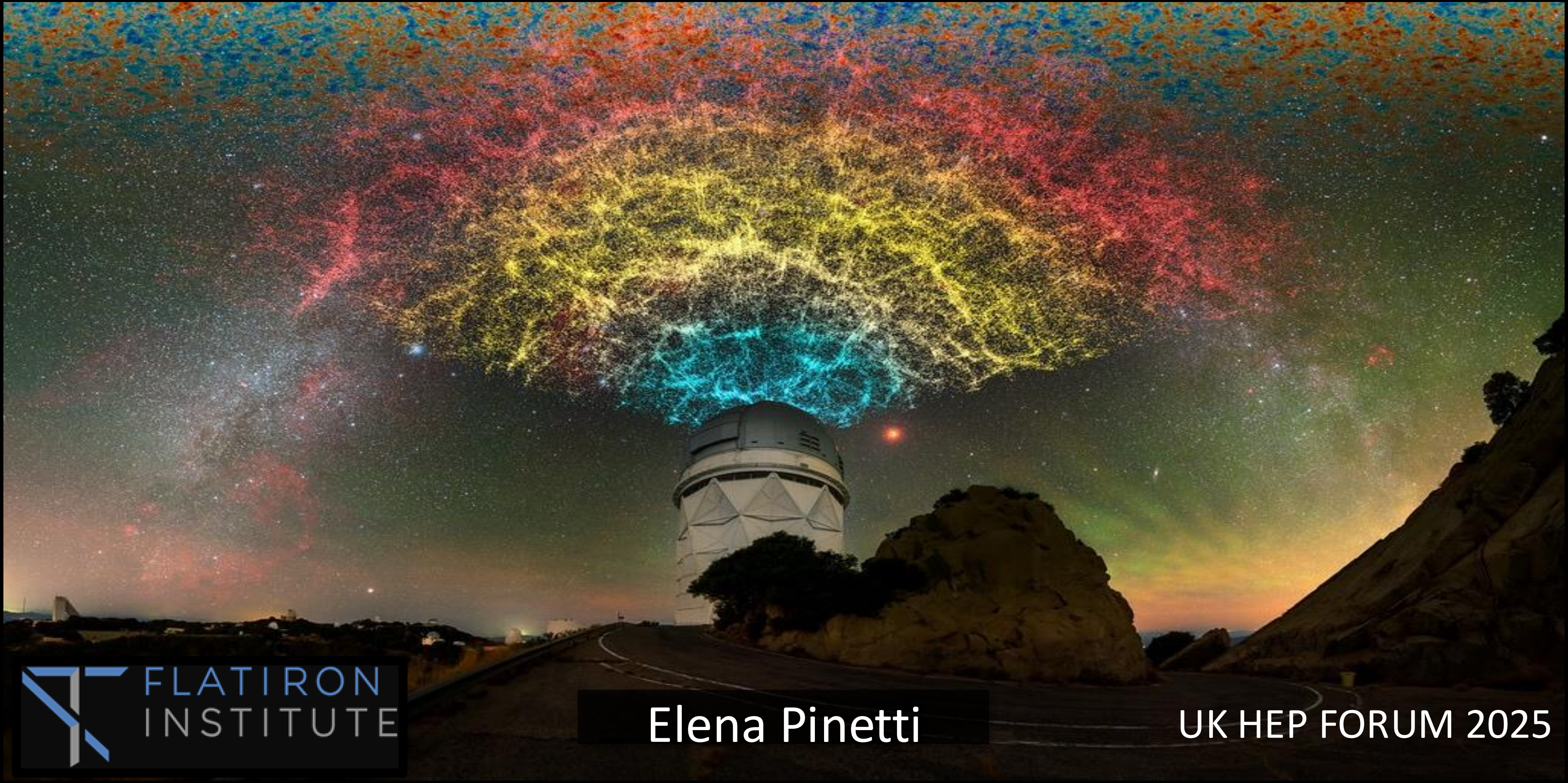
Indirect searches of dark matter



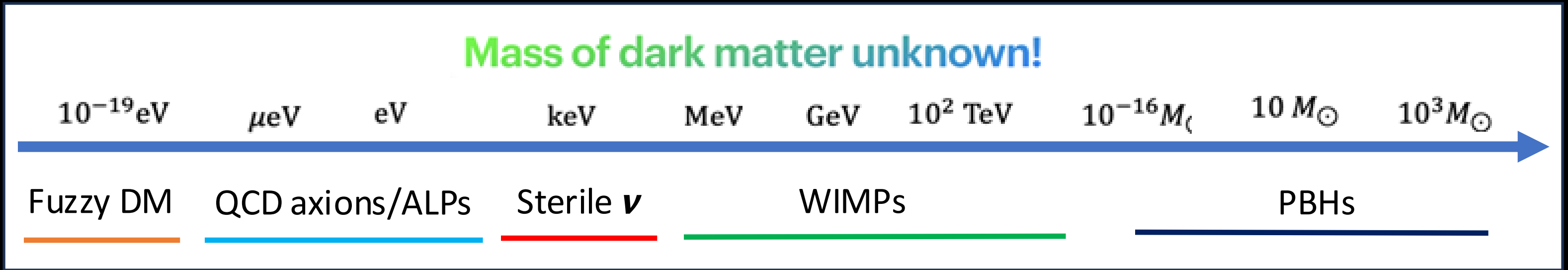
FLATIRON INSTITUTE

Elena Pinetti

UK HEP FORUM 2025


Dark matter in the Universe


Dark Matter Candidates



See Dark Matter Theory Overview by Malcolm Fairbairn

See Axion Dark Matter Overview by Martin Bauer

Indirect searches of dark matter

- Detection of signals from DM annihilation, decay or interactions in the cosmos

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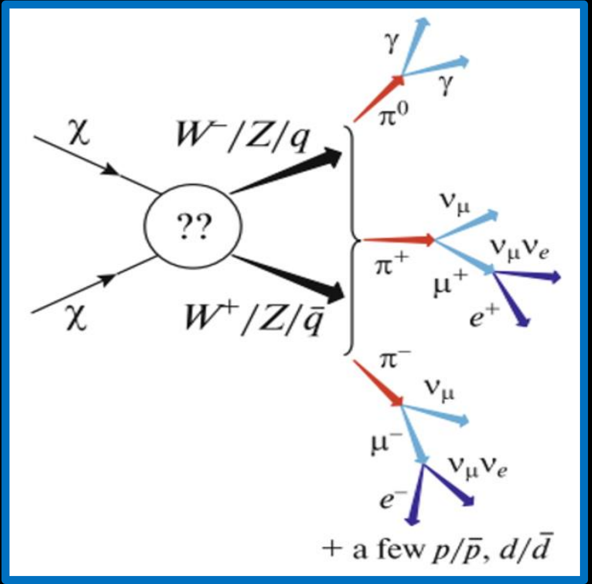
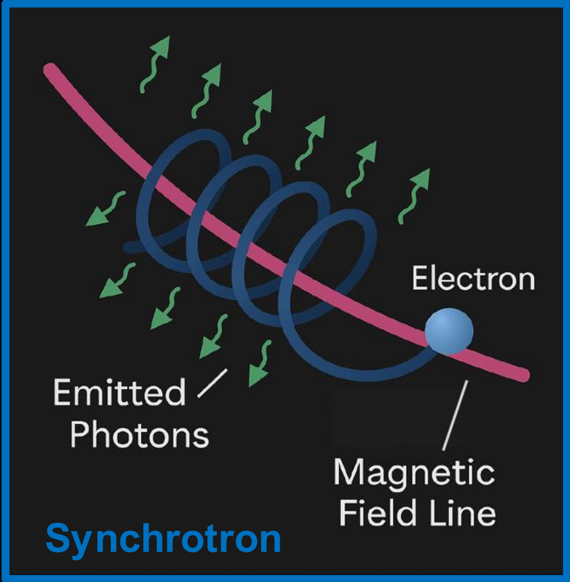
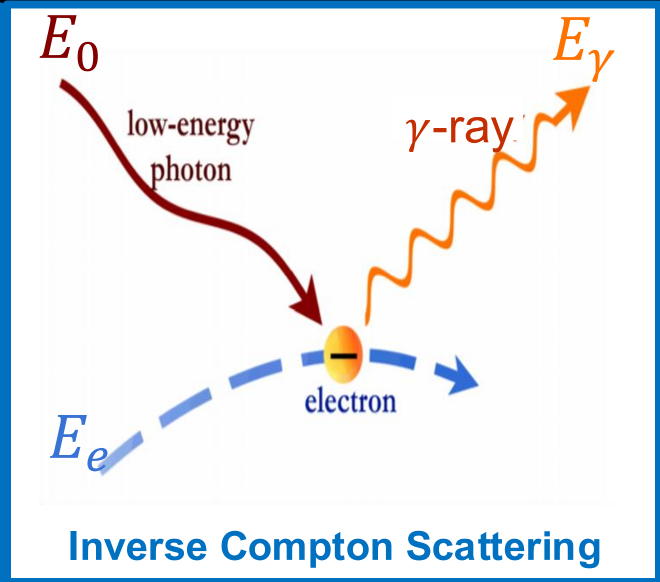
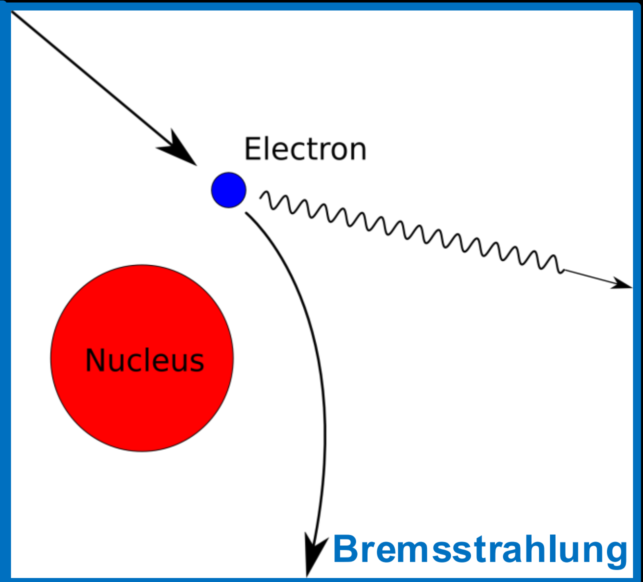
Primary products



Secondary emission








HEROES
VS
VILLAINS

Can we discover dark matter with indirect detection?

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1 Unique signatures of dark matter (model dependent)

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2 Modelling the astrophysical background (hard and scary)

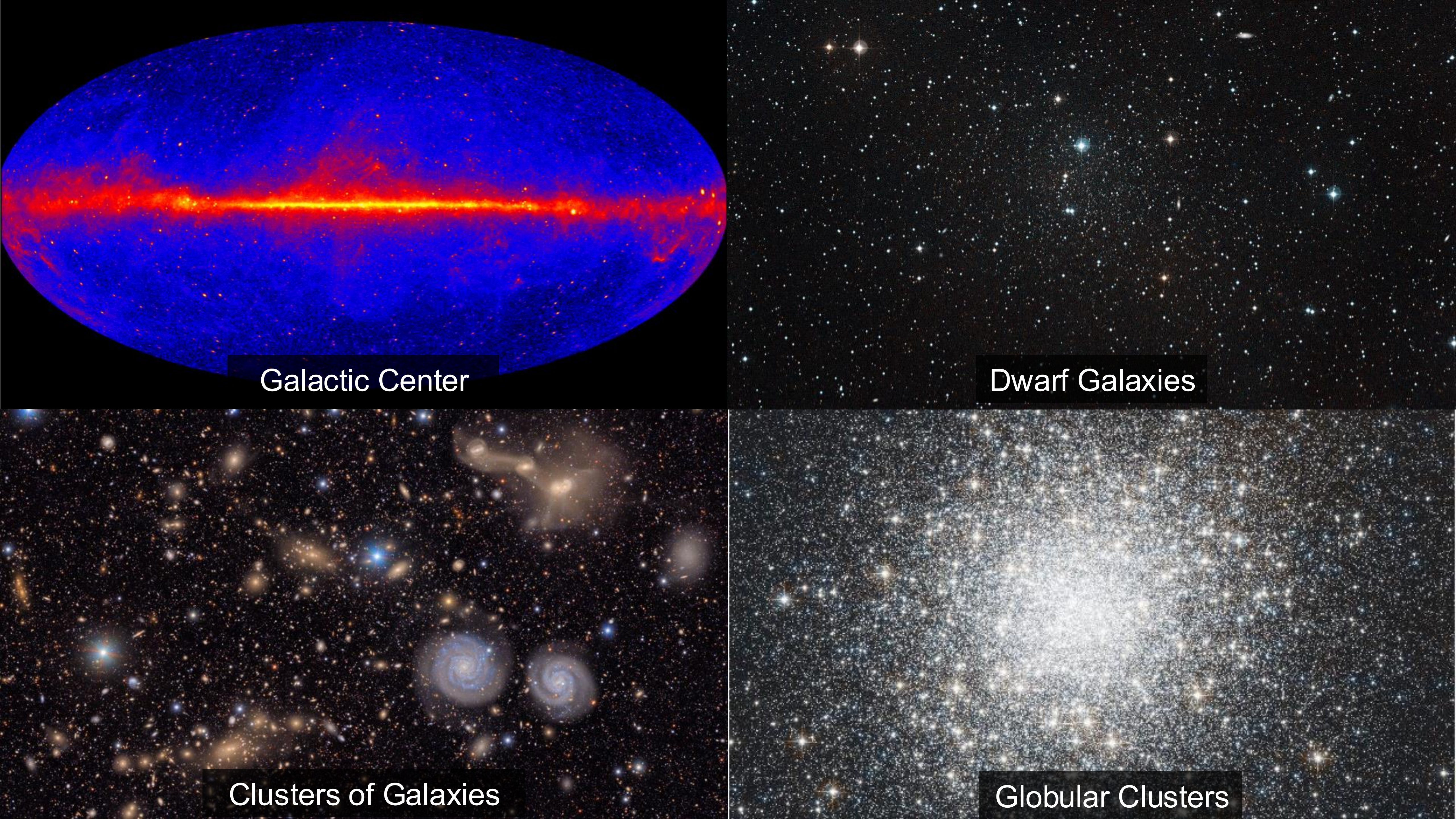
Can we discover dark matter with indirect detection?

