Marco Taoso
INFN-Torino

Istituto Nazionale di Fisica Nucleare

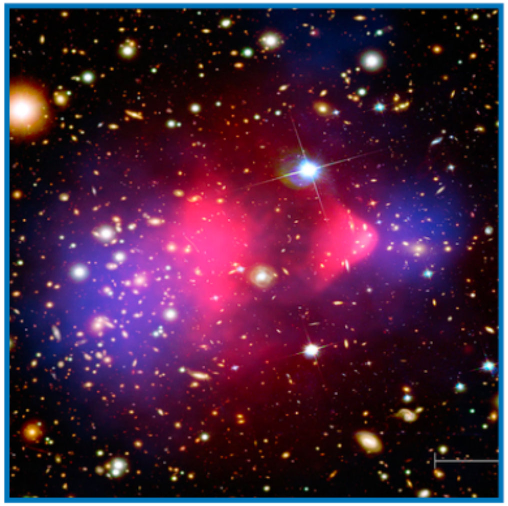
# Searching for axion dark matter from dwarf spheroidal galaxies and the Sun

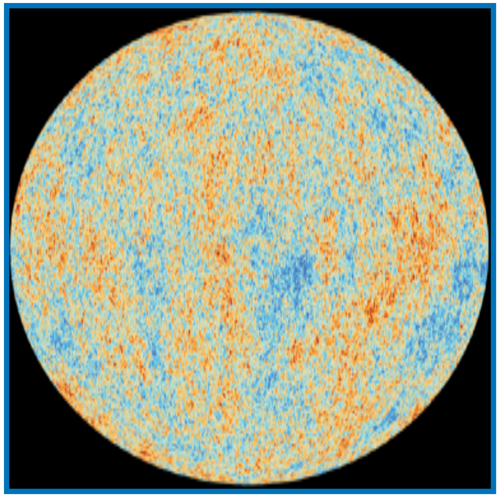
PPC 2024
Oct 14-18, 2024

# Motivations for the axion

The QCD axion originally proposed as a solution of the **strong CP problem**

**Axion** and its generalisation **Axion-Like Particles**: dark matter candidates

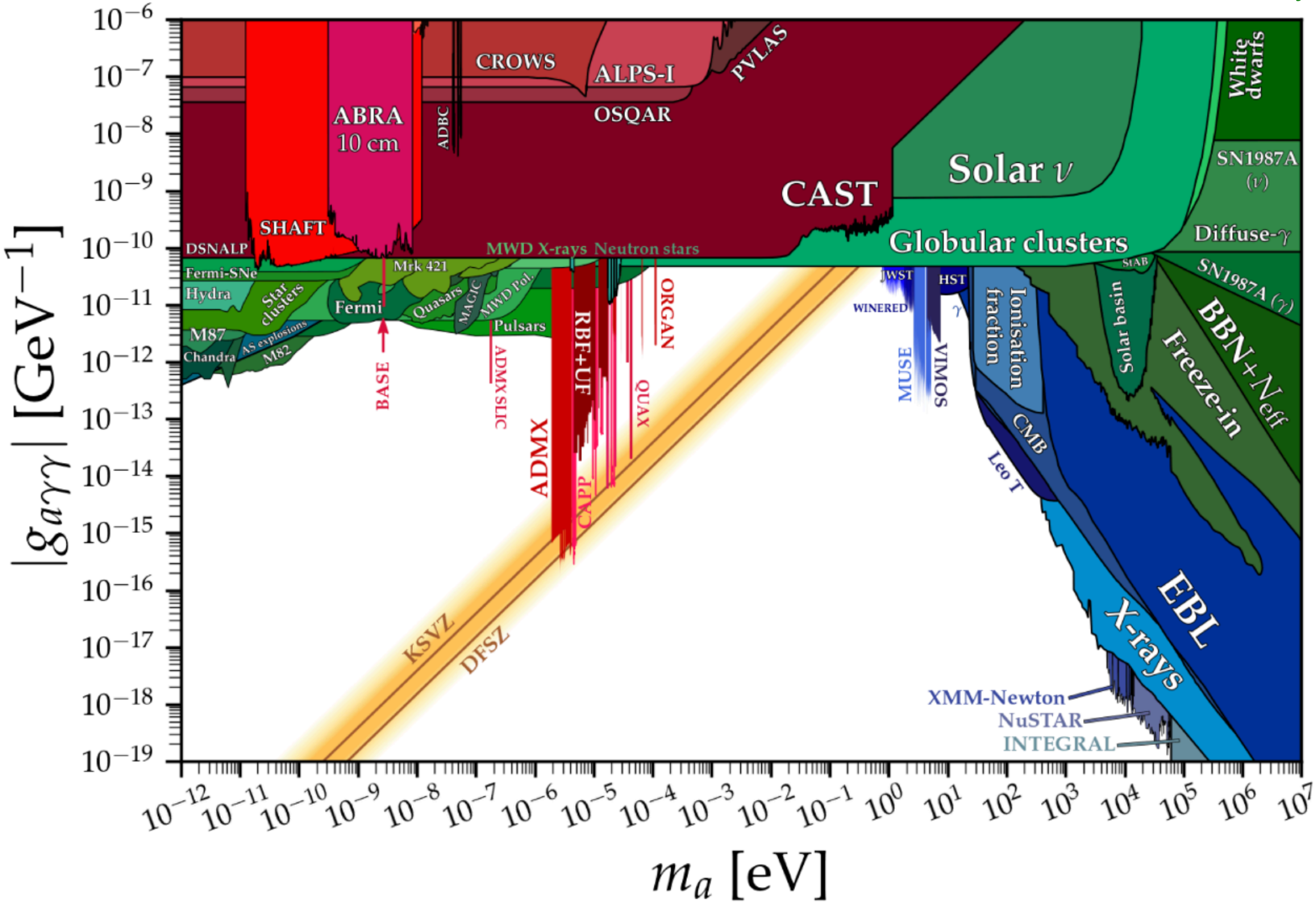




# Axion-Like Particles (ALPs)

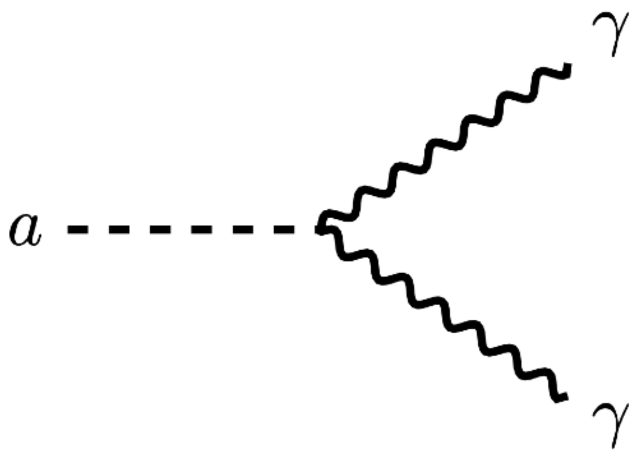
$$\mathcal{L} = \frac{1}{4} g_{a\gamma\gamma}\, a\, F_{\mu\nu}\tilde{F}_{\mu\nu} = -g_{a\gamma\gamma}\, a\, \vec{E}\cdot\vec{B}$$

Cajohare AxionLimits

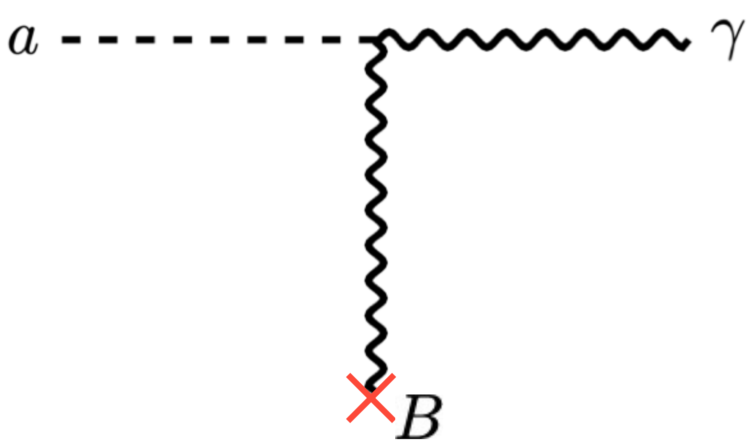


# ALP-photon interaction

$$\mathcal{L} = \frac{1}{4} g_{a\gamma\gamma}\, a\, F_{\mu\nu}\tilde{F}_{\mu\nu} = -g_{a\gamma\gamma}\, a\, \vec{E}\cdot\vec{B}$$




