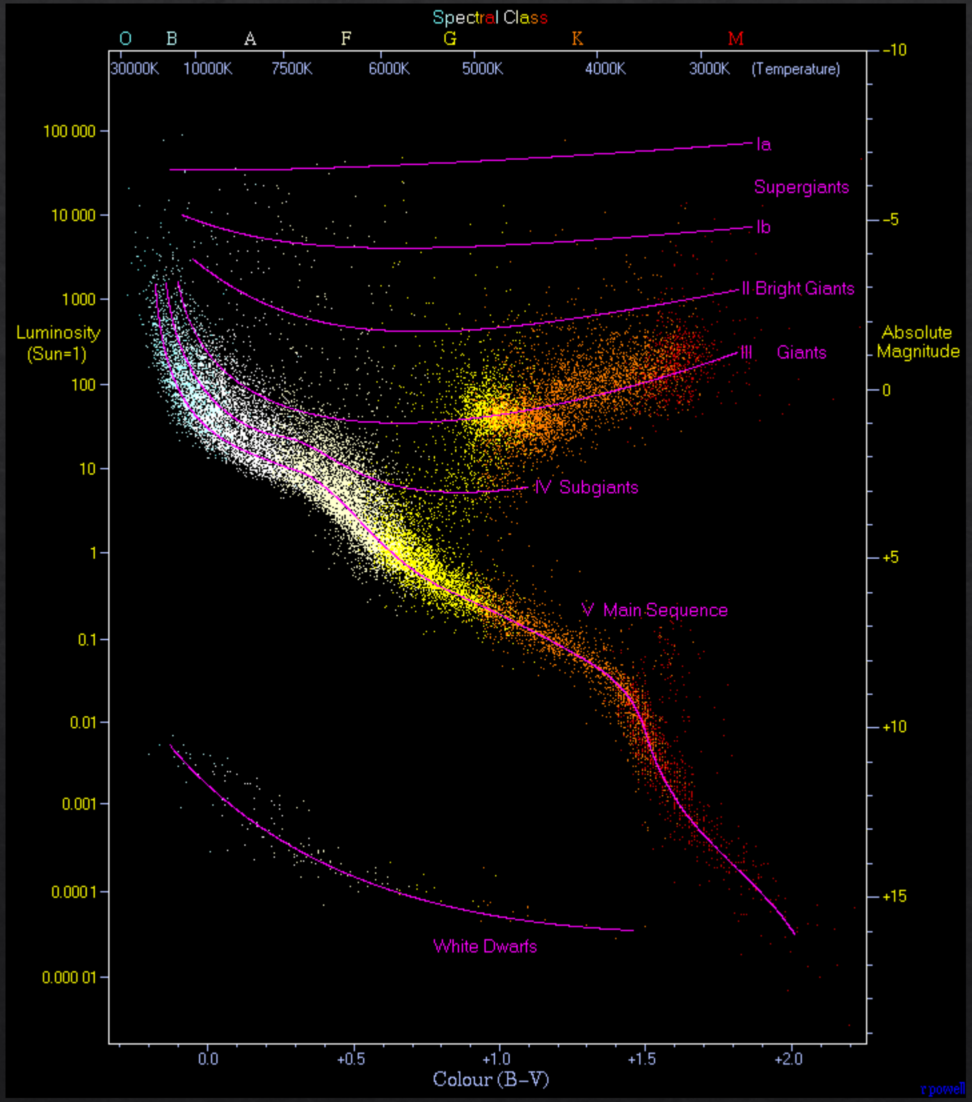
- Decay to X-ray, distort the CXB

$$\Gamma_{a\to\gamma\gamma} = 2\ \text{Gyr} \left(\frac{g_{a\gamma\gamma}}{10^{-10}\ \text{GeV}^{-1}}\right)^{-2} \left(\frac{m_a}{\text{keV}}\right)^{-4} \left(\frac{E_a}{4.5\ \text{keV}}\right)$$



