Robust bounds on ALP dark matter from dwarf spheroidal galaxies in the optical MUSE-Faint survey

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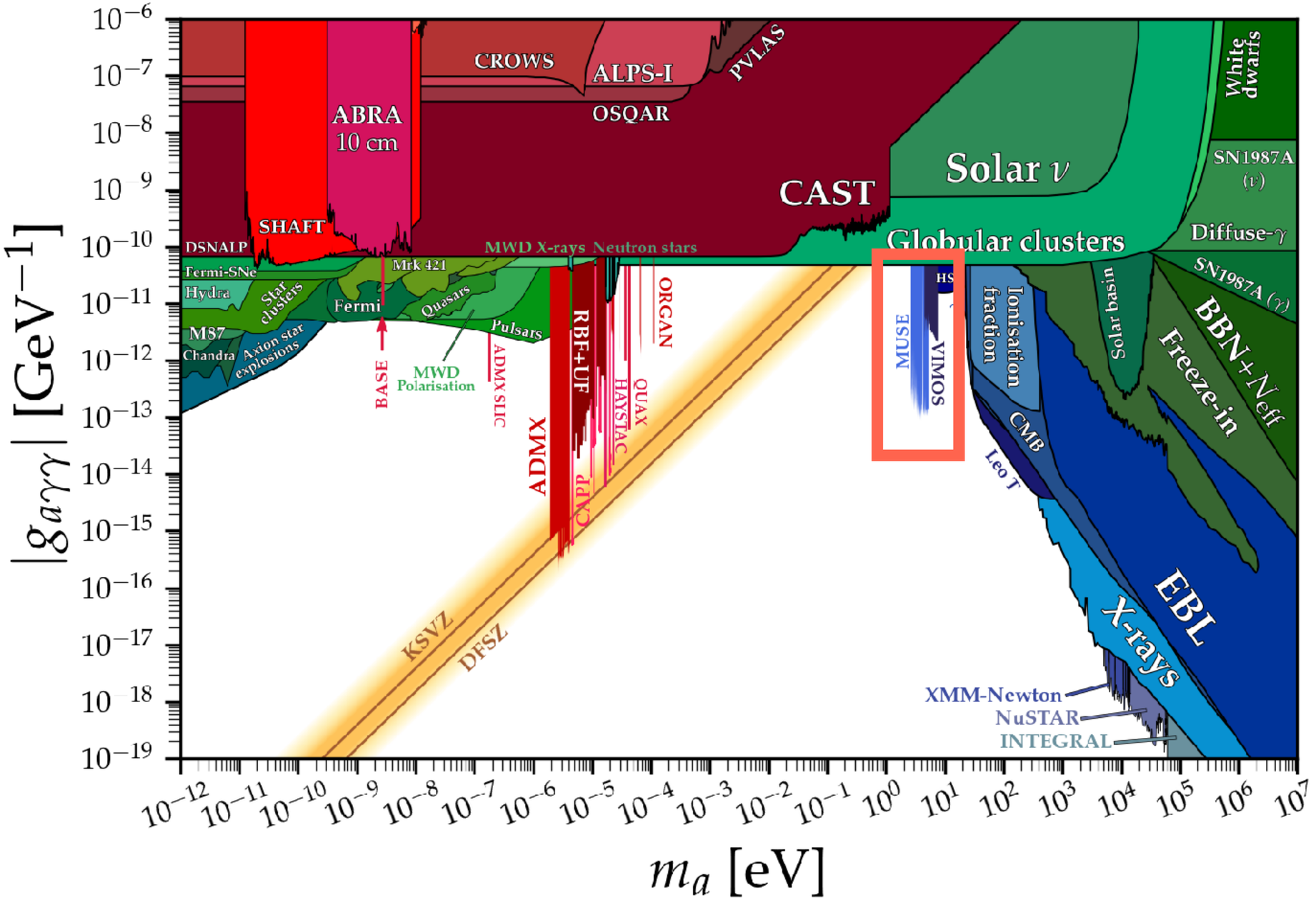
arXiv:2307.07403

axions++ 2023
Annecy, 27.09.2023

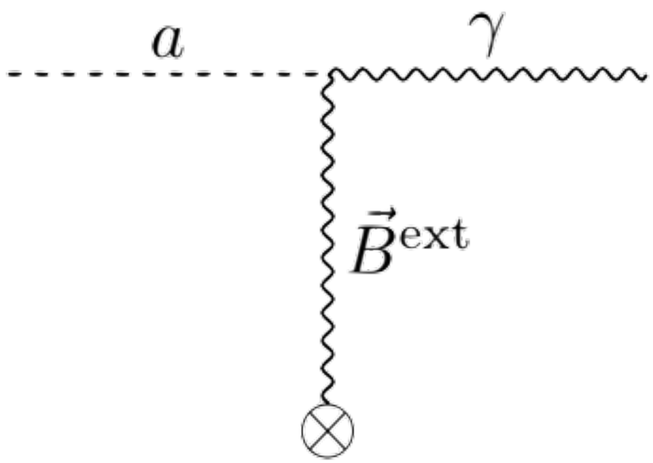
Istituto Nazionale di Fisica Nucleare
Sezione di Torino

