Searching QCD Axion and Axion-like Particle (ALP) Dark Matter with JWST

Akash Kumar Saha

Based on

arXiv: 2503.14582

AKS, Subhadip Bouri, Anirban Das, Abhishek Dubey, and Ranjan Laha

center for high energy physics

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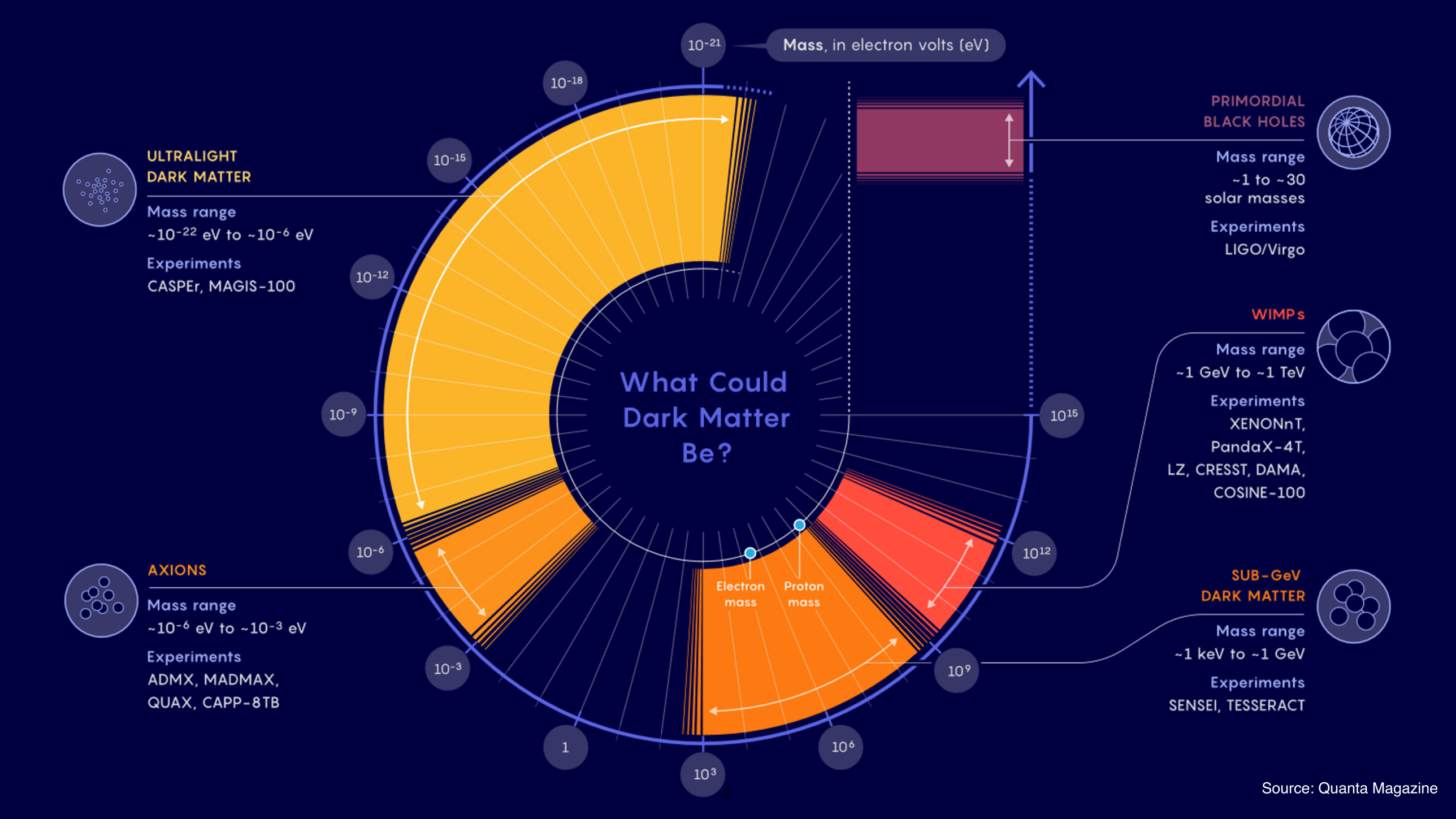
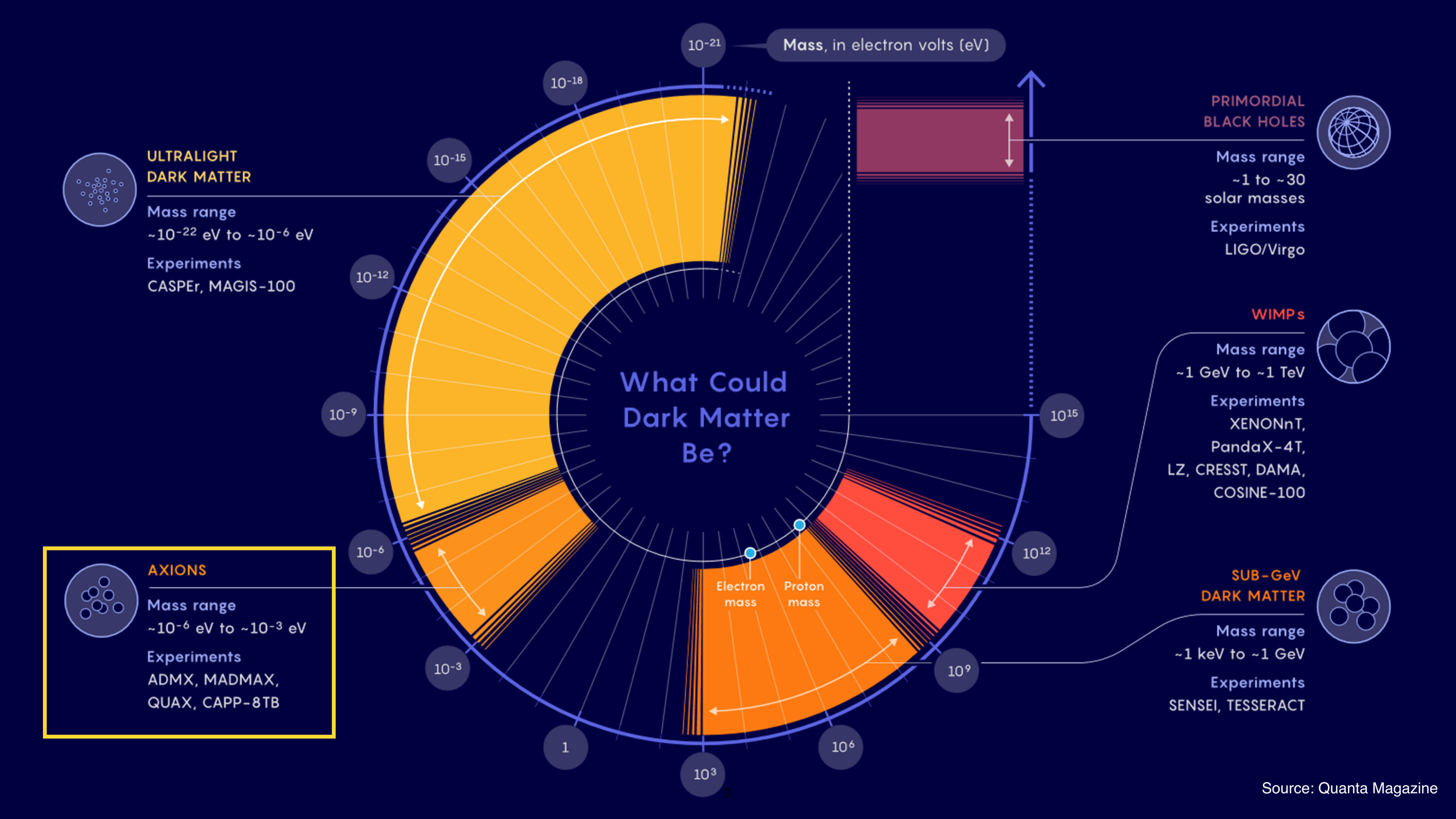


Source: Quanta Magazine



Source: Quanta Magazine

QCD Axion and ALPs

Lecture 3 by Prof. JiJi Fan

Strong CP Problem

↓

Peccei Quinn solution:

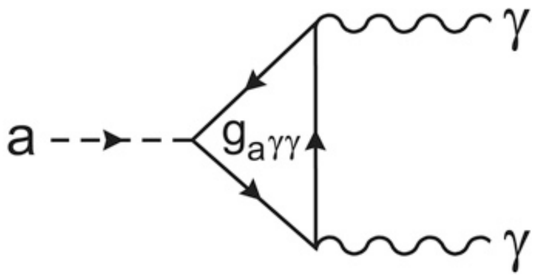
Impose a global U(1) symmetry that makes the theta dynamical → Appearance of QCD axion

Axion-like particles (ALPs):

