Axions in astrophysics and cosmology

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Axion Lagrangian

Axions are pseudoscalars which interact with SM particles as

$$\mathcal{L}_{\mathrm{ax}} = \frac{1}{2}\partial_\mu a \partial^\mu a - \xi \frac{a}{f_a}\frac{g^2}{32\pi^2}\tilde{G}^a_{\mu\nu}G^{\mu\nu a} + \\ + \frac{g_a}{2m}\bar{\Psi}\gamma^\mu\gamma^5\Psi\partial_\mu a - \frac{g_{a\gamma}}{4}a\tilde{F}^{\mu\nu}F_{\mu\nu} - \frac{1}{2}m_a^2 a^2$$

where f_a is a typical energy scale, the Peccei-Quinn scale, and m_a is the axion mass

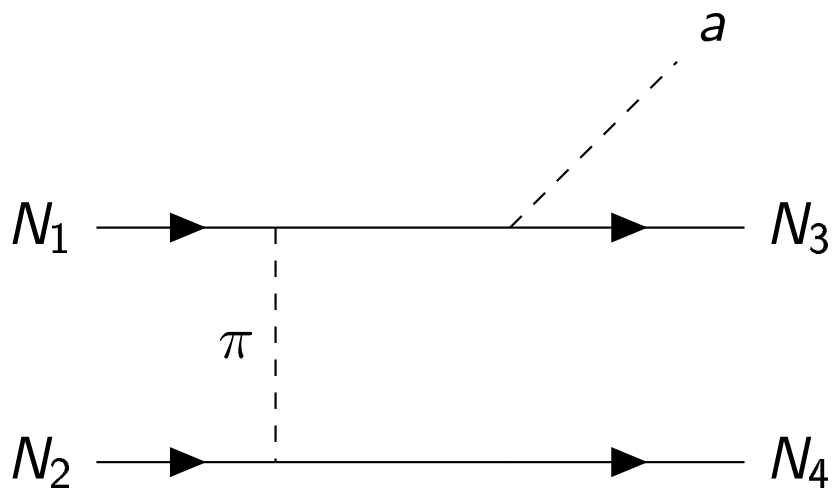
Axions could solve

- The strong CP problem
- The origin of dark matter
- Some stellar anomalies

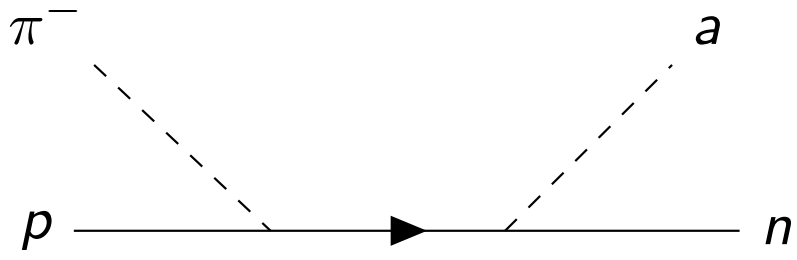
Axion production channels

Axions coupled to nucleons

NN bremsstrahlung



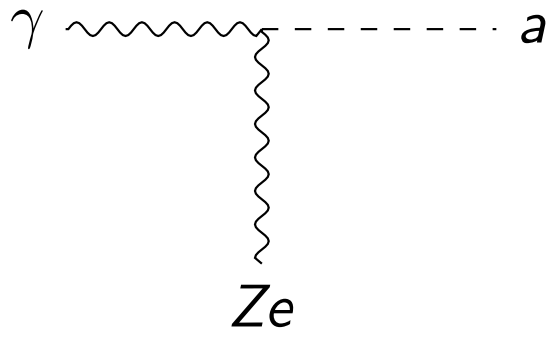
Pion-axion conversion



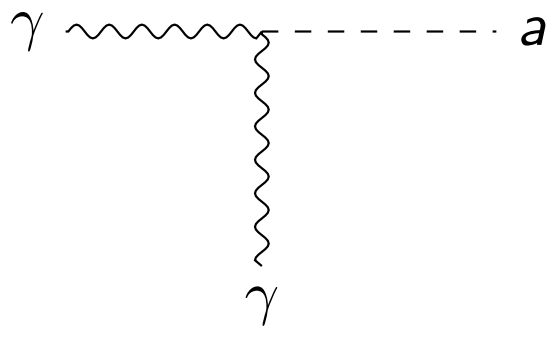
Axion production channels

Axions coupled to photons

Primakoff conversion



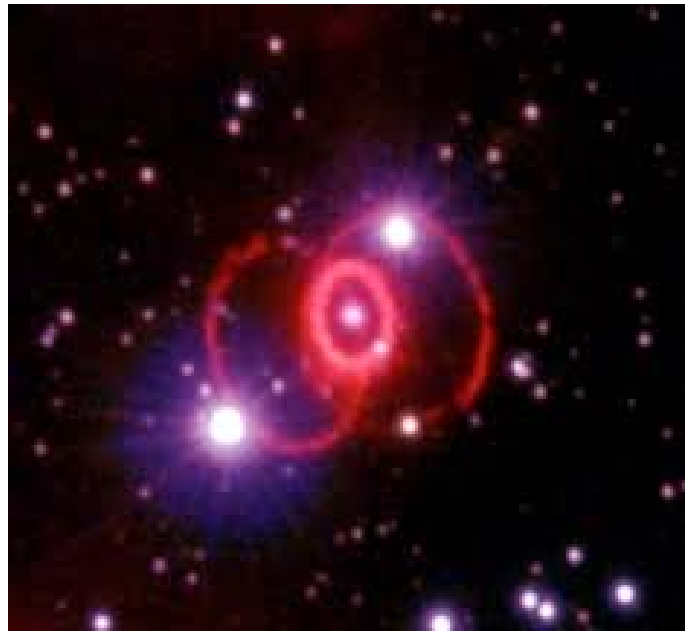
Inverse Decay



The energy-loss argument

G. Raffelt, Lect. Notes Phys. **741** (2008)

Stars produce axions which escape, draining energy from the core



Axions affect strongly the SN explosion if

$$\epsilon_a > 10^{19}\,\mathrm{erg\,g^{-1}\,s^{-1}}$$

and HB star evolution if

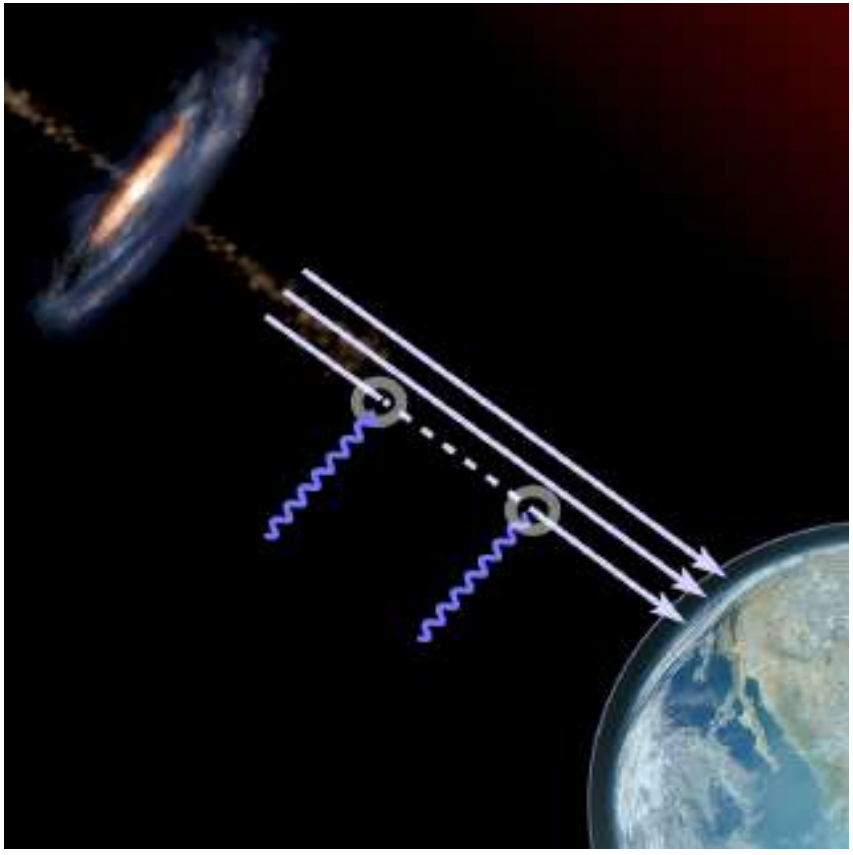
$$\epsilon_a > 10\,\mathrm{erg\,g^{-1}\,s^{-1}}$$

