Marco Taoso
INFN-Torino

Istituto Nazionale di Fisica Nucleare

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

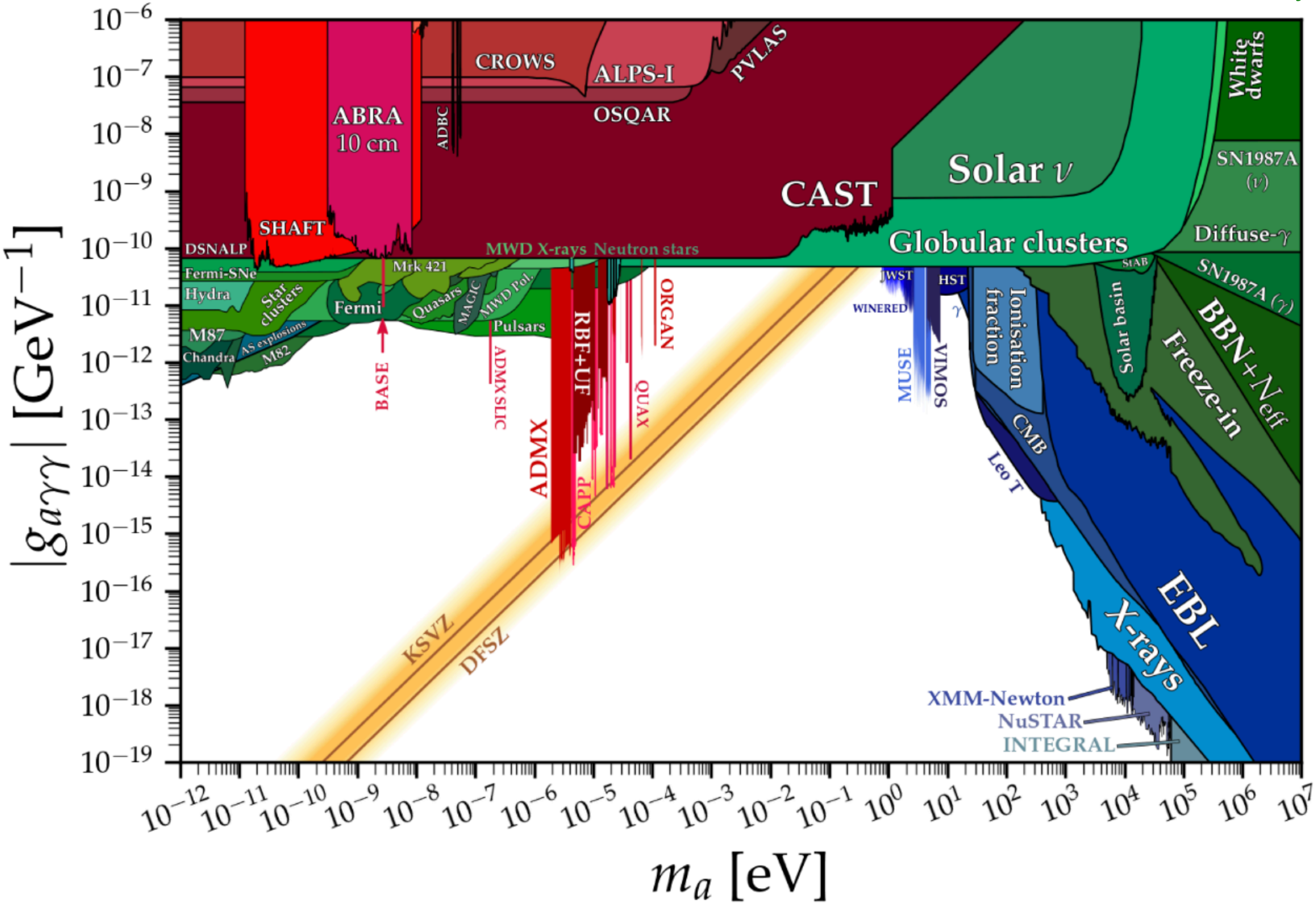
DSU 2024

Sept 8-14, 2024

Axion-like particles (ALPs)

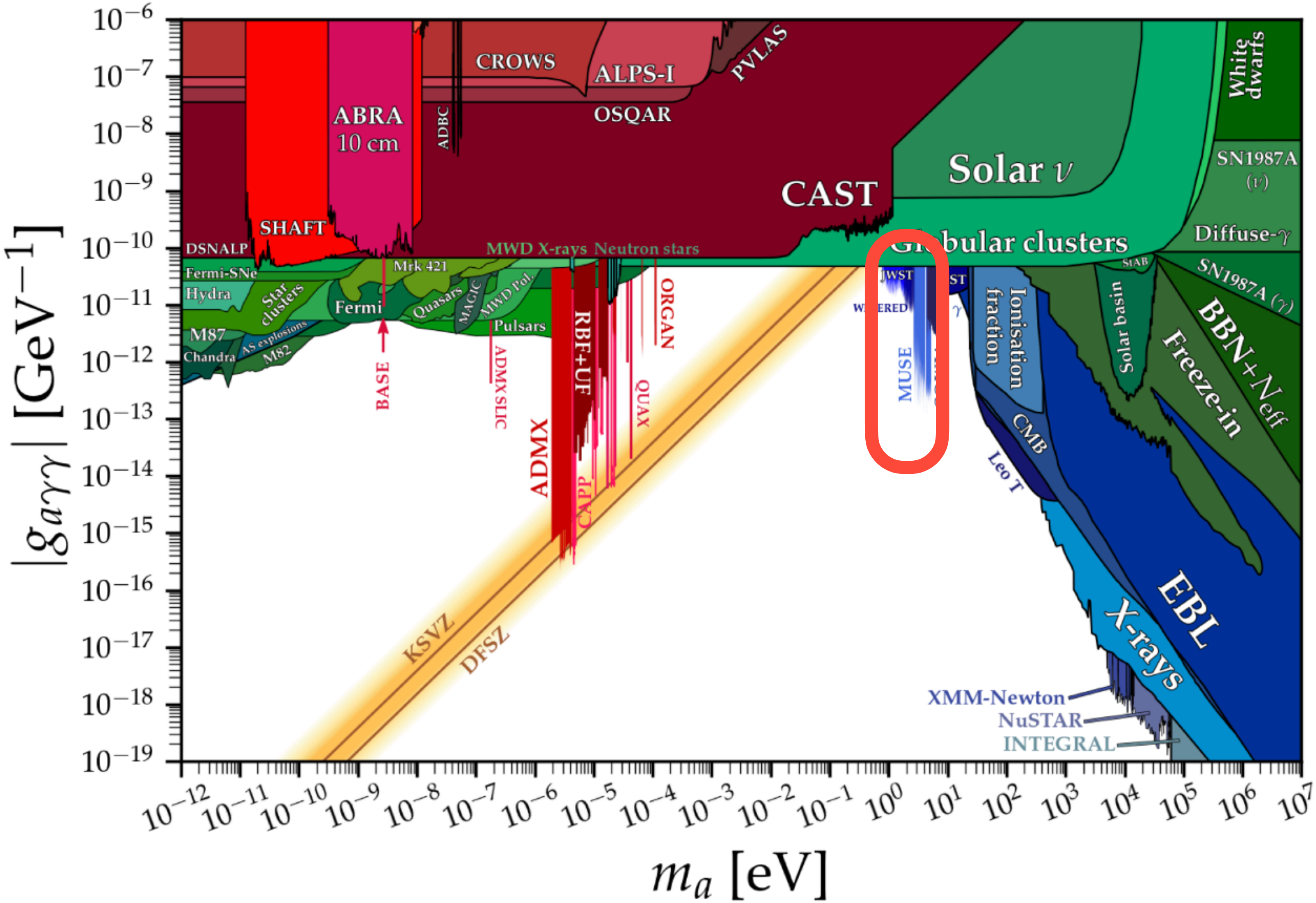
$$\mathcal{L} = \frac{1}{4} g_{a\gamma\gamma}\, a\, F_{\mu\nu}\tilde{F}_{\mu\nu} = -g_{a\gamma\gamma}\, a\, \vec{E}\cdot\vec{B}$$