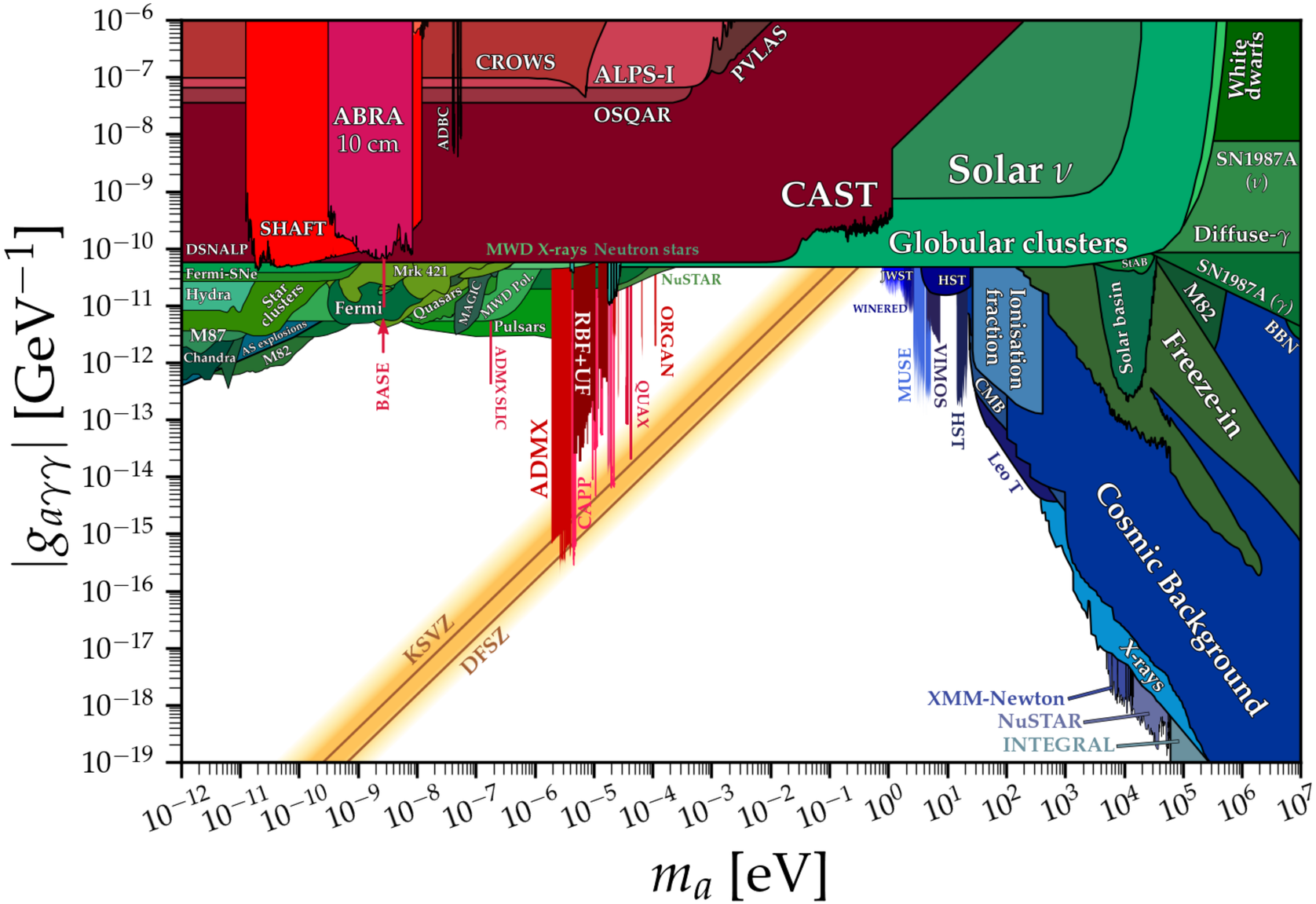
Generic predictions from higher dimensional theories like String theory → Doesn't need to solve the Strong CP problem

Ref: Dark Matter: Evidence, Theory and Constraints, by David J E Marsh, David Ellis and Viraf M Mehta, Princeton University Press

Wide range of parameter space



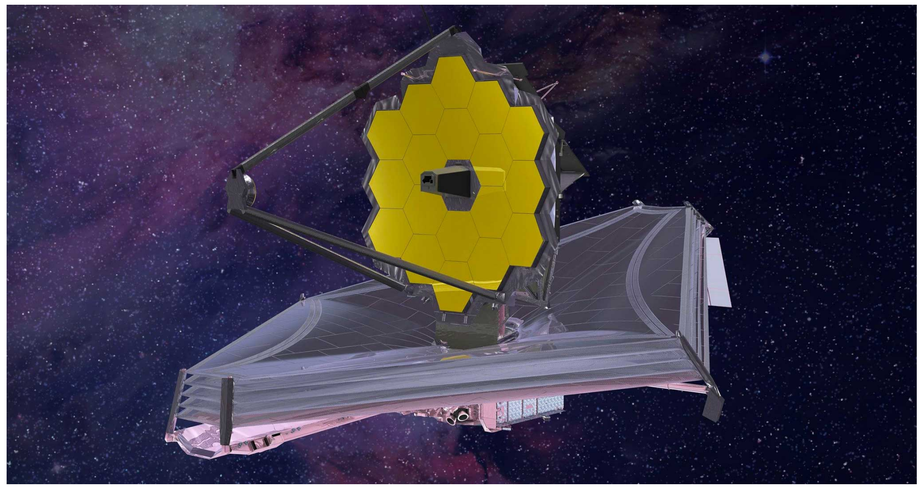
$$\mathcal{L} = \frac{g_{a\gamma\gamma}}{4} a F_{\mu\nu} \tilde{F}^{\mu\nu}$$



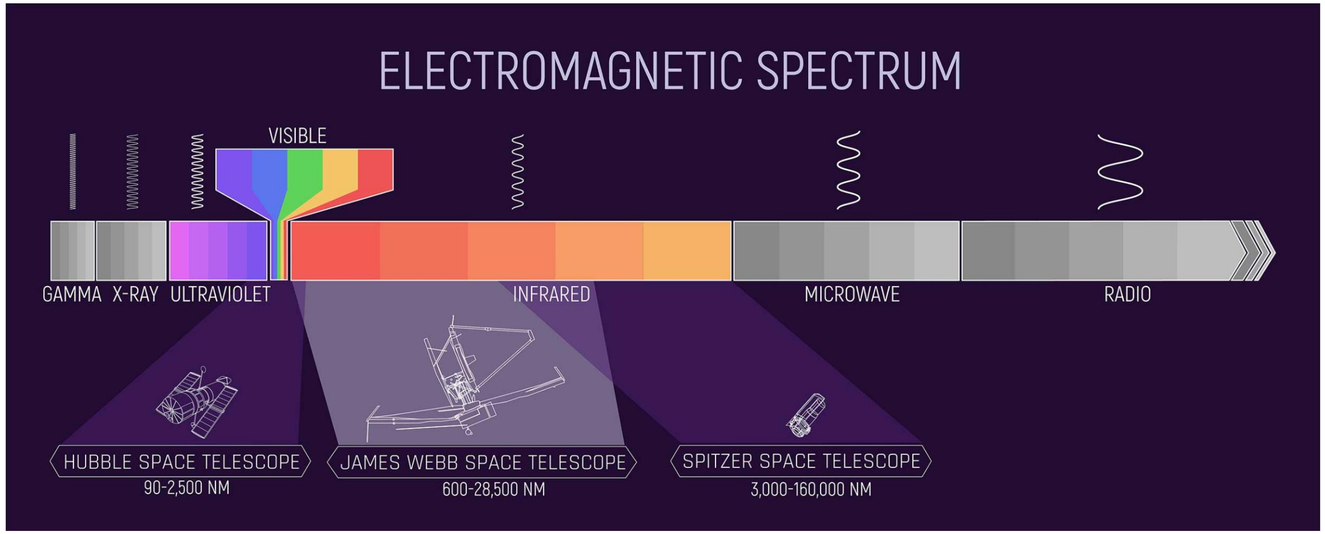
Credit: https://ned.ipac.caltech.edu

Credit: https://github.com/cajohare/AxionLimits

James Webb Space Telescope

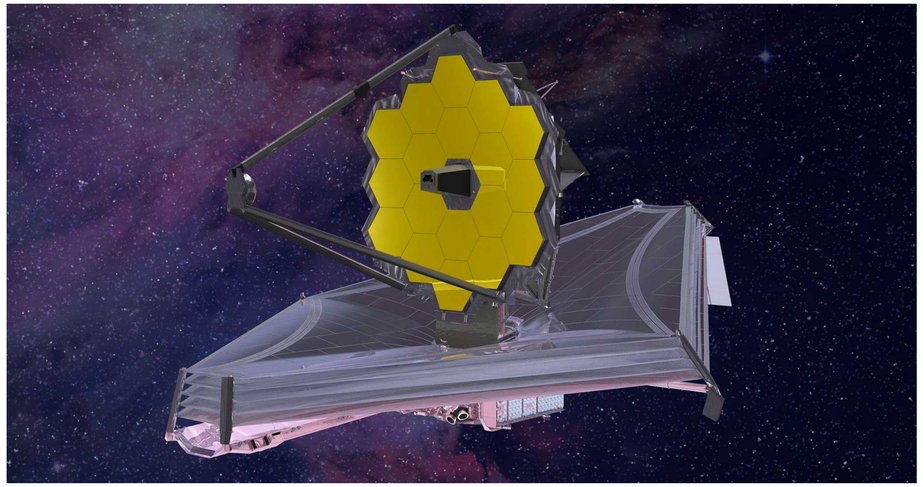


Credit: Northrop Grumman



Credit: NASA and J. Olmsted [STScI]

James Webb Space Telescope



Credit: Northrop Grumman

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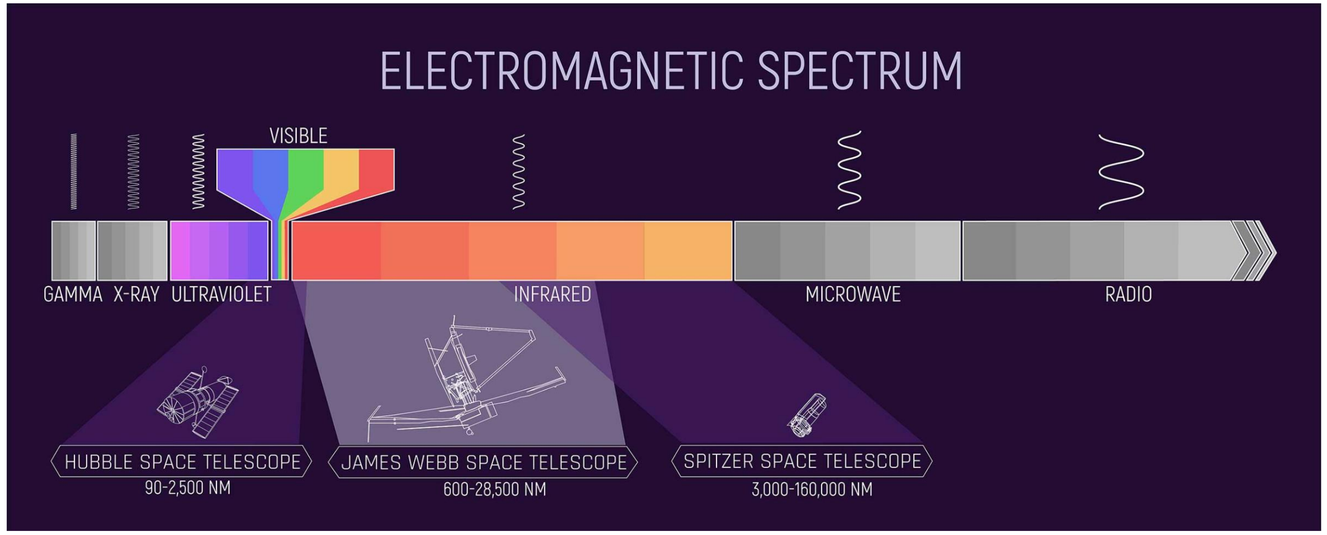
James Webb Space Telescope Finds First Evidence of Einstein Zig-Zag Phenomenon In a Distant Quasar