1. Unique signatures of dark matter (model dependent)

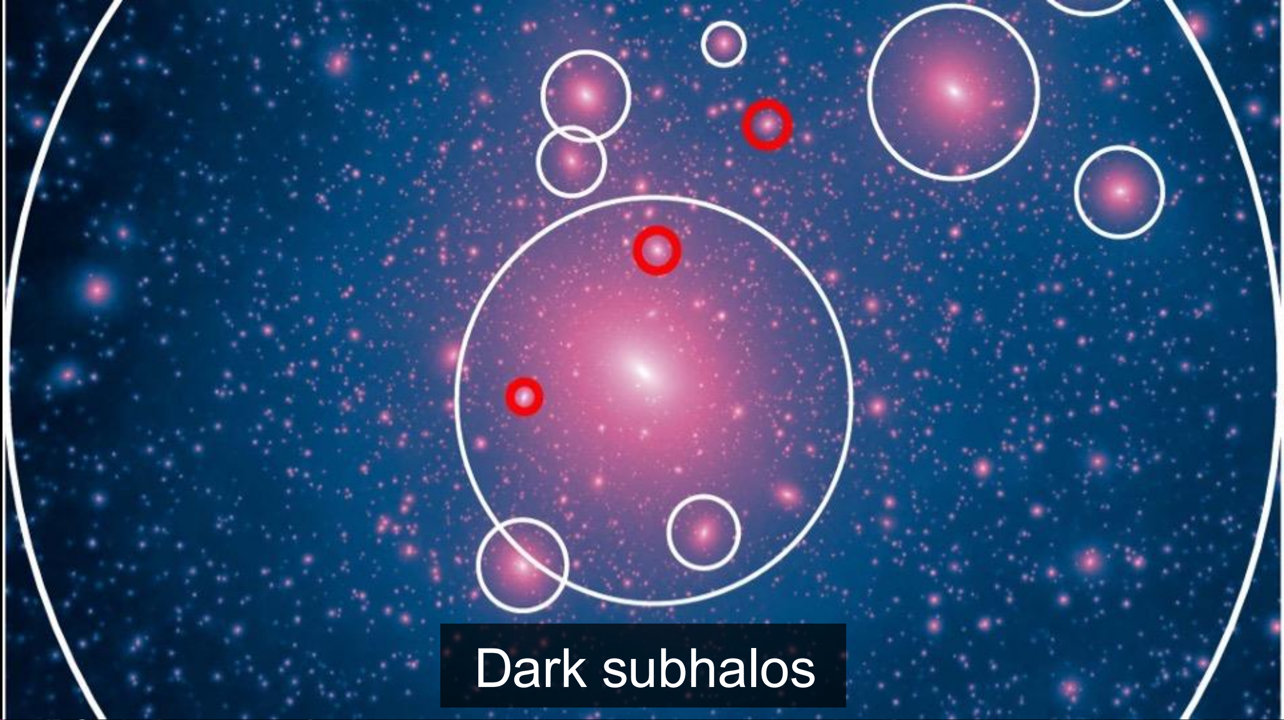
2. Modelling the astrophysical background (hard and scary)

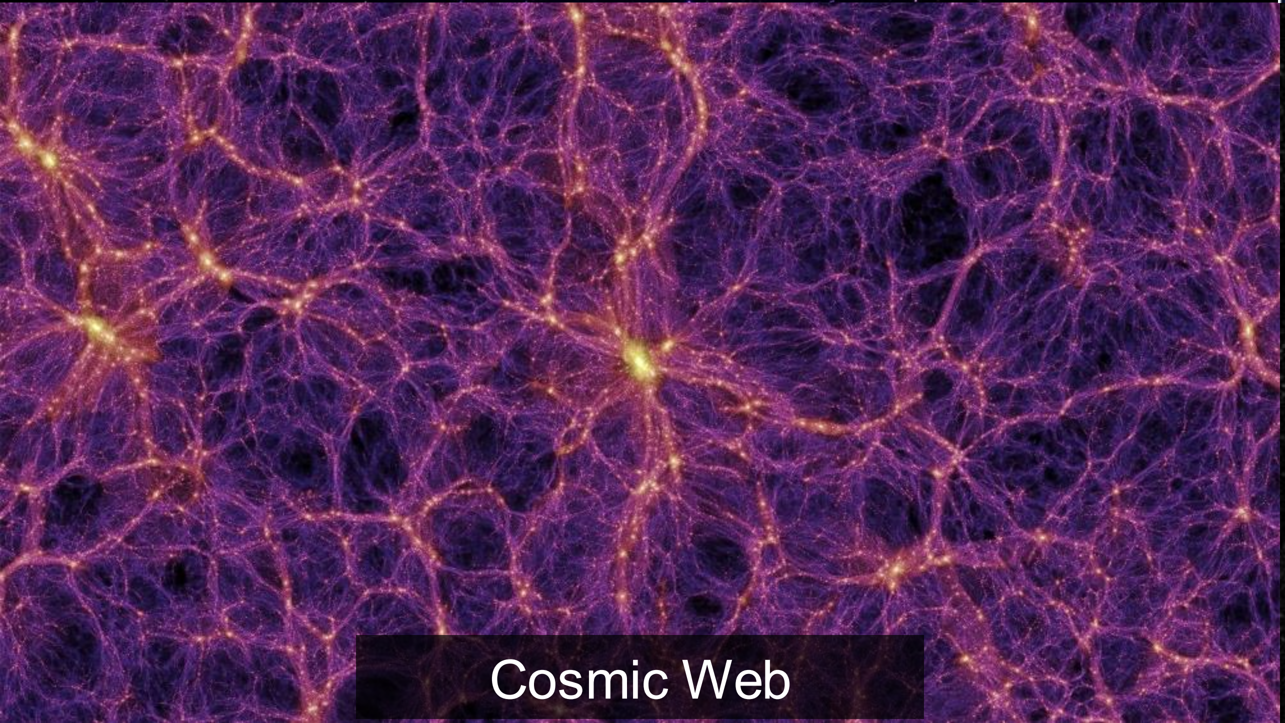
3. Promising targets/astrophysical environments (creative and fun!)

Where should we look?


Galactic Center
Dwarf Galaxies
Clusters of Galaxies
Globular Clusters


Blank Sky


Dark subhalos


Cosmic Web

Cosmic Voids

Dark matter detection around the world

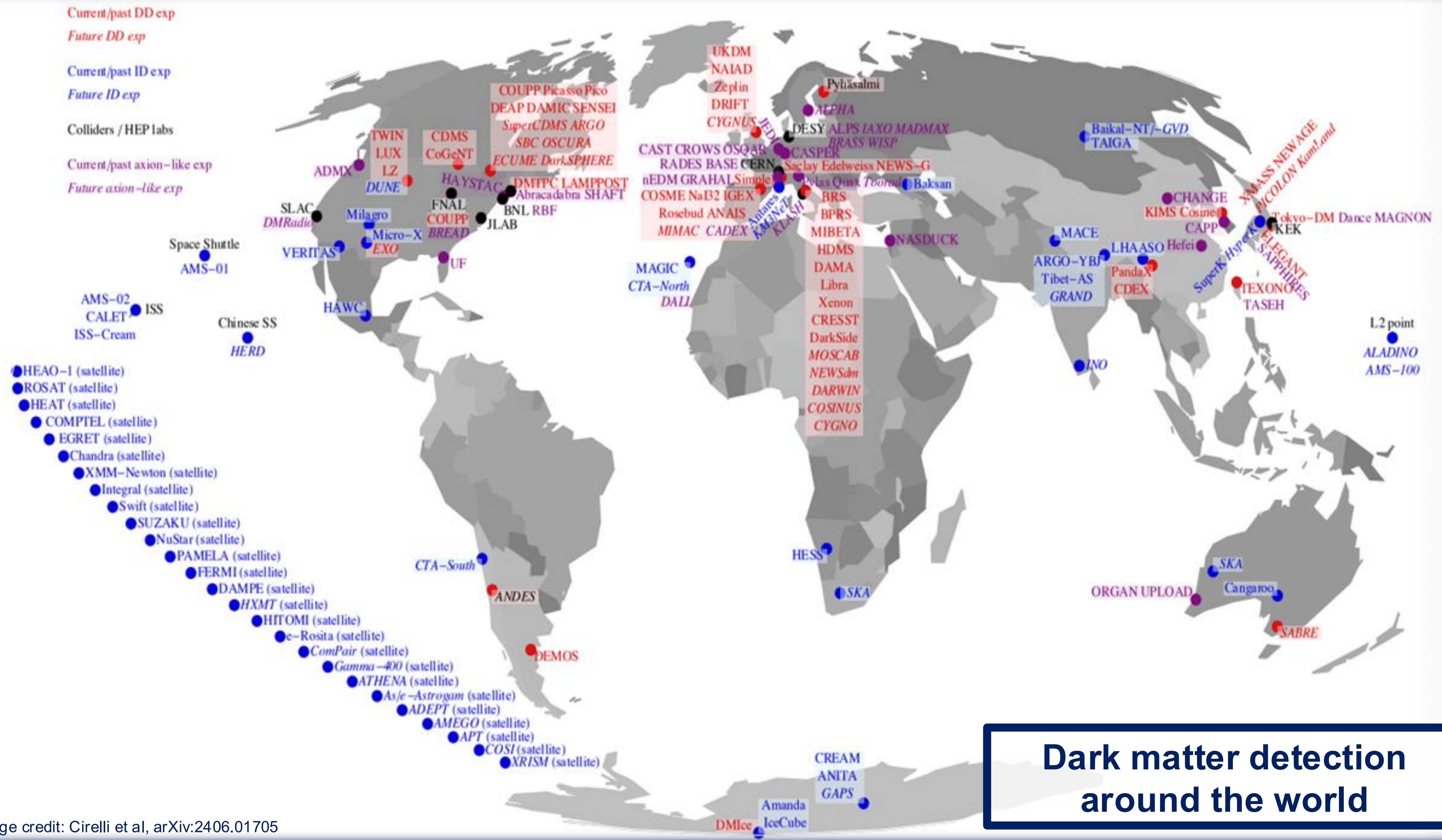
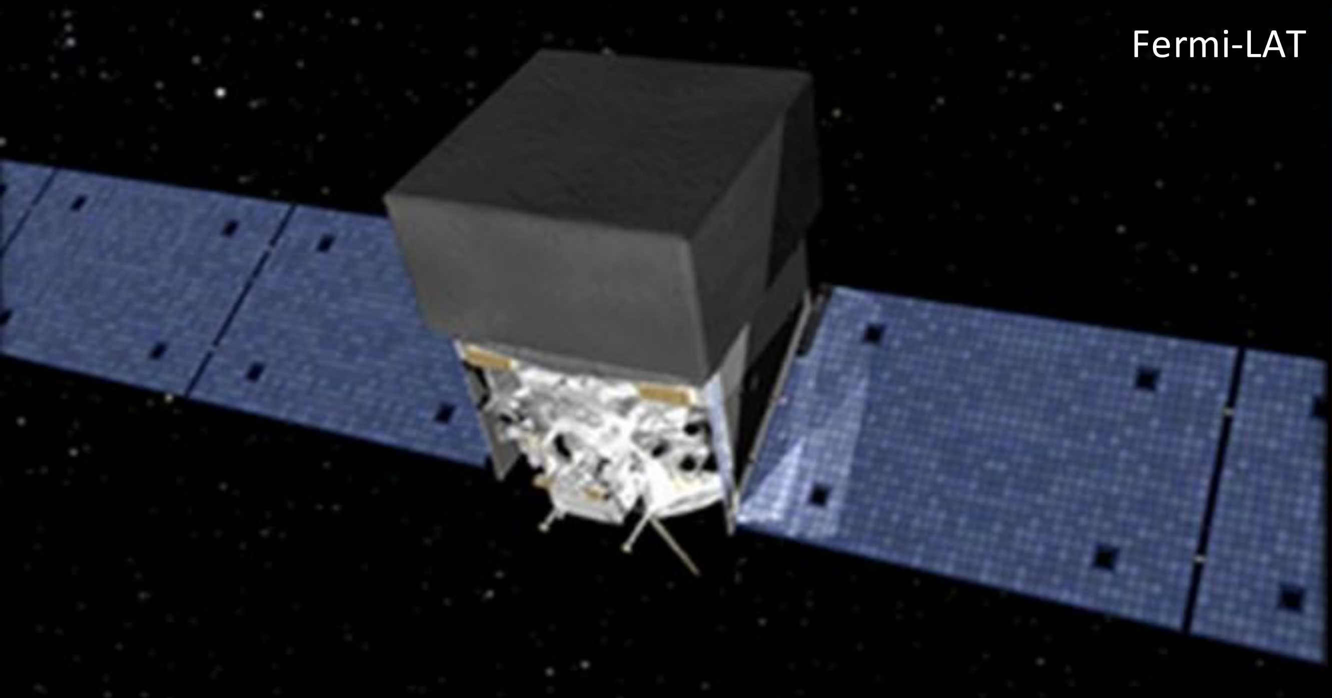


Image credit: Cirelli et al, arXiv:2406.01705

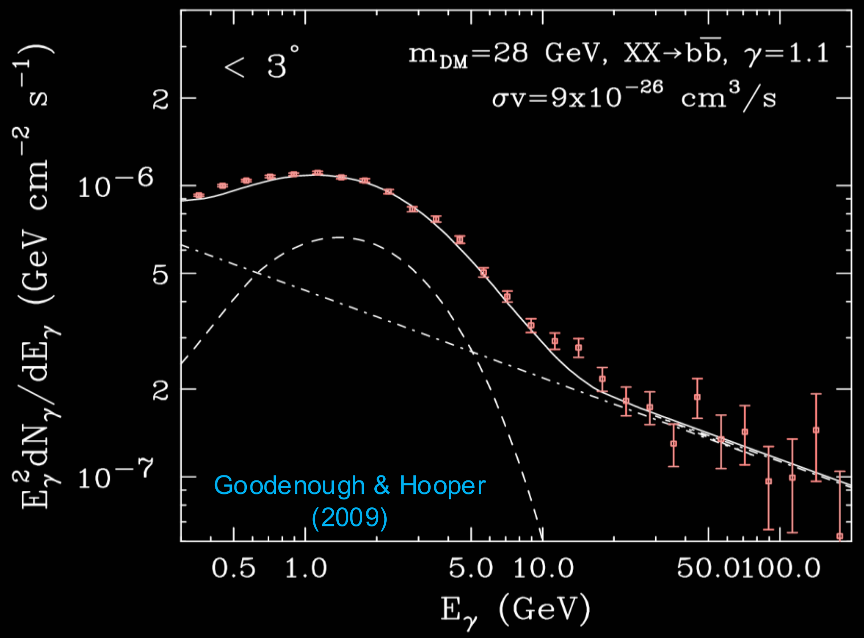
Outline

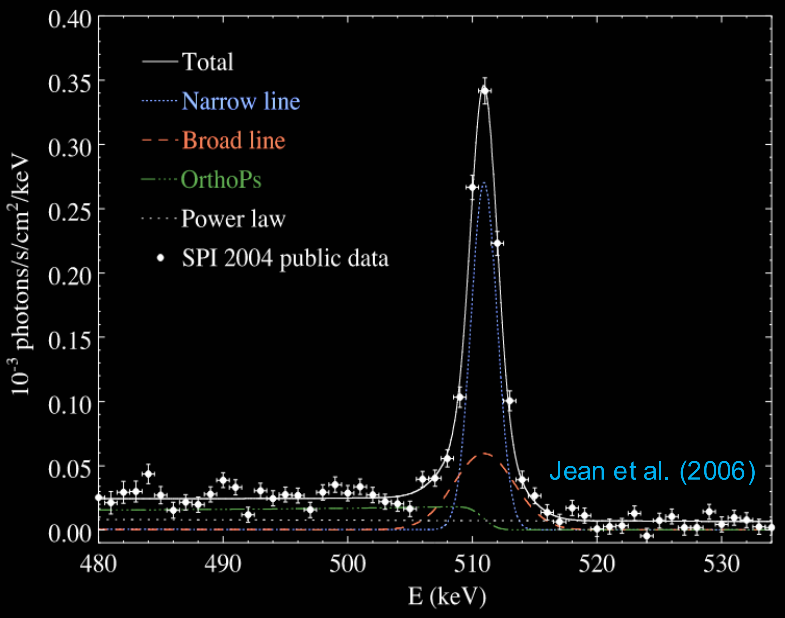
- ❑ Current status of indirect searches
- ❑ Longstanding and emerging anomalies
- ❑ Promising prospects for future searches

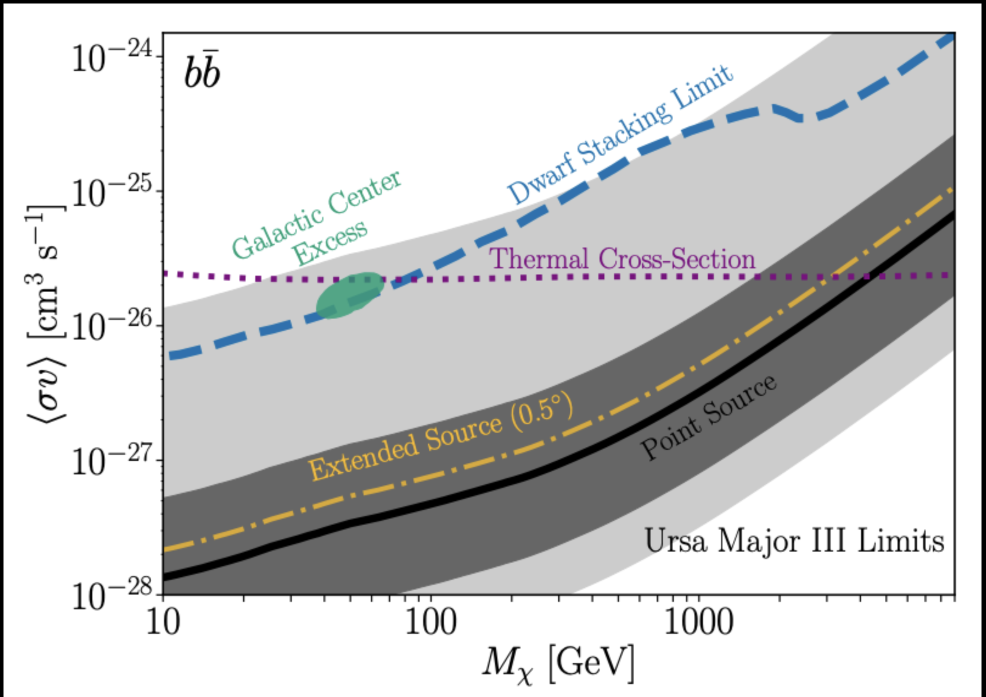


Dark matter searches with gamma-rays

Gamma-ray Anomalies







No Observational Evidence for Dark Matter Nor a Large Metallicity Spread in the Extreme Milky Way Satellite Ursa Major III / UNIONS 1