Cajohare AxionLimits



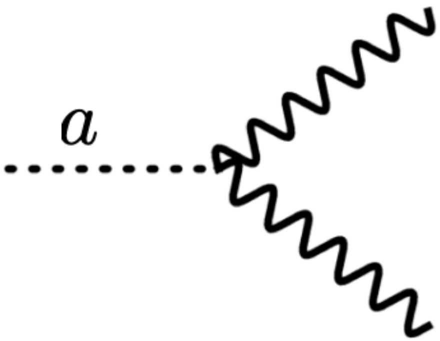
Axion-like particles (ALPs)

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

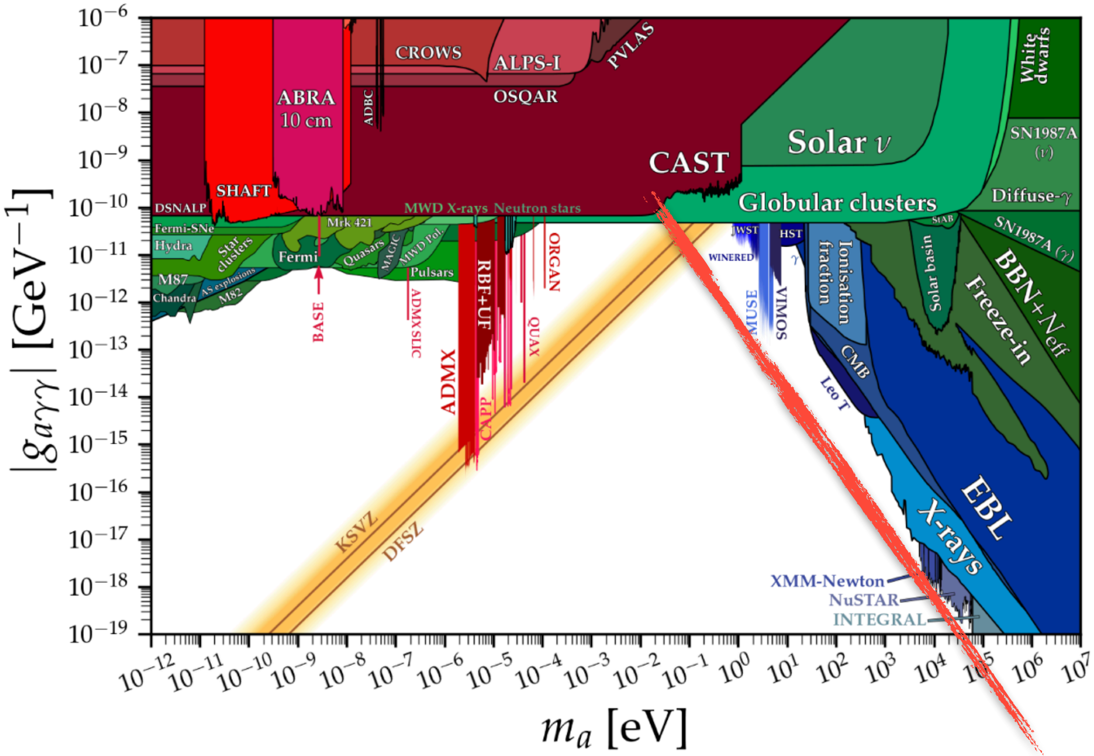


ALP decays

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



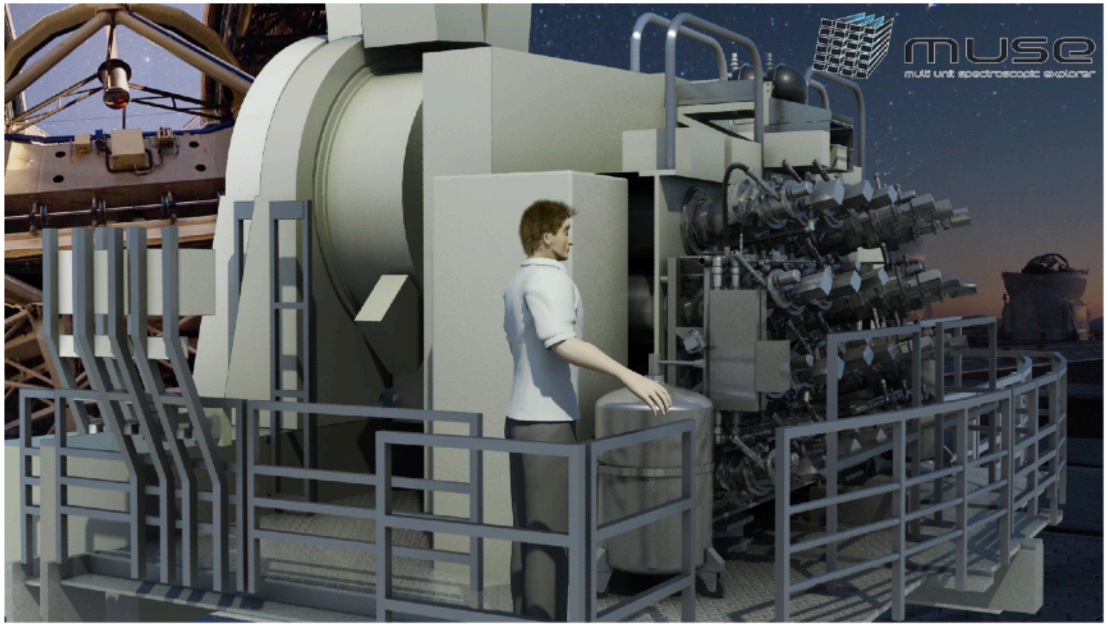
$$\Gamma_{a\to\gamma\gamma} \sim 10^{-22}\,\mathrm{yr}^{-1} \left(\frac{g_{a\gamma\gamma}}{10^{-13}\,\mathrm{GeV}^{-1}} \right)^2 \left(\frac{m_a}{4\,\mathrm{eV}} \right)^3$$



