WG3 Report

Astrophysics goals and challenges

Giuseppe Lucente,
SLAC

Maurizio Giannotti,
Universidad de Zaragoza & CAPA

3rd General Meeting of COST Action COSMIC WISPers

9-12 September, 2025

The WG3 at Glance

173 Participants (increased by 30%)

Group Leader:
Maurizio Giannotti (U. of Zaragoza & CAPA) mgiannotti@unizar.es

Group Co-Leaders:
Giuseppe Lucente (SLAC) lucenteg@slac.stanford.edu
Elisa Todarello (U. of Nottingham) elisa.todarello@nottingham.ac.uk
Oscar Straniero (INAF & INFN Rome) oscar.straniero@inaf.it

Mailing List wispers_wg3@inaf.it

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Large overlap with WG2, Dark Matter and Cosmology

Leaders: Edoardo Vitagliano, Marco Gorghetto,
Maria Benito Castano & Mathieu Kaltschmidt

Objectives

- Study the impact of WISPs in astrophysics.
- Identify observables.
- Identify opportunities.
- Cross Working Groups discussions to clarify the possible detection strategies.
- Clarify the next generation needs to detect astrophysics WISP signatures.
- Promote a roadmap to proceed with our tasks.

Objectives

Objectives: promote the studies of the signatures of WISPs in astroparticle physics and facilitate the creation of networks to tackle these problems

- WISP oscillations into photons,
- WISP-induced energy loss in stellar systems
- WISP fluxes from astrophysics and experimental sensitivity to detect them (→ connection to WG4)
- signatures from gravitational waves and from primordial black-hole superradiance
- Astrophysical signatures of DM WISPs (e.g., DM ALP conversion in B) → connection to WG2
- Selection of models with specific properties of astrophysical relevance (e.g. Astrophobic models, photophilic models, etc.) → connection to WG1
- …

Our work

1- Monthly meetings

Offer opportunities for (mostly) young researchers to present their work and to discuss their findings with the larger community.
Create networks.

2- Organization of small workshops

3- Realization of a repository of axion astrophysical fluxes

4- Preparation of the White Paper

5- Preparation of pedagogical material

Currently, under discussion

Monthly Meetings

Different topics. All the material is available at the → WG3 Agenda

- October: **Antonio Gomez,** ``*Constraining Light QCD Axions with Isolated Neutron Star Cooling*''
- November: **Camilo Garcia Cely,** ``*Gravitational wave spectrum of the Sun*''
- December: **Konstantin Springmann,** ``*A systematic approach to axion production at finite density*''
- January: **Michael Zantendeschi,** ``*Ultralight black holes burdened by their memory: a new window for dark matter*''
- February: **Qingyu Gan,** ``*Graviton/Axion-Photon conversion in the Stochastic magnetic field*''
- March: **Marco Manno,** ``*ALPs Production from Light Primordial Black Holes: The Role of Superradiance*''
- June: **Marina Cermeno Gavilán,** ``*New probes of supernova axion-like particles in neutrino water Cherenkov detectors*''
- July: **Tanmay Kumar Poddar,** ``*Constraints on ultralight scalars from compact stars*''

Networking

Short term missions

- 01/09/25 – 12/09/25: **Gaetano Di Marco** (IFIC), ``*Constraining axion-like particles properties from the synergy between Monte Carlo simulations and gamma-ray observations*''.

- 03/06/25 – 10/06/2025: **Zakaria Belkhadria** (U. of Cagliari), ``*Probing the Dark Sector: Black Holes, Gravitational Waves, and Beyond Standard Model Fields*''.

- 13/04/25 – 27/04/25: **Oindrila Ghosh** (U. of Stockholm), ``*Astrophysical probes of axion-like particles and high-frequency gravitational waves*''.

- 16/03/25-01/04/25: **Christopher Eckner** (U. of Nova Gorica), ``*Hunting ALPs in the Extragalactic Sky: Building a Simulation-Based Inference Framework for Gamma-Ray Observations*''.

- 20/02/25 – 25/04/25: **Gaetano Di Marco** (IFIC): ``*Simulations of astrophysical gamma rays oscillating into axion-like particles*'' .

- 03/02/2025 – 07/02/2025: **Alessandro Lella** (U. of Bari). ``*Astrophysical probes for High-Frequency gravitational waves*''.

Networking

Summer School in Annecy

Jamie McDonald will present a set of lectures on
→ WISPs and Compact Objects

Tutor Alessandro Lella

Previous Editions

2024: Calore, lectures on high energy astrophysics Tutor Christopher Eckner, see Lecture Notes)

2023: Raffelt, lectures on stellar astrophysics
Tutor Andrea Caputo, see Lecture Notes)

Online Workshop (18 – 19 Feb 2025)

Organizers: María Benito, Diego Blas, Maurizio Giannotti and Oscar Straniero

Overlap with WG2

274 partecipants

This online workshop is intended for extensive discussions on the distinctive features in galactic dynamics that imprint the different empirically allowed properties of dark matter, such as its mass (e.g., ultra-light, axions, WDM-like, WIMP-like, PBHs) or interaction type (FDM, SIDM, CDM). Our goal is to further investigate the possibility of leveraging galactic dynamics as a tool to probe the nature of dark matter, with a special emphasis on understanding how particular dynamical tracers in galaxies can be used to constrain specific general properties of dark matter.

The workshop will last two days, each with three invited talks (30 minutes per talk). Each day will conclude with a one-hour discussion session, bringing the total duration per day to 2.5 hours.

Online Workshop (18 – 19 Feb 2025)

Organizers: María Benito, Diego Blas, Maurizio Giannotti, Oscar Straniero, Shin'ichiro Ando

10:00
- **Is gravity the only dark matter interaction that matters in the physics of galaxies?** *Jesús Zavala* — 10:00 - 10:30
- **Dark matter density profiles on galactic and sub-galactic scales** *Kohei Hayashi* — 10:30 - 11:00

11:00
- **Gravitational dynamical probes of the nature of dark matter in galaxies** *Kfir Blum* — 11:00 - 11:30
- **OPEN DISCUSSION** — 11:30 - 12:30

12:00

15:00
- **Tidal stripping and the fate of dark substructures of the Milky Way** *Jens Stücker* — 15:30 - 16:00

16:00
- **What can dwarf galaxies reveal about the nature of dark matter?** *Ethan O. Nadler* — 16:00 - 16:30
- **Motivations for self-interacting dark matter and its viable signatures** *Manoj Kaplinghat* — 16:30 - 17:00

17:00
- **OPEN DISCUSSION** — 17:00 - 18:00

18:00

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12:00		

Ideas for other workshops?