ALP decay




ALP-photon conversion

# Axion-like particles (ALPs)

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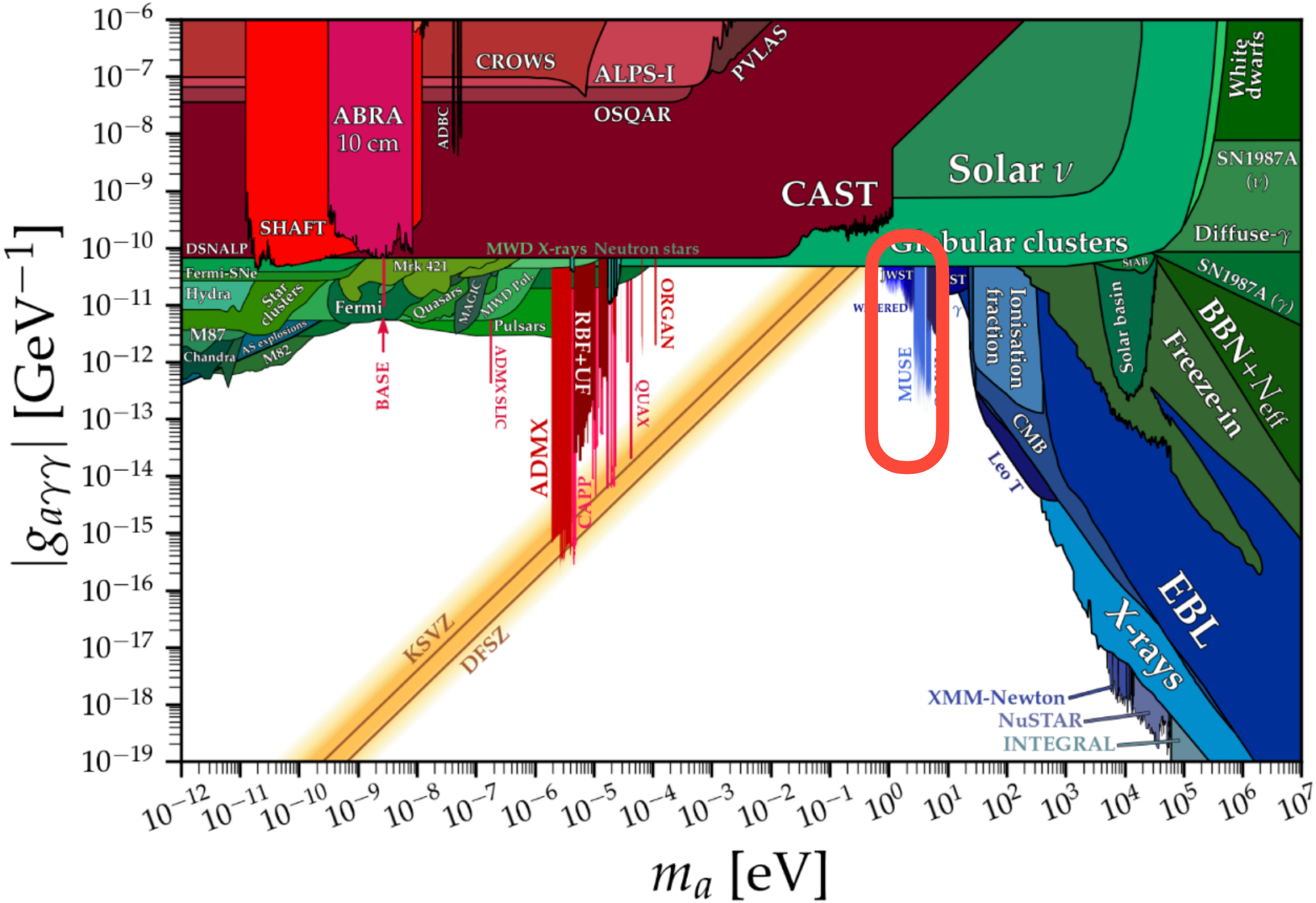
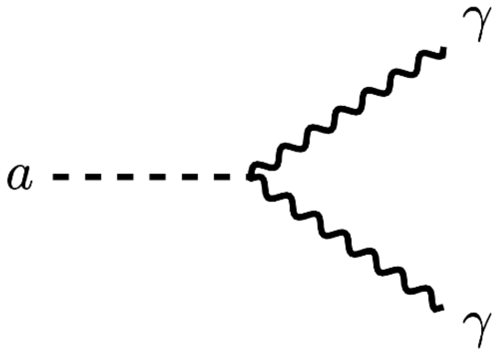
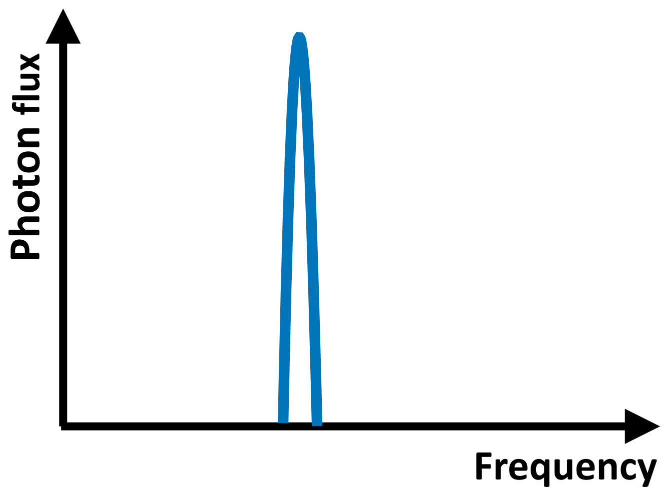


# ALP decays

$$\mathcal{L} = \frac{1}{4} g_{a\gamma\gamma}\, a\, F_{\mu\nu}\tilde{F}_{\mu\nu} = -g_{a\gamma\gamma}\, a\, \vec{E}\cdot\vec{B}$$

$$\Gamma_{a\to\gamma\gamma} \sim 10^{-22}\,\mathrm{yr}^{-1}\left(\frac{g_{a\gamma\gamma}}{10^{-13}\,\mathrm{GeV}^{-1}}\right)^2\left(\frac{m_a}{4\,\mathrm{eV}}\right)^3$$




Axion DM signal: optical line

# MUSE

**MUSE** Multi Unit Spectroscopic Explorer

Wavelength range

$$4700\,\text{Å} < \lambda < 9350\text{Å}$$

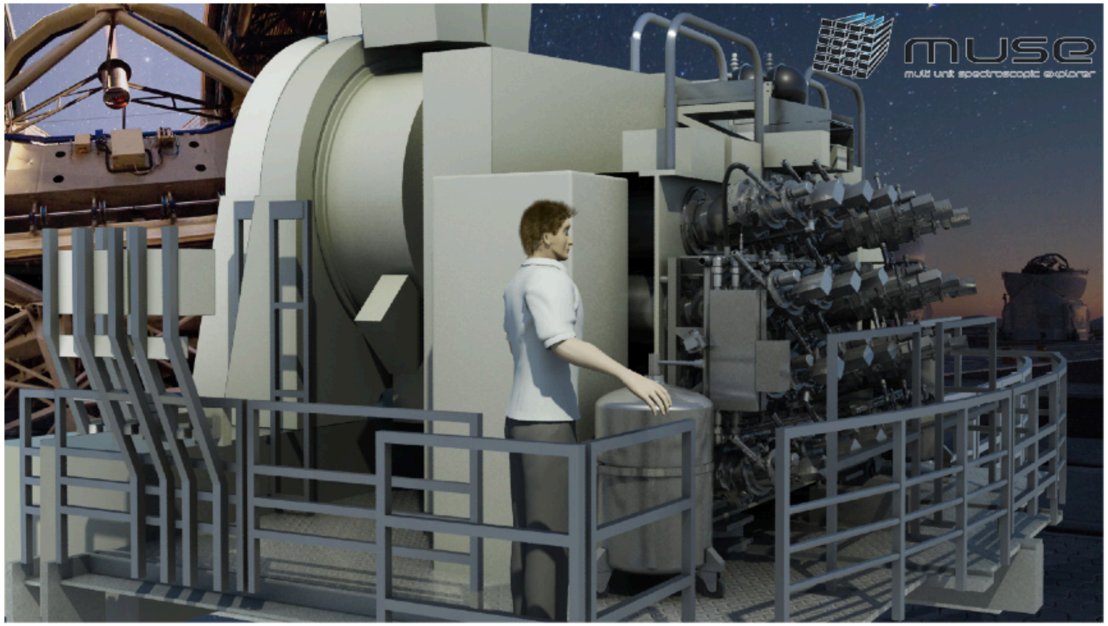
$$2.7\,\text{eV} < m_a < 5.3\,\text{eV}$$

