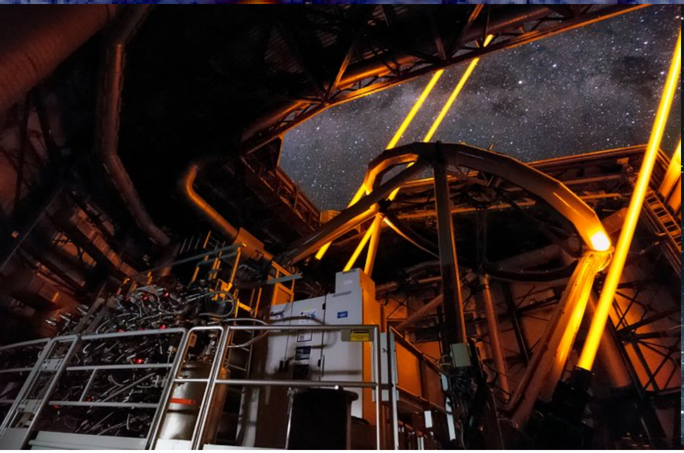
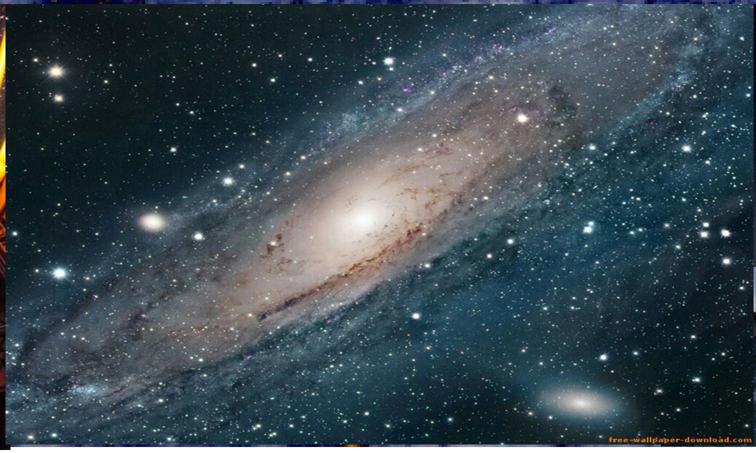
Searching for ALP Decays in the Sky





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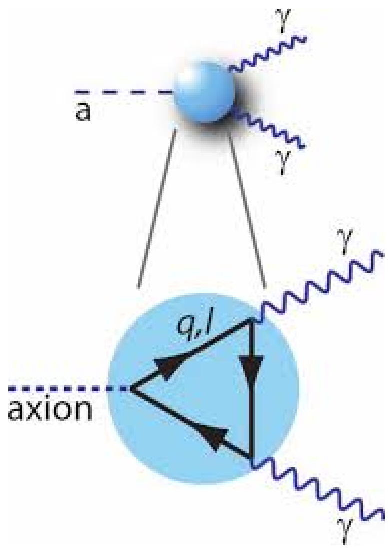
ALP DM
Axion-like particles constitute (a fraction of) the DM content in the Universe

PHOTON COUPLING
ALP-photon coupling described by the low-energy effective Lagrangian:

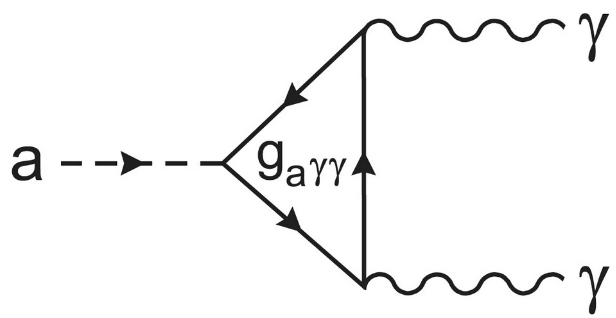
$$\mathcal{L} = -\frac{1}{4} g_{a\gamma\gamma}\, a\, F_{\mu\nu}\tilde{F}_{\mu\nu}$$



ALP phenomenology (photons)

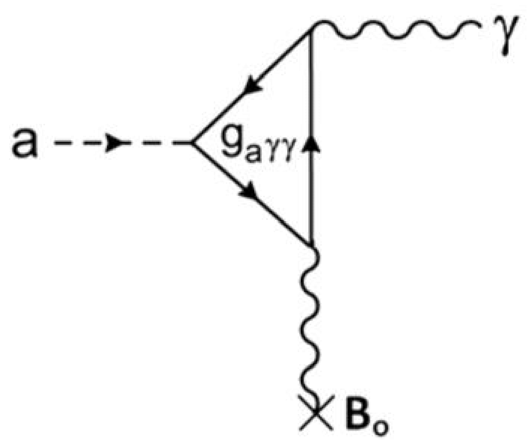
The ALP-photon coupling → phenomenology related to

decay



discussed in this talk

conversion



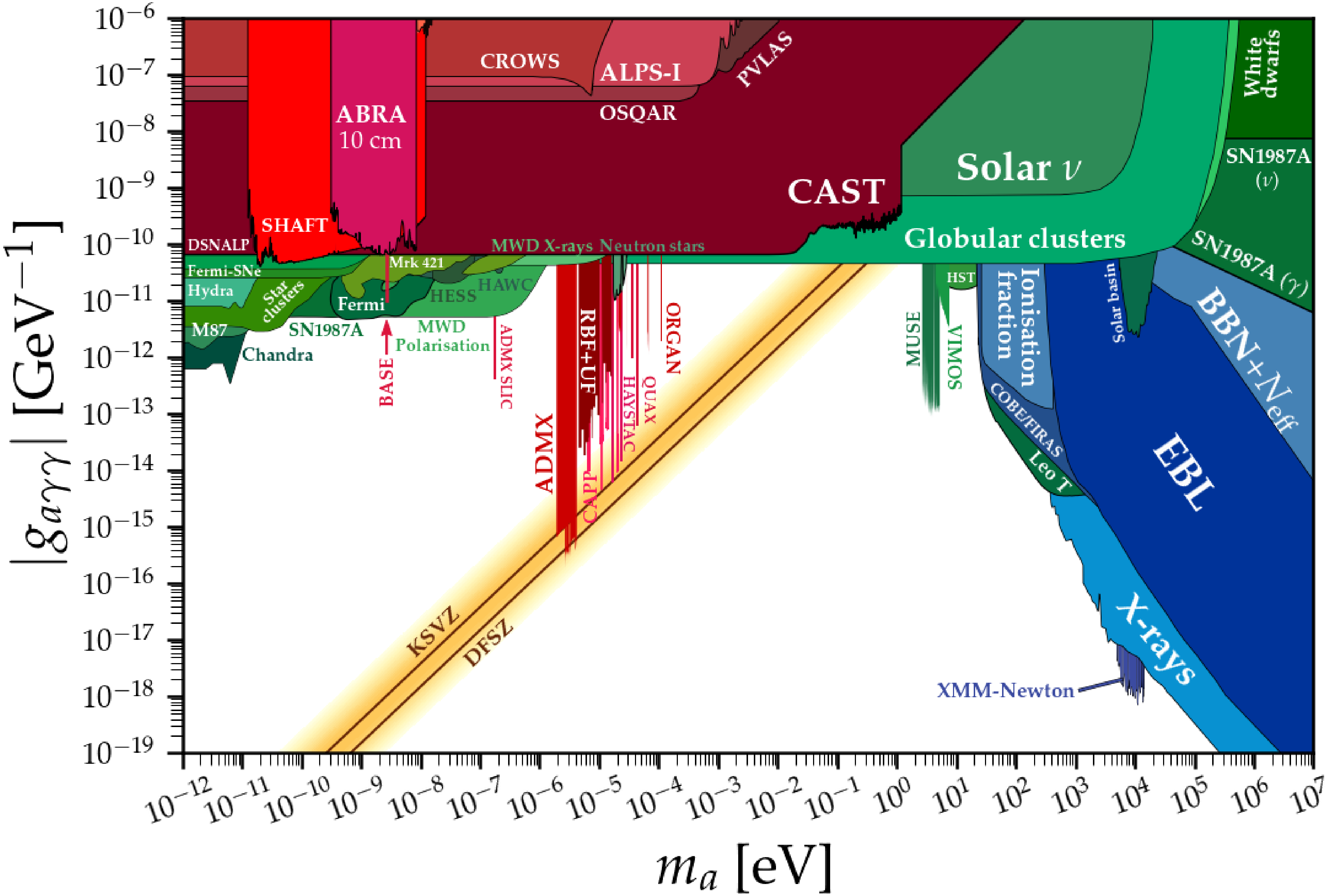
needs large magnetic field

- *created in lab (haloscopes)*
- *extreme astro objects (e.g. neutron stars)*

Or **inverse processes** (γ-ray tansparency, stellar cooling, ...)
see talks by Marsh, Bernal, Rodd, Escudero, ...

Bounds on ALPs

https://github.com/cajohare/AxionLimits



Outline

Looking for a photon <u>monochromatic emission</u> at $E_\gamma \sim m_a/2$ given by ALP decay from regions with high dark-matter density

For a good story:

Who? What? When? Where? Why?