ALP-photon oscillations

The ALP-photon interaction

$$\mathcal{L} = g_{a\gamma} a \, \mathbf{E} \cdot \mathbf{B}$$

allows for photon-ALP conversions in the Galactic or stellar B fields



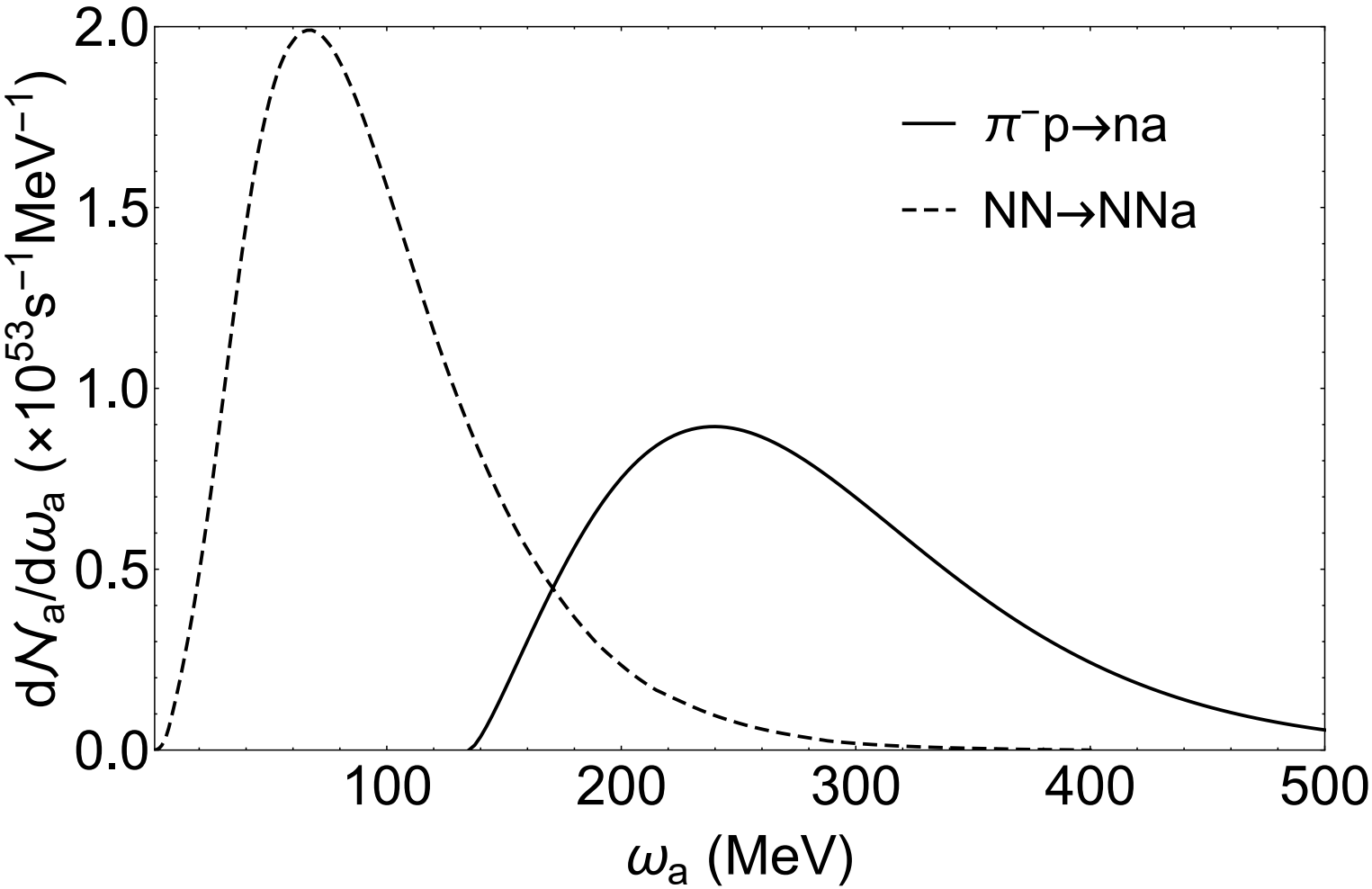
Enhanced Supernova Axion Emission and its Implications

In collaboration with B. Fore, M. Giannotti, A. Mirizzi and S. Reddy

arXiv:2010.02943 [hep-ph]

Pions in SN1987A

Axions are produced by pion-axion conversion ($Y_\pi \sim 1\%$)



The SN cooling bound is $\times 2$ stronger

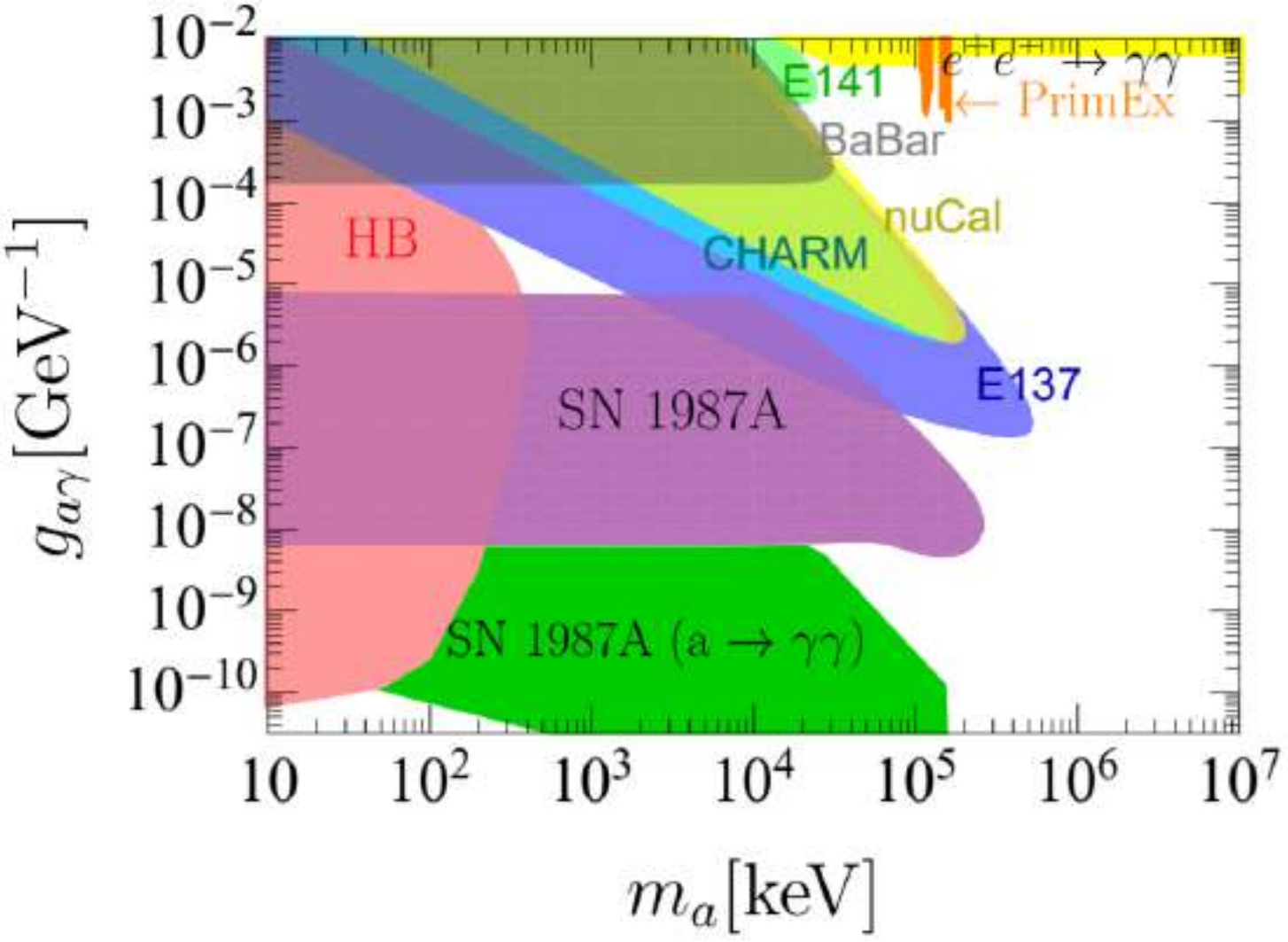
Heavy axion-like particles and core-collapse supernovae: constraints and impact on the explosion mechanism