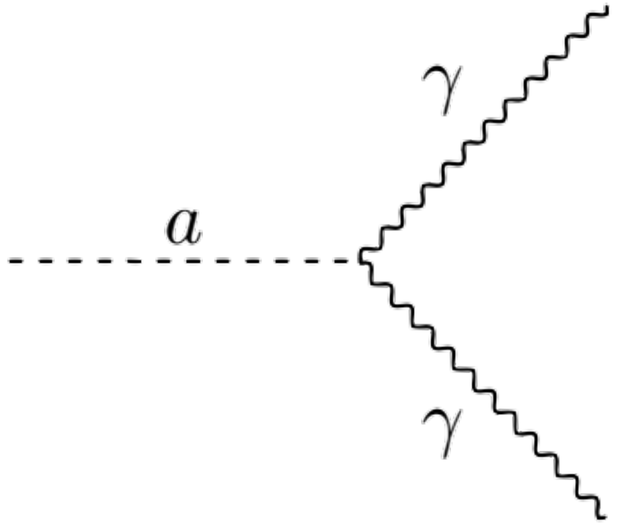


cajohare/axionlimits: Axionlimits

ALP-photon interaction

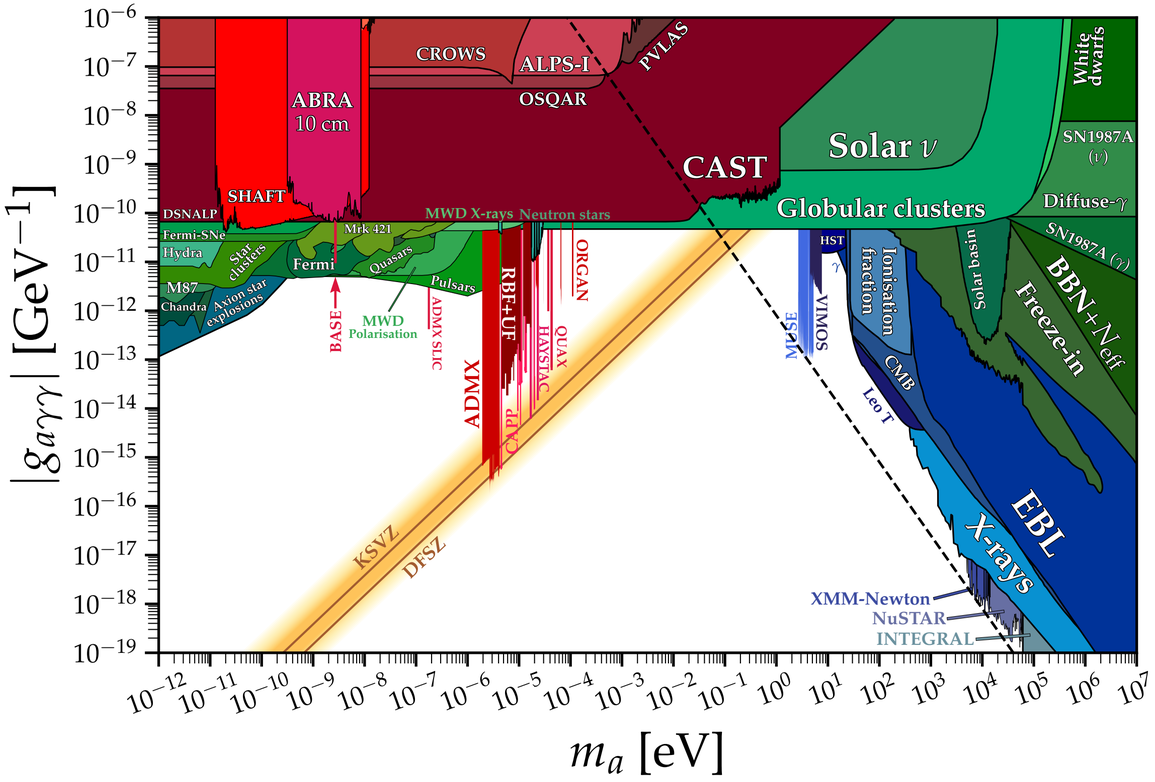
$$\mathcal{L}_{a\gamma\gamma} = \frac{1}{4} g a F_{\mu\nu} \tilde{F}^{\mu\nu}$$





Decay rate

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



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Look for radiation from ALP decay

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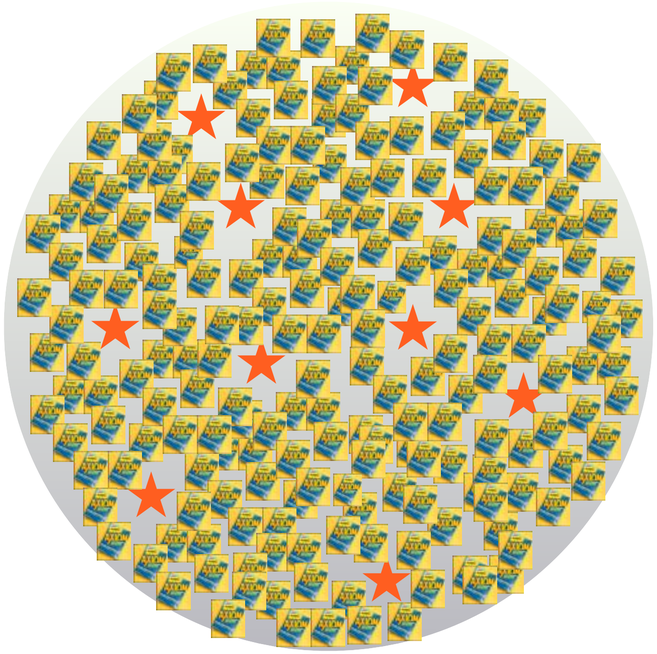
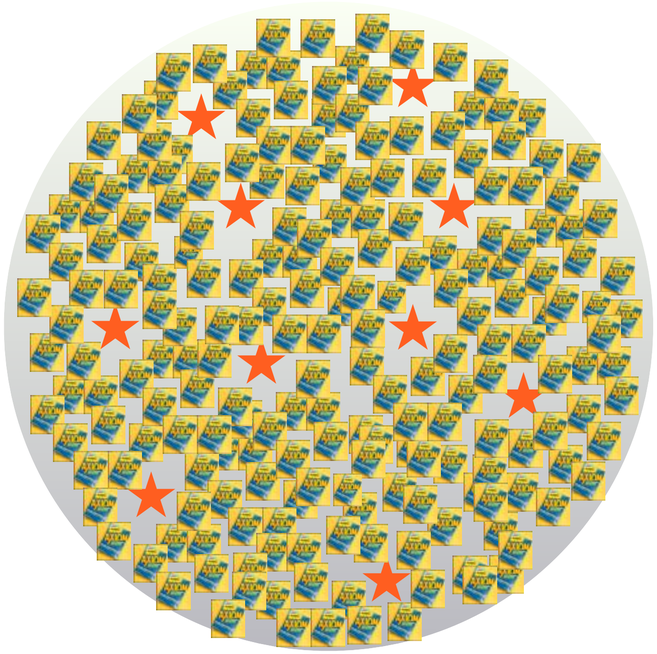
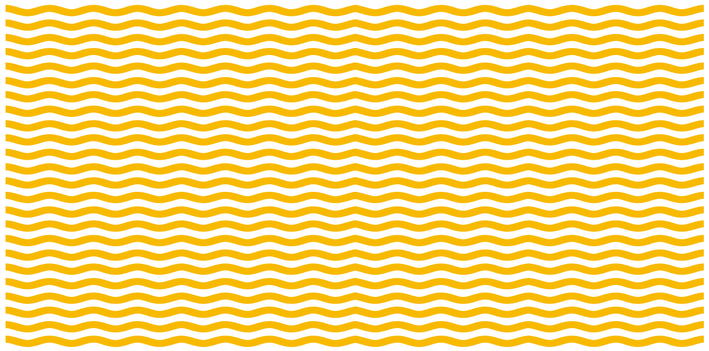
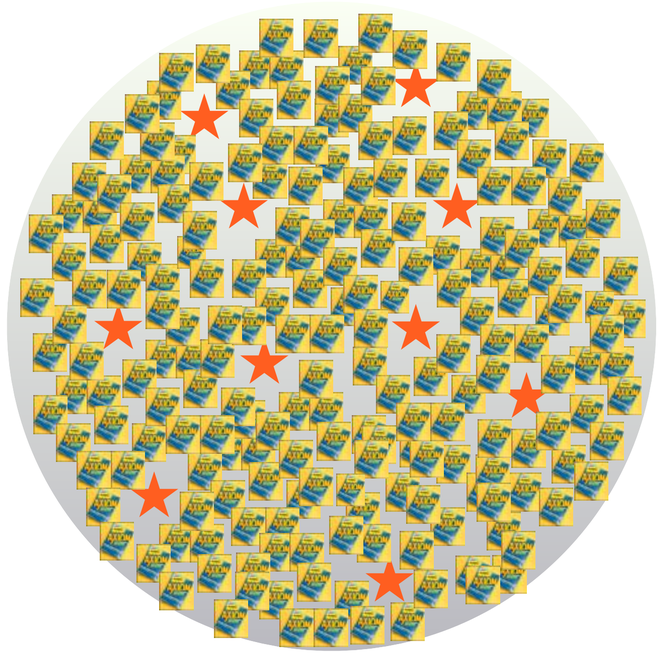


