



Search for sub-MeV ALPs from horizontal branch stars

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axions - motivation

- QCD axion solves the strong CP problem

$$\mathcal{L}_{\text{QCD}} \supset - \left(\bar{\mathbf{q}}_L m_q e^{i\theta_Y} \mathbf{q}_R + \text{h.c.} \right) - \frac{\alpha_s}{8\pi} G_{\mu\nu}^a \widetilde{G}_a^{\mu\nu} \theta_{\text{QCD}} = - \frac{\alpha_s}{8\pi} G_{\mu\nu}^a \widetilde{G}_a^{\mu\nu} \theta$$

$|\theta| \lesssim 10^{-10}$

C. Abel et al. 2001.11966

- Heavy QCD axion/axion-like particles

- compactifications in string theory J. M. Pendlebury et al. 1509.04411

- mediator for DM-SM particles interactions Y. Hochberg et al. 1806.10139

- relaxion models P. W. Graham et al. 1504.07551

- heavy QCD axions with preferred f_a K. Choi, 0308024

P. Svrcek & E. Witten, 0605206

Heavy axion constraints

beam dump experiments & colliders

BaBar
E137
E141
CHARM
LEP
...



Image: BaBar collaboration

cosmology

CMB spectra
 ΔN_{eff}
D & He abundance
extragalactic BG
...

Image: Planck collaboration

Sun
Globular Cluster
SNe
WD mass
...



Image: NASA

astrophysics

My work:
Search for hard X-rays/gamma-rays
from decays of axions produced in
horizontal branch stars in globular
cluster

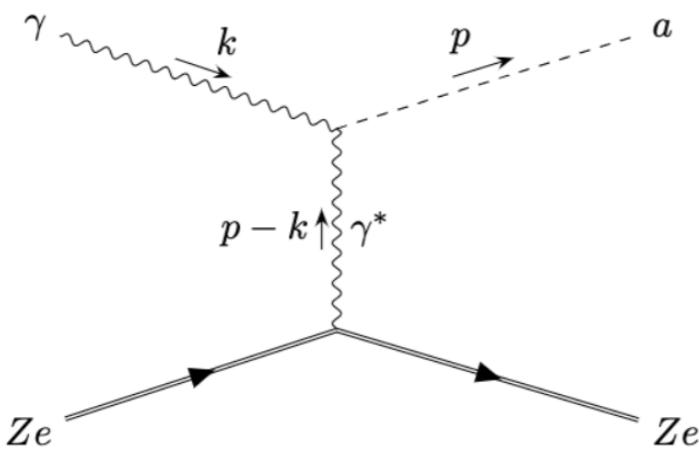


Axion production in stars

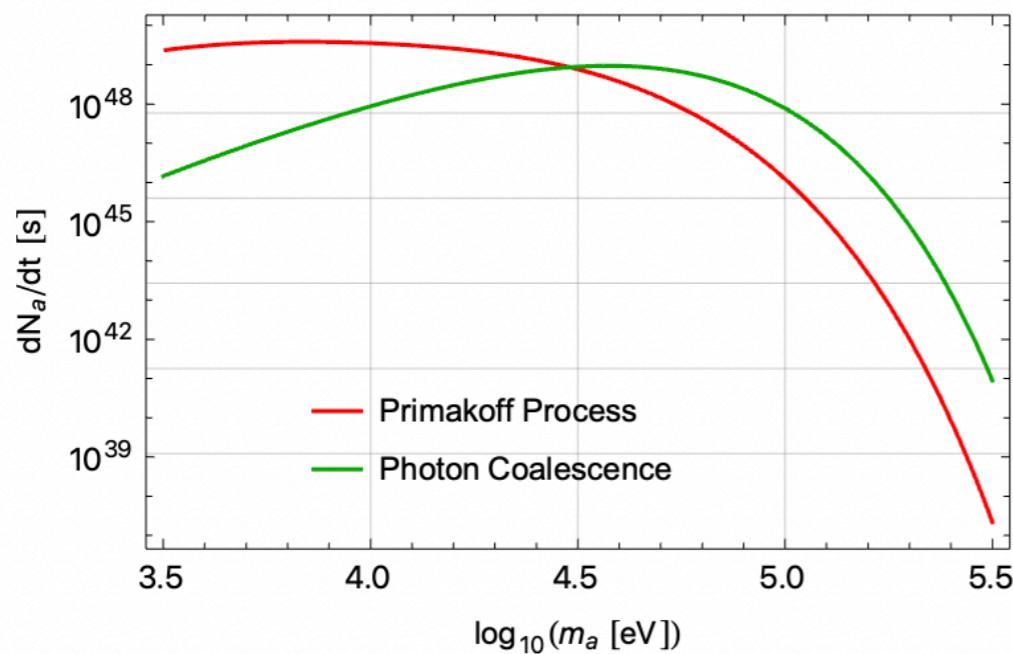
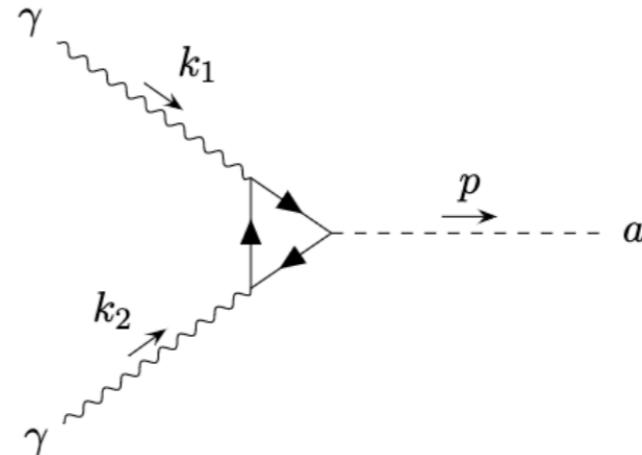
Consider keV-MeV QCD axions/ALPs coupled to photons:

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

Primakoff process ($\gamma + Ze \rightarrow a + Ze$)



Photon coalescence ($2\gamma \rightarrow a$)



Debye shielding

$$\kappa^2 = \frac{4\pi\alpha}{T} \left(n_e^{eff} + \sum_j Z_j^2 n_j^{eff} \right)$$

Horizontal branch stars

Advantages of HB stars:

- High core temperature

$$\frac{d^2 N_a}{d E_a dt} \propto e^{-E/T}$$

- Small radius of photosphere

$$l_a \sim 50R_\odot \left(\frac{100 \text{ keV}}{m_a} \right)^3 \left(\frac{10^{-6} \text{ GeV}^{-1}}{g_{a\gamma}} \right)^2$$

- number of HB stars is not small

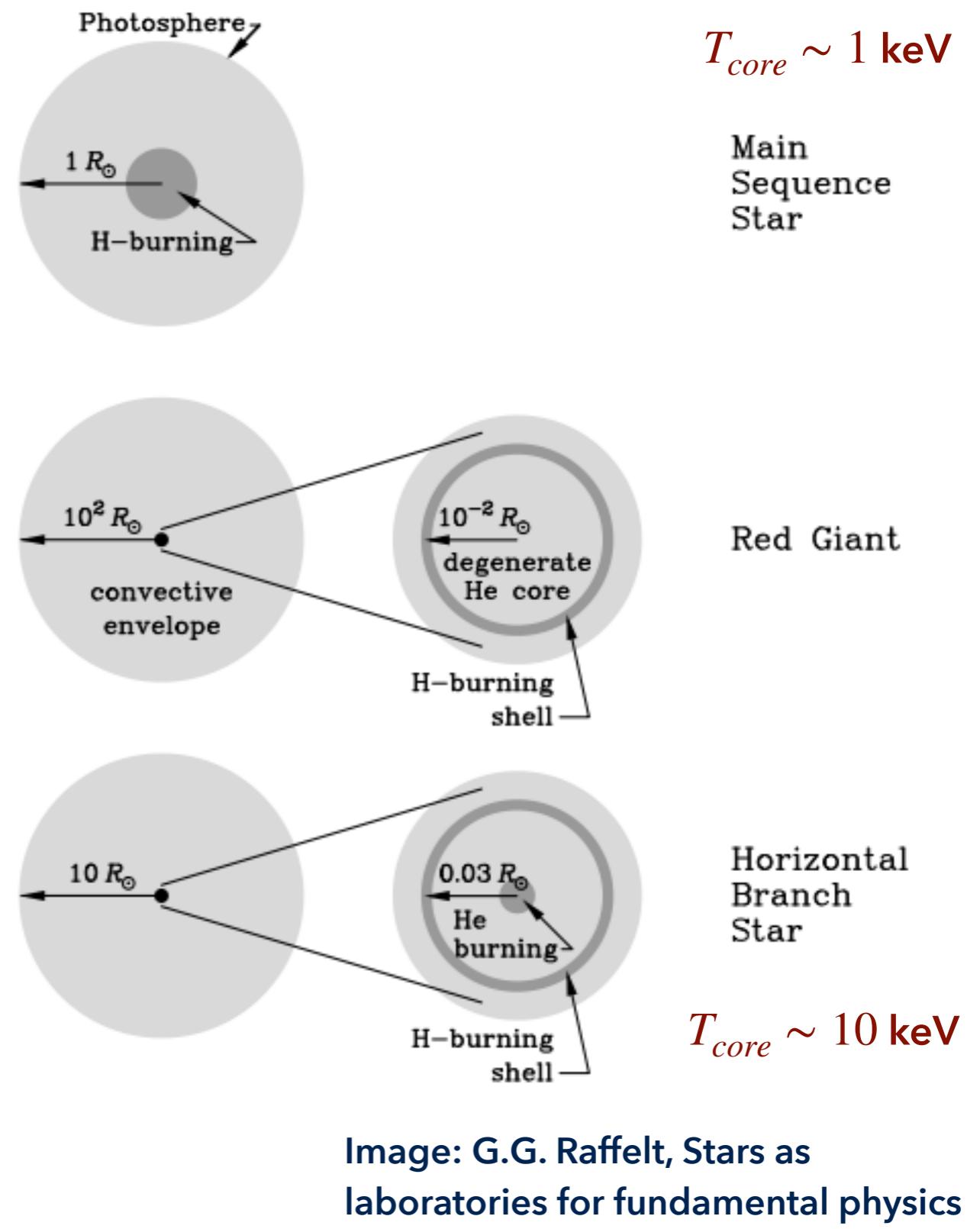
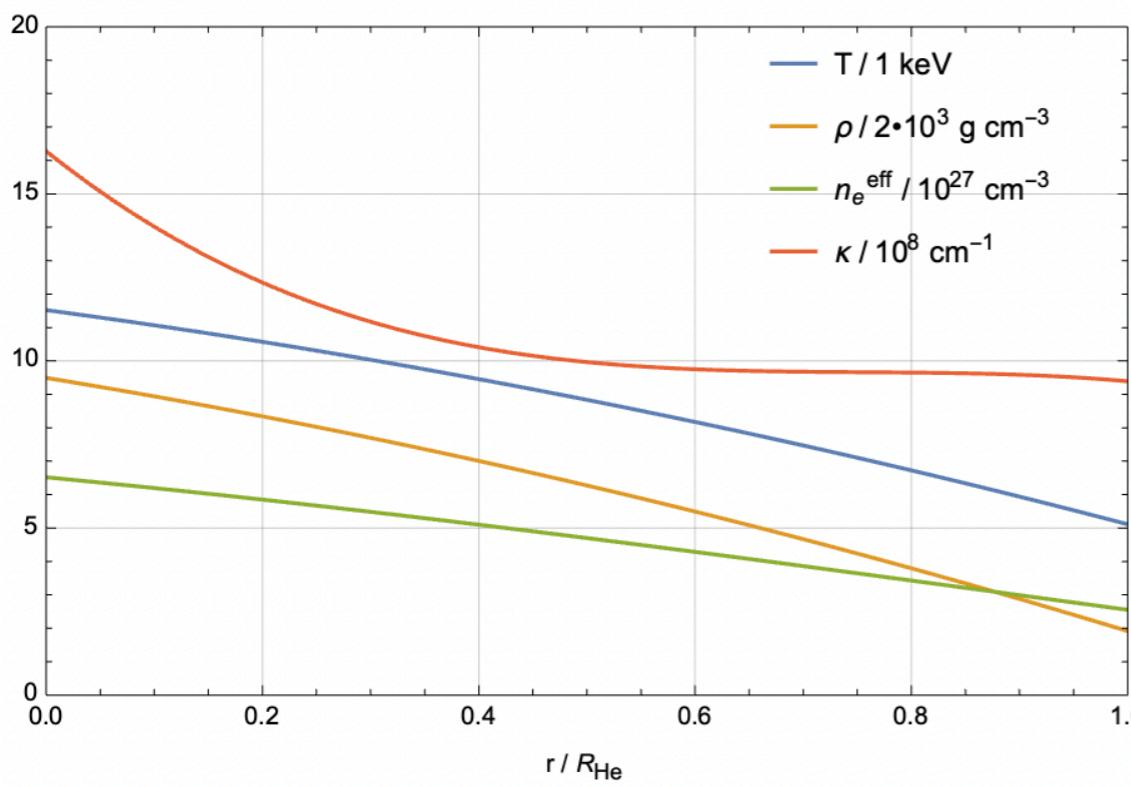


Image: G.G. Raffelt, Stars as laboratories for fundamental physics

Globular cluster

Globular cluster: millions of gravitationally bounded stars

NGC 2808

- Large:

$$n_{HB} = 1200$$

- Close to the earth:

$$d = 31.3 \text{ kly}$$

- Away from the Galactic center:

$$\text{dec.} = -64^\circ 51' 48''$$



Image: ESA

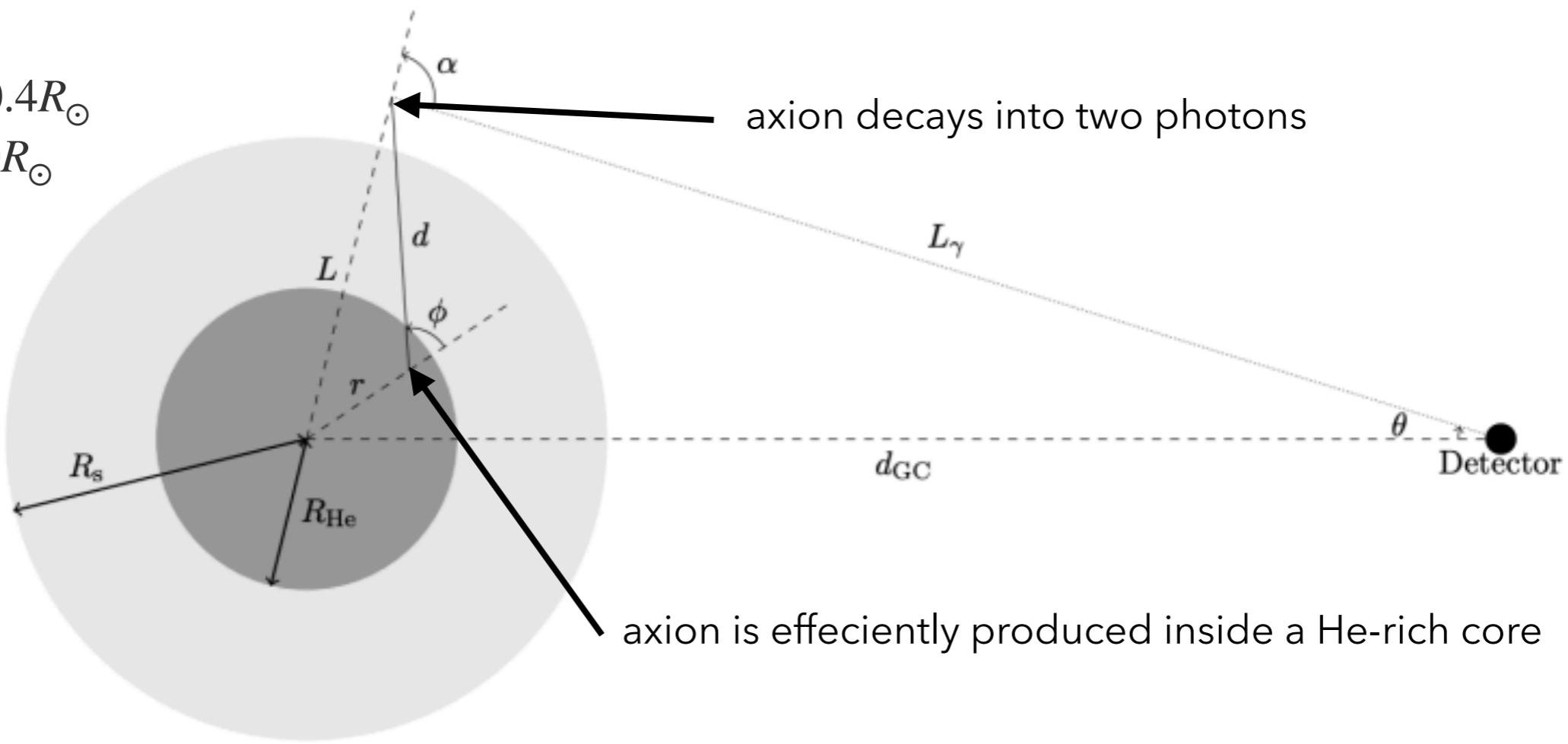
Possible backgrounds:

- inverse compton
- bremsstrahlung
- π_0
- emissions from pulsars

Photon flux at the earth

$$R_{He} \sim 0.4 R_{\odot}$$

$$R_s \sim 20 R_{\odot}$$



2 photons
from each decay

$$d\tilde{F}_{\gamma} = 2 \cdot \frac{1}{4\pi d_{GC}^2} \cdot \frac{dN}{d\omega} d\omega \cdot f_{c_{\alpha}}(\omega, c_{\alpha}) dc_{\alpha} \cdot$$