In collaboration with G. Lucente, T. Fischer, M. Giannotti and A. Mirizzi

arXiv:2008.04918 [hep-ph]

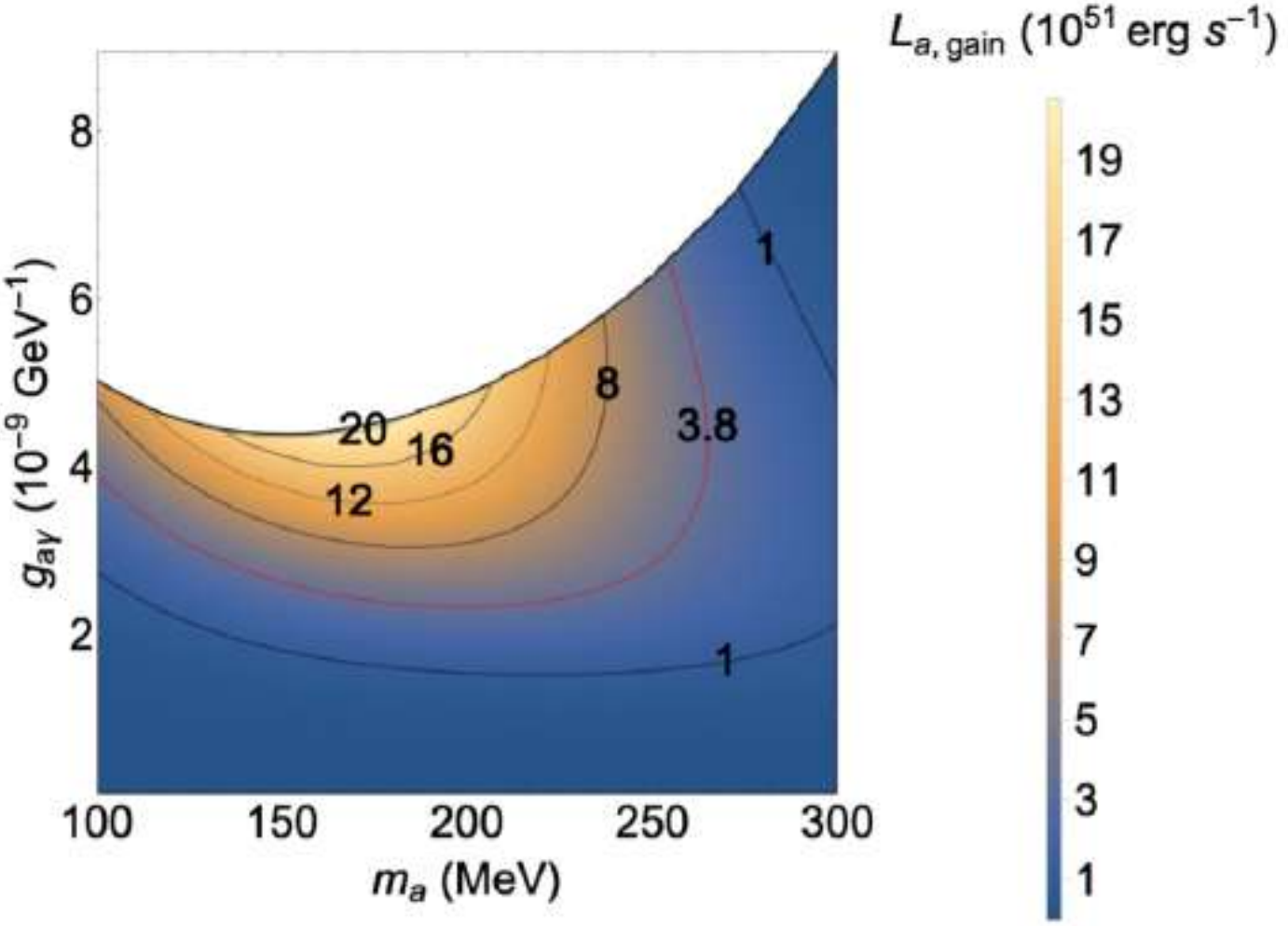
Axion-Like Particles from SNe: SN1987A bound

ALP are produced via Primakoff conversion and Inverse Decay



Can ALP revitalize the SN shock?

Massive ALP could decay inside the SN revitalizing the shock



Energy deposited at $t_{\mathrm{pb}} = 0.3\,\mathrm{s}$, the red line indicates where the ALP deposit the same energy as neutrinos

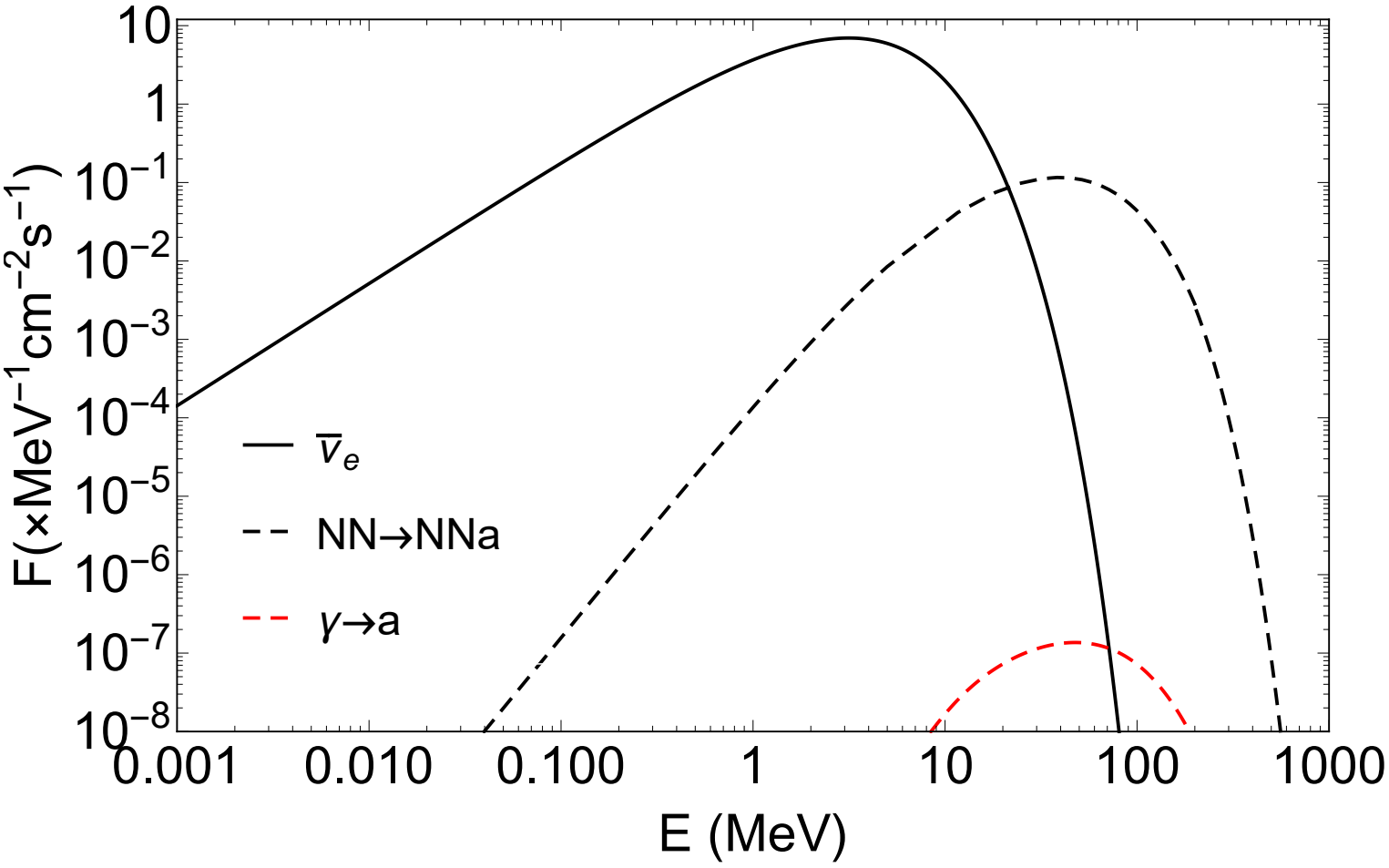
Bounds on axion-like particles from the diffuse supernova flux