Spectral resolution

$$\lambda/\Delta\lambda > 10^3$$

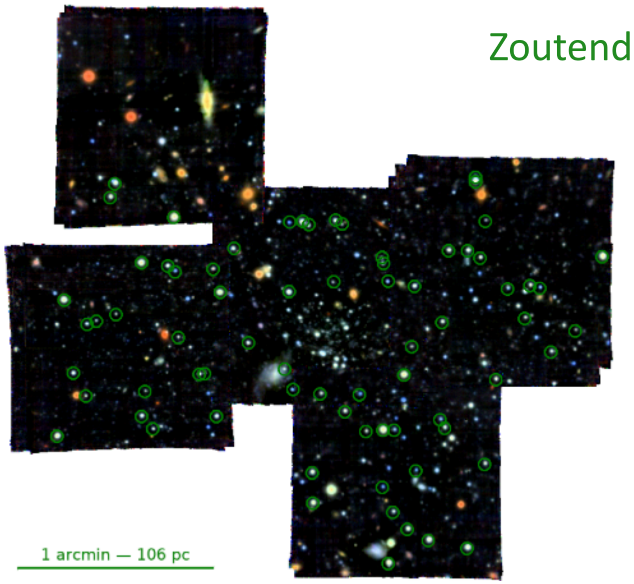
Field of view $1' \times 1'$

Spatial sampling $0.2''$

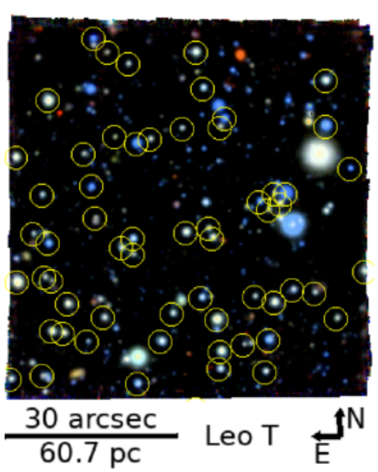


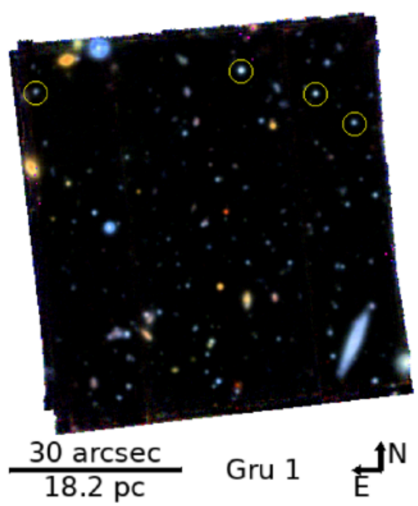
# The MUSE-Faint Survey

Zoutendijk et al. A&A, arXiv:2112.09374




**We analysed MUSE observations of 5 targets:**
**LeoT, Gru 1, Hydra II, Eridanus 2, Sculpture**

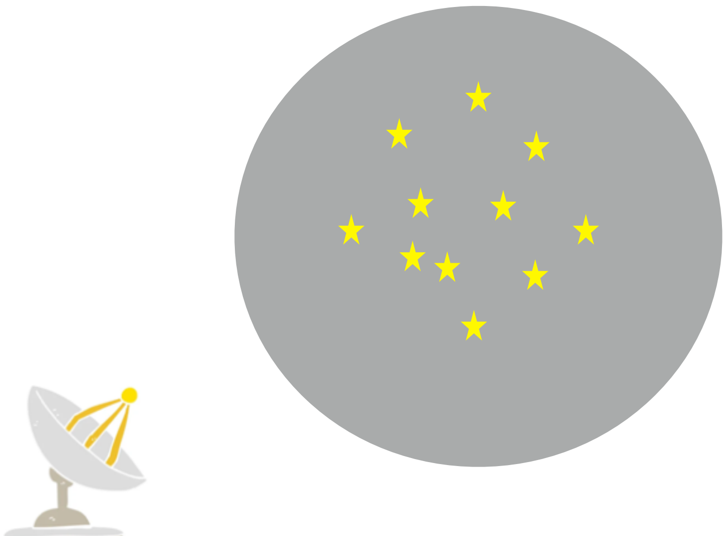



# ALP signal

$$S_\lambda(\theta) = \frac{\Gamma_a}{4\pi}\frac{1}{\sqrt{2\pi}\sigma_\lambda}\exp\left[-\frac{(\lambda-\lambda_{obs})^2}{2\sigma_\lambda^2}\right]\int d\Omega\, d\ell \rho_a[r(\theta,\Omega,\ell)]\, B(\Omega)\ .$$

Dark matter density profile



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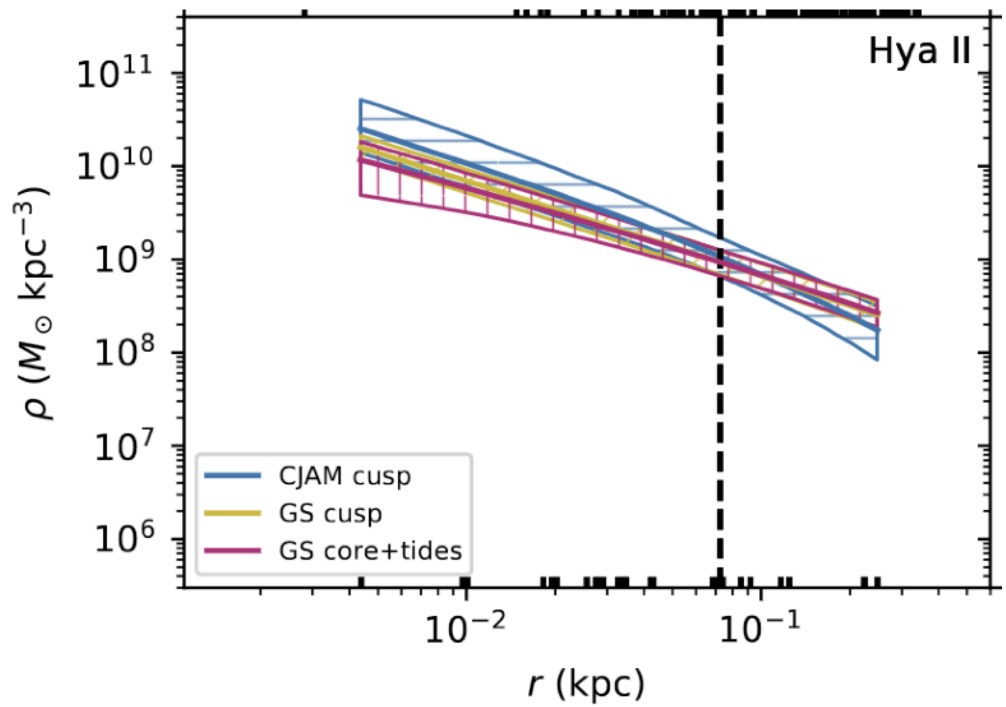

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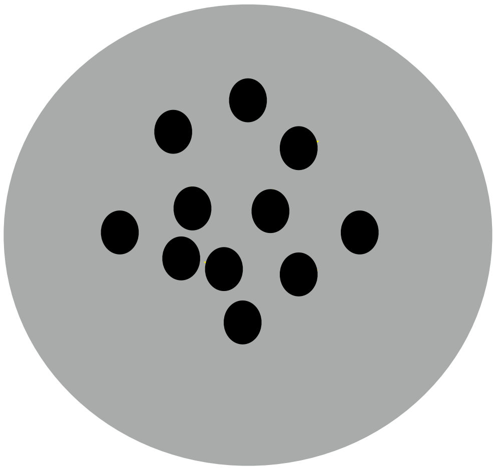

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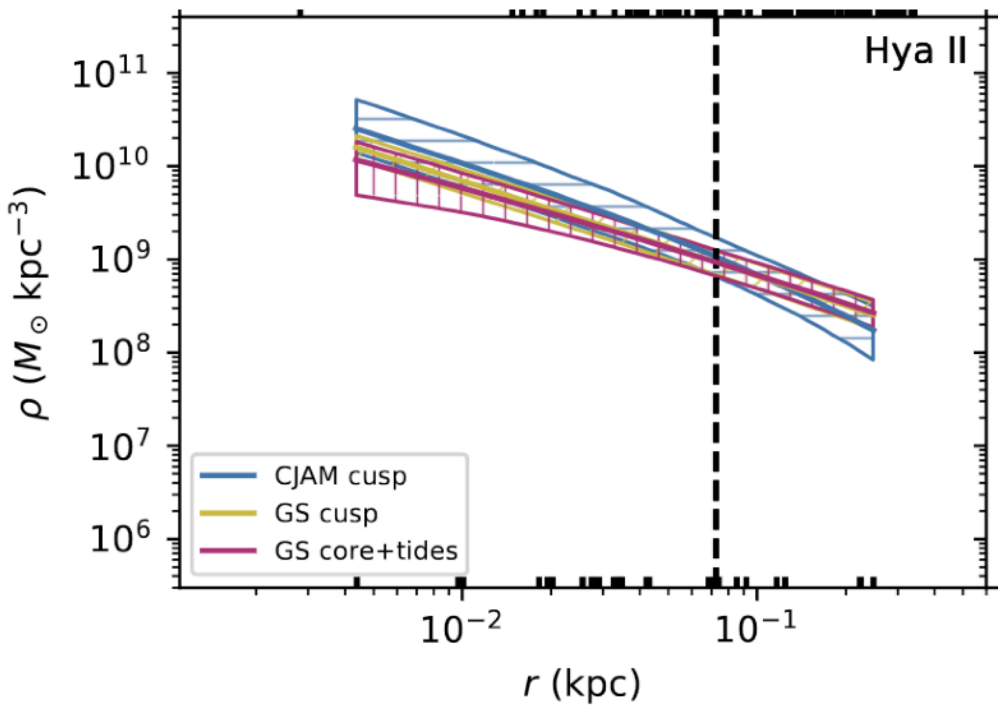
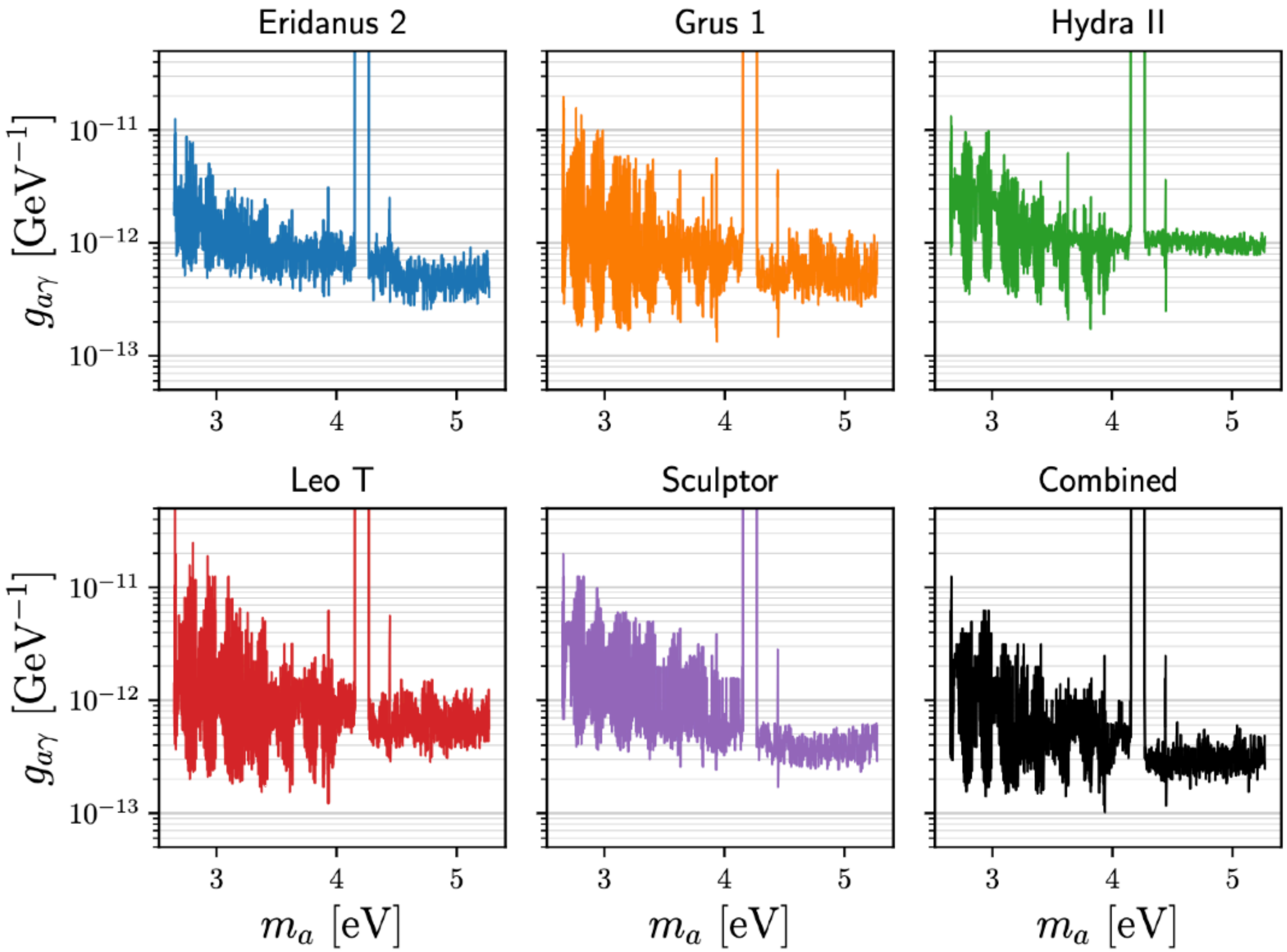