JWST Captures Unseen Details of Exoplanets in HR 8799 and 51 Eridani Systems



Credit: NASA and J. Olmsted [STScI]

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Photometric detection at 7.7 µm of a galaxy beyond redshift 14 with JWST/MIRI

SPACE.com

James Webb Space Telescope's First Deep Field Image Is Mind-Boggling

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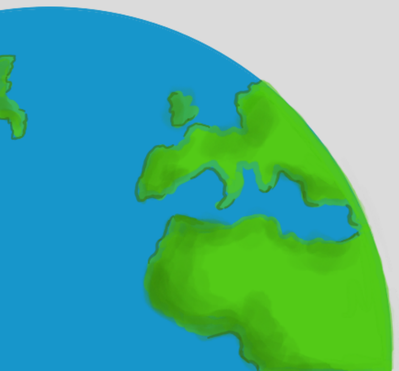
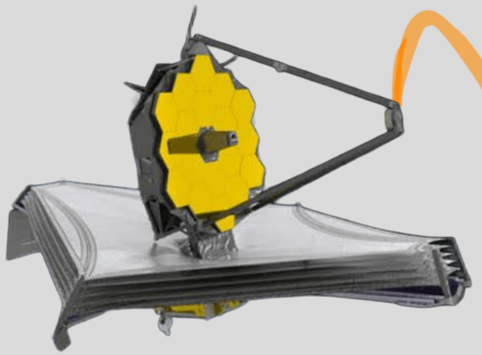
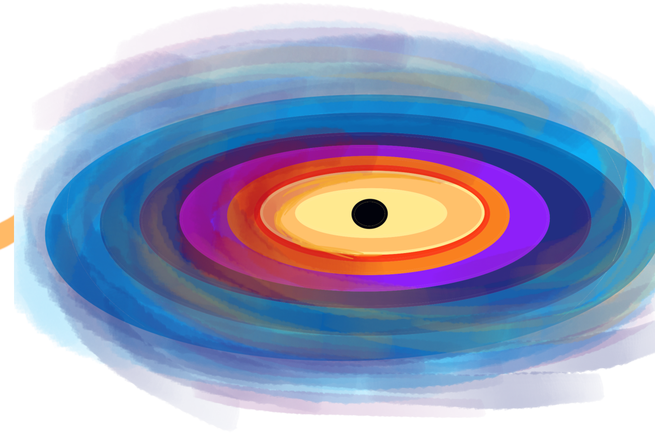
JWST Finds an Unexpectedly Bright and Mature Galaxy