In collaboration with F. Calore, M. Giannotti, J. Jaeckel and A. Mirizzi

arXiv:2008.11741 [hep-ph]

DSNALPB

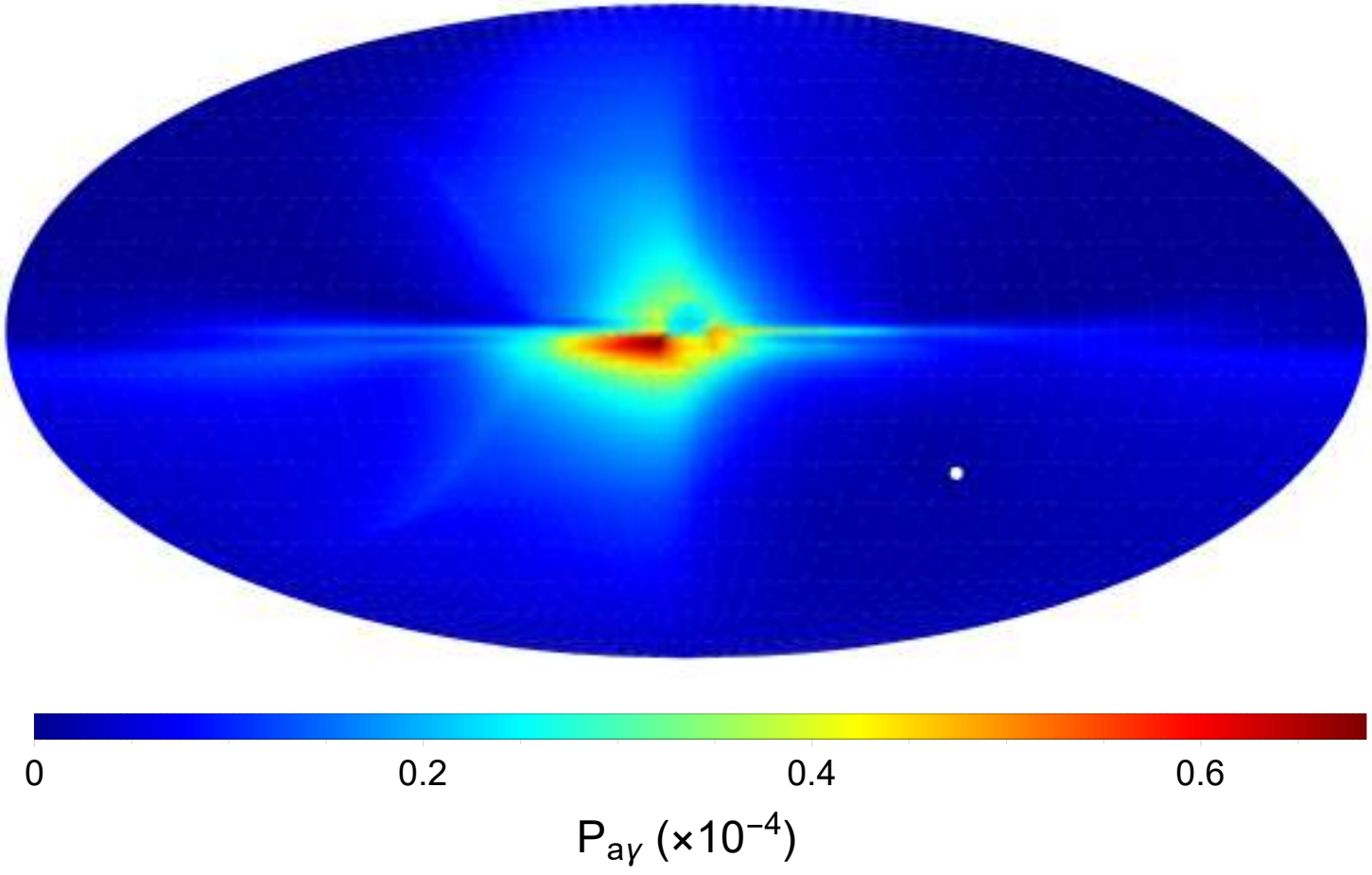
In analogy to neutrinos, the DSNALPB is created by all past SNe



DSNALPB with $g_{ap} = 1.2 \times 10^{-9}$ and $g_{a\gamma} = 5.3 \times 10^{-12}\,\mathrm{GeV}^{-1}$

ALP conversion into photons

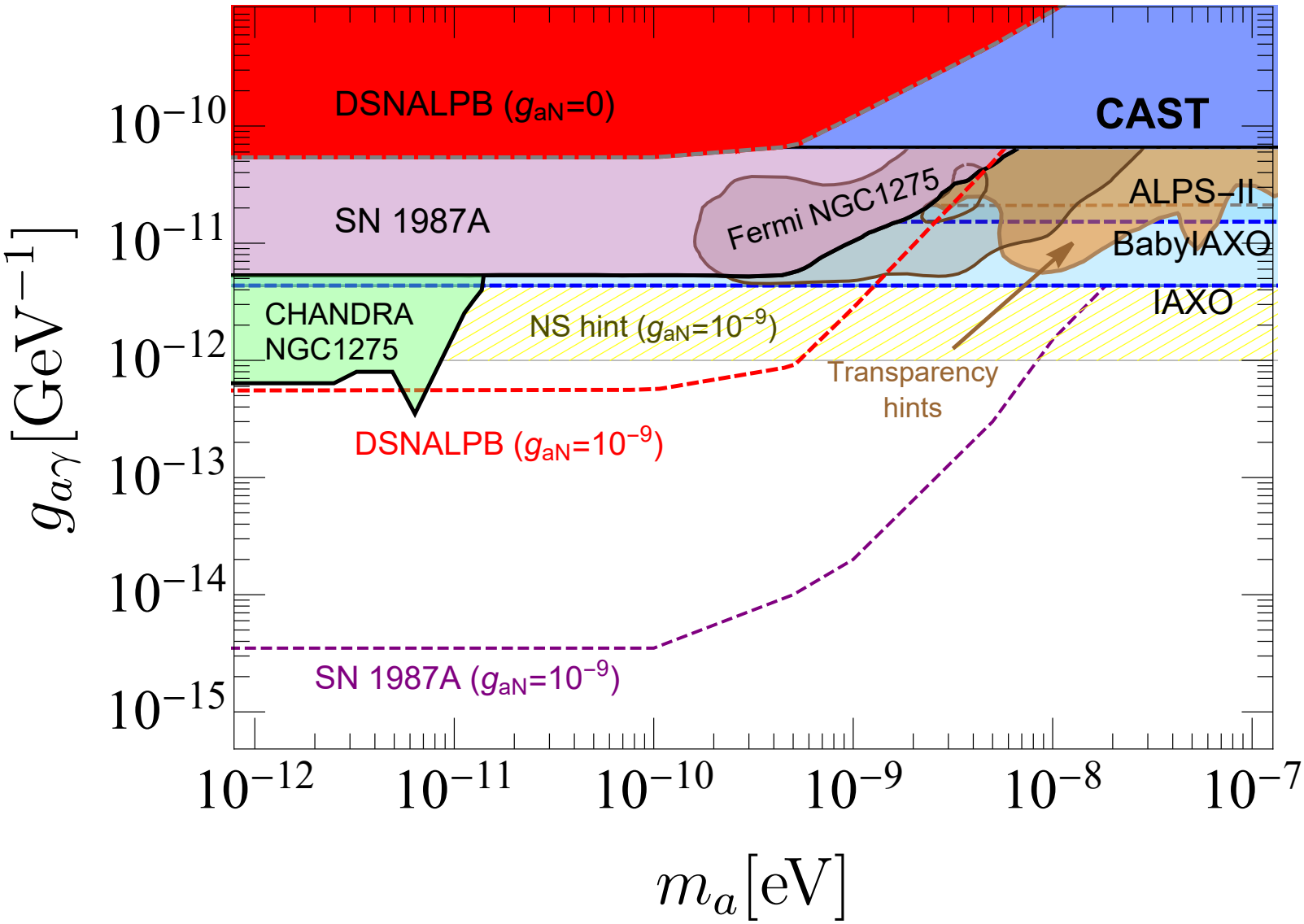
The Galactic magnetic field will convert into photons both the DSNALPB and the point-like ALP flux from SN1987A (white dot)



Conversion probability for $m_a \ll E = 50\,\mathrm{MeV}$, $g_{a\gamma} = 3 \times 10^{-13}\,\mathrm{GeV}^{-1}$

