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Hunting axions with the James Webb Space Telescope

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TMEX2025 – 10 January 2025

This talk is based on…

Hunting Dark Matter Lines in the Infrared Background with the James Webb Space Telescope

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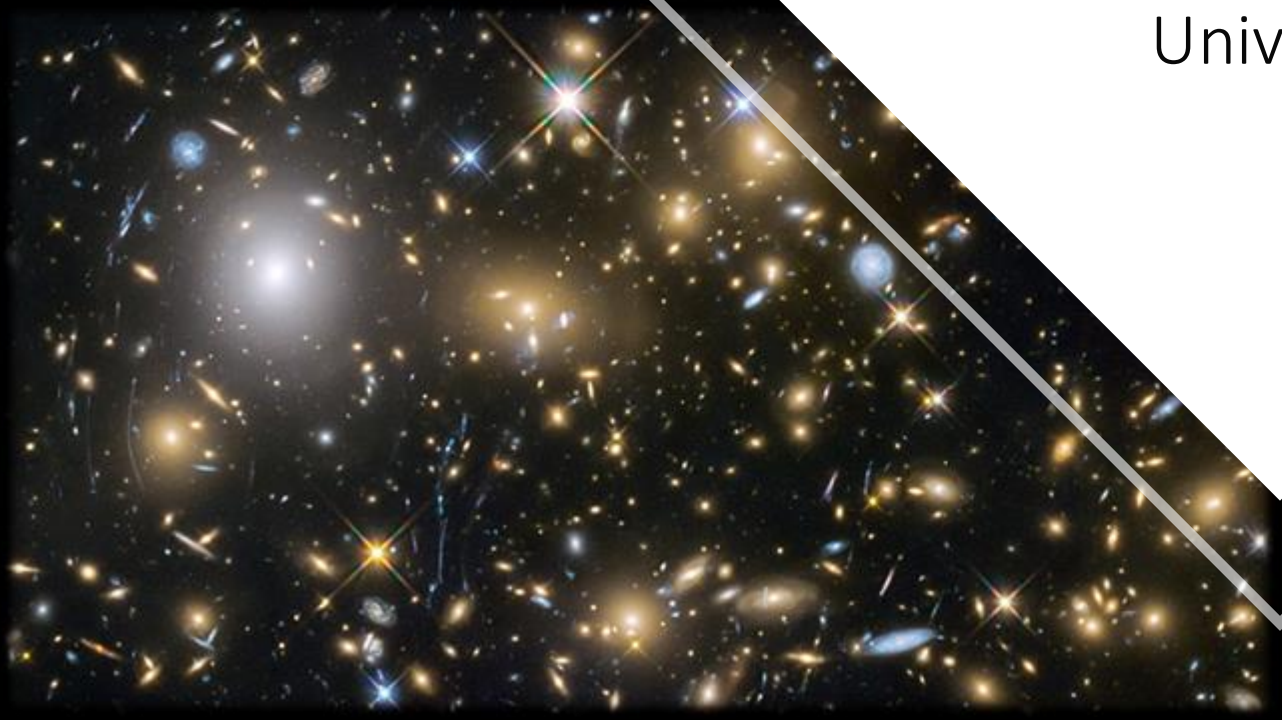
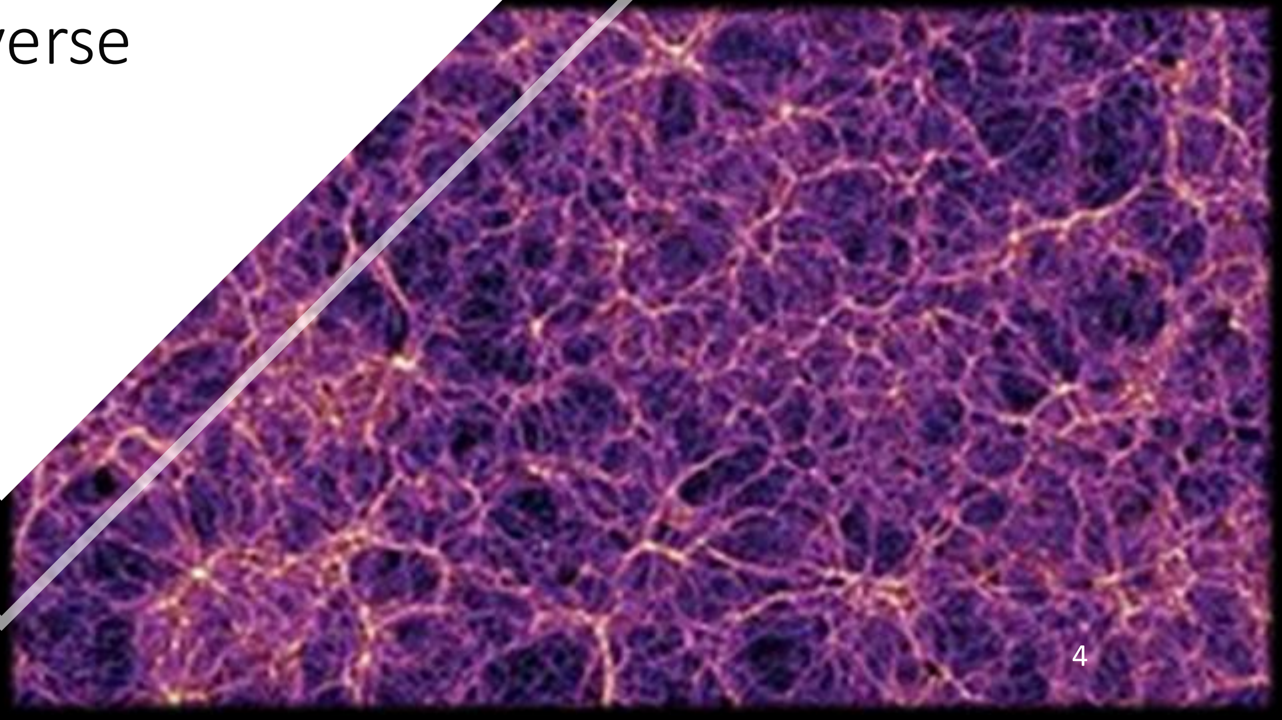
Abstract. Dark matter particles with a mass around 1 eV can decay into near-infrared photons. Utilising available public blank sky observations from the NIRSpec IFU on the James Webb Space Telescope (JWST), we search for a narrow emission line due to decaying dark matter and derive leading constraints in the mass range 0.8-3 eV on the decay rate to photons, and more specifically, on the axion-photon coupling for the case of axion-like particles. We exclude $\tau < 6.7 \cdot 10^{26}$ s at $m_{\rm DM} \simeq 0.9$ eV and, in the case of axions, $g_{a\gamma\gamma} > 9.4 \cdot 10^{-12}$ GeV^{-1} for $m_a = 2.15$ eV. Our results do not rely on dedicated observations, rather we use blank sky observations intended for sky subtraction, and thus our reach may be automatically strengthened as JWST continues to observe.

Outline

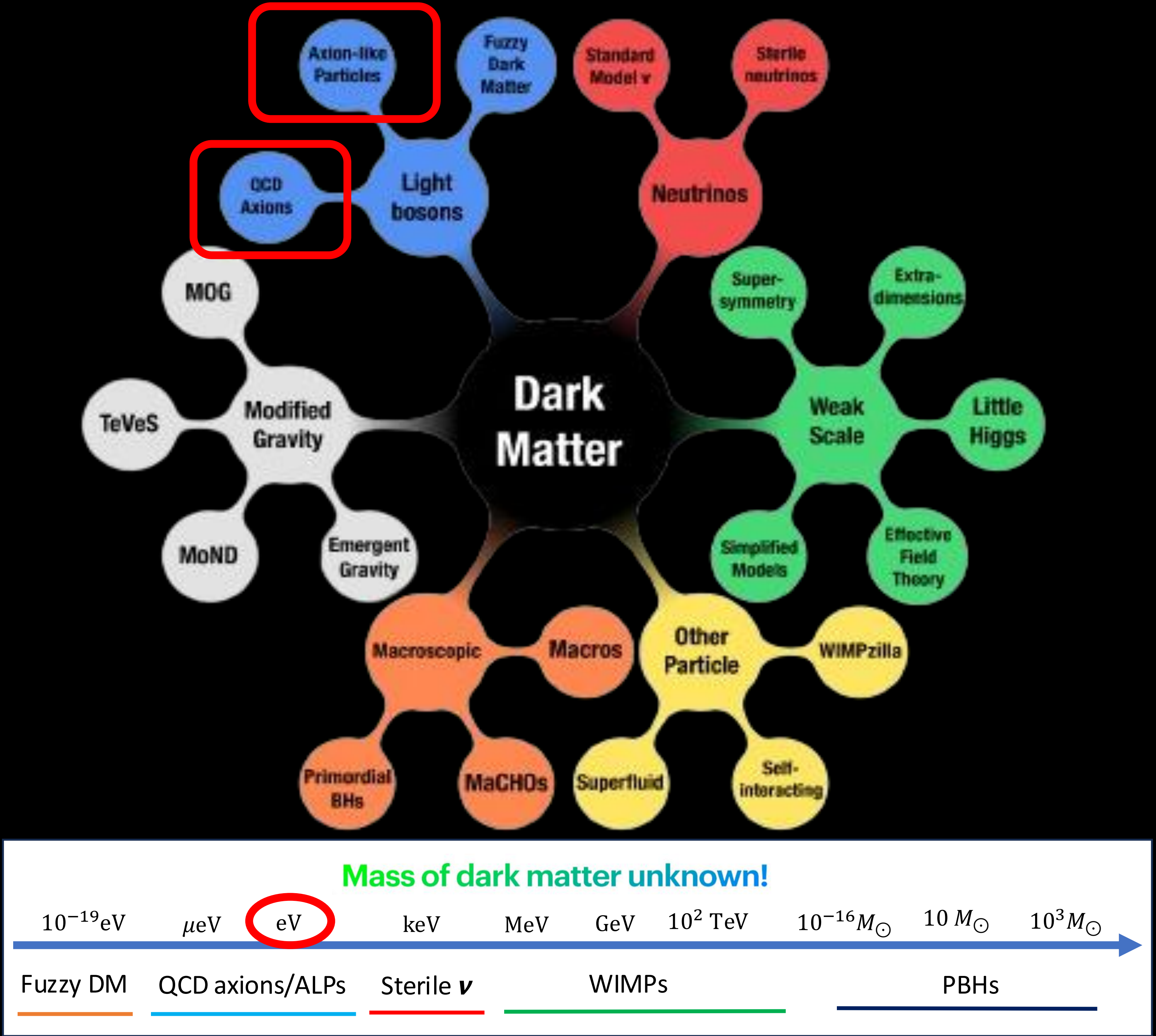
- ❑ Dark matter signal
- ❑ James Webb Space Telescope
- ❑ Results & Prospects