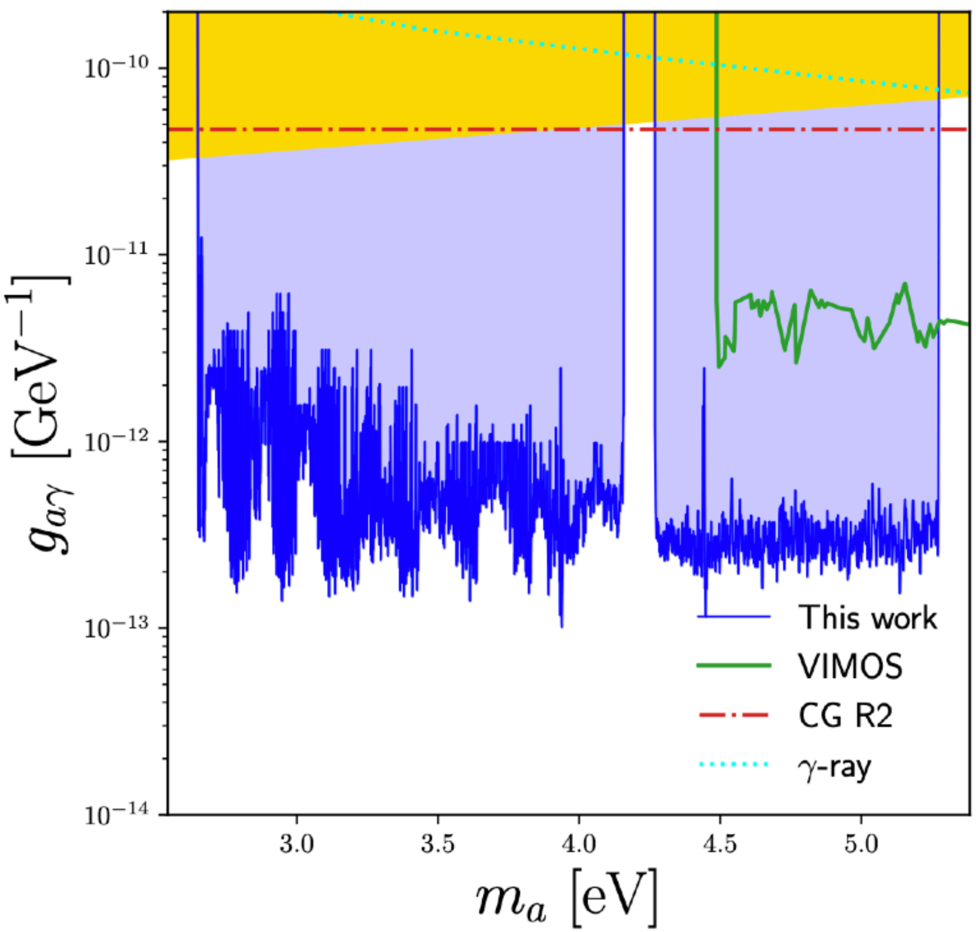
# Results

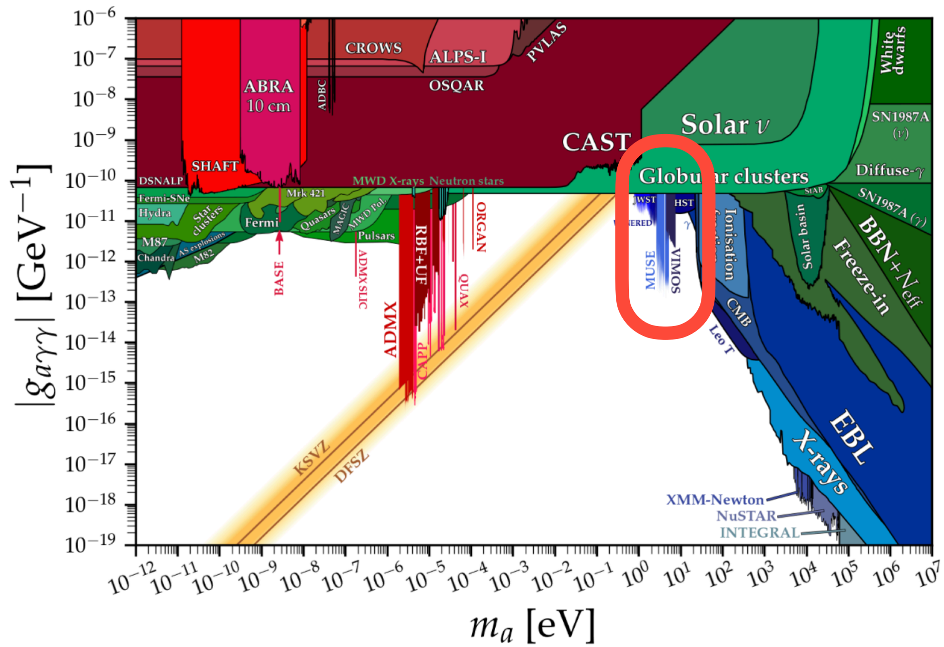



Todarello, MT +, JCAP 05 (2024) 043

# Results

Todarello, MT +,  JCAP 05 (2024) 043




Other searches:

| | |
|---|---|
| VIMOS | Grin et al. PRD 75 (2007) 15018 |
| JWST | Janish, Pinetti, arXiv:2310.15395 |
| JWST | Ray et al. arXiv:2311.04987 |
| WINERED | Yin et al. arXiv:2402.07976 |