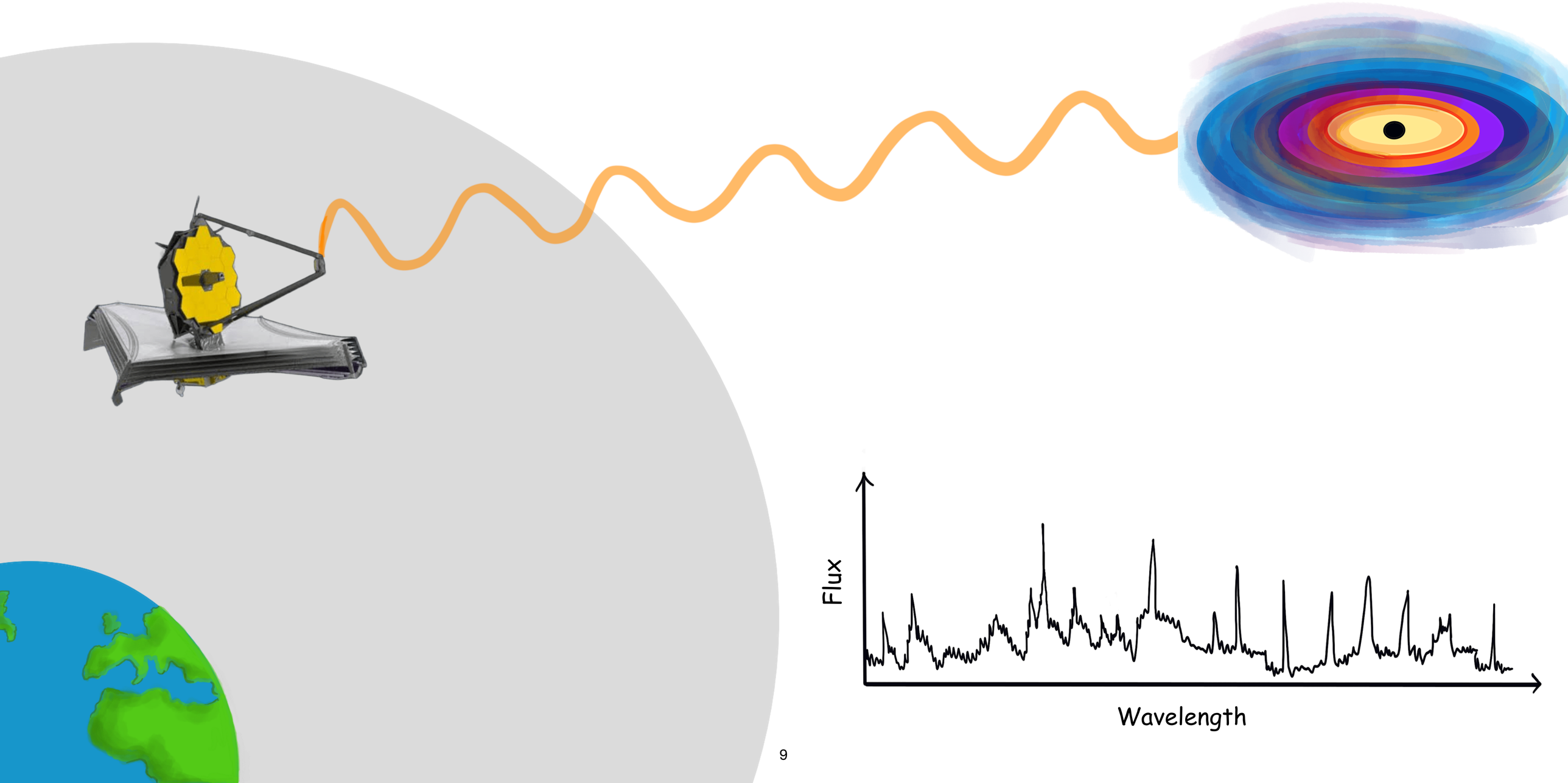
DM hunting with JWST







DM hunting with JWST



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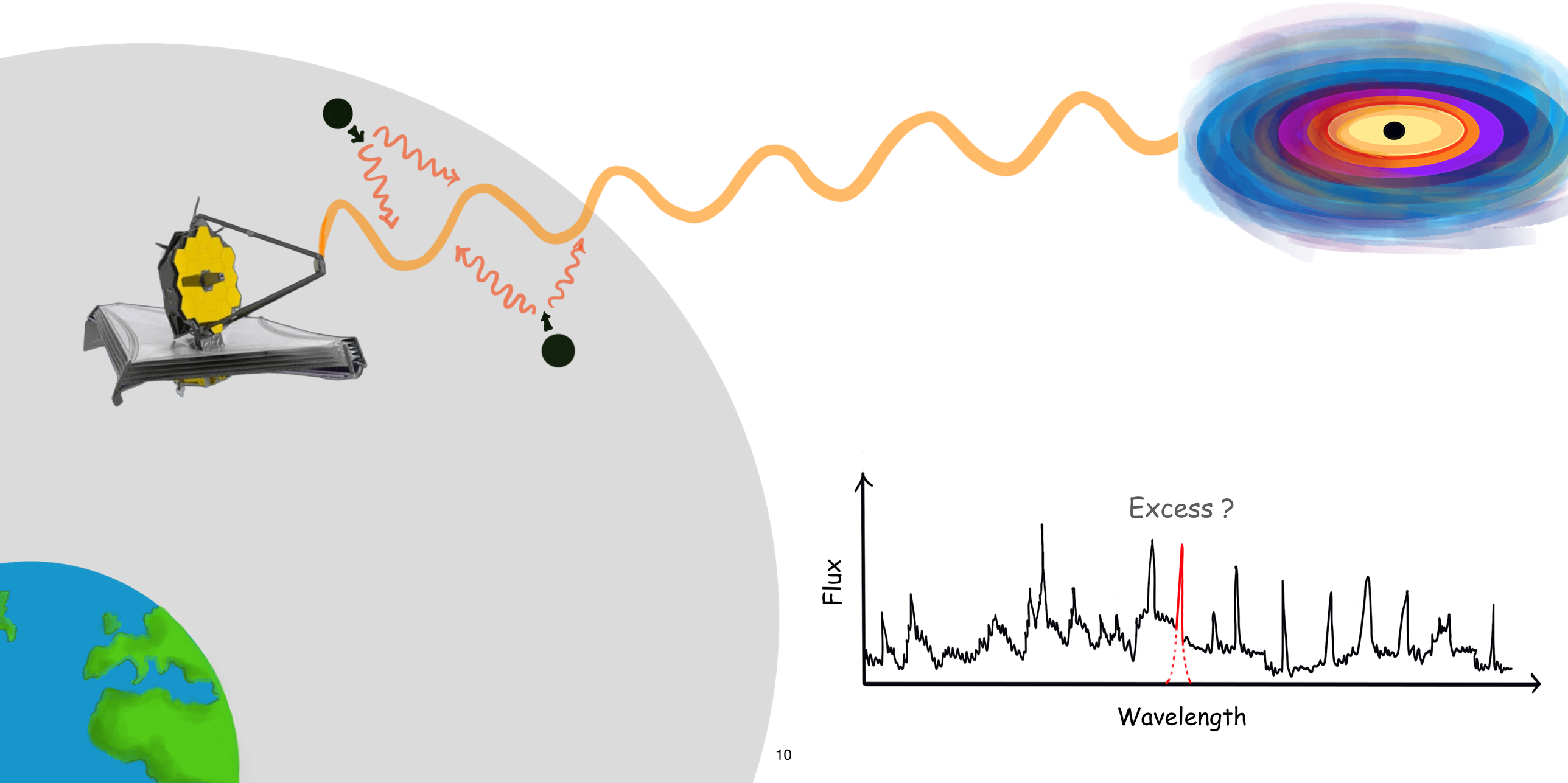
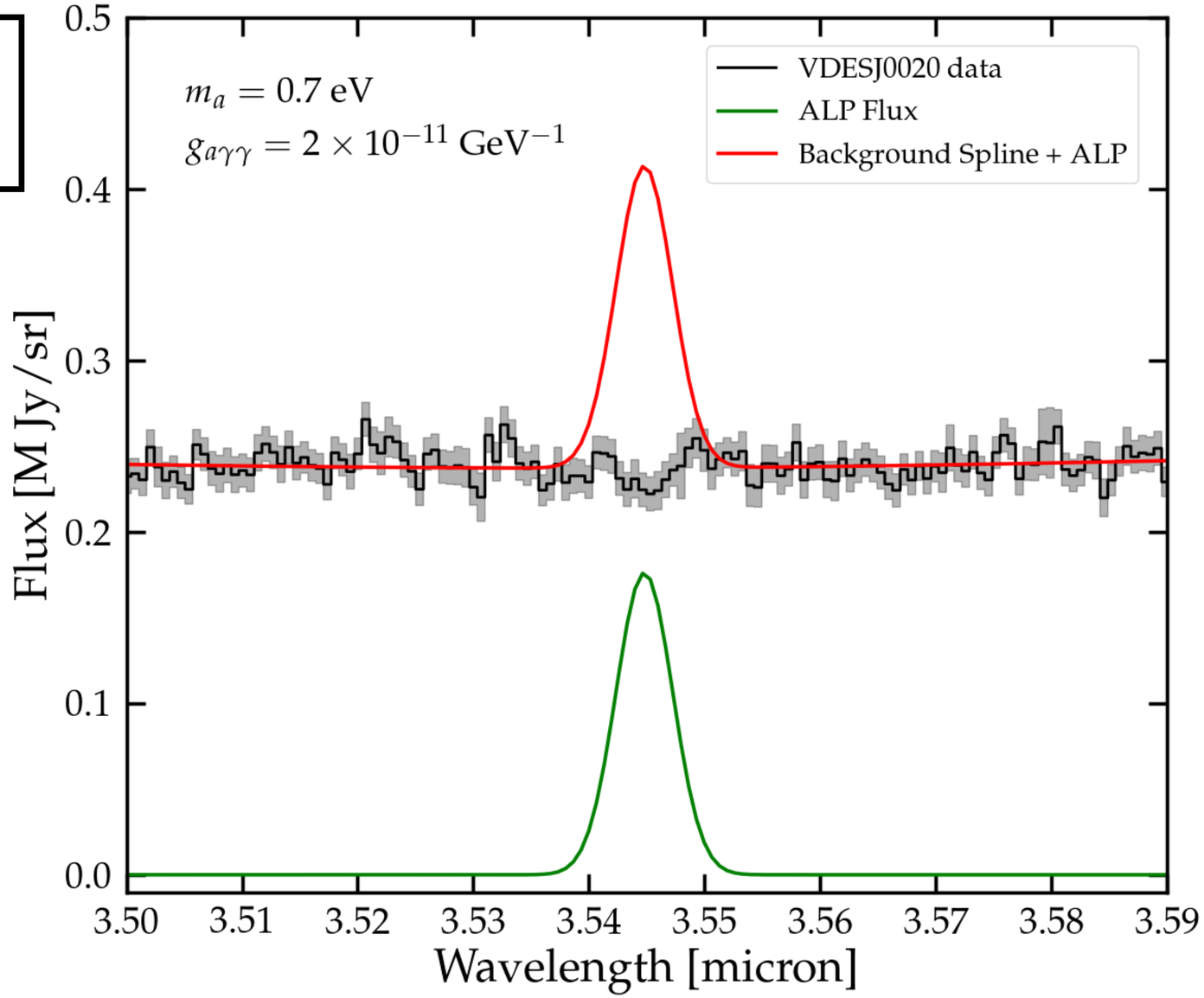


DM hunting with JWST

NIRSpec integral field unit (IFU) ~ 0.90 - 5.27 micrometers



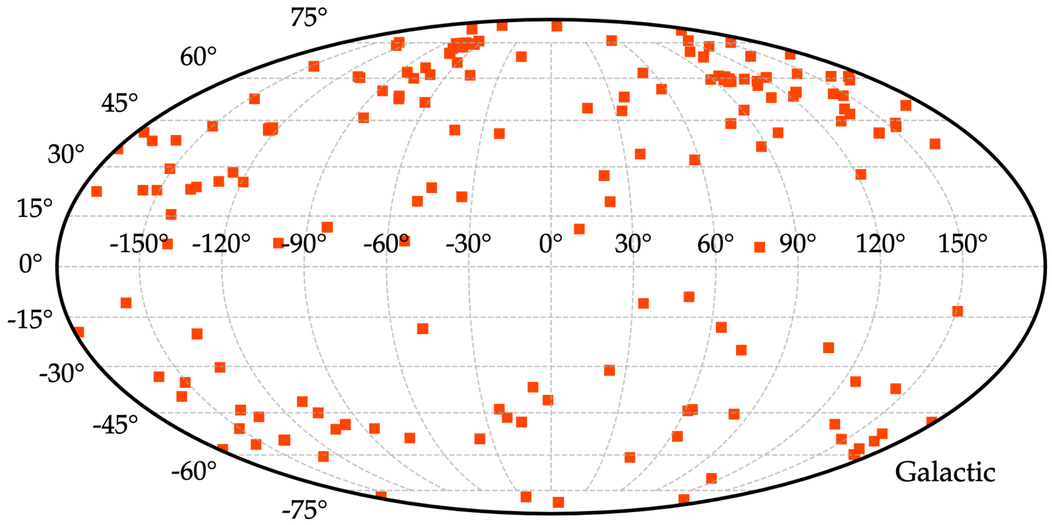
AKS, Subhadip Bouri, Anirban Das, Abhishek Dubey and Ranjan Laha

arXiv: 2503.14582

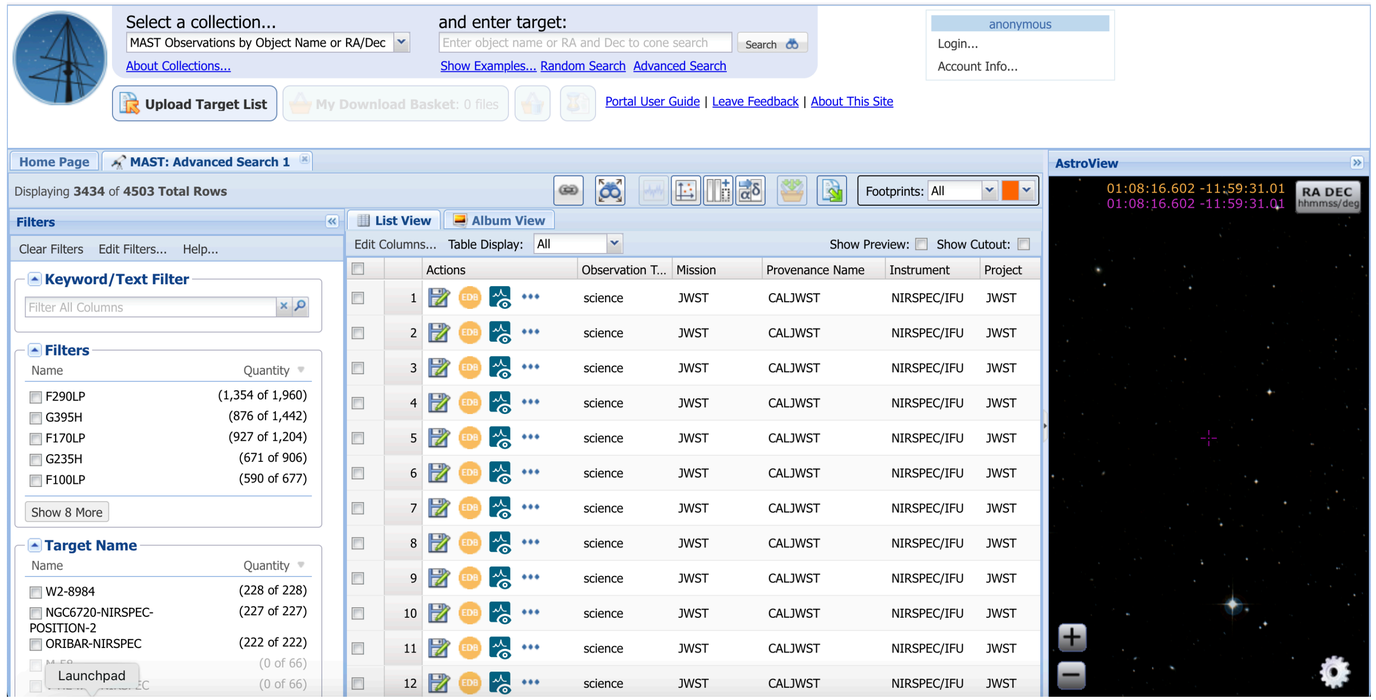
JWST targets used

Dataset DOI: https://archive.stsci.edu/doi/resolve/resolve.html?doi=10.17909/3e5f-nv69