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

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

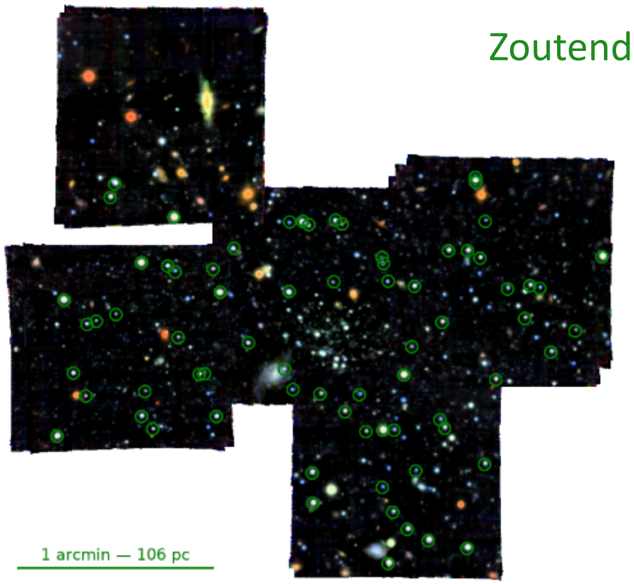
Field of view $1' \times 1'$

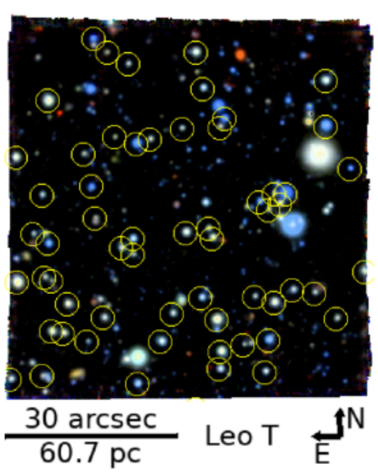
Spatial sampling $0.2''$

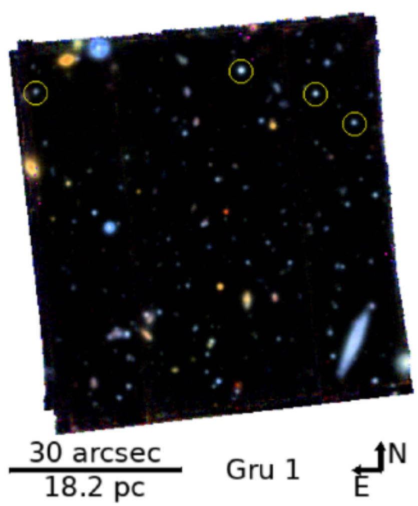
The MUSE-Faint Survey

Zoutendijk et al. A&A, arXiv:2112.09374