Look for radiation from ALP decay





Look for radiation from ALP decay



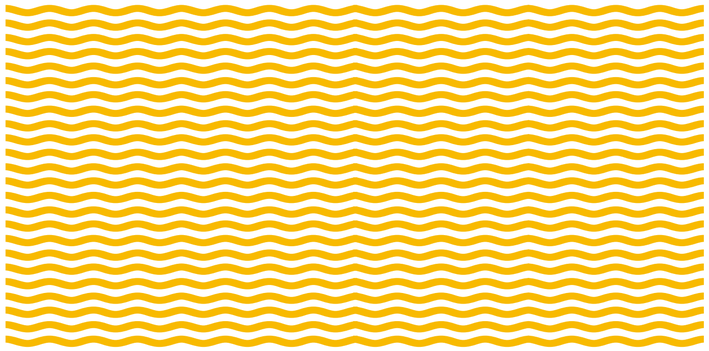
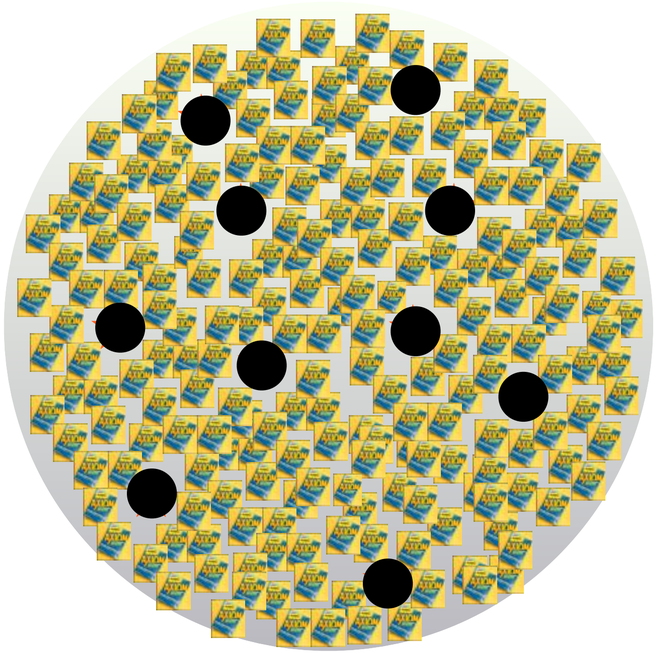
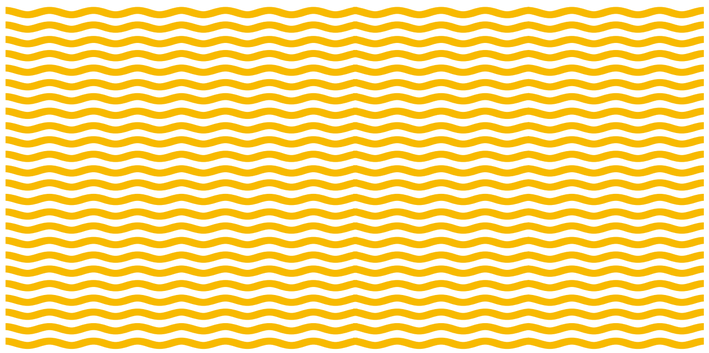


Photo by ESO/G. Hüdepohl (atacamaphoto.com)

Look for radiation from ALP decay





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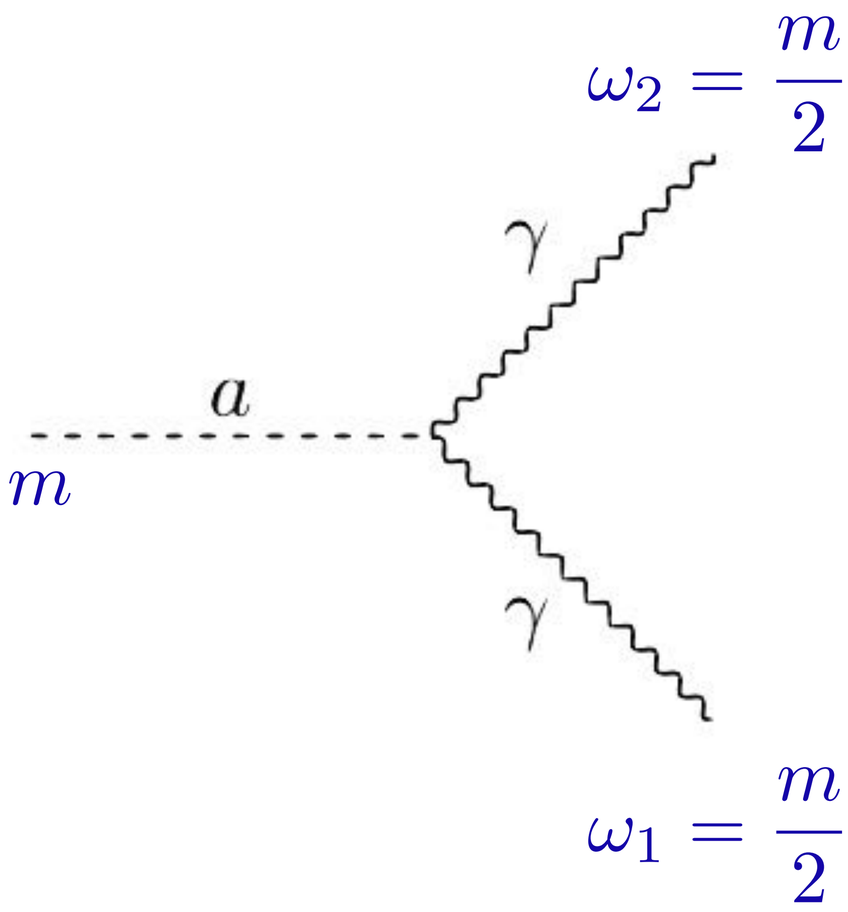
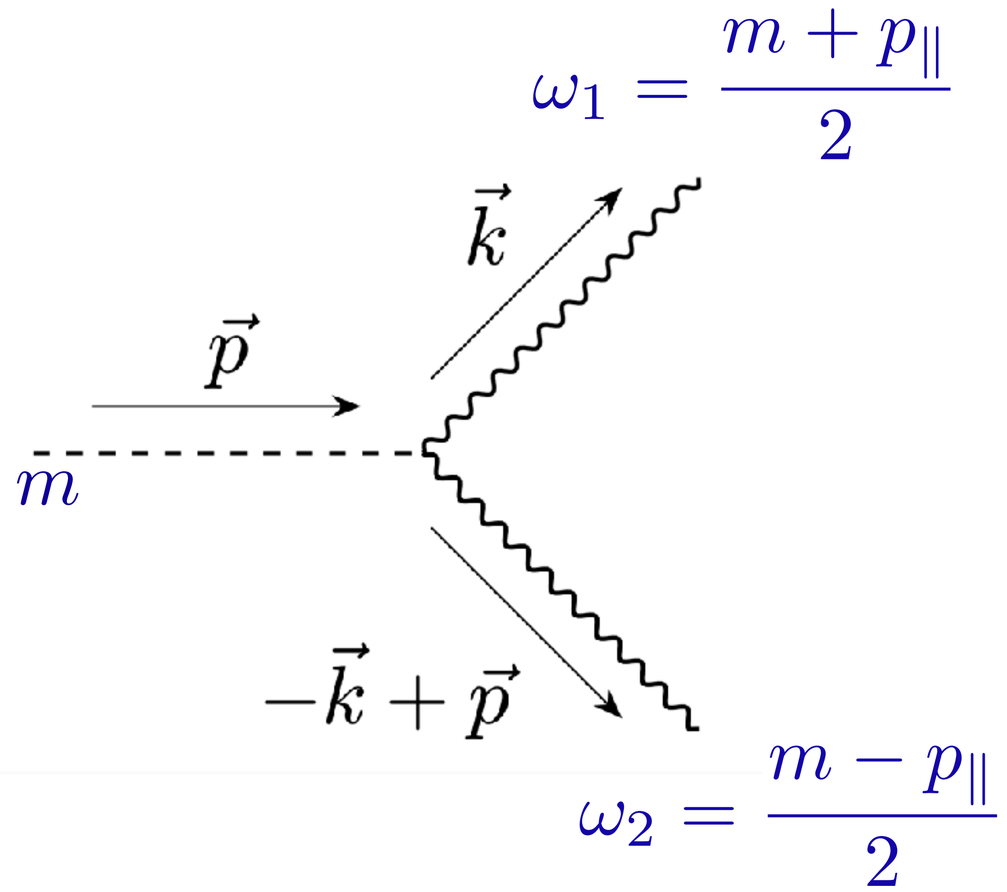
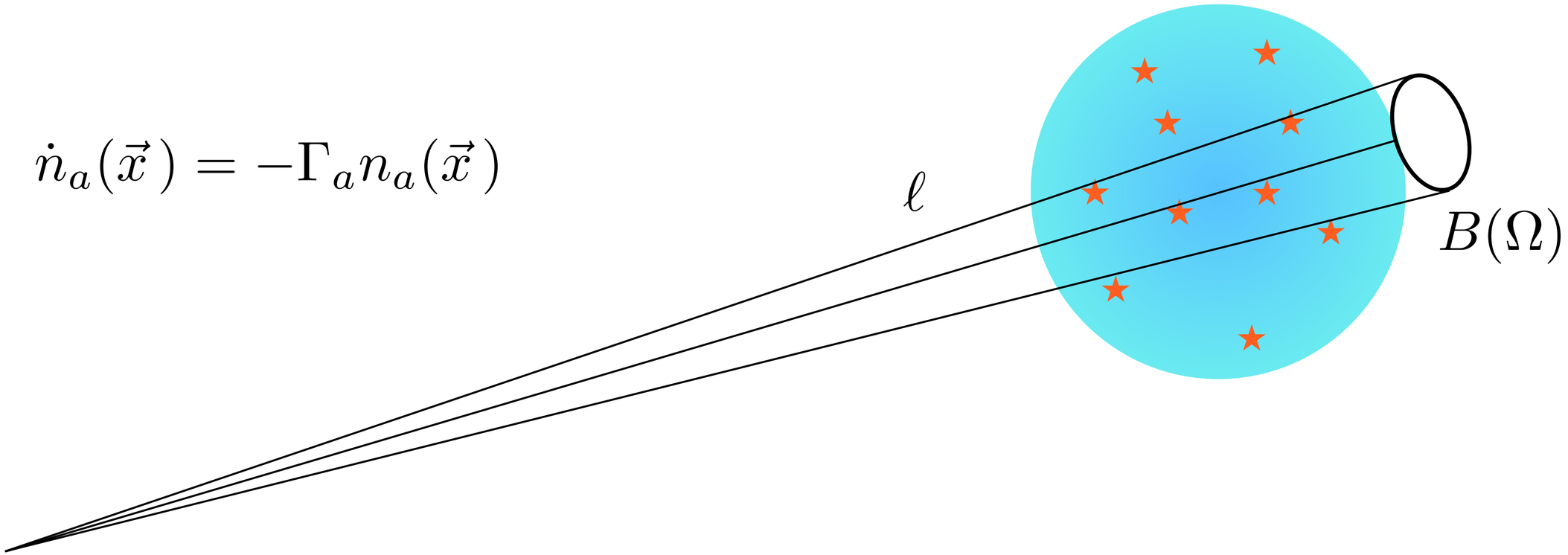
Kinematics