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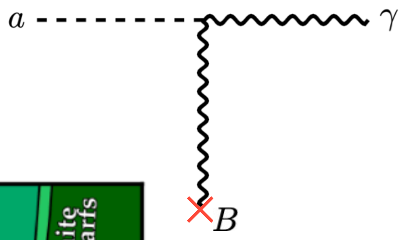
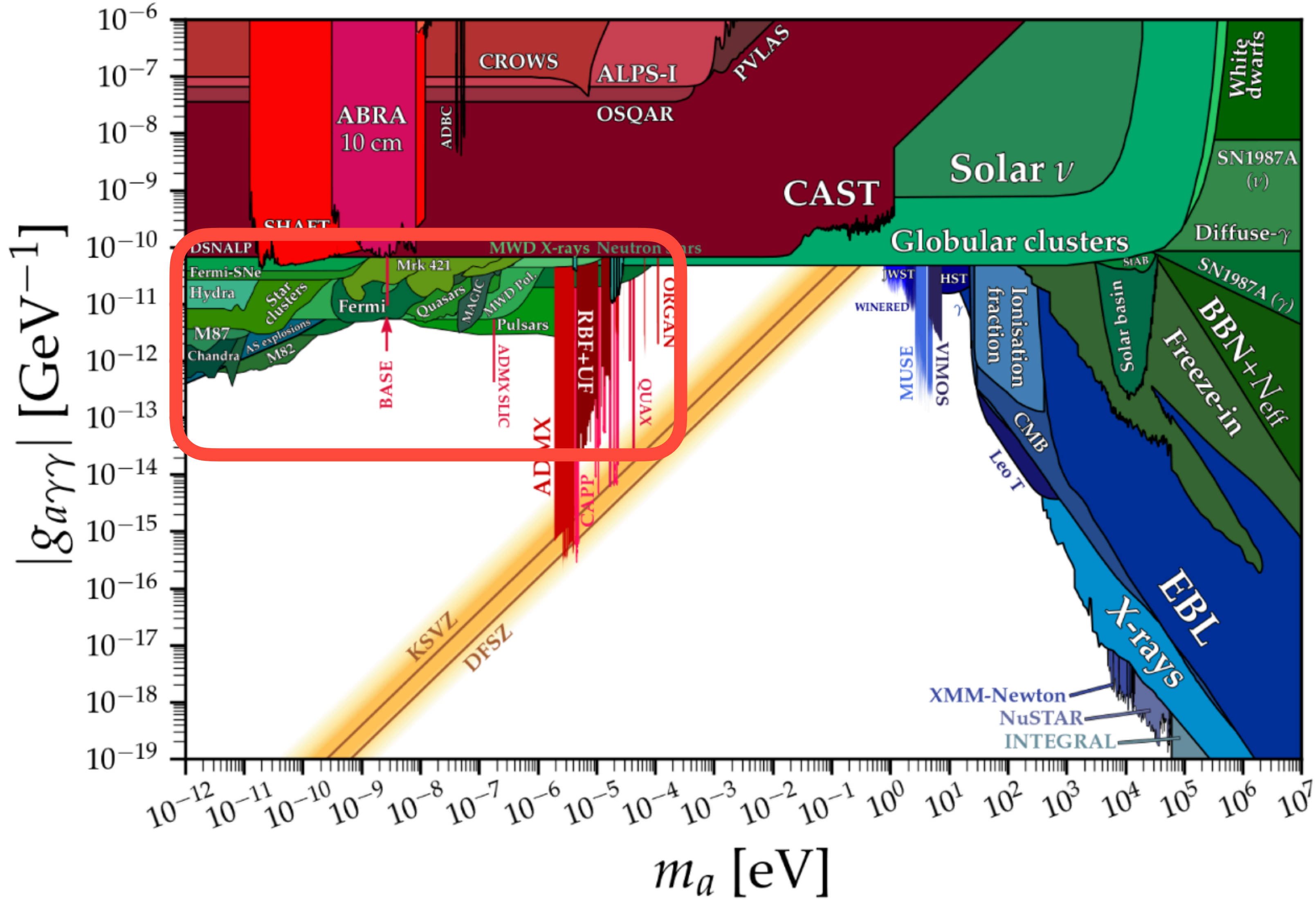
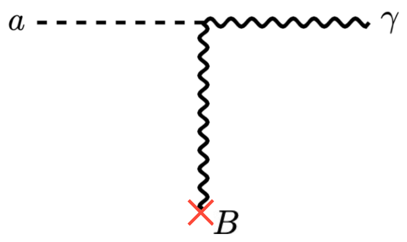
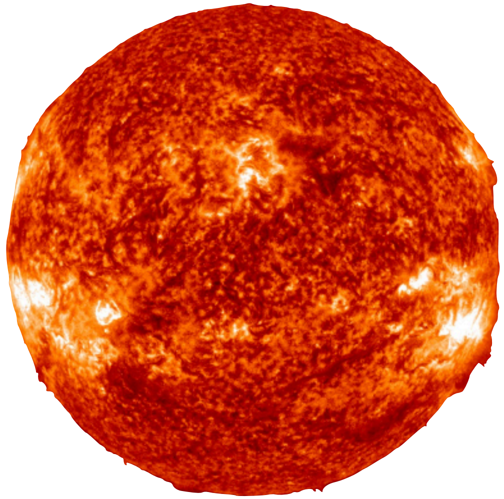


# ALP-photon conversion in the Sun



**Possibility n. 1**

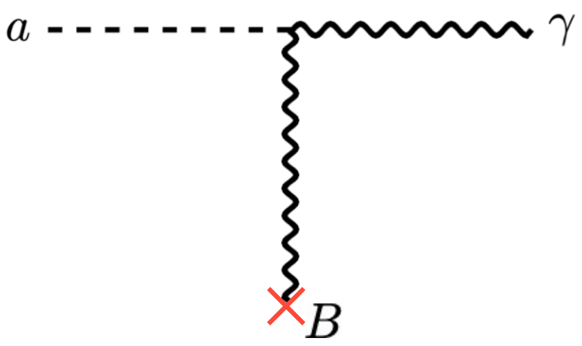
**Relativistic** axions produced in the core of the Sun and converted into photons in the solar atmosphere

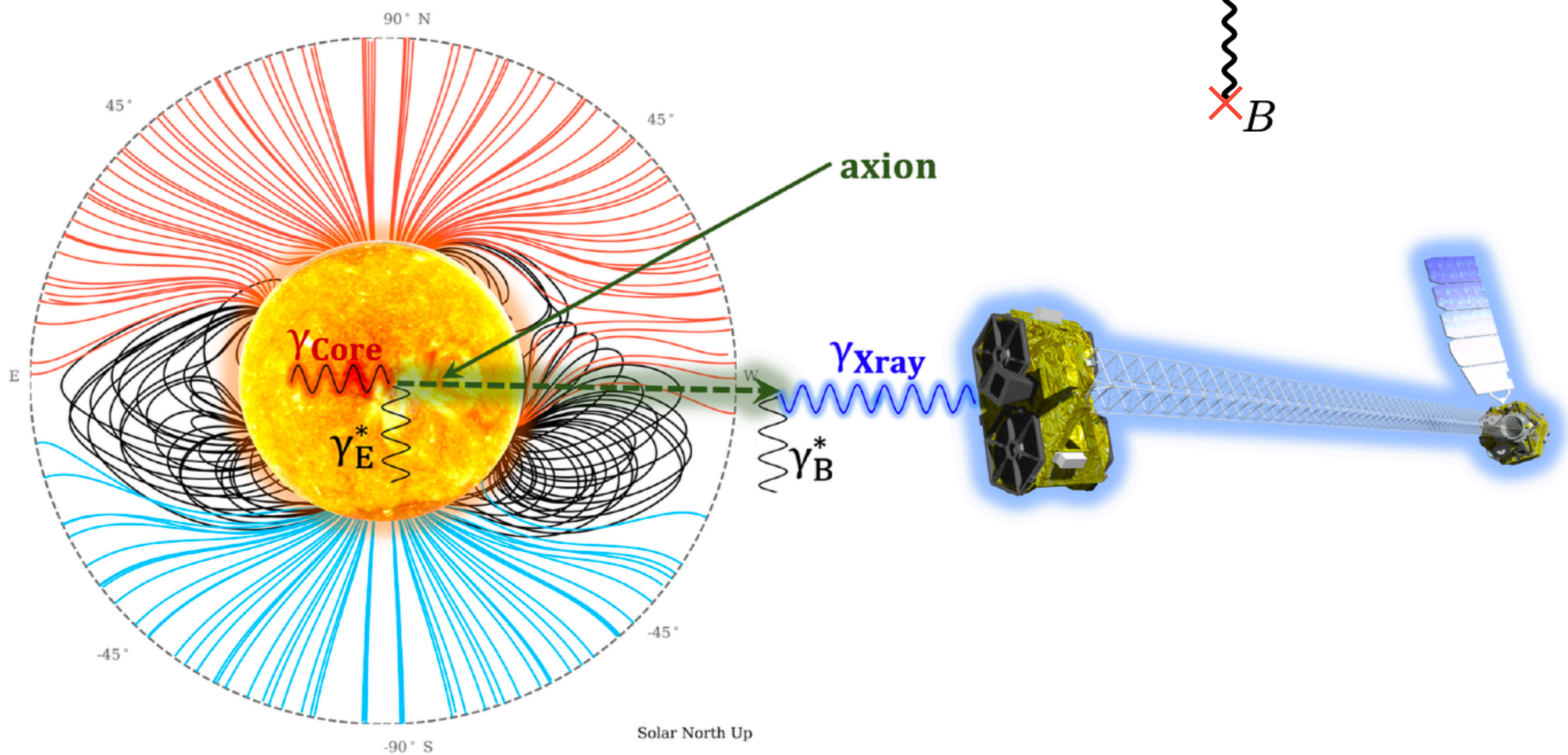
**Possibility n. 2**

$\mathcal{O}(\mu eV)$ **ALP dark matter** conversion into photons in the solar atmosphere