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



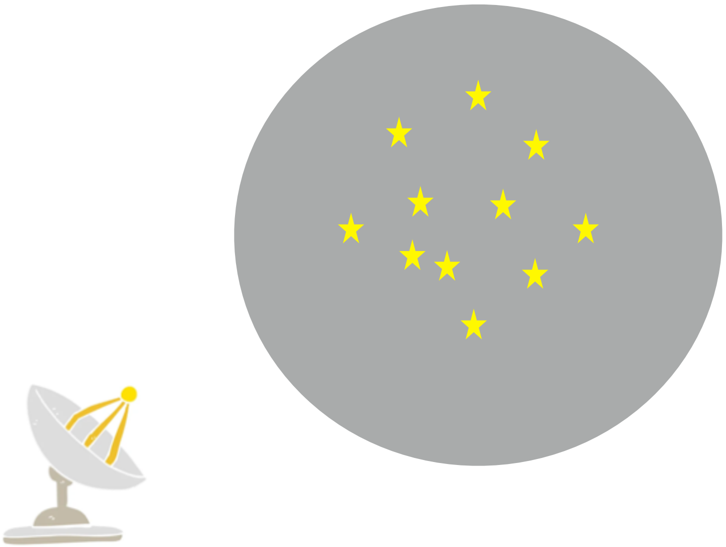




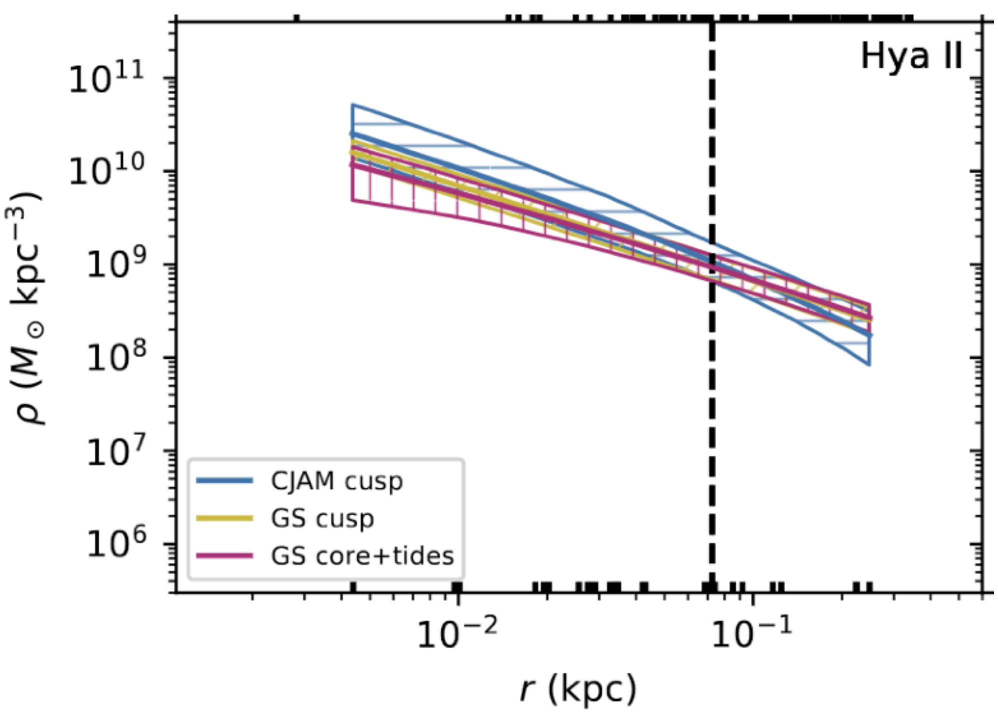
ALP signal

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

Dark matter density profile



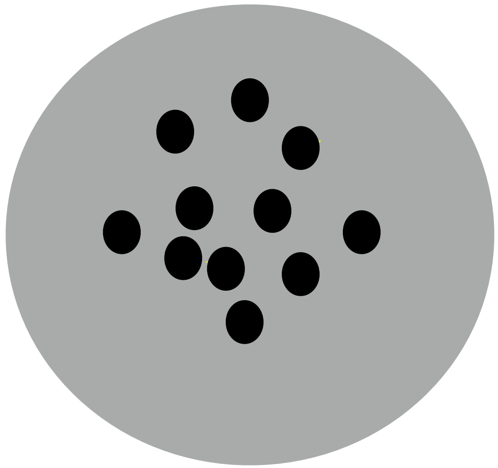
Zoutendijk et al. A&A, arXiv:2112.09374



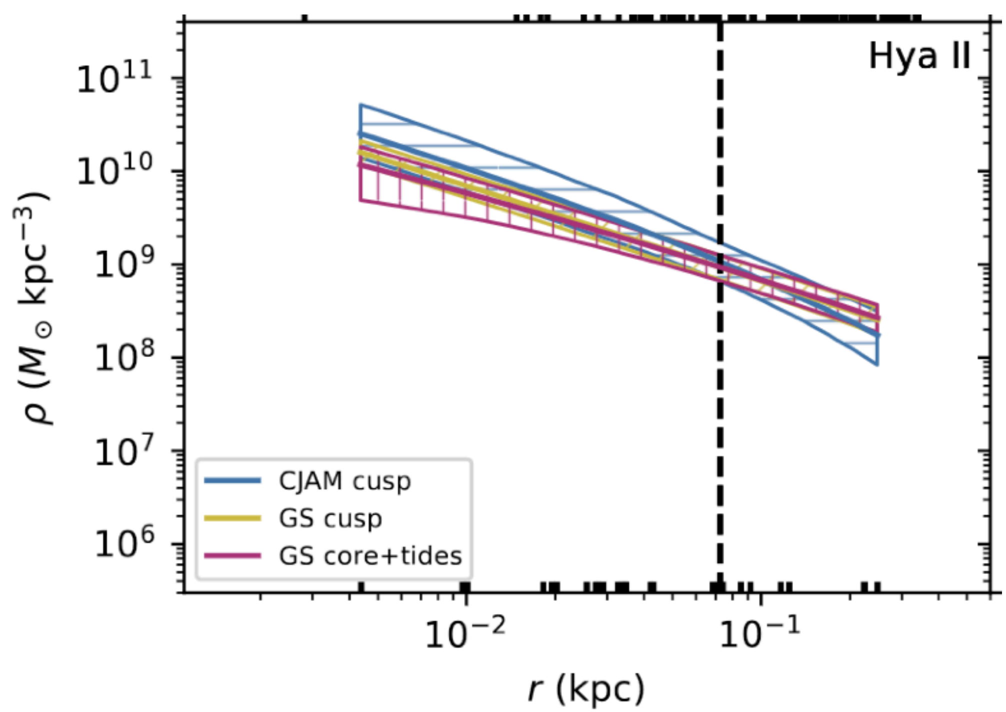
ALP signal

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