William Cerny,[1] Daisy Bissonette,[2] Alexander P. Ji,[2,3,4] Marla Geha,[1] Anirudh Chiti,[2,3] Simon E.T. Smith,[5] Joshua D. Simon,[6] Andrew B. Pace,[7] Evan N. Kirby,[8] Kim A. Venn,[5] Ting S. Li,[9] and Alice M. Luna[2,3]

Crnogorcevic & Linden, PRD 109 (2024) 8, 083018

Cerny et al, arXiv:2510.02431

Sub-GeV Dark Matter

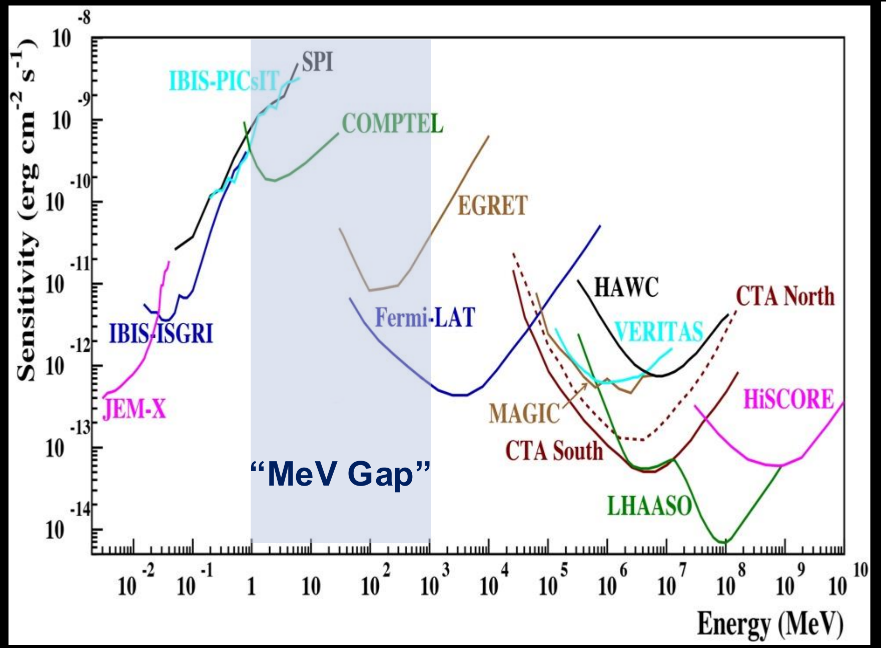
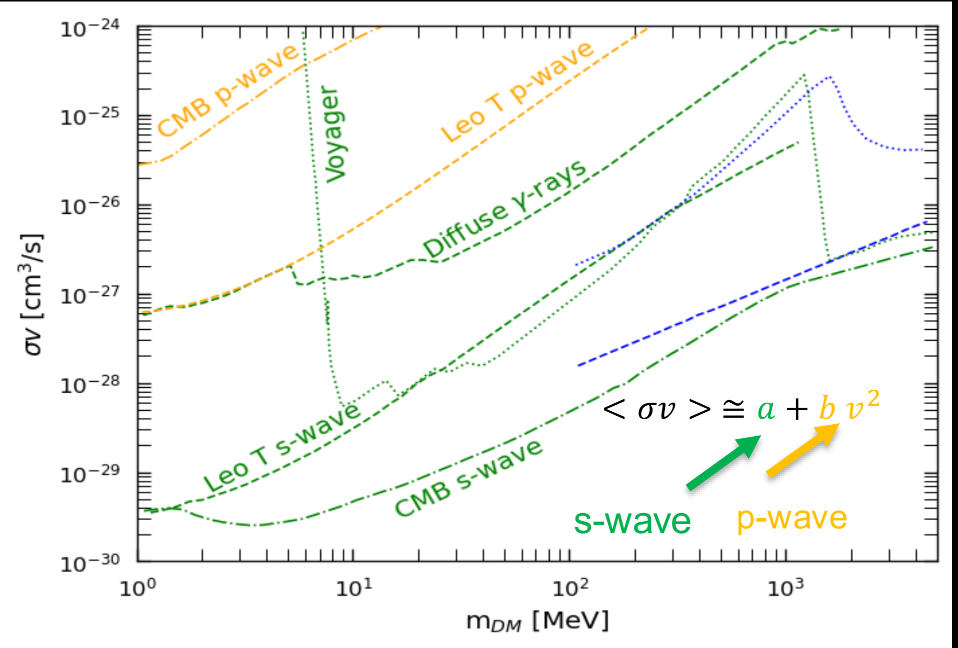


Figure adapted from Tatischeff+ arxiv:1805.06435

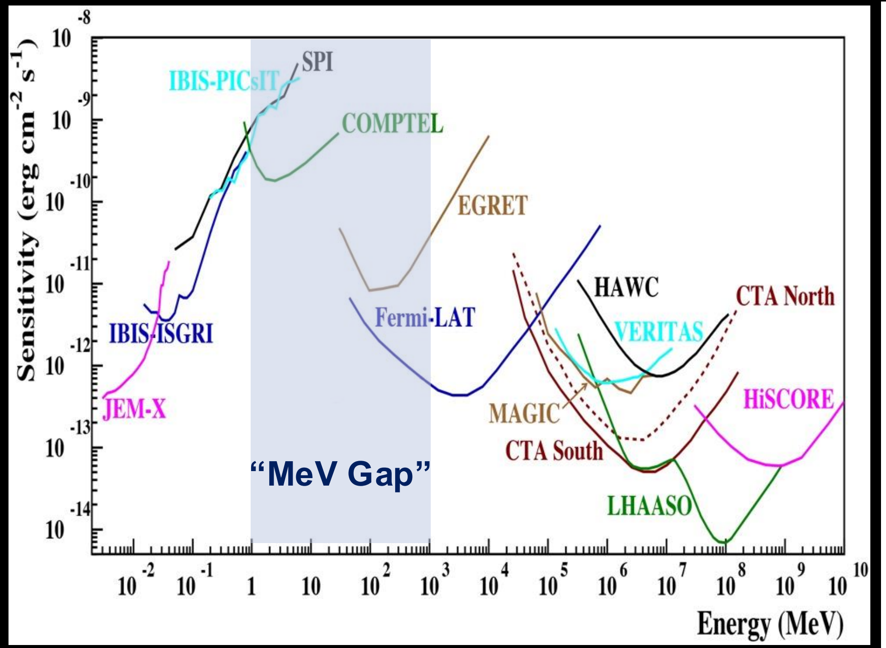


Slatyer, PRD 93 (2016) 023527 Wadekar et al, *PRD*106 (2022) 7, 075007

Essig+, JHEP 11 (2013) 193 Boudaud et al., PRL. 119 (2017) 021103

See Light Dark Matter Searches by Ashlea Kemp on Tuesday

Sub-GeV Dark Matter



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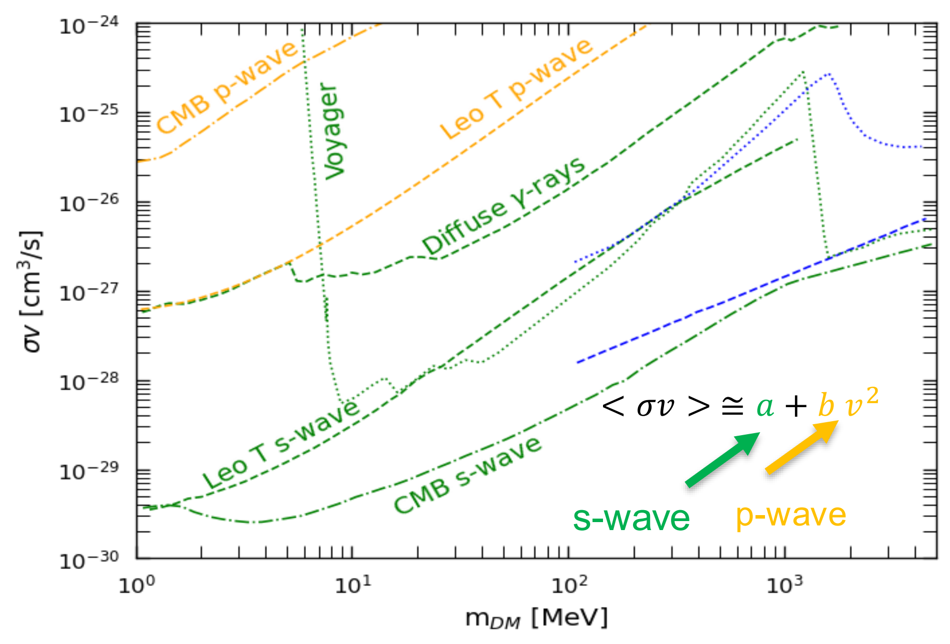


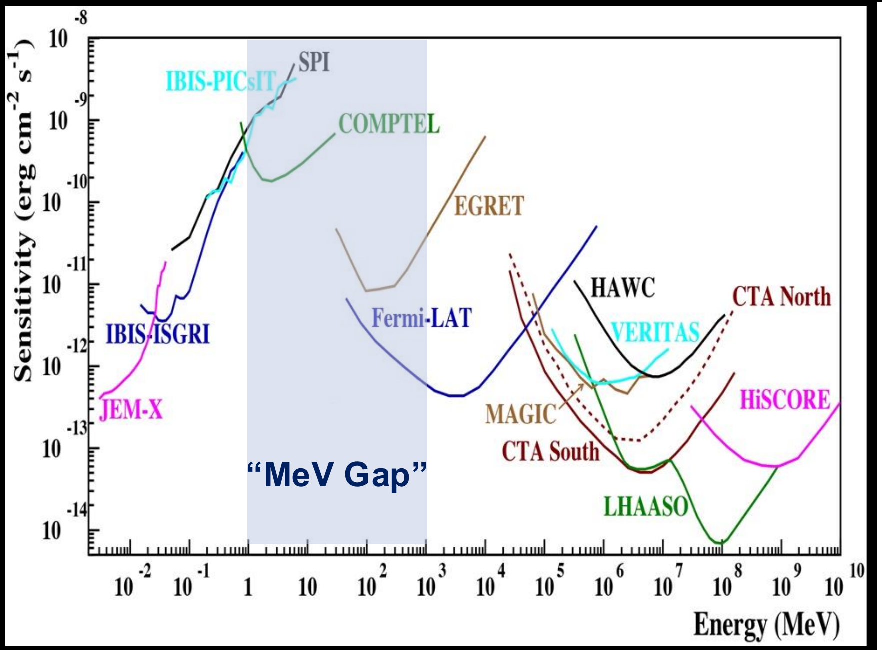
Slatyer, PRD 93 (2016) 023527 Wadekar et al, *PRD*106 (2022) 7, 075007

Essig+, JHEP 11 (2013) 193 Boudaud et al., PRL. 119 (2017) 021103

1. Can we have "unique signatures" of sub-GeV DM?

2. Can we place strong constraints beyond CMB?

Sub-GeV Dark Matter



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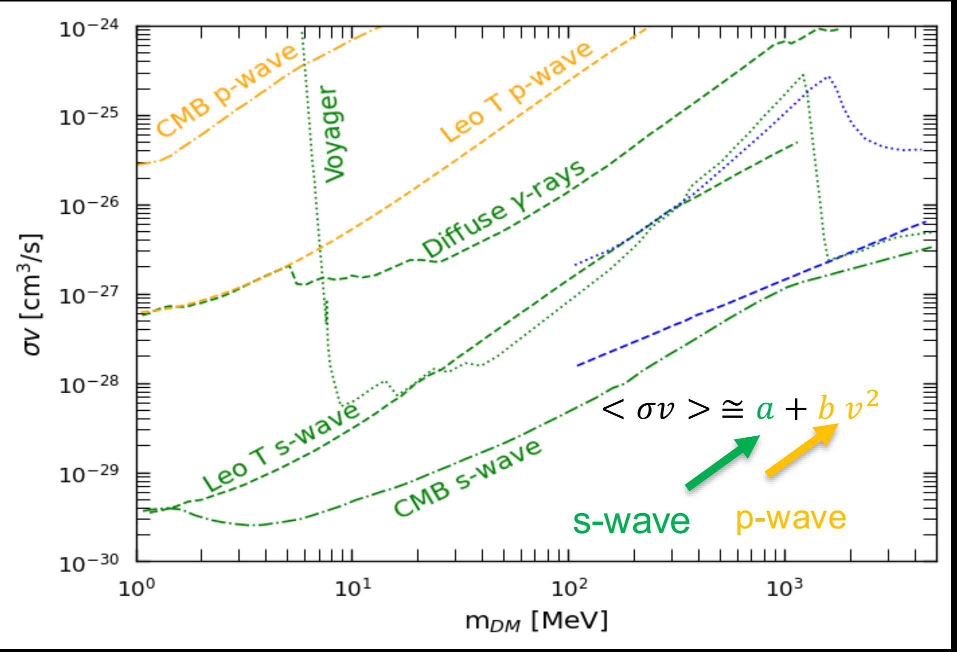