Dark matter in the Universe

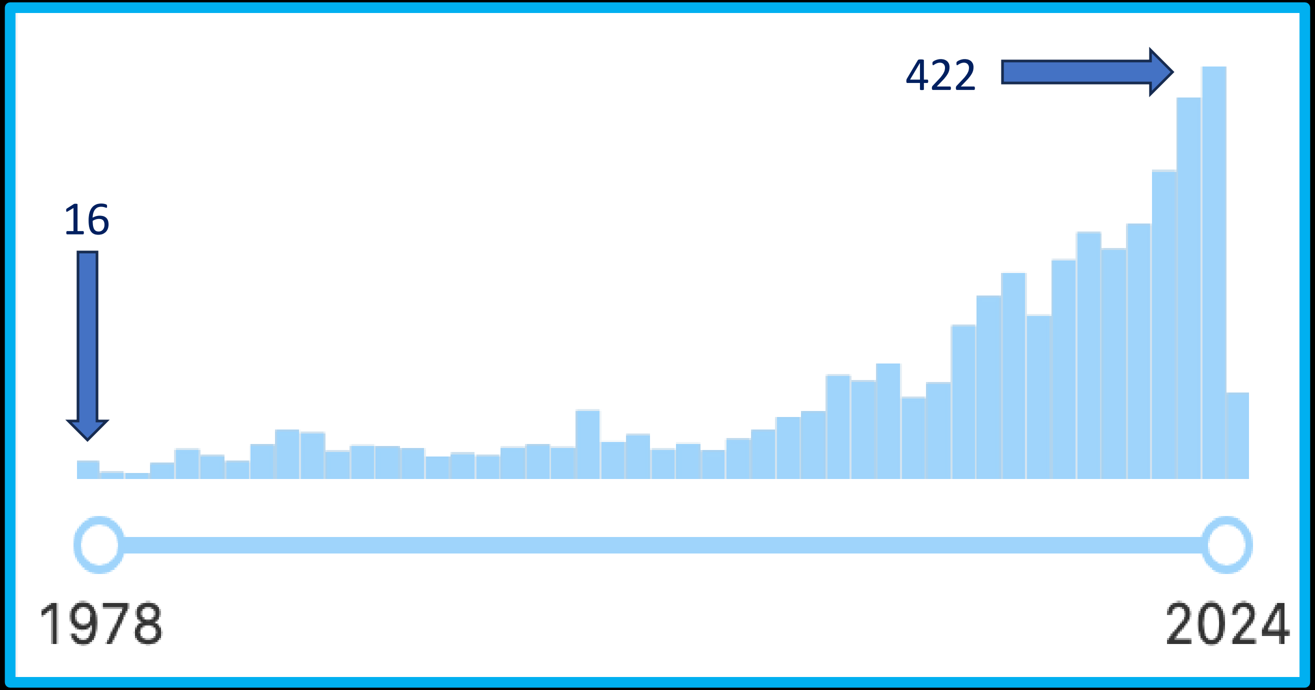


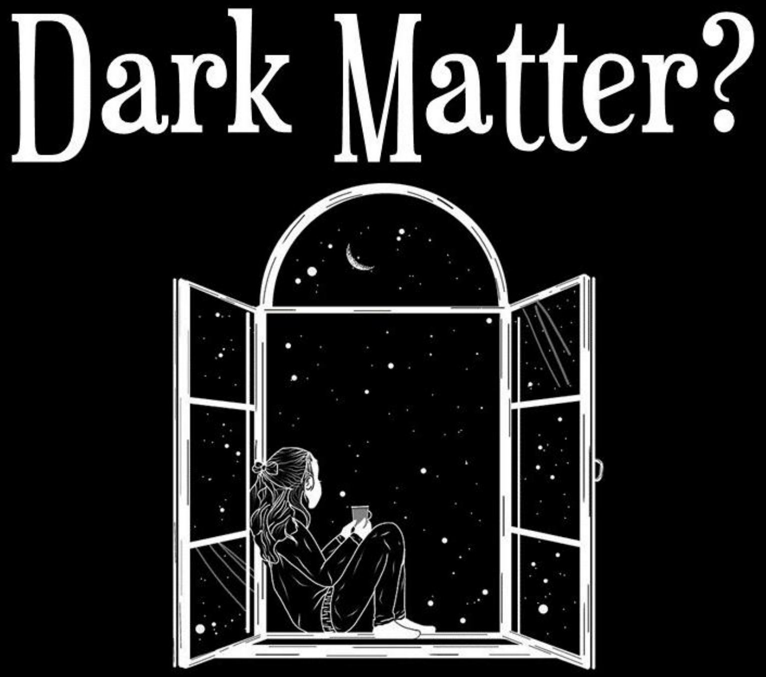


Dark Matter candidates



Axions as dark matter





Key ideas

1. Axion-like particles are a generalization of the QCD axions. They can be DM particles.

2. The focus of the talk is on the interaction between axions and photons

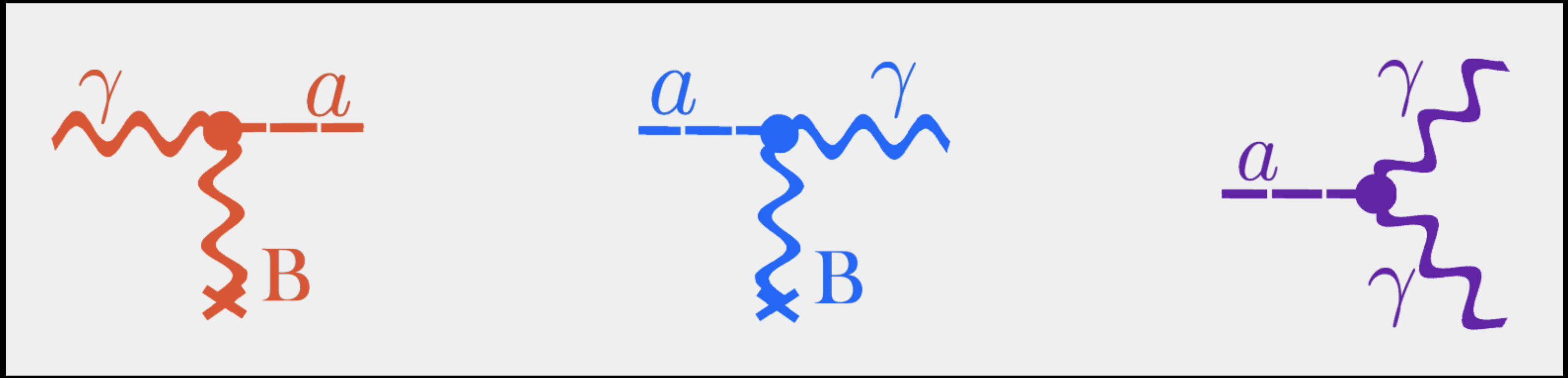
3. This interaction is characterised by the parameter $g_{a\gamma\gamma}$ and this is what we want to constrain.

Axion-photon interactions

1. Primakov production in stars: $\gamma \to a$

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

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



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Dark matter signal

Dark matter signal

$$\frac{d\phi_{DM}}{dE\,d\Omega} = \frac{\Gamma_\gamma}{4\pi\, m_a} \frac{dN}{dE} D$$