# NuSTAR as an axion Helioscope

**Possibility n. 1**

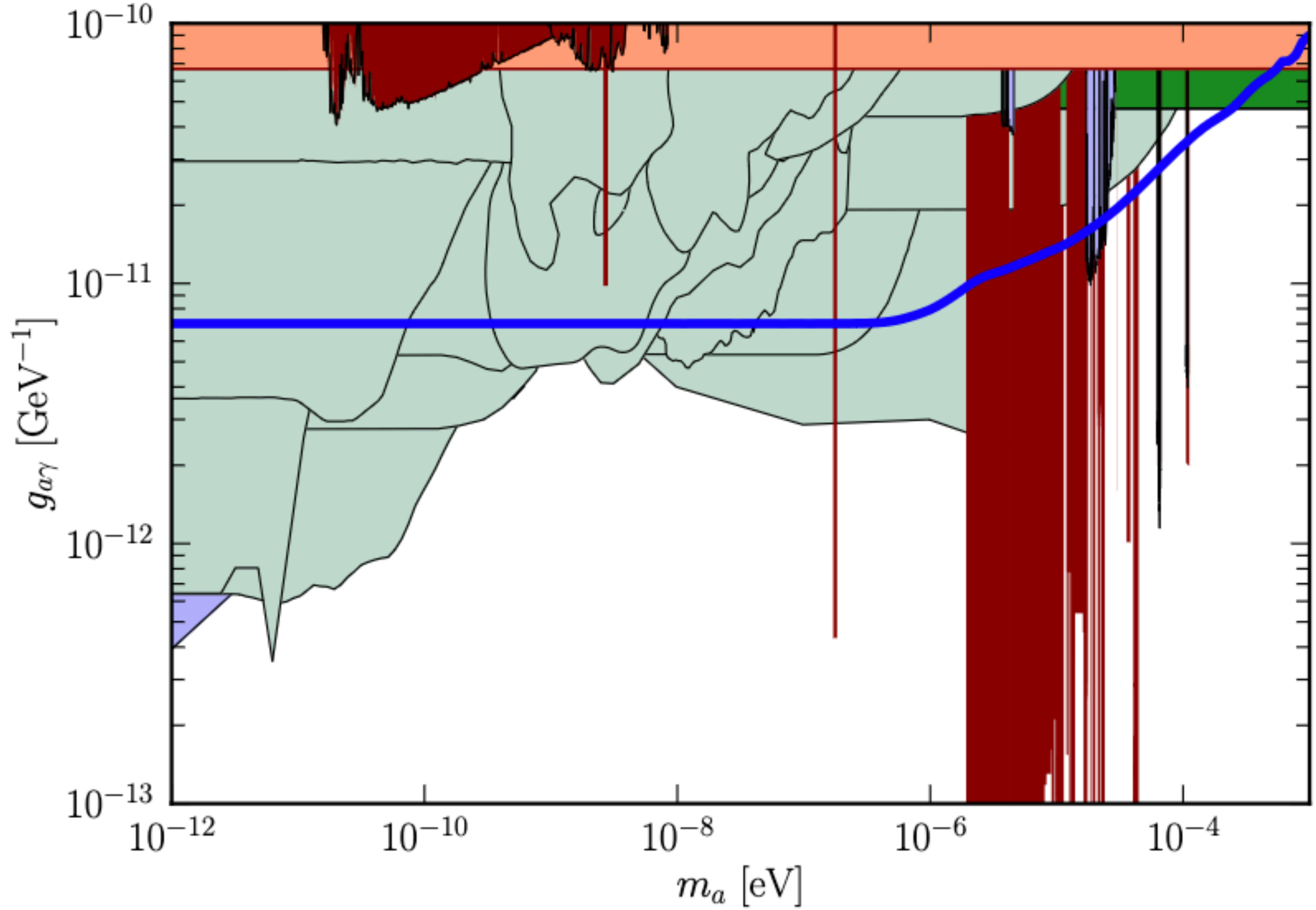


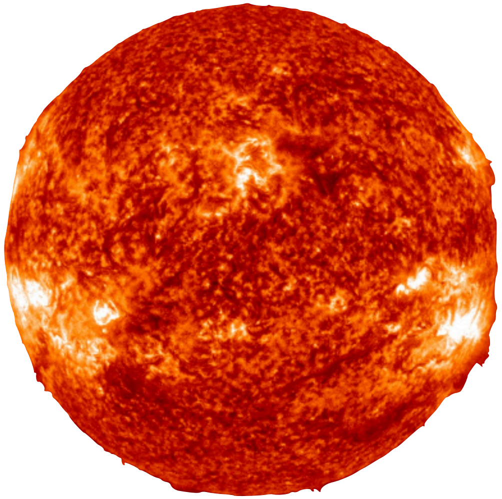
# NuSTAR as an axion Helioscope

Strong and robust limits

Ruz, Todarello, Vogel, MT +, arXiv 2407.03828



# ALP-photon conversion in the Sun



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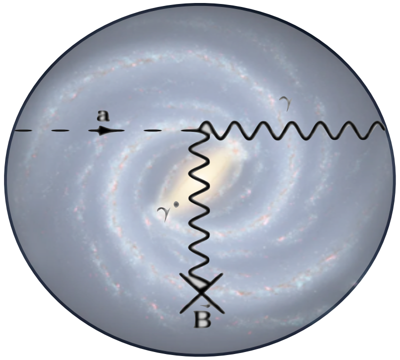
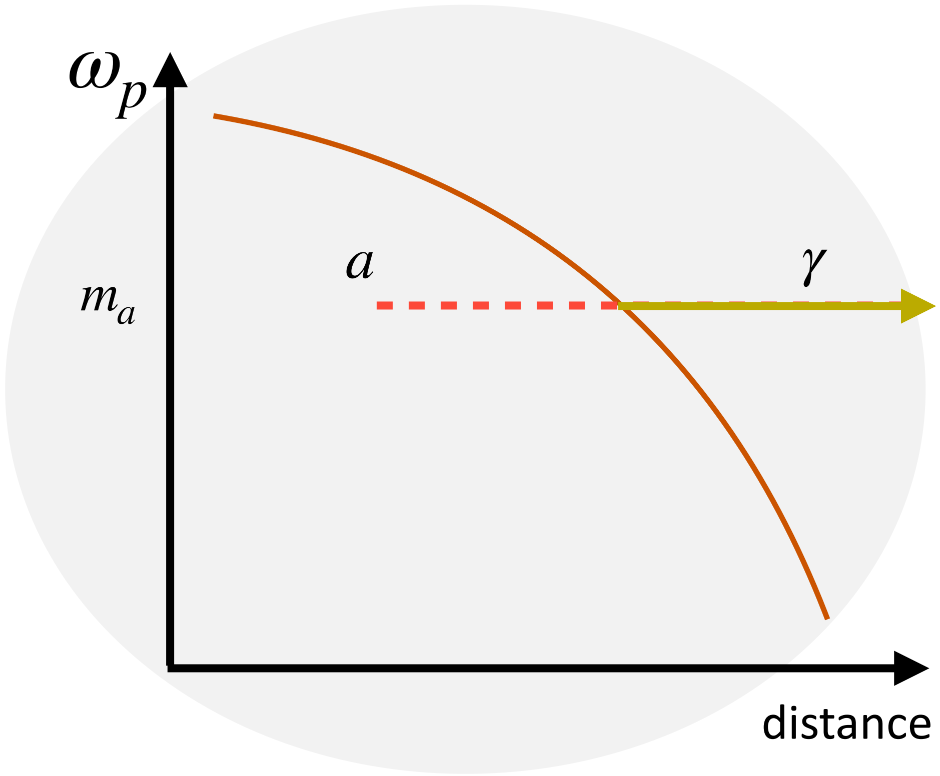
# Axion-photon conversion

$$\mathcal{L}_{a\gamma} = -\frac{1}{4} g_{a\gamma} F_{\mu\nu} \tilde{F}^{\mu\nu} a = g_{a\gamma} \mathbf{E} \cdot \mathbf{B} a$$




$$\omega_p^2 = e^2 n_e / m_e$$




Conversion probability boosted at resonance:
when axion mass matches plasma frequency (effective photon mass)

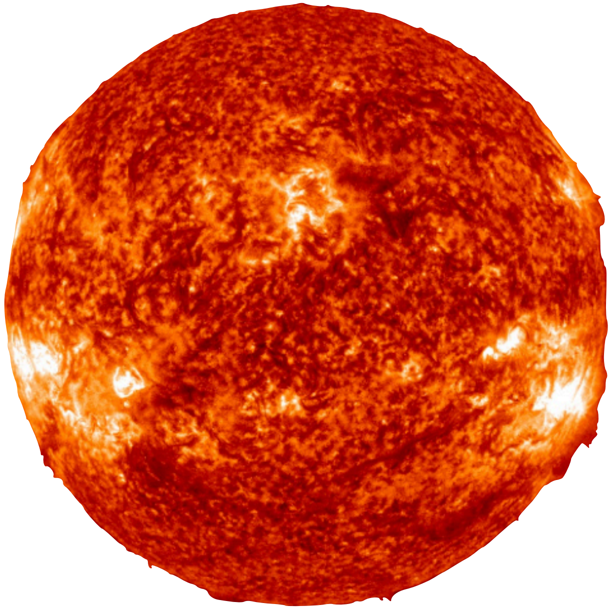
Axion DM signal:
radio line

Neutron star excellent targets

Pshirkov, Popov (2009); Hook et al. (2018); Safdi et al. (2018); Battye et al. (2019); Witte et al. (2021), Millar et al. (2021); Foster et al. (2022); +…

# Axion-photon conversion in the Sun

Dark photon conversion in the Sun
An et al. PRL 126 (2021) 18



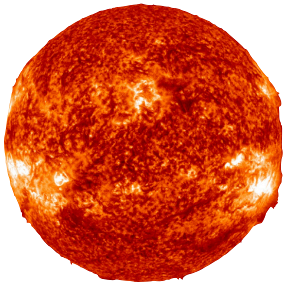
Conversion of axion dark matter in the solar atmosphere

$$P_{a\to\gamma} \simeq \frac{\pi}{2}\frac{g_{a\gamma}^2 B^2}{v_a \omega'_{p|res}} \qquad \omega'_{p|res} = d\omega_p/dr$$