	Tidal stripping and the fate of dark substructures of the Milky Way	*Jens Stücker* 15:30 - 16:00
16:00	**What can dwarf galaxies reveal about the nature of dark matter?**	*Ethan O. Nadler* 16:00 - 16:30
	Motivations for self-interacting dark matter and its viable signatures	*Manoj Kaplinghat* 16:30 - 17:00
17:00	**OPEN DISCUSSION**	17:00 - 18:00
18:00		

COST White Paper

General overview of WISP Physics

4 sections:

1.Theory

2.Cosmology

3.Astrophysics

4.Experiments

COST White Paper

Astrophysics Section

1. Astrophysical Sources
and
Related bounds

2. Astronomical Technology
and
Opportunities

COST White Paper

Contents

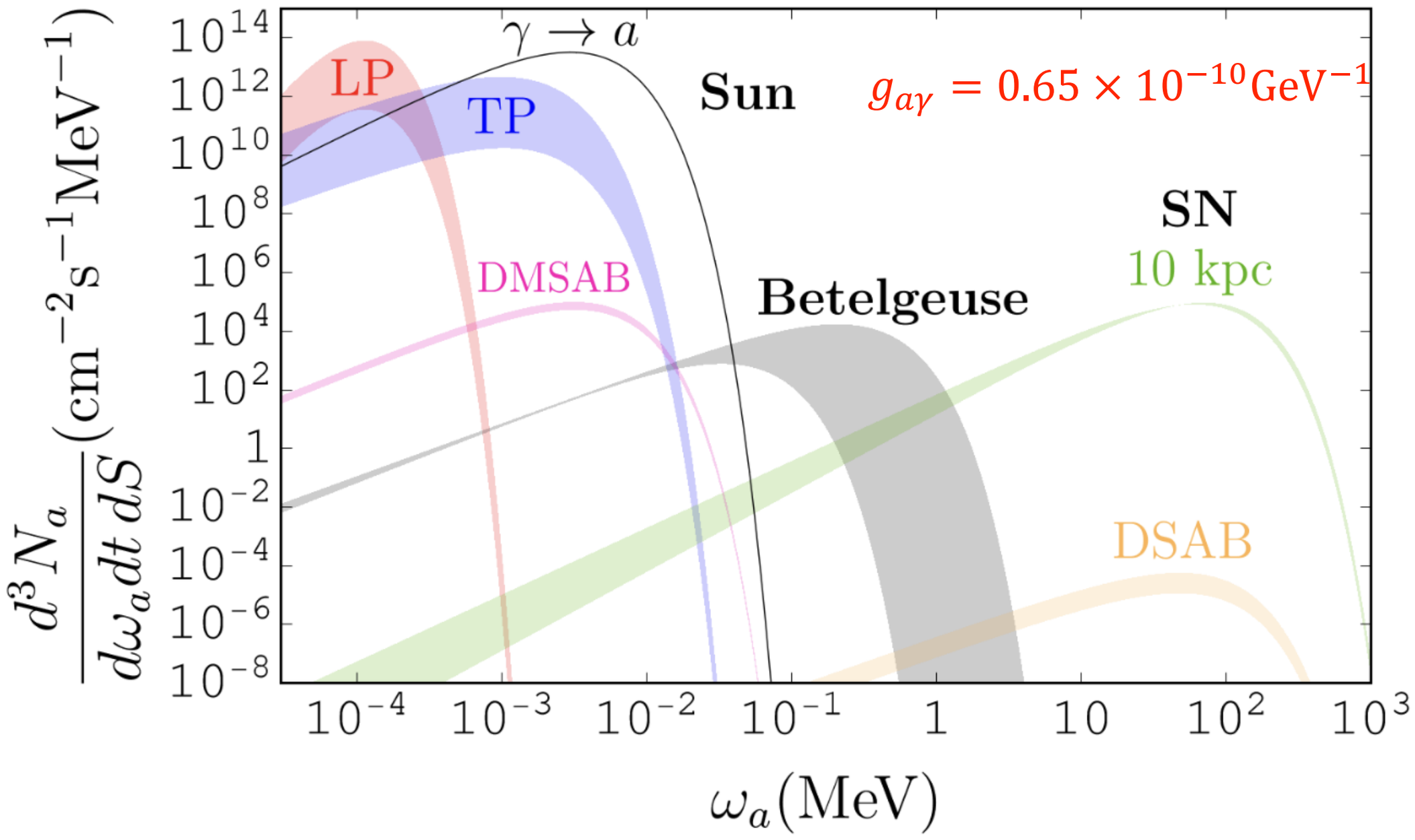
130 pages, 22 contributions

General Introduction on Astrophysical Probes of FIPs

Added subsection on spin-2 particles

Time to merge with other Sections

Astrophysical Axion Fluxes



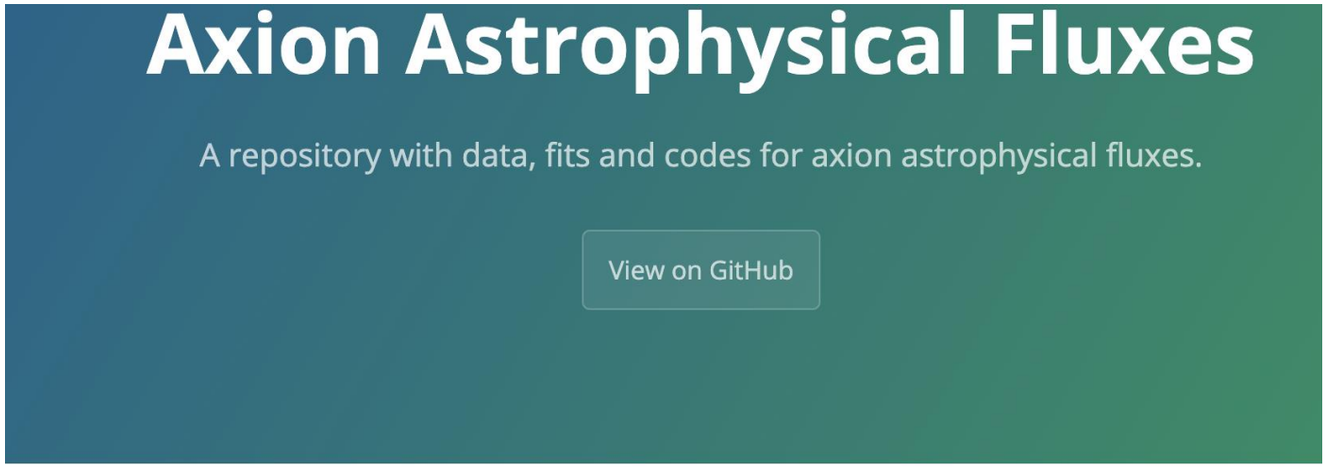
Different sources: different main production channels and energy ranges.

Opportunities for detection → Characterization of axion fluxes is fundamental!

Astrophysical Axion Fluxes

Collection of axion fluxes from different astrophysical sources.

For each source:
data and fit of the flux



Realized by:

Giovanni Grilli di Cortona
Alessandro Lella
Giuseppe Lucente
Pierluca Carenza

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Available on Grilli di Cortona's GitHub page
https://ggrillidc.github.io/AxionAstrophysicalFluxes/

Solar Axions

An accurate fit of solar axion fluxes at Earth obtained after integrating over the AGSS09 solar model [Serenelli et al. 2009, Serenelli 2010] is given by:

$$\frac{d\Phi_a}{dE_a} = C_0 \left(\frac{g_{ax}}{g_{\rm ref}}\right)^2 \left(\frac{E}{E_0}\right)^\beta e^{-(1+\beta)\frac{E}{E_0}},$$

where the axion parameters are shown in the following Table:

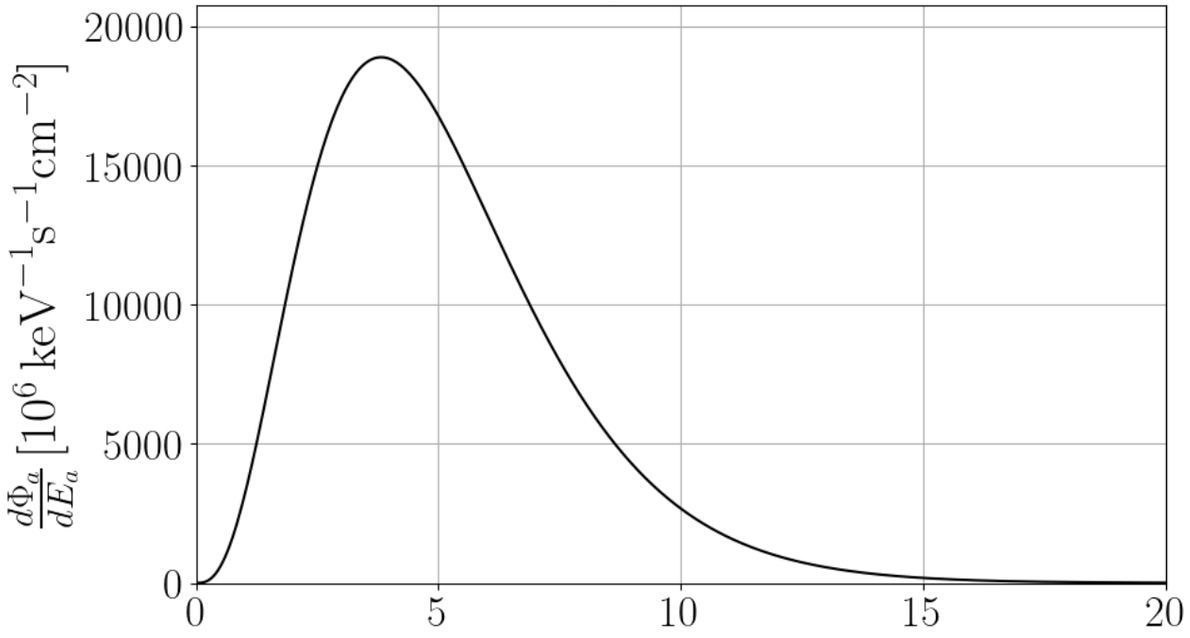
	$g_{\rm ref}$	$C_0\ (\mathrm{keV}^{-1}\ \mathrm{s}^{-1}\ \mathrm{cm}^{-2})$	$E_0\ (\mathrm{keV})$	β
Primakoff, $x = \gamma$	$10^{-12}\ \mathrm{GeV}^{-1}$	$(2.19 \pm 0.08)\ 10^8$	4.17 ± 0.02	2.531 ± 0.008
Bremsstrahlung, $x = e$	10^{-12}	$(3.847 \pm 0.007)\ 10^{11}$	1.63 ± 0.01	0.8063 ± 0.0003
Compton, $x = e$	10^{-12}	$(8.8 \pm 0.1)\ 10^{11}$	5.10 ± 0.03	2.979 ± 0.001

Table: *Summary of the fitting parameters to reproduce the axion emission from the Sun via Primakoff (coupling to photons $g_{a\gamma}$), Bremsstrahlung, and Compton (coupling to electrons g_{ae}), see [Hoof et al., Wu and Xu] and the GitHub code. The uncertainty on the fitting parameters includes the most recent solar models [Magg et al. 2022].*

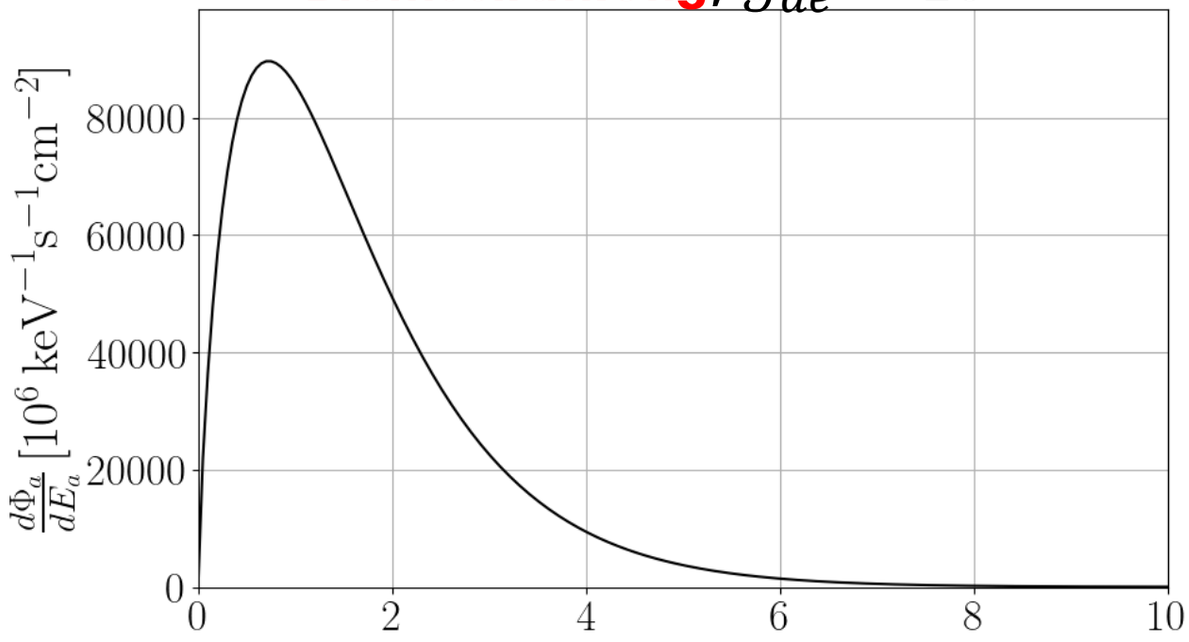
https://ggrillidc.github.io/AxionAstrophysicalFluxes/