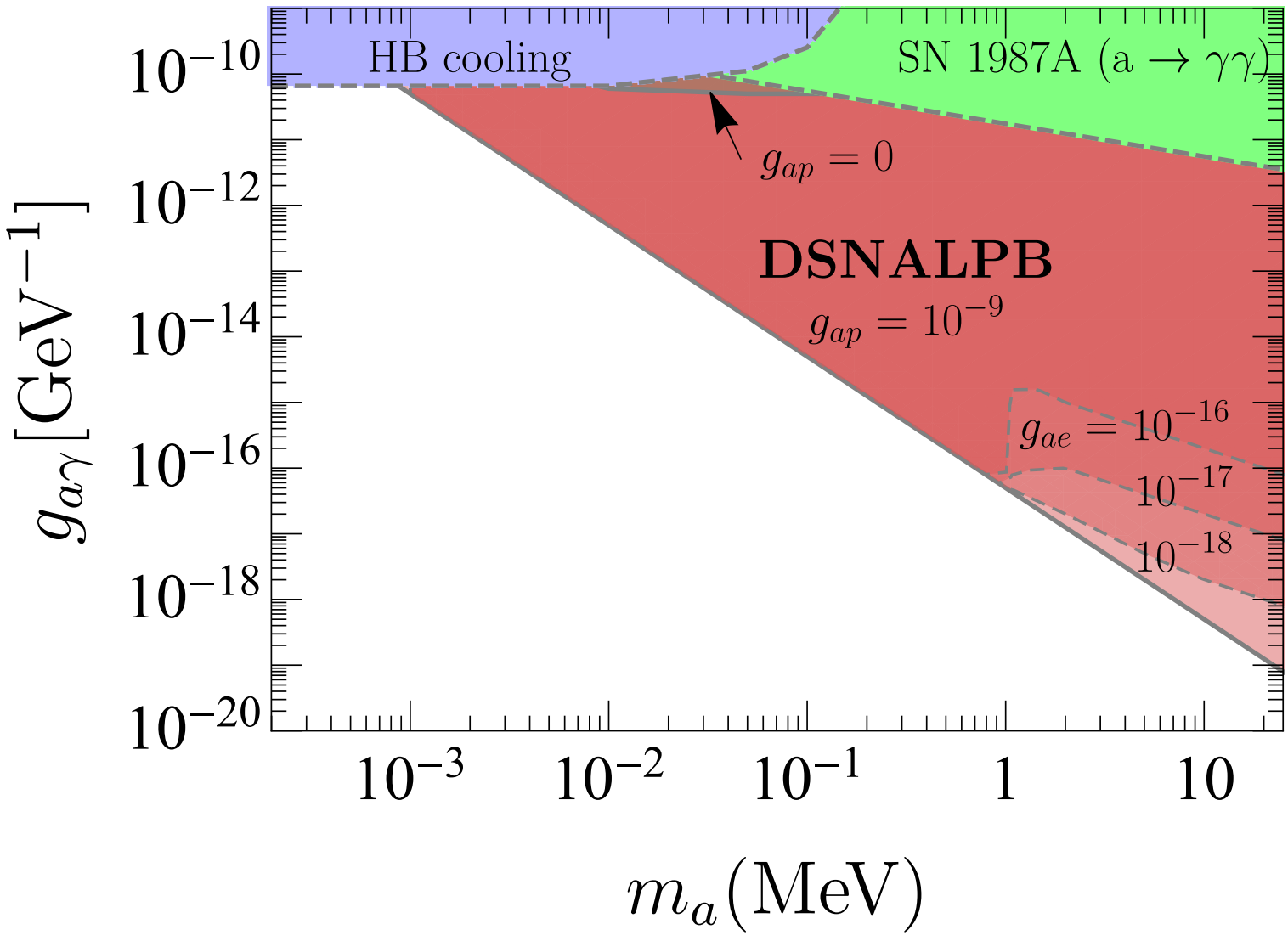
Bound on neV-scale ALPs

Diffuse -ray background constrained by Fermi-LAT



Bound on MeV-scale ALPs

Diffuse -ray background constrained by Fermi-LAT+COMPTEL



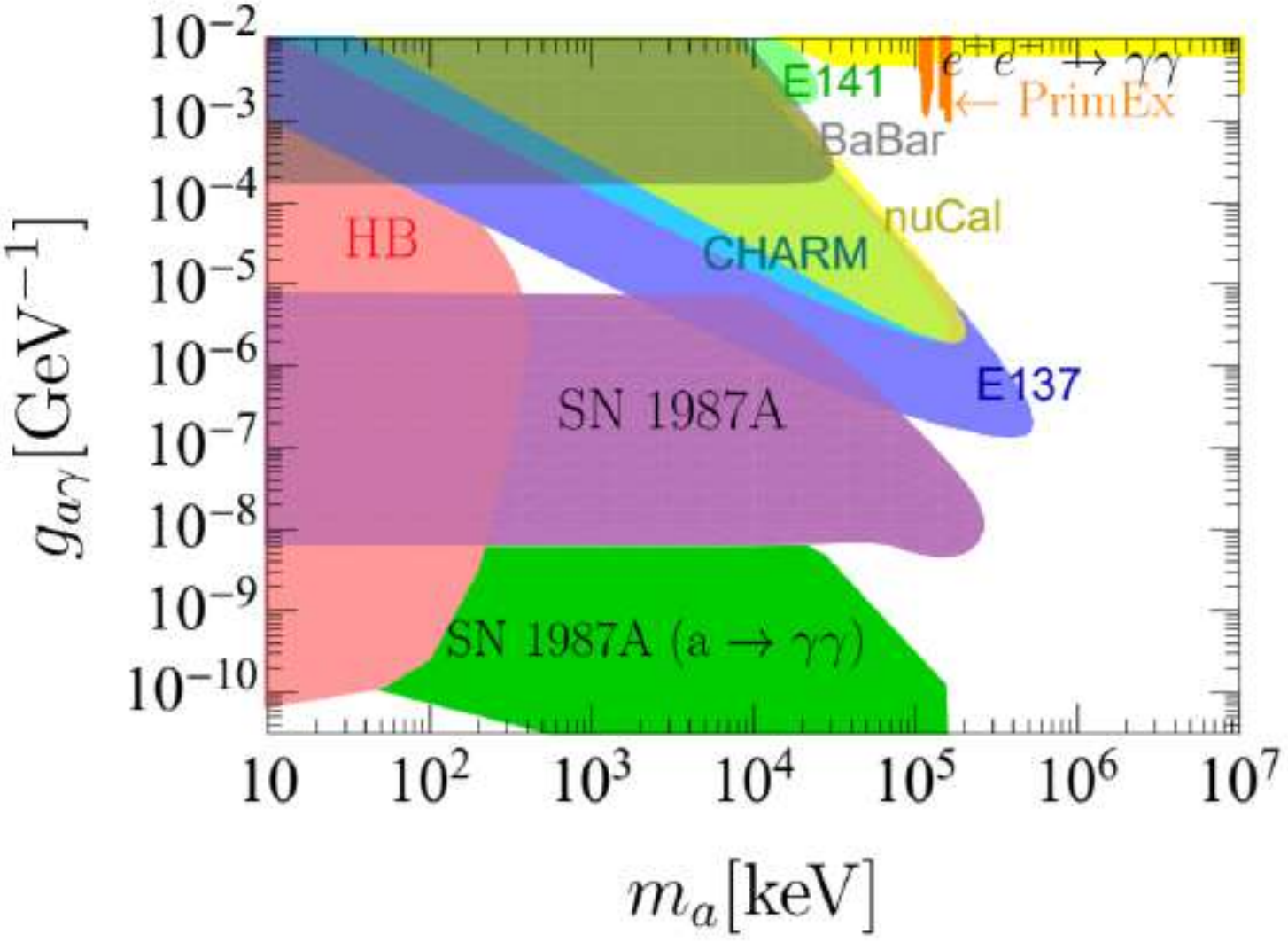
Constraints on the coupling with photons of heavy axion-like-particles from Globular Clusters

In collaboration with O. Straniero, B. Döbrich, M. Giannotti, G. Lucente and A. Mirizzi

arXiv:2004.08399 [hep-ph]

HB star bound on heavy ALPs

A small region is unconstrained: the "cosmological triangle"