Emission rate

Axion mass

Emission spectrum

D-factor

Axion-photon coupling

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

Axion-photon coupling

Axion field

EM field

$$\Gamma_\gamma = \frac{1}{\tau} = \frac{g_{a\gamma\gamma}^2\, m_a^3}{64\pi}$$

Emission rate

Axion mass

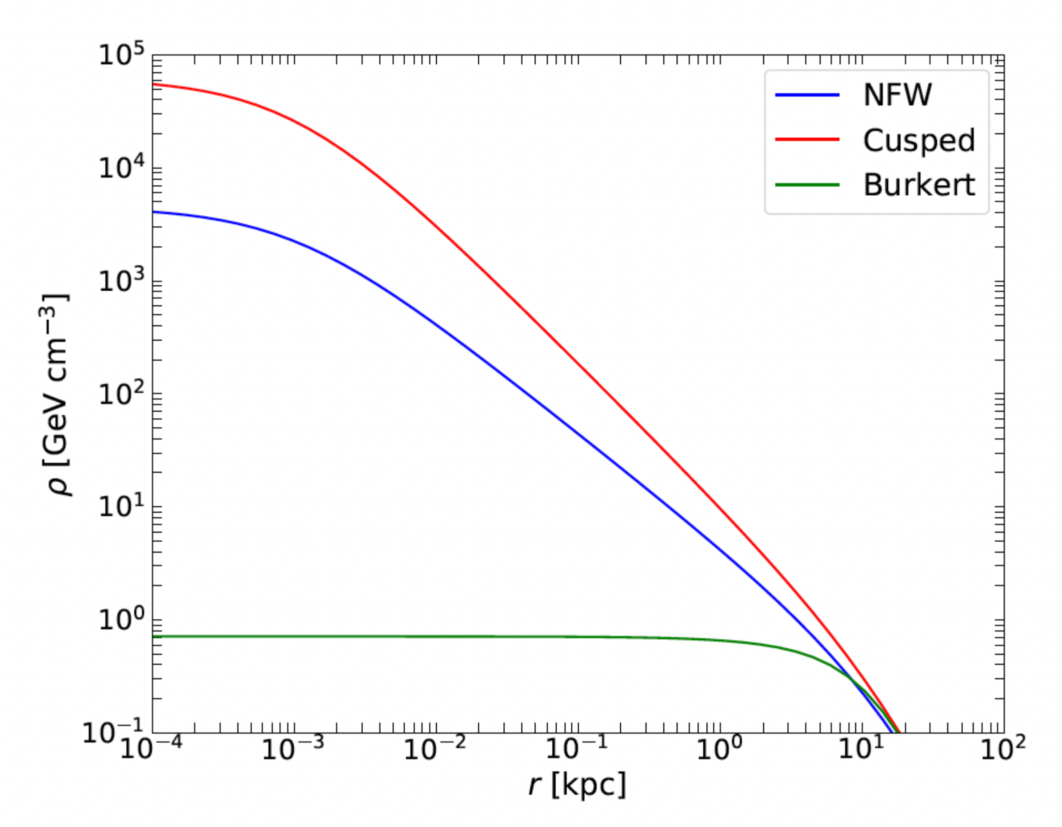
D-factor

$$D(\theta) = \int_0^\infty ds\, \rho(r(s,\theta))$$

$$\rho(r) = \frac{\rho_s}{\frac{r}{r_s}\left(1 + \frac{r}{r_s}\right)}$$ NFW profile

$$\rho_s = 0.18\ \mathrm{GeV/cm^3}$$

$$r_s = 24\ \mathrm{kpc}$$



Photon emission spectrum

$$\frac{dN}{dE_\gamma} = \delta\left(E_\gamma - \frac{m_a}{2}\right)$$

$$\frac{df}{d\nu} * W$$

Doppler effect

Instrumental response

James Webb Space Telescope

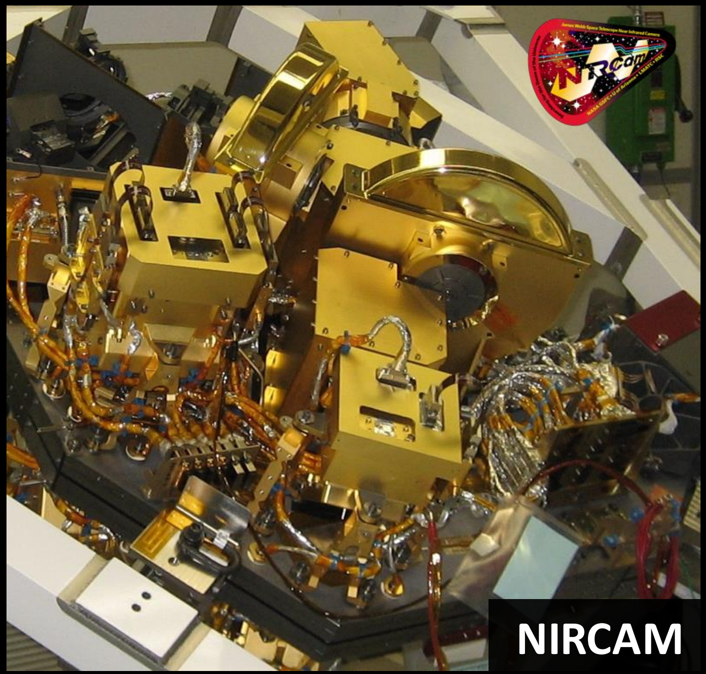
JWST launch

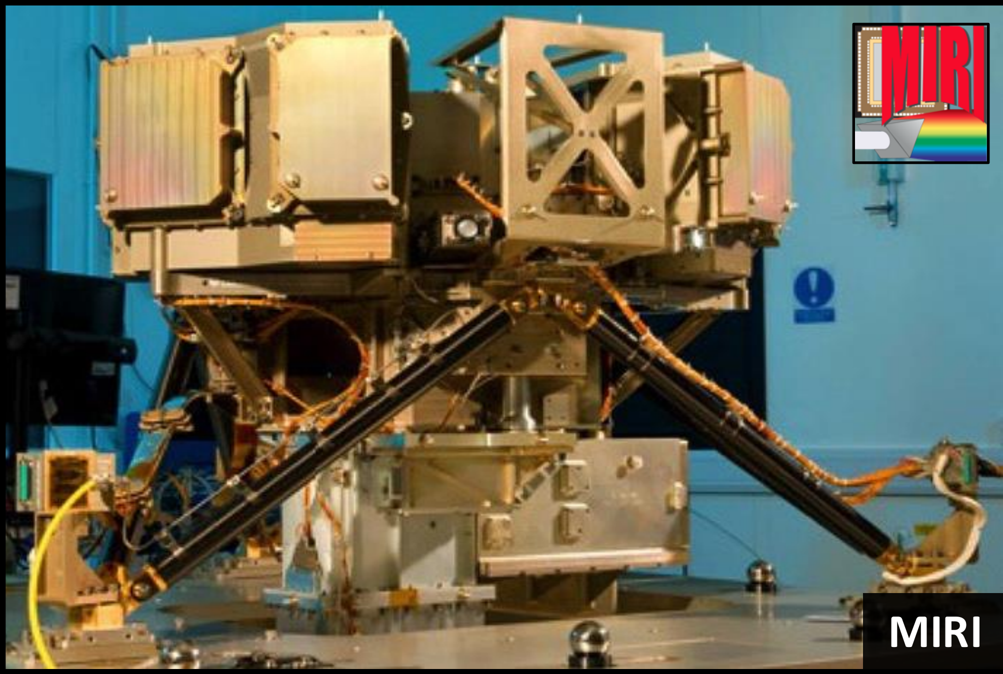
Launch: 25 December 2021 from French Guiana

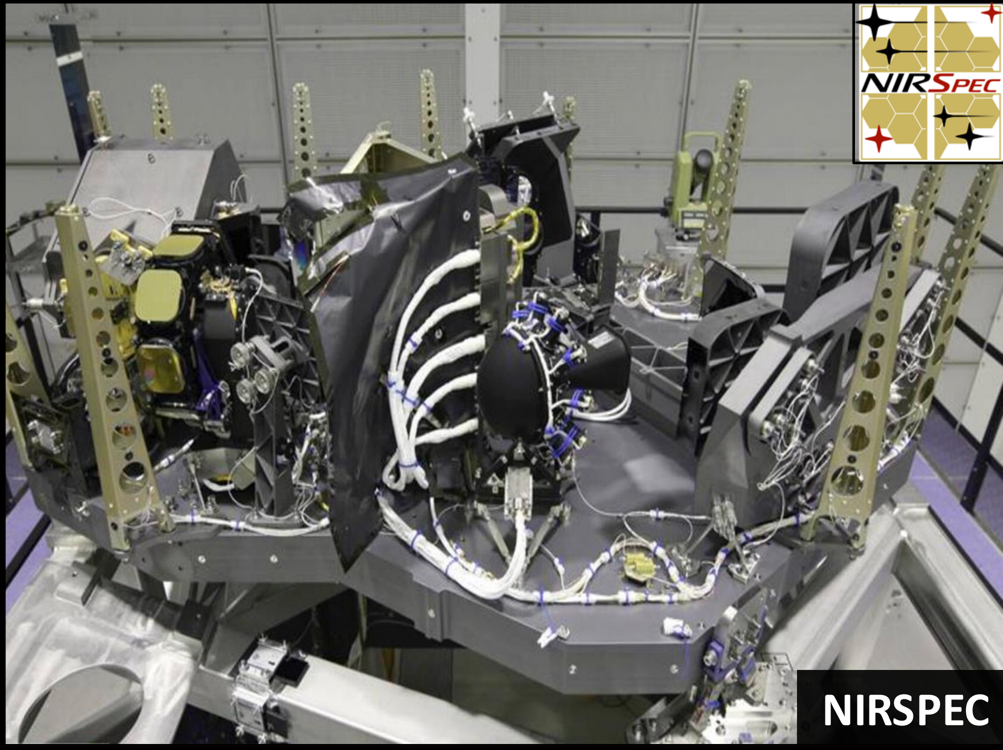
Arianespace Ariane 5 rocket

It does not orbit around the Earth like the Hubble Space Telescope, it orbits the Sun 1.5×10^6 km away from Earth at L2 (2nd Lagrange point)