Slatyer, PRD 93 (2016) 023527

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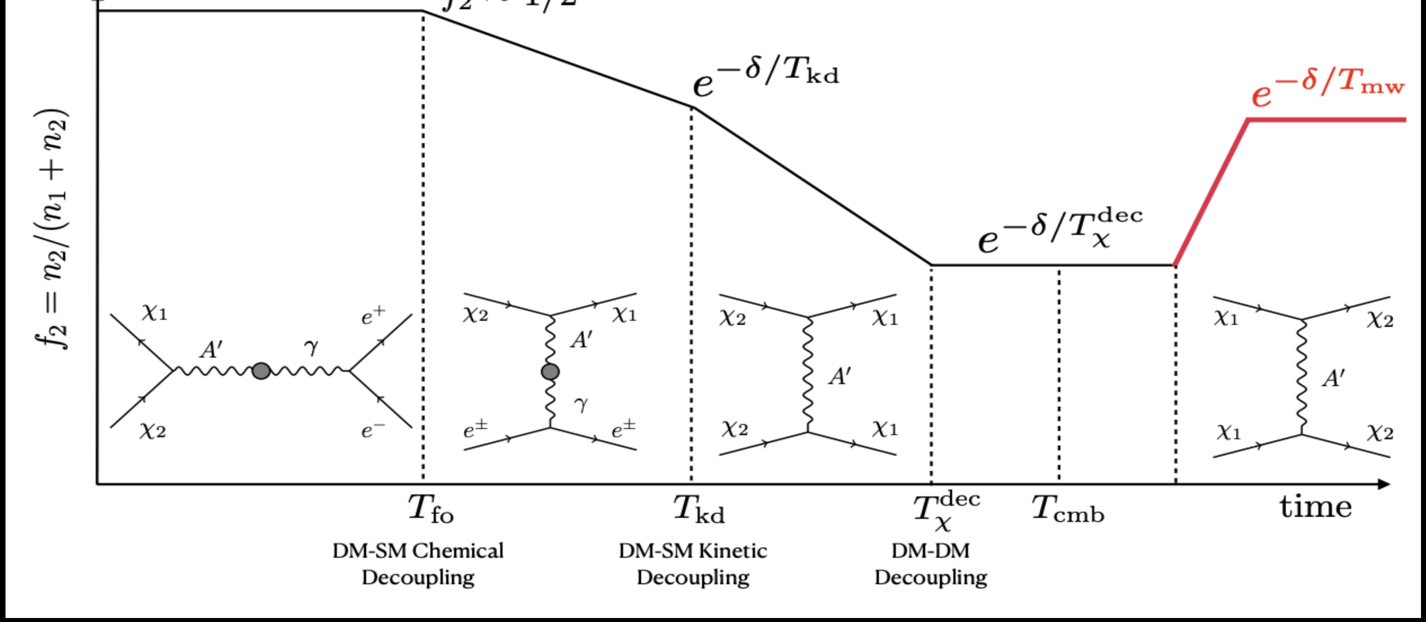
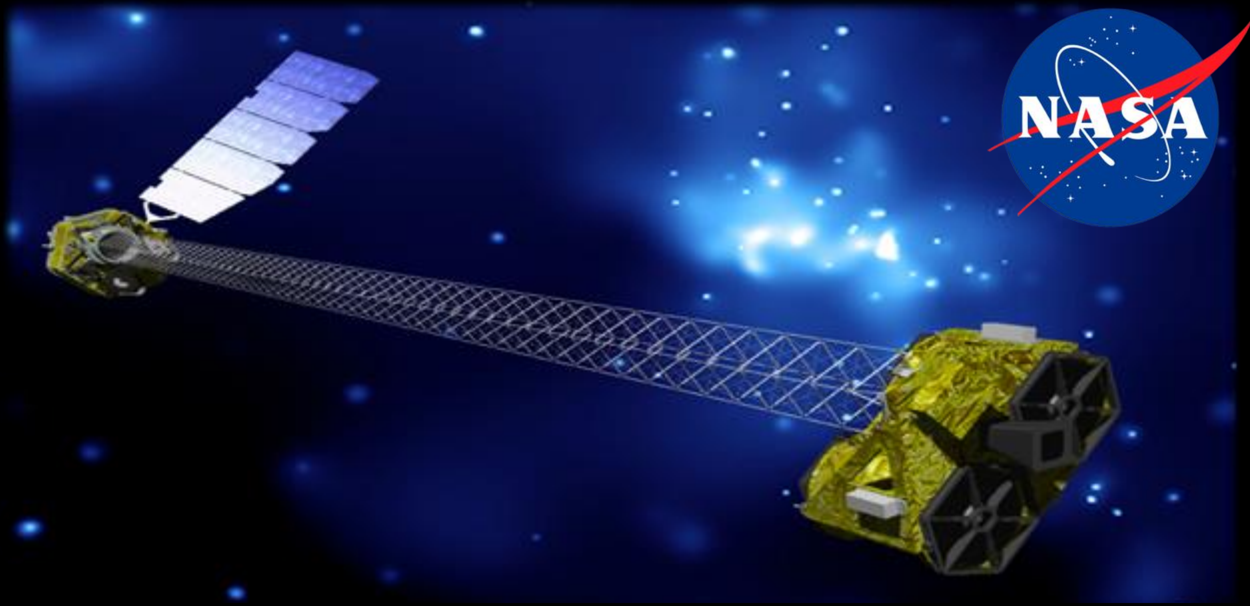
Essig+, JHEP 11 (2013) 193

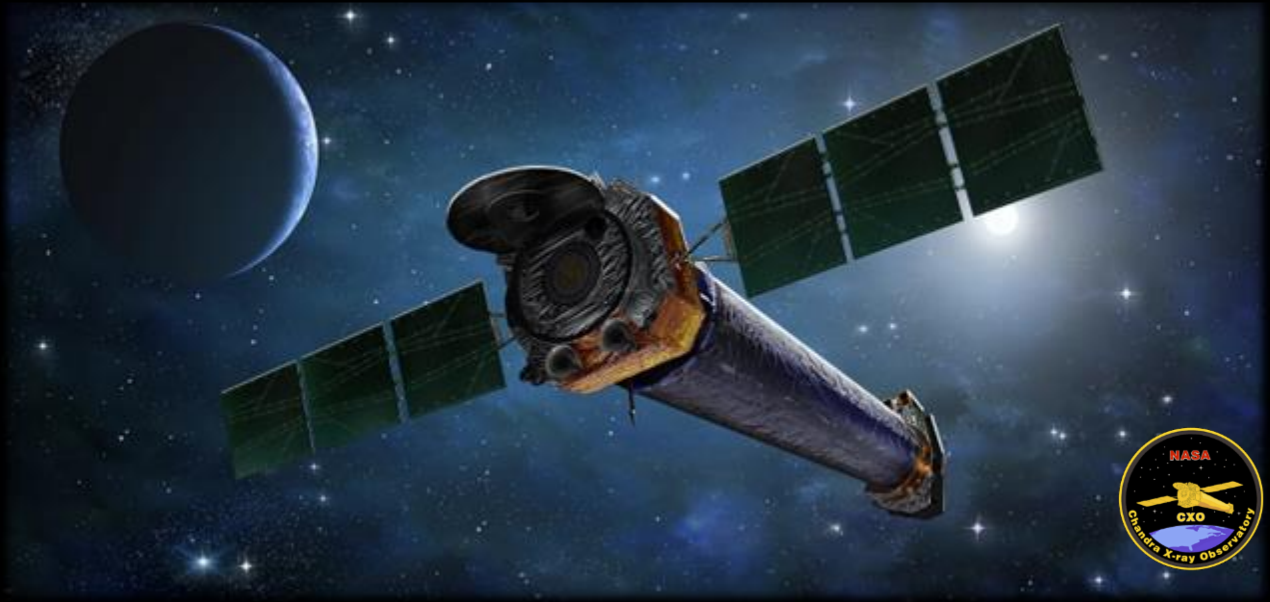
Boudaud et al., PRL. 119 (2017) 021103

Berlin, Krnjaic, **EP**, Phys.Rev.D 110 (2024) 3, 035015

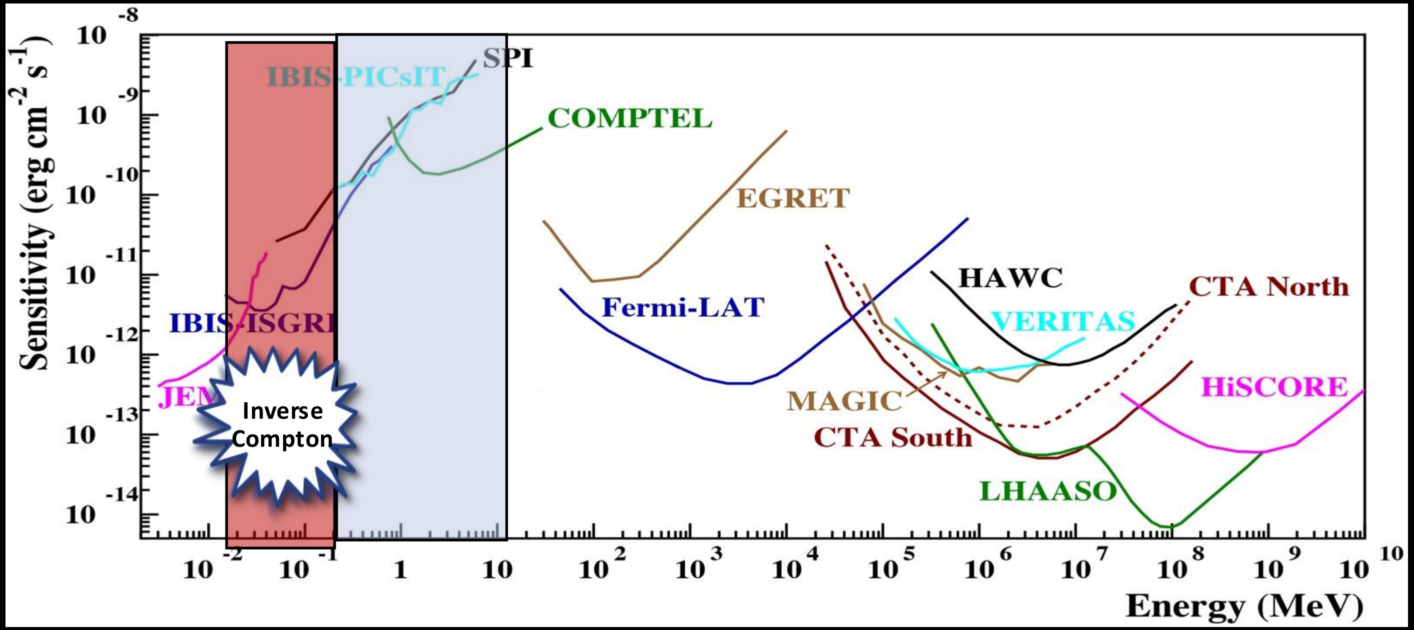




Dark matter searches with X-rays



Sub-GeV Dark Matter



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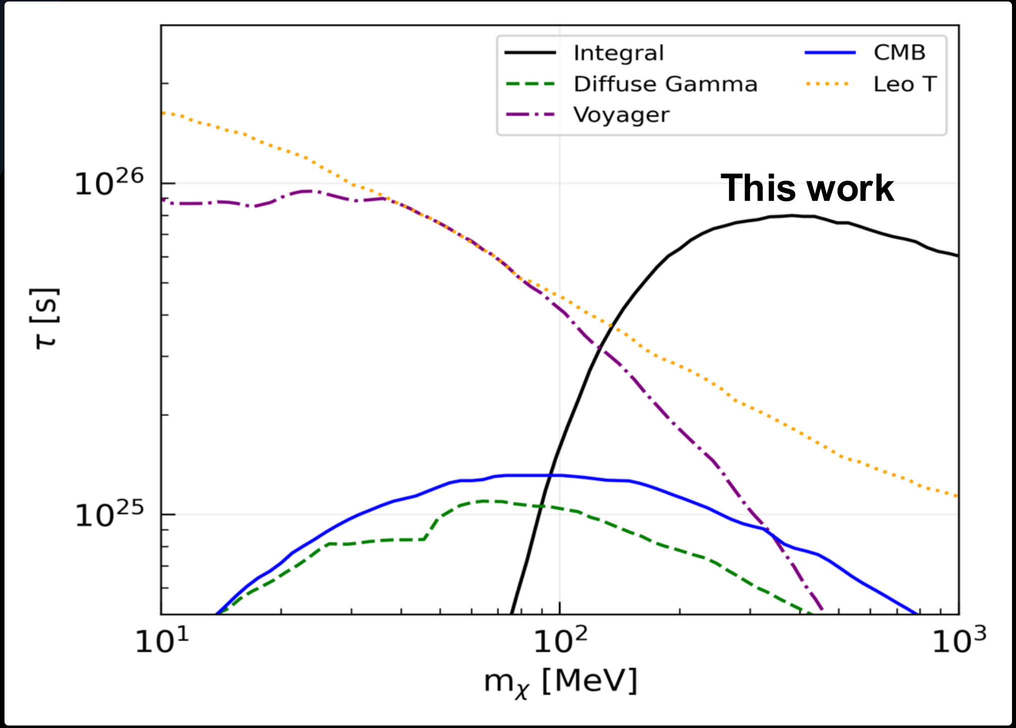
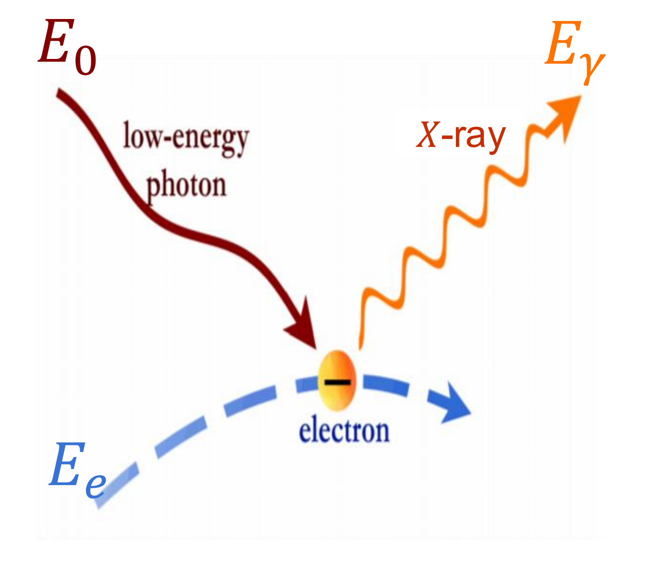
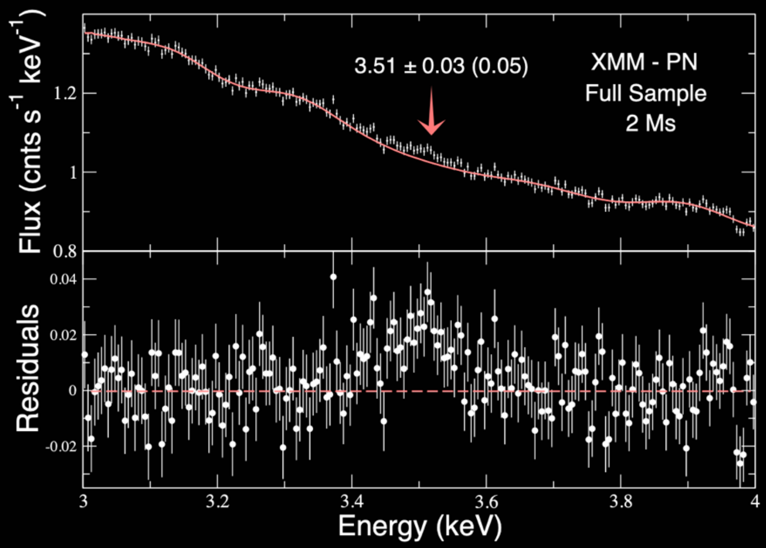


Adapted from Cirelli, Fornengo, **EP**, Roach, JCAP 07 (2023) 026

$$\chi(\chi) \longrightarrow (\ldots) \rightarrow e^{+}\, e^{-}$$



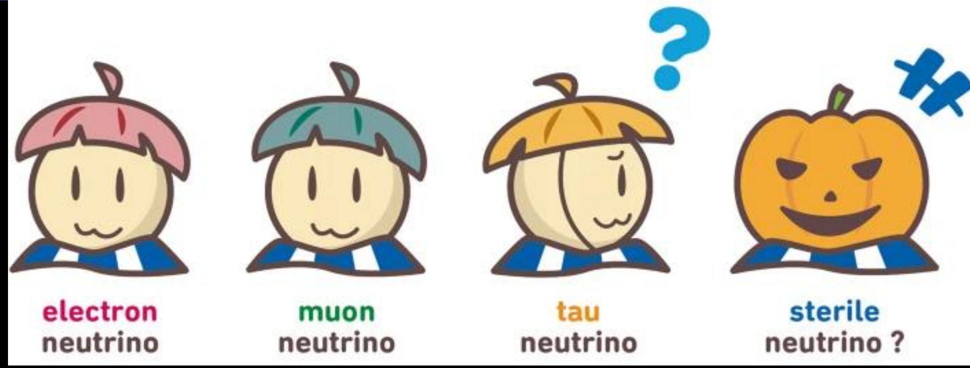
3.5 keV line?