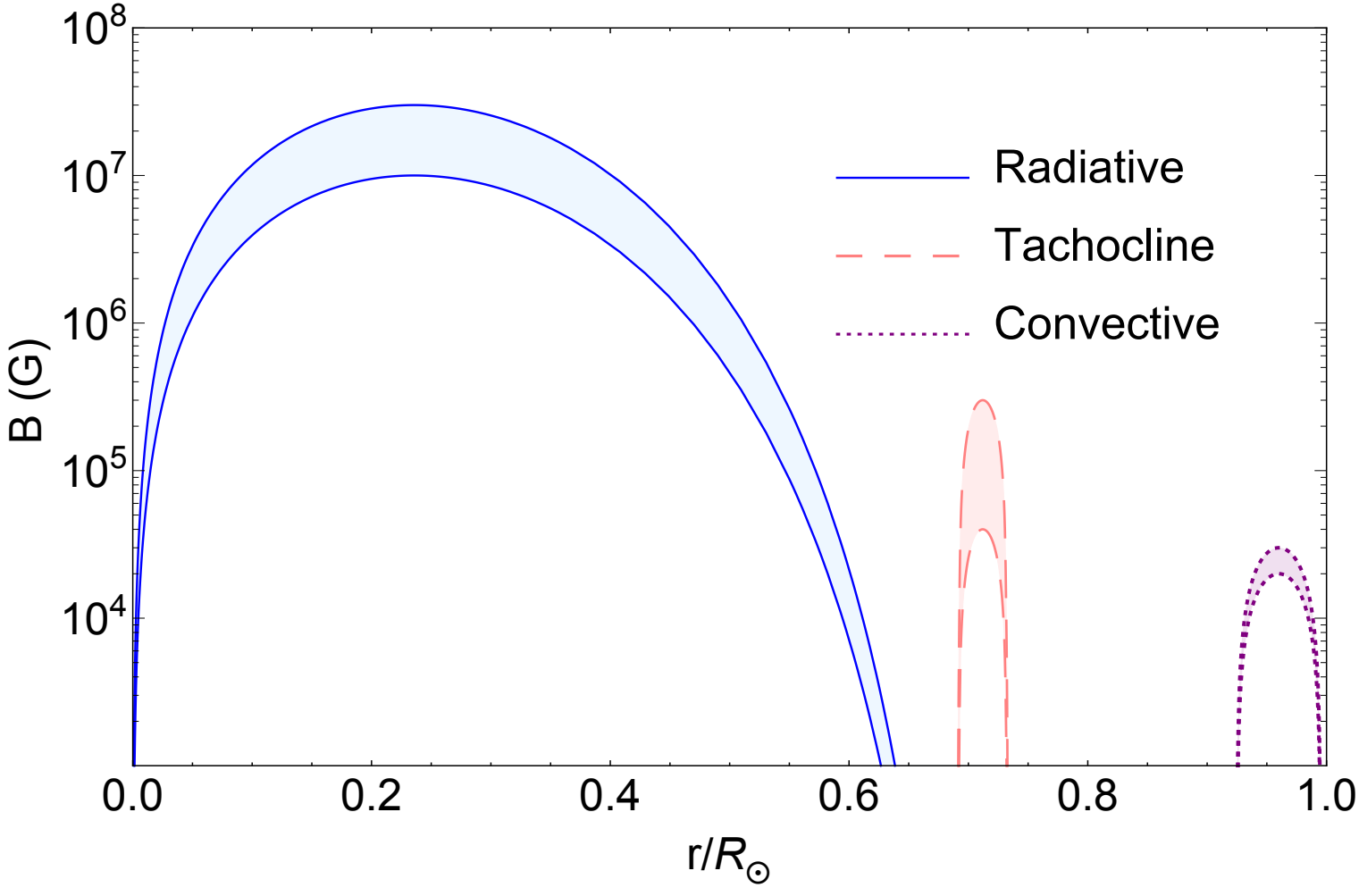
Production of axion-like particles from photon conversions in large-scale solar magnetic fields

In collaboration with E. Guarini, J. Galan, M. Giannotti and A. Mirizzi

arXiv:2010.06601 [hep-ph]

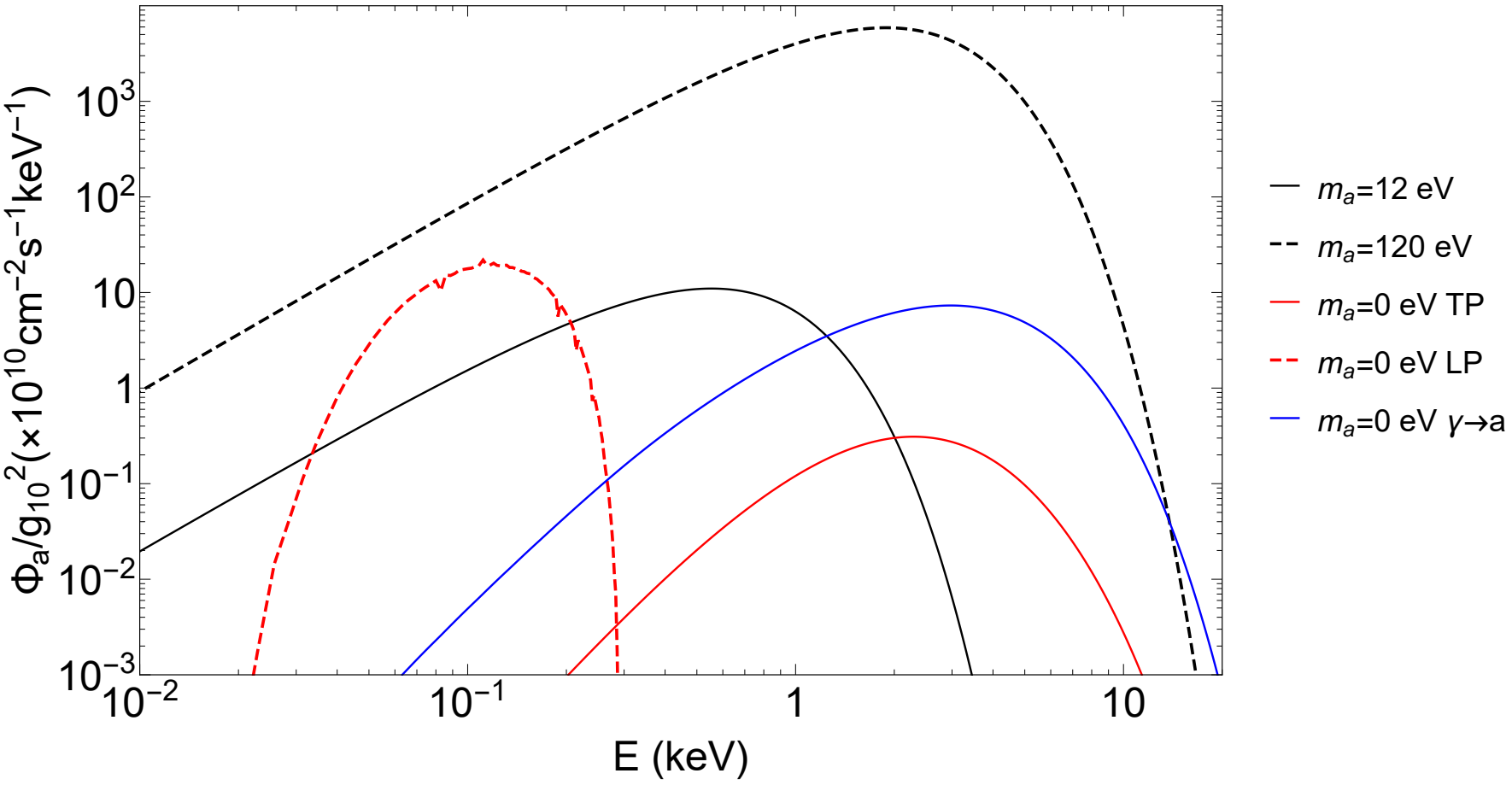
A new production channel

Photons convert into axions in the solar magnetic field



Comparison of the fluxes

New phenomenology is related to this flux



Reconciling hints on axion-like-particles from high-energy gamma rays with stellar bounds