Example: Solar axions

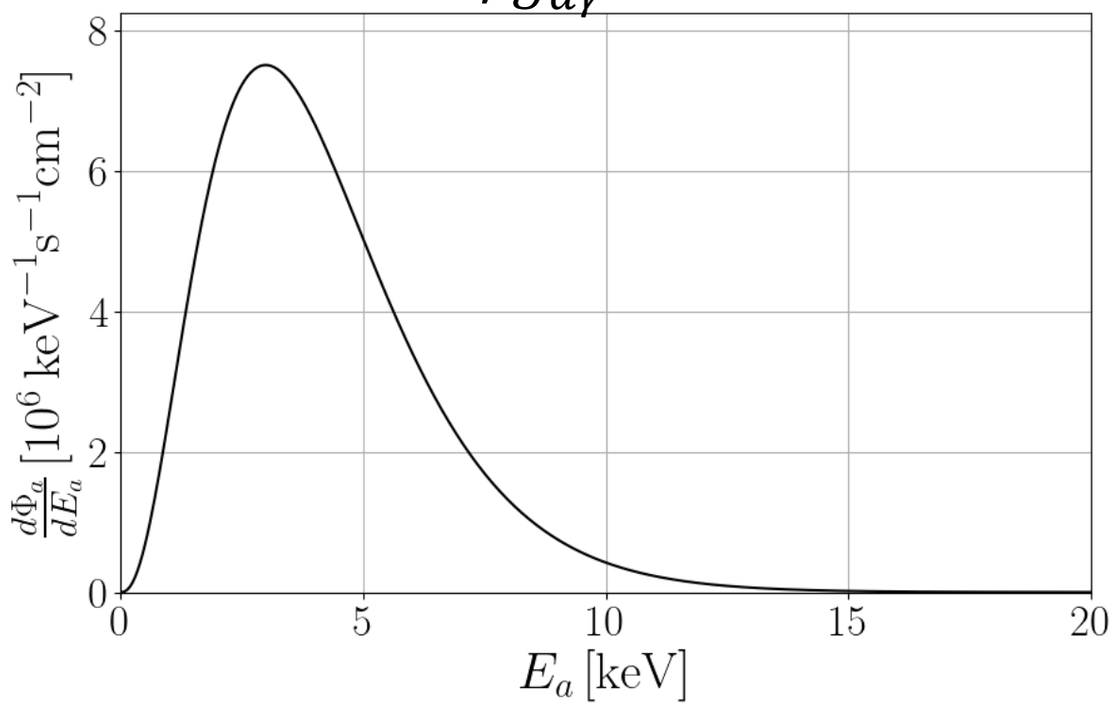
Compton, $g_{ae} = 10^{-12}$



Bremsstrahlung, $g_{ae} = 10^{-12}$



Primakoff, $g_{a\gamma} = 10^{-12}\ \mathrm{GeV}^{-1}$



Red Supergiants axions

ALP production in massive stars at supergiant stages is dominated by their couplings to photons and electrons. The dominant ALP production process induced by the ALP-photon interaction is the Primakoff effect, $\gamma + Ze \to a + Ze$, corresponding to the conversion of a thermal photon into an ALP in the electrostatic field of charged particles in the stellar plasma [Carlson].

On the other hand, axions interacting with electrons are mainly produced via Compton scattering, $\gamma + e \to e + a$ [Raffelt], and the electron-ion Bremsstrahlung, $e + Ze \to e + Ze + a$ [Carenza and Lucente].

The total amount of ALPs produced by the star is obtained by integrating the production rates over the entire volume of the star. The Red-Giant Branch (RGB) ALP production spectrum integrated over the star volume can be fitted as

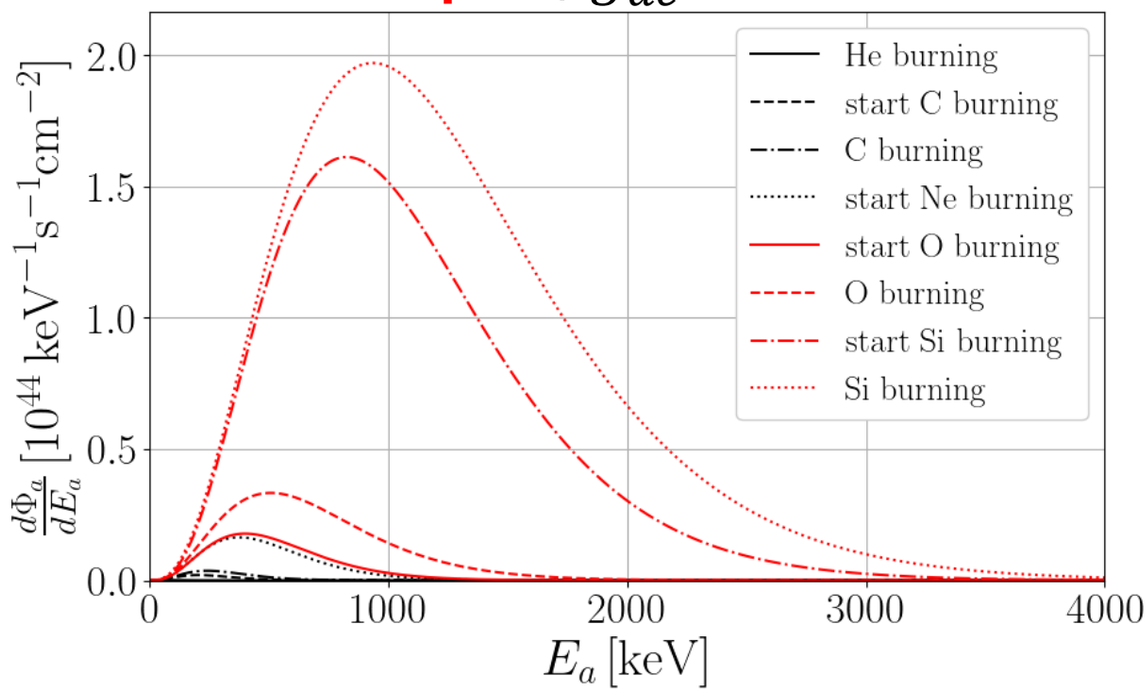
$$\frac{dN_a}{dEdt} = \frac{10^{42}}{\mathrm{keV\,s}} \left[\mathcal{C}_B\, g_{13}^2 \left(\frac{E}{E_{0,B}} \right)^{\beta_B} e^{-(\beta_B+1)E/E_{0,B}} + \mathcal{C}_C\, g_{13}^2 \left(\frac{E}{E_{0,C}} \right)^{\beta_C} e^{-(\beta_C+1)E/E_{0,C}} + \mathcal{C}_P\, g_{11}^2 \left(\frac{E}{E_{0,P}} \right)^{\beta_P} e^{-(\beta_P+1)E/E_{0,P}} \right],$$

where $g_{11} \equiv g_{a\gamma}/10^{-11}\,\mathrm{GeV}^{-1}$, $g_{13} \equiv g_{ae}/10^{-13}$, $\mathcal{C}_{B/C/P}$ are normalization constants, $E_{0,B/C/P}$ is the average energy and $\beta_{B/C/P}$ is the spectral index for Bremsstrahlung, Compton and Primakoff processes, respectively.

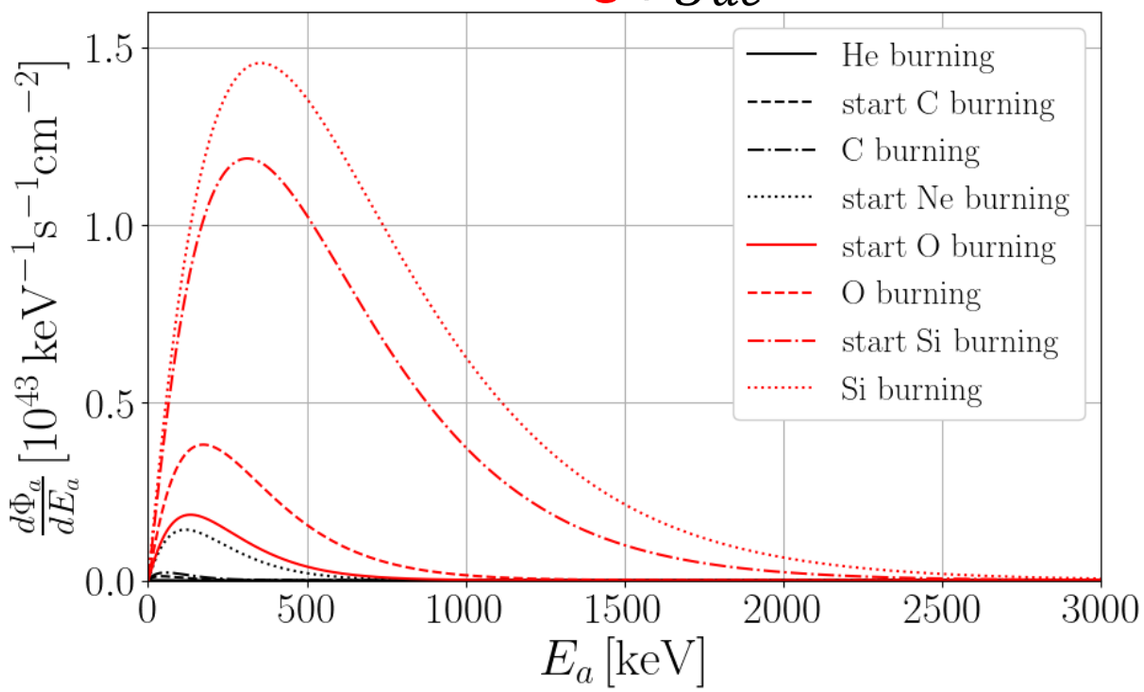
https://ggrillidc.github.io/AxionAstrophysicalFluxes/