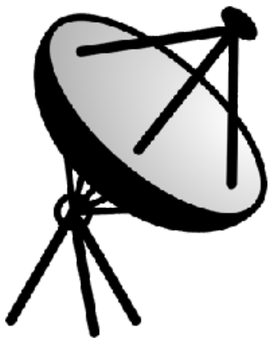

$\omega_2 = \frac{m}{2}$
γ
a
m
γ
$\omega_1 = \frac{m}{2}$


$\omega_1 = \frac{m + p_{\|}}{2}$
$\vec{k}$
$\vec{p}$
m
$-\vec{k} + \vec{p}$
$\omega_2 = \frac{m - p_{\|}}{2}$

Flux density from ALP decay

$$\dot{n}_a(\vec{x}\,) = -\Gamma_a n_a(\vec{x}\,)$$





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

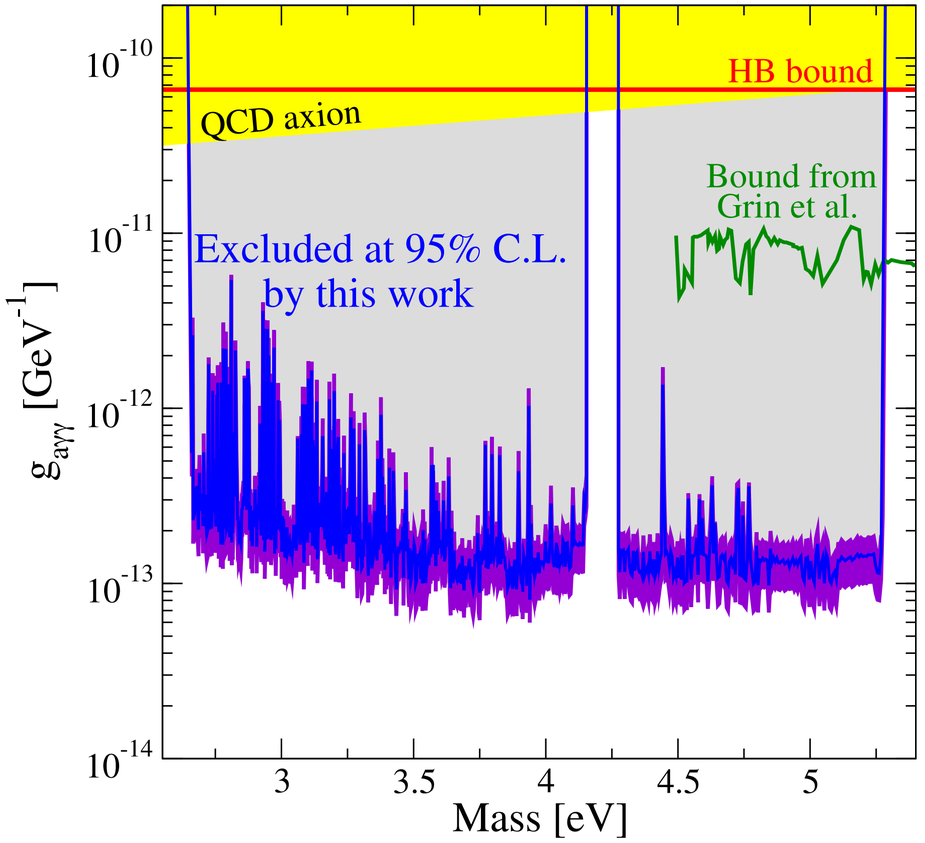
ELSEVIER

Physics Letters B

Volume 814, 10 March 2021, 136075

Searching for light in the darkness: Bounds on ALP dark matter with the optical MUSE-faint survey

Marco Regis [a, b], Marco Taoso [b], Daniel Vaz [c, d], Jarle Brinchmann [c, e], Sebastiaan L. Zoutendijk [e], Nicolas F. Bouché [f], Matthias Steinmetz [g]



- One dwarf spheroidal: Leo T ⟶ **Five dwarf spheroidals**
- $\int d\ell\, \rho_a$ derived from D-factor from V. Bonnivard, et al., MNRAS 453 (1) (2015) 849–867

⟶ **Likelihood for dark matter profile available from MUSE collaboration**

Dwarf Galaxies

- Dark matter rich
- High mass-to-light ratio
- Typical mass $10^8 - 10^9\ M_\odot$
- Typical radius $1\ \mathrm{kpc}$
- DM energy density $\rho \sim 4\ \mathrm{GeV\ cm^{-3}}$
- Distance $100\ \mathrm{kpc}$

Sculptor dwarf galaxy. Photo by ESO.