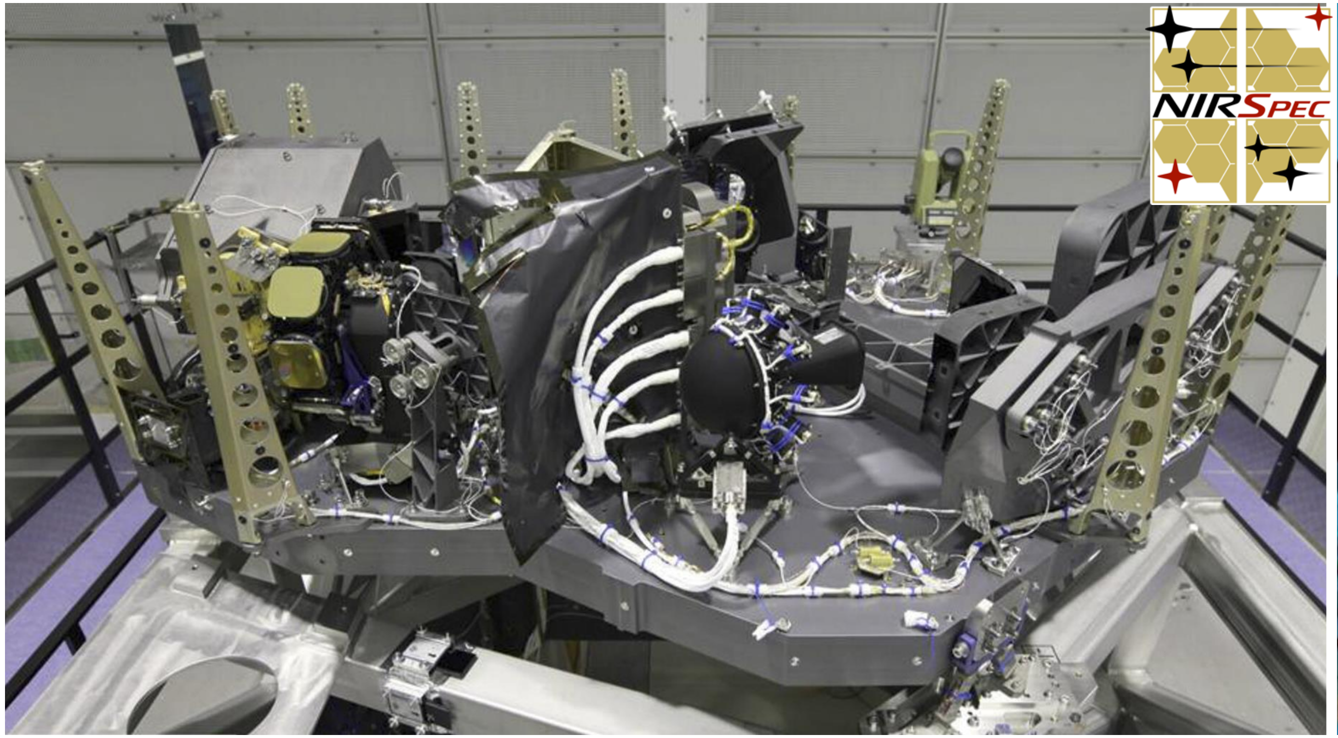
JWST Instruments

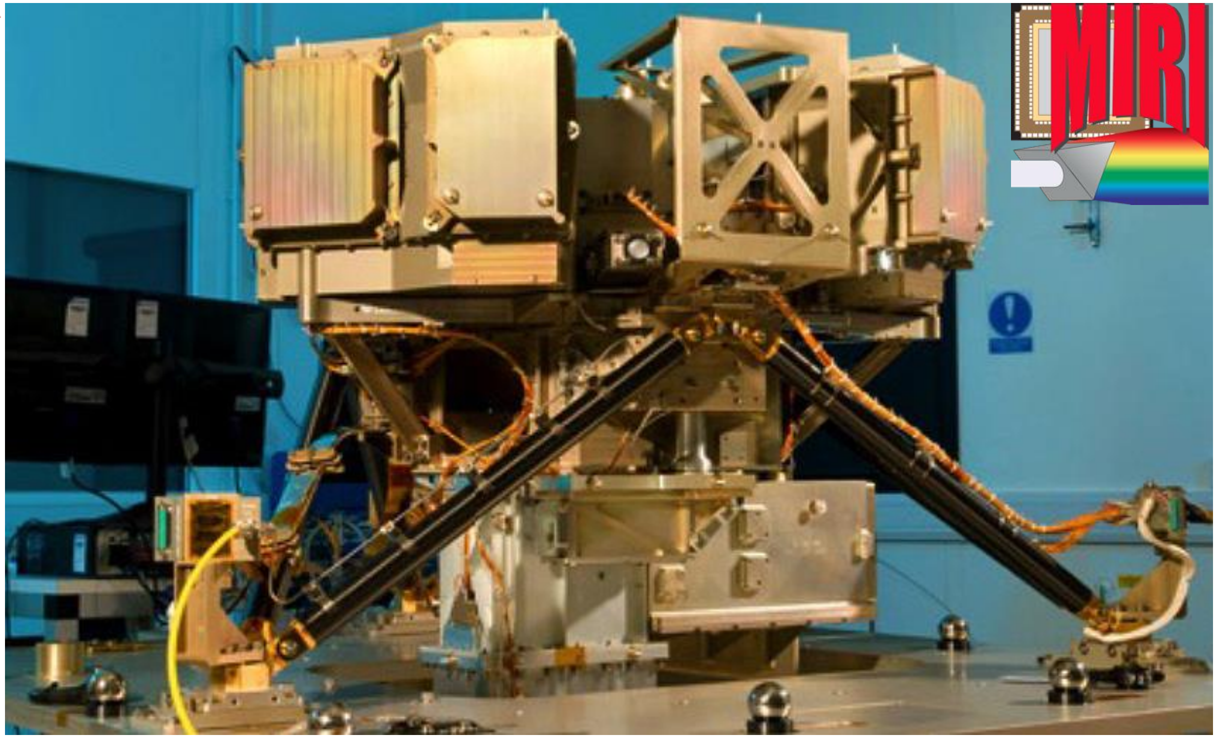






NIRSPEC and MIRI





NIRSpec: Near-Infrared Spectrograph

$\Delta\lambda = 0.6 - 5\ \mu m$

MIRI: Mid-Infrared Instrument

$\Delta\lambda = 4.9 - 27.9\ \mu m$

JWST collaboration

Observations

Blank-sky observations (diffuse)

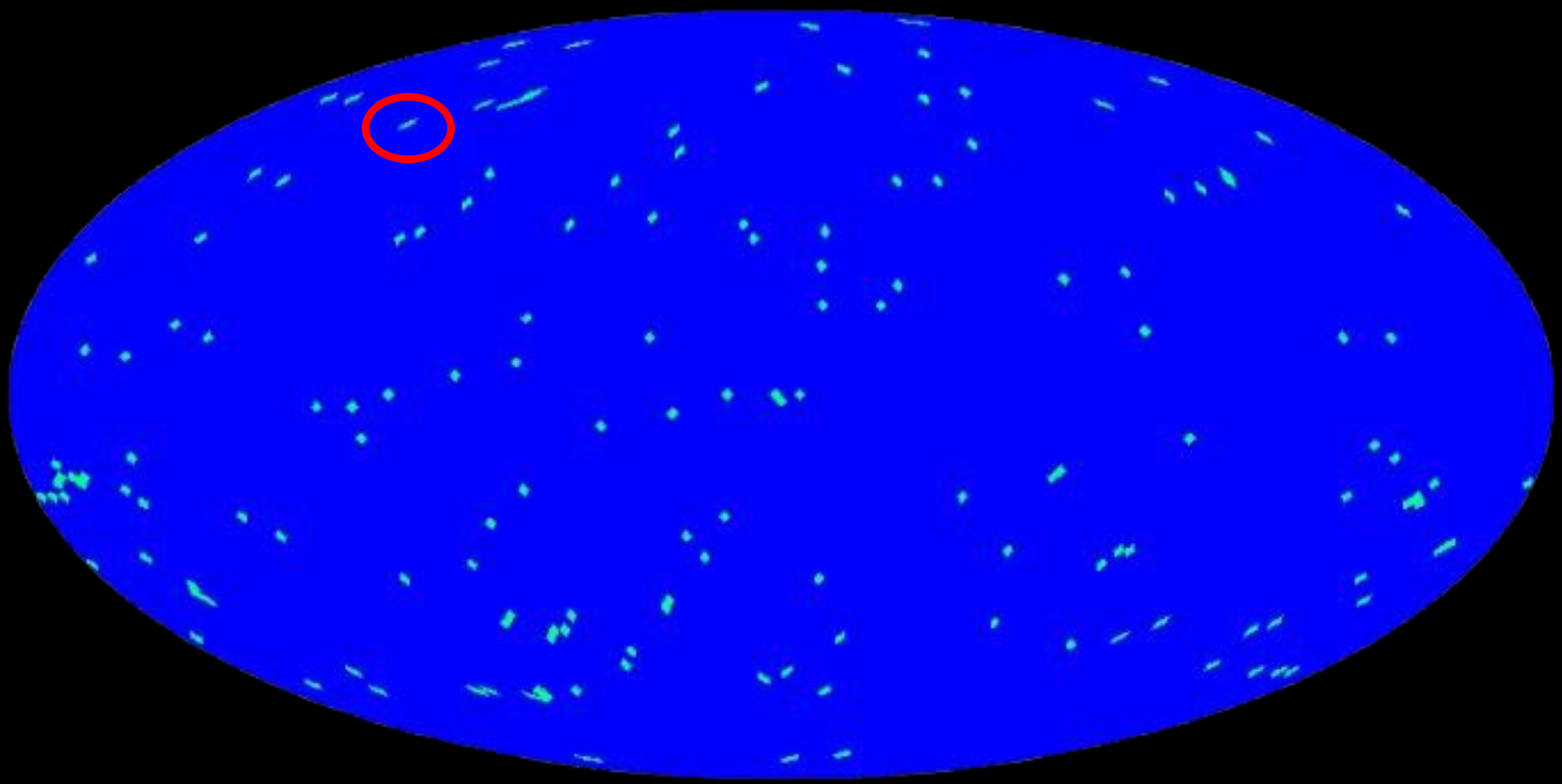
Pros:
- Tons of archival data
- No need to apply for time on the telescope
- DM signal-to-background more favourable

Cons:
- The DM signal might be low if the location is far from the GC
- Less deep than target observations