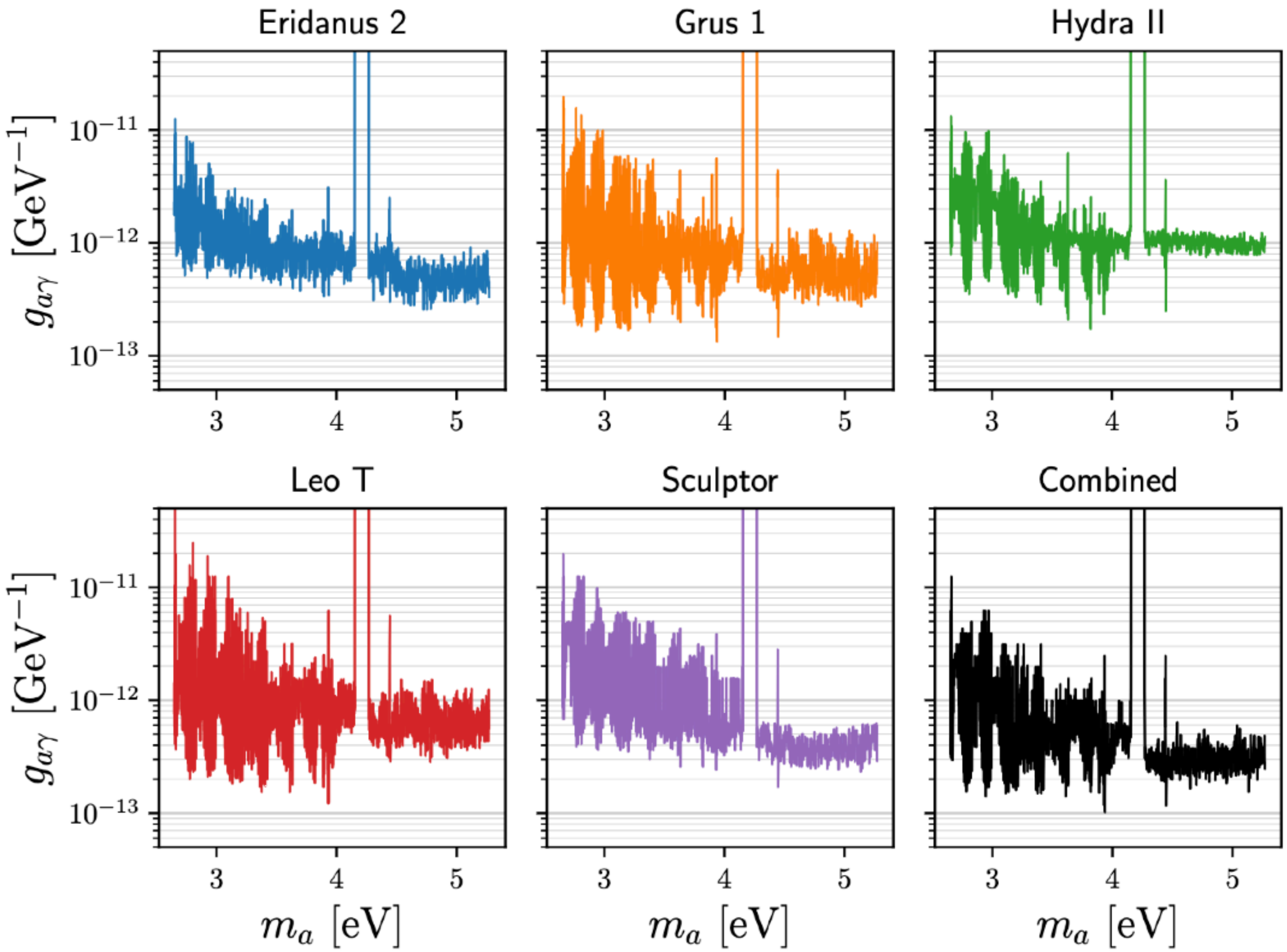
Dark matter density profile



Zoutendijk et al. A&A, arXiv:2112.09374



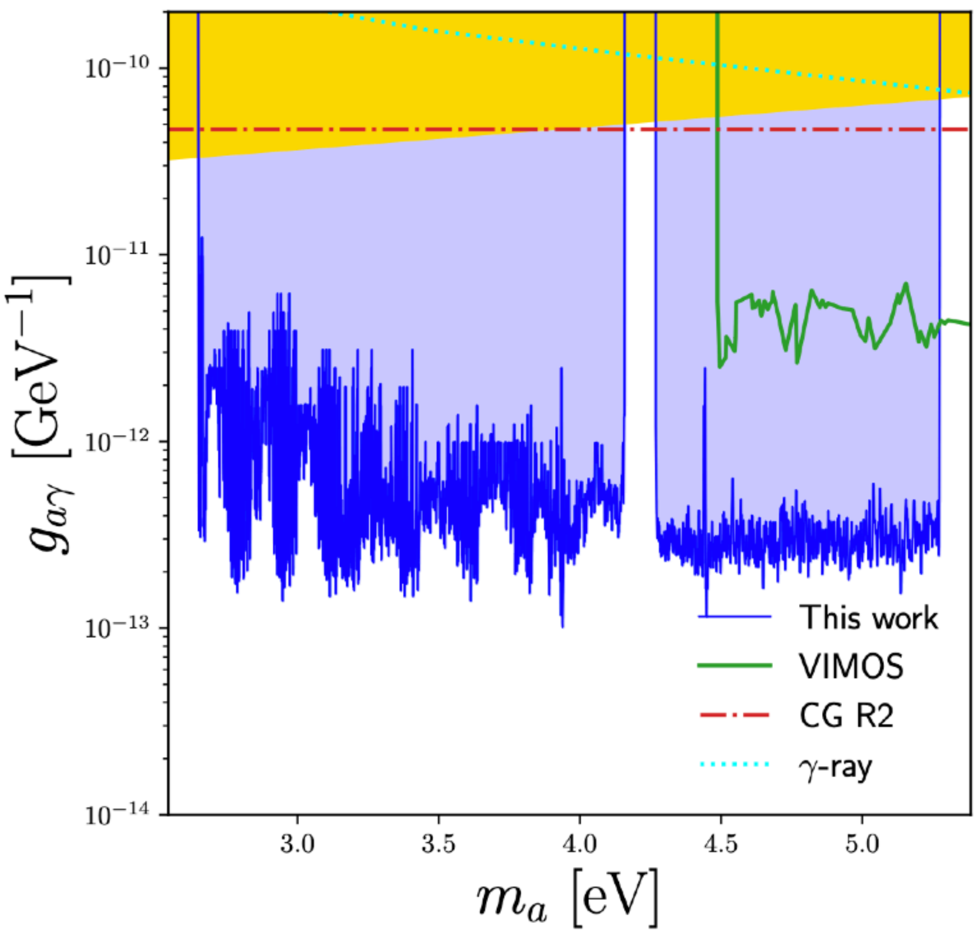
Results

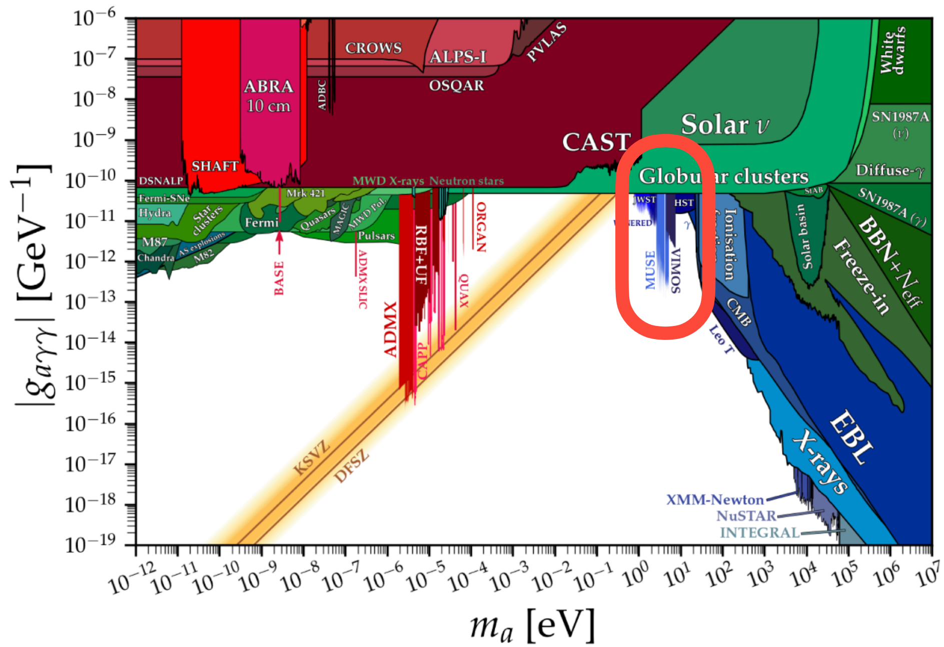


Todarello, MT +, JCAP 05 (2024) 043

Results

Todarello, MT +, JCAP 05 (2024) 043



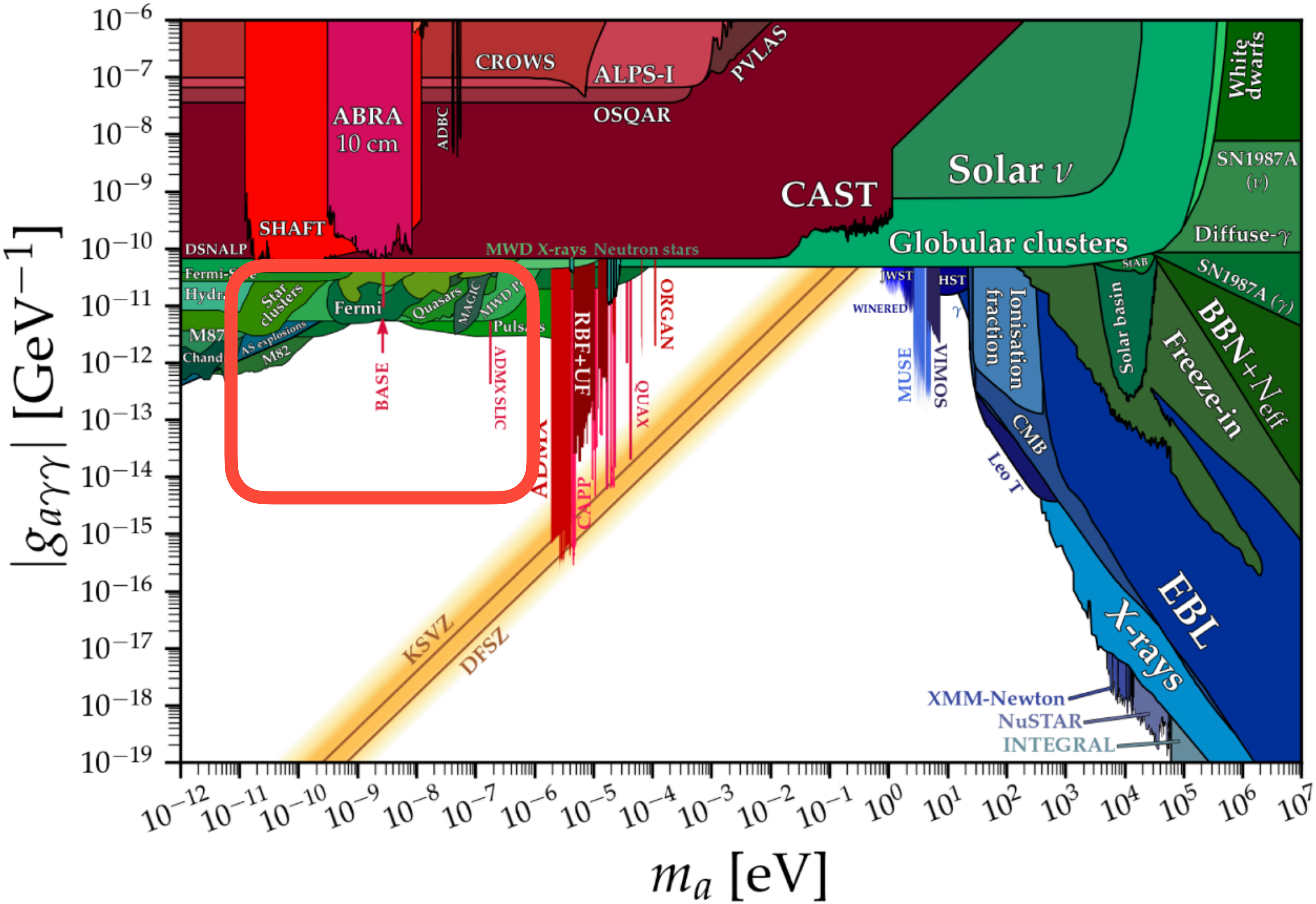


Other searches:

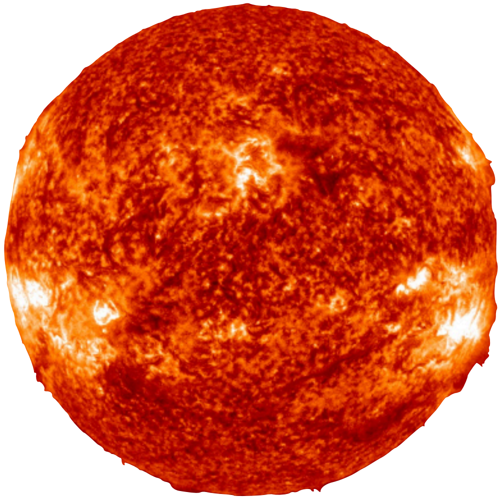
VIMOS	Grin et al. PRD 75 (2007) 15018
JWST	Janish, Pinetti, arXiv:2310.15395
JWST	Ray et al. arXiv:2311.04987
WINERED	Yin et al. arXiv:2402.07976

Axion-like particles (ALPs)

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



ALP-photon conversion in the Sun



Possibility n. 1

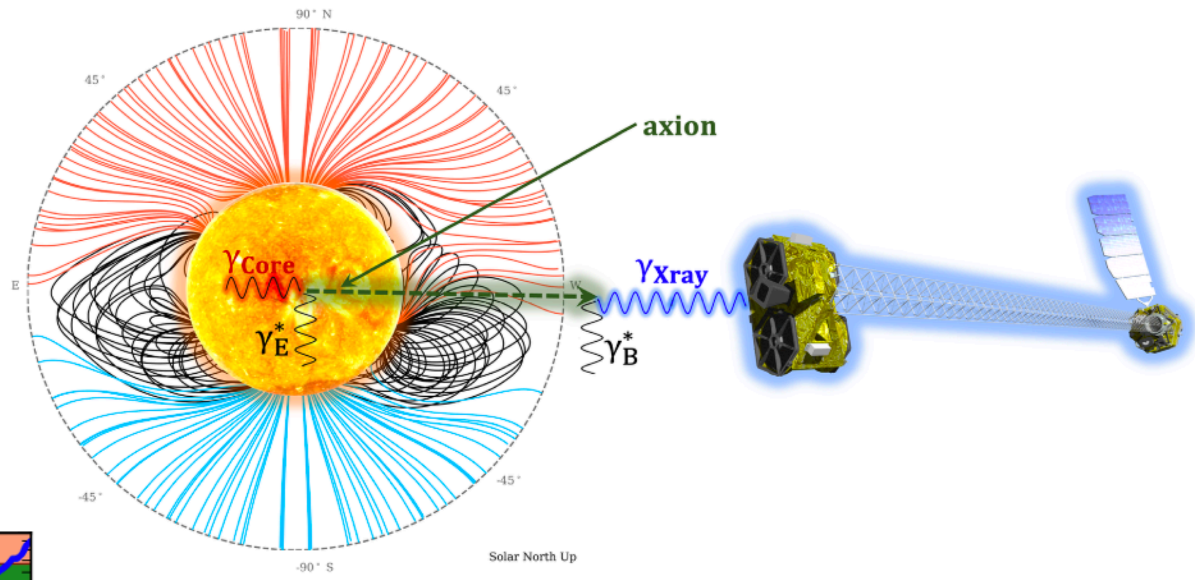
Relativistic axions produced in the core of the Sun and converted into photons in the solar atmosphere