The MUSE instrument

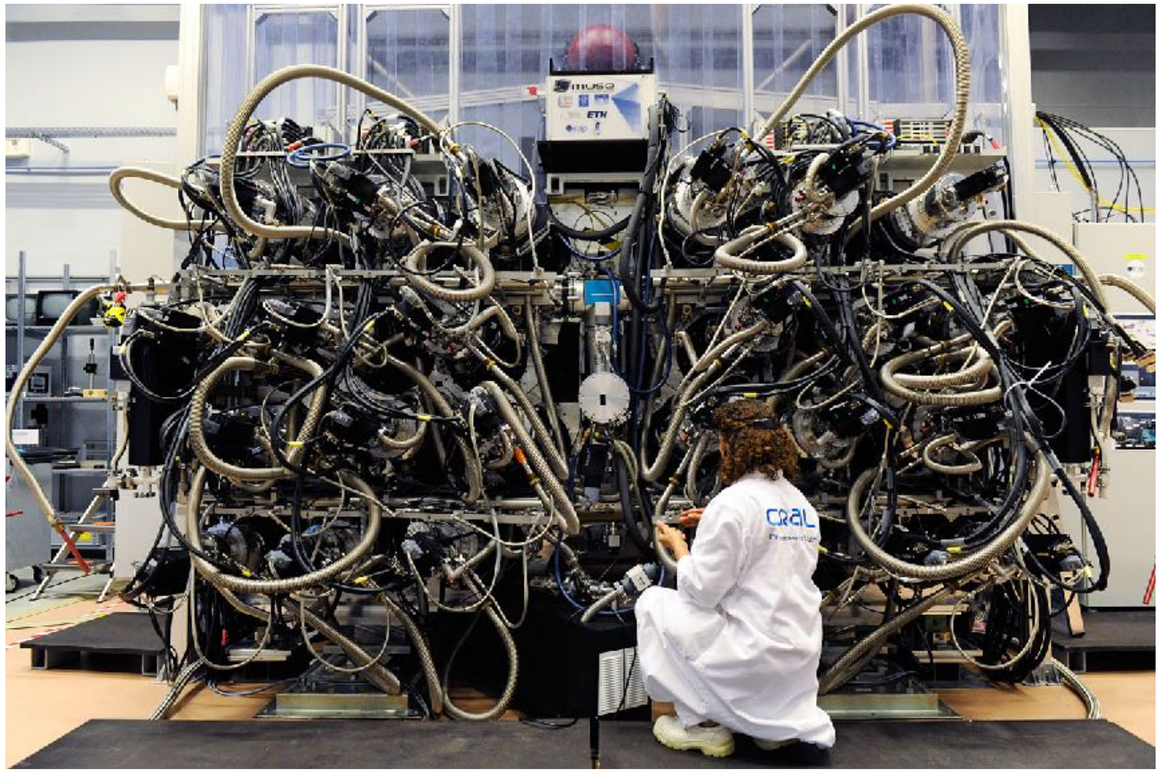
Multi Unit Spectroscopic Explorer

- Measures flux in ~3720 channels

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

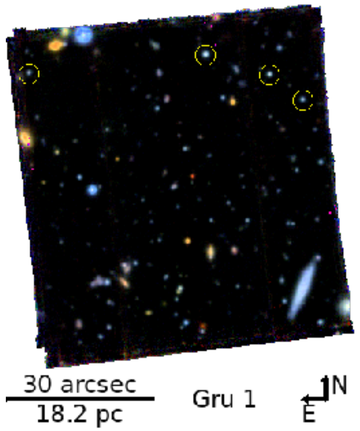
$$2.65\ \text{eV} < m < 5.27\ \text{eV}$$

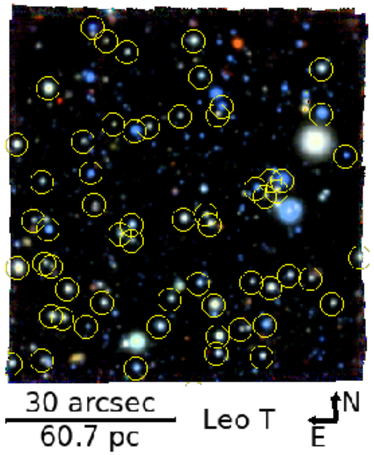
- Wavelength sampling $1.25\ \text{Å}$
- Spectral resolution $\lambda/\Delta\lambda > 10^3$
- Field of view $1' \times 1'$
- Spatial resolution $\sim 0.5''$