267 distinct target galaxies



Source: https://mast.stsci.edu/portal/Mashup/Clients/Mast/Portal.html



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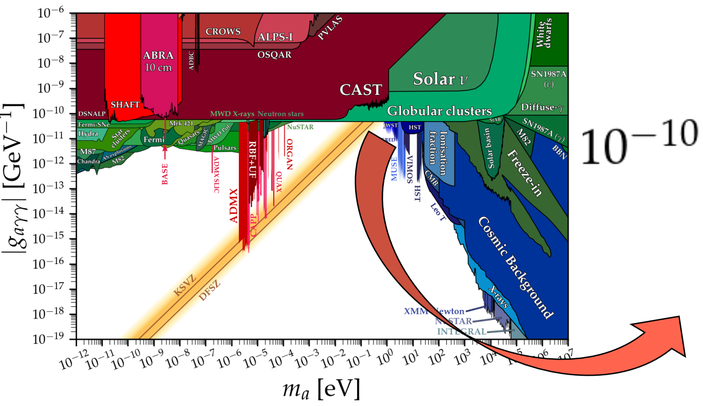
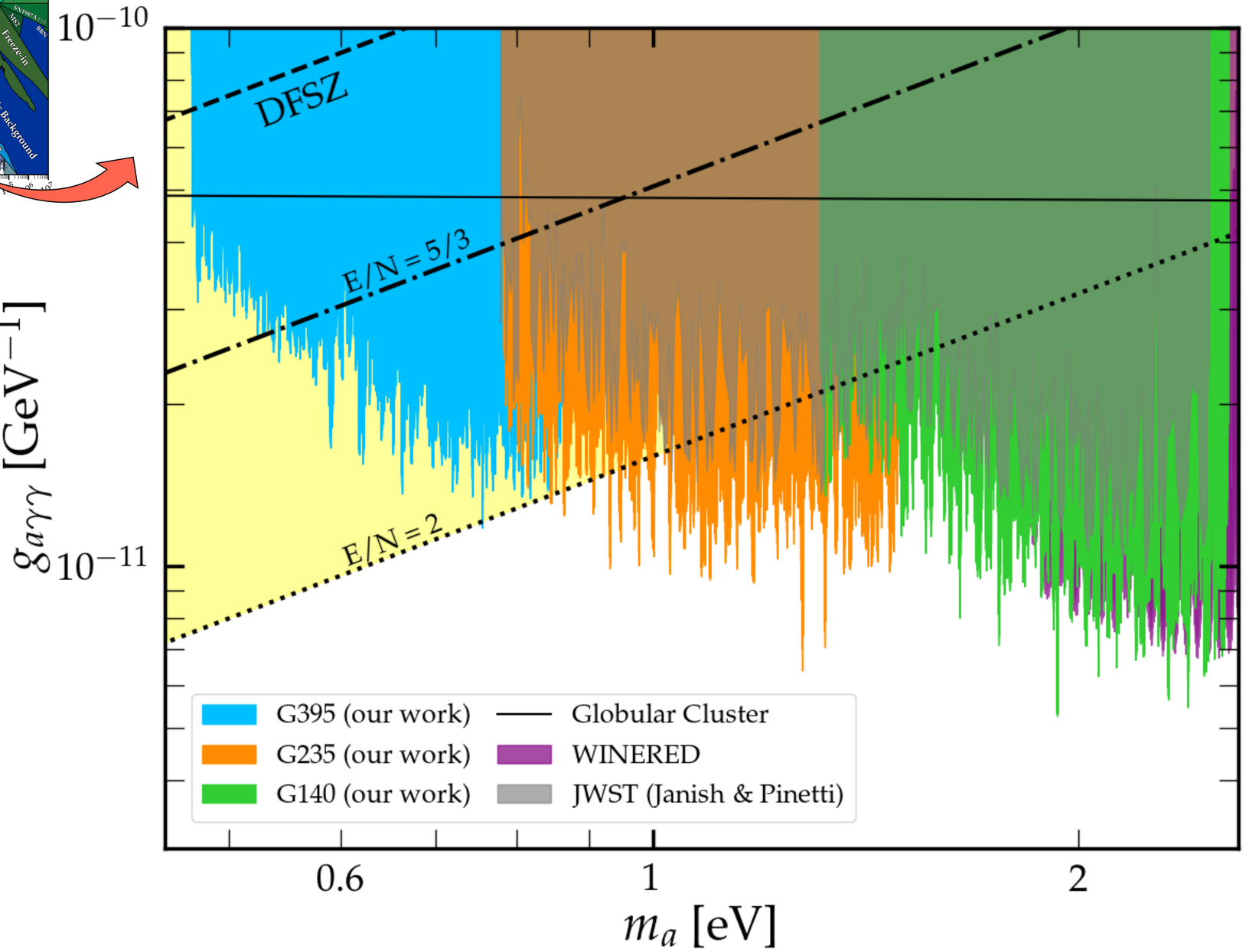
Our Limits

Credit: https://github.com/cajohare/AxionLimits





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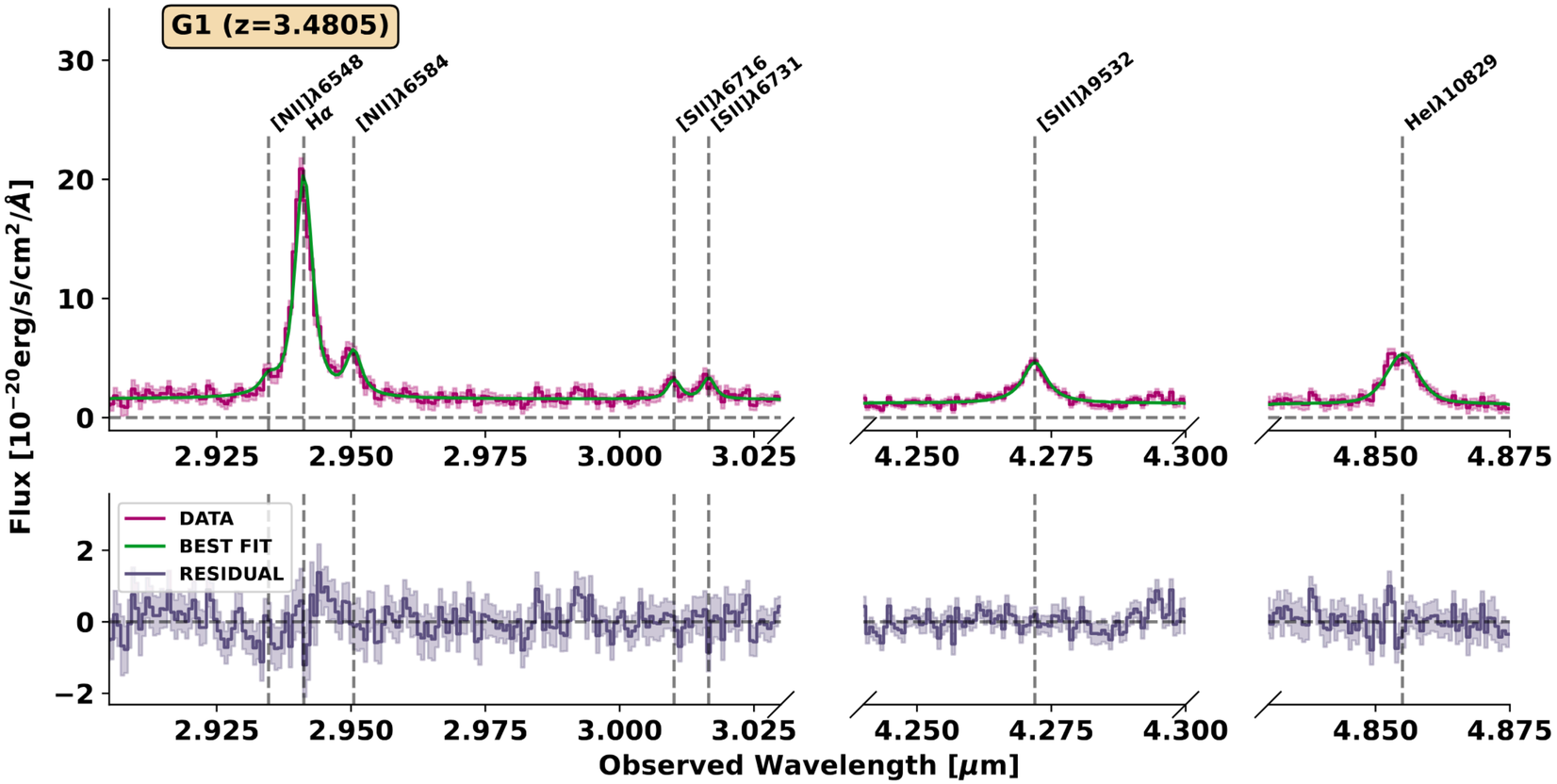
See also: Elena Pinetti, arXiv: 2503.11753

Future Prospects



arXiv: 2308.16620

We need to model the known molecular lines properly to search for any DM signal

Conclusions

- QCD axions and ALPs are one of the most well-motivated DM candidates

- Given the coupling to photons, MW axions can decay to photons and contribute to spectroscopic observations made by JWST

- Using the public JWST datasets we put world-leading constraints on QCD axion and ALP DM coupling to photons

- Future JWST observations of DM rich targets like dwarf galaxies, with a better understanding of background will become important tools in discovering the non-gravitational nature of DM