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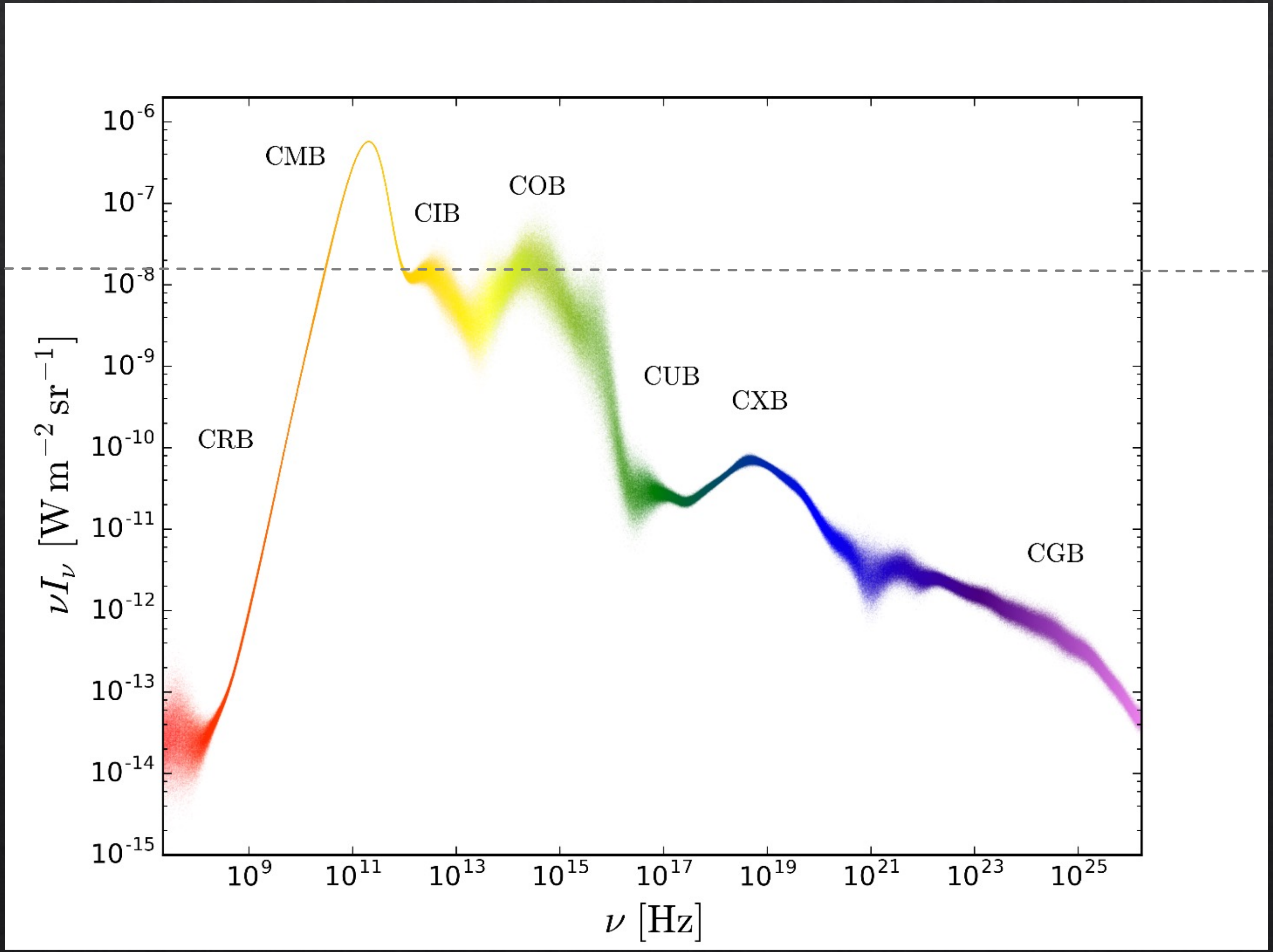
Quick Estimate