GN-z11

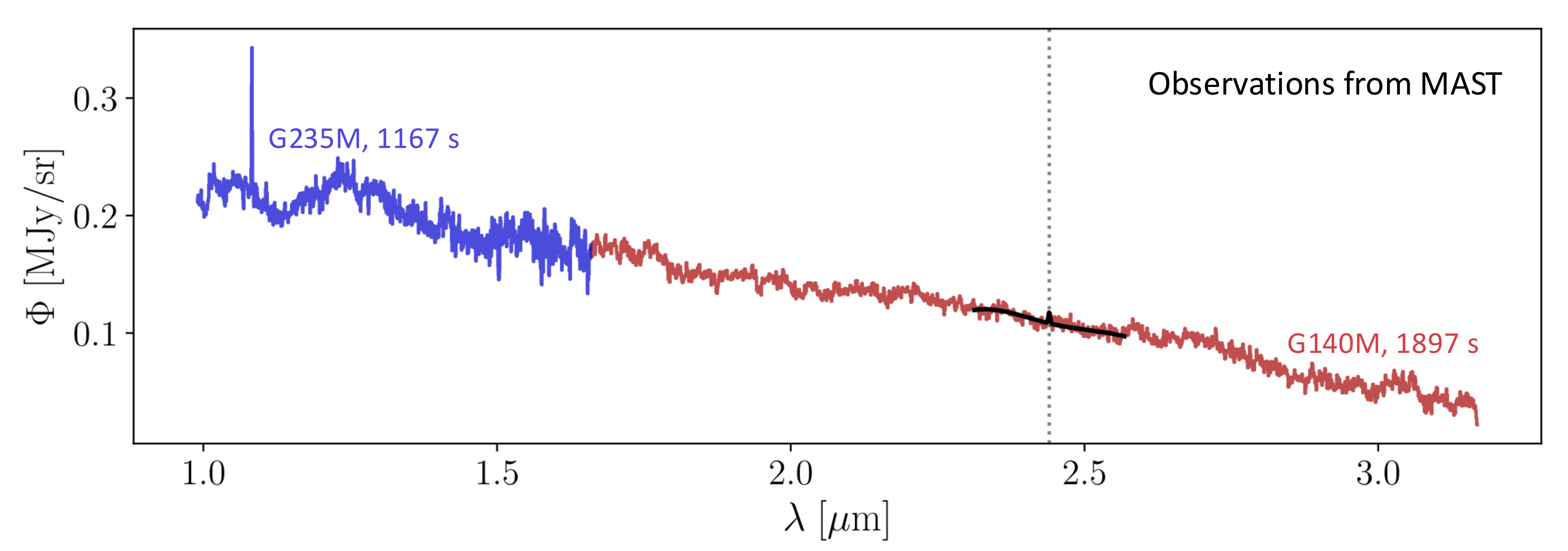
- High-redshift galaxy (z=10.6) in the constellation of Ursa Major
- Most distant known galaxy until 2022 (when JWST discovered JADES-GS-z13-0)
- Fun fact: Maiolino et al (2024) discovered that GN-z11 contains the most distant (aka earliest) black hole known in the Universe

GN-z11



- $(b, \ell) = (54.8°, 126°)$
- $D = 2.3 \times 10^{22}$ GeV/cm^2
- 2 observations: 1167s and 1897 s (less than 1h)

Blank-sky flux

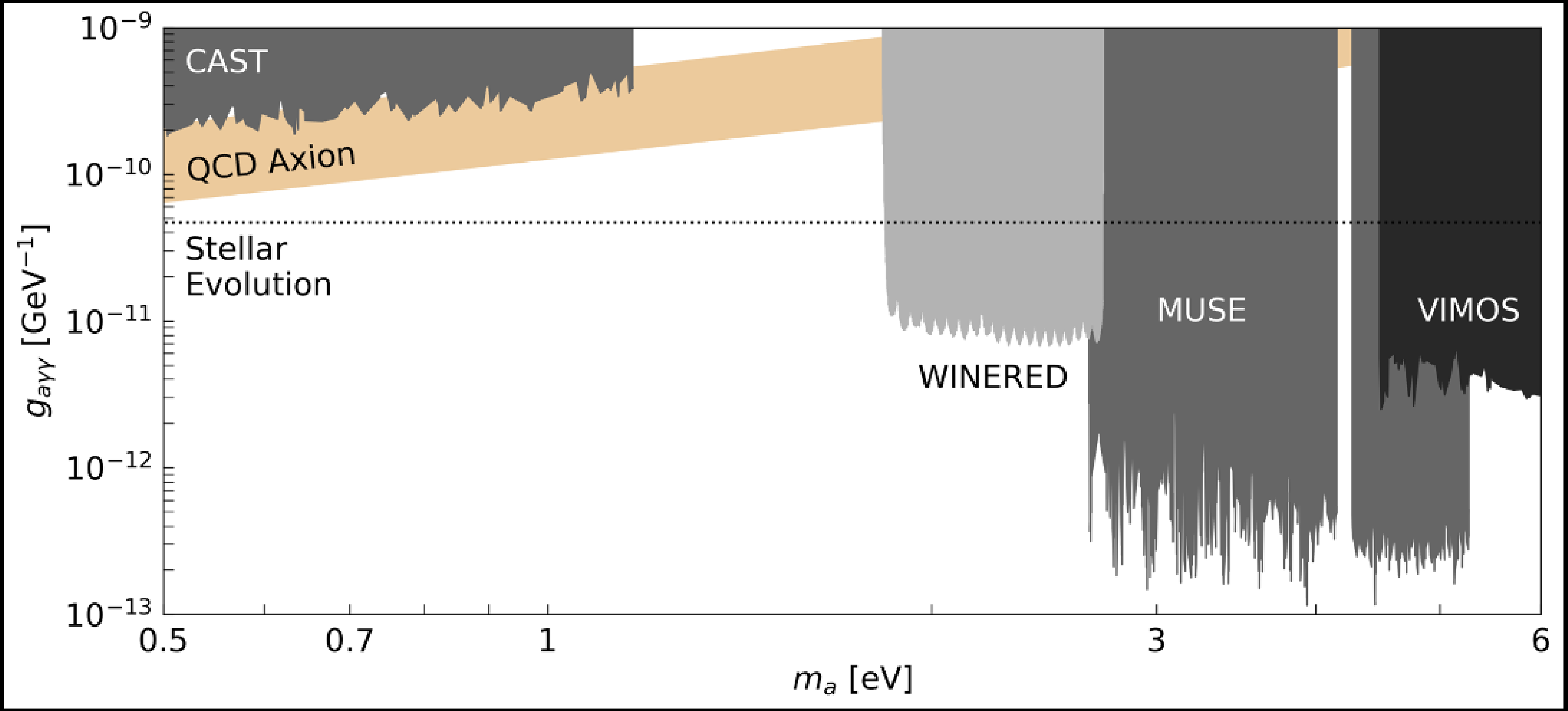


$m_a = 1\ \text{eV}$ $g_{a\gamma\gamma} = 1.1 \times 10^{-11}\text{GeV}^{-1}$

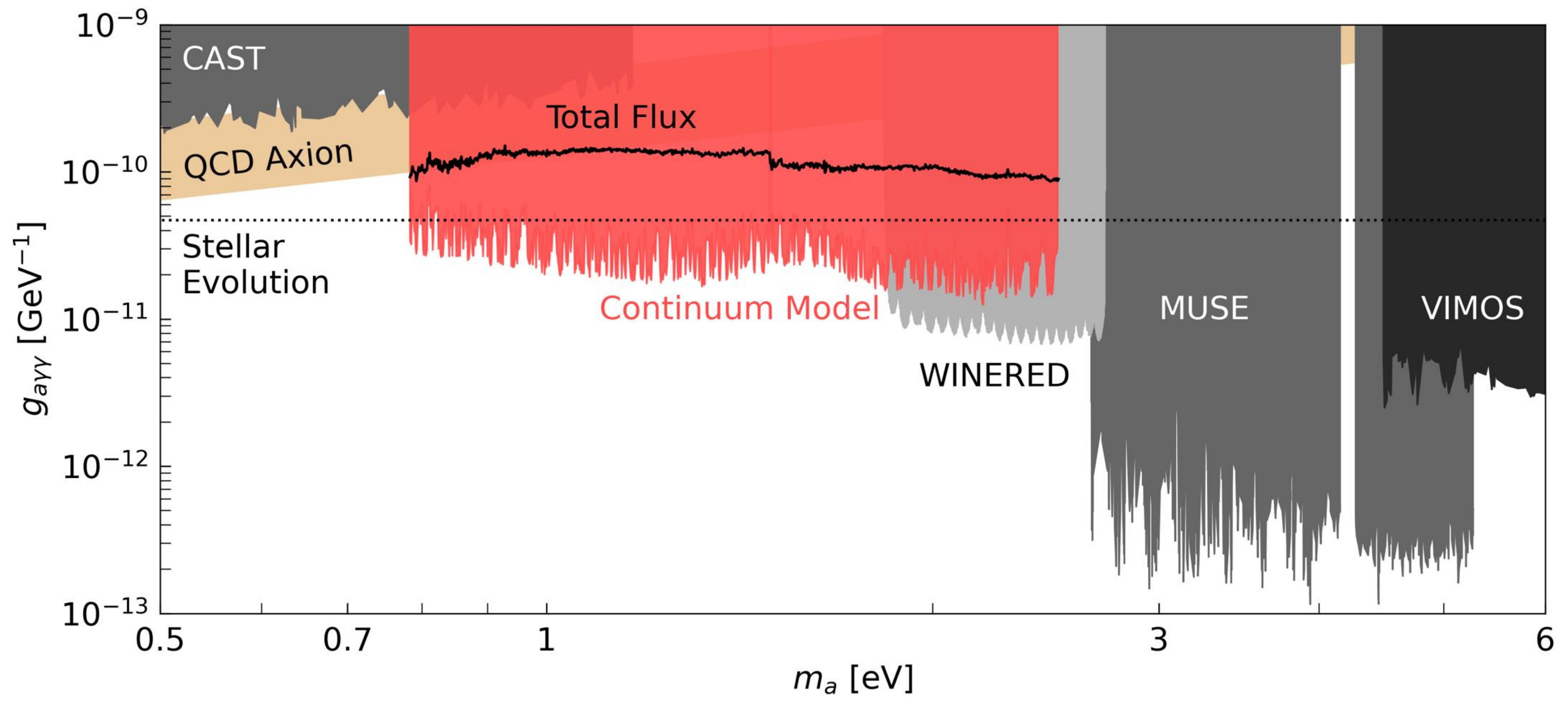
Janish & **EP**, arXiv:2310.15395, Accepted on PRL