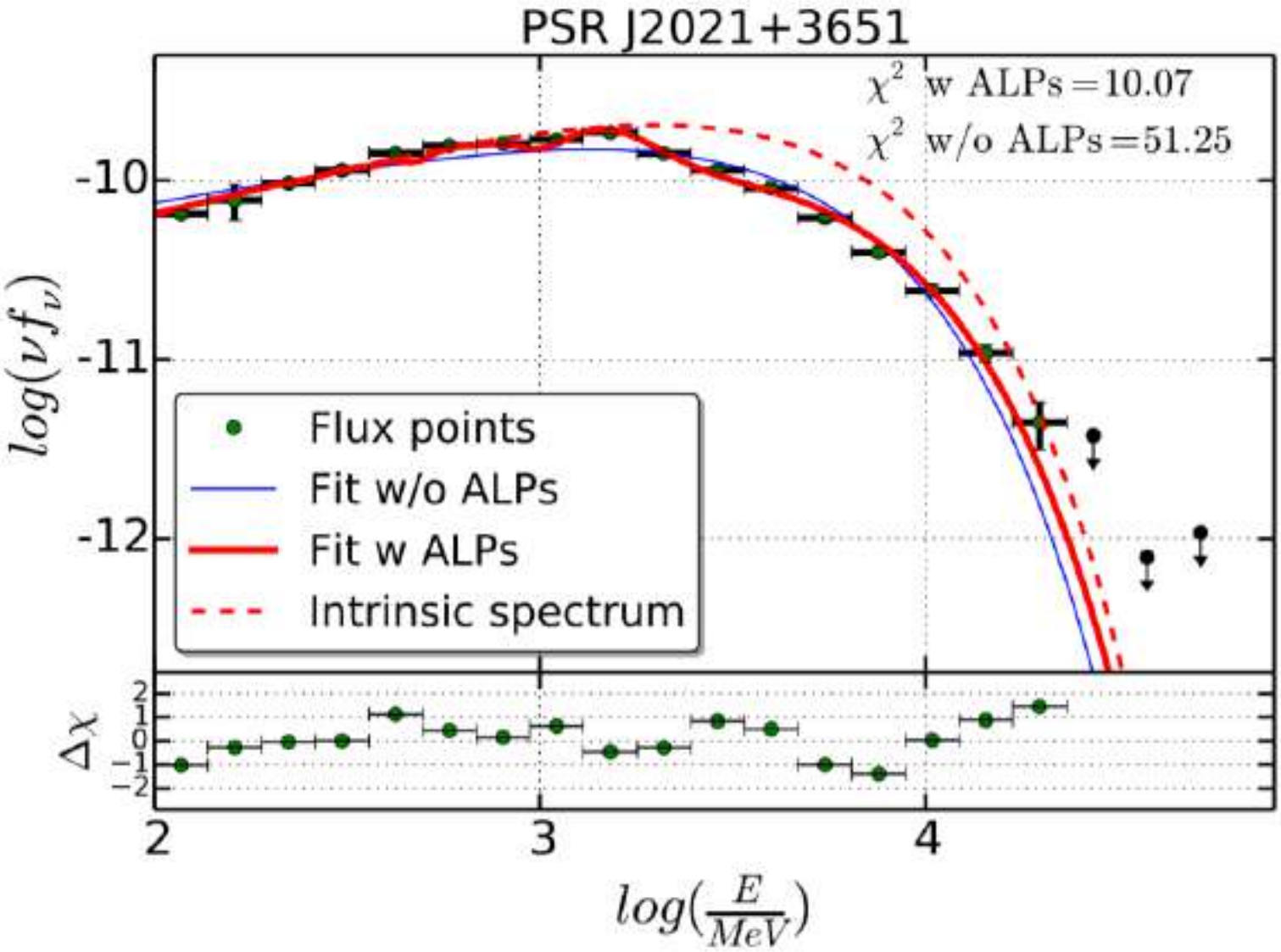
In collaboration with G. A. Pallathadka, F. Calore, M. Giannotti, D. Horns, J. Majumdar, A. Mirizzi, A. Ringwald, A. Sokolov and F. Stief

arXiv:2008.08100 [hep-ph]

Updated PSR hint on ultralight ALPs

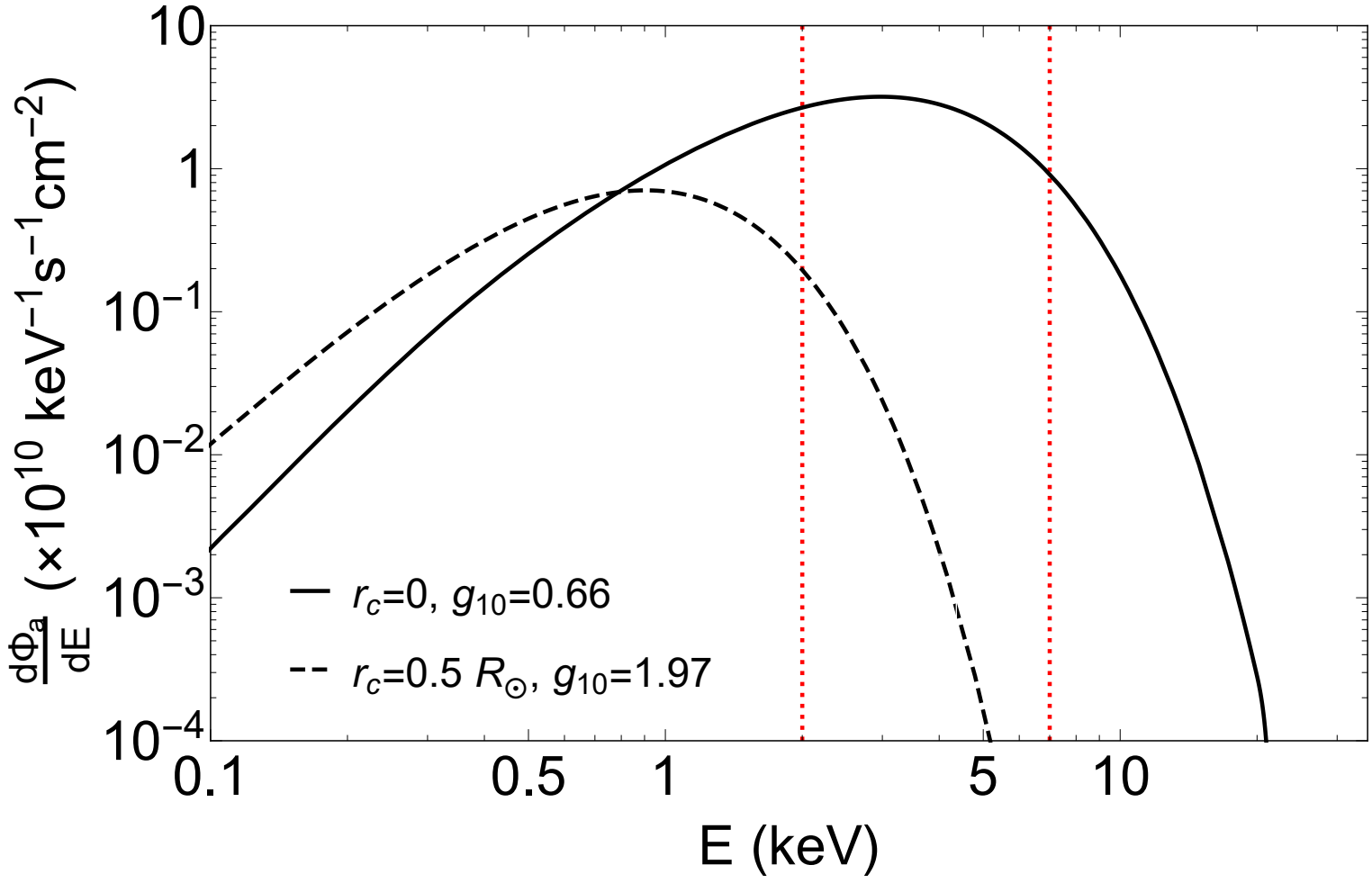
J. Majumdar, F. Calore and D. Horns, JCAP **04** (2018), 048

ALP with $m_a = 4\,\text{neV}$ and $g_{a\gamma} = 1.97 \times 10^{-10}\,\text{GeV}^{-1}$