COB is dominated by stars

Stellar cooling limit

$$g_{a\gamma\gamma} \lesssim 7\times10^{-11}\text{GeV}^{-1}$$

$L_a \lesssim 10^{-3} L_\odot$ and peaks at $E \sim$ keV

May probe below the cooling limit

R. Hill, K. Masui, D. Scott (2018), CAST collaboration, S. Andriamonje et al., (2007)

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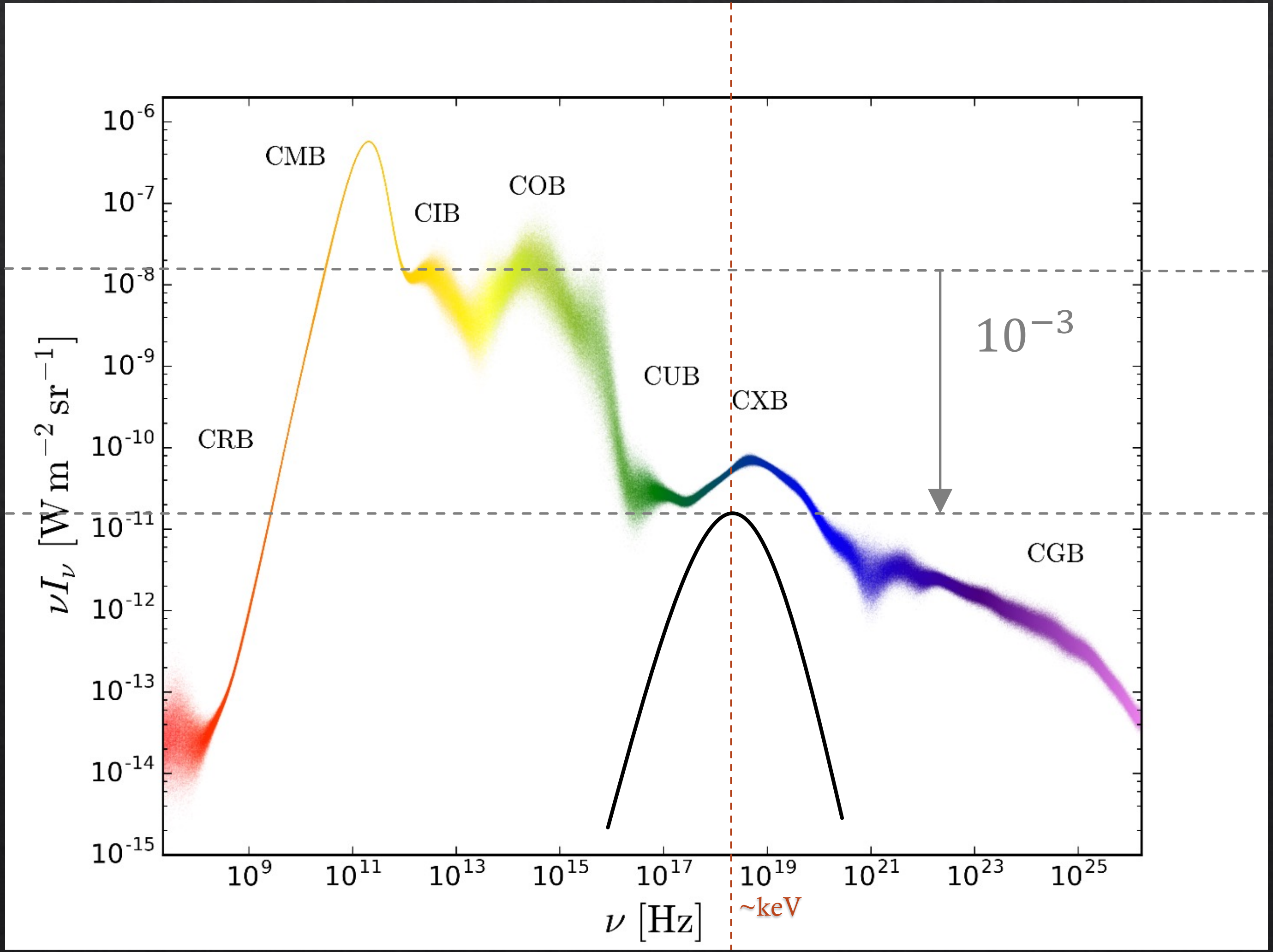

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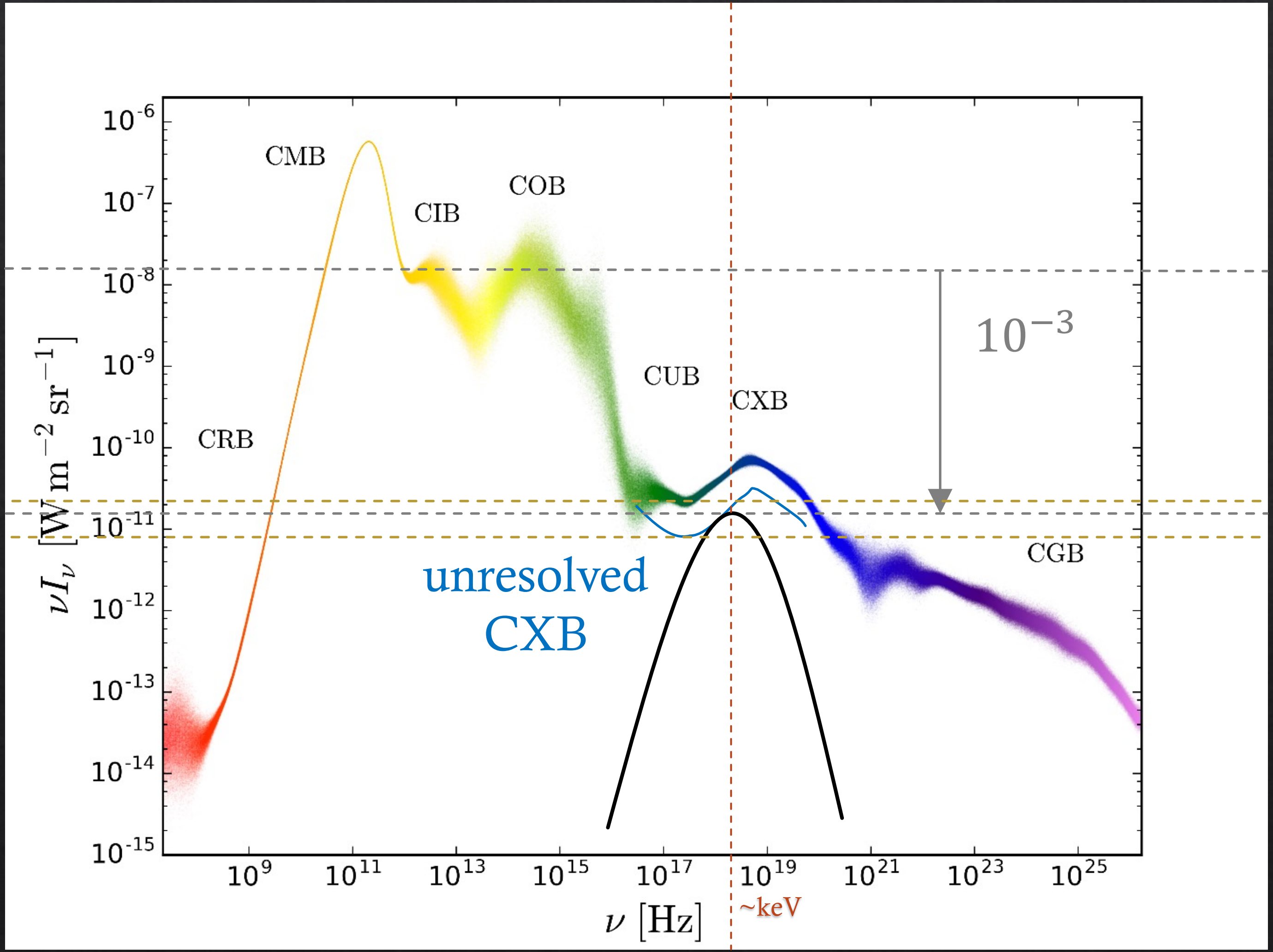