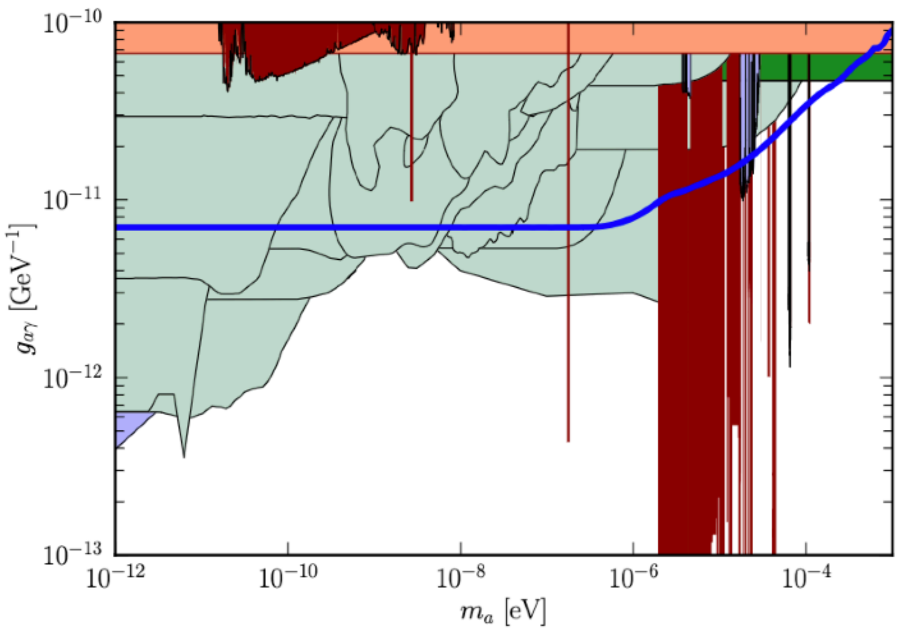
Possibility n. 2

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

NuSTAR as an axion Helioscope

Possibility n. 1





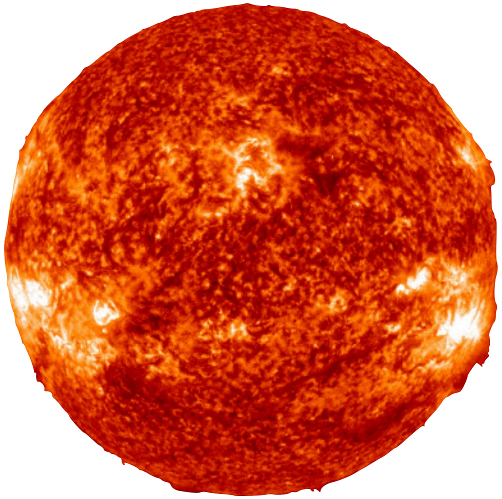
Strong and robust limits

Ruz, Todarello, Vogel, MT +, arXiv 2407.03828

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

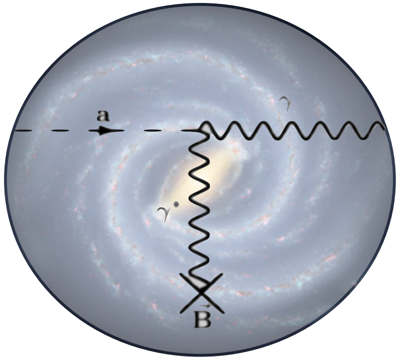


Possibility n. 2

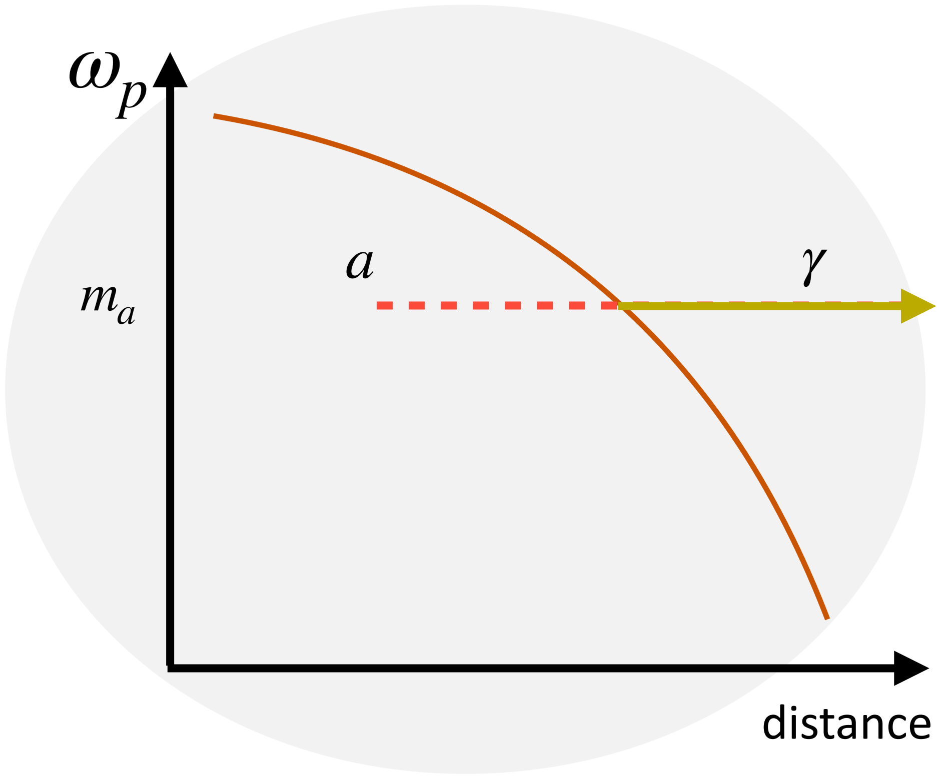
$\mathcal{O}(\mu eV)$ **ALP dark matter** conversion into photons in the solar atmosphere

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)

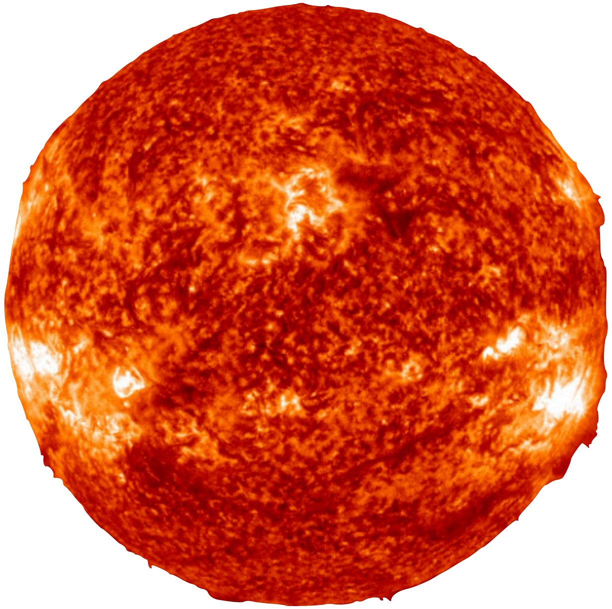
Axion DM signal:
radio line

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



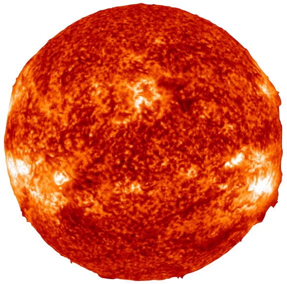
Conversion of axion dark matter in the solar atmosphere

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

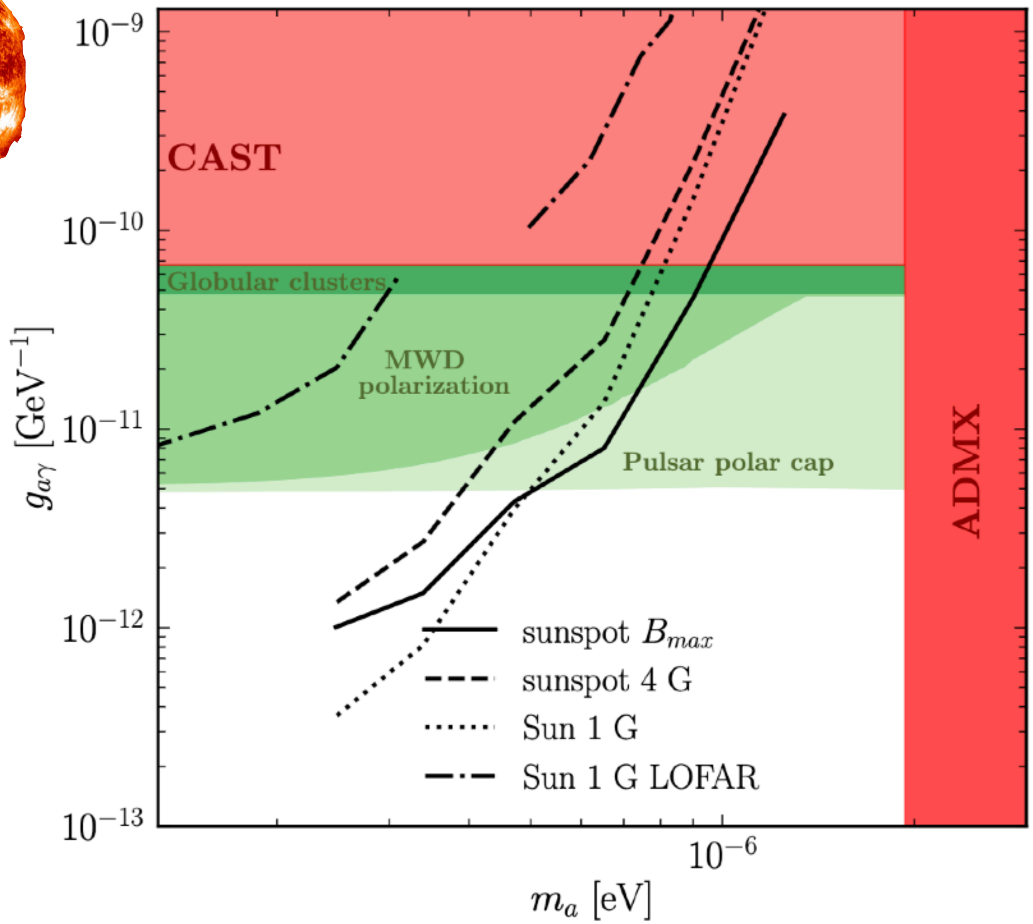
$$S = \int \frac{d\Omega}{4\pi\,\Delta\nu}\, \rho_a\, v_a\, P_{a\to\gamma}\, e^{-\tau}$$

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

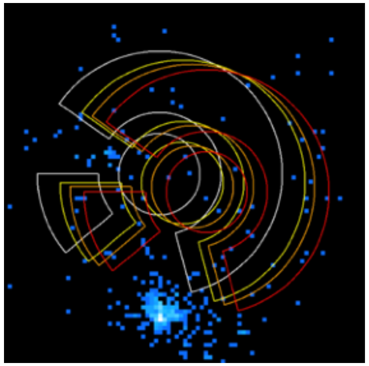
$\mathcal{O}(\mu eV)$ ALP dark matter conversion in the Sun atmosphere: prospects for SKA radio obs