ALPs at CAST

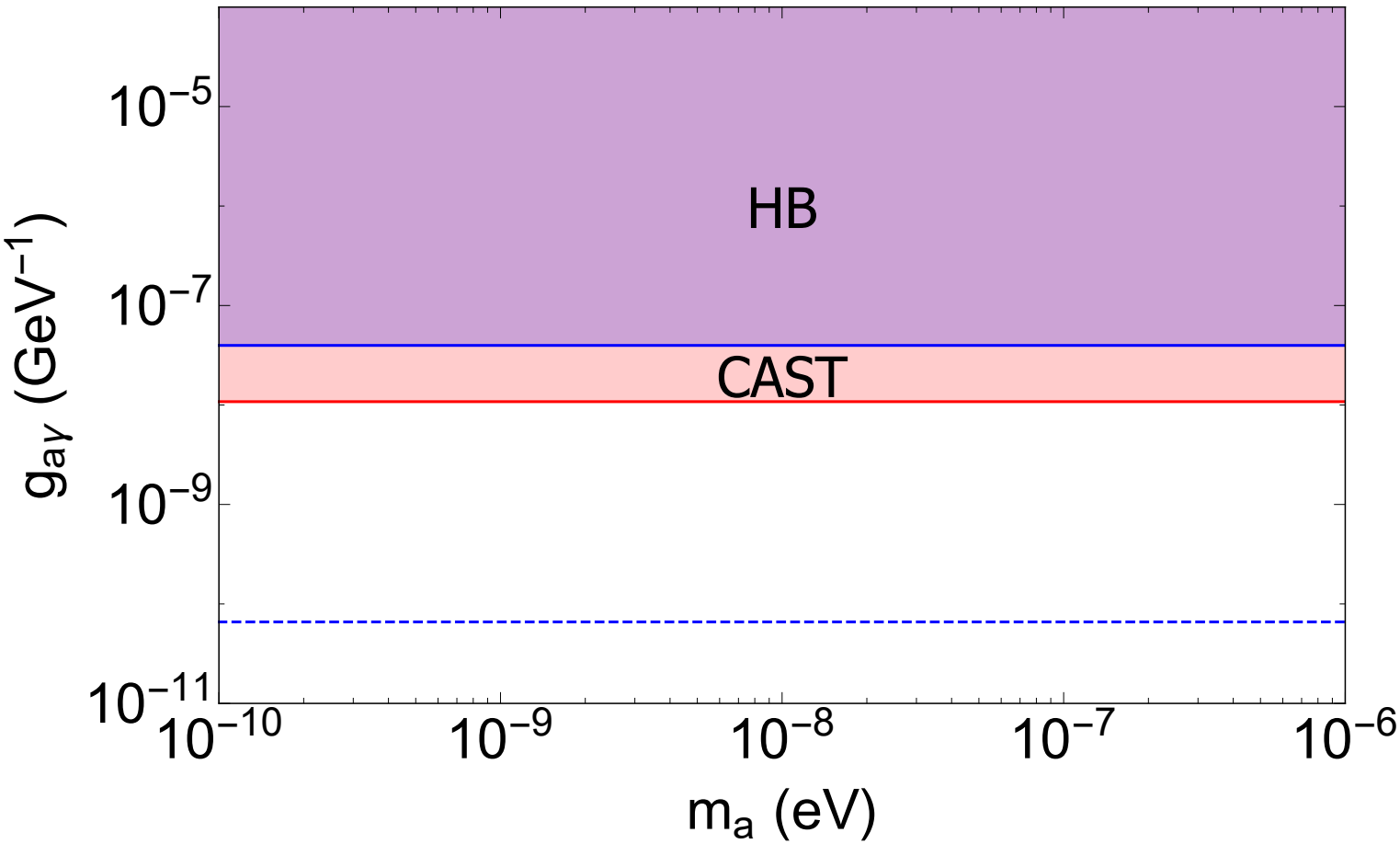
The CAST bound evaded by environmental effects: $g_{a\gamma}(\eta)$



The new bound is $g_{a\gamma} < 2.37 \times 10^{-9}\,\mathrm{GeV}^{-1}$.

HB and SN bound

If $r_c = 0.5\,R_\odot$, assuming that $g_{a\gamma}(\rho)$, then $\rho_c = 1.3\,\mathrm{g\,cm^{-3}}$
The HB bound is relaxed to $g_{a\gamma} < 4 \times 10^{-8}\,\mathrm{GeV^{-1}}$

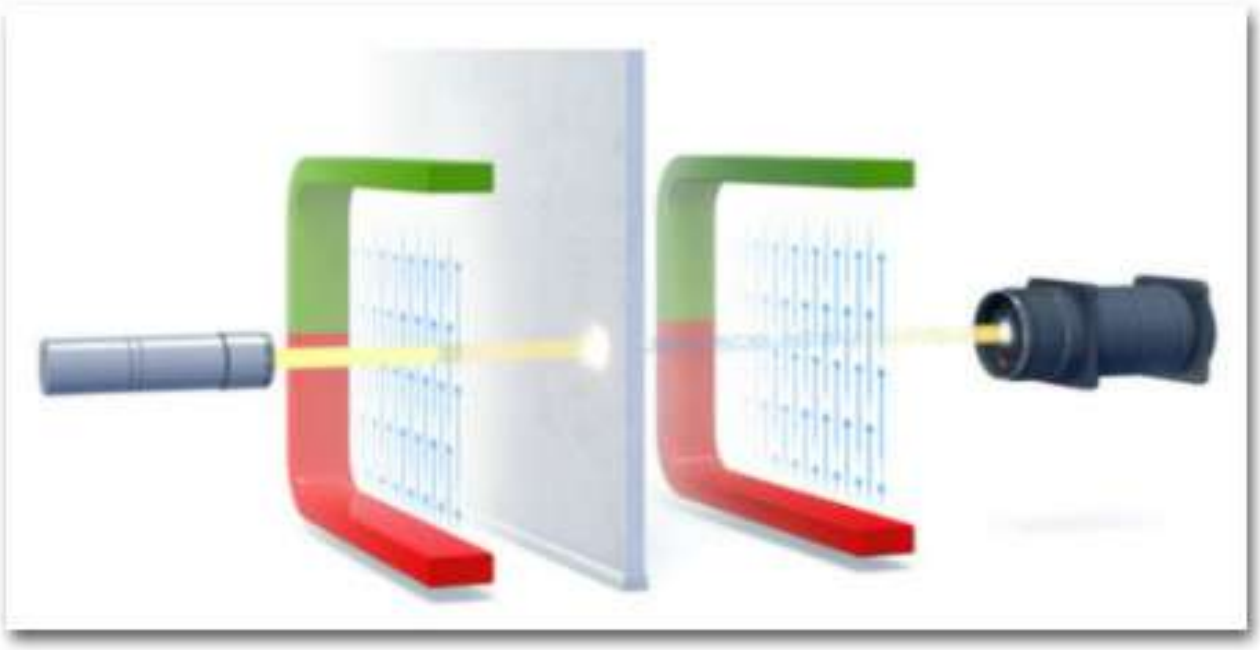


The SN bound disappears because $\rho \sim 10^{14}\,\mathrm{g\,cm^{-3}}$

ALPS II

R. Bähre *et al.*, JINST **8** (2013), T09001

The future LSTW experiment, ALPS II, can easily detect ALPs with $m_a \ll 10^{-4}\,\text{eV}$ and $g_{a\gamma} = 1.97 \times 10^{-10}\,\text{GeV}^{-1}$



Schools attended:

- Winter School on Multi-Messenger Astrophysics, Asiago (Italy), 14 - 23 Jan. 2020

Conferences:

- Workshop "Axion cosmology," Munich (Germany), 17-28 Feb. 2020
- New Frontiers in Theoretical Physics - Convegno nazionale di fisica teorica, e-conference, 27-29 May 2020
- DESY Virtual Theory Forum, e-conference, 22-25 Sep. 2020
- IBS-ICTP Workshop on Axion-Like Particles, e-conference, 21-23 Oct. 2020

Scientific collaborations:

- Scientific collaboration with O. Straniero
  Osservatorio Astronomico dell'Abruzzo, Teramo (Italy), Dec. 2019

Exams: Completed

Talks:

- "*Improved axion emissivity from a supernova and the SN1987A bound*"
  Department of Physics, Bari (Italy), 17 Dec. 2019
- "*Stellar bounds on axions and ALPs*"
  Munich Institute for Astro- and Particle Physics (MIAPP), Munich (Germany), 26 Feb. 2020
- "*Constraints on the coupling with photons of heavy axion-like-particles from Globular Clusters*"
  online talk for the IAXO, MADMAX and ALPS collaborations, 28 May 2020
- "*Reconciling hints on axion-like-particles from high-energy gamma rays with stellar bounds*"
  online talk for the Virtual Axion Institute, hosted by Kai Schmitz and Valerie Domcke, 1 Sep. 2020
- "*Bounds on axion-like particles from the diffuse supernova flux*"
  online talk for the DESY Virtual Theory Forum 2020, 22 Sep. 2020

Thanks for your attention