Example: Red Supergiants axions

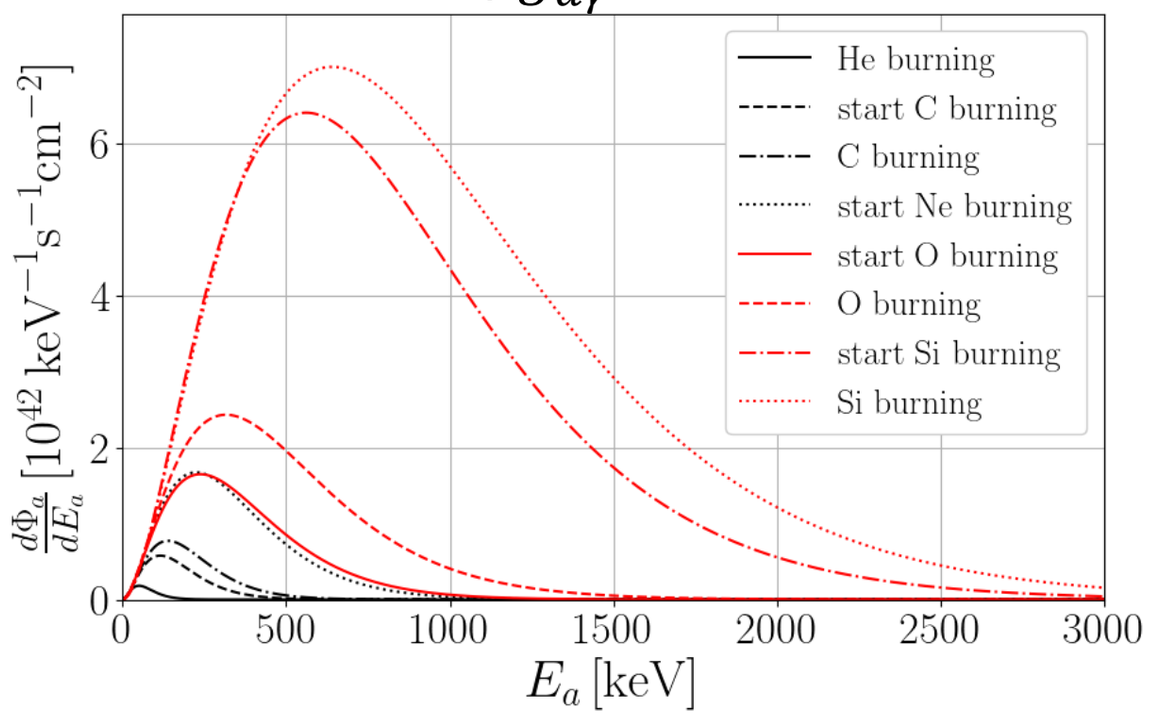
Compton, $g_{ae} = 10^{-13}$



Bremsstrahlung , $g_{ae} = 10^{-13}$



Primakoff , $g_{a\gamma} = 10^{-11}\ \mathrm{GeV}^{-1}$



This Meeting

We followed the same White Paper division in the organization of plenary talks in this Meeting.

WG3 Plenary Talks

1. Astrophysical Sources
and
Related bounds

- **Konstantin Springmann,**
``Theoretical Progress on SN axions"
- **Francesca Chadha-Day,**
``Axion Superradiance"

2. Astronomical Technology
and
Opportunities

- **Jaime Ruz,**
``X-ray observations"
- **Marco Regis,**
``Radio observations"

This Meeting

WG3 Parallel Talks

X-ray Searches for Axions: The M82 and Betelgeuse Case…
Francisco Candon

ARCHIMEDES experiment *Domenico D'Urso*
Hall 2, Sofia Unviersity 15:30 - 15:50

Probing axion-like particles with multimessenger observa…
Francesca Lecce

Recent Developments in Axion Detection with MADMAX
Anton Ivanov

Axion production and conversion in astrophysical transients *Ángel Gil Muyor*
Aula, Sofia University 16:10 - 16:30

Coffee break
Main lobby, Sofia University 16:30 - 17:00

Relaxing supernova constraints: how nucleophobic axion…
Vincenzo Fiorentino

Precision test of fundamental physics with matter wave i…
Nicola Poli

Probing axion-like particles with very-high-energy gamma…
Ivana Batkovic

Hunting for Dark Matter using Levitated Superconductors
Jackson Fowler

Sensitivity of CTAO to axion-like particles from blazars: a machine learning approach *Francesco Schiavone*
Aula, Sofia University 17:40 - 18:00

Probing Ultralight Scalars through Compact Stars and Precision Tests of Gravity *Tanmoy Poddar*
Aula, Sofia University 18:00 - 18:20

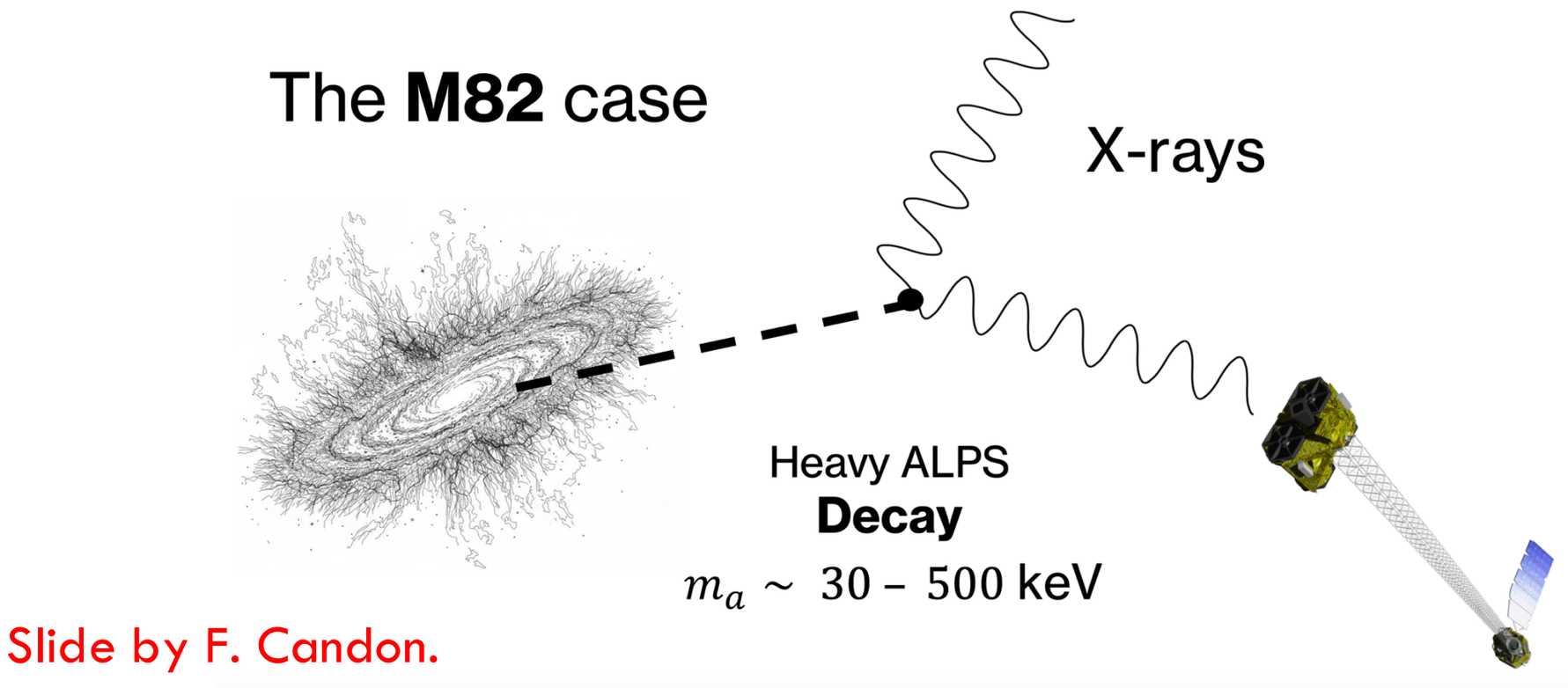
This afternoon many interesting talks focusing on different recent ideas.