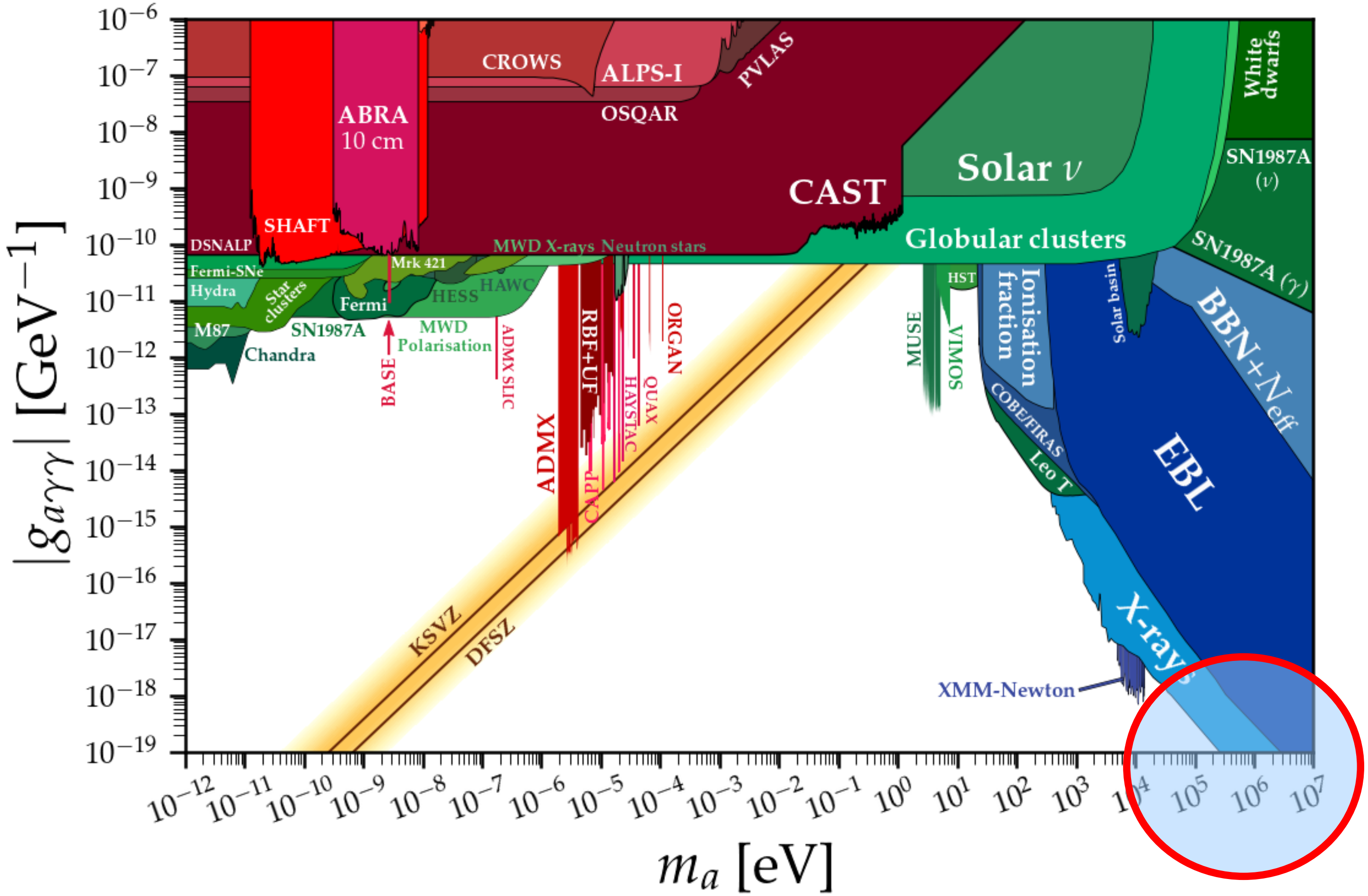
Outline

Looking for a photon monochromatic emission at $E_\gamma \sim m_a/2$
given by ALP decay
from regions with high dark-matter density

For a good story:
Who? What? When? Where? Why?

... let's take a journey across
different mass ranges and astrophysical targets
to see current bounds and near-future prospects

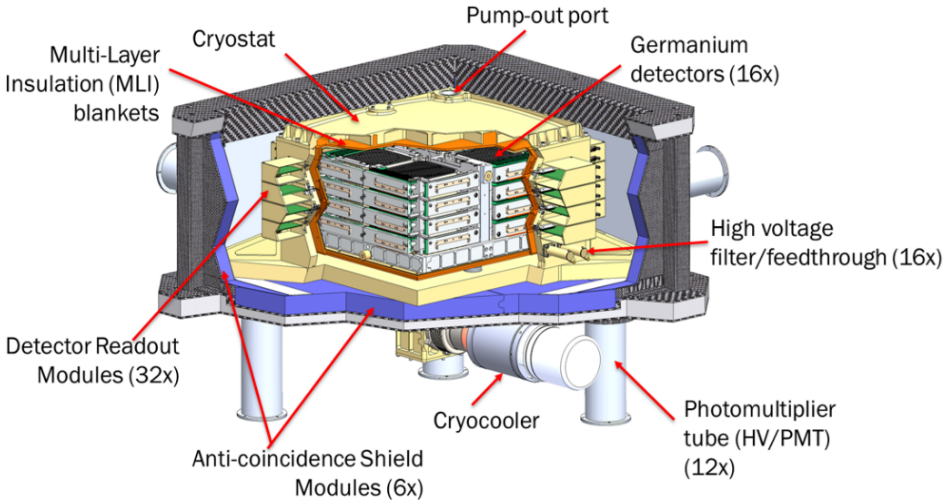
MeV ALPs (gamma-rays)

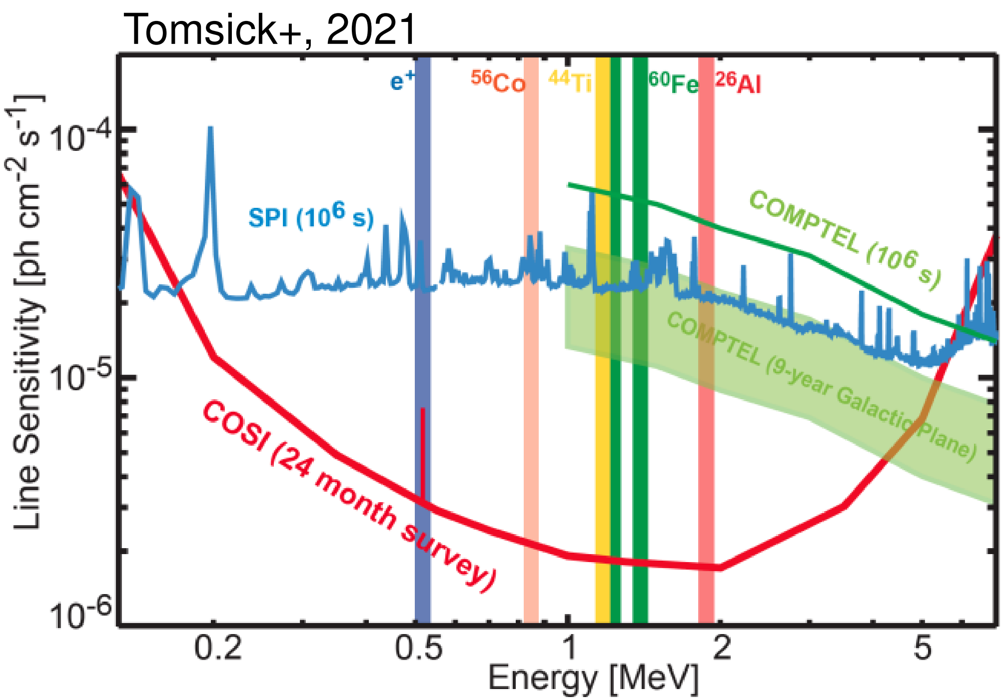


COSI telescope

Compton Spectrometer and Imager (COSI)
wide-FOV telescope designed to survey the γ-ray sky at 0.2-5 MeV
→ Imaging with high-resolution spectroscopy ($\Delta E/E \sim$ few x 10^{-3})

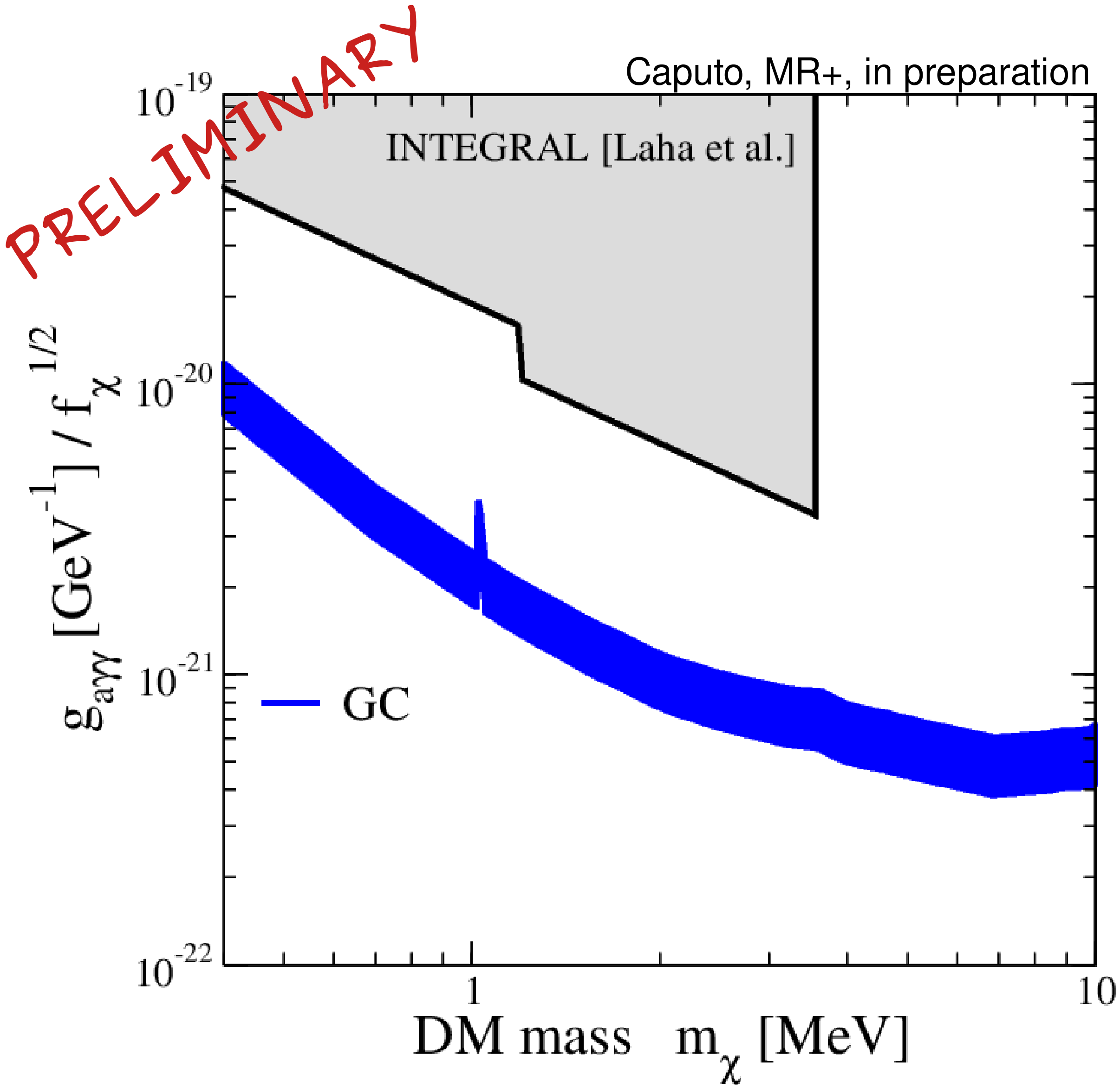
selected by NASA in October 2021, to be launched within 5 years