Results

Bounds in the literature



JWST bounds

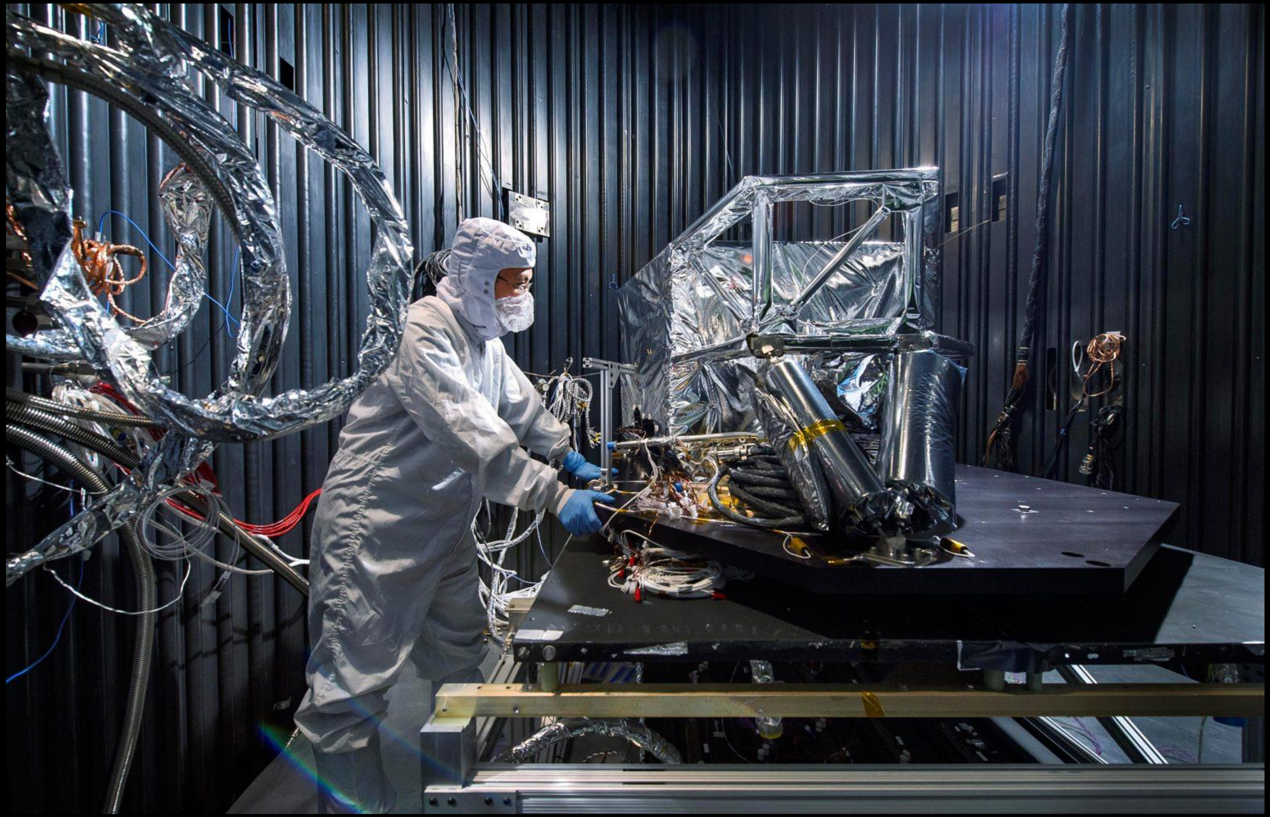


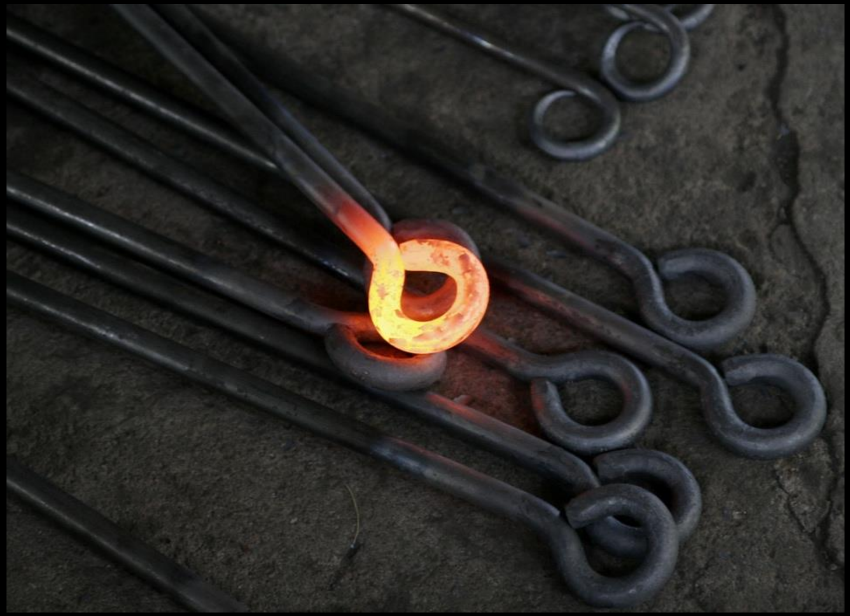
Janish & **EP**, arXiv:2310.15395, Accepted on PRL

Astrophysical backgrounds

Thermal self-emission

Thermal self-emission: instruments, or even the spacecraft itself, can emit infrared light because of thermal radiation (i.e. thermal motion of the particles in matter above 0 K)





NASA testing the Webb telescope's MIRI thermal shield in a thermal vacuum chamber at NASA's Goddard Space Flight Center in Greenbelt, MD. Credit: NASA

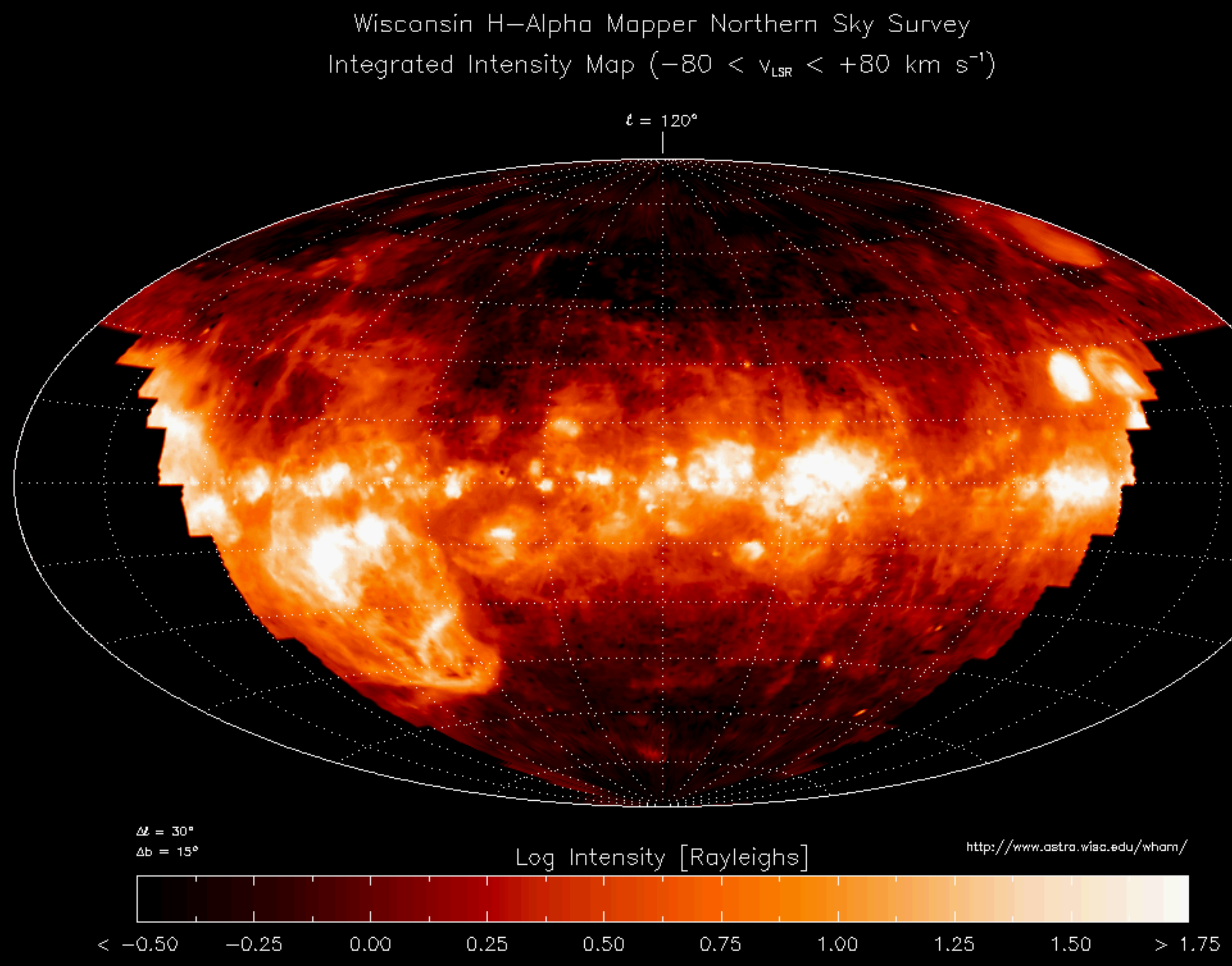
Stray light

Stray light: unwanted light that reaches a detector but does not originate from the intended source of observation (light from outside the fov, reflections within the telescope)

Insterstellar medium

ISM: interstellar medium background associated with the dust emission within our Galaxy

Examples:
- Interstellar dust grains absorb starlight and then re-emit the energy in infrared
- Spectral lines from highly excited states of hydrogen