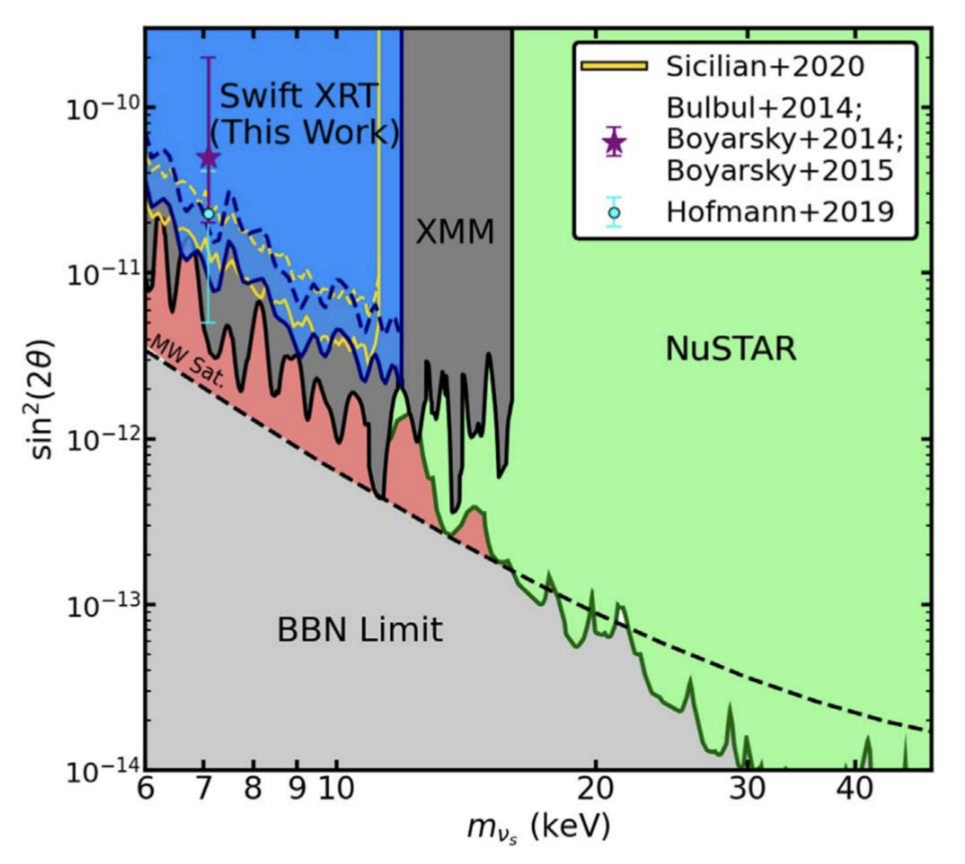


In 2014 two independent groups reported an unidentified line at 3.5 keV with XMM-Newton and Chandra in clusters and M31

Boyarsky et al, PRL 113, 251301

Bulbul et al, APJ 789, 13

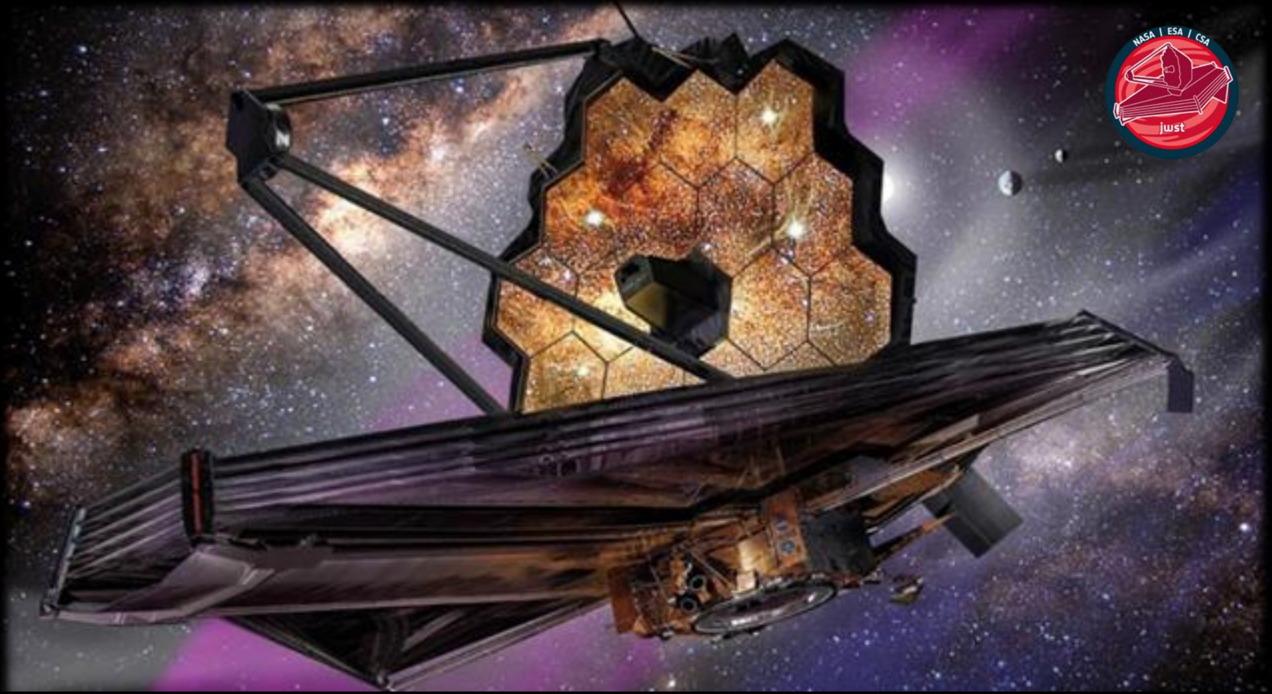




Sicilian et al, APJ 941 (2022) 1, 2

$$\nu_s \longrightarrow \nu + \gamma \qquad \text{with } m_{\nu_s} = 7\ \text{keV}$$

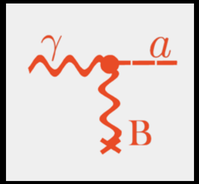
- ❑ Atomic lines (e.g. potassium, sulfur etc) Jeltema et al, MNRAS 450 (2015) 2
- ❑ The existence of the line is highly disputed Dessert et al, APJ 964 (2024) 2,185 1, 2
- ❑ Excluded (except Shi-Fuller mechanism with large lepton asymmetry) Vogel et al, arXiv:2509.05631 Akita et al, arXiv:2507.20659



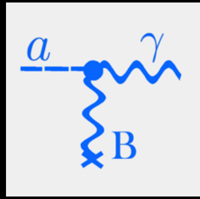
Axion searches with infrared and optical light

Axions at the eV scale

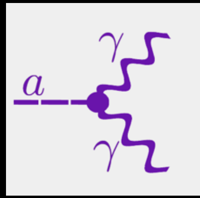
1 Primakoff production in stars: $\gamma \to a$

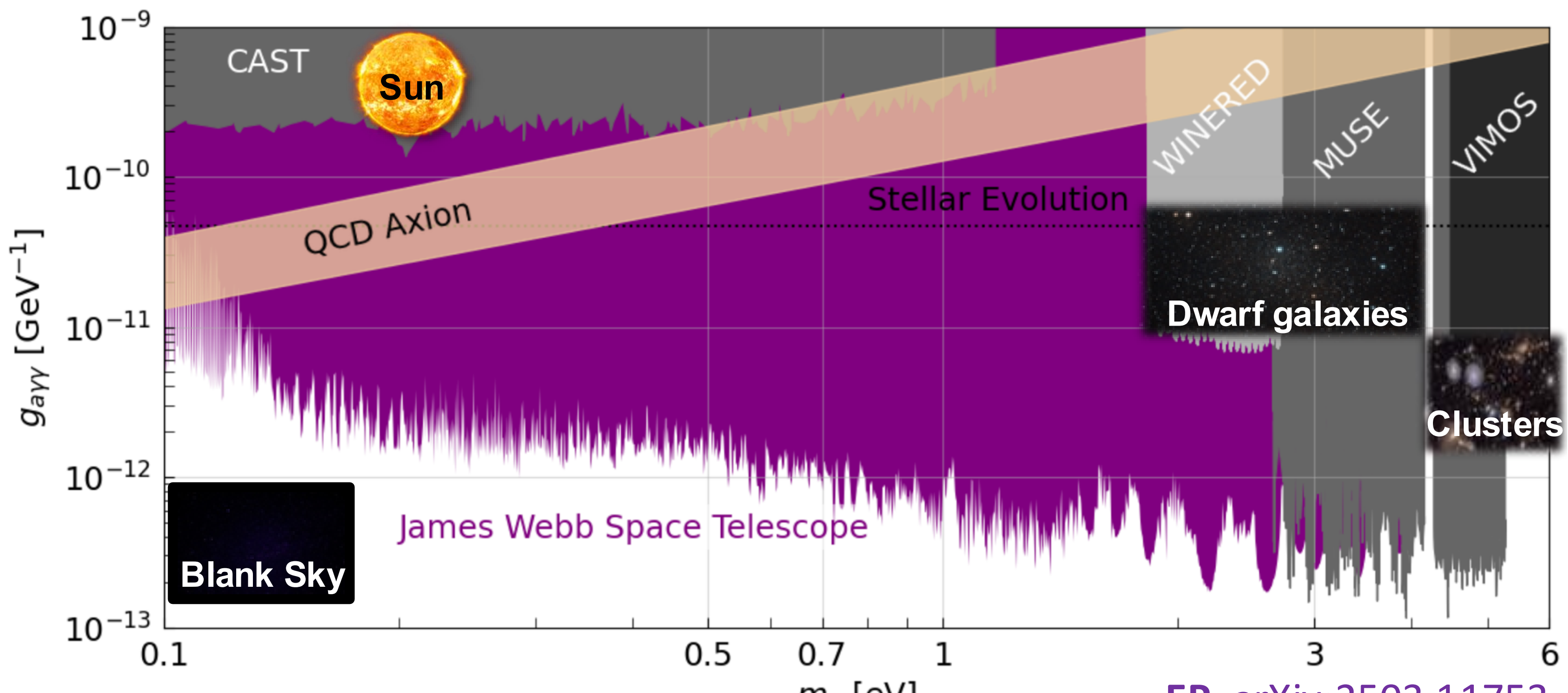


2 Conversion $a \leftrightarrow \gamma$ in laboratory and astrophysical B-fields



3 Axion decay $a \to \gamma\gamma$



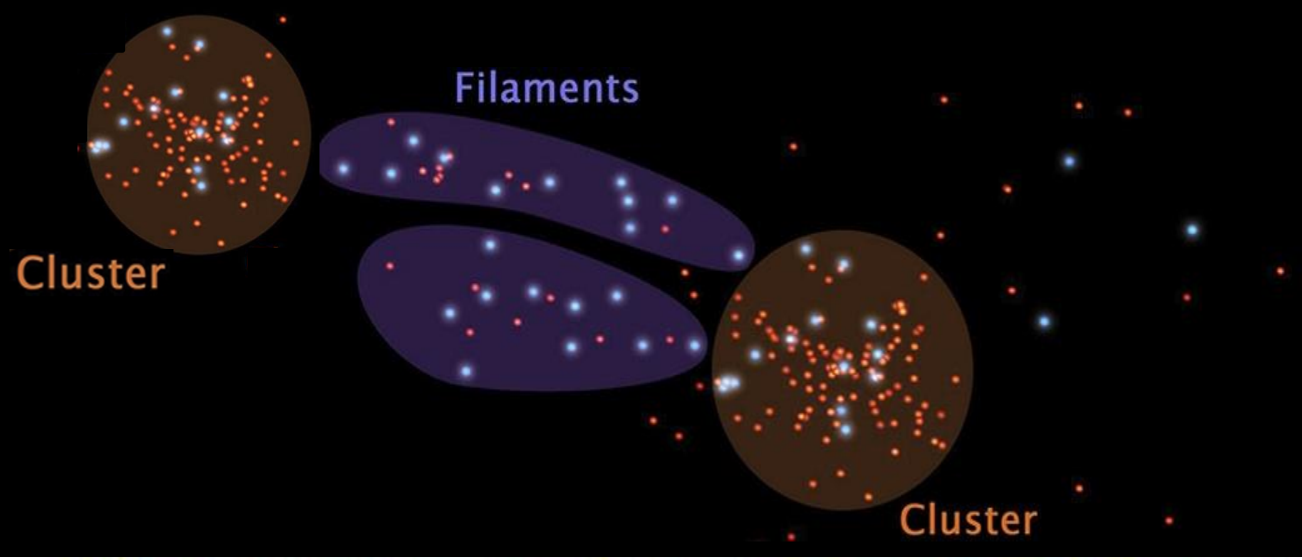


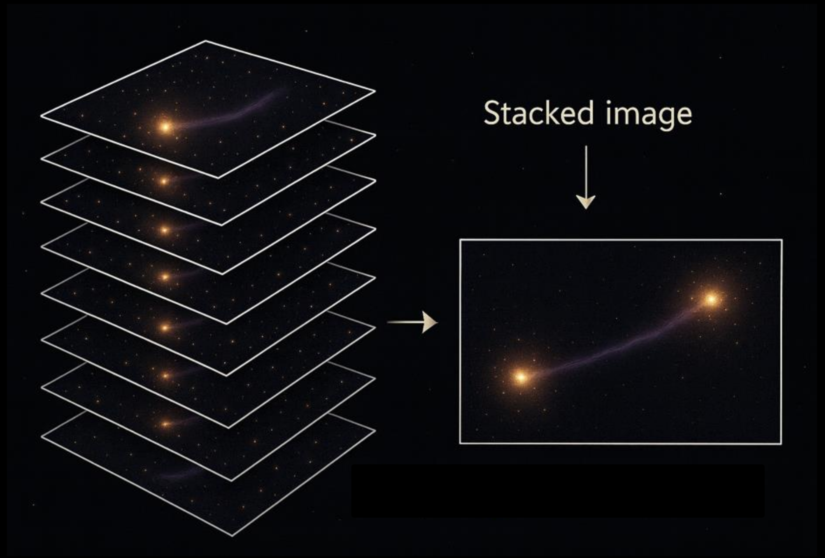
EP, arXiv:2503.11753

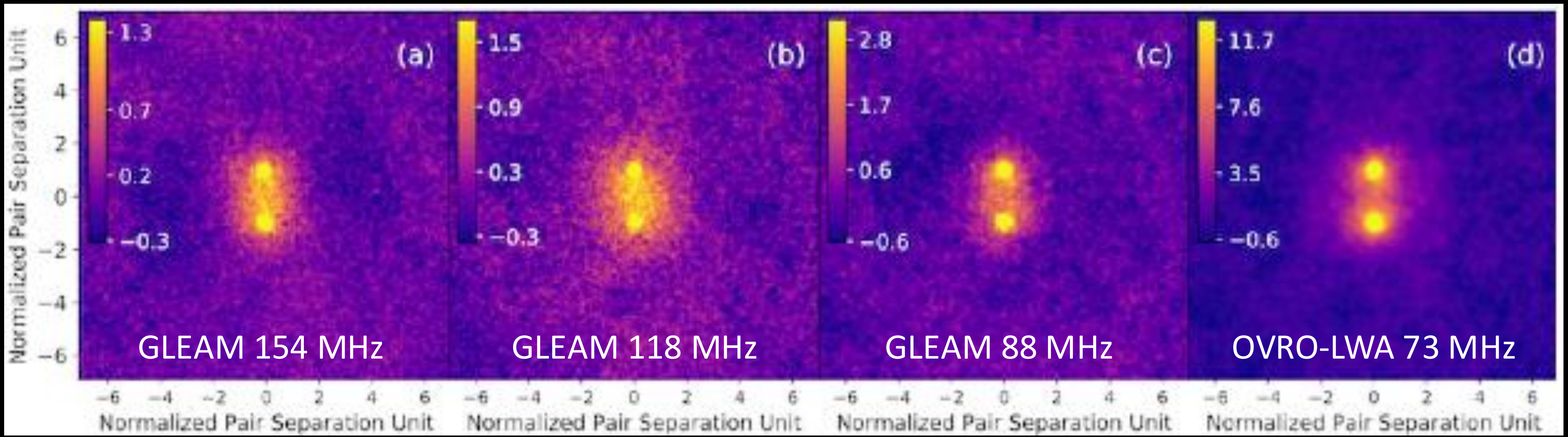
See Axion Dark Matter Overview by Martin Bauer on Tuesday

Radio searches in the cosmic web

Dark matter searches with the cosmic web





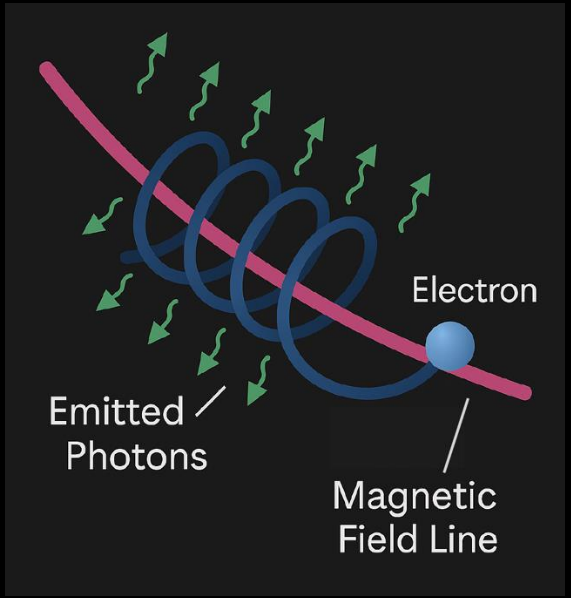


Vernstrom et al (including **EP**), MNRAS 505 (2021) 3, 4178-4196

Dark matter searches with the cosmic web

$$\chi \to e^+ \, e^-$$

Synchrotron radiation



$m_{\mathrm{DM}} = 30$ GeV

$\tau = 2 \times 10^{27}$ s

$B = 30$ nG

Mean DM density profile

ν [MHz]	T_b^{obs} [K]	T_b^{DM} [K]
154	0.10 ± 0.04	0.10
118	0.22 ± 0.06	0.22
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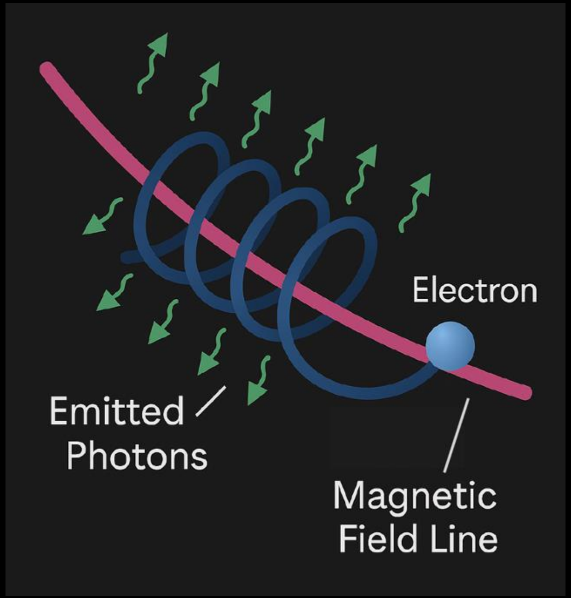

Why haven't we observed this signal elsewhere?