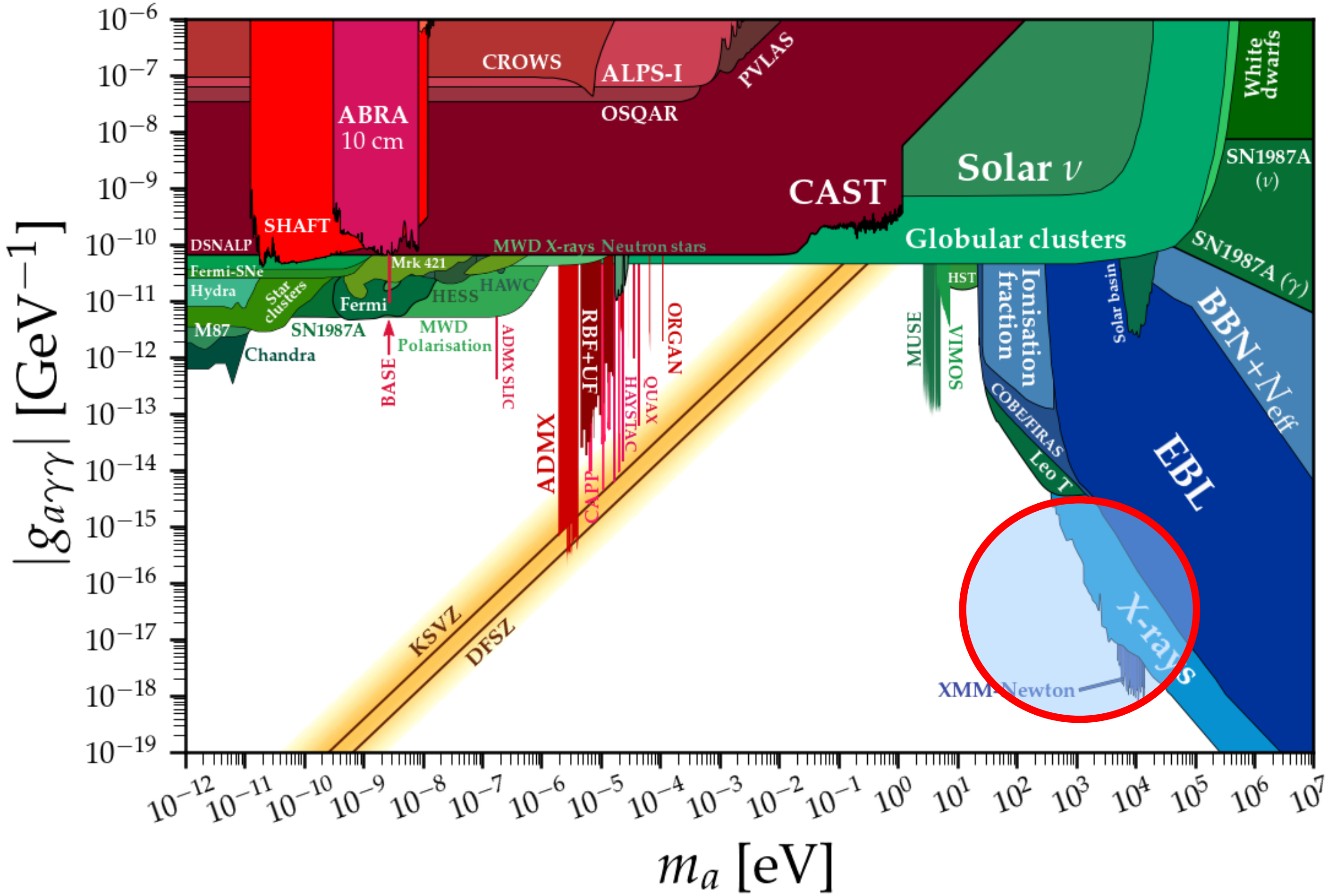


COSI sensitivity to MeV ALPs

Projected sensitivity compared to current bounds



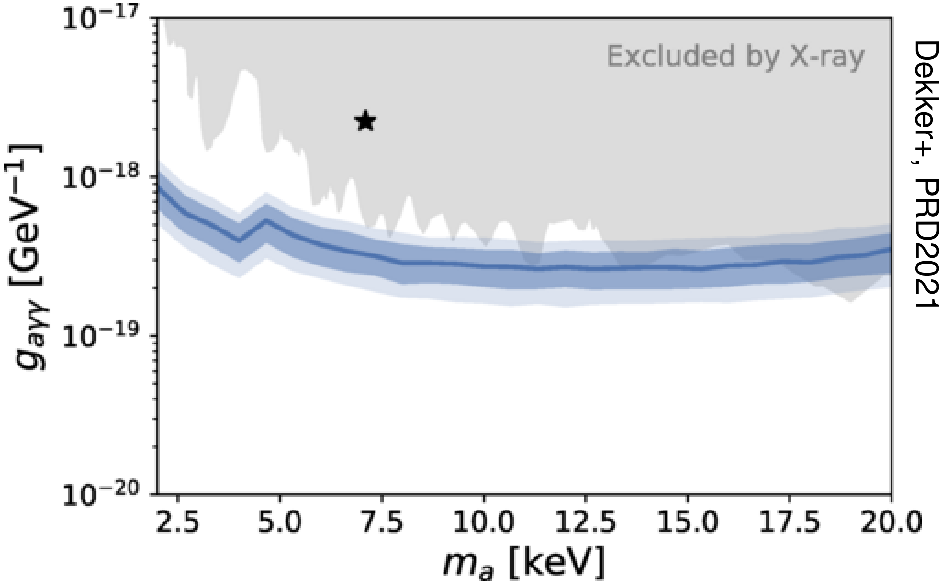
keV ALPs (X-rays)



X-rays and ALPs

eROSITA [0.2-8 keV]

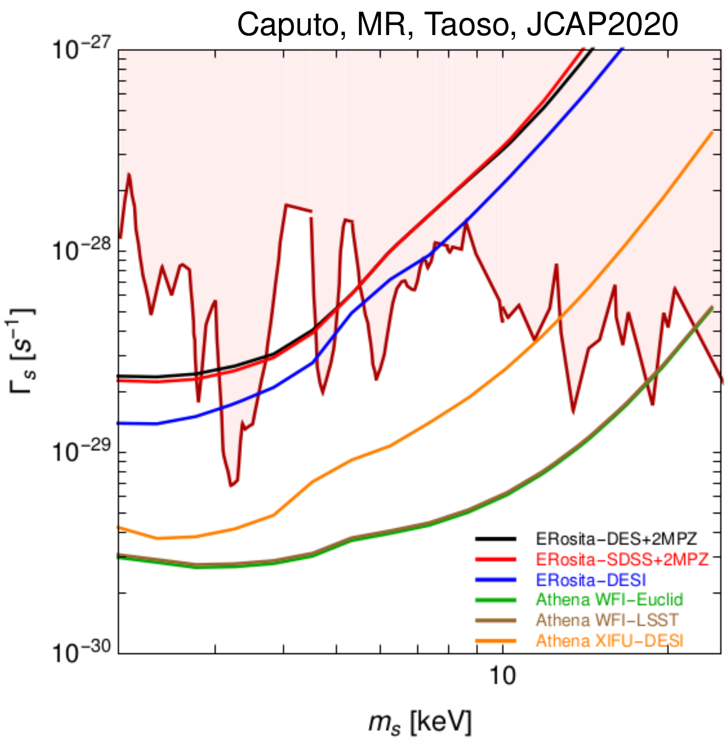
data from Dec. 2019 to Feb. 2022
(about half-way)



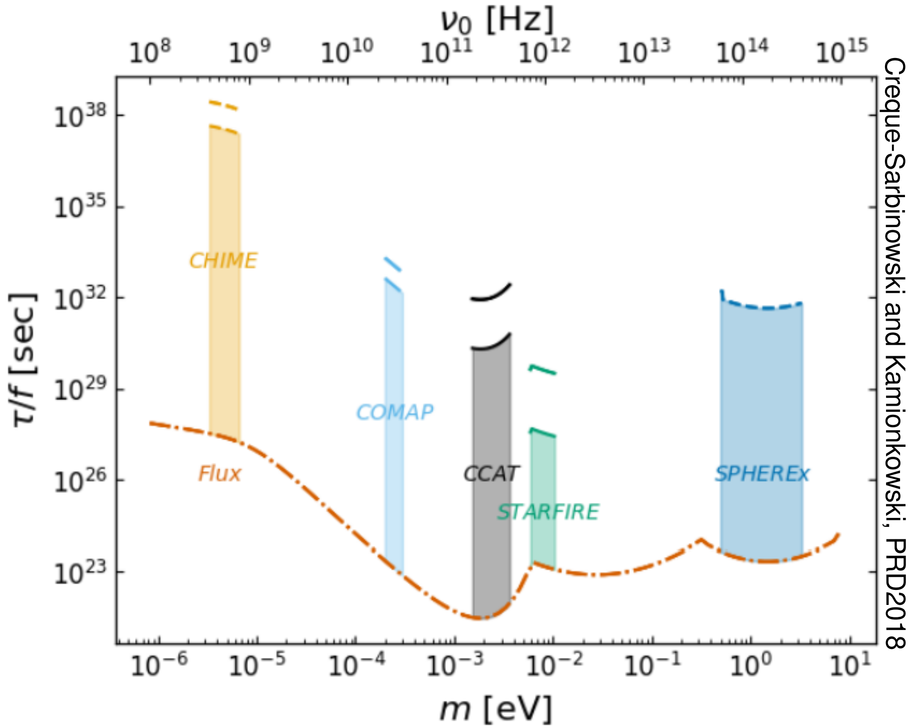
Line Intensity Mapping

ALP decay → photons at $E_e = m_a/2$ in the rest frame
If the ALP is at redshift z_e, we see $\mathbf{E_{obs} = m_a/2/(1+z_e)}$