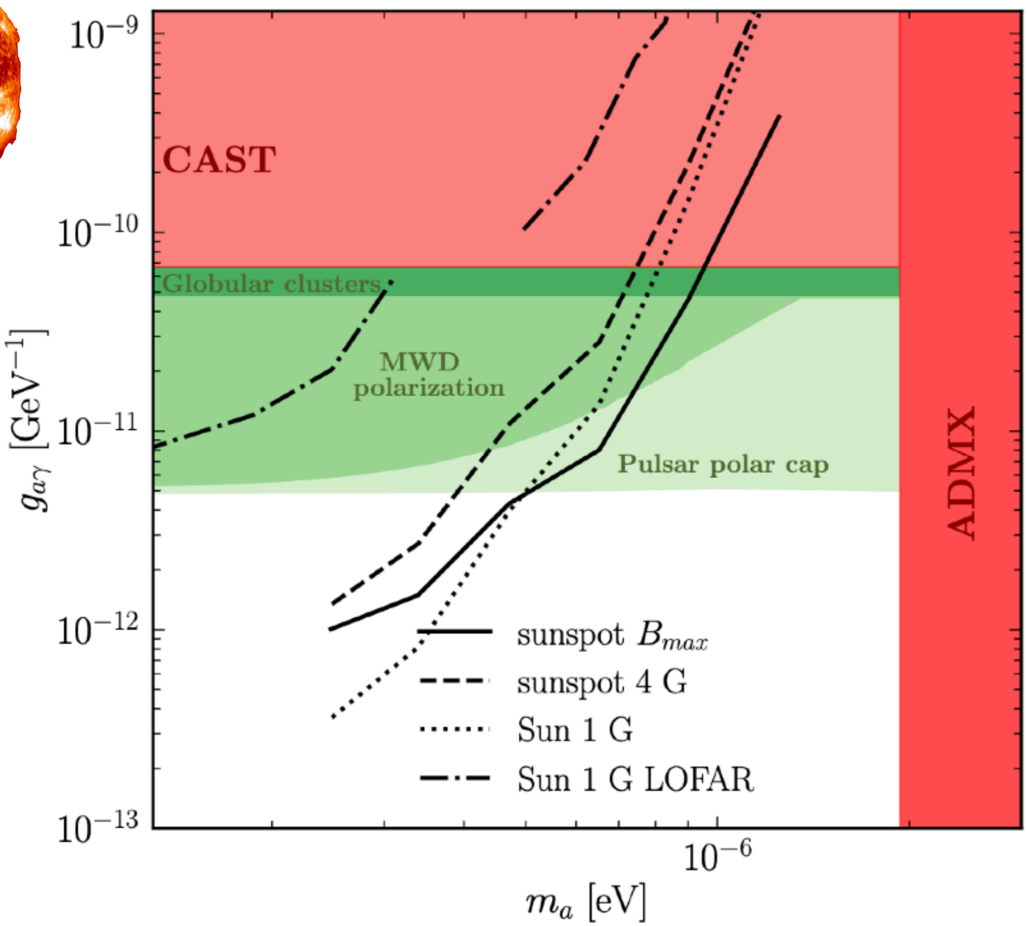
$$S = \int \frac{d\Omega}{4\pi\,\Delta\nu}\,\rho_a\, v_a\, P_{a\to\gamma}\, e^{-\tau}$$

Absorption of the generated radio photons due to cyclotron and bremsstrahlung processes

# Prospects with future radio instruments



Todarello, Regis, MT +, Giannotti, Ruz, Vogel PLB 854(2024)138752




Prospects for the
Square Kilometer Array (SKA)
radio telescope

Searches with existing LOFAR data not very sensitive to ALPs (good for dark photons)

An et al. Nature Comm 15 (2024) 1

# Conclusions

eV ALP dark matter decays into photons : strong limits from MUSE optical obs

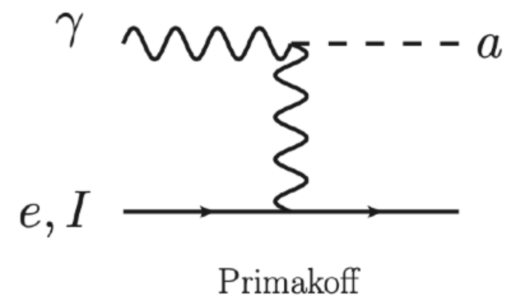
$\mathcal{O}(\mu eV)$ ALP dark matter conversion in the Sun atmosphere: prospects for SKA radio obs

Conversion of relativistic axions in the Sun: strong bounds from NuSTAR X-ray obs