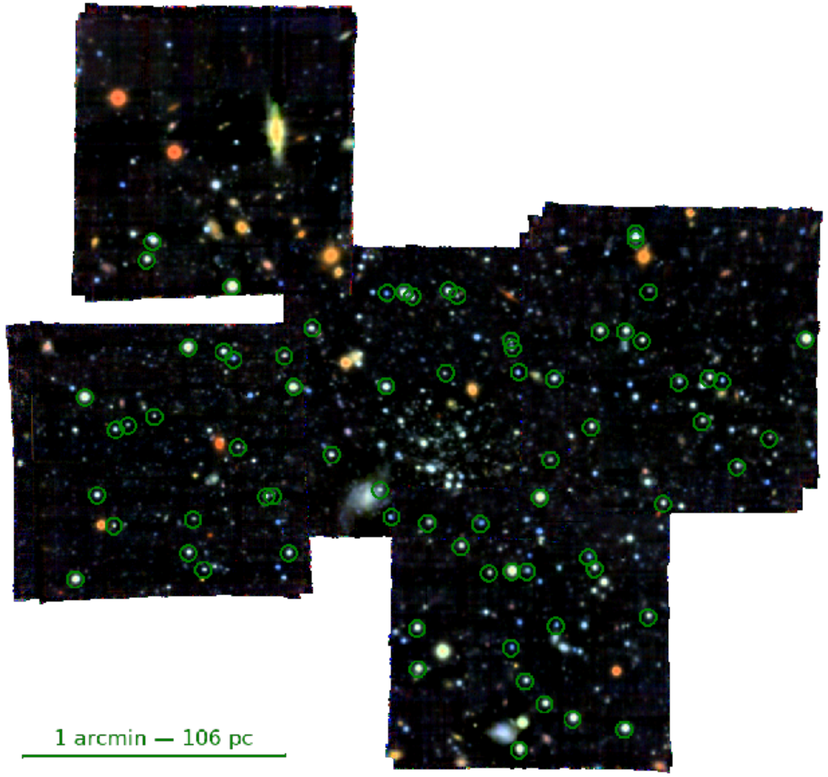


muse
multi unit spectroscopic explorer

The MUSE-Faint Survey

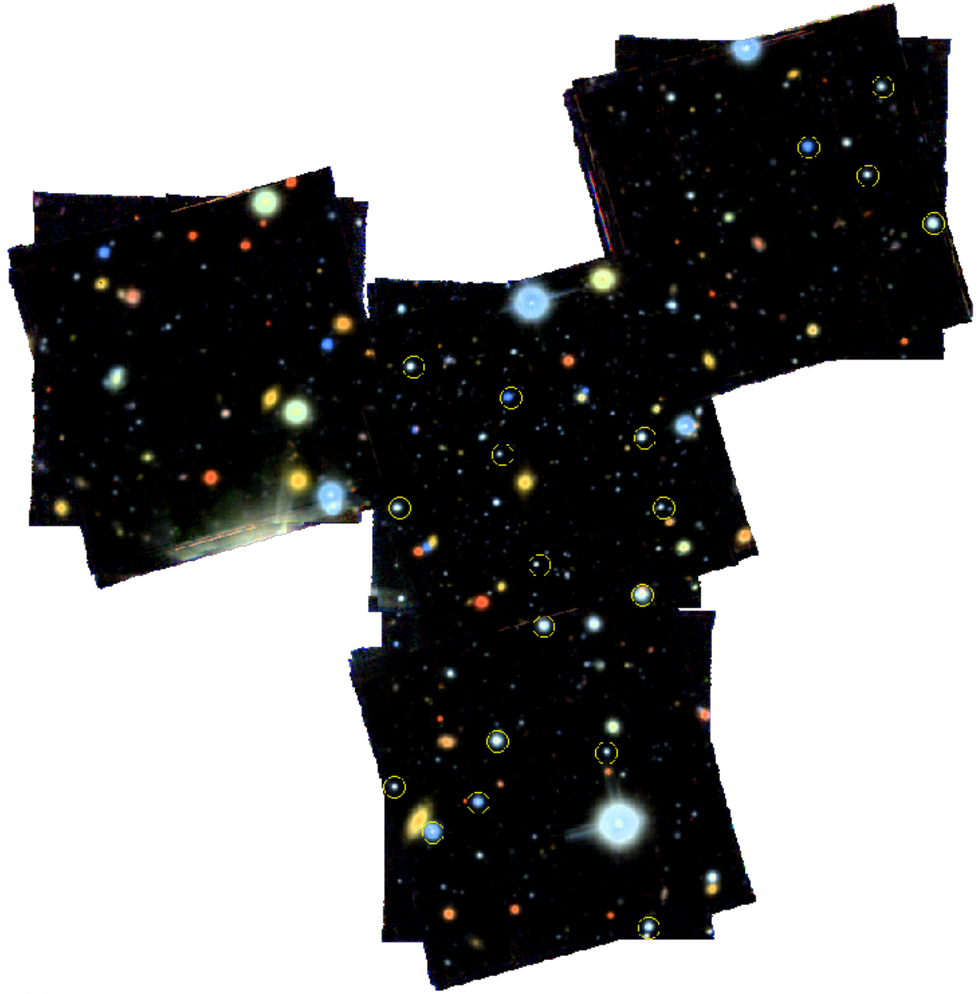






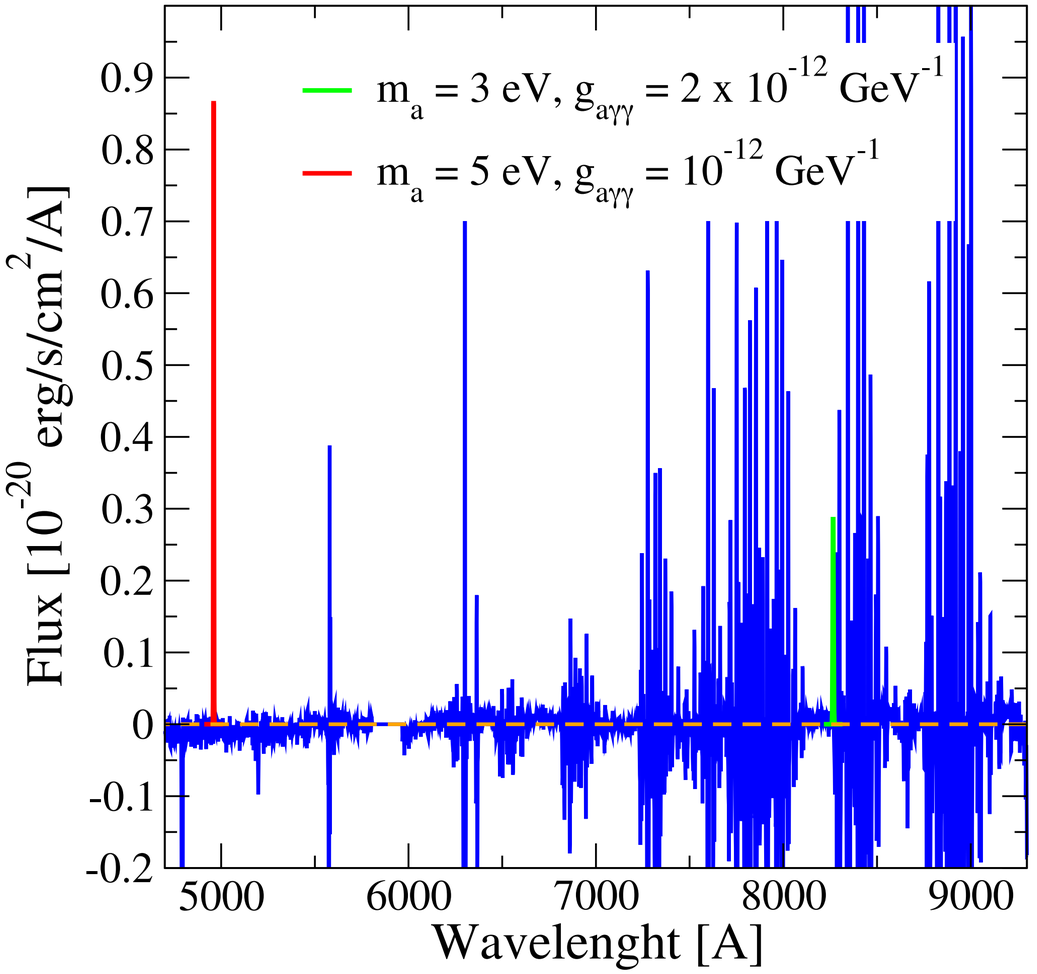
Eri 2

+ **Sculptor**

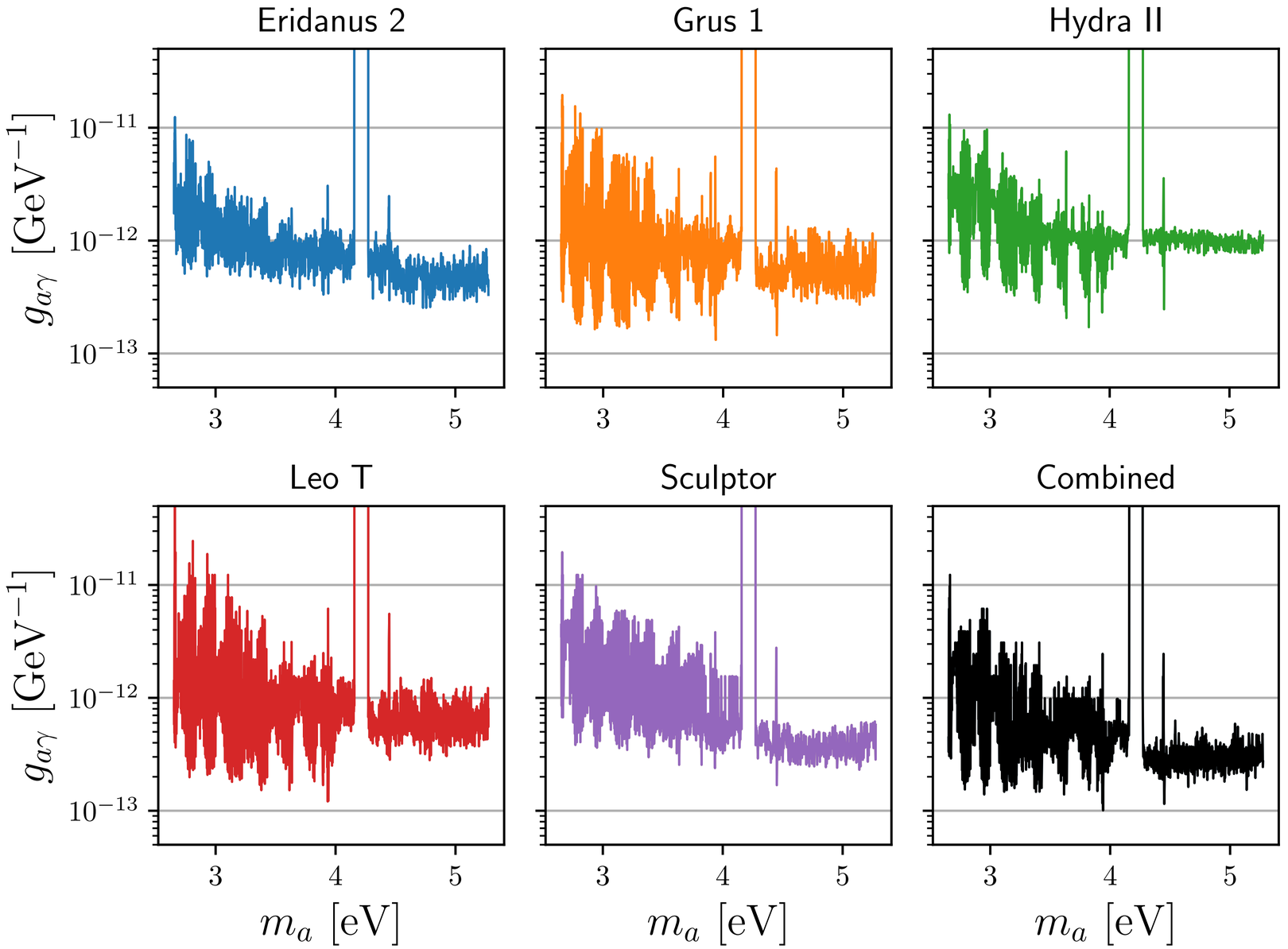


Zoutendijk+, The MUSE-Faint survey. III, 2112.09374