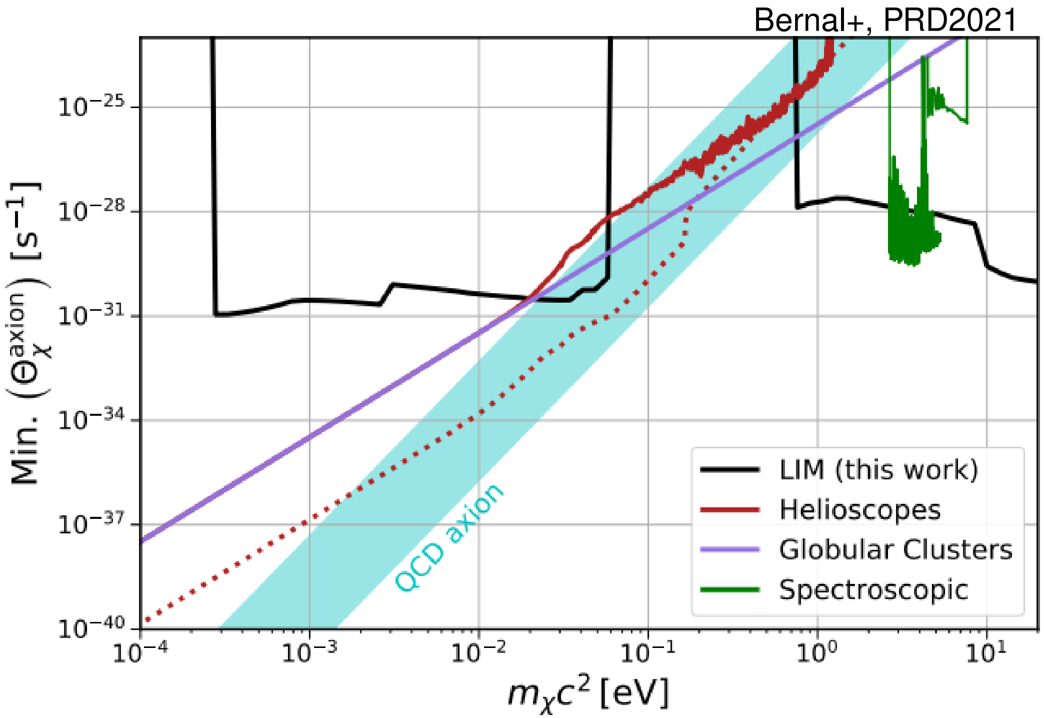
→ The ALP emission should show a **correlation with large-scale structures** at redshift $z = z_e$ and no correlation with LSS at $z \neq z_e$.



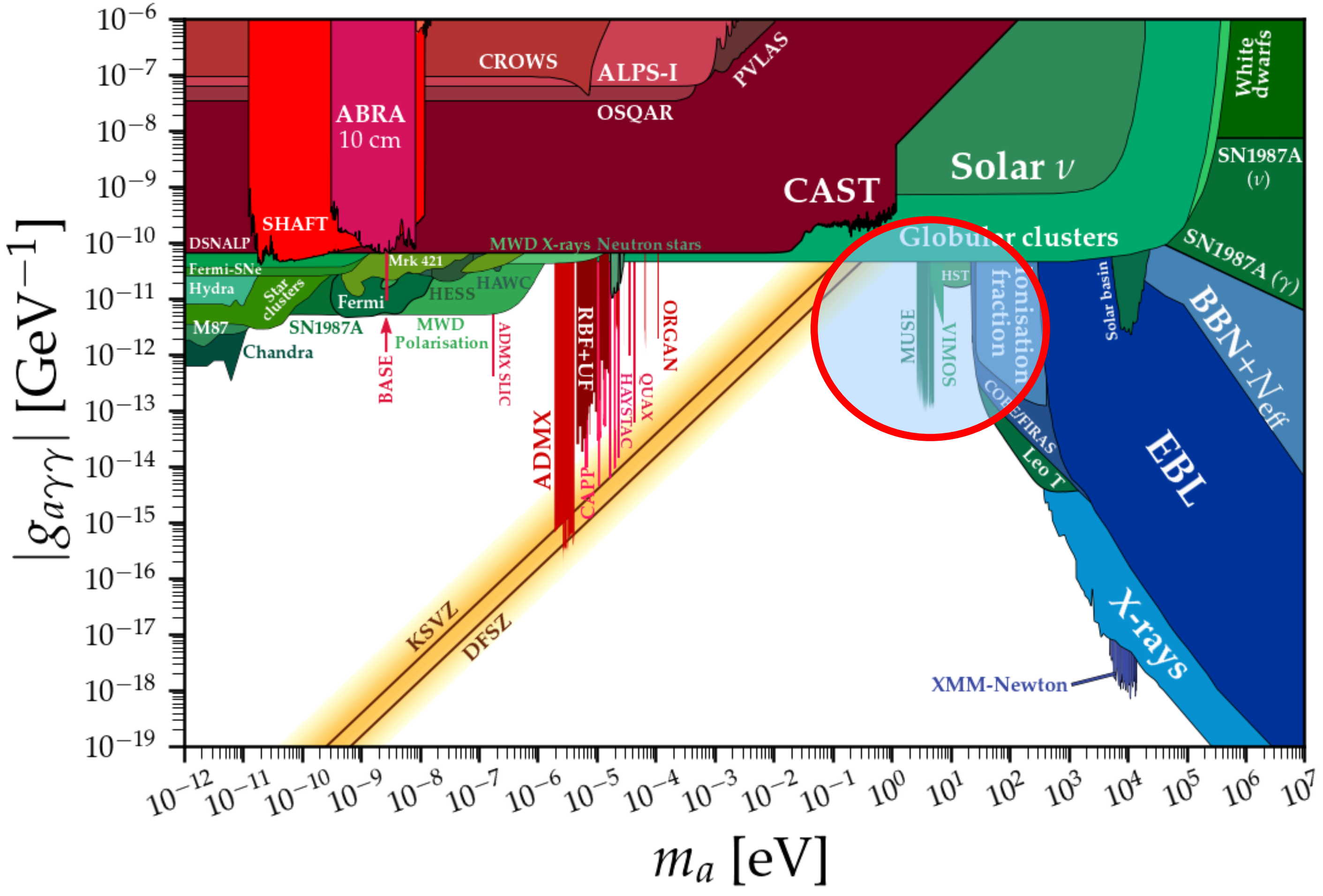
ALPs and Line Intensity Mapping



If DM is made of ALPs
→ line intensity mapping competing with lensing, galaxy counts, etc.. in cosmological searches



eV ALPs (optical)



ALP signal

To observe photons from ALP decays we need an experiment with:
- good frequency resolution
- decent FoV
- good angular resolution
- good sensitivity

... and observing the DARKNESS!

→ muse
multi unit spectroscopic explorer

on the VLT at Paranal Observatory (ESO)

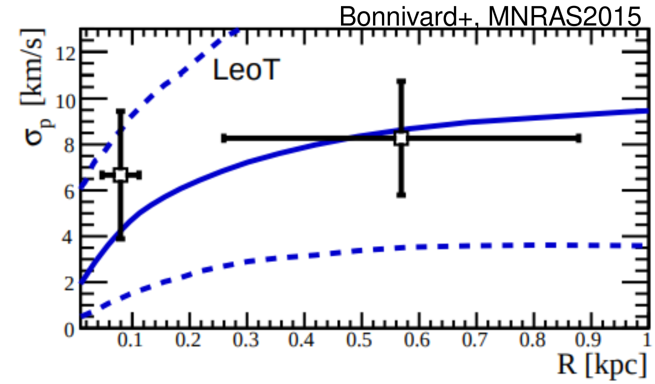
λ = 465-930 nm
ang. res. < 1 arcsec
spectr. res. $\Delta E/E < 10^{-3}$