Expansion of the possible WISP sources

Starburst Galaxies *Ning & Safdi*, *Phys.Rev.Lett.* 134 (2025)

WISPs produced by all the stars in the Galaxy → cumulative flux enhance single-star signal.

Observable X-ray signal after conversion or decay. F. Candon's talk



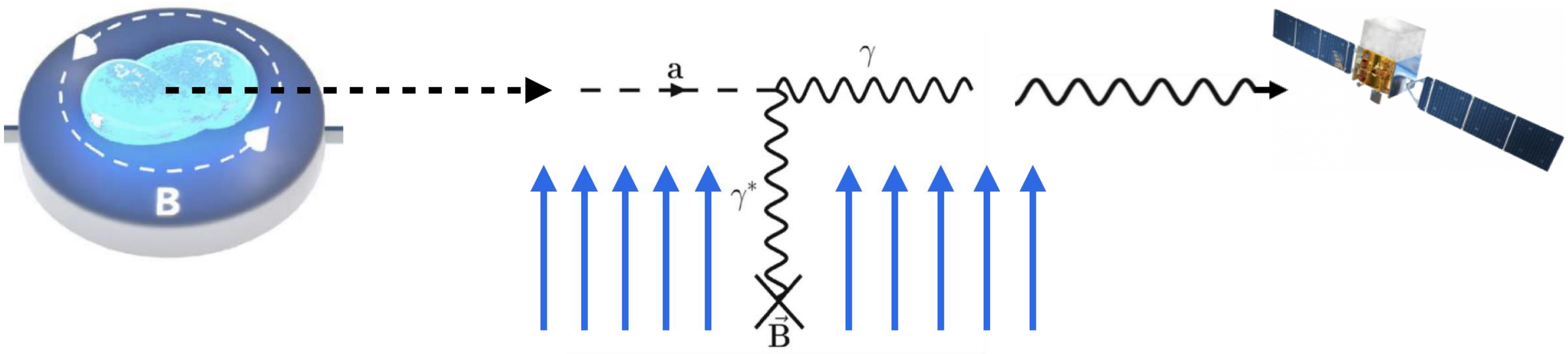
Slide by F. Candon.

Expansion of possible WISP sources

Neutron Star Mergers

Axions produced in NSMs and converting in external magnetic fields: forecasts and possible uncertainties.

F. Lecce and A. Gil Muyor's talks

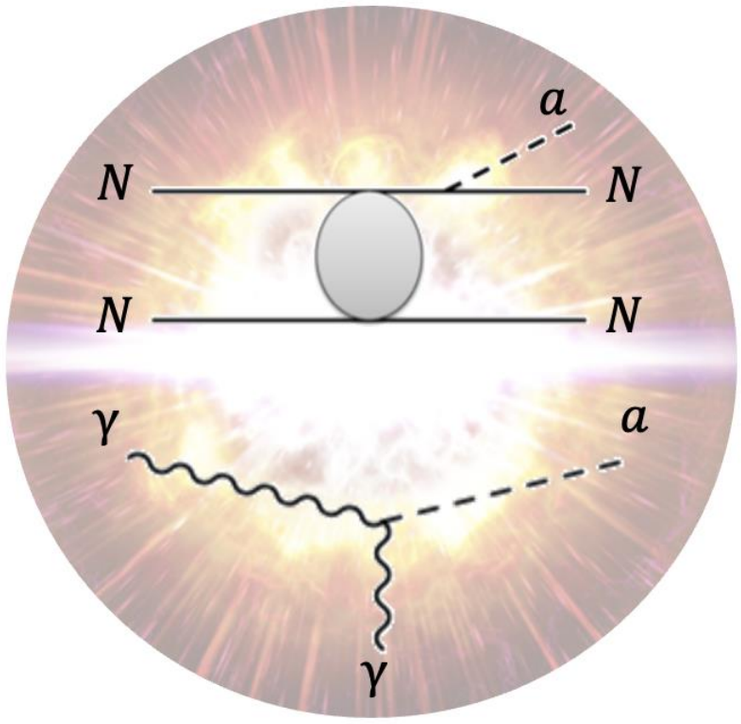


Axion production in supernovae

Important theoretical progress on SN axions. K. Springmann's talk

Uncertainties related to axion production and conversions in SNe. A. Gil Muyor's talk

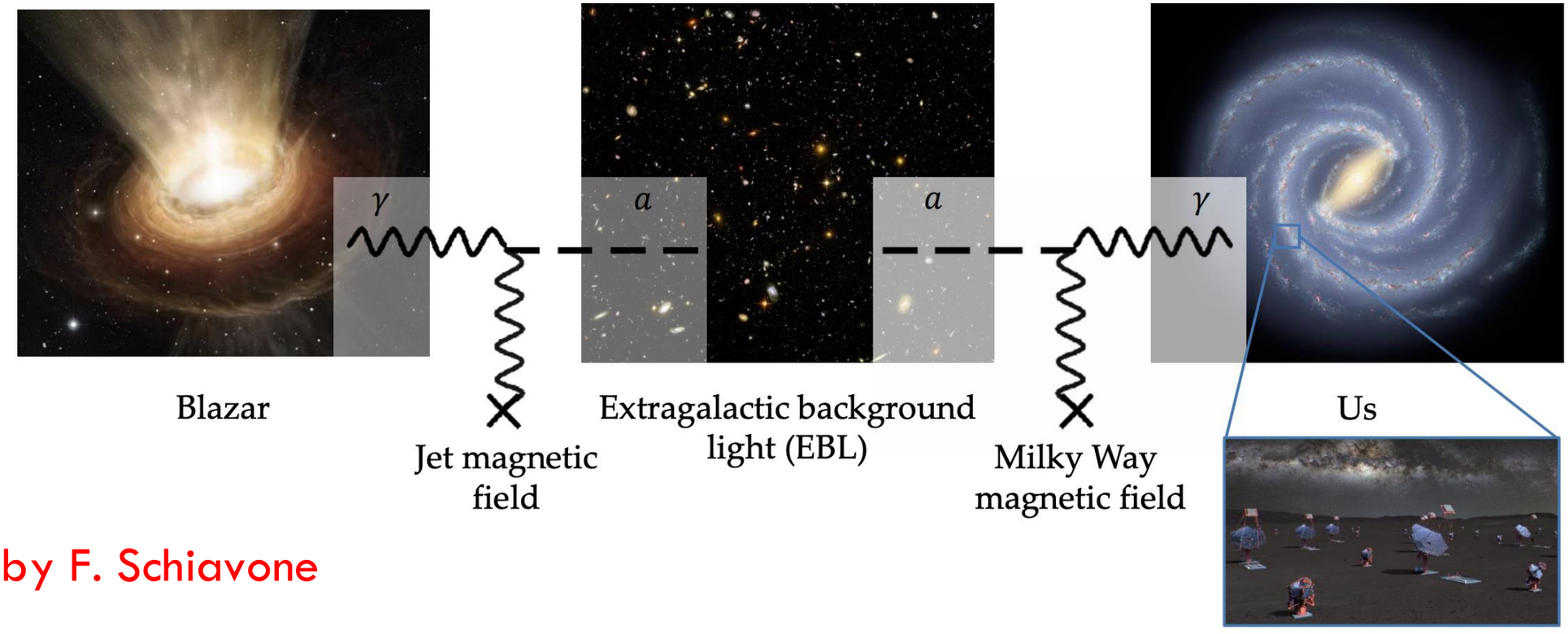
Possible ways to evade SN constraints. V. Fiorentino's talk