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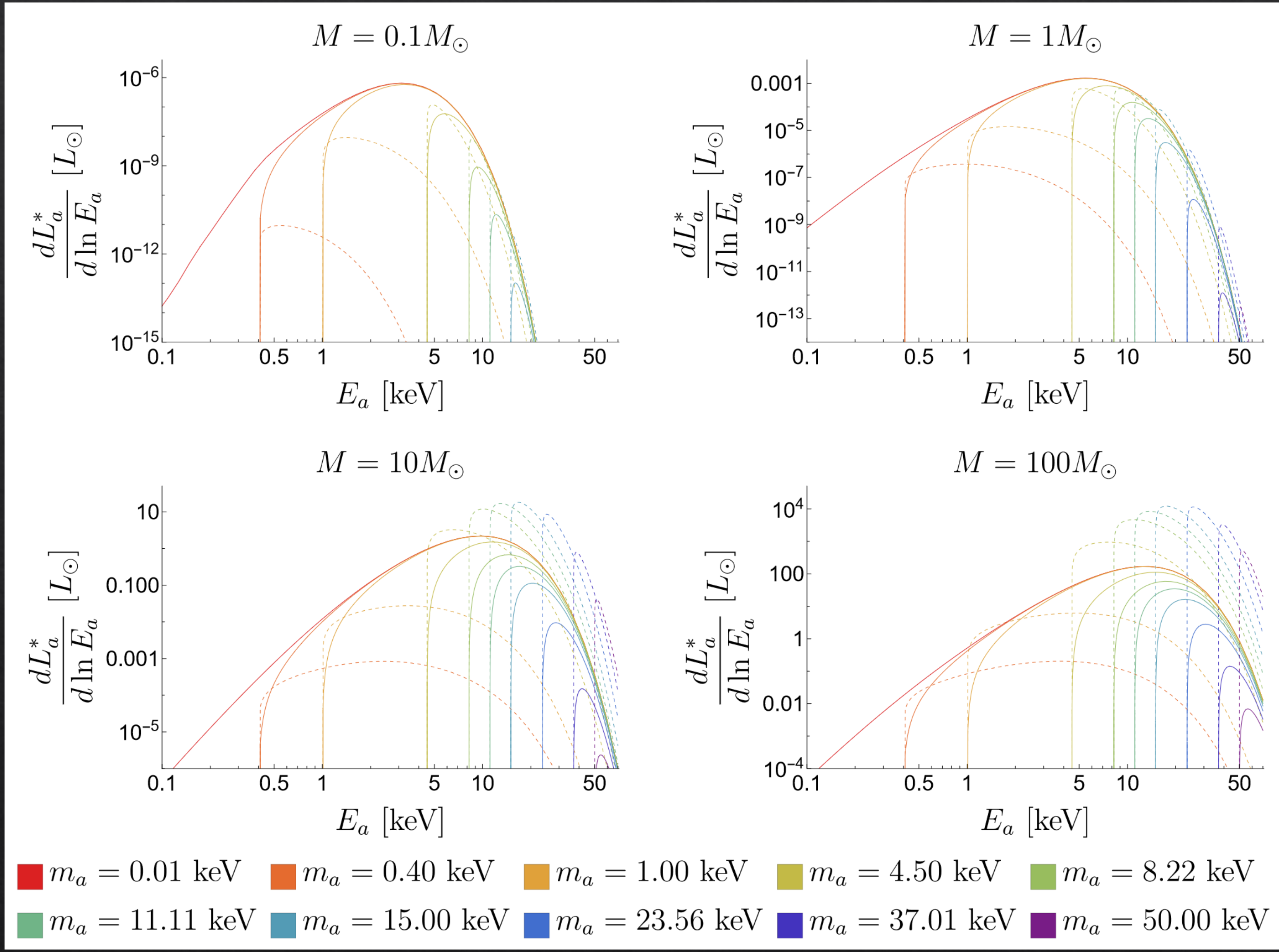
Axion Luminosity Spectrum from a single star