Credit: Roland Bacon/ESO

MUSE observations of LeoT dwarf galaxy

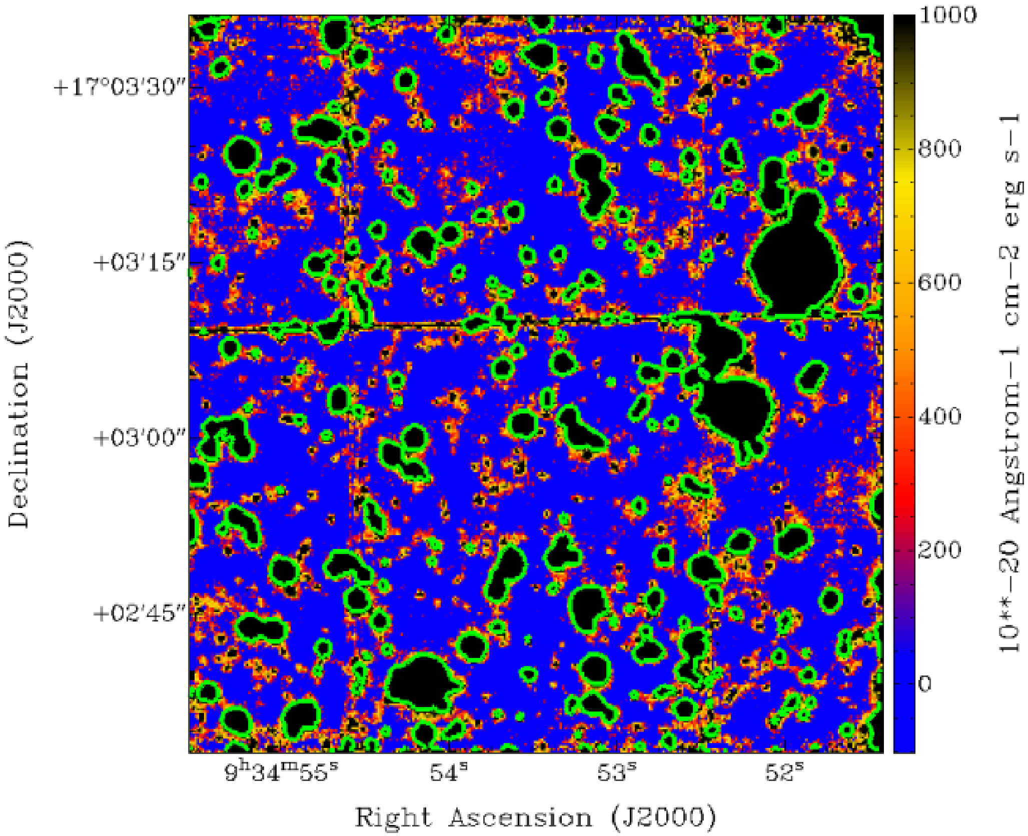
Target: **LeoT dwarf galaxy**

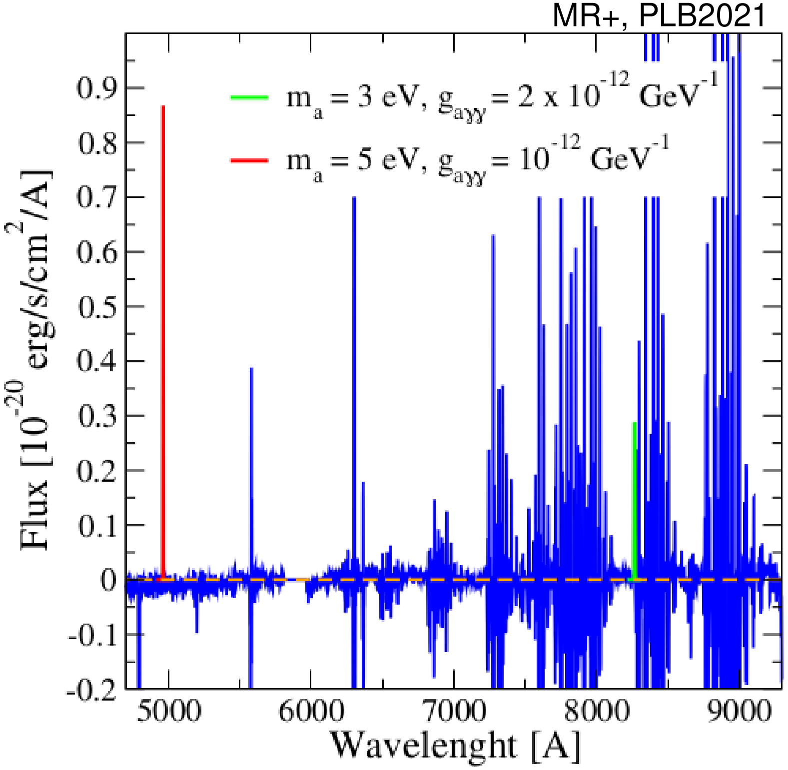
D = 417 kpc, M ~ 10^7 M_{sun}



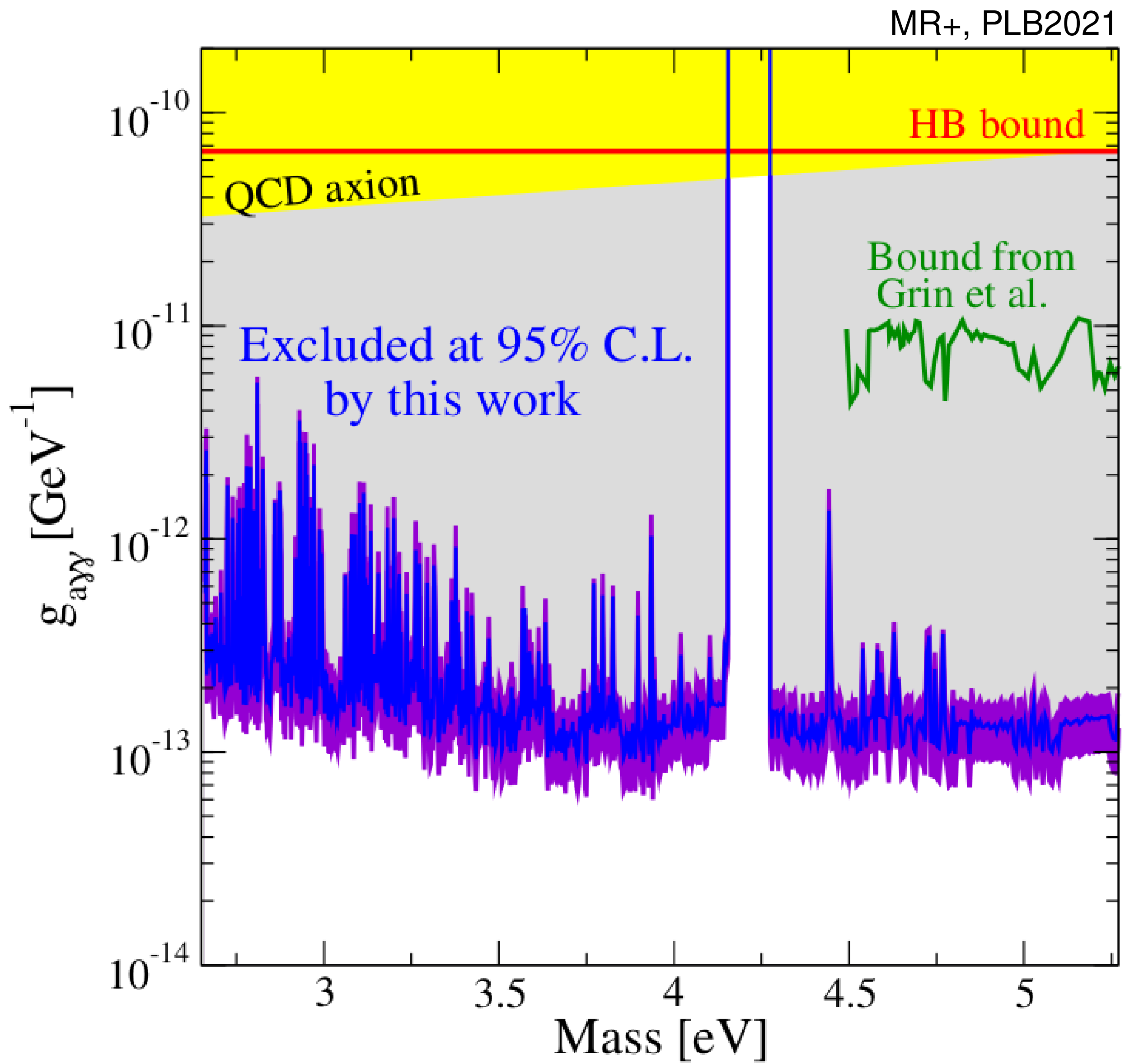
MUSE observations:

3.75 hours covering 1 x 1 $arcmin^2$





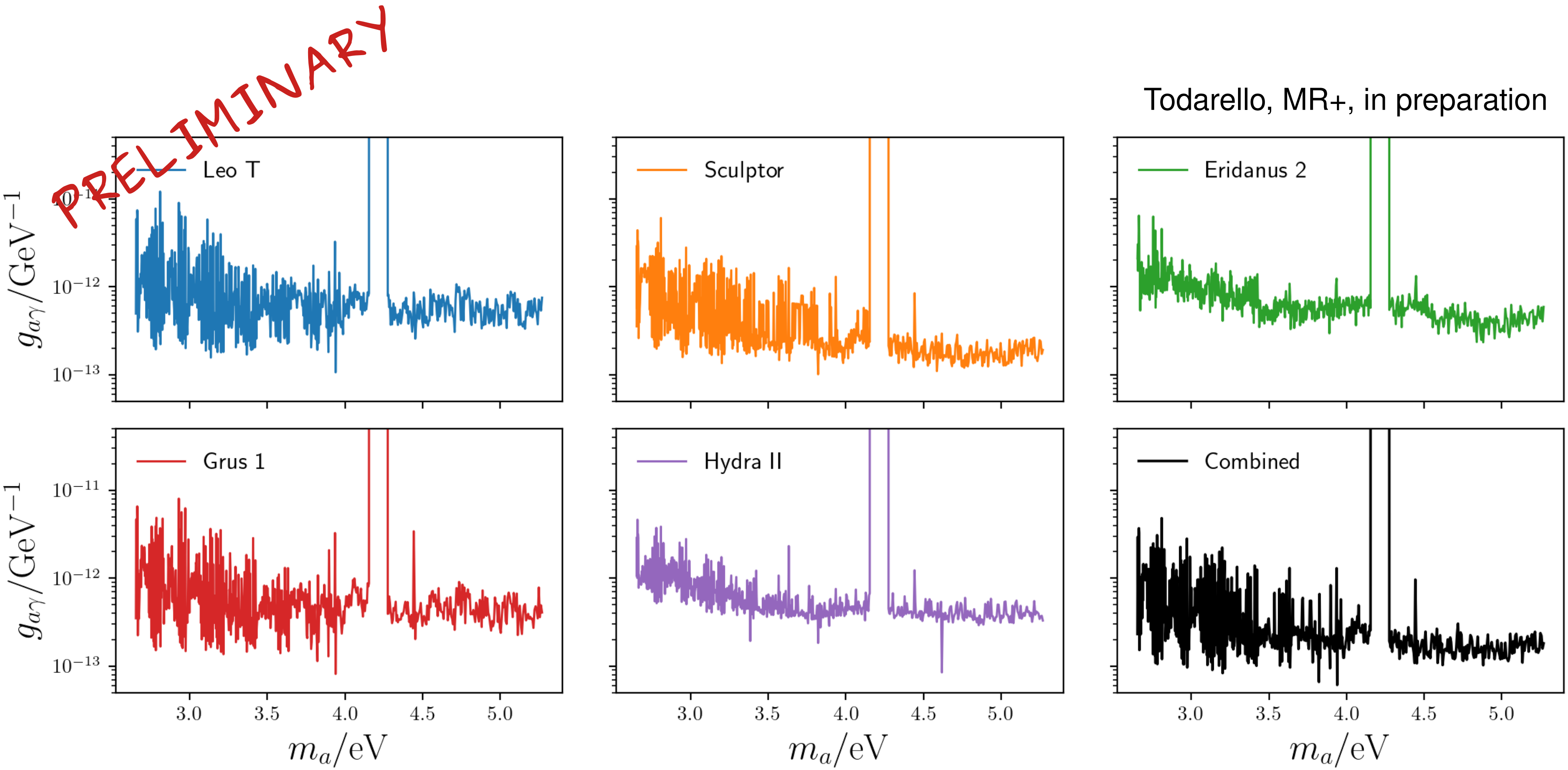
Bounds on ALPs from LeoT observations



Bounds on ALPs from dSphs

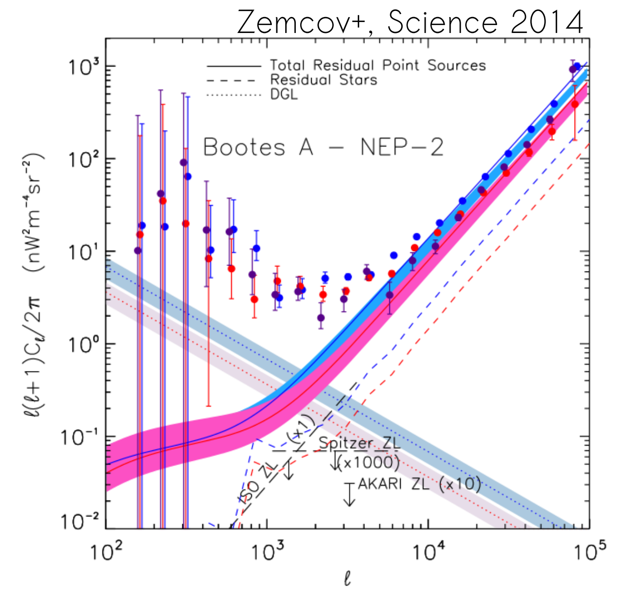
Systematic analysis including a sample of dwarf spheroidal galaxies

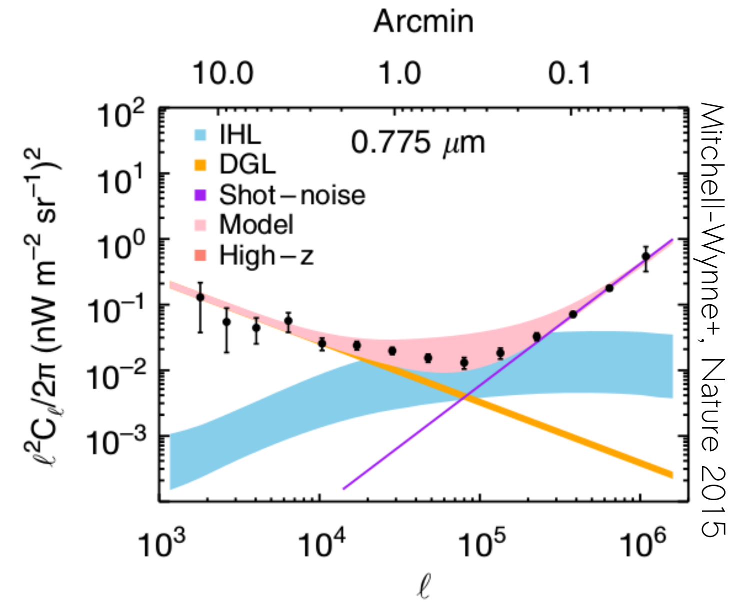
Todarello, MR+, in preparation



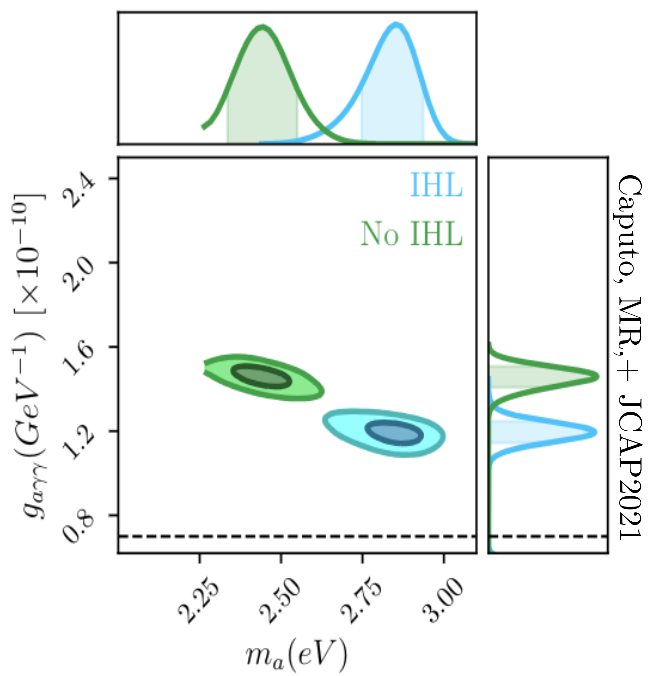
NIRB and Axion-like Particles

Excess in the NIRB autocorrelation angular power spectrum (0.6-4.5 μm)





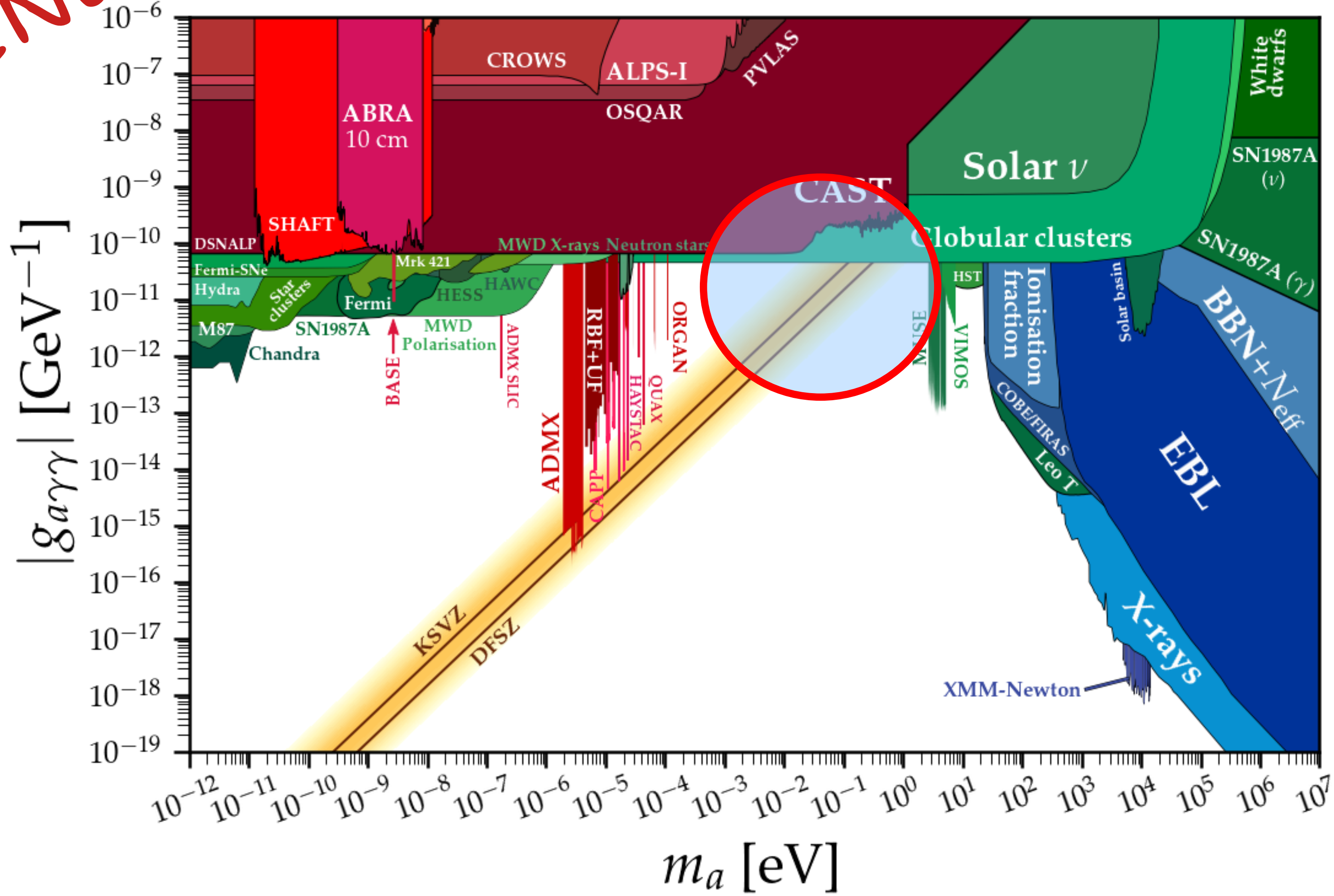
ALP interpretation of the NIRB excess **revisited**:



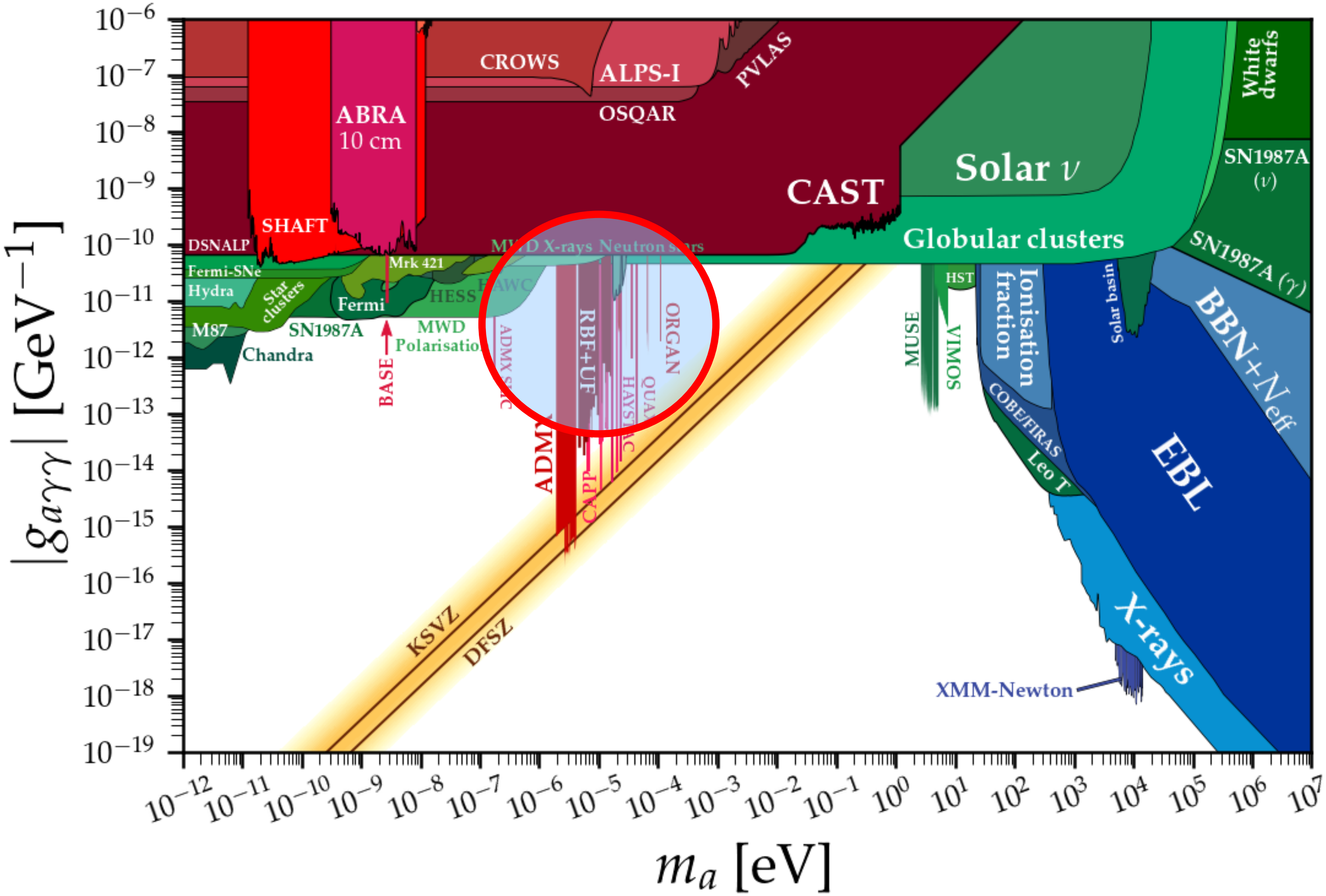
→ more from JWST

few meV ALPs (far infrared)

MISSING!



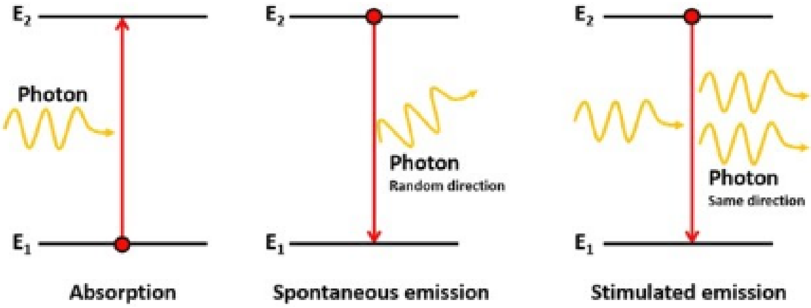
μeV ALPs (radio)



$$\Gamma_a \equiv g_{a\gamma\gamma}^2 m_a^3/(64\pi)$$

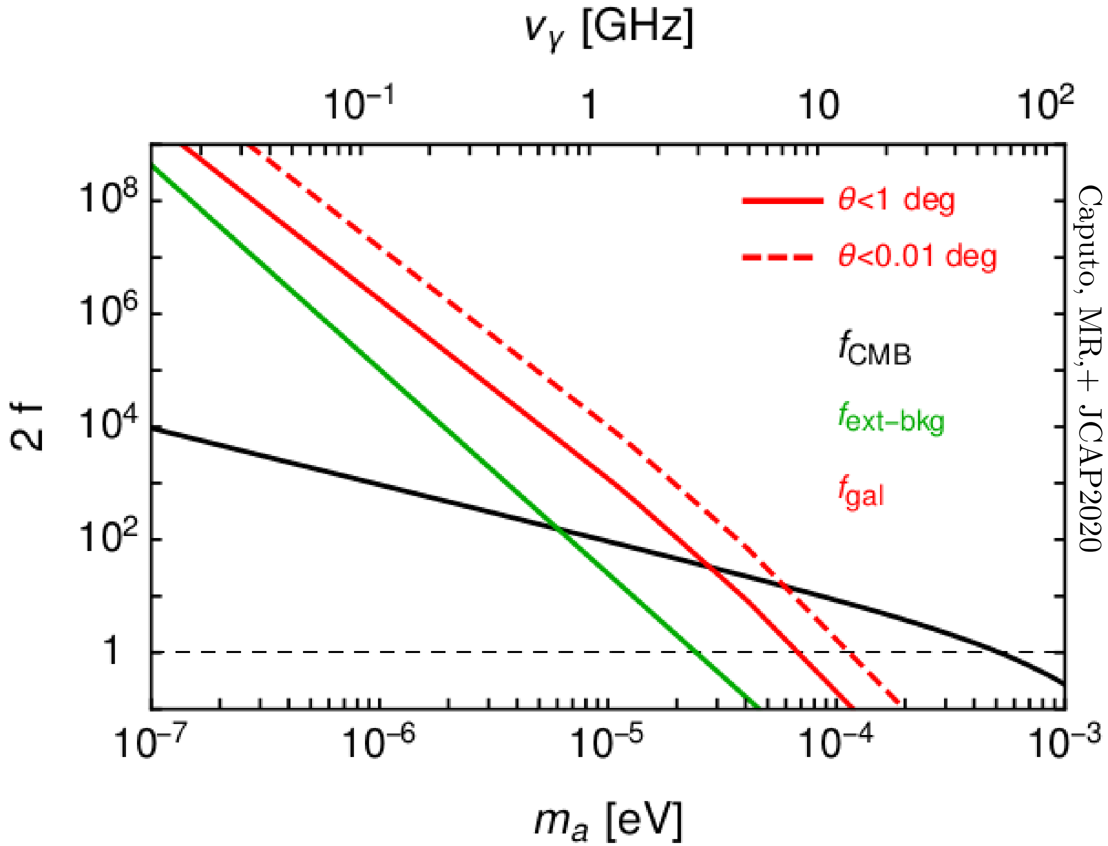
ALP stimulated decay

Stimulated decay



$$2\,f = \frac{\text{stimulated emission}}{\text{spontaneous emission}}$$

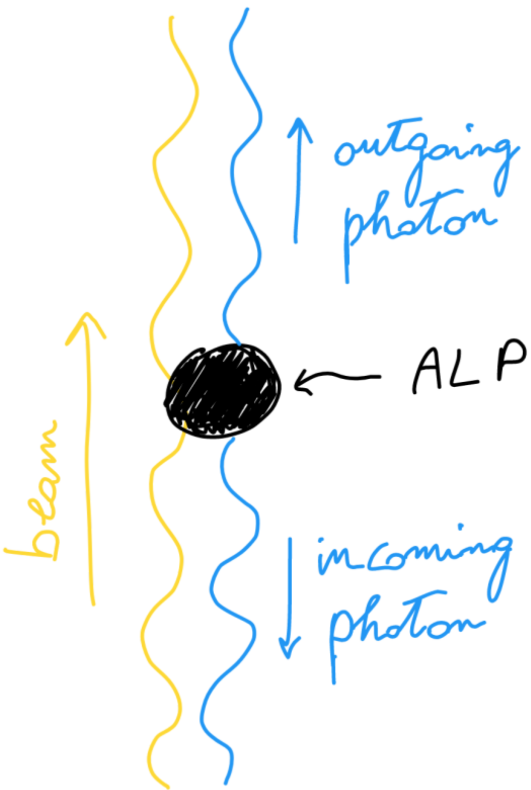
$$f_\gamma = \frac{\pi^2 \rho_\gamma}{E_\gamma^3}$$



$$S_{\rm decay} = \frac{\Gamma_a}{4\pi\Delta\nu} \int d\Omega\, d\ell\, \rho_a(\ell,\Omega)\,[1 + 2 f_\gamma(\ell,\Omega,m_a)]$$

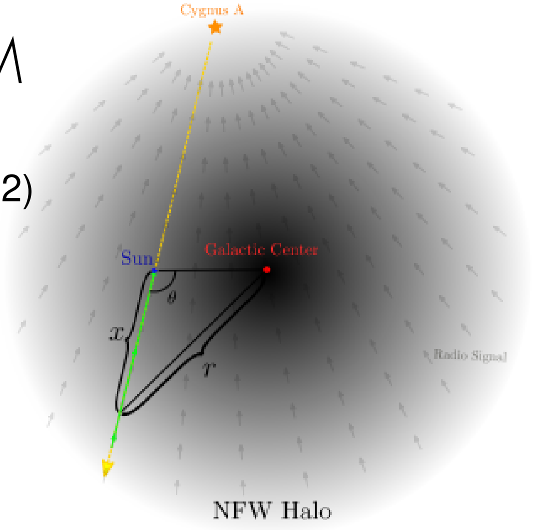
ALP stimulated decay - echo

IDEA: **listening for the echo of a powerful radio beam**
(i.e. faint radio line traveling in the ~opposite direction due to axion stimulated decay)



ARTIFICIAL BEAM
(Arza&Sikivie PRL2019, Arza&Todarello PRD2022)

ASTRO BEAM
(Ghosh+ 2020
Sun+ PRD2022
Buen-Abad+ PRD2022)



$$S_g = \frac{g^2_{a\gamma\gamma}}{16} S_{\nu,0}(\nu_a) \int \rho(x_d)\,\mathrm{d}x_d$$

ALP stimulated decay - projected limits

A "**golden era**" for **radio astronomy** has been starting with the **SKAO** and its precursors

SKA1-Low: 100 hours @ 100 MHz
→ 180 μJy/beam
(line sensitivity for $\Delta\nu/\nu = 10^{-4}$)

Credit: SKA Organisation

stimulated decay inside the source

$$S \simeq 100\,\mu\mathrm{Jy} \left(\frac{g_{a\gamma\gamma}}{10^{-11}\,\mathrm{GeV}^{-1}}\right)^{2} \left(\frac{10^{-4}}{\sigma}\right) \left(\frac{m_a}{\mu\mathrm{eV}}\right)^{3-1} \frac{2f}{10^{7}} \frac{D}{10^{13}\,\frac{\mathrm{GeV}}{\mathrm{cm}^2}}$$

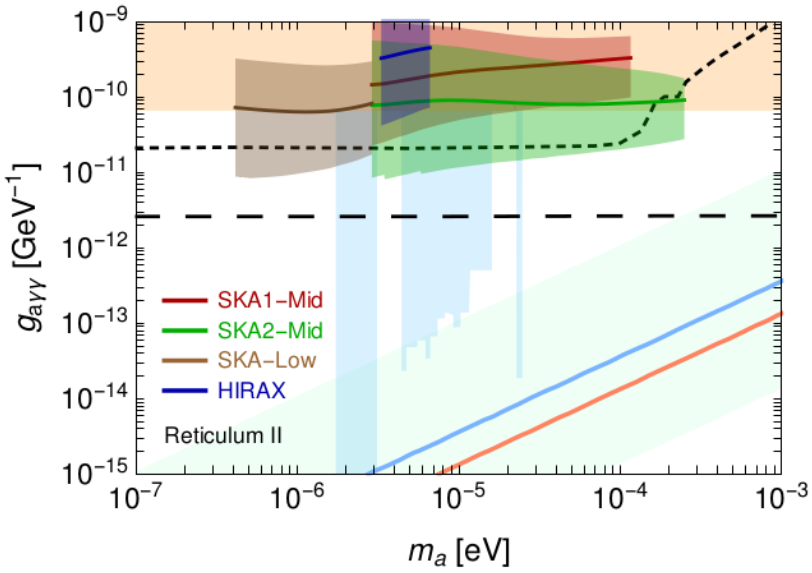
echo from stimulated decay

$$S \simeq 10\,\mu\mathrm{Jy} \left(\frac{g_{a\gamma\gamma}}{10^{-11}}\right)^{2} \left(\frac{10^{-3}}{\sigma}\right) \left(\frac{\mu\mathrm{eV}}{m_a}\right) \left(\frac{S_0}{10^{4}\,\mathrm{Jy}}\right) \left(\frac{\rho}{0.4\,\frac{\mathrm{GeV}}{\mathrm{cm}^3}}\right) \left(\frac{x_d^{max}}{20\,\mathrm{kpc}}\right)$$

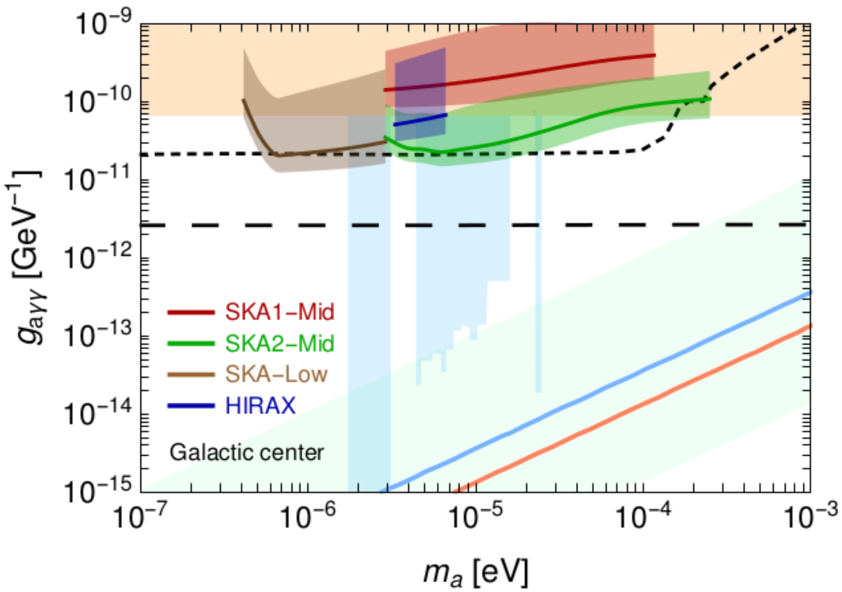
ALP stimulated decay - projected limits

Caputo, MR,+ JCAP2019

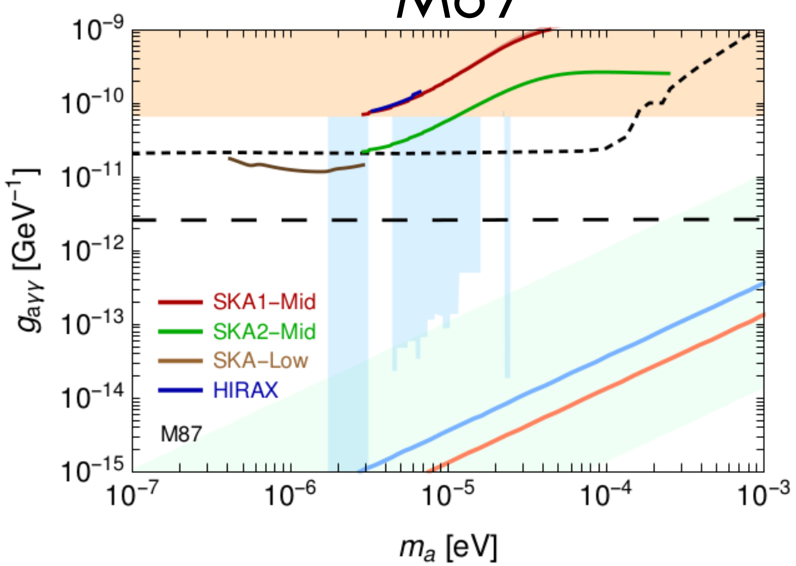
Dwarf spheroidal galaxy



Galactic Center



M87

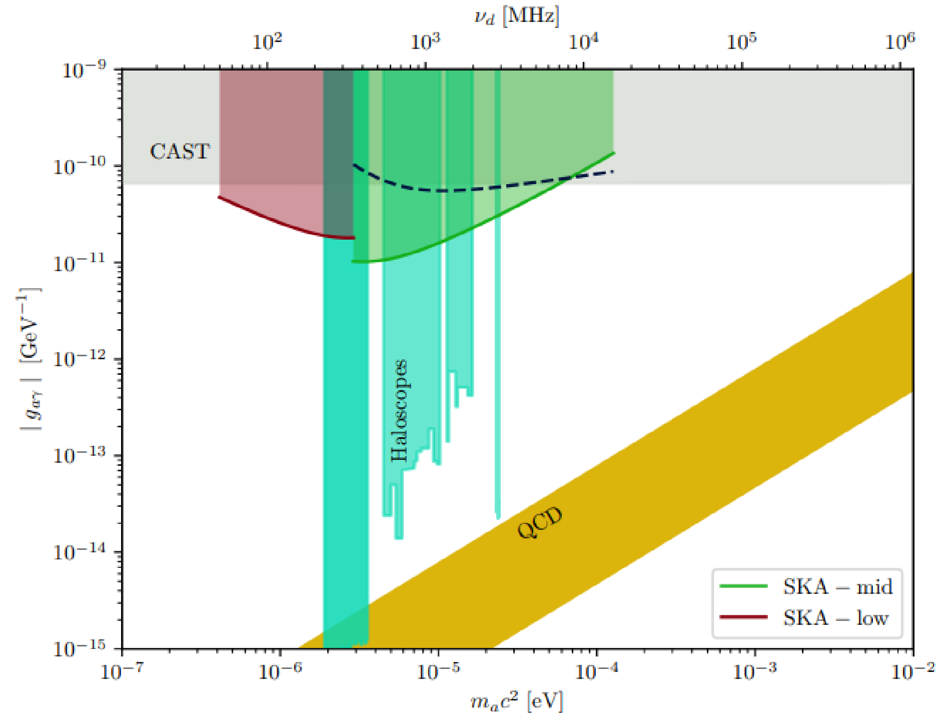


See also
Caputo+ PRD2018
Battye+ PRD2020
Ayad&Beck JCAP2022

ALP stimulated decay - axion echo

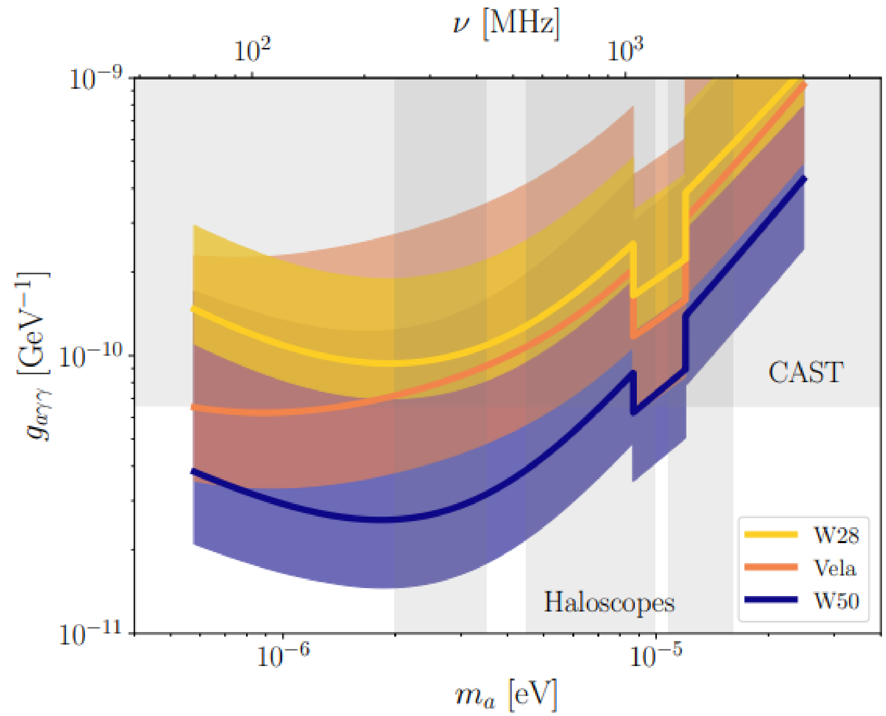
(Ghosh+, 2020)

Source: Cygnus A



(Sun+ PRD2022, Buen-Abad+ PRD2022)

Source: Galactic SN remnants



Summarizing

It is a period with no strong bias concerning the particle dark matter mass
→ **multi-wavelength approach**

Searching for ALP decays in the sky will likely play a crucial role in shaping the allowed fraction of the ALP parameter space