Very High-Energy gamma-rays

Axions from extragalactic sources may imprint signatures in very high-energy gamma-rays.

I. Batkovic and F. Schiavone's talks



Slide by F. Schiavone

Other WISPs

New developments on:

- Scalars T. Poddar's talk

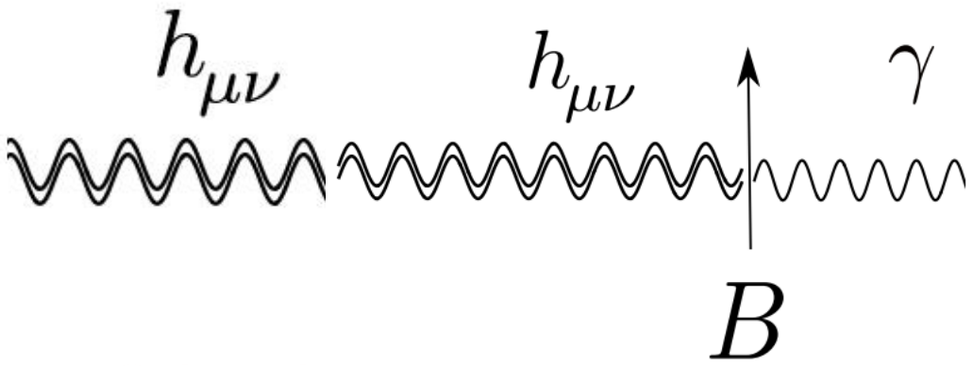
  Fiorillo et al., 2506.19906 [hep-ph], Poddar and Dighe, 2501.02286 [hep-ph]

- Dark Photons

  Caputo et al., Phys.Rev.Lett. 134 (2025) 15

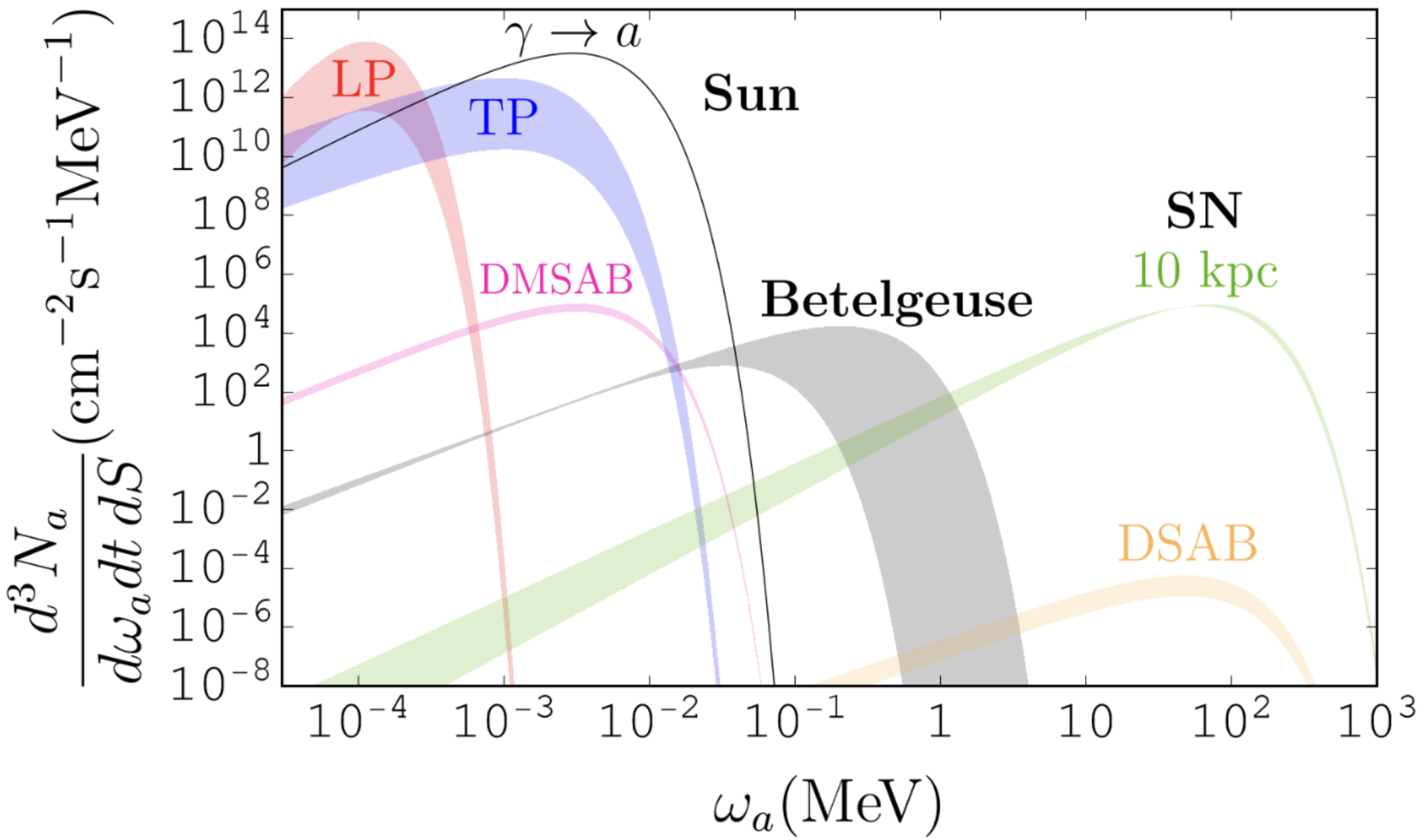
- Spin-2 particles C. Garcia Cely's yesterday talk

  Garcia Cely and Ringwald, *Phys.Rev.Lett.* 135 (2025) 6



Adapted from C. Garcia Cely's slides

Opportunities: Axion Telescopes?



$g_{a\gamma} = 0.65 \times 10^{-10}\mathrm{GeV}^{-1}$

Opportunities: Axion Telescopes?

Detecting stellar axions would allow to understand a lot about stars.