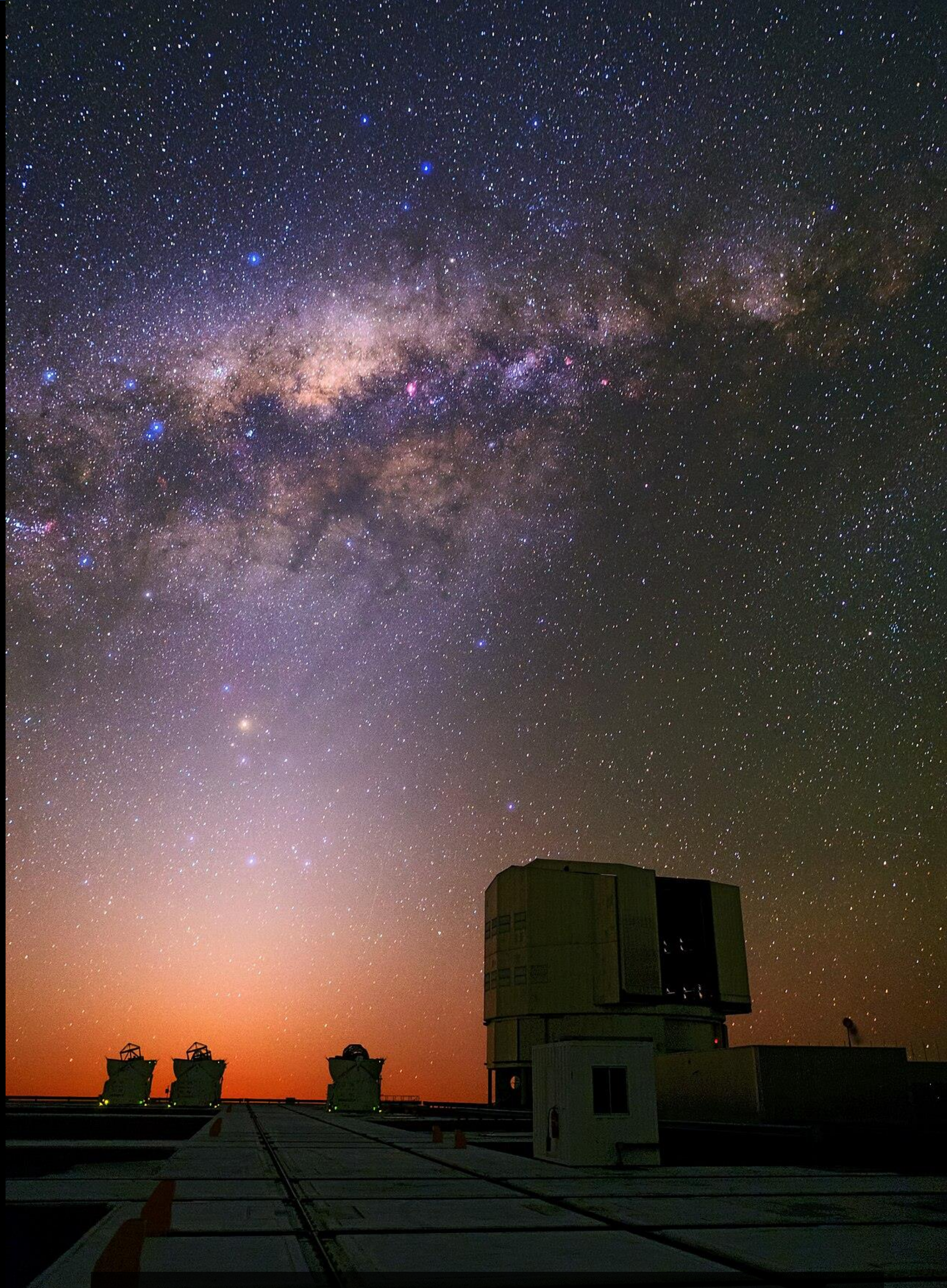


Zodiacal light

Zodiacal light ("false dawn") originates from sunlight scattered by dust particles in the Solar System

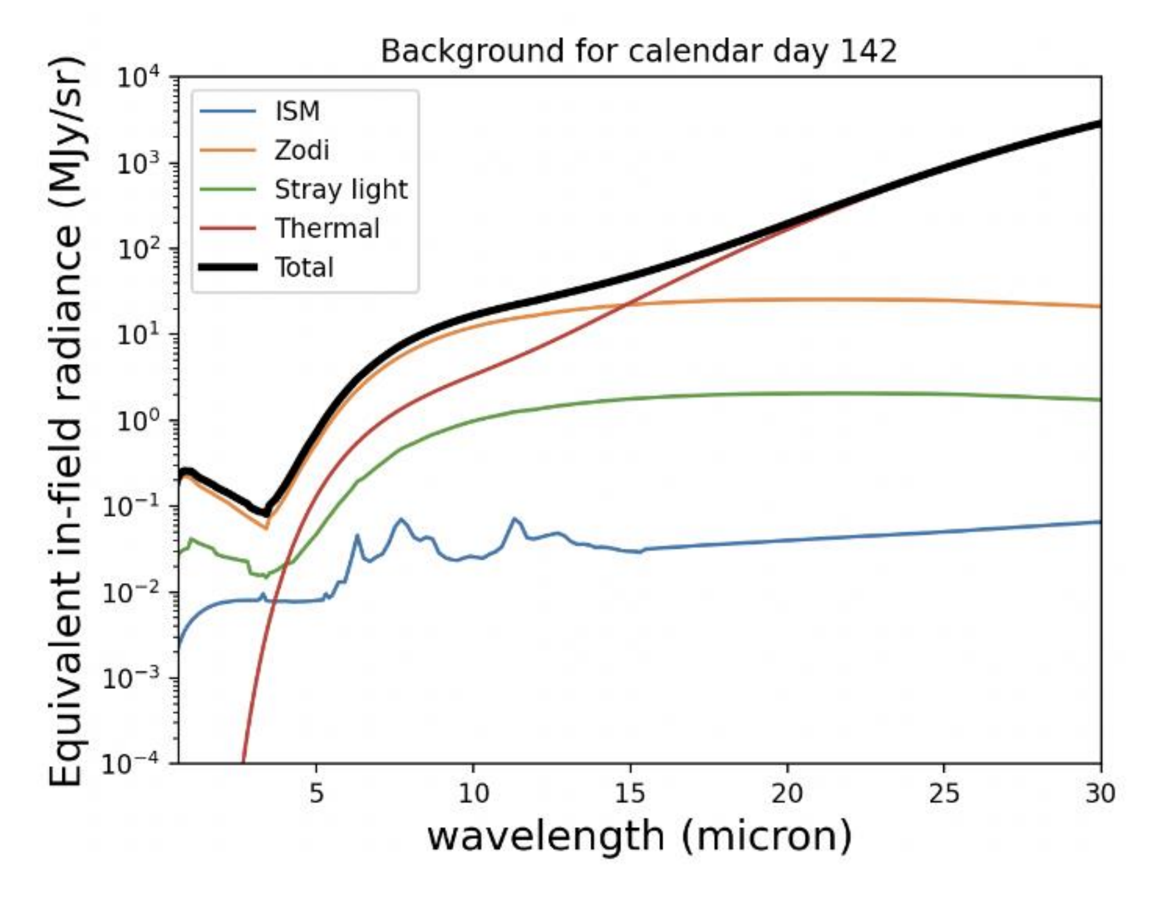
Moon, Apollo 15

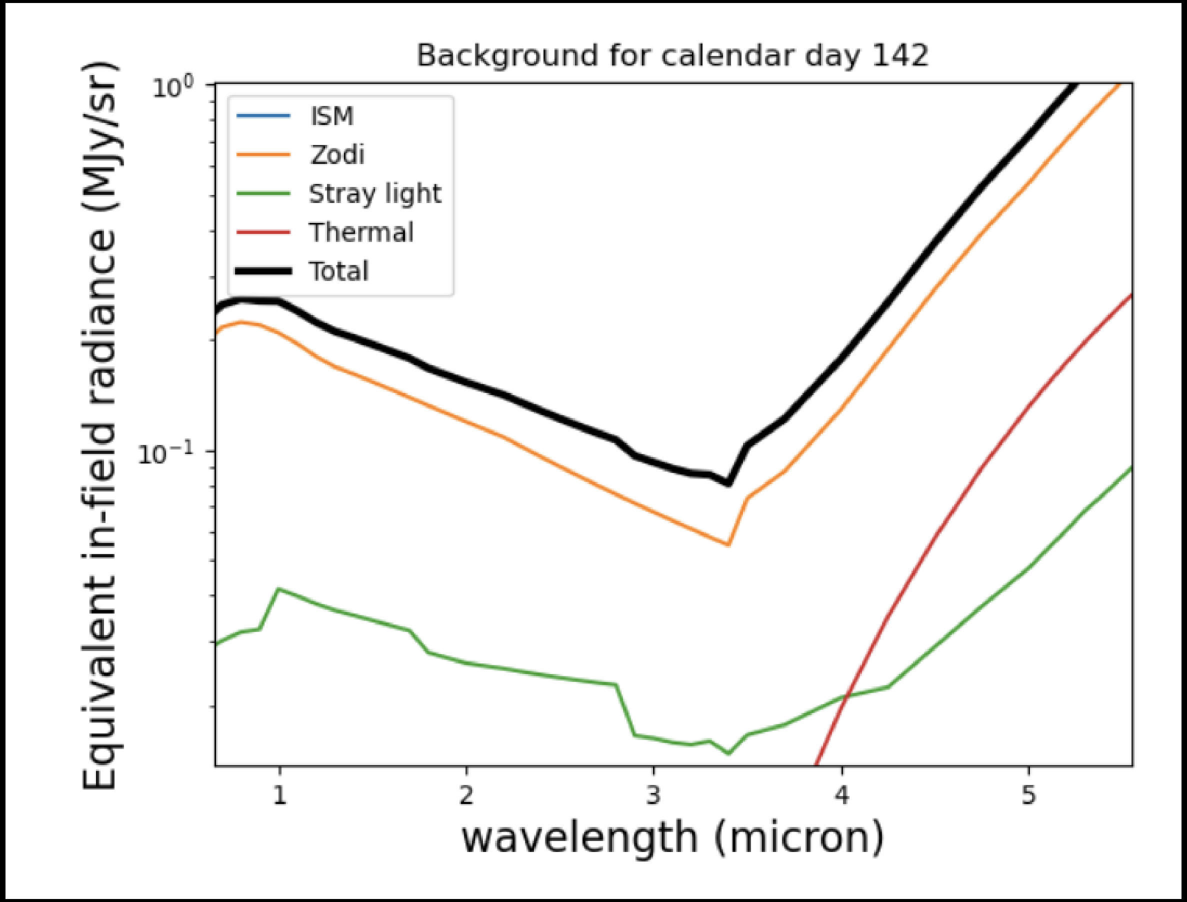
Brian May, guitarist of Queen



Very Large Telescope, Atacama Desert (Chile)