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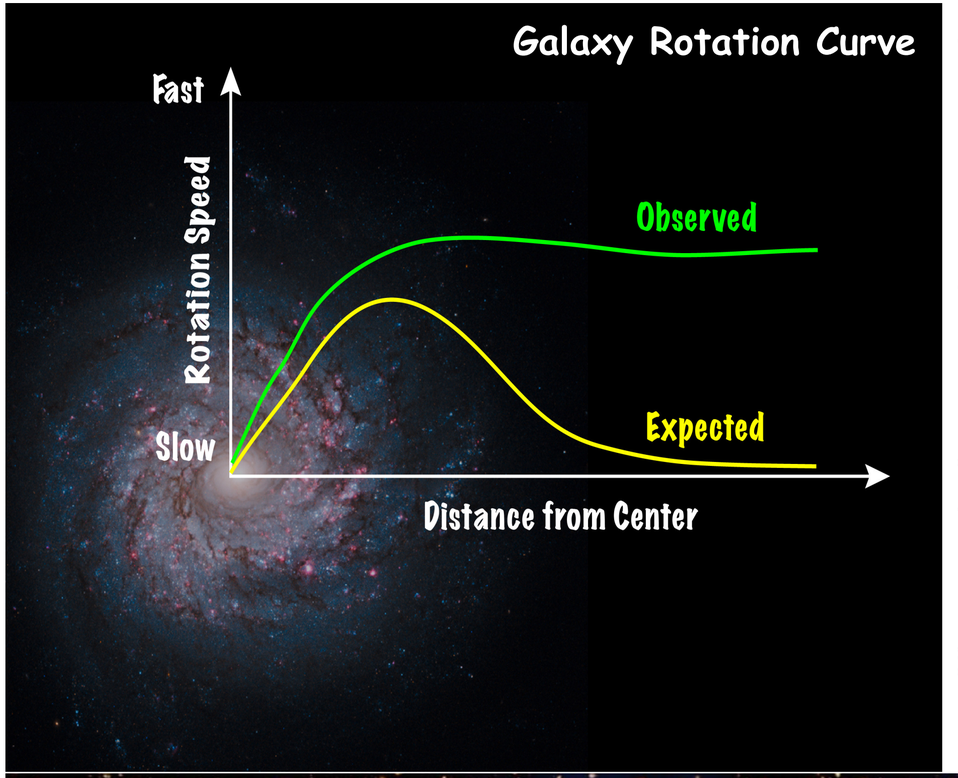
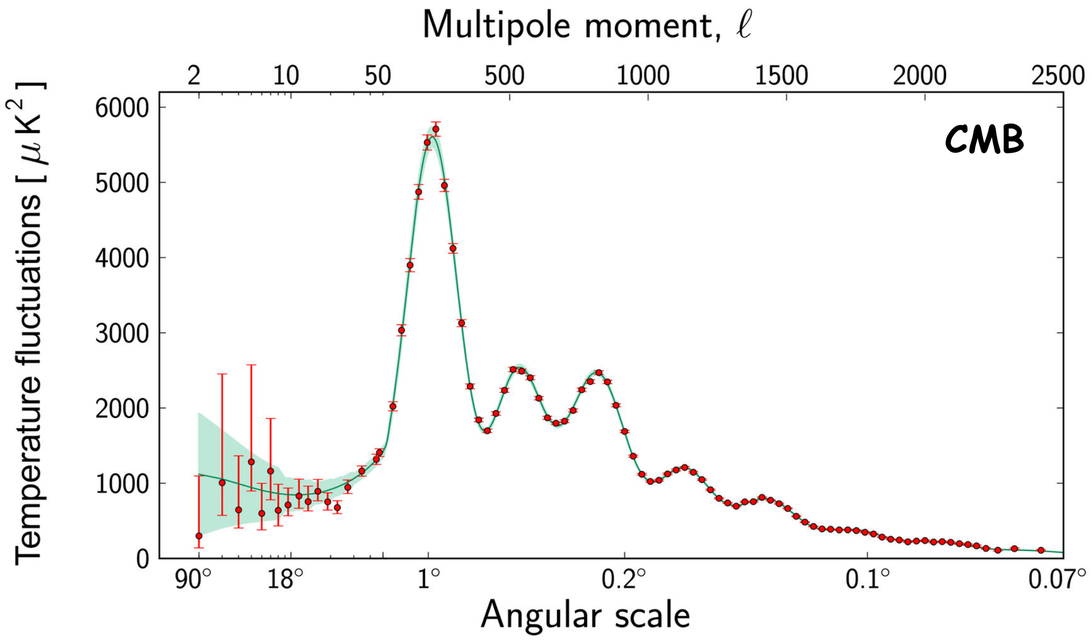
Thank You

Email: akashks@iisc.ac.in

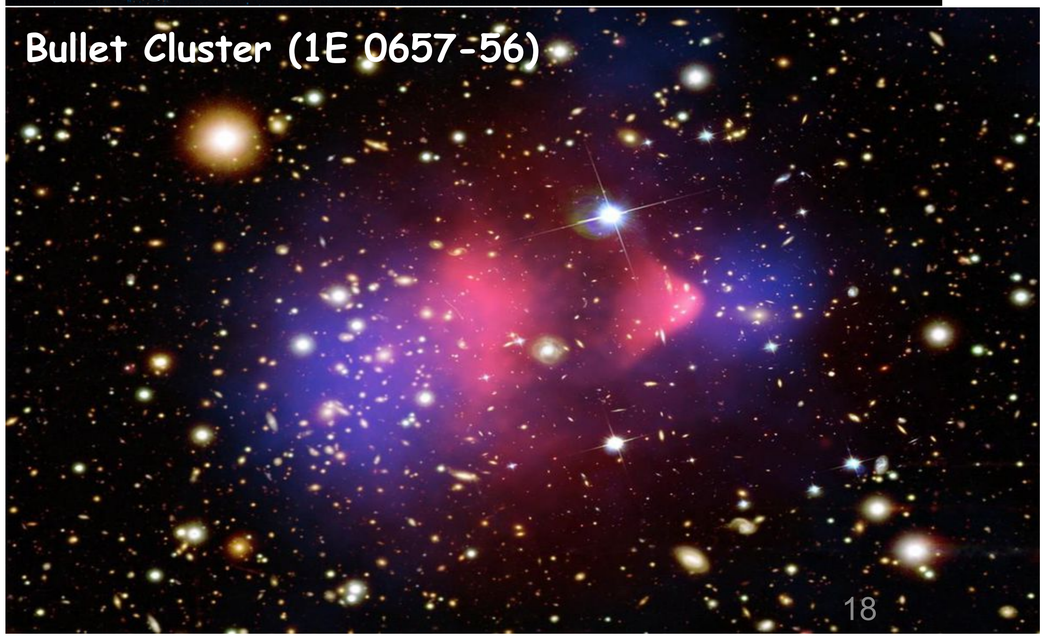
Backup Slides



https://writescience.files.wordpress.com/2015/05/galaxyrotationcurve.jpg

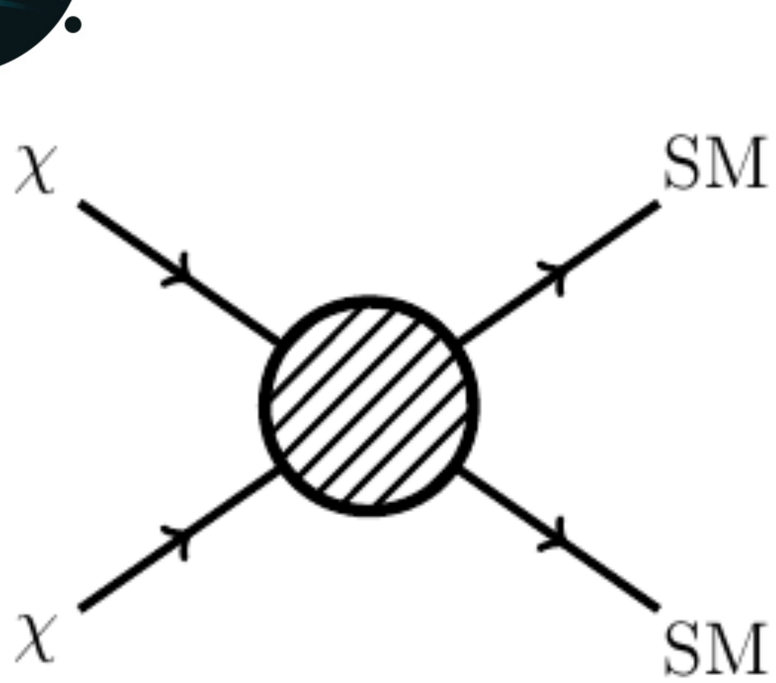


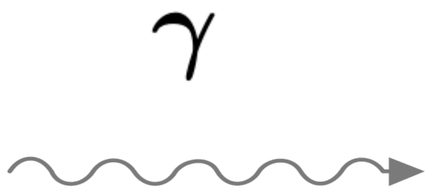
ESA and the Planck Collaboration



X-ray: NASA/CXC/CfA/M.Markevitch et al.; Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.; Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/D.Clowe et al.

Indirect detection

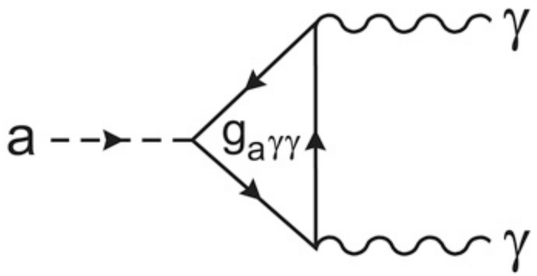




Credit: Flip Tanedo

https://stock.adobe.com/in/

Wide range of parameter space



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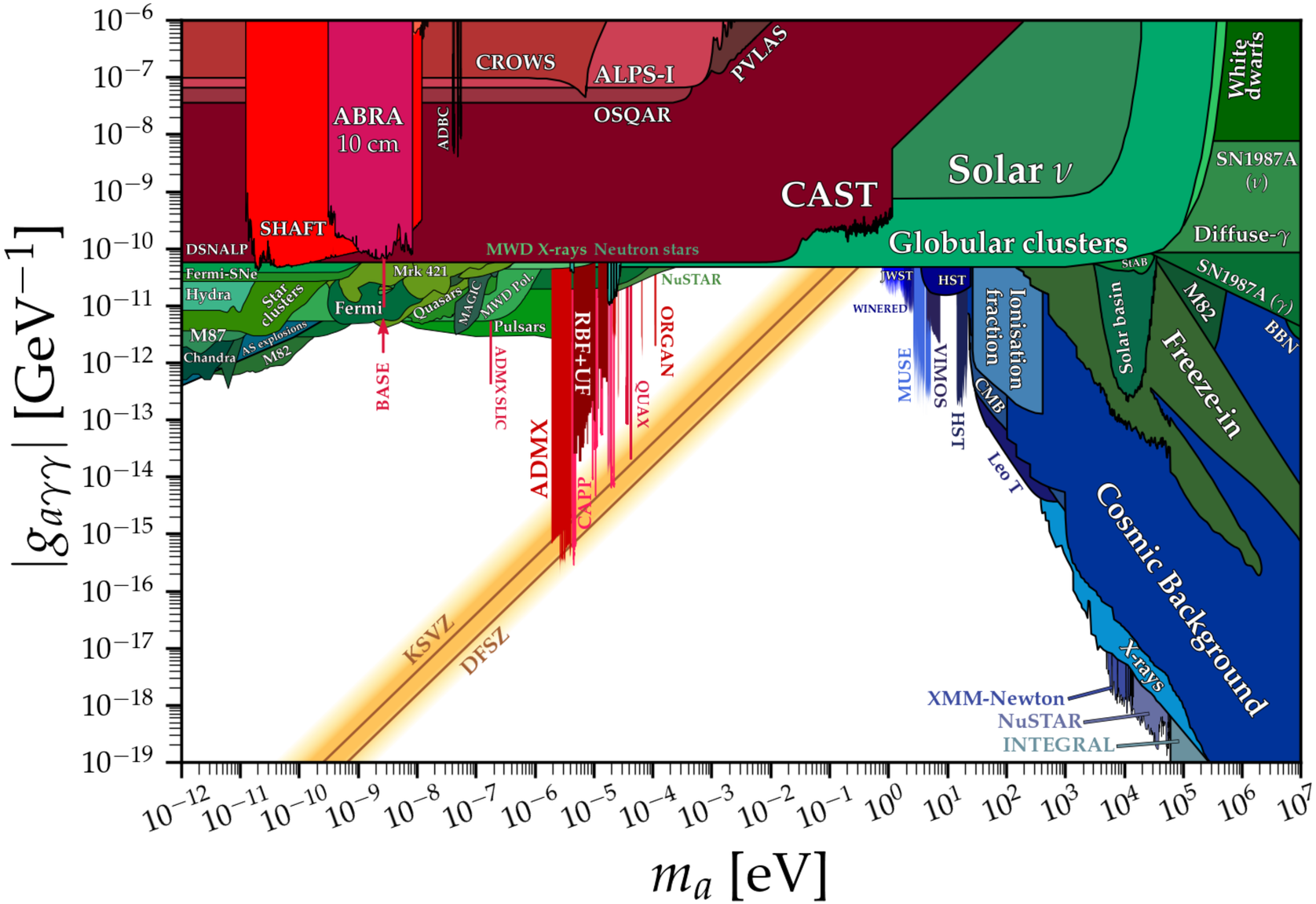