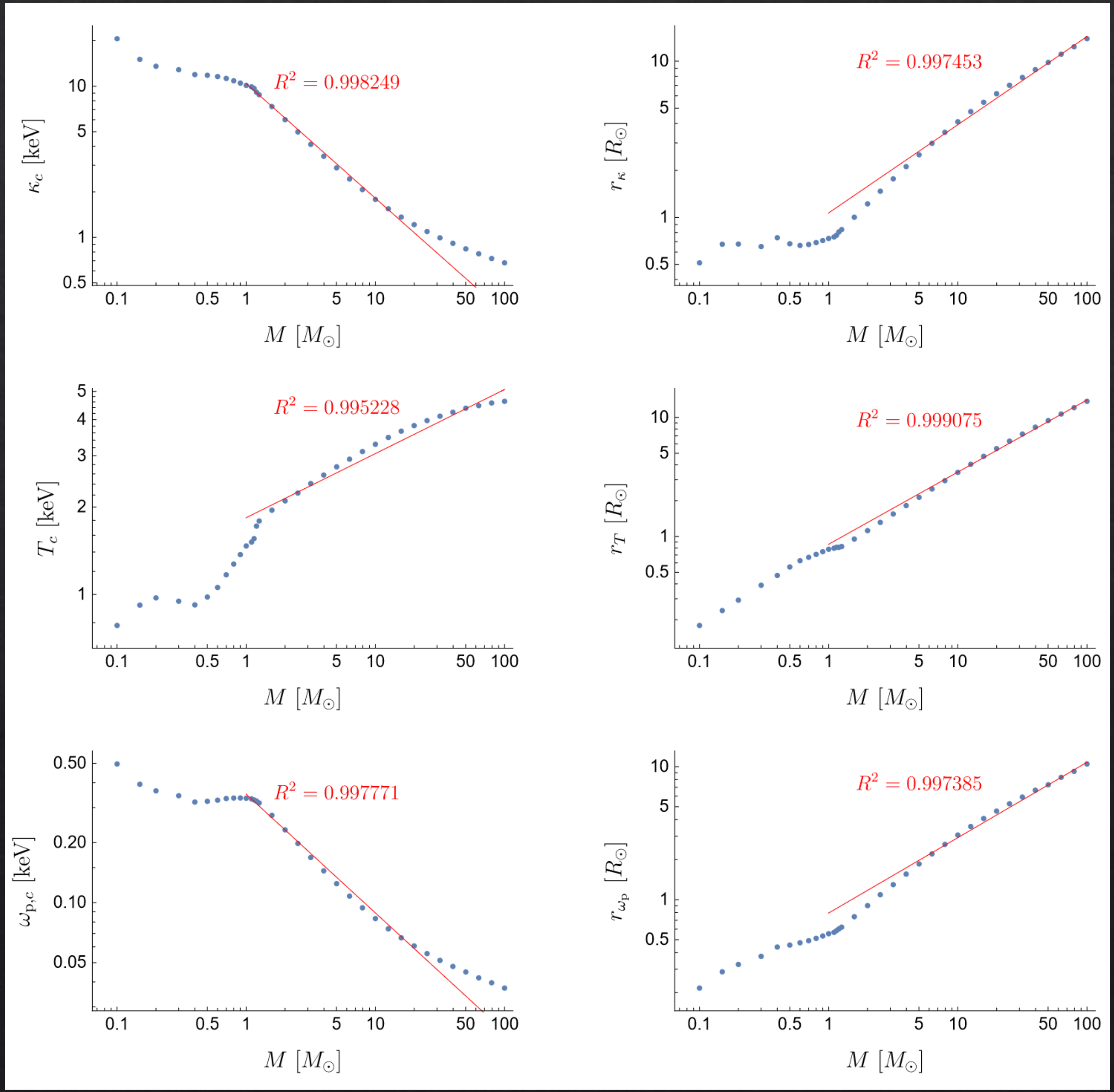
Axion Luminosity Spectrum from a single star

$$L_a^* \sim r_T^3 \left(E_a \frac{d\dot{n}_a{}^*}{dE_a} \right)_{peak} \Delta E_a$$