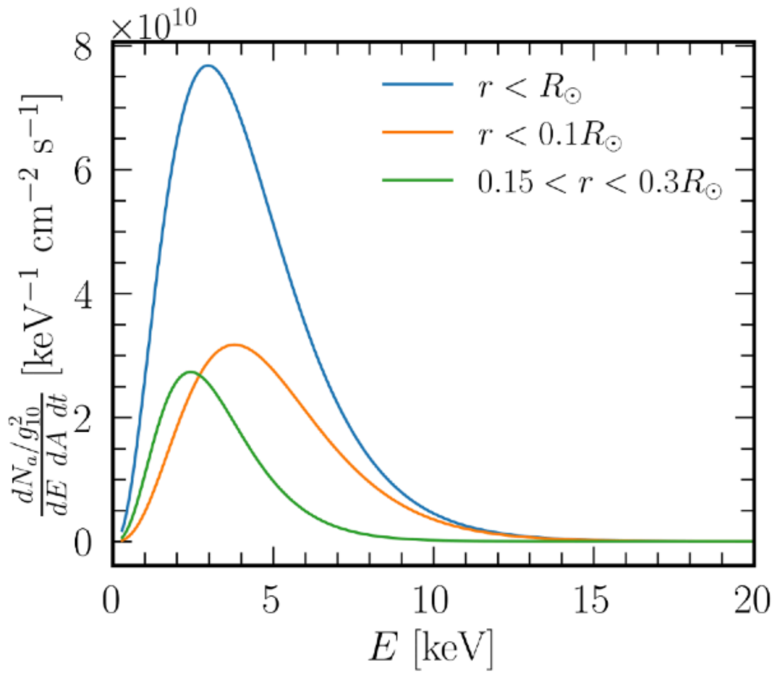
# Additional material

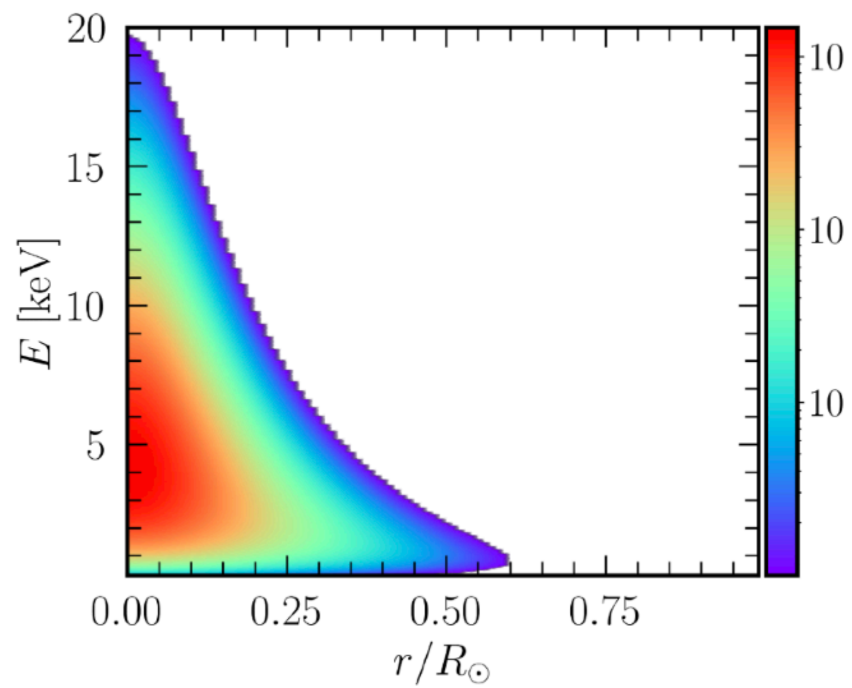
# Relativistic axions from the Sun

Axion flux from the inner solar region



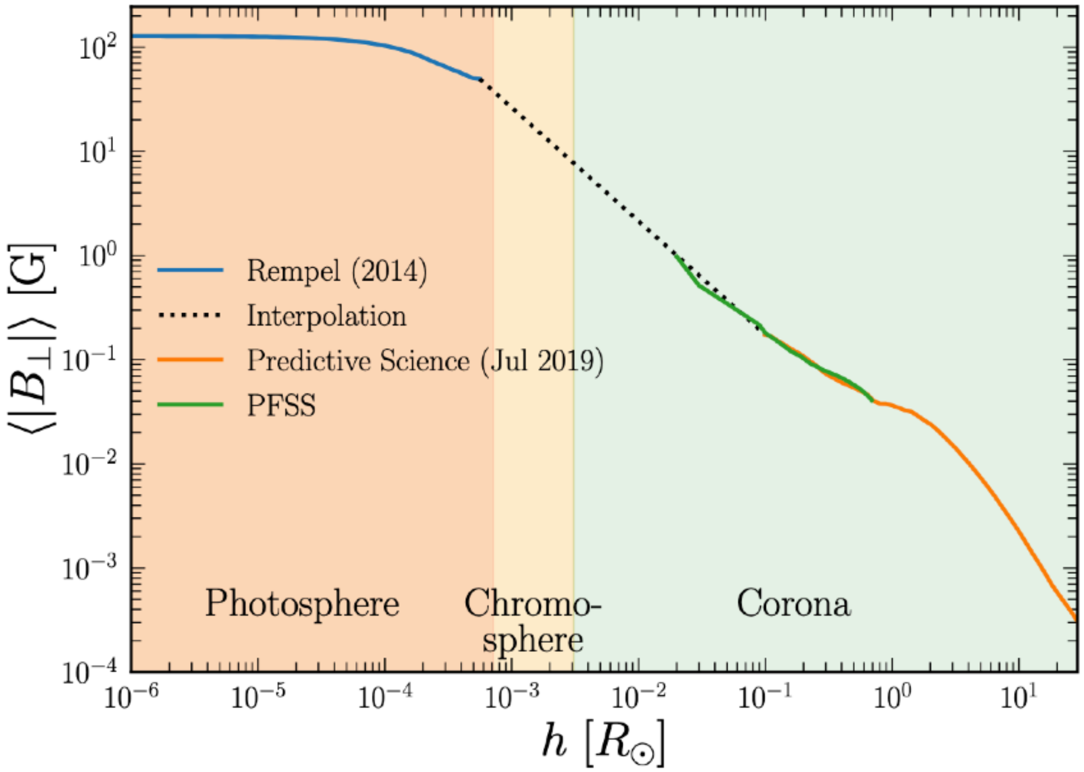

Flux well understood
see e.g. Hoof, Jaeckel Thormaehlen, JCAP 10 (2024) 024



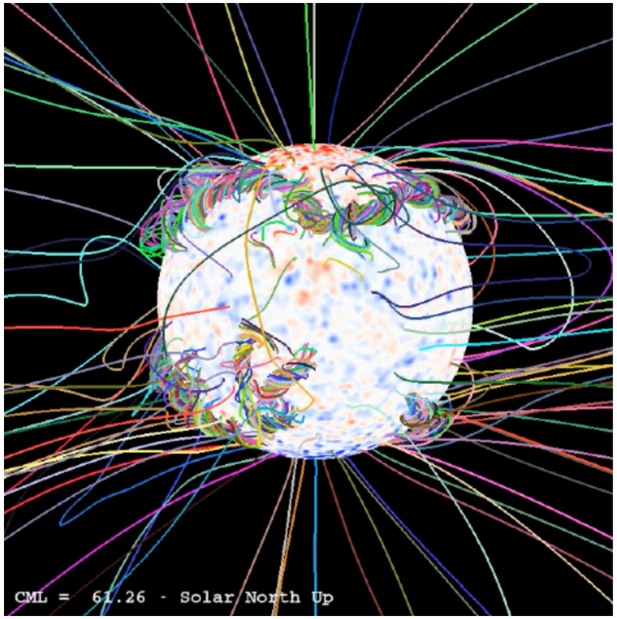



# Magnetic field in solar atmosphere

Magnetic field for the Quiet Sun

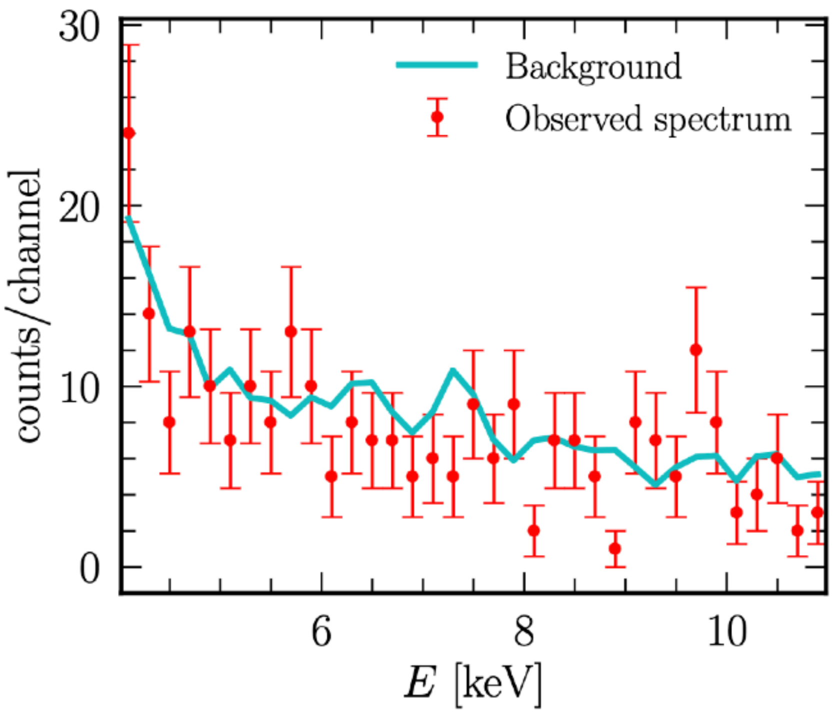


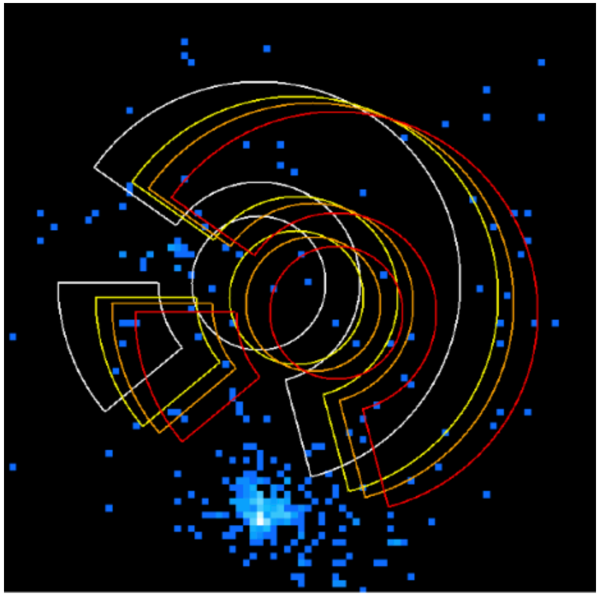

Predictive Science Inc.
for 2019 solar eclipse



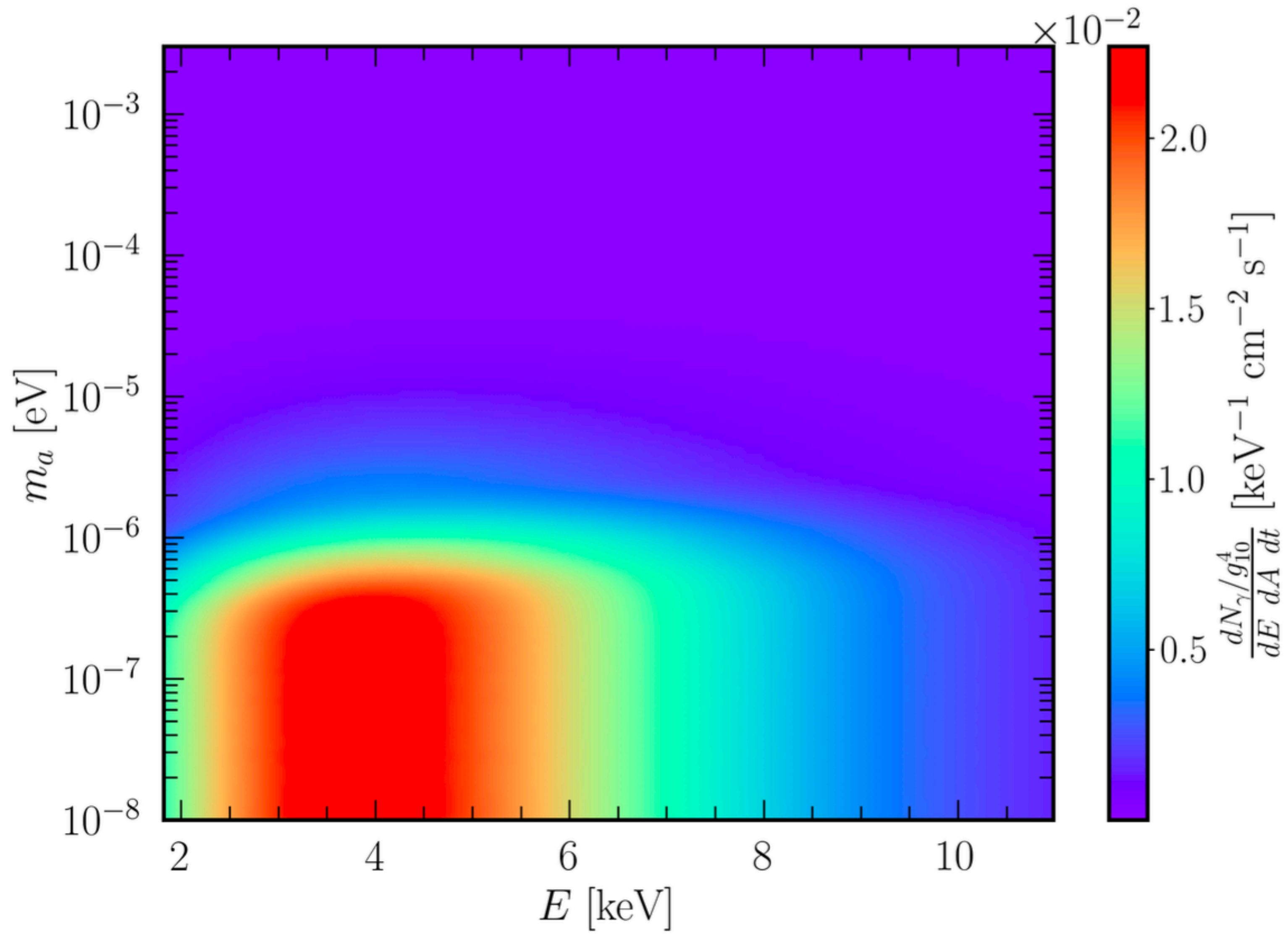
# NuSTAR data

NuSTAR X-rays observations of the Sun



# Solar X-ray emission from axions



# Radio line from ALP DM conversion