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QCD Axion and ALPs

Lecture 3 by Prof. JiJi Fan

Strong CP Problem

$$\mathcal{L}_\Theta = \bar{\Theta}\frac{g_3^2}{32\pi^2}\mathrm{Tr}\left[G_{\mu\nu}\tilde{G}^{\mu\nu}\right]$$

$$\overline{\Theta} = \Theta + \arg\det\mathcal{M}_Q$$

Neutron electric dipole moment (EDM)

$$d_n = 3.6\times10^{-16}\cdot\overline{\Theta}\,\underbrace{e}_{\text{charge of an electron}}\,\overbrace{\text{cm.}}^{\text{length of dipole}}$$

$$d_n \lesssim 10^{-26}e\,\text{cm}$$

$$\Rightarrow \overline{\Theta} \lesssim 10^{-10}.\,!!$$

Peccei Quinn solution:

Impose a global U(1) symmetry that makes the theta dynamical ➡ Appearance of QCD axion

Axion-like particles (ALPs):

Generic predictions from higher dimensional theories like String theory ➡ Doesn't need to solve the Strong CP problem

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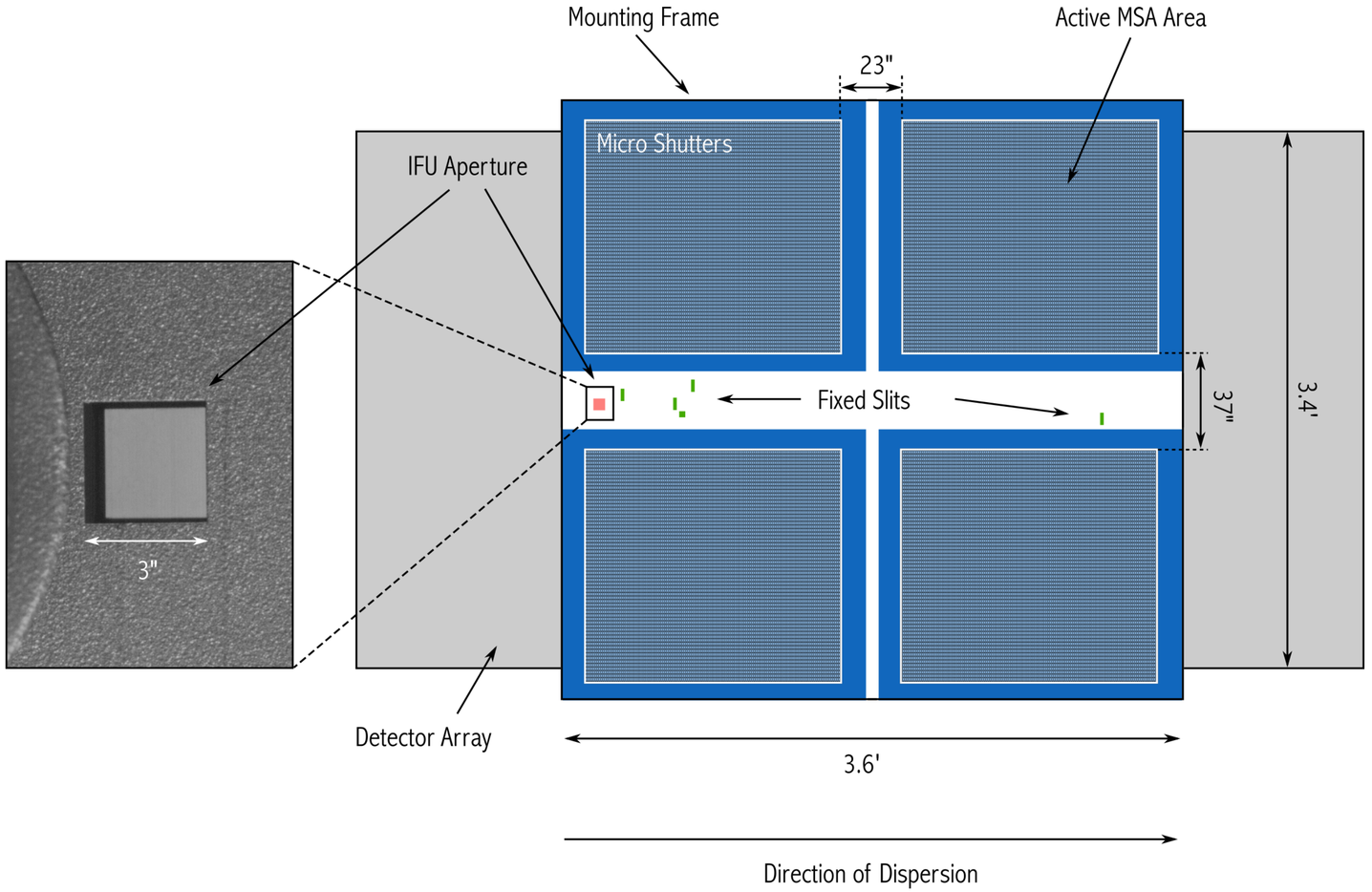
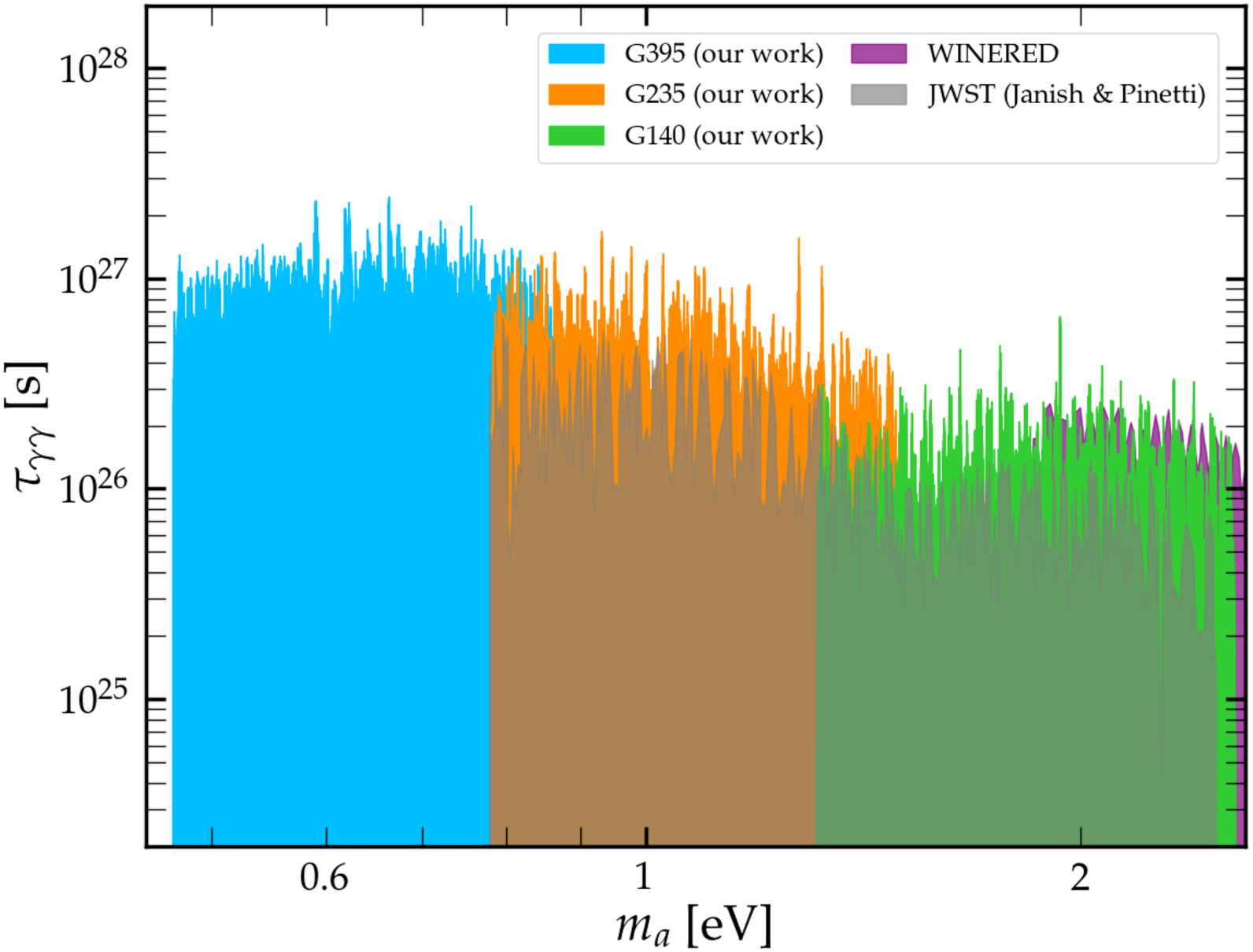
NIRSpec IFU