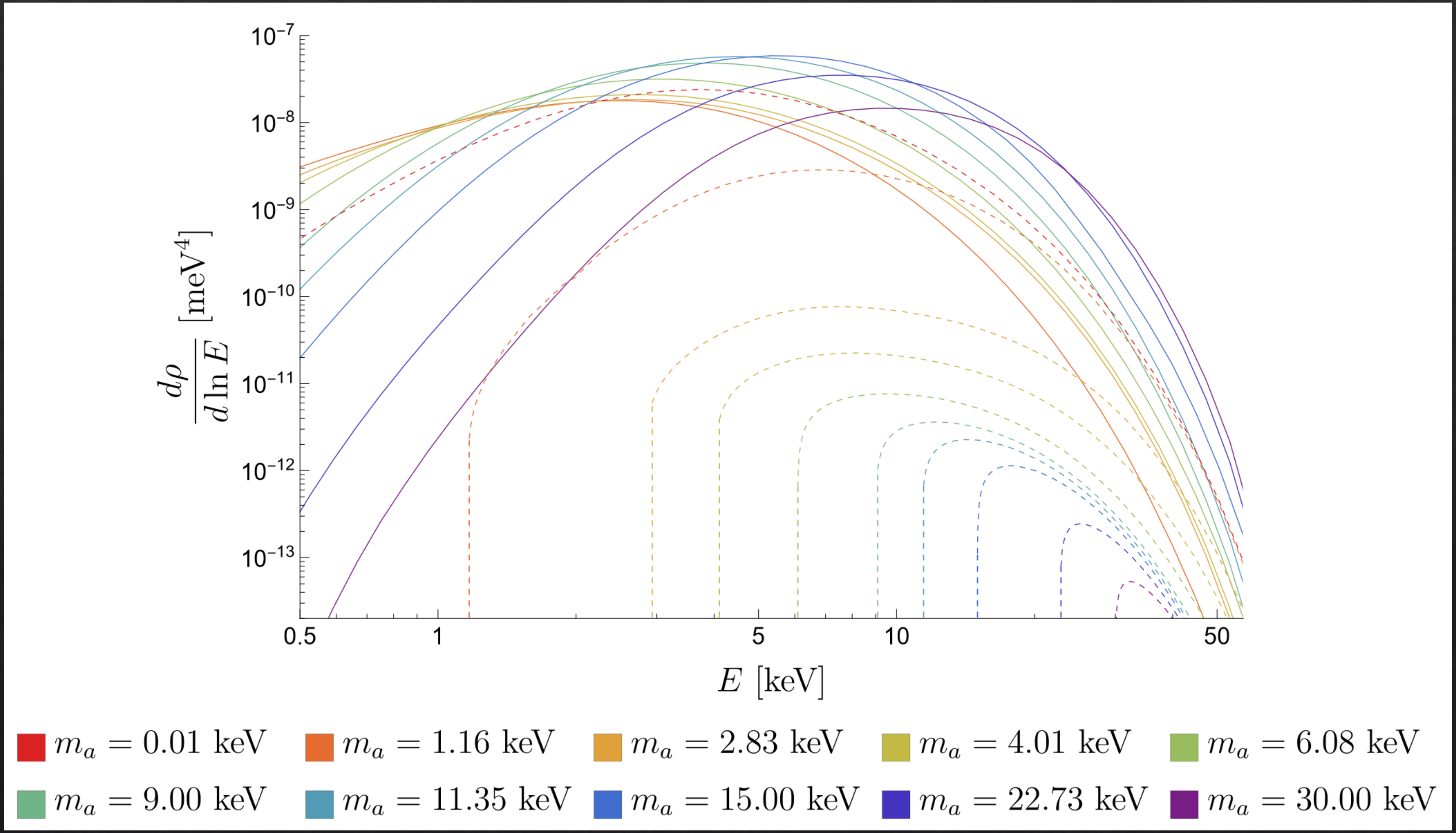
$$L_a^*|_{Prim.} \sim g_{a\gamma\gamma}^2 r_T(M)^3 \kappa_c(M)^2 T_c(M)^2 [\max(3T_c(M), m_a)]^3 \; e^{-m_a/T_c(M)}$$

$$L_a^*|_{Coal.} \sim g_{a\gamma\gamma}^2 r_T(M)^3 m_a{}^5 T_c(M)^2 e^{-m_a/T_c(M)}$$