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

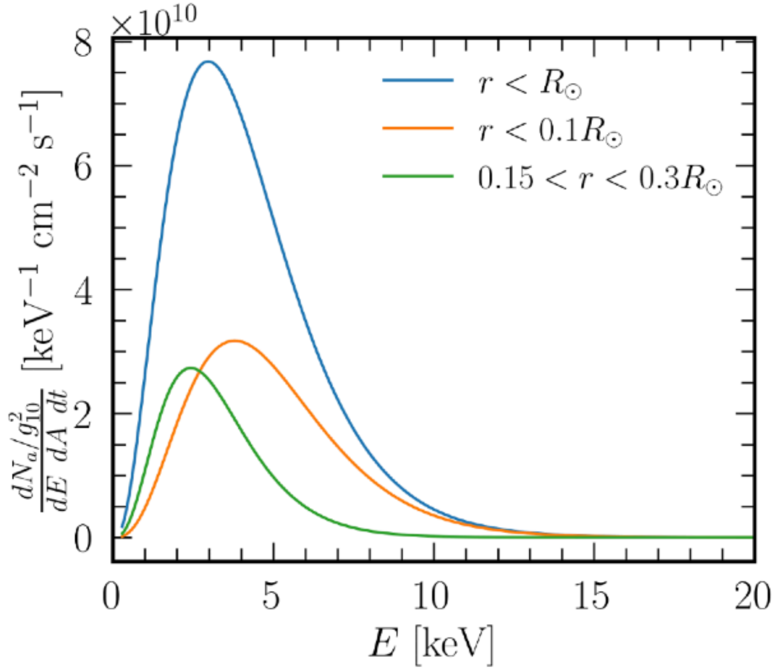
Additional material

Relativistic axions from the Sun

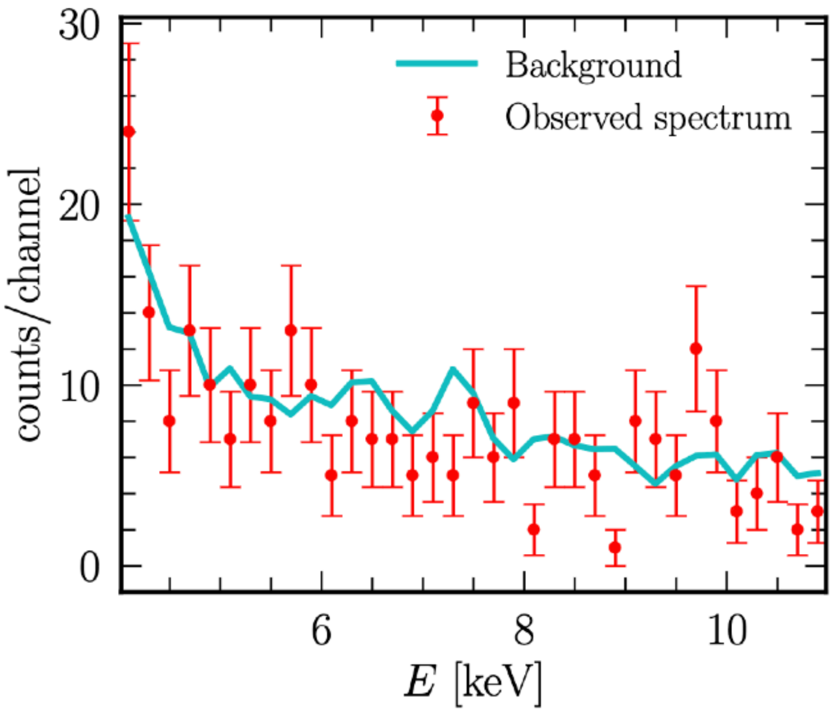
NuSTAR as an axion Helioscope



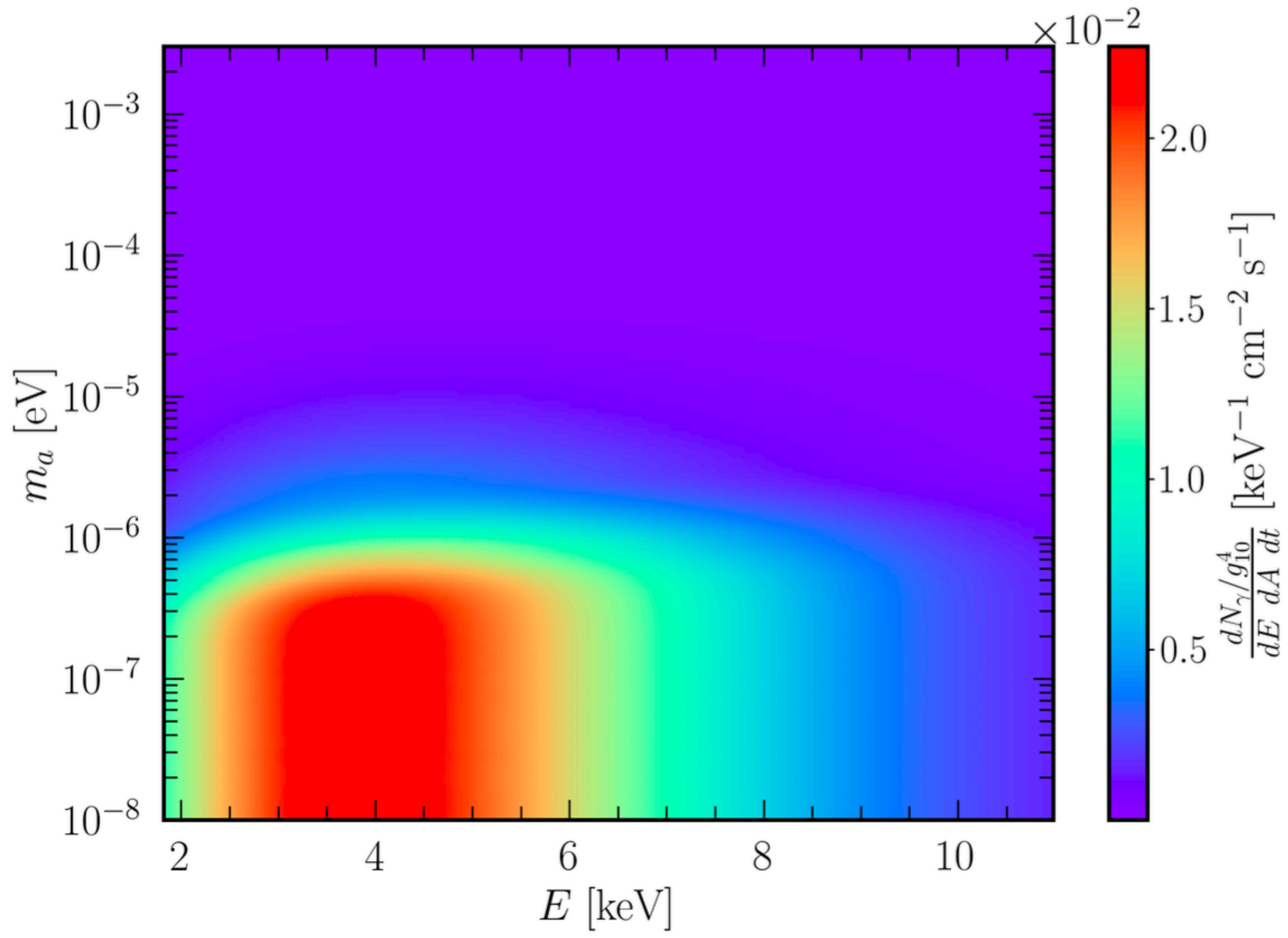
Axion flux from the inner solar region



NuSTAR X-rays observations of the Sun



Solar X-ray emission from axions



Radio line from ALP DM conversion