Credit: https://jwst-docs.stsci.edu/

Our Limits



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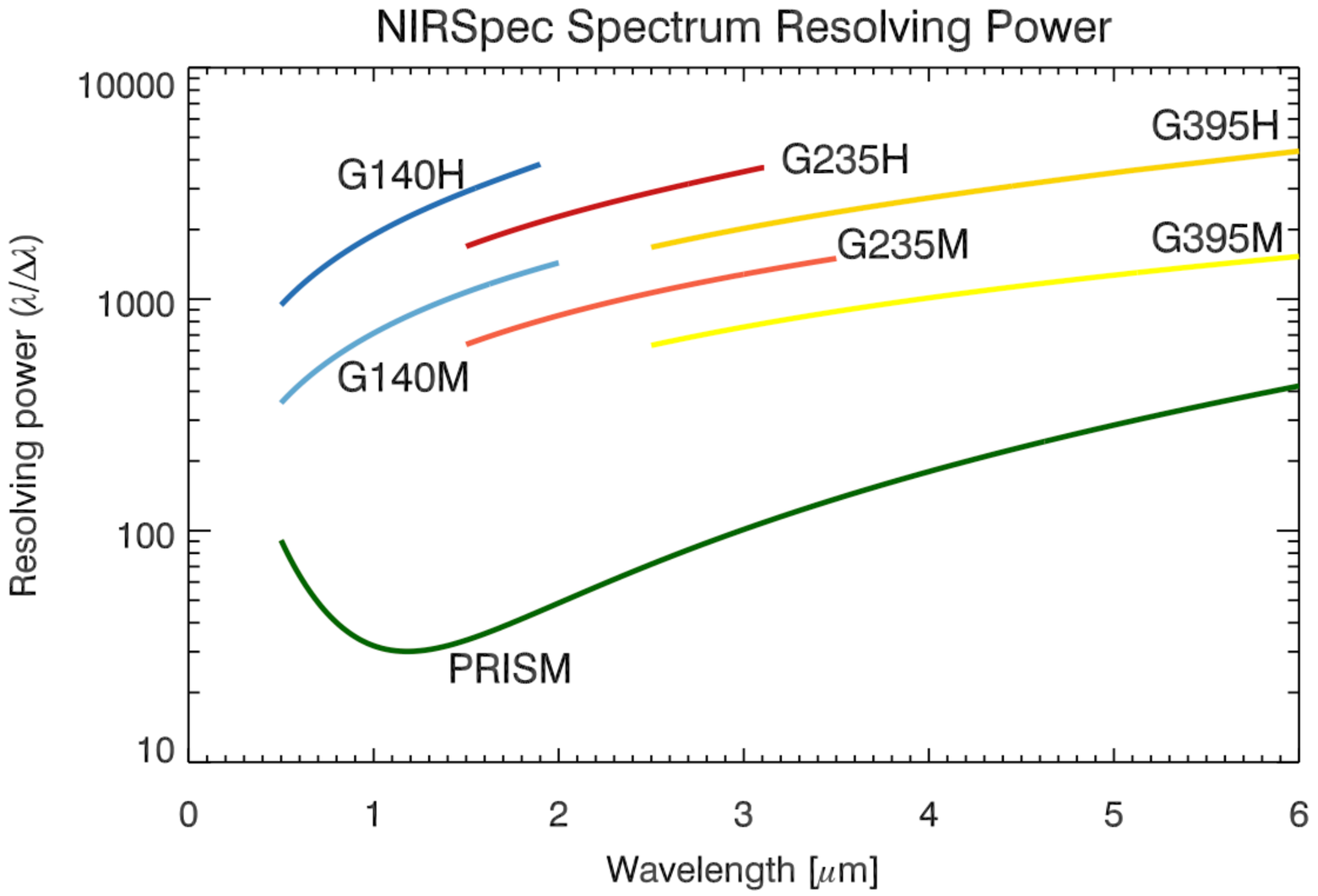
JWST dispersers



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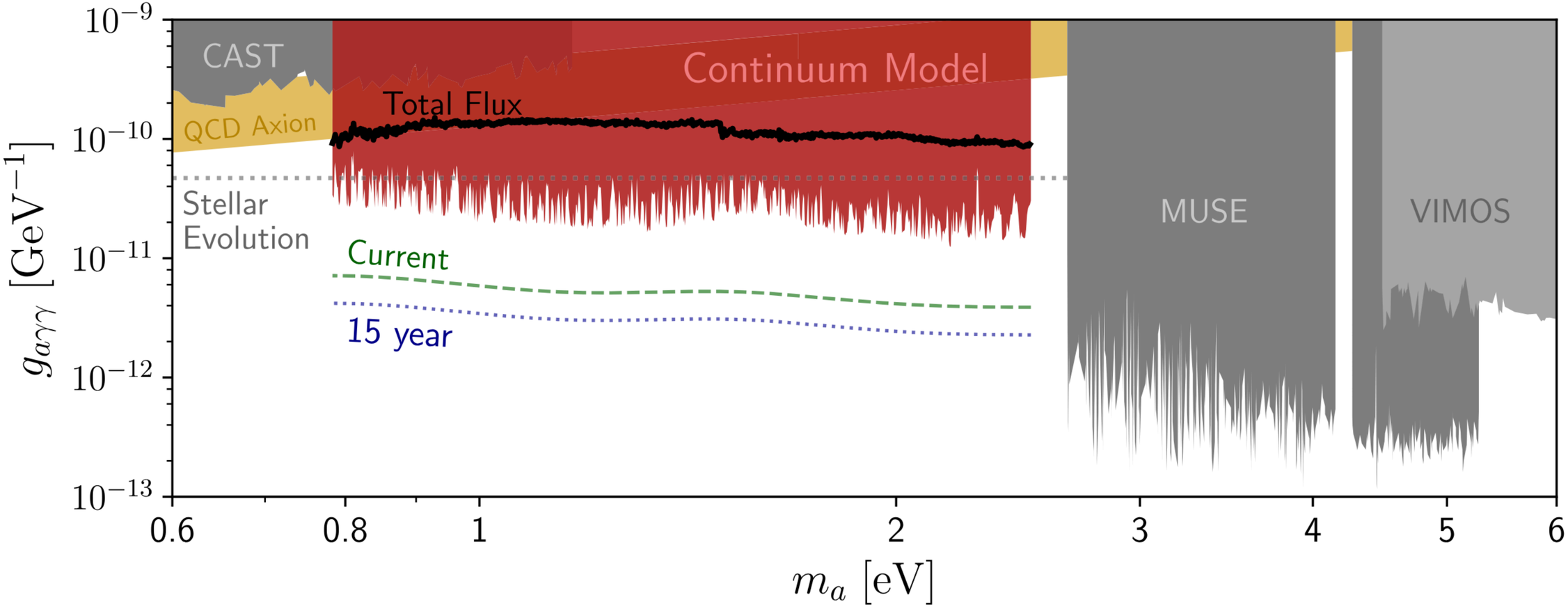
Previous Limits



Ryan Janish, Elena Pinetti

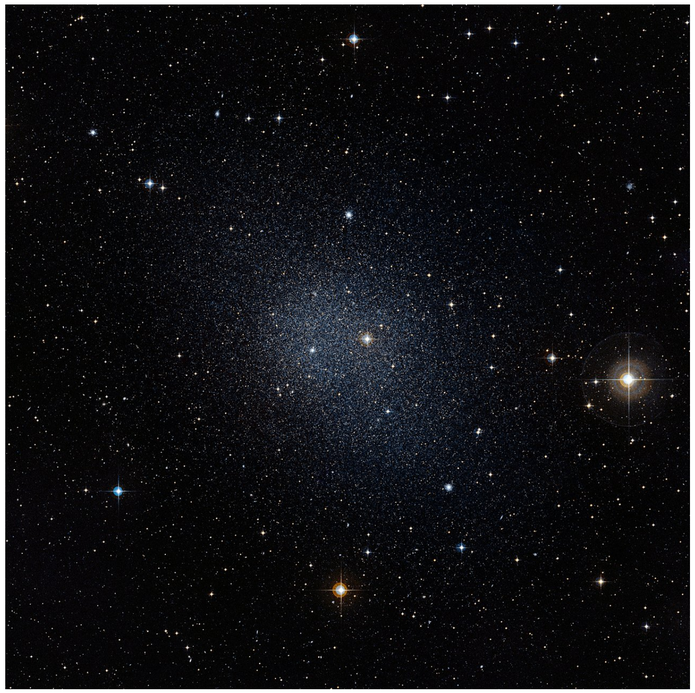
PRL 134.071002 (arXiv: 2310.15395)

Future Prospects

- Dwarf galaxies are known to be DM rich targets with minimal astrophysical backgrounds

- Spectroscopic observations of dwarf galaxies by telescopes like HST, WINERED have put leading constraints on ALP DM parameter space

- Future JWST spectroscopic observations of dwarf galaxies can provide the strongest limits for QCD axion and ALP DM.



(Credit: ESO/Digitized Sky Survey 2)

Fornax dwarf galaxy

JWST dispersers

Table 1. Instrument configurations, spectral resolutions, and wavelength ranges for the NIRSpec IFU

Disperser-filter combination	Nominal resolving power	Wavelength range (μm)
G140M/F070LP	~1,000	0.90–1.27
G140M/F100LP		0.97–1.89
G235M/F170LP		1.66–3.17
G395M/F290LP		2.87–5.27
G140H/F070LP	~2,700	0.95–1.27
G140H/F100LP		0.97–1.89
G235H/F170LP		1.66–3.17
G395H/F290LP		2.87–5.27
PRISM/CLEAR	~100	0.6–5.3

Credit: https://jwst-docs.stsci.edu/

Axion Decay

Resulting photon peak wavelength : $\lambda_a = 4\pi/m_a$

Flux : $$\Phi_a \equiv \frac{1}{\Delta\Omega}\frac{d\phi}{d\lambda} = \frac{m_a}{2}\frac{\Gamma}{4\pi m_a}\frac{dN}{d\lambda}\frac{\mathcal{D}(\ell,b)}{\Delta\Omega}$$

$$\frac{dN}{d\lambda} = 2 \times \frac{1}{\sqrt{2\pi w^2}} \exp\left[-\frac{(\lambda-\lambda_a)^2}{2w^2}\right]$$

with

$$w^2 = \left(\frac{\Delta\lambda}{2\sqrt{2\ln 2}}\right)^2 + \lambda_a^2\sigma_v^2 \ .$$

Most constraining JWST targets