spectral fluence of
axions at the earth

angular distribution
of photons

$$\frac{\exp[-L/l_a(\omega)]}{l_a(\omega)} dL \cdot$$

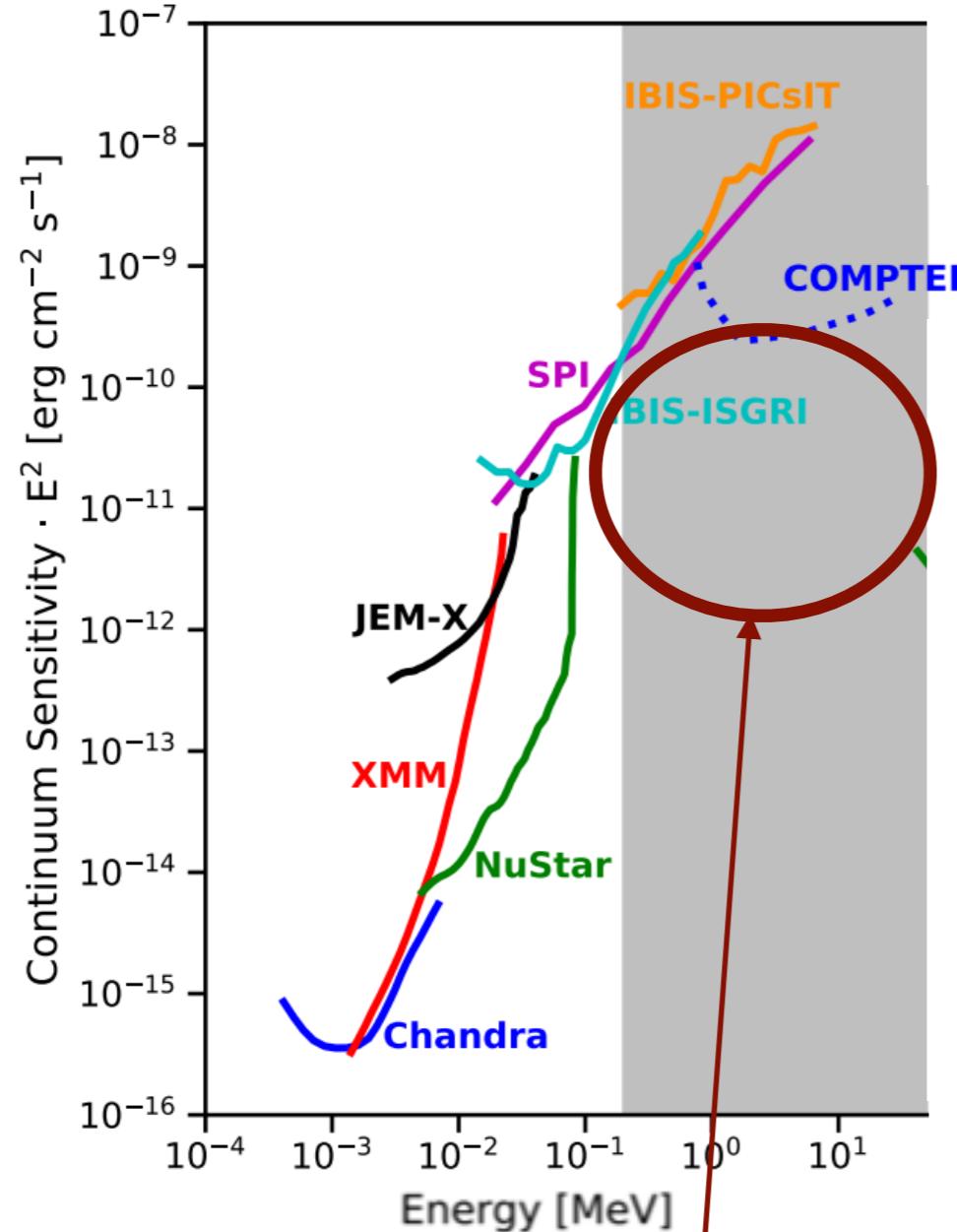
decay probability

constraints on ω, c_{α}, L

$$\Theta_{\text{cons.}}(\omega, c_{\alpha}, L)$$

Telescopes

G. Lucchetta et al. 2204.01325

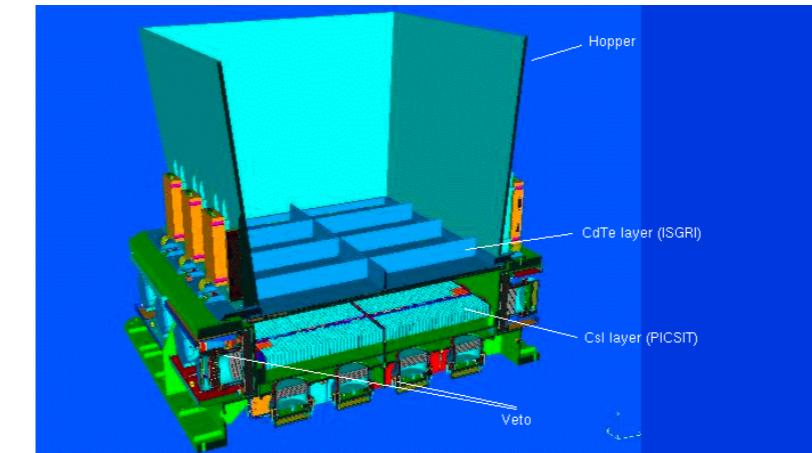


IBIS-ISGRI

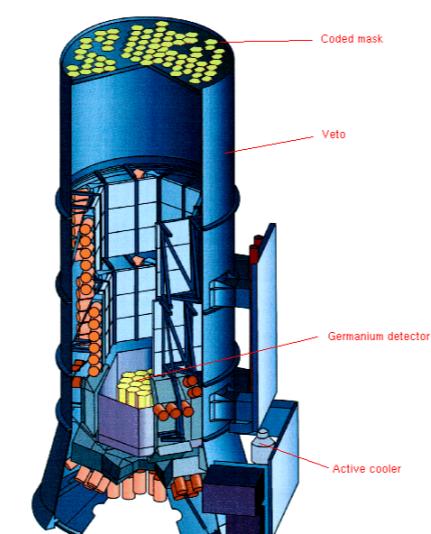
G. Di Cocco et al. A&A 411 1 (2003)