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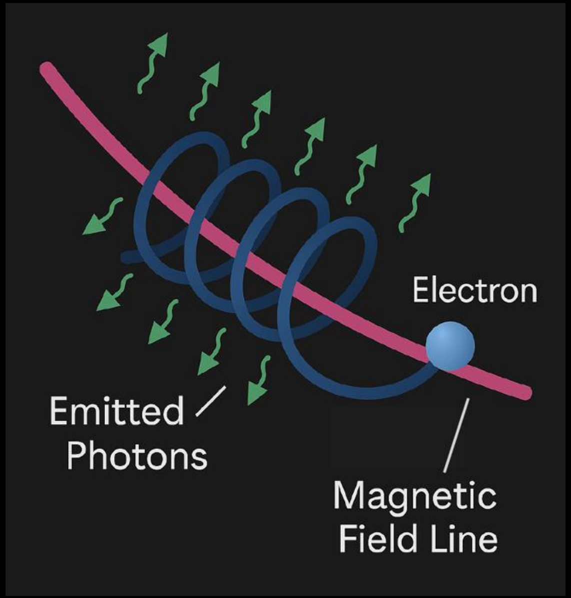

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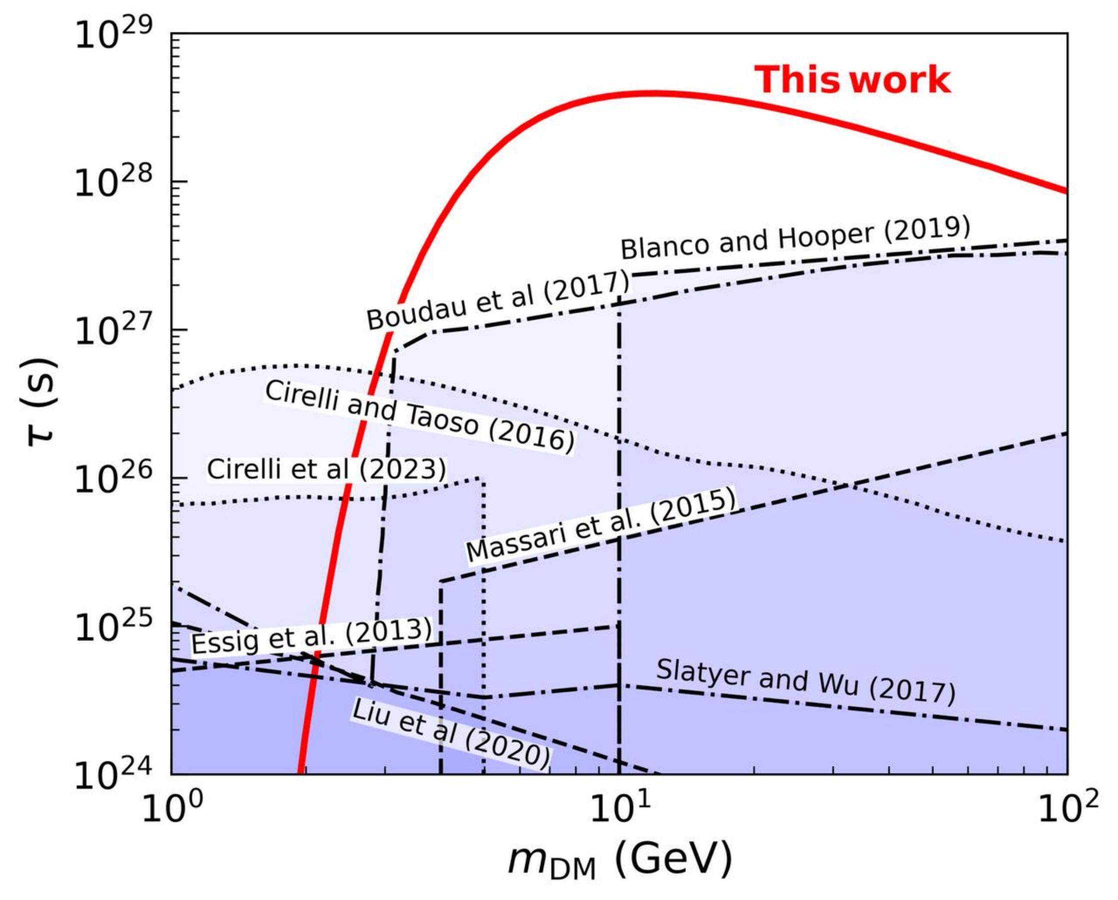
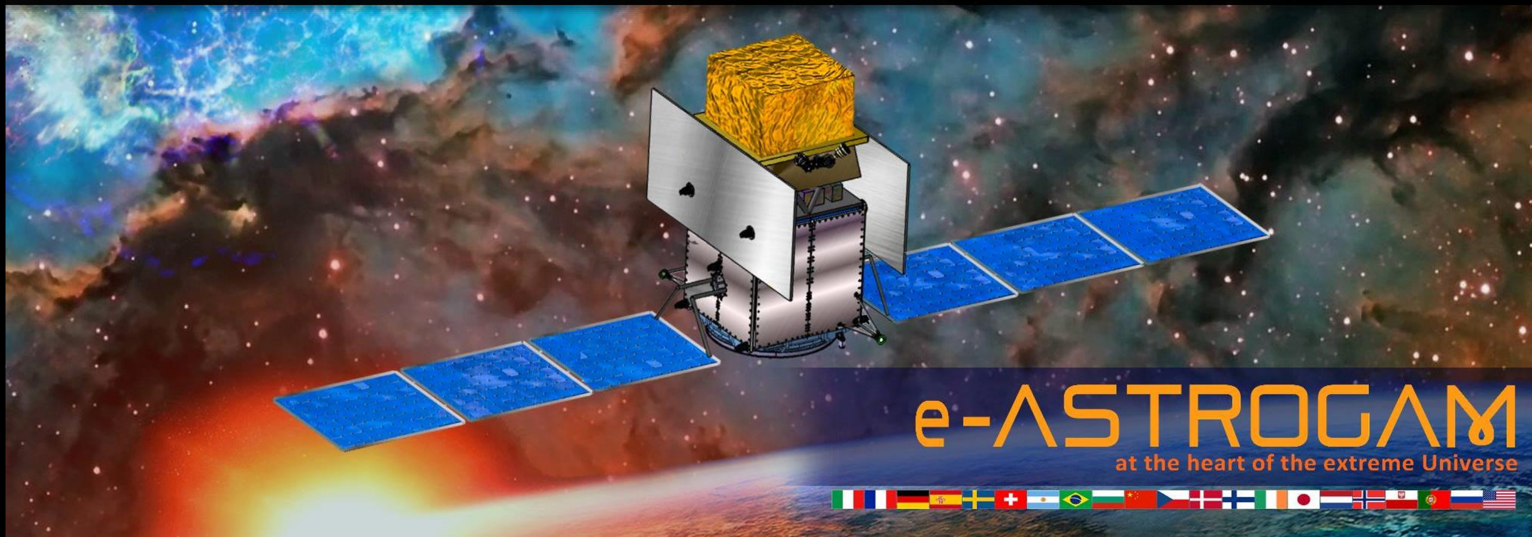


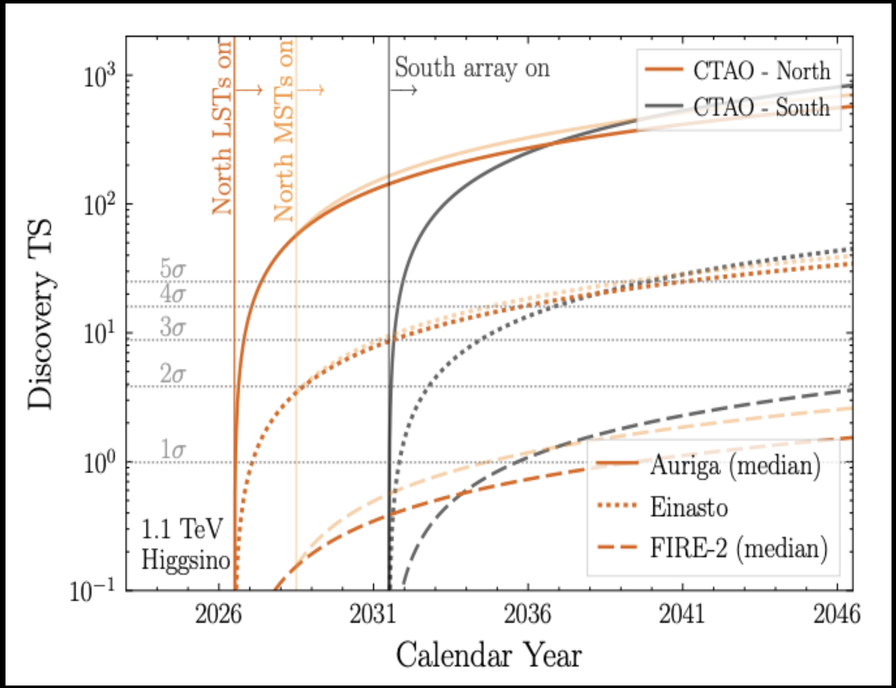
EP, Vienneau, Bozorgnia, arXiv:2504.08025

An eye toward the future

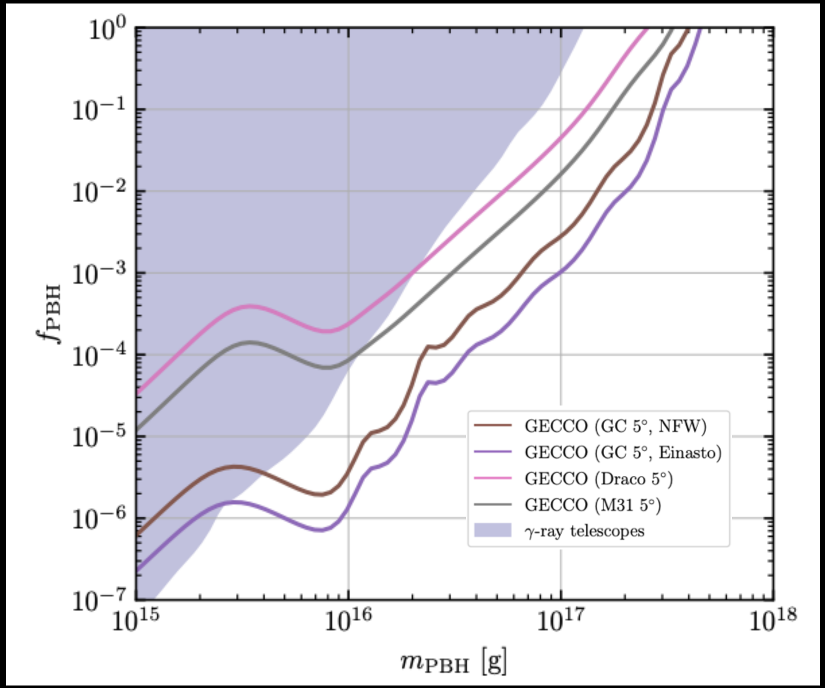
Future gamma-ray searches



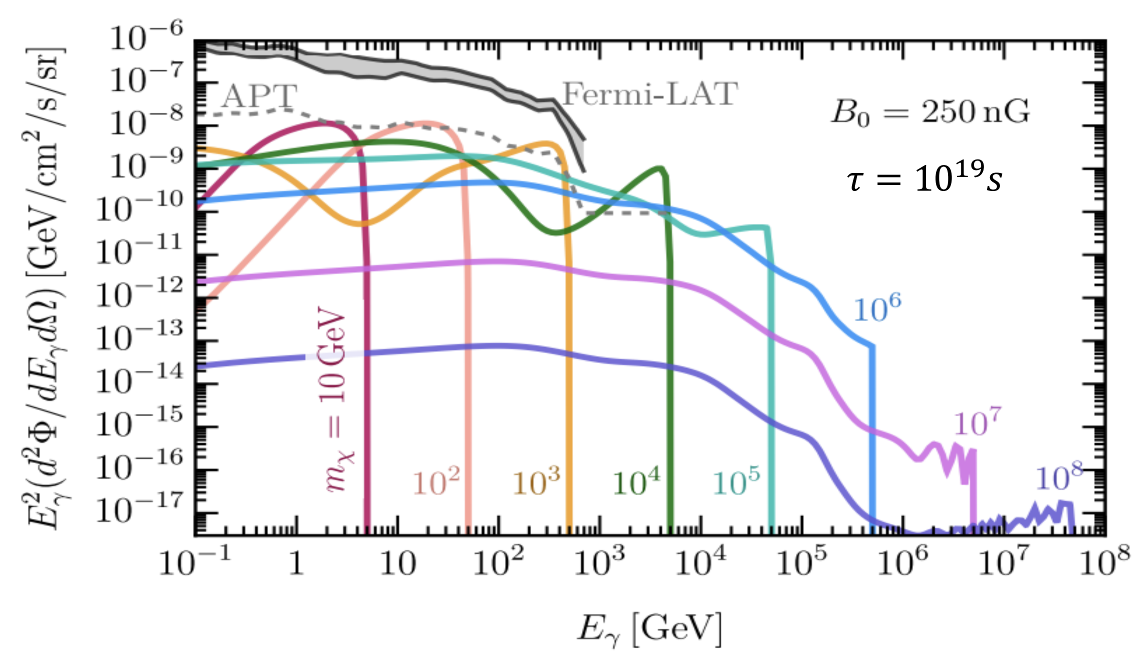
Future γ-ray searches



Abe et al, arXiv:2506.08084



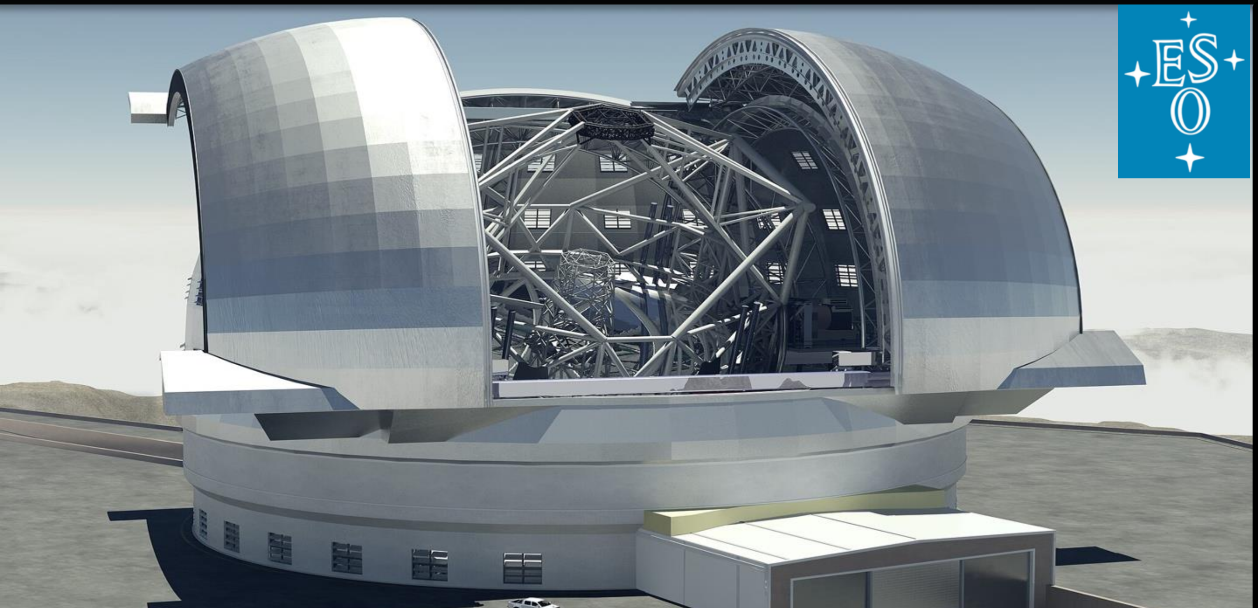
Coogan et al, PRD 107(2), 023022 (2023)