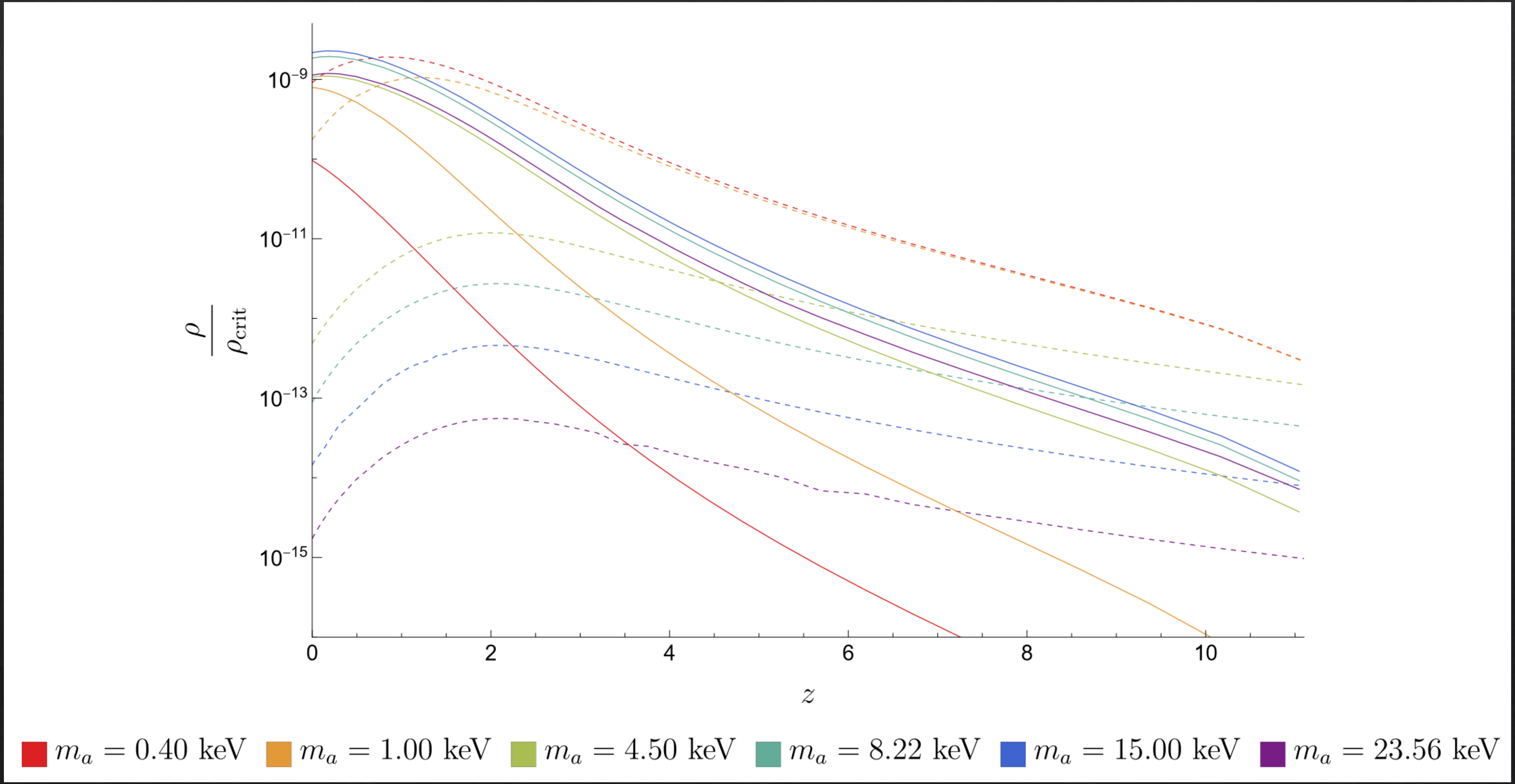
Simple MESA fits



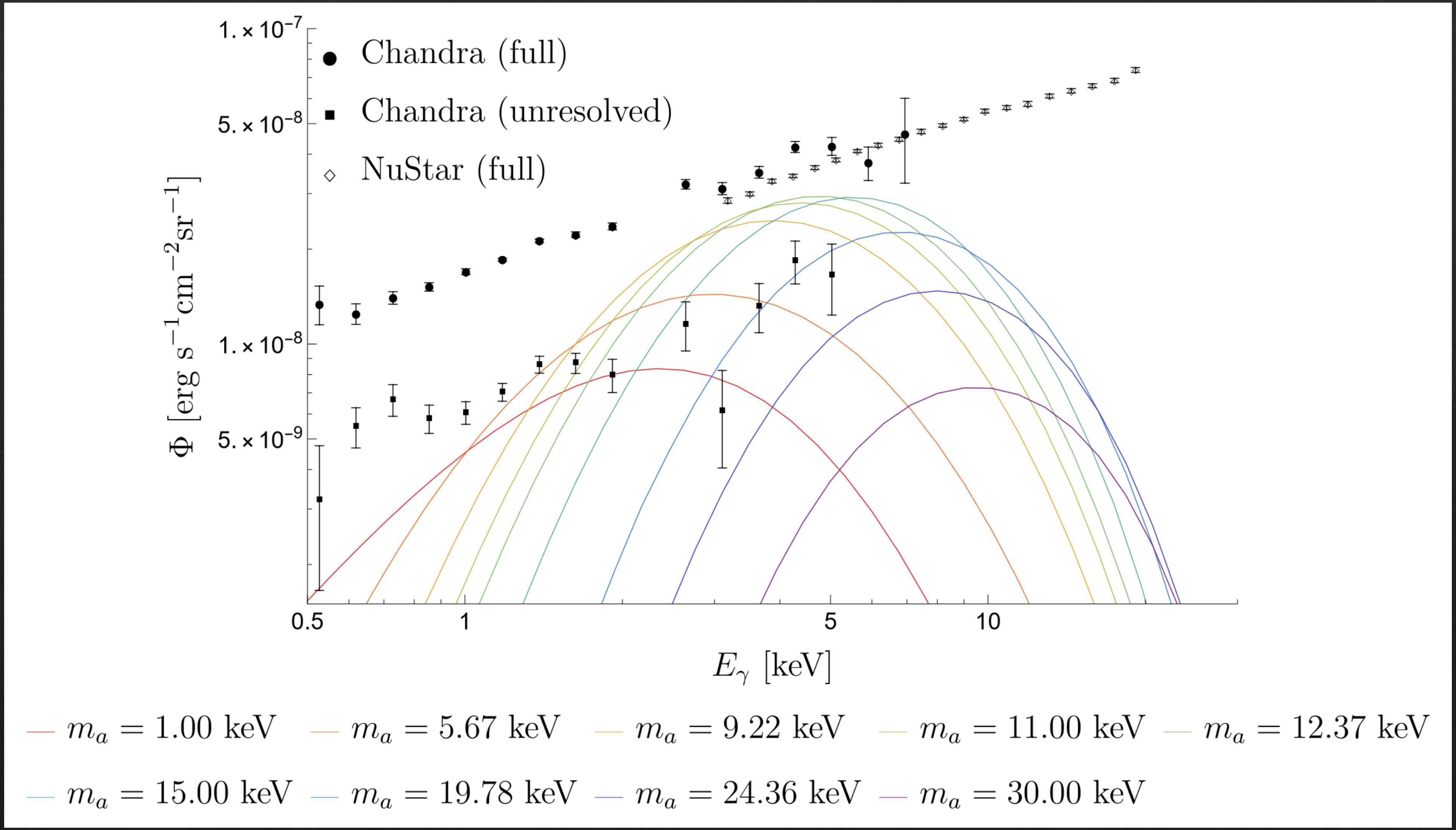
Stellar axion background (StAB) Spectrum