Astrophysical backgrounds





Backgrounds from: https://jwst-docs.stsci.edu/jwst-other-tools/jwst-backgrounds-tool#gsc.tab=0

Decay lifetime

$$\Gamma_{a\to\gamma\gamma} = \frac{g_{a\gamma\gamma}^2\, m_a^3}{64\pi}$$

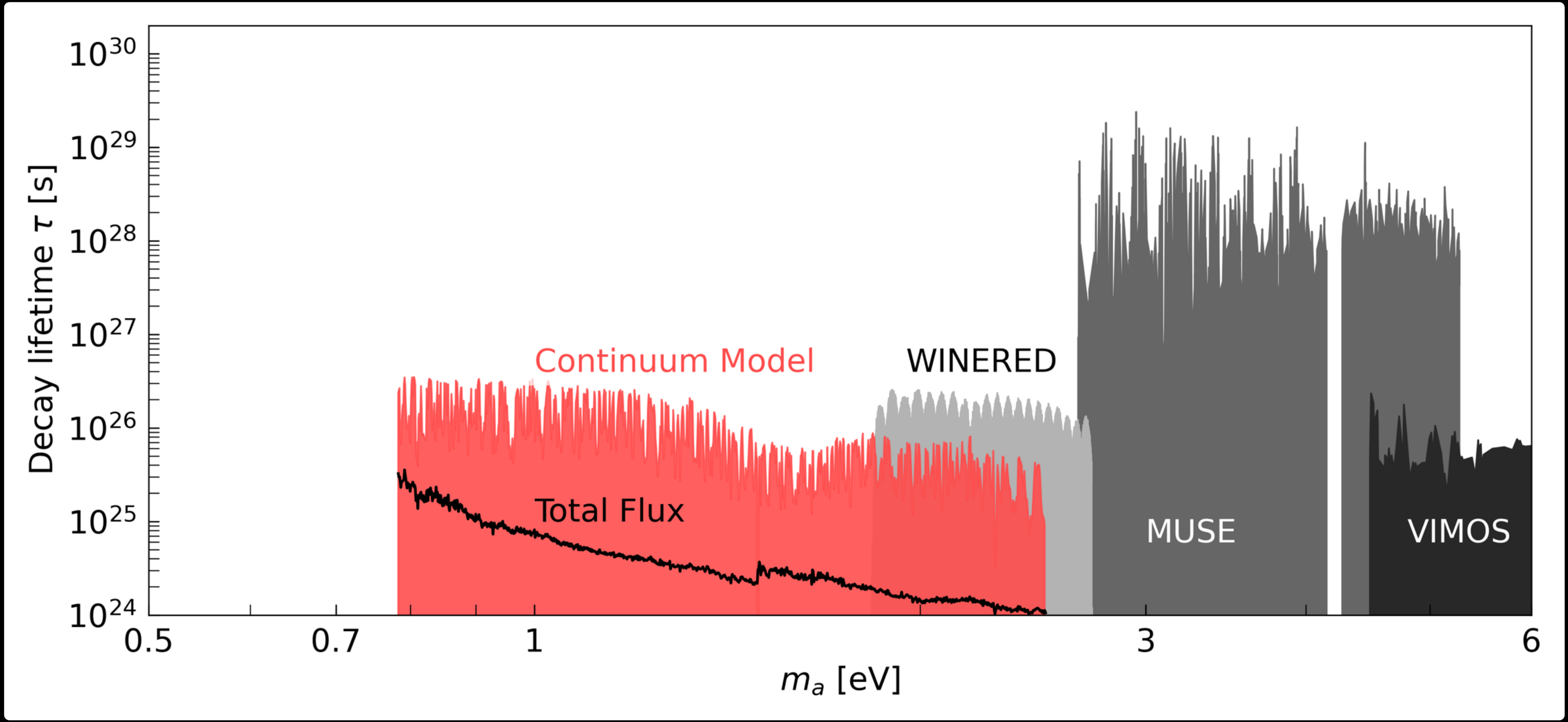
Emission rate

Axion mass

$$\tau_{a\to\gamma\gamma} = \frac{1}{\Gamma_{a\to\gamma\gamma}}$$

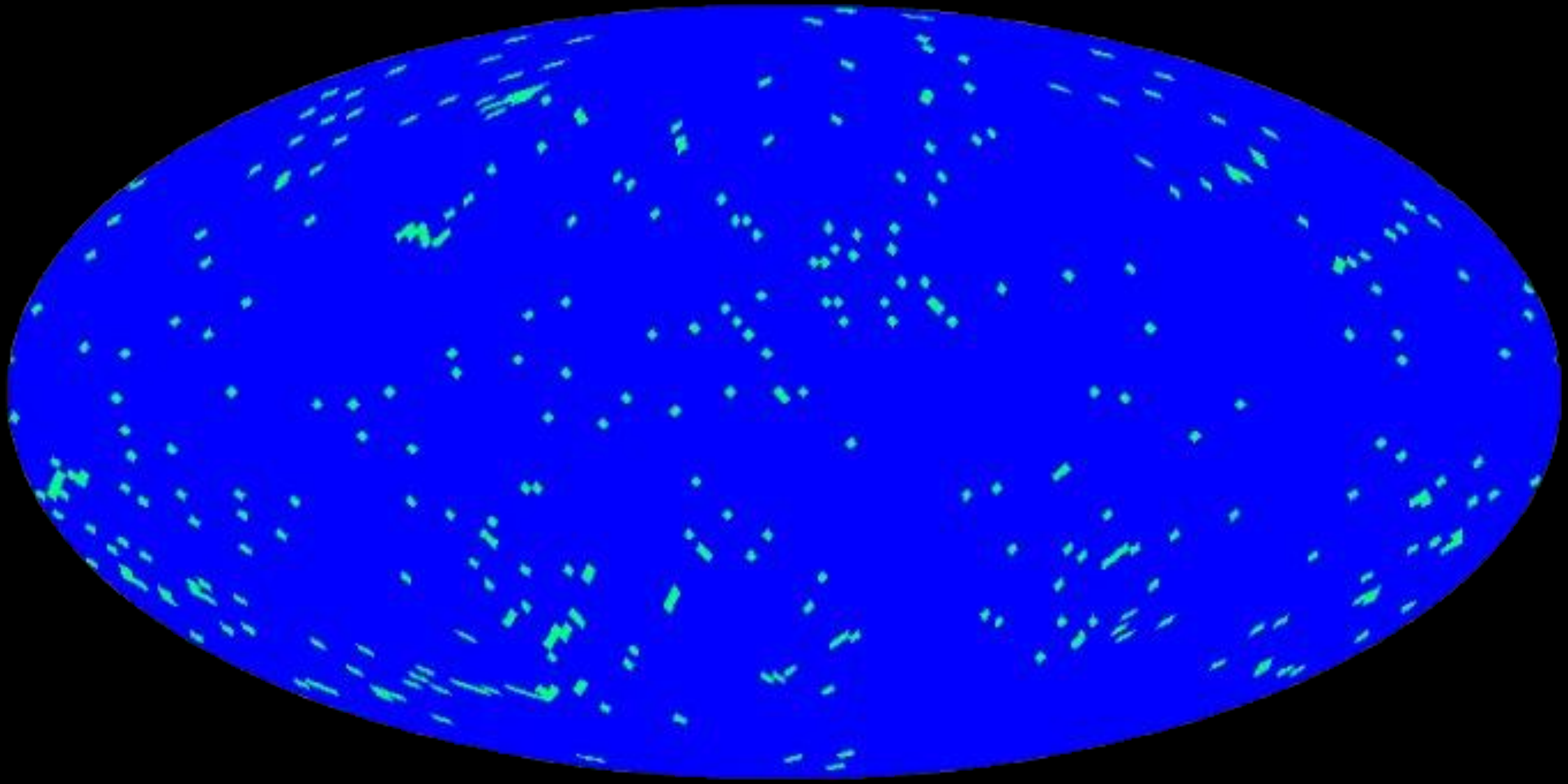
$$\left(\frac{5.5\times 10^{-7}\,\mathrm{GeV}^{-1}}{\ldots}\right)^2 \left(\frac{1\ \mathrm{eV}}{\ldots}\right)^3$$

Bounds on the decay lifetime



An eye toward the future

More JWST observations



- 1000+ targets
- More statistics and better targets
- Both NIRSPEC and MIRI

EMIR @ Gran Telescopio Canarias

EMIR: Espectrógrafo Multi-objeto Infra-Rojo, Infrared Multiobject Spectrograph

Location: Roque de los Muchachos Observatory (La Palma, Canary Islands)

Multi-object medium-resolution spectrograph and wide-field imager

Wavelength: near-infrared (0.9-2.5 μm)

IAC collaborators: Jorge Camalich, Jorge Terol Calvo and Francisco Garzon Lopez

Infrared & Optical observations

Infrared observations: Spitzer, KECK, Euclid, …

Optical observations: HST, VLT, DESI, HETDEX…

Summary & Conclusions

1. Infrared observations from different targets (dwarfs, blank sky, …) are a powerful way to probe dark matter

2. Infrared telescopes, in particular JWST, provide competitive bounds

3. Numerous observations are already available and more data are on their way: This is just the beginning!

Summary & Conclusions

Thank you for your attention!

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