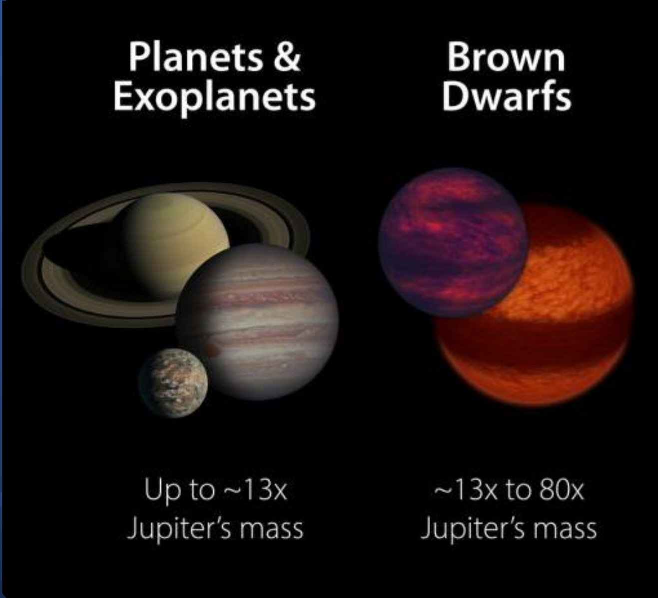
Graviton-Photon Conversion in cosmological filaments produce an irreducible gamma-ray signal

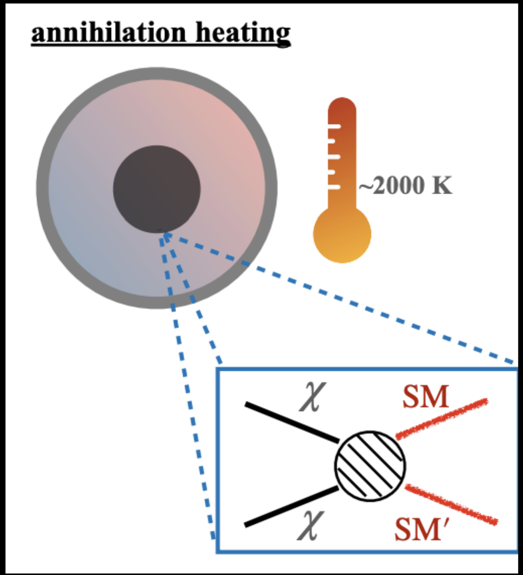
Dunsky, Krnjaic, **EP**, 2503.19019

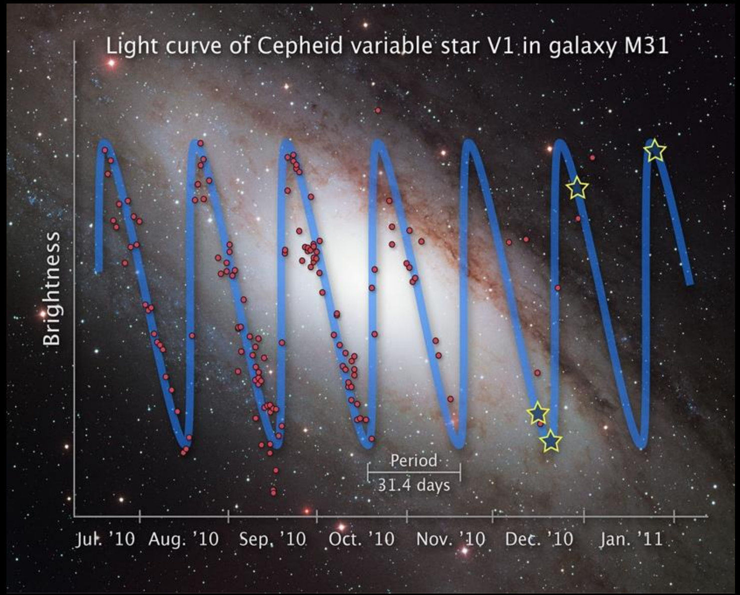
Future infrared and optical searches



Exoplanets & Stars

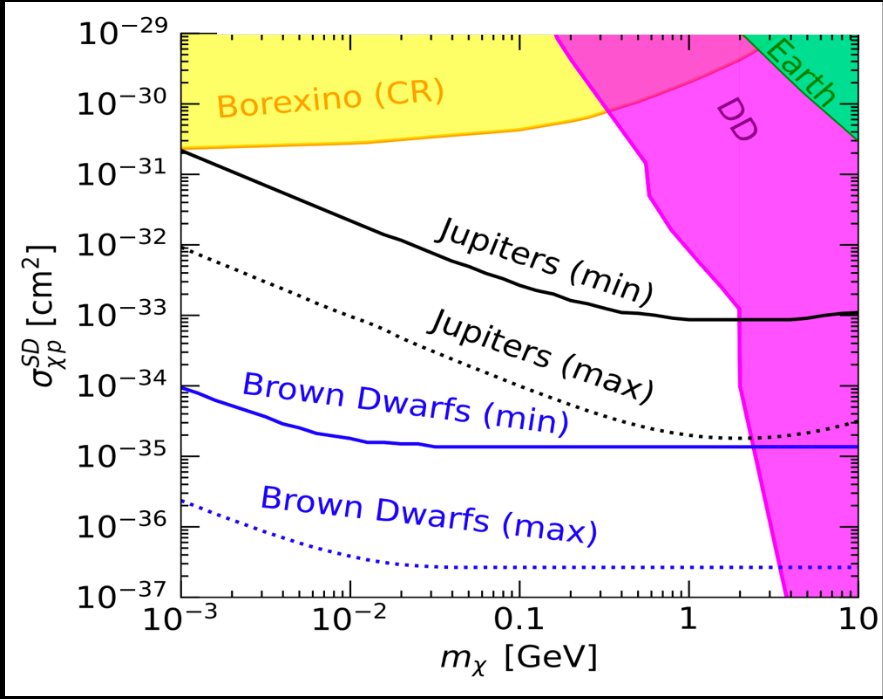




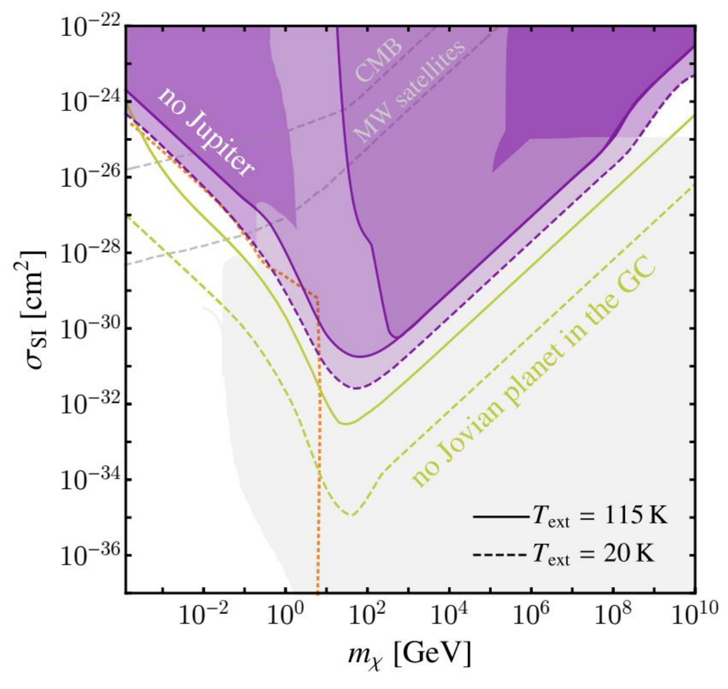


See also white dwarf: McCullough & Fairbairn, PRD 81 (2010) 083520

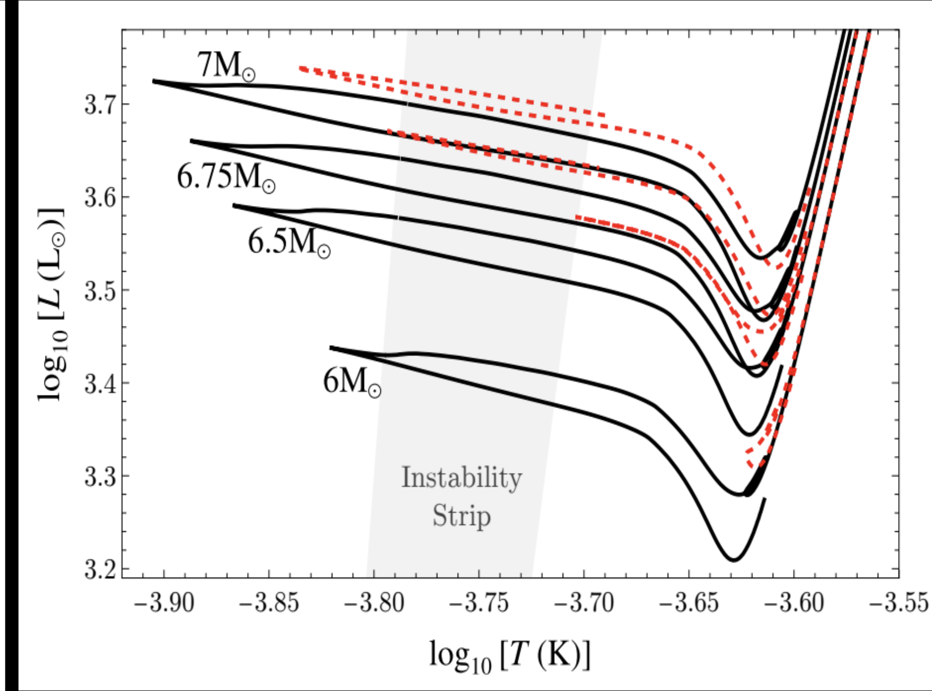
See also Hubble Tension's talk by Di Valentino



Leane & Smirnov, PRL 126 (2021) 16, 161101



Croon & Smirnov, JCAP 11 (2024), 046



Croon et al, arXiv:2510.02641

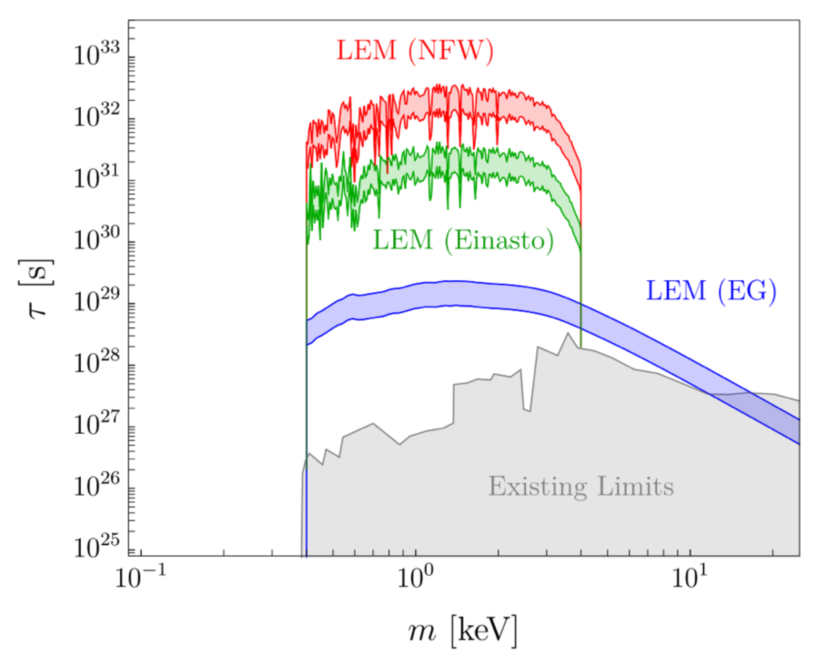

LEM
LINE EMISSION MAPPER


RNO-G
Radio Neutrino Observatory - Greenland

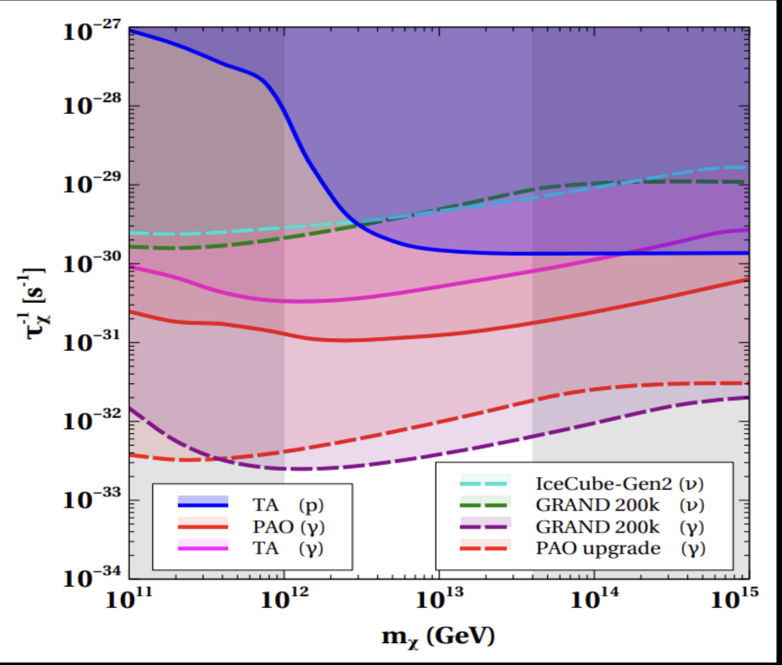

GENERAL ANTIPARTICLE SPECTROMETER
GAPS
NASA · JAXA · INFN


SKAO

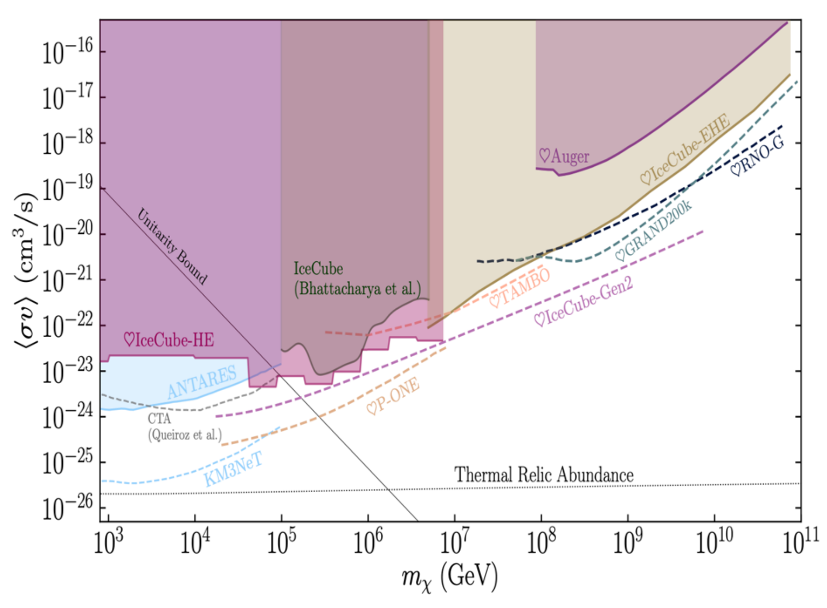
X-rays, neutrinos and cosmic rays



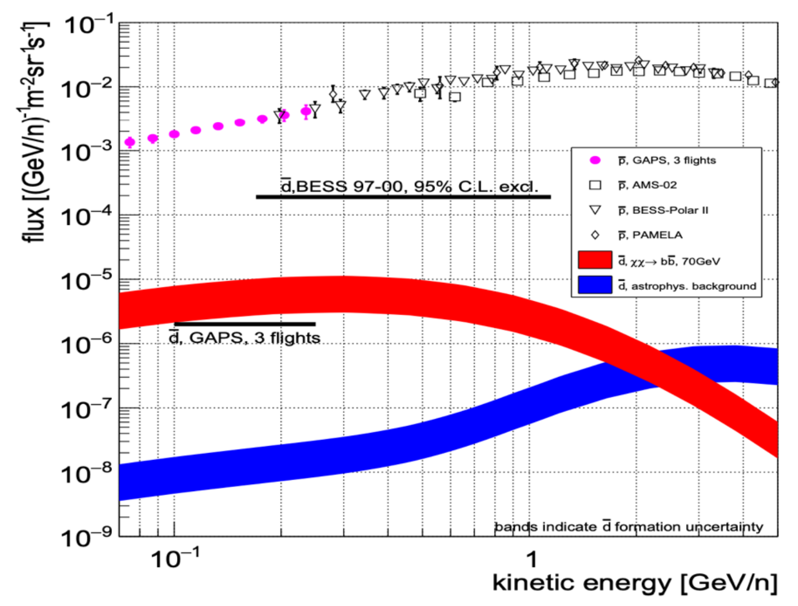
Krnjaic & **EP**, PRD 109 (2024) 9, 095027