StAB energy density over time



StAB constraints from CXB



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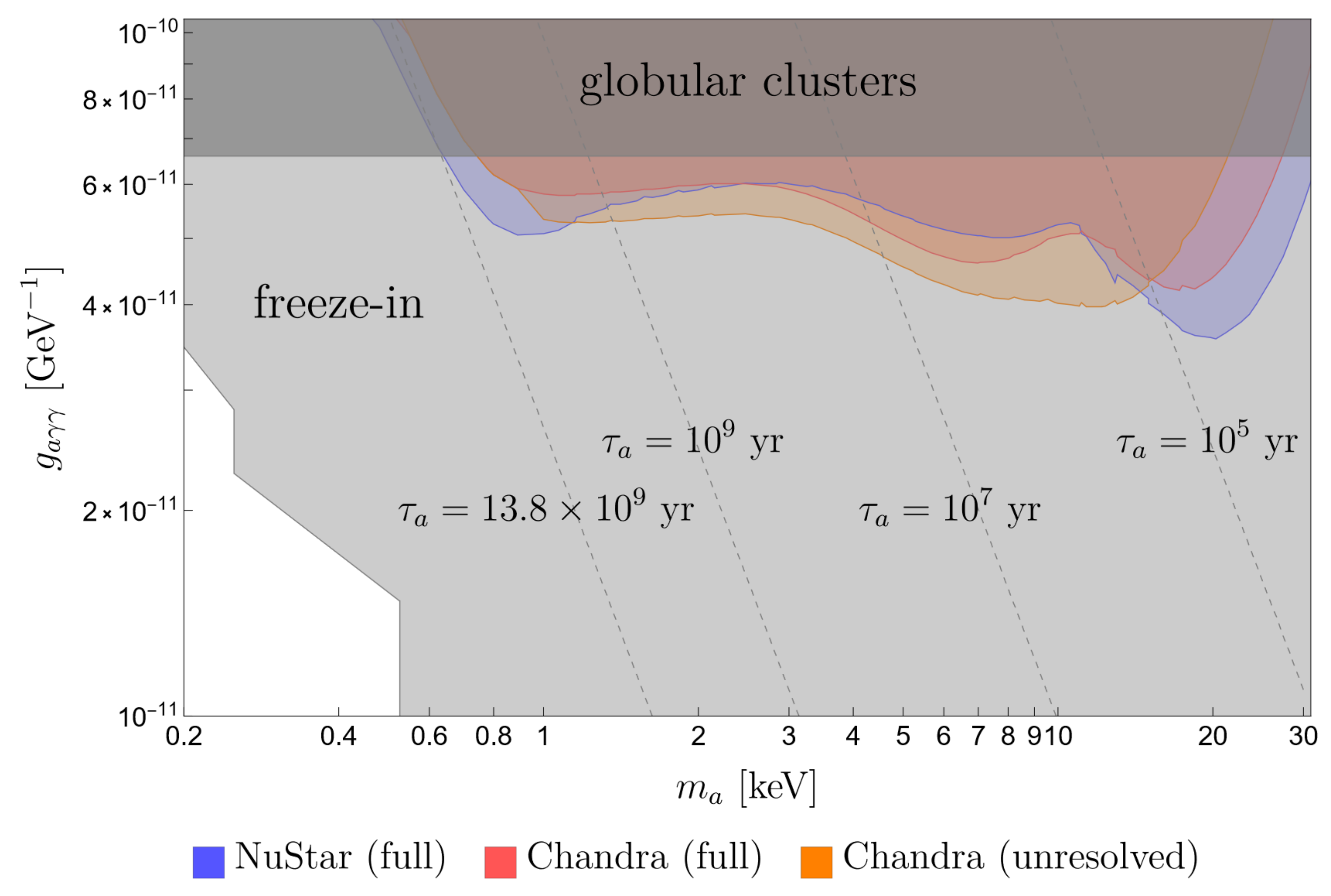

Summary

- Axion spectrum from single star
- Diffuse keV axion background from all stars throughout the Universe history
- Decay to X-ray, distort CXB
- Simple MESA fit for important stellar properties
- Future: other particles, pop. III stars

Pre-print: arXiv:2307.11216