- Solar magnetic field

C. A. J. O'Hare, A. Caputo, A. J. Millar, E. Vitagliano Phys.Rev.D 102 (2020) 4

- Solar temperature profile

S. Hoof, J. Jaeckel, L. J. Thormaehlen, *JCAP* 10 (2023) 024

- Solar chemical composition

J. Jaeckel, L. J. Thormaehlen, Phys.Rev.D 100 (2019) 12

- Supergiant evolution

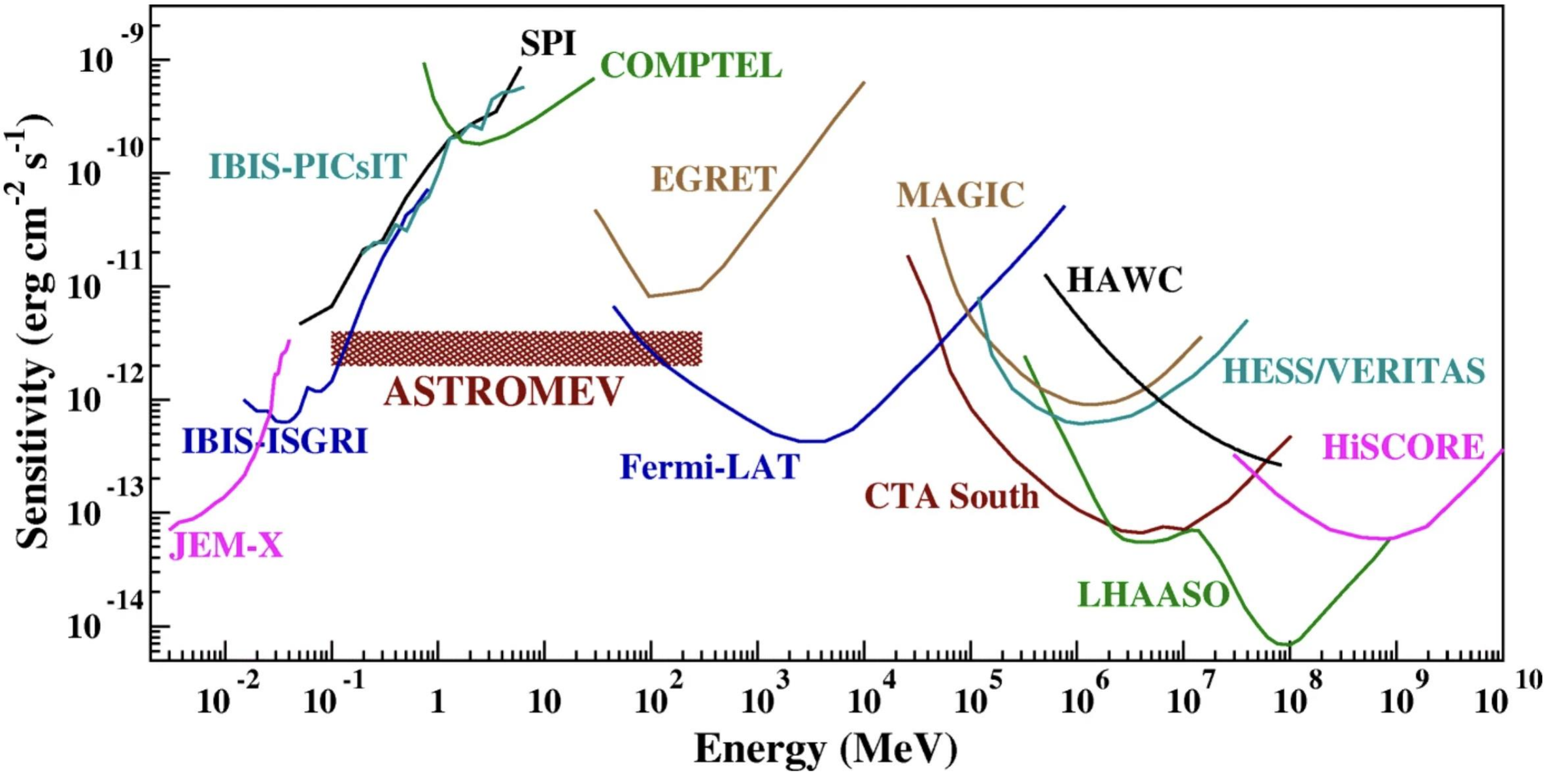
M. Xiao, et al., Phys. Rev. D 106 (2022)

- SN axions

A. Lella, F. Calore et al., JCAP 11 (2024) 009;
P. Carenza, J.A. Garcia Pascual, et al. JCAP 07 (2025), 075

The MeV Gap

How do we approach this issue?

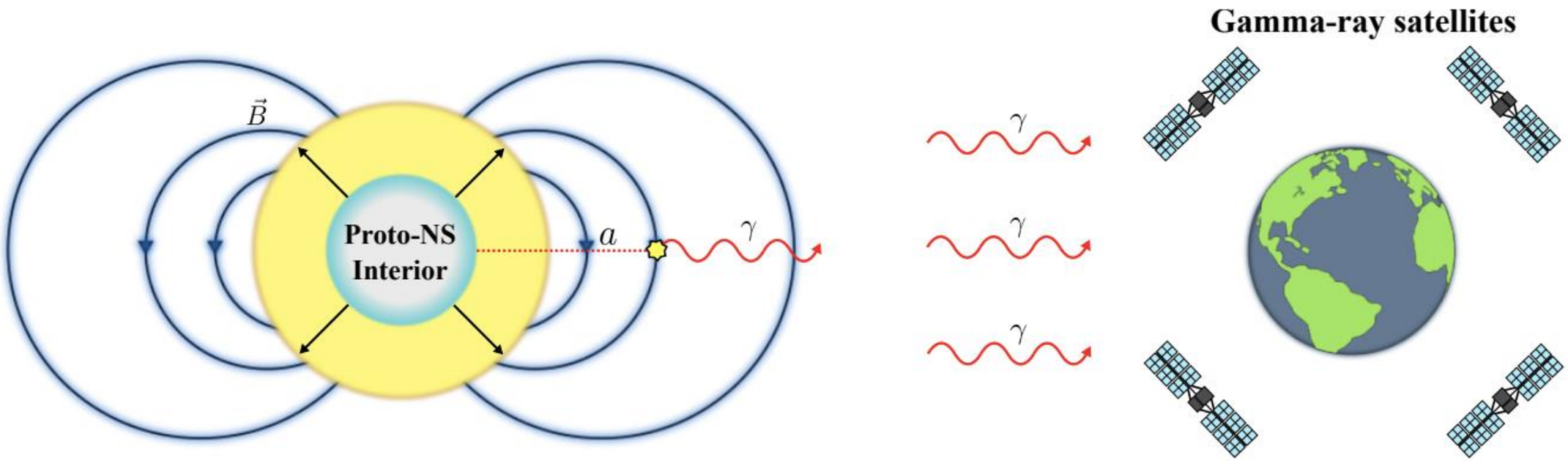


New Ideas?

GALactic AXion Instrument for Supernova (GALAXIS).

Recently received funding for prototype detector!

Safdi's talk at ICRC25



Manzari, Park, Safdi, Savoray *Phys.Rev.Lett.* 133 (2024) 21

FUTURE

Possible ideas for the next year

- Organize a couple of lectures on astrophysical instrumentation or other topics in WISP astrophysics.
- Online Workshop on the MeV Gap (if time allows).
- More dialogue with astrophysics community?

Any candidate interested in helping?
Other ideas?