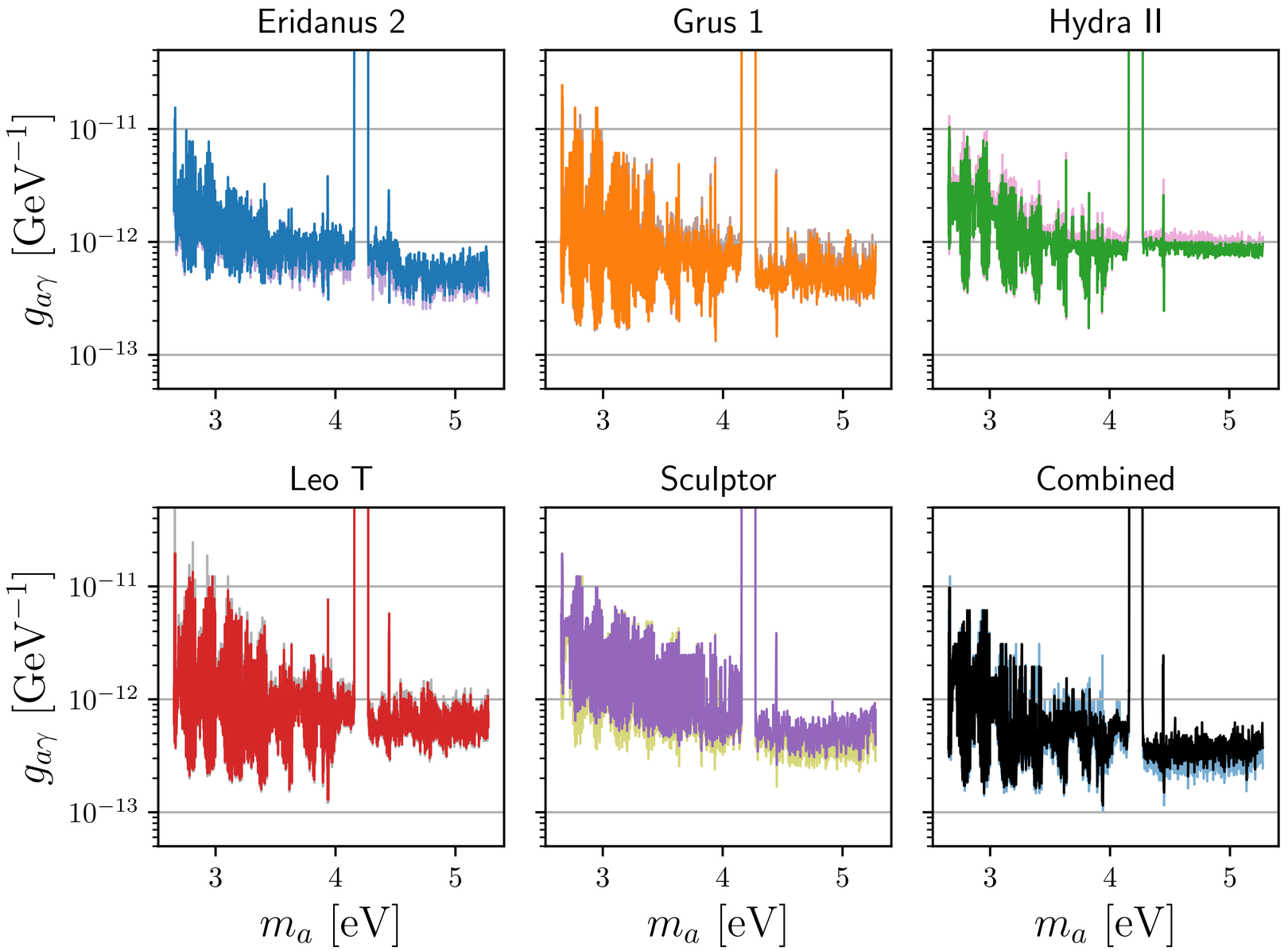
Signal


m_a = 3 eV, $g_{a\gamma\gamma}$ = 2 x 10^{-12} GeV^{-1}
m_a = 5 eV, $g_{a\gamma\gamma}$ = 10^{-12} GeV^{-1}
Flux [10^{-20} erg/s/cm^2/A]
Wavelenght [A]
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
5000
6000
7000
8000
9000

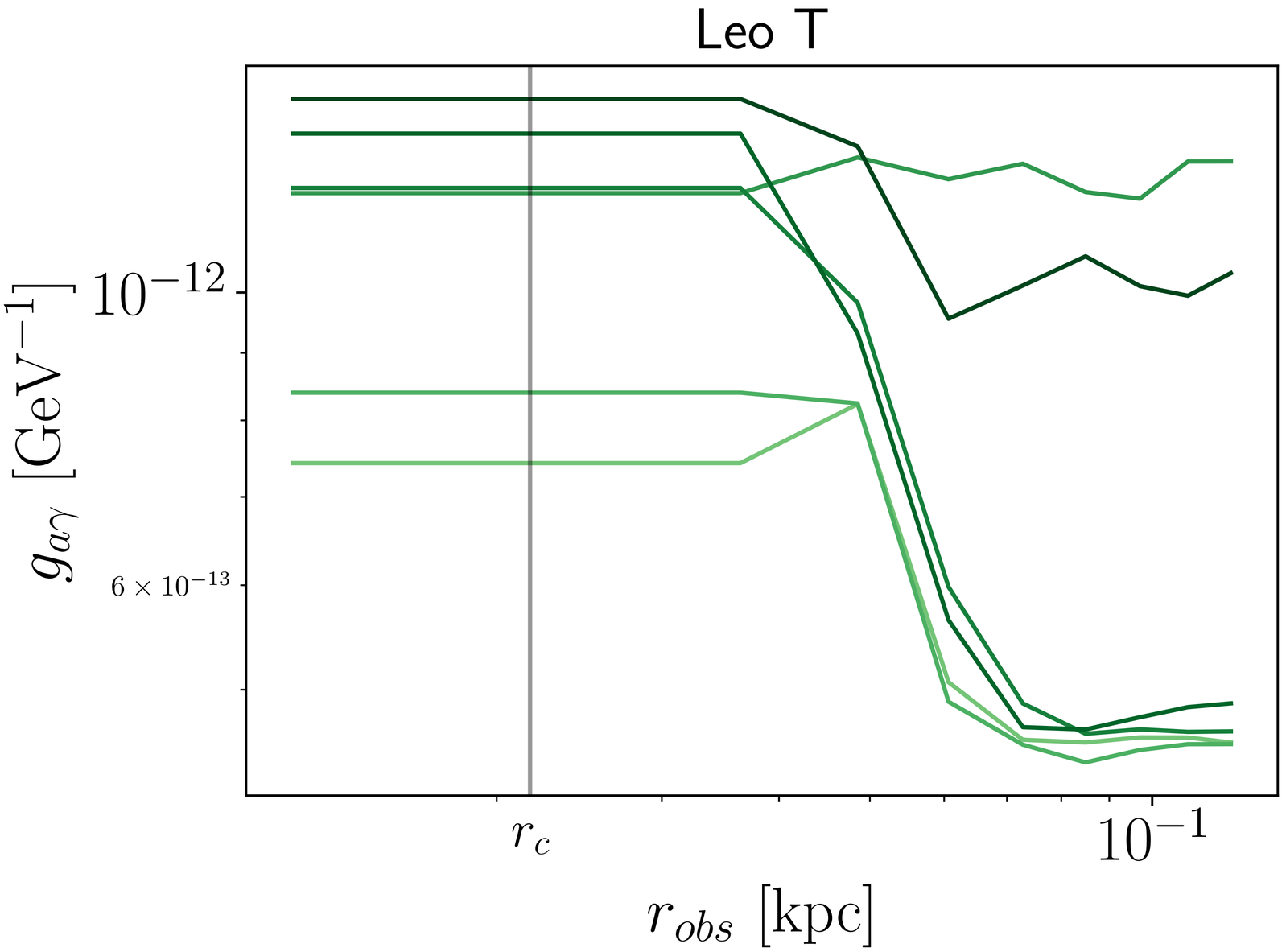
NFW profile

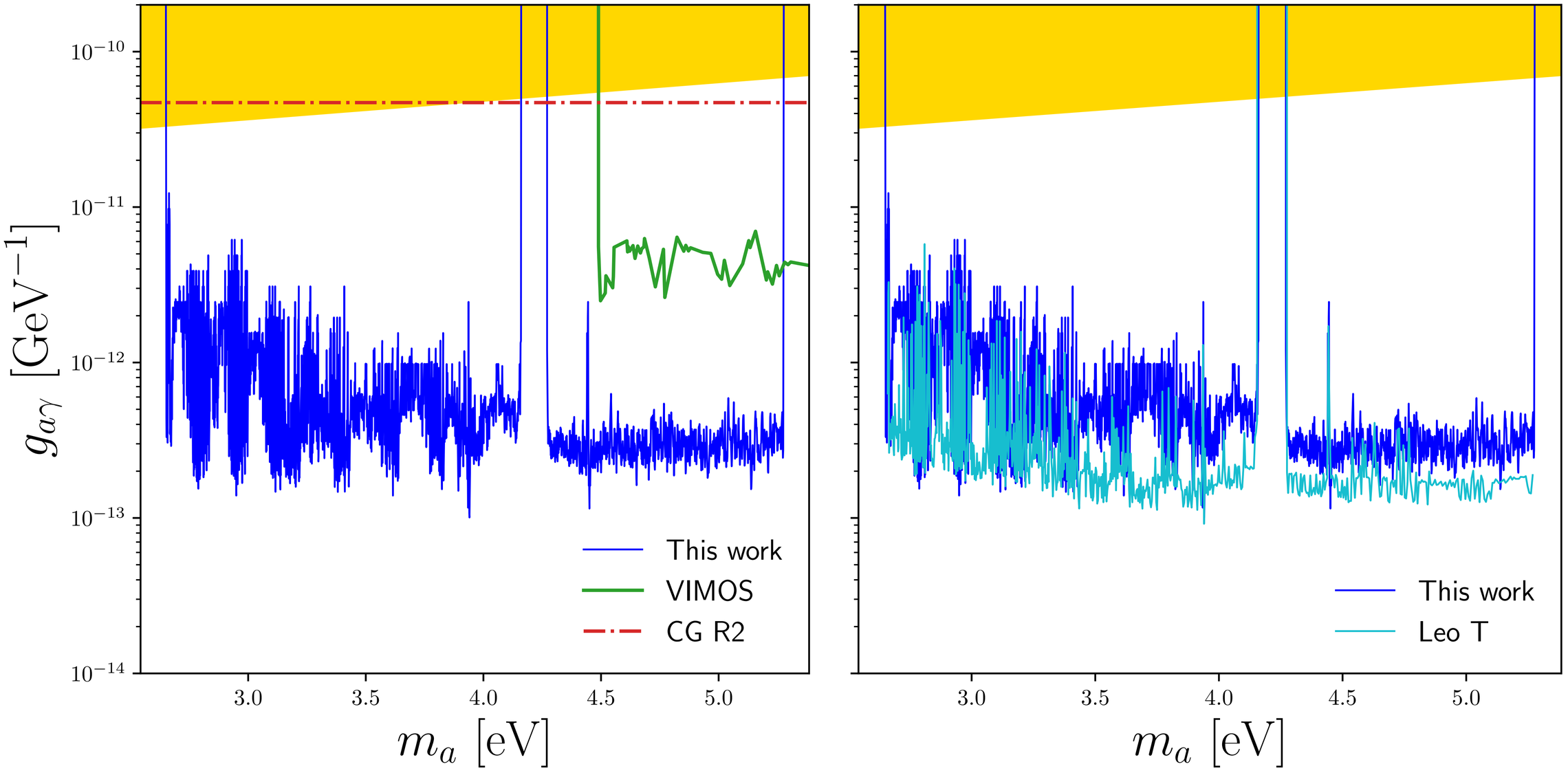

Eridanus 2
Grus 1
Hydra II
Leo T
Sculptor
Combined
$g_{a\gamma}$ [GeV^{-1}]
10^{-11}
10^{-12}
10^{-13}
3
4
5
m_a [eV]

Cored profile



Integration radius




10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
$g_{a\gamma}$ [GeV^{-1}]
3.0
3.5
4.0
4.5
5.0
m_a [eV]
This work
VIMOS
CG R2
This work
Leo T
3.0
3.5
4.0
4.5
5.0
m_a [eV]

Conclusions

- Strongest bound in mass range $2.7 - 5.3\ \mathrm{eV}$
- Improved robustness
- No evidence for axion dark matter found
- **Infrared?**
  - PRD 106, 095025, 2305.1341
  - Forecast sensitivity $g \sim 10^{-11}\ \mathrm{GeV}^{-1}$ for $m \sim 0.5 - 2\ \mathrm{eV}$ looking at dwarf galaxies