Sarmah et al, PRD 111 (2025) 8, 083048

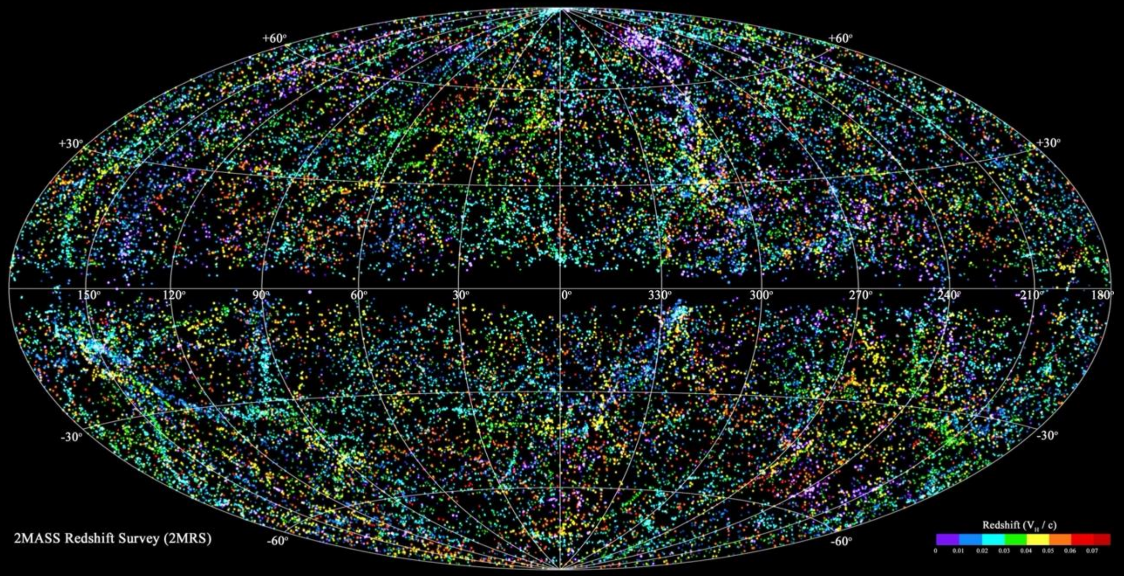


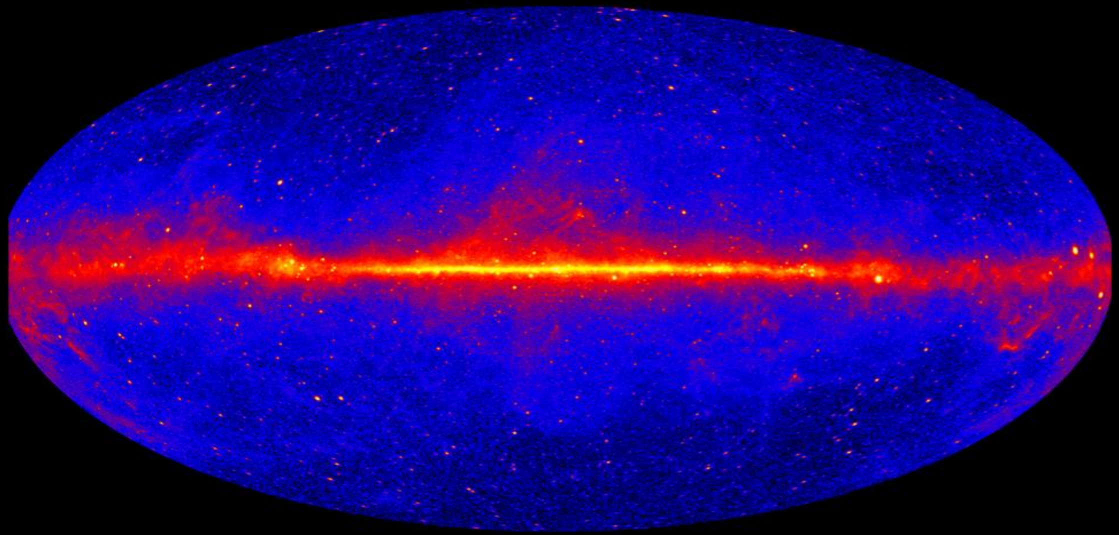
Arguelles et al,Rev. Mod. Phys. 93 (2021) 3, 035007



GAPS Collab, arXiv:2310.10181

Observational Synergies





Gravitational tracers

Galaxy catalogues

Clusters catalogues

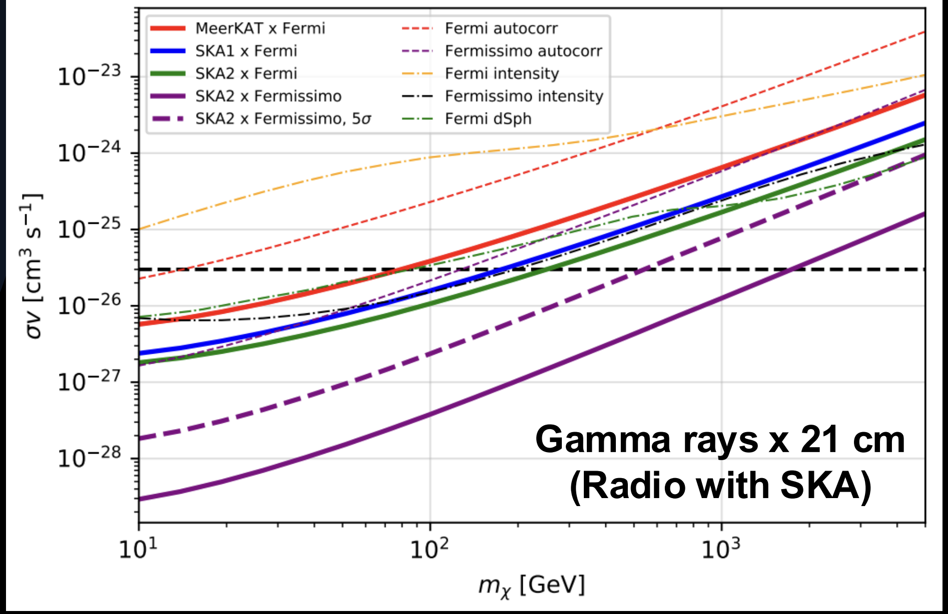
Neutral hydrogen

Weak lensing

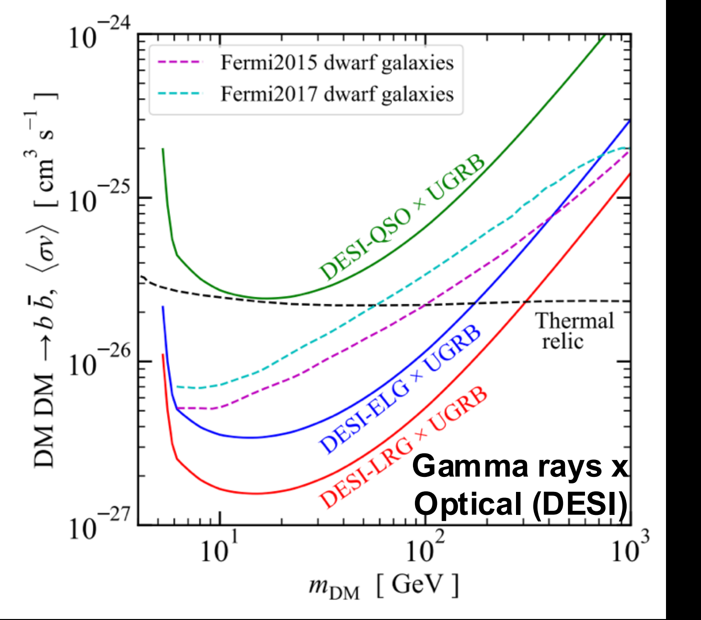
DM signals

- γ rays
- X rays
- IR emission
- Radio waves

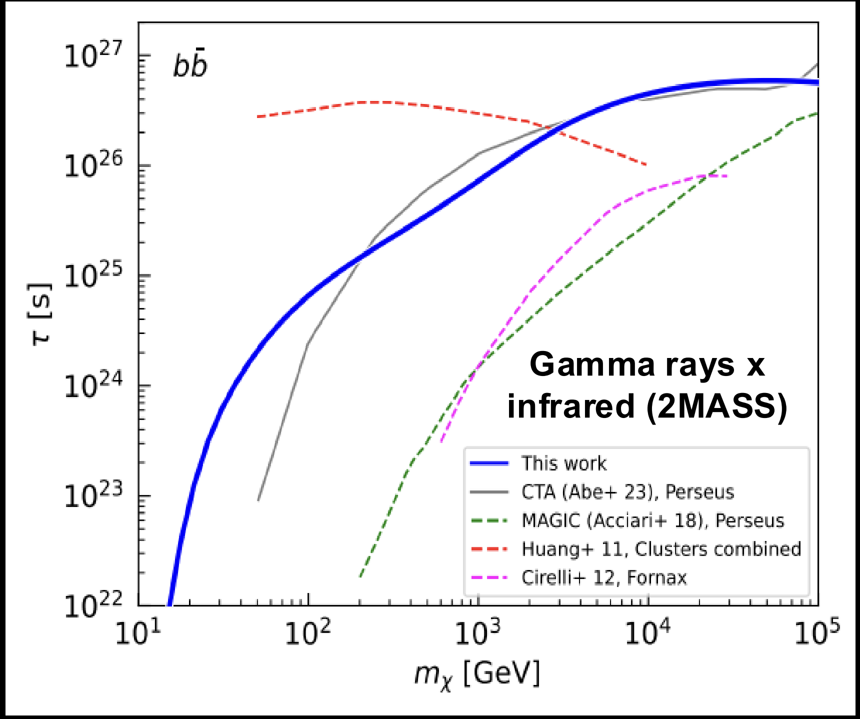
Observational Synergies



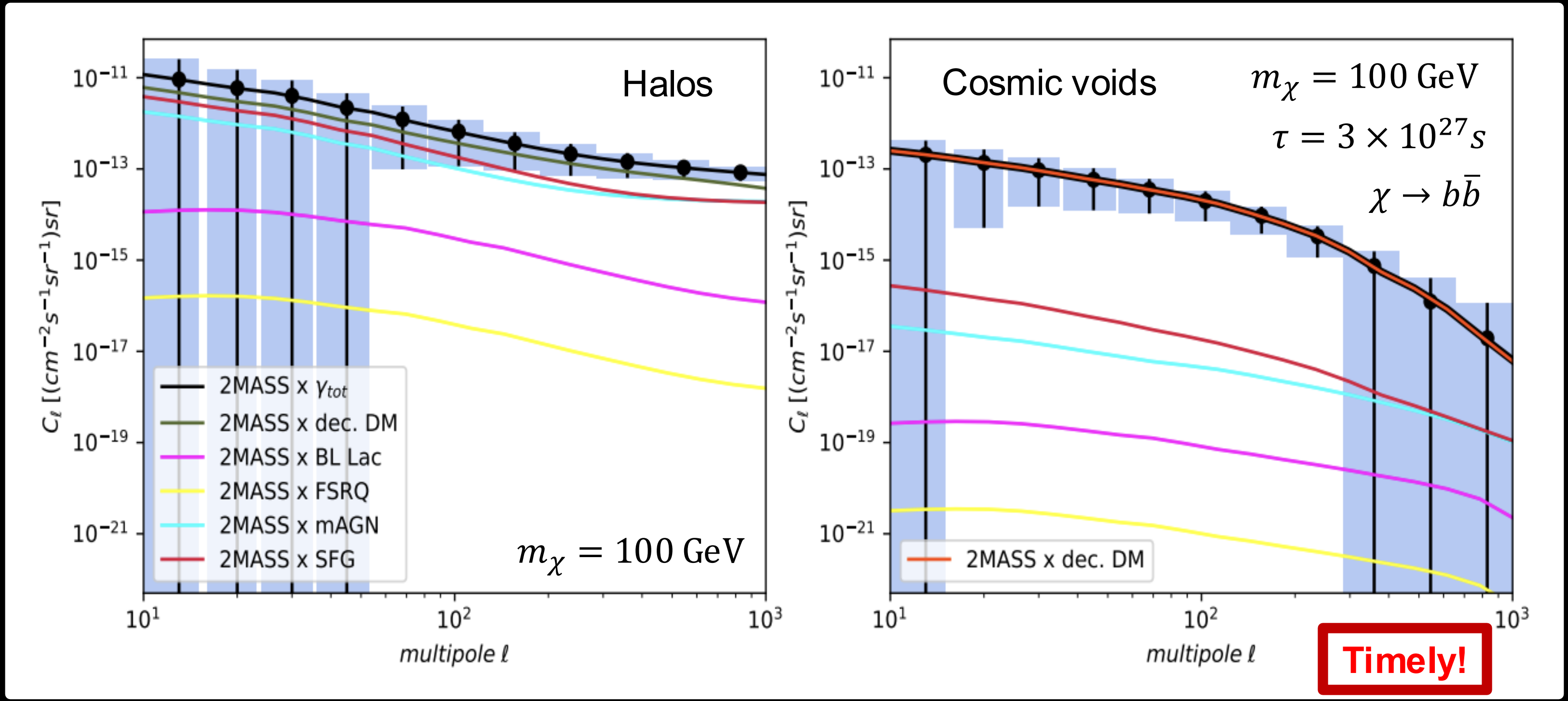
EP et al, JCAP 07 (2020) 044



Zhou, Bernal, **EP** et al, arXiv:2410.00375



EP et al, arXiv:2505.20383



Arcari, **EP**, Fornengo, JCAP 11 (2022) 011

Summary & Conclusions

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2. Vibrant field with new ideas and detection strategies emerging at the intersection of particle physics, cosmology and astrophysics

3. Future prospects are exciting with upcoming telescopes set to deliver unprecedented sensitivity!

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