IBIS-PICsIT

G. Vedrenne et al. A&A 411 1 (2003)



SPI G. Vedrenne et al. A&A 411 1 (2003)



NuSTAR F. A. Harrison et al. 1301.7307

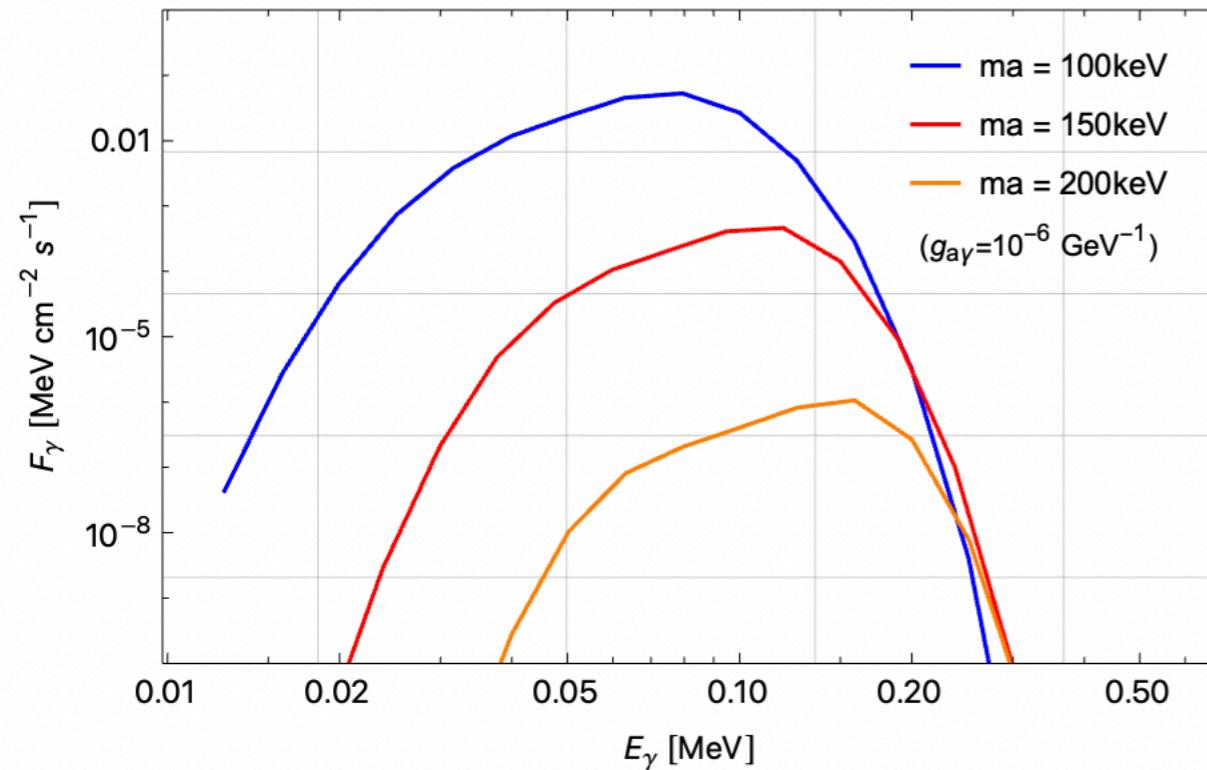


Future telescopes:

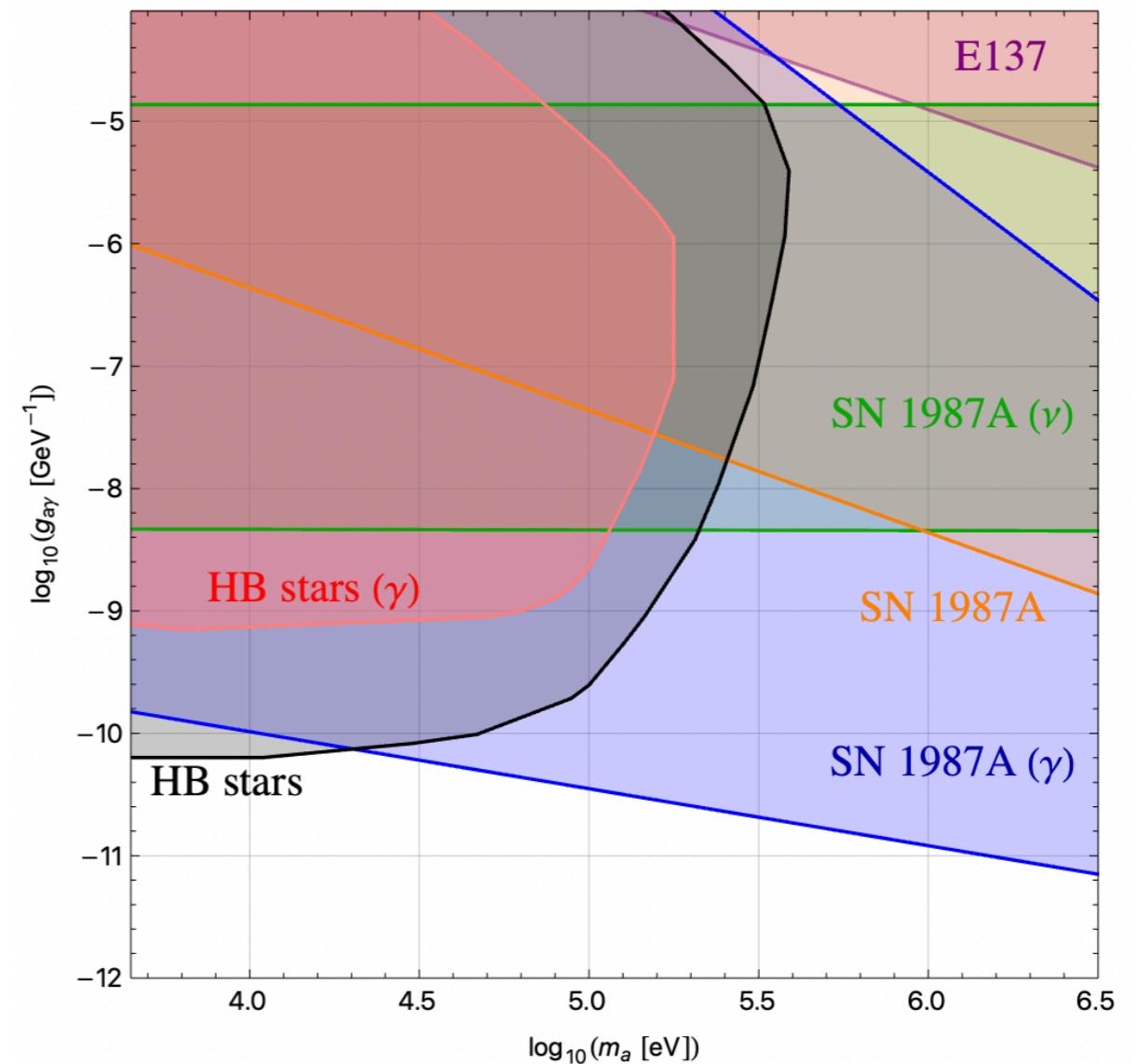
- ASTROGAM A. De Angelis et al. 2102.02460
- AMEGO-X R. Caputo et al. 1907.07558
- GECCO E Orlando et al. 2112.07190

Results

fluence



constraints



- the fluence peaks at $E_\gamma \simeq m_a/2$
- can exclude $g_{a\gamma} \gtrsim 8 \times 10^{-10}$ GeV $^{-1}$ for $m_a \lesssim 100$ keV
- doesn't depend on the helium fraction of GCs

Conclusion

- heavy keV-MeV axions are predicted in several models
- heavy axions are efficiently produced in the plasma of horizontal branch stars
- Photons from their decays will be detected by current hard X-ray telescopes or future MeV gamma-ray telescopes if $g_{a\gamma} \gtrsim 8 \times 10^{-10} \text{ GeV}^{-1}$ for $m_a \lesssim 100 \text{ keV}$
- Bounds don't depend on the helium fraction Y , which is not measured precisely

Backup slides

Production spectra

Primakoff process:

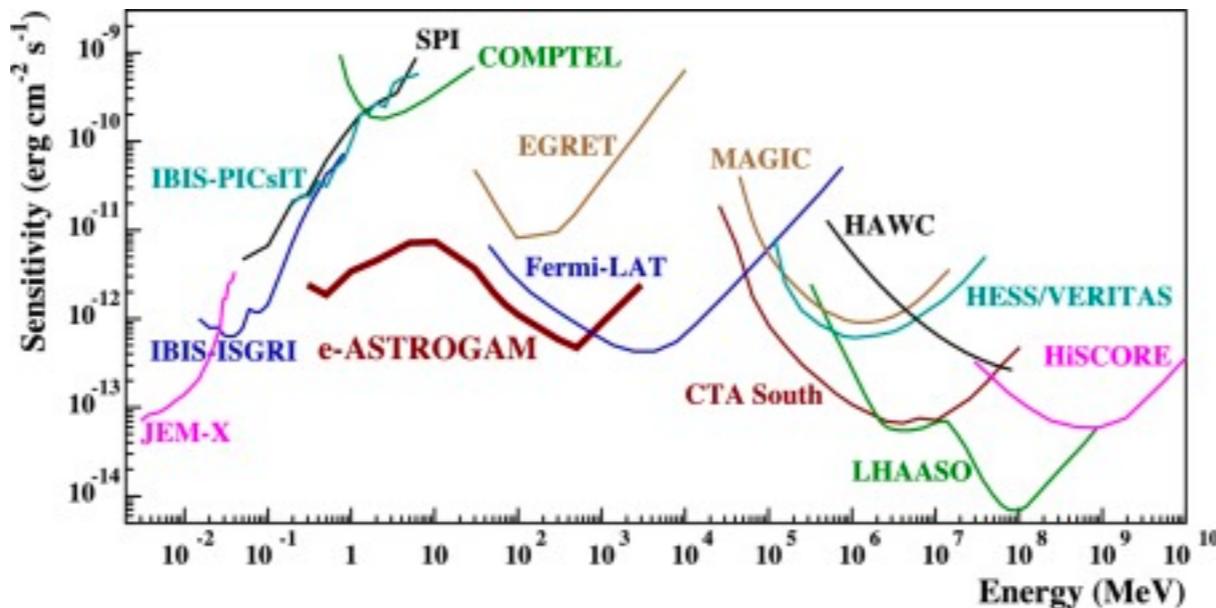
$$\frac{d^2N_a}{dEdt}(r, t, E) = \frac{\beta_\gamma}{e^{E/T} - 1} \frac{g_{a\gamma}^2 T \kappa^2}{32\pi^3} p E \\ \left\{ \frac{[(k+p)^2 + \kappa^2] [(k-p)^2 + \kappa^2]}{4pk\kappa^2} \ln \left[\frac{(k+p)^2 + \kappa^2}{(k-p)^2 + \kappa^2} \right] - \frac{(k^2 - p^2)^2}{4kp\kappa^2} \ln \left[\frac{(k+p)^2}{(k-p)^2} \right] - 1 \right\}$$

Photon coalescence:

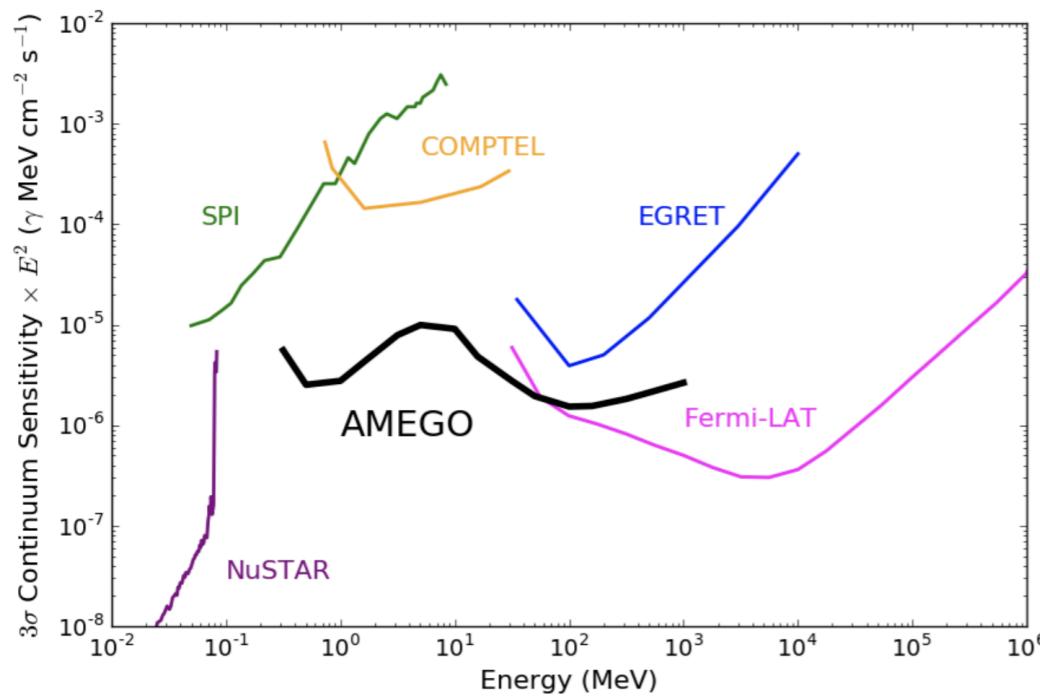
$$\frac{d^2N_a}{dEdt}(r, t, E) = \frac{g_{a\gamma}^2}{128\pi^3} m_a^4 \sqrt{E^2 - m_a^2} \left(1 - \frac{4\omega_{pl}^2}{m_a^2} \right)^{3/2} e^{-E/T}$$

Future MeV gamma-ray detectors

e-ASTROGAM:



AMEGO-X:



GECCO:

