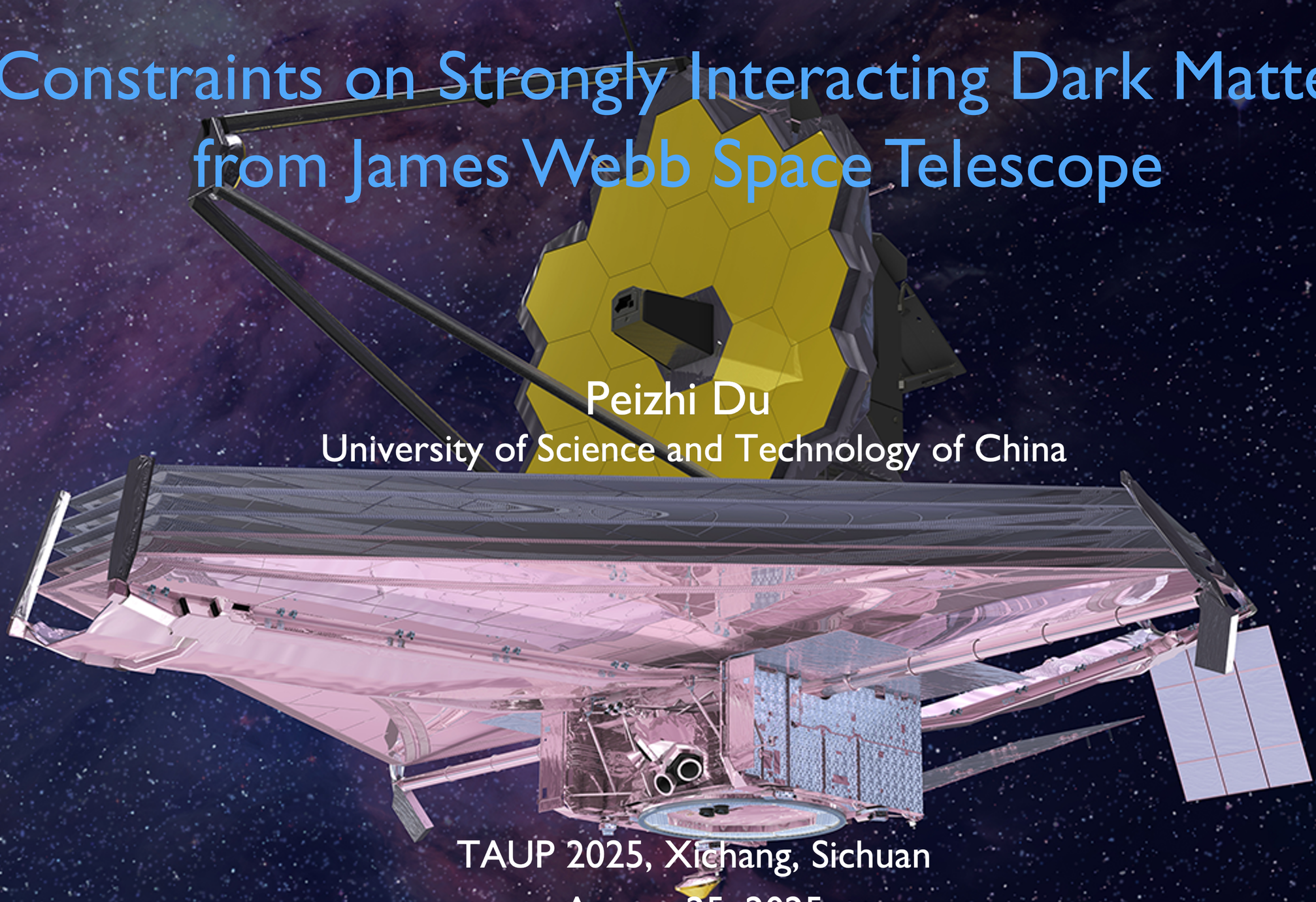
Constraints on Strongly Interacting Dark Matter from James Webb Space Telescope

Peizhi Du
University of Science and Technology of China

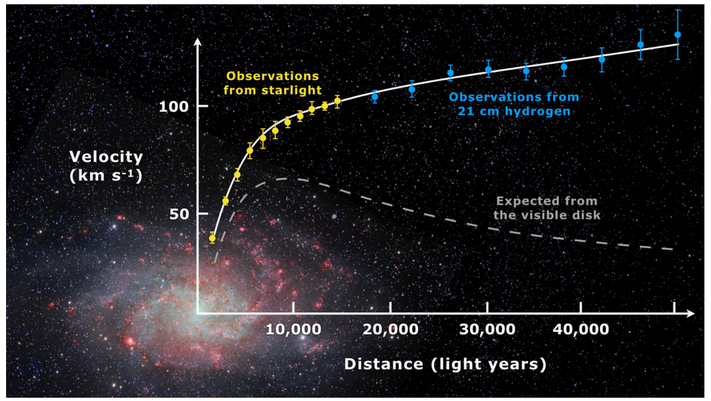


TAUP 2025, Xichang, Sichuan
August 25, 2025

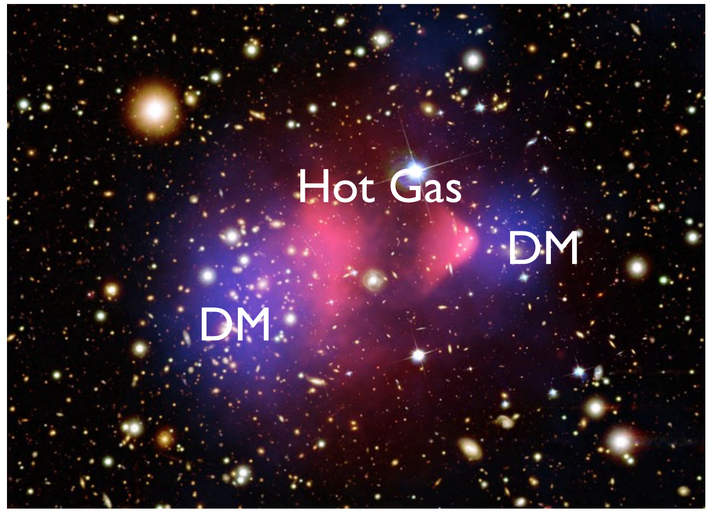
image from JWST official website

Dark Matter

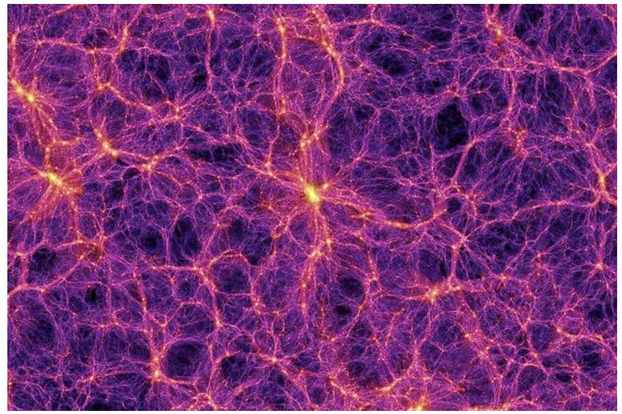
Numerous evidence for the existance of DM



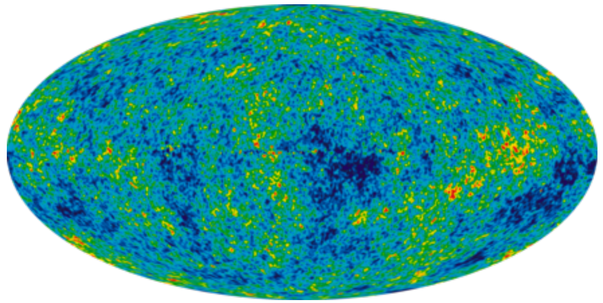
Galaxy (10^4-10^5 ly)



Galaxy Cluster (~10^6 ly)



Large Scale Structure (~10^7 ly)



Cosmic Microwave Background (~10^{10} ly)

What we know about DM

- Abundant: 85% of matter
- Massive/stable
- Gravitational interactions

What we don't know about DM

- Particle Nature
- Mass
- Interactions with visible matter?
- DM self-interactions?

…

What could Dark Matter be

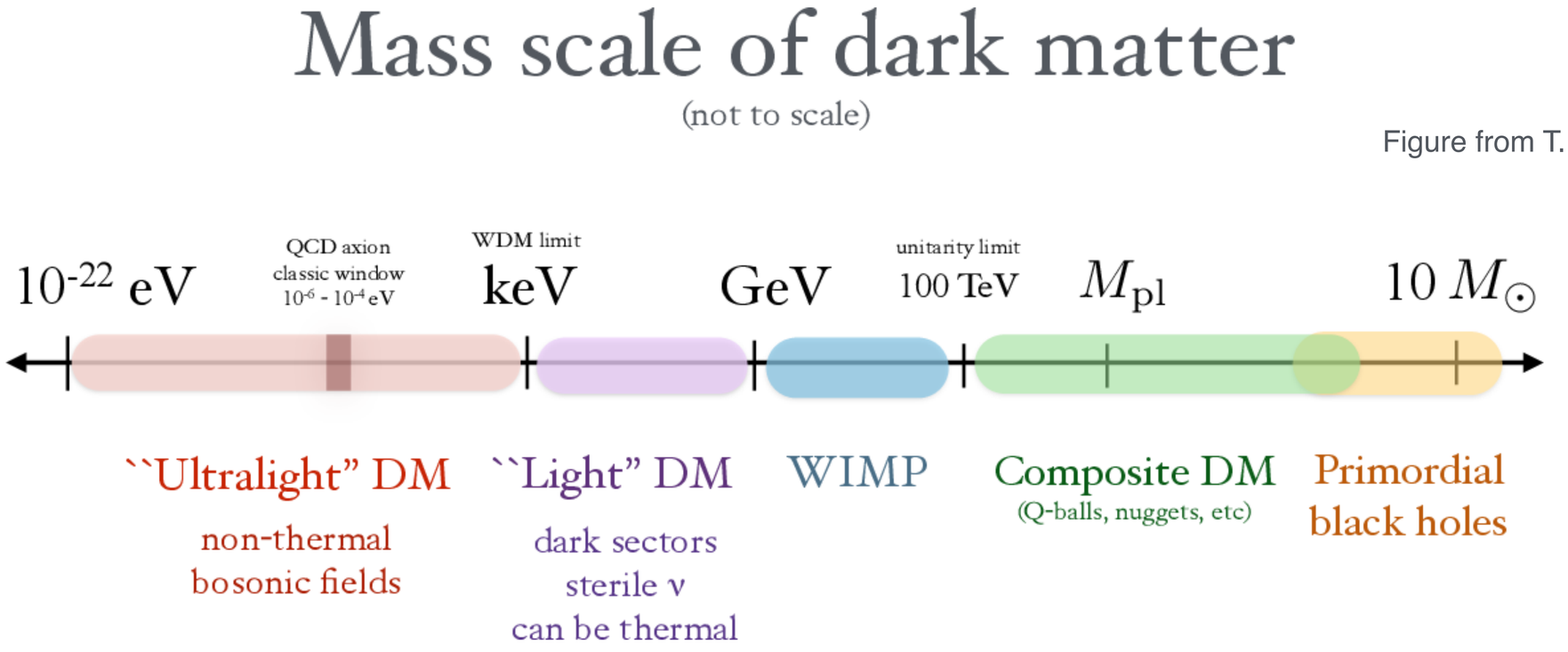
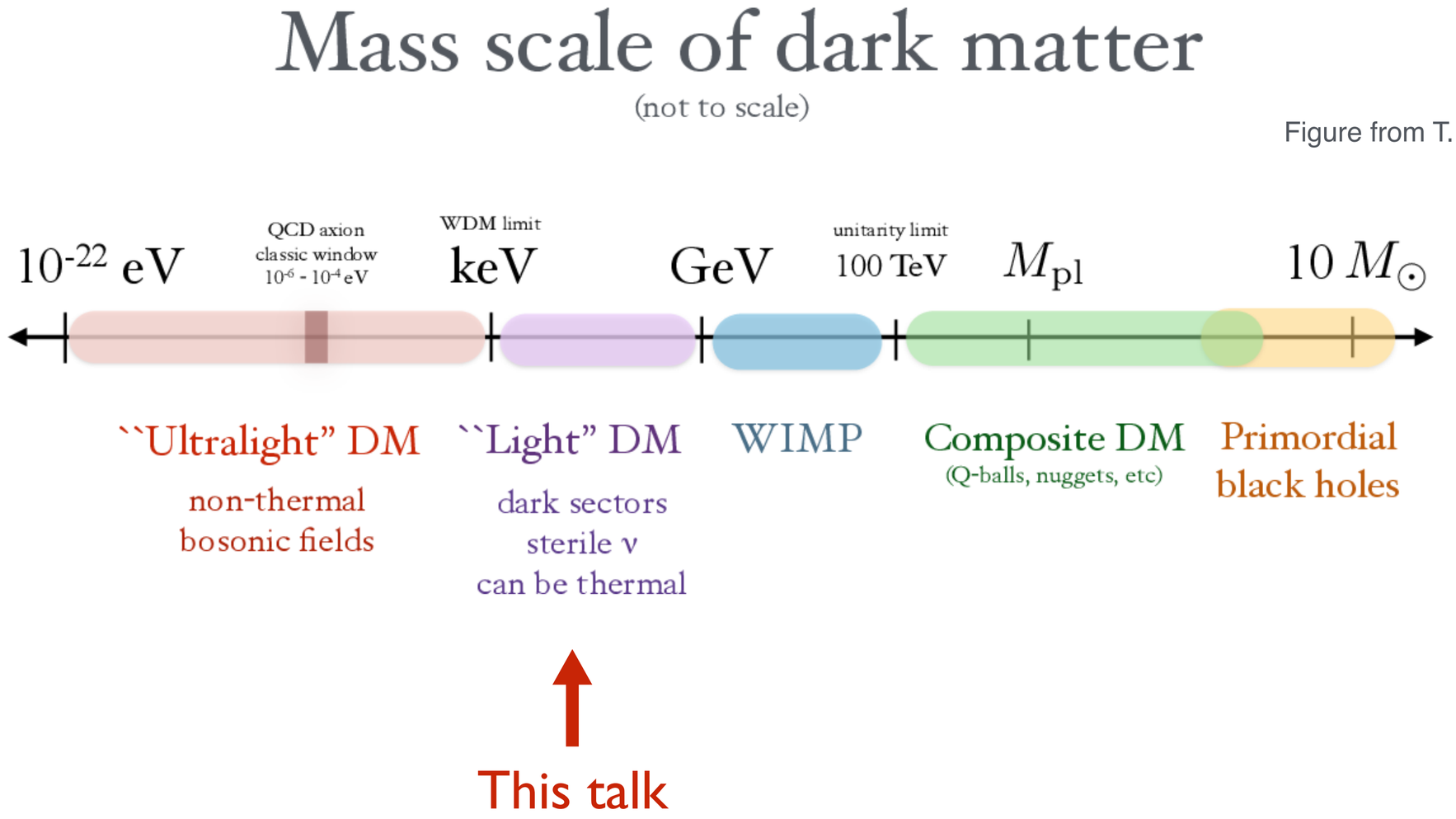


Figure from T. Lin (arXiv:1904.07915)

What could Dark Matter be



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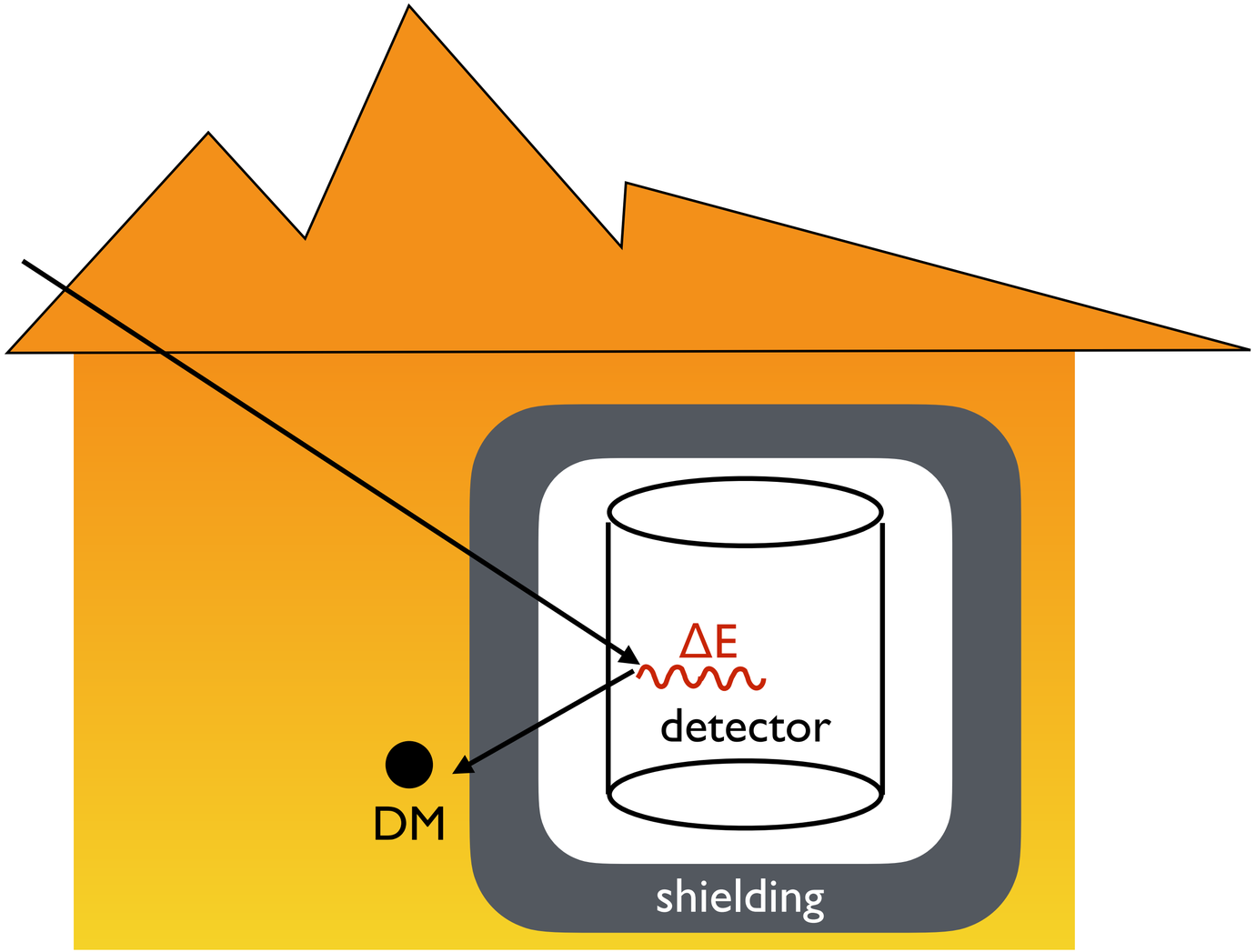
How to look for DM: Direct Detection of DM



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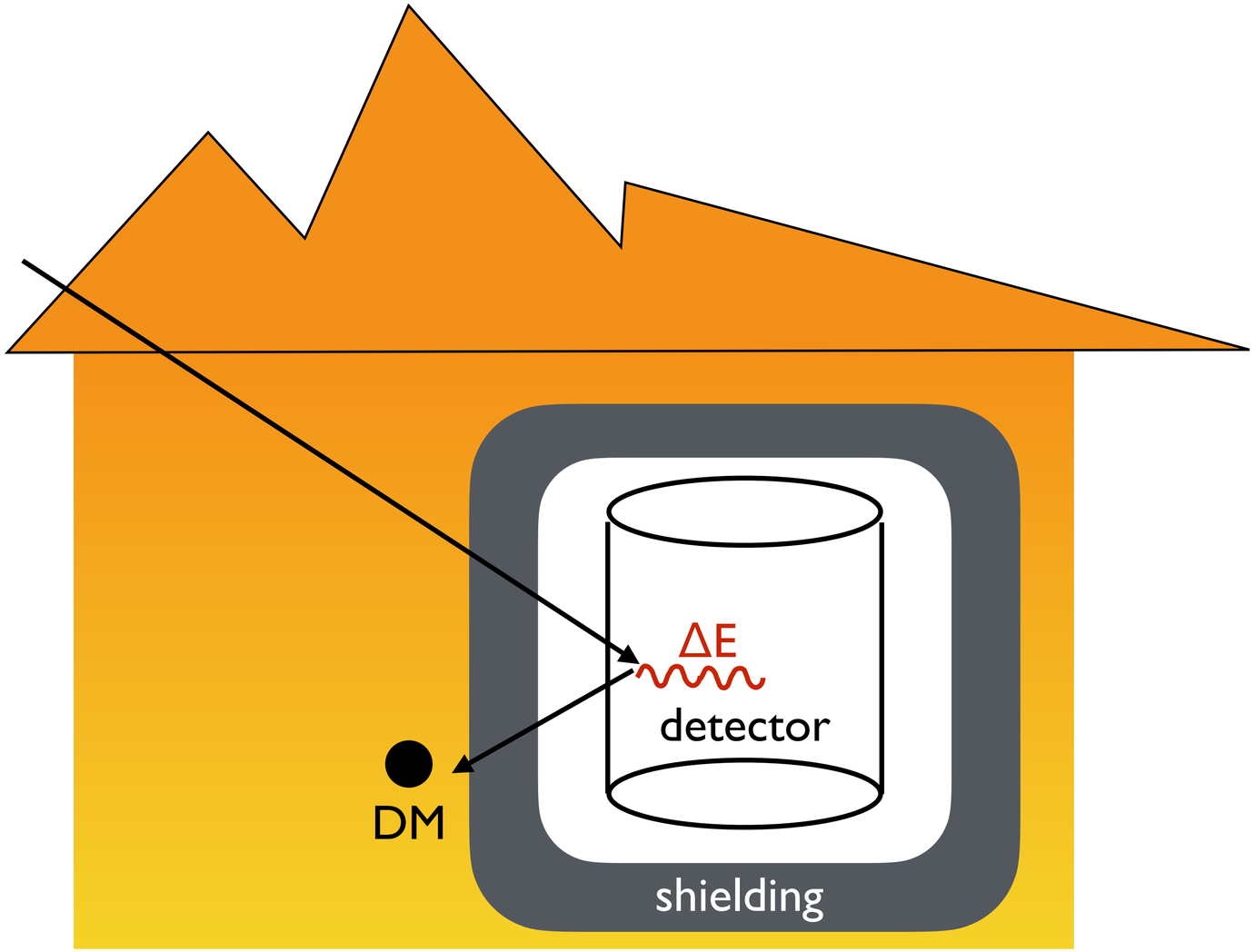
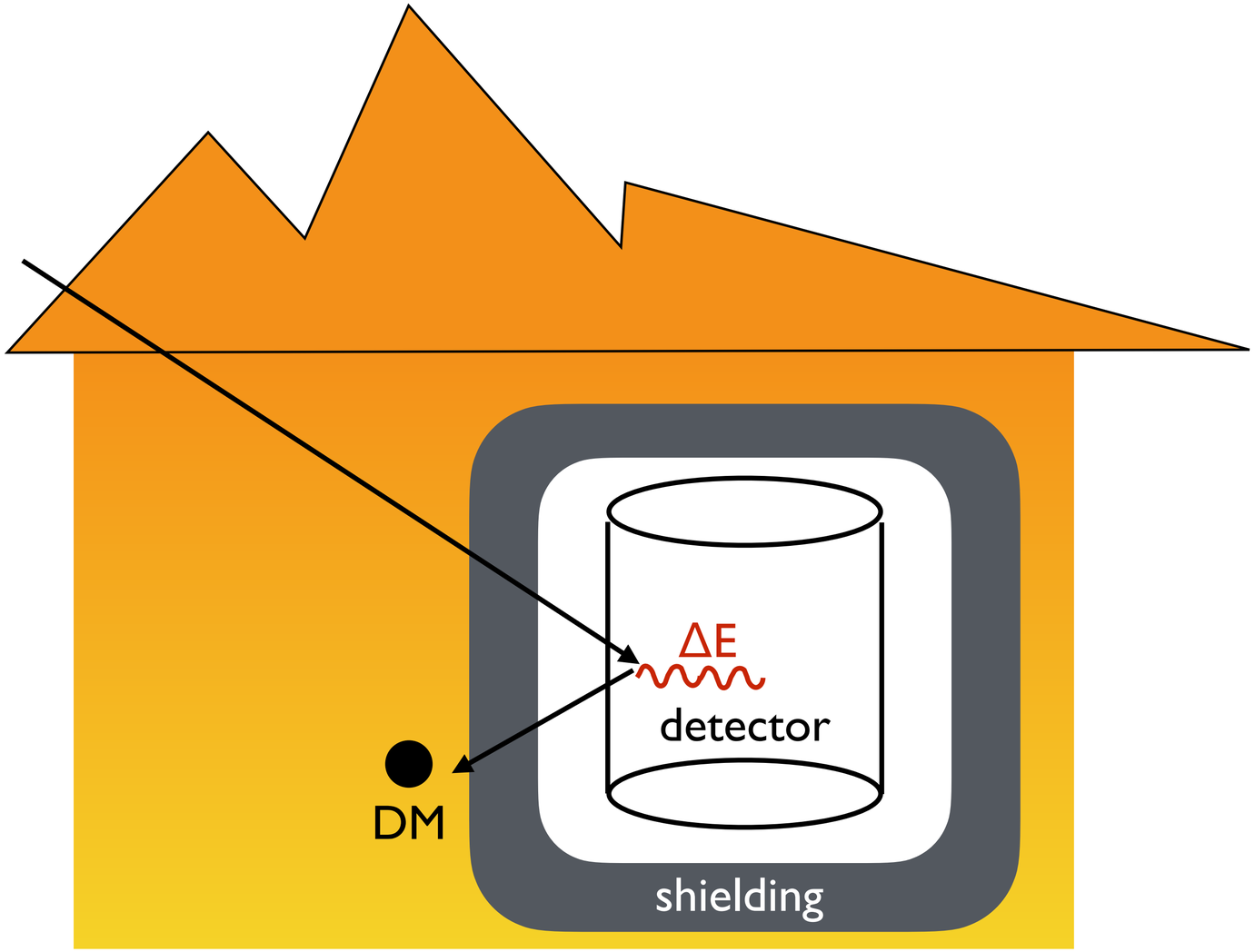


WIMP

Light DM

How to look for DM: Direct Detection of DM



WIMP

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

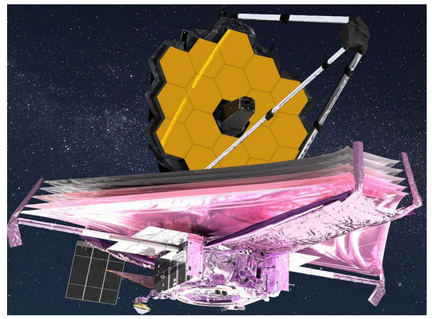
CDEX

XENON

Light DM

ensei

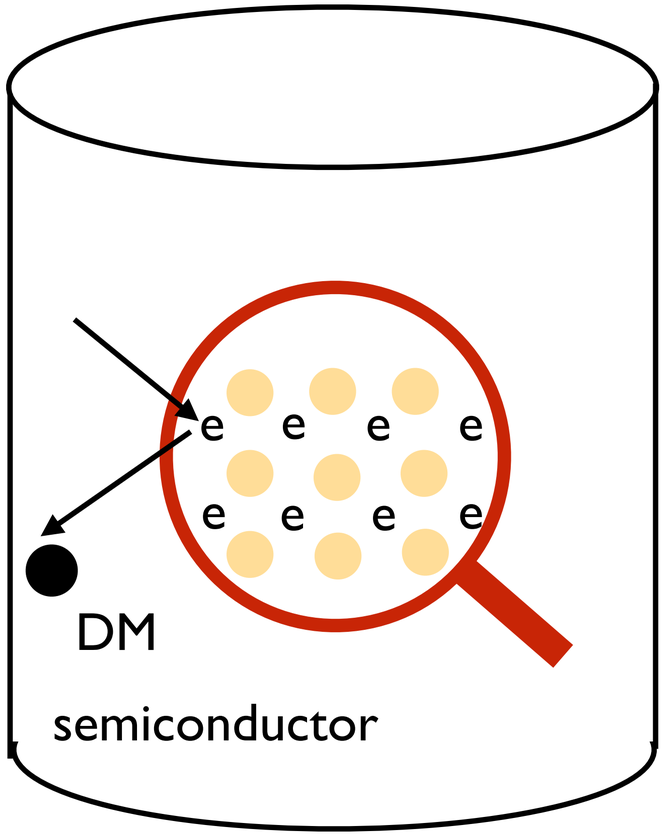
SUPER CDMS
Cryogenic Dark Matter Search



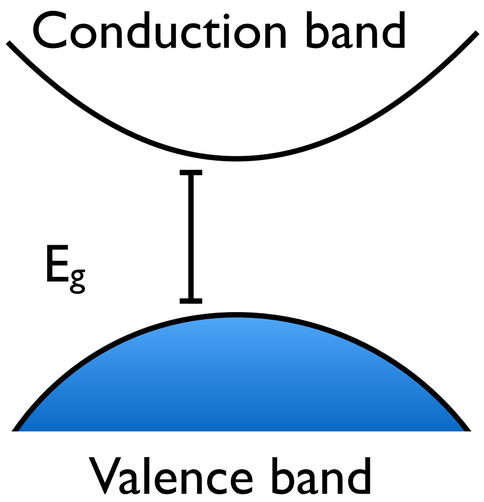
Space detectors

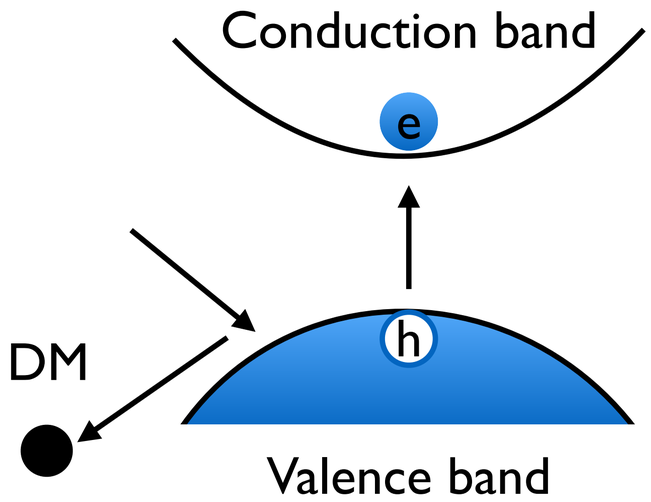
Direct Detection of Light DM

Essig, Mardon, Volansky, *PRD* 2012



DM-electron scattering





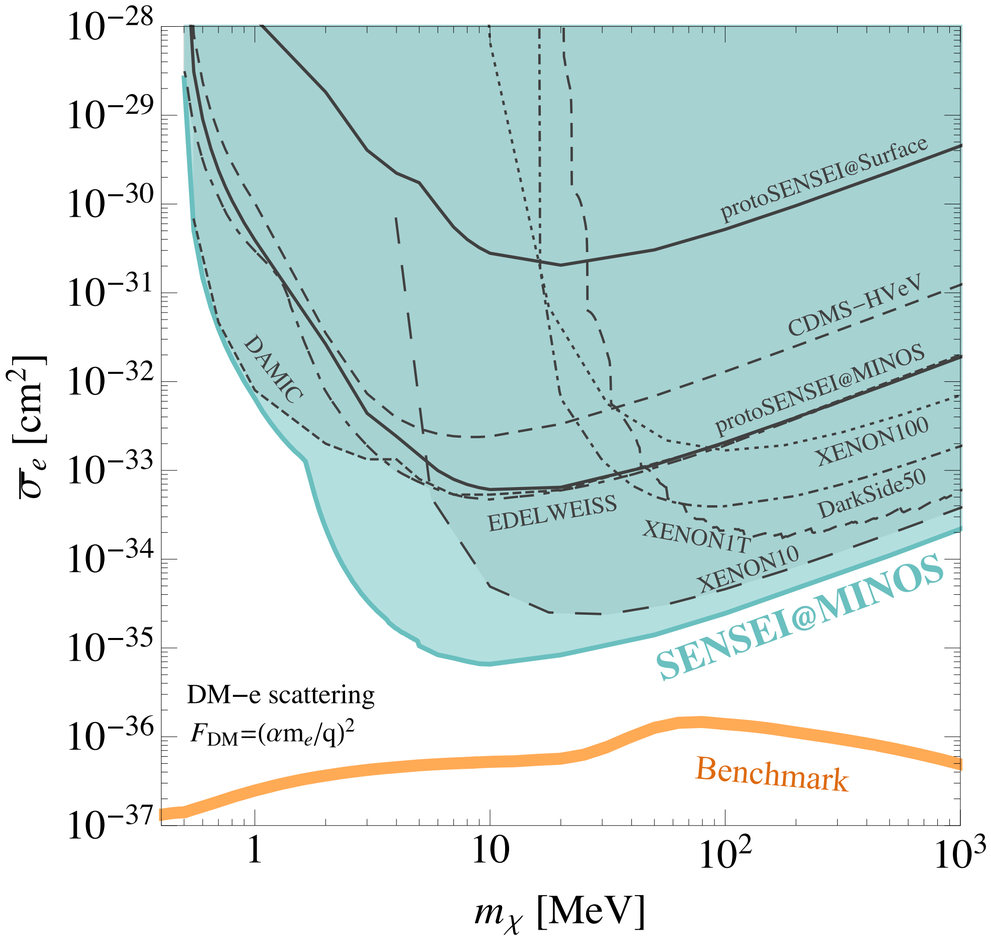
Energy transfer: $E_{\rm ER} \lesssim \frac{1}{2} m_\chi v^2$

Signals: eh pairs

Threshold: bandgap E_g~1 eV

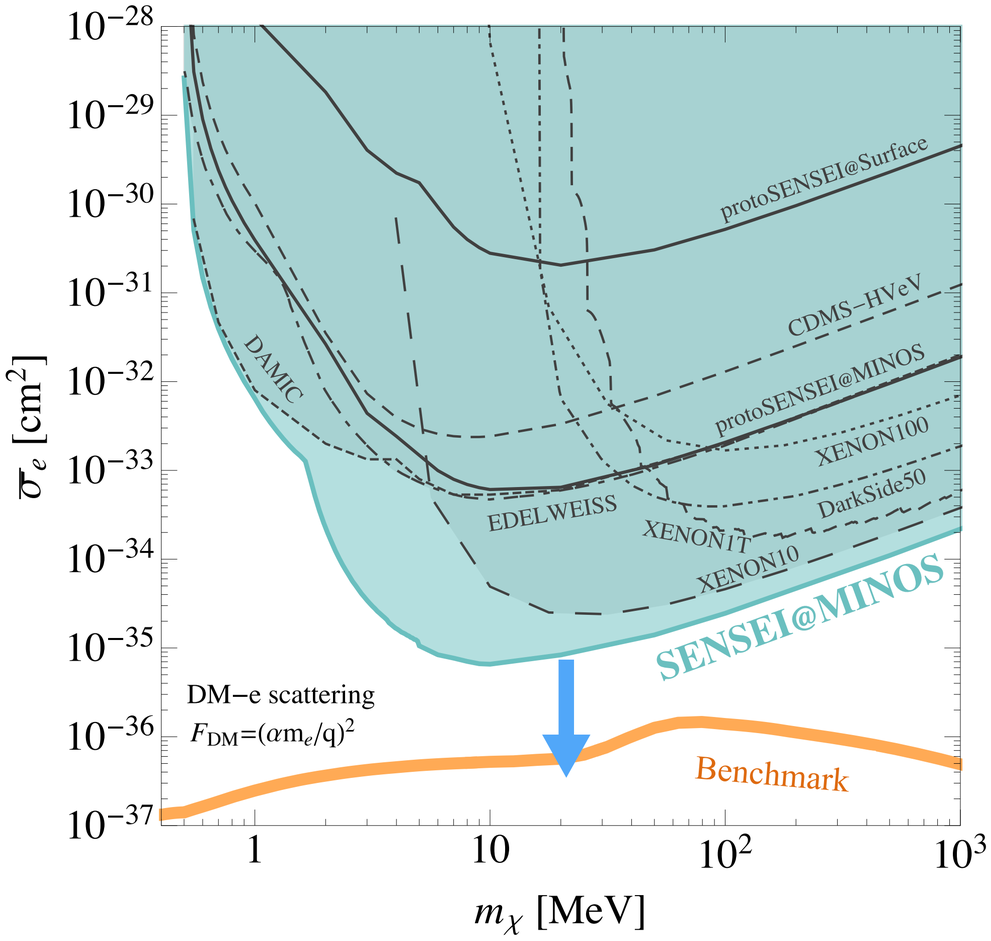
Current Constraints

Figure from SENSEI, *PRL* 2020



Current Constraints

Figure from SENSEI, *PRL* 2020

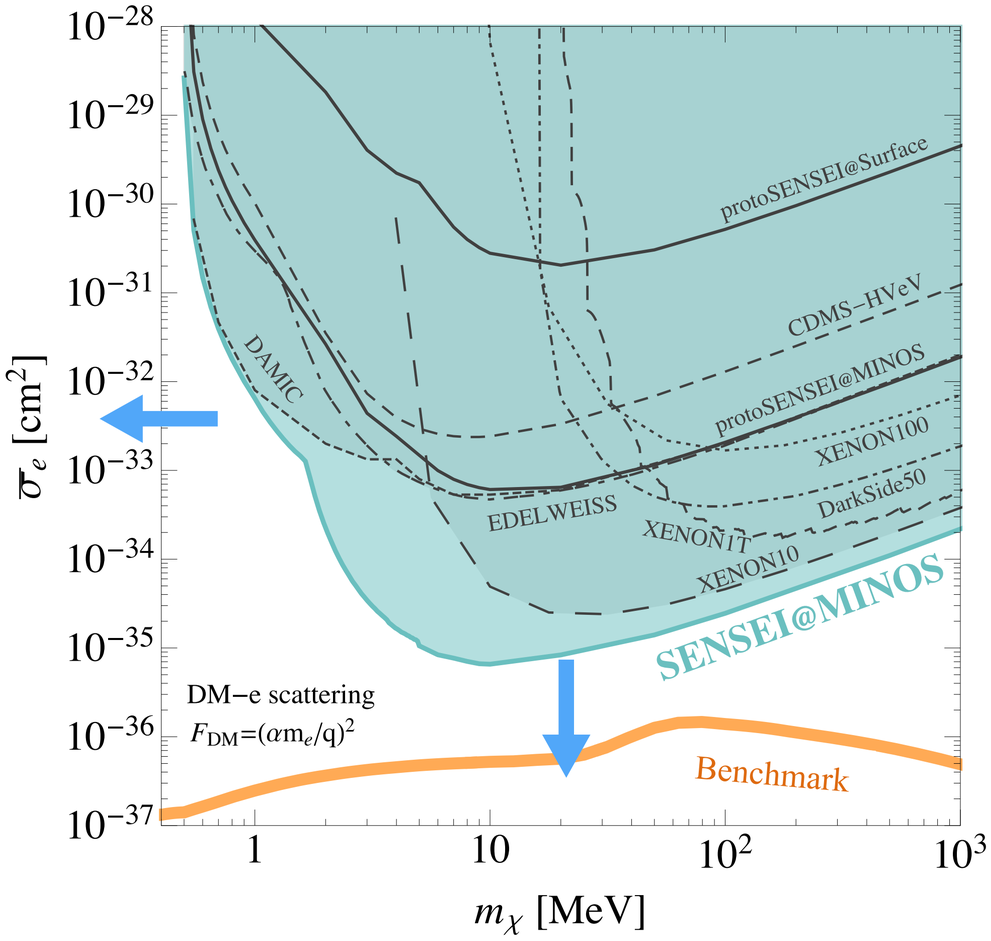


Exploring the parameter space

Probing the theory benchmark

Current Constraints

Figure from SENSEI, *PRL* 2020



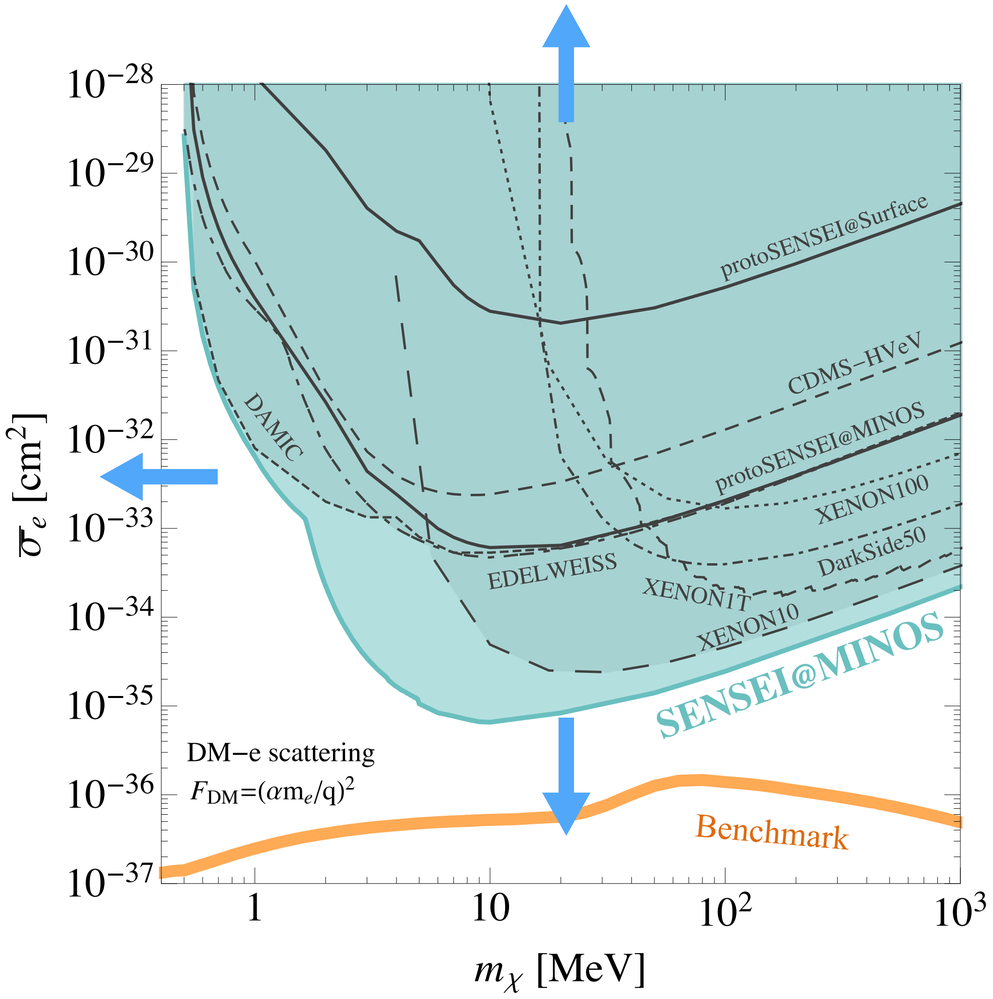
Exploring the parameter space

Probing the theory benchmark

Probing DM lighter than MeV

Current Constraints

Figure from SENSEI, *PRL* 2020



Exploring the parameter space

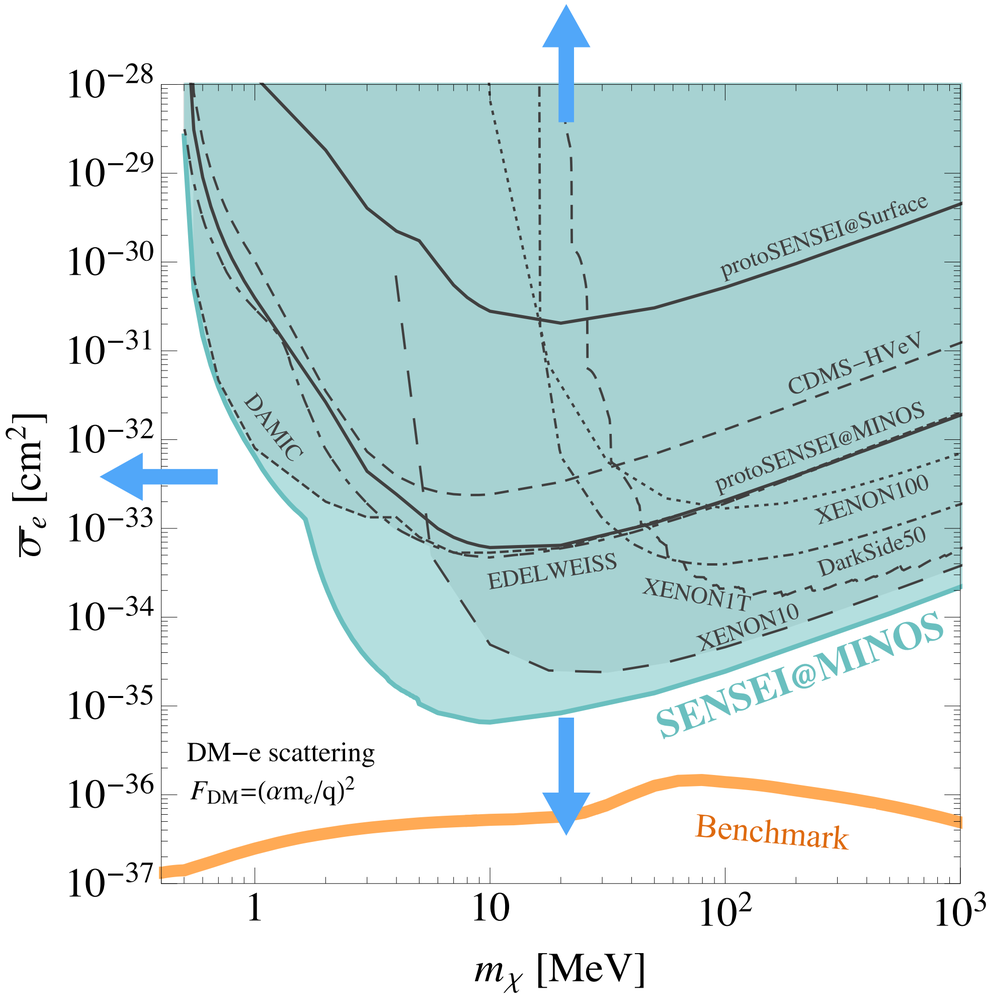
Probing the theory benchmark

Probing DM lighter than MeV

Probing strongly interacting DM

Current Constraints

Figure from SENSEI, *PRL* 2020



Exploring the parameter space

Probing the theory benchmark

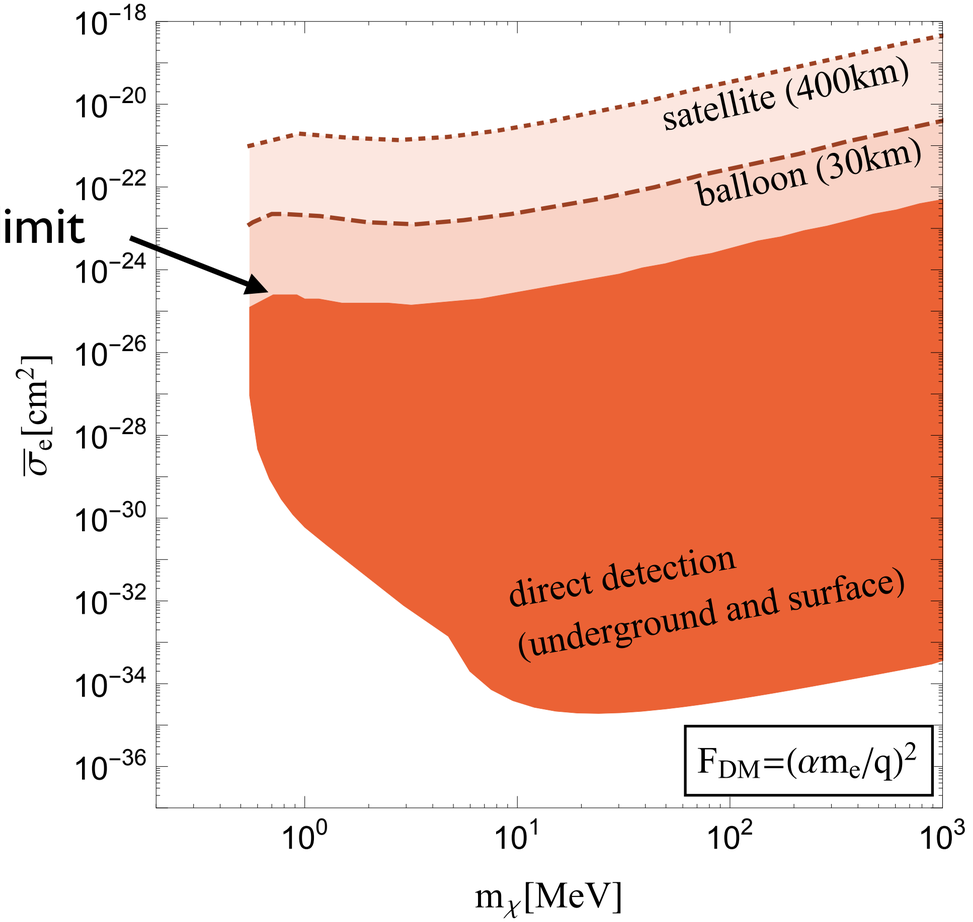
Probing DM lighter than MeV

Probing strongly interacting DM

Space-based detectors

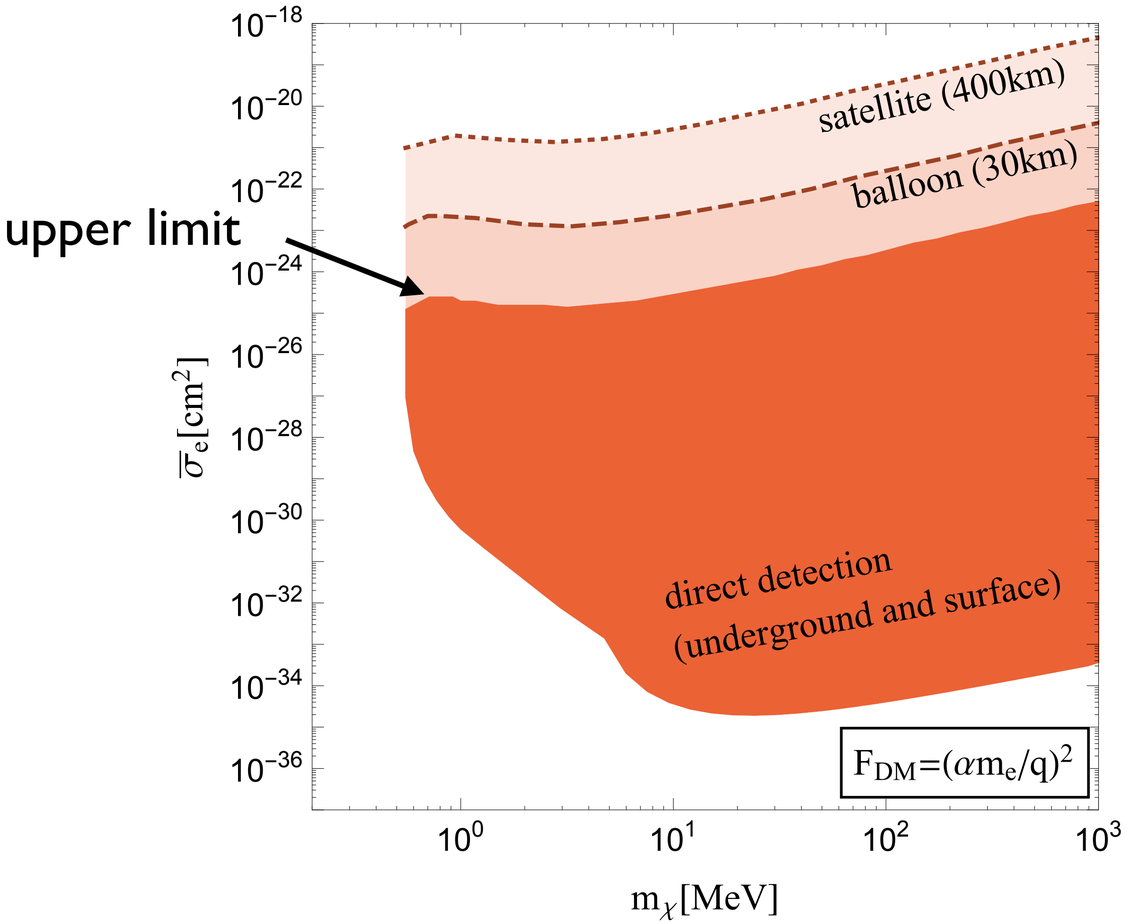
Upper limit of ground-based detectors

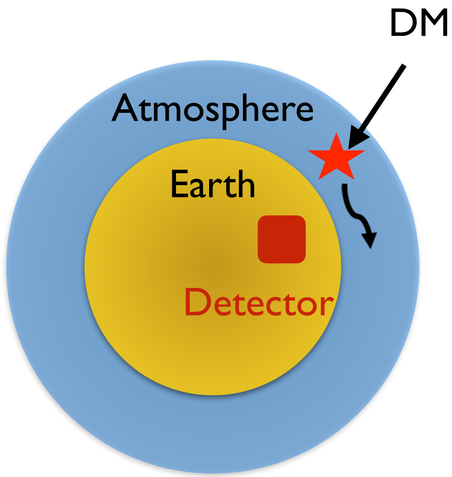
upper limit



Emken, Essig, Kouvaris, Sholapurkar, *JCAP*, 2019

Upper limit of ground-based detectors

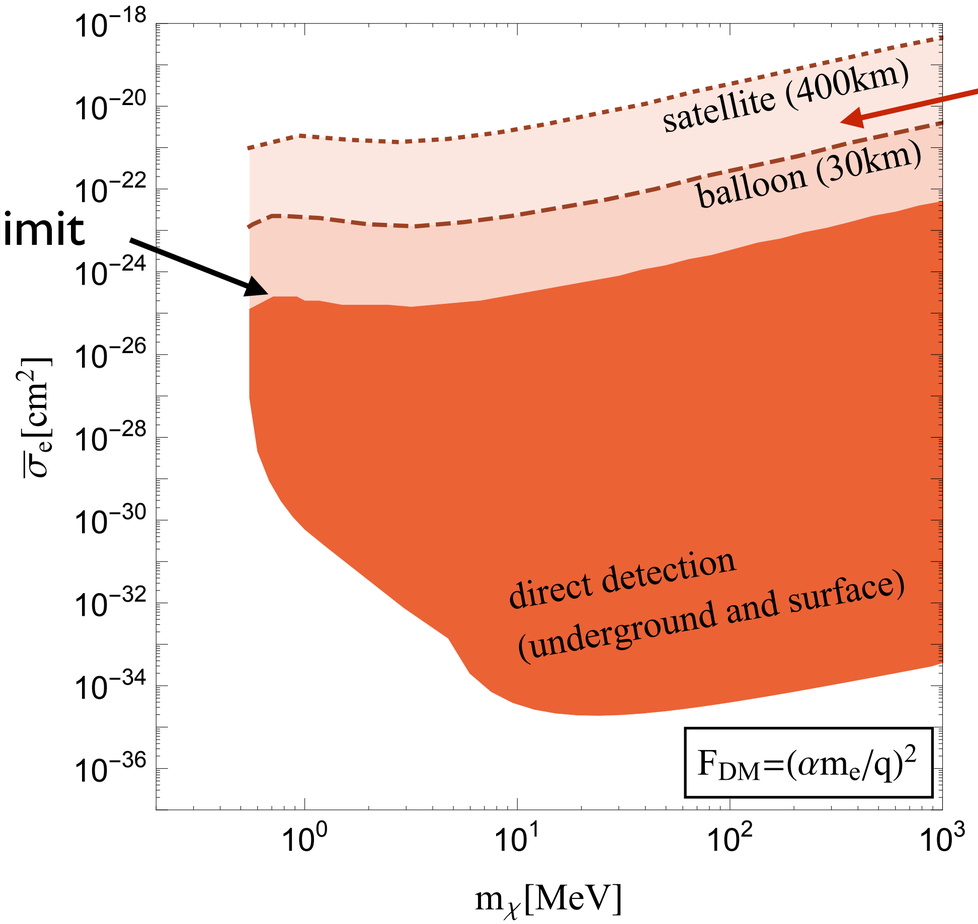




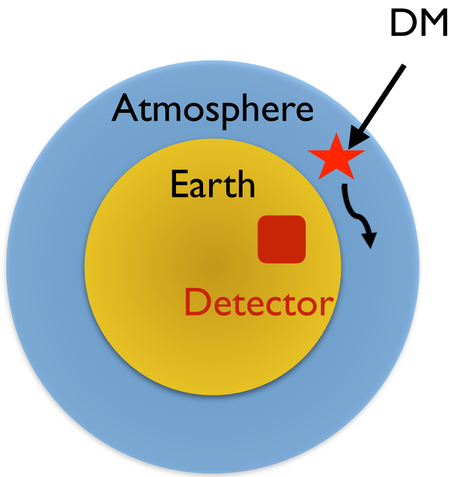
Strongly interacting DM will be significantly slowed before reach ground based detectors

Emken, Essig, Kouvaris, Sholapurkar, *JCAP*, 2019

Upper limit of ground-based detectors



Has strongly interacting DM already been ruled out by other astro/cosmo constraints?



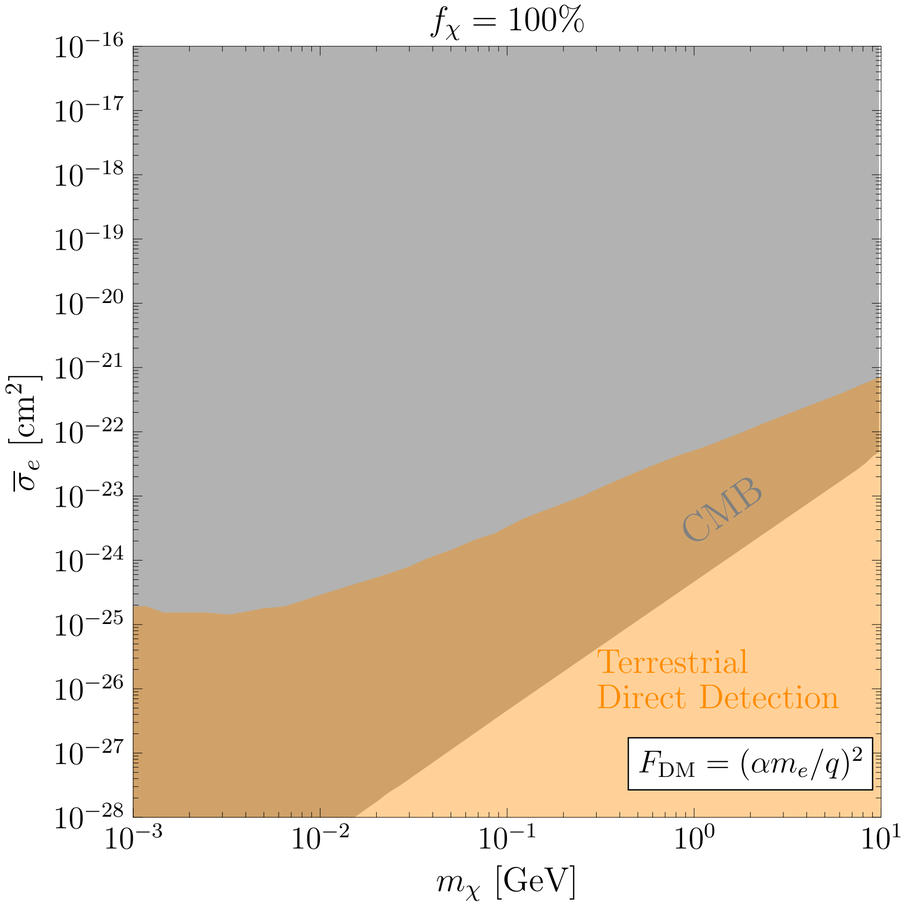
Strongly interacting DM will be significantly slowed before reach ground based detectors

Emken, Essig, Kouvaris, Sholapurkar, *JCAP*, 2019

Parameter space for strongly interacting DM

$$f_\chi \equiv \frac{\rho_\chi}{\rho_{\rm DM}}$$

fraction of interacting DM component



No room for strongly interacting DM if $f_\chi = 100\%$

Emken, Essig, Kouvaris, Sholapurkar, *JCAP*, 2019

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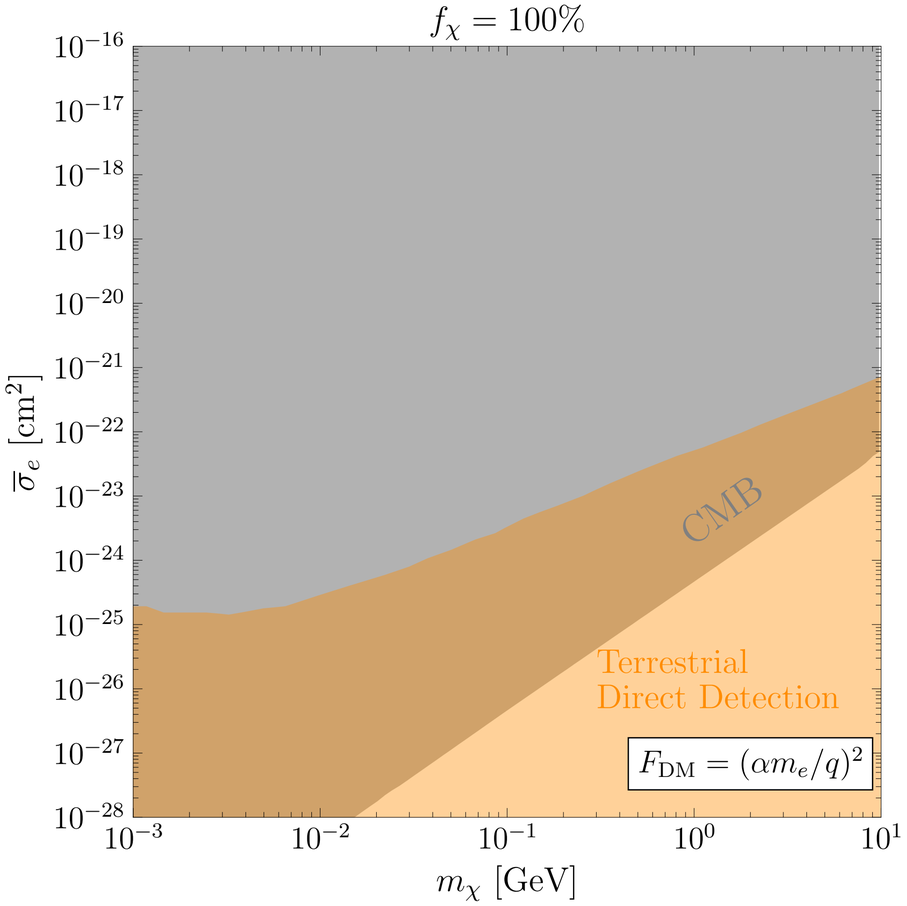
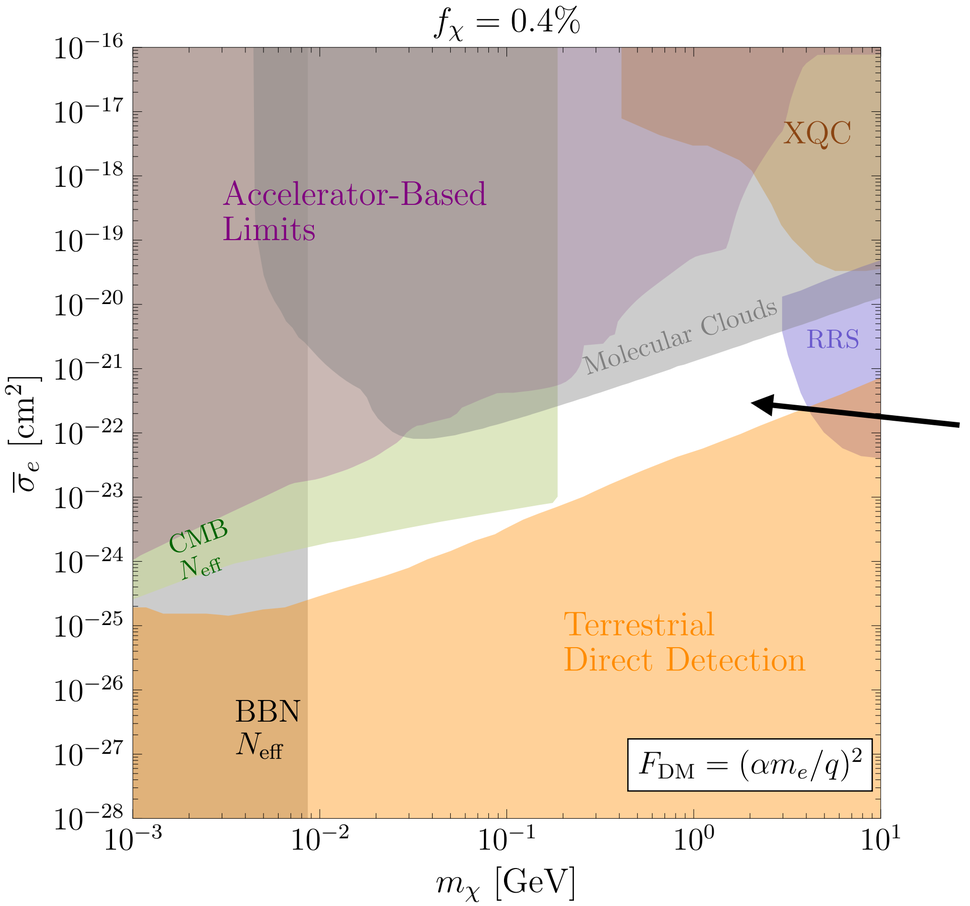


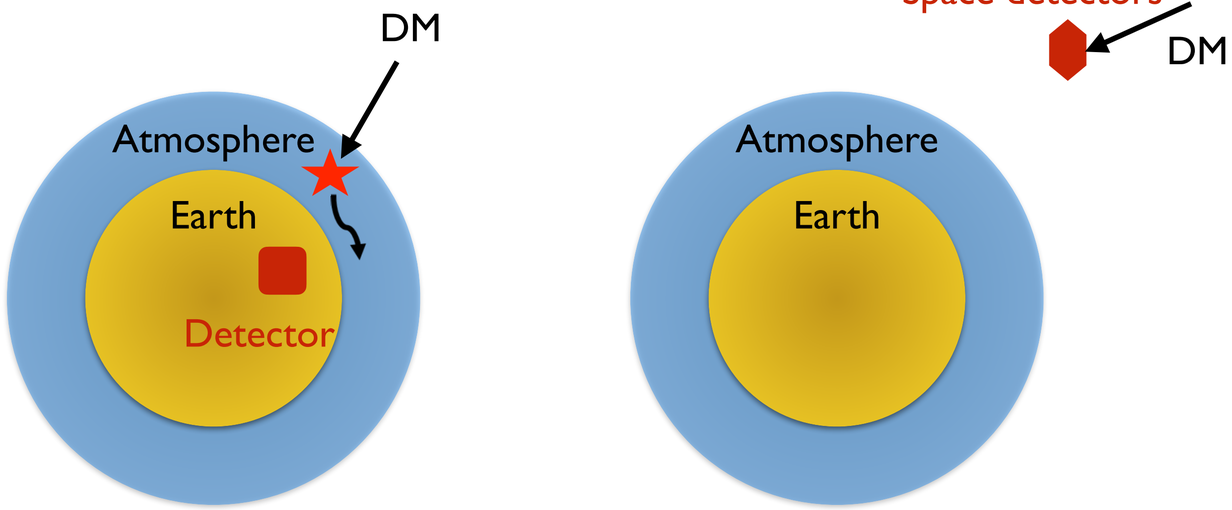


No room for strongly interacting DM if $f_\chi = 100\%$

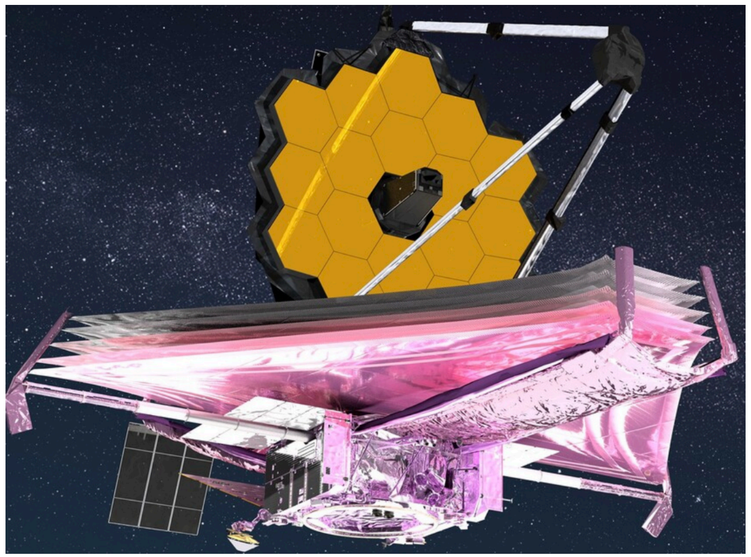
Unconstrained window for $f_\chi \lesssim 0.4\%$

Emken, Essig, Kouvaris, Sholapurkar, *JCAP*, 2019

Going to the space



JWST



Space detectors can probe strongly interacting DM due to lack of atmospheric shielding

- IR detector: HgCdTe (E_{th}~0.2 eV)
- Low noise:
  dark current < 0.01 e/pixel/s

JWST images

Astrophyiscal images

NGC 6072

JWST images

Astrophyiscal images

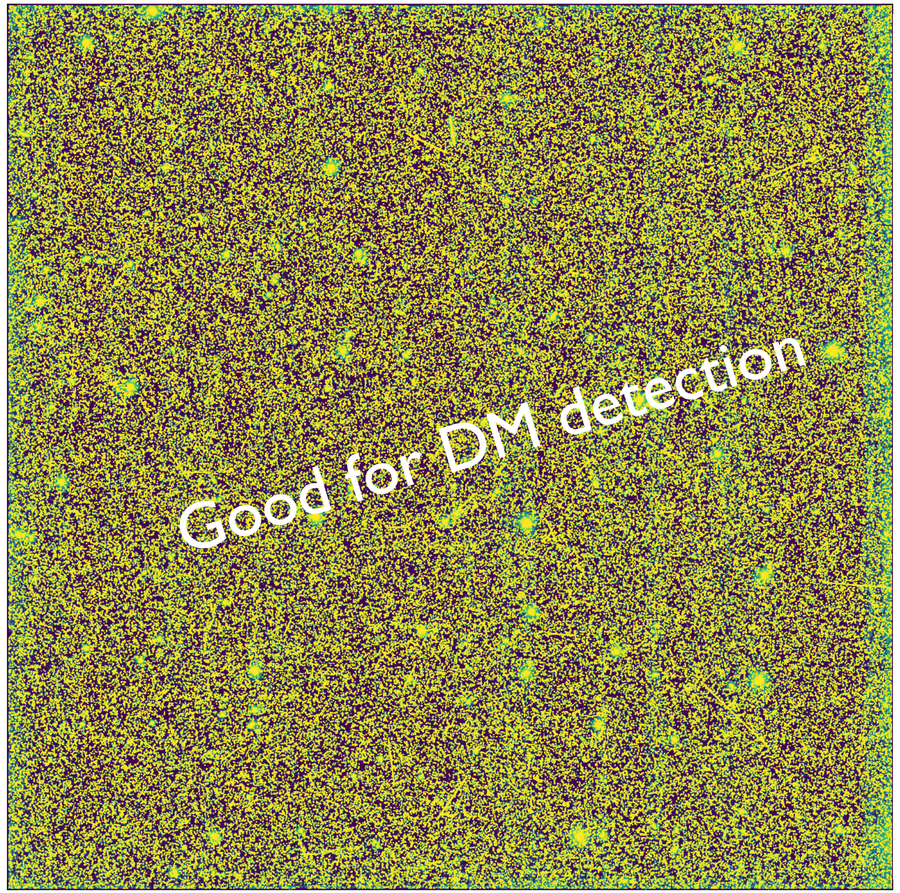
NGC 6072

JWST images

Astrophyiscal images

NGC 6072

Dark images

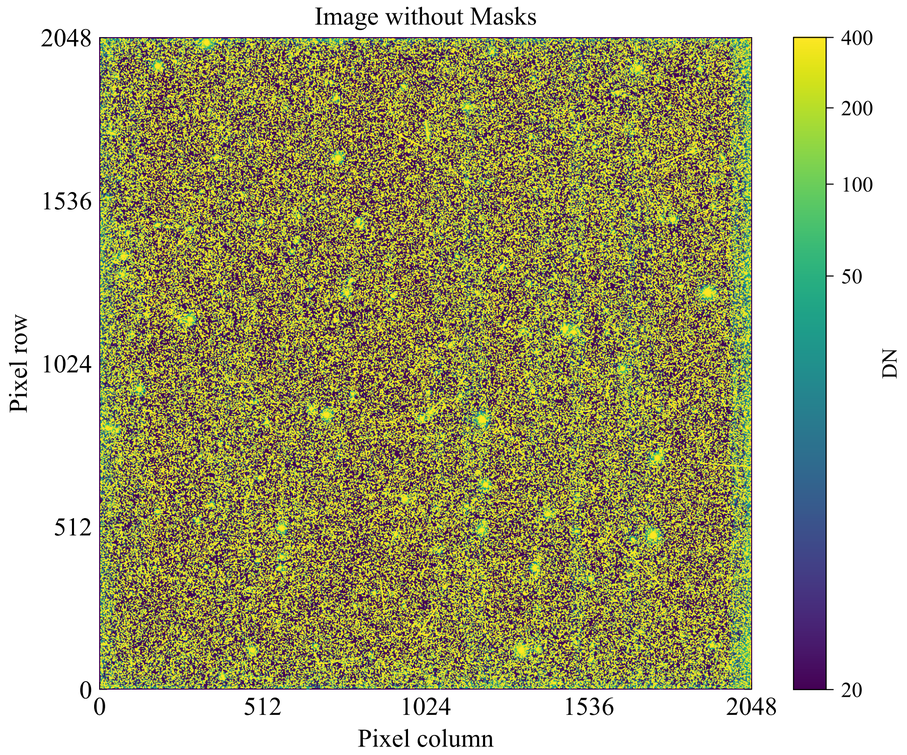


for background calibration

JWST dark images and masks

Dark images from JWST NIRSpec

Exposure: 3560 s
Time between frames: 14.6 s
# of frames: 244



data after basic JWST pipeline

JWST dark images and masks

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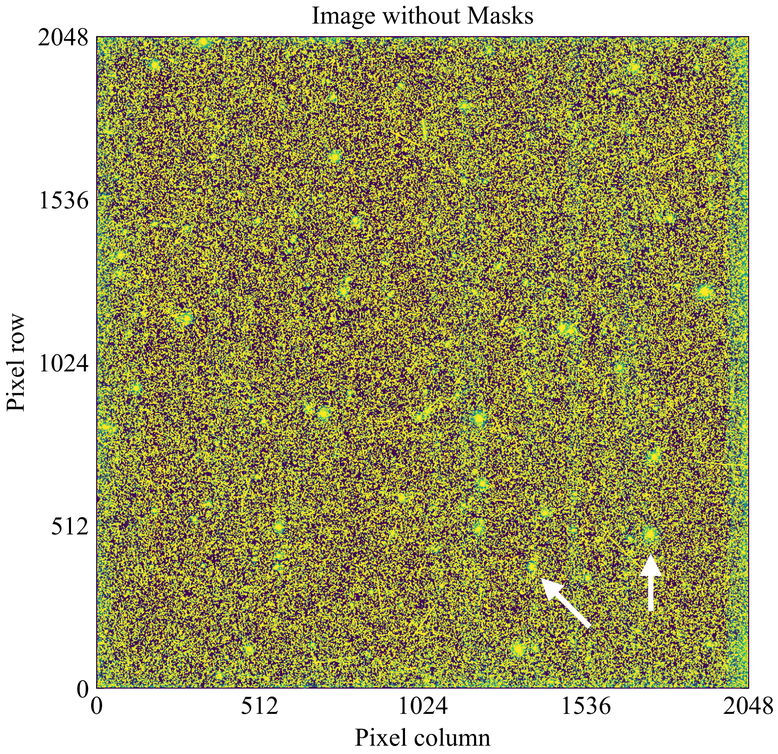

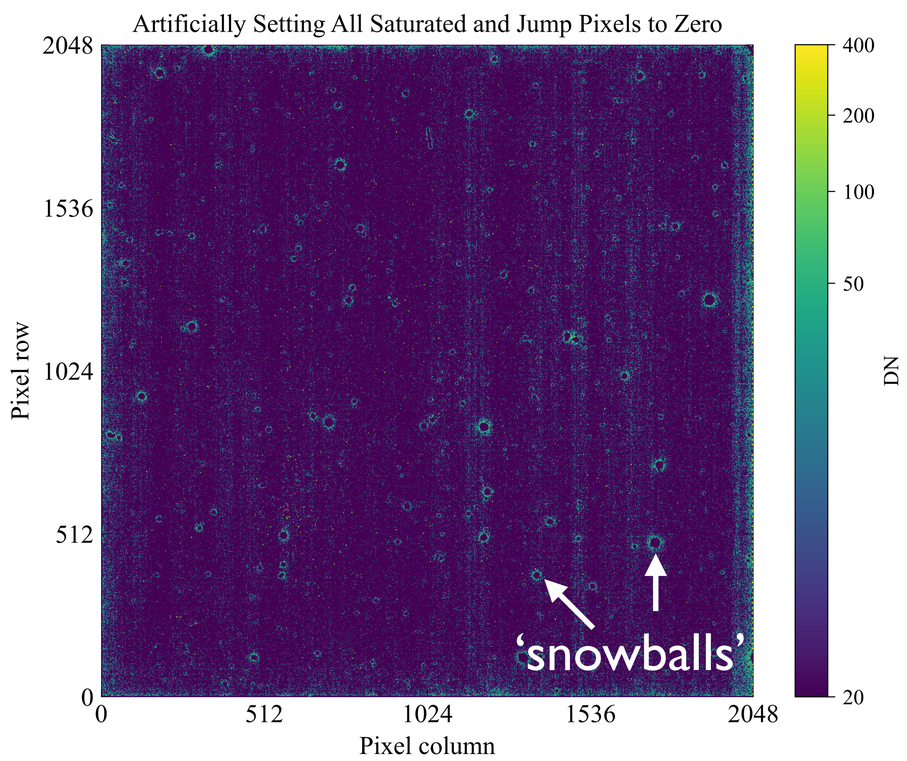

data after basic JWST pipeline

Our customized masks

PD, Essig, Rauscher, Xu, *PRL*, 2025

JWST dark images and masks

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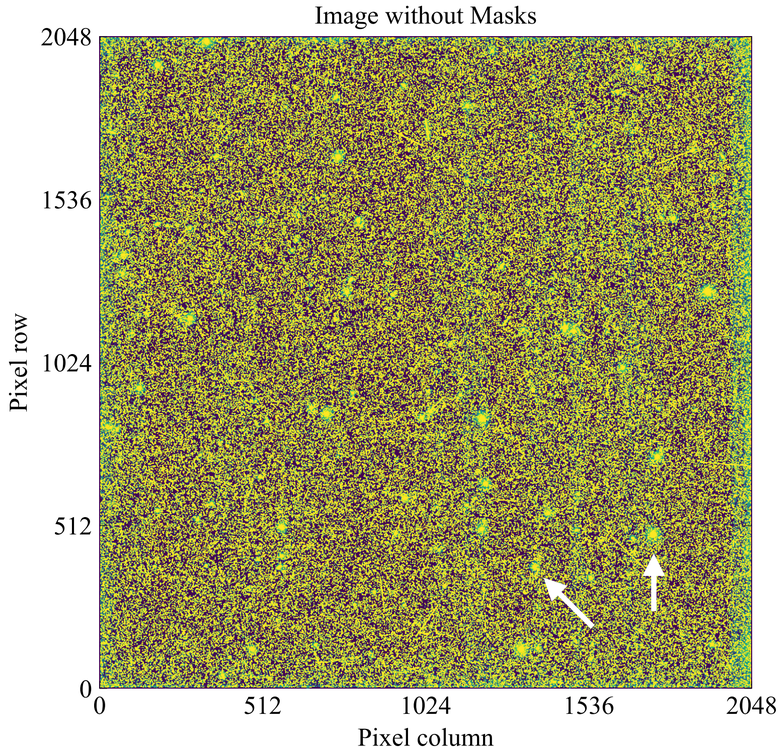

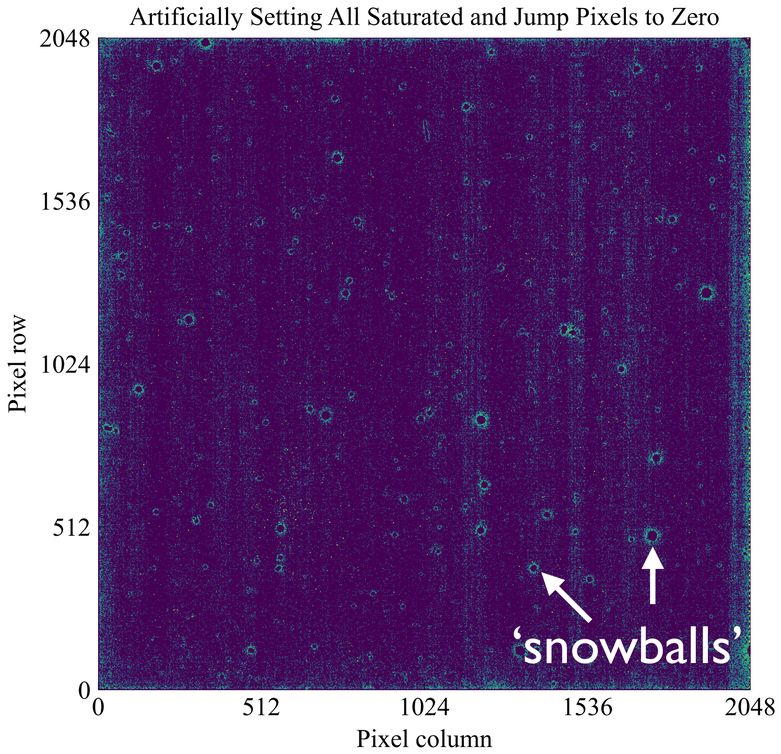

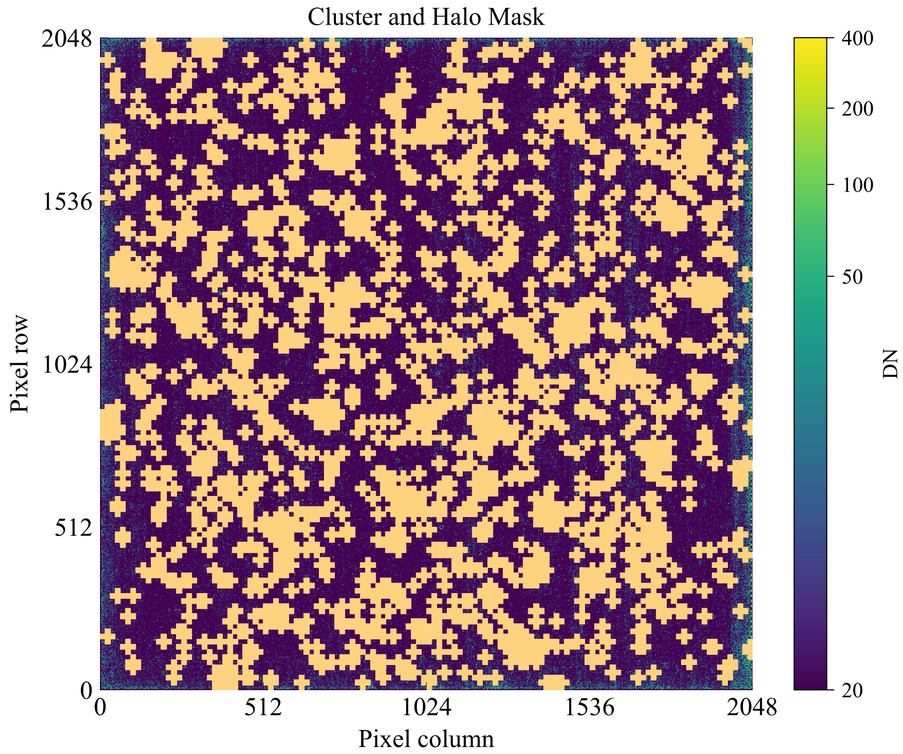

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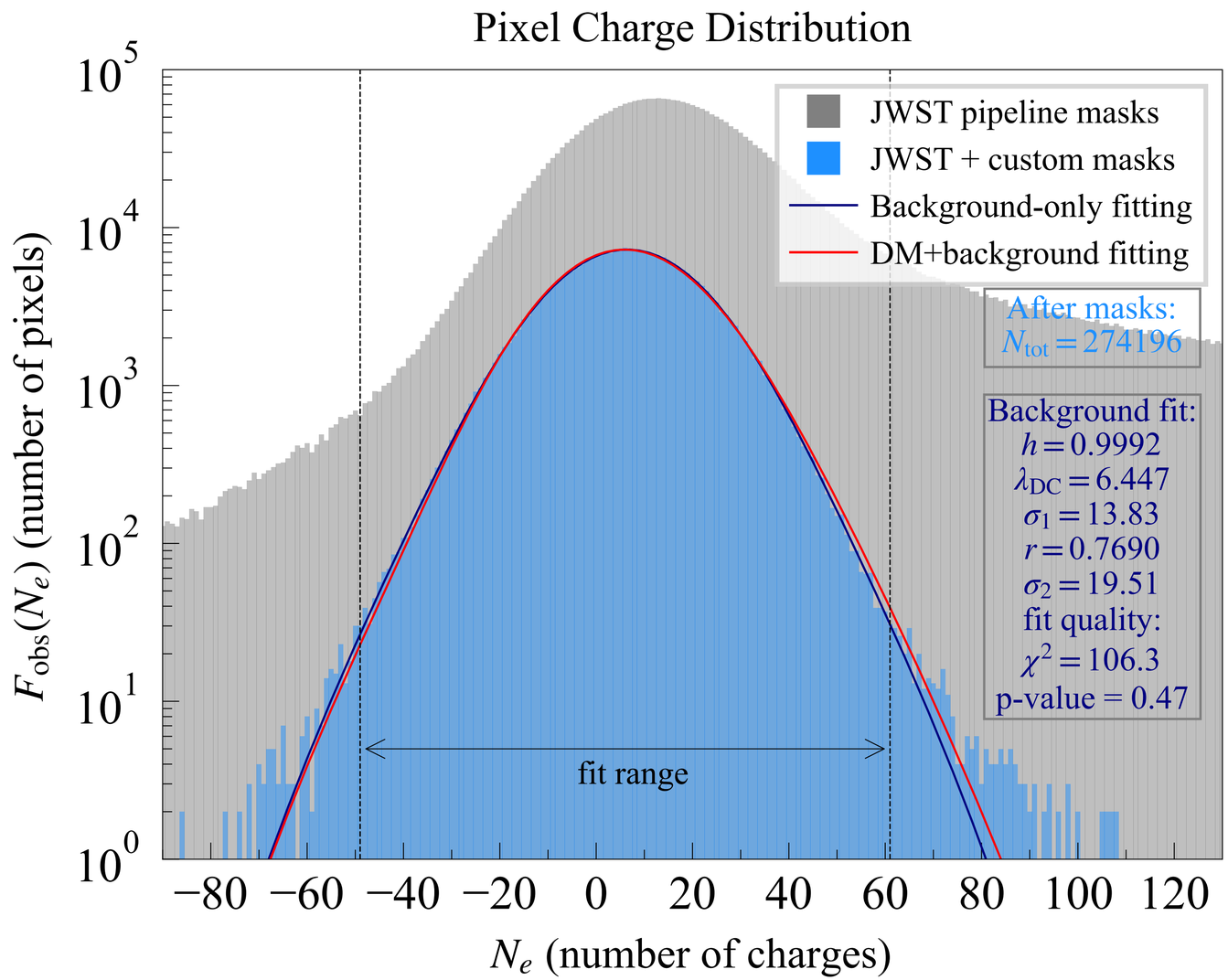
PD, Essig, Rauscher, Xu, *PRL*, 2025

JWST dark images after masks



- Background model: Poisson distributed dark current with Gaussian smearing

  Exposure: 3560 s

  Mean dark current: ~0.002/pixel/s

- Signal model: DM events for a certain mass, crosssection and fraction

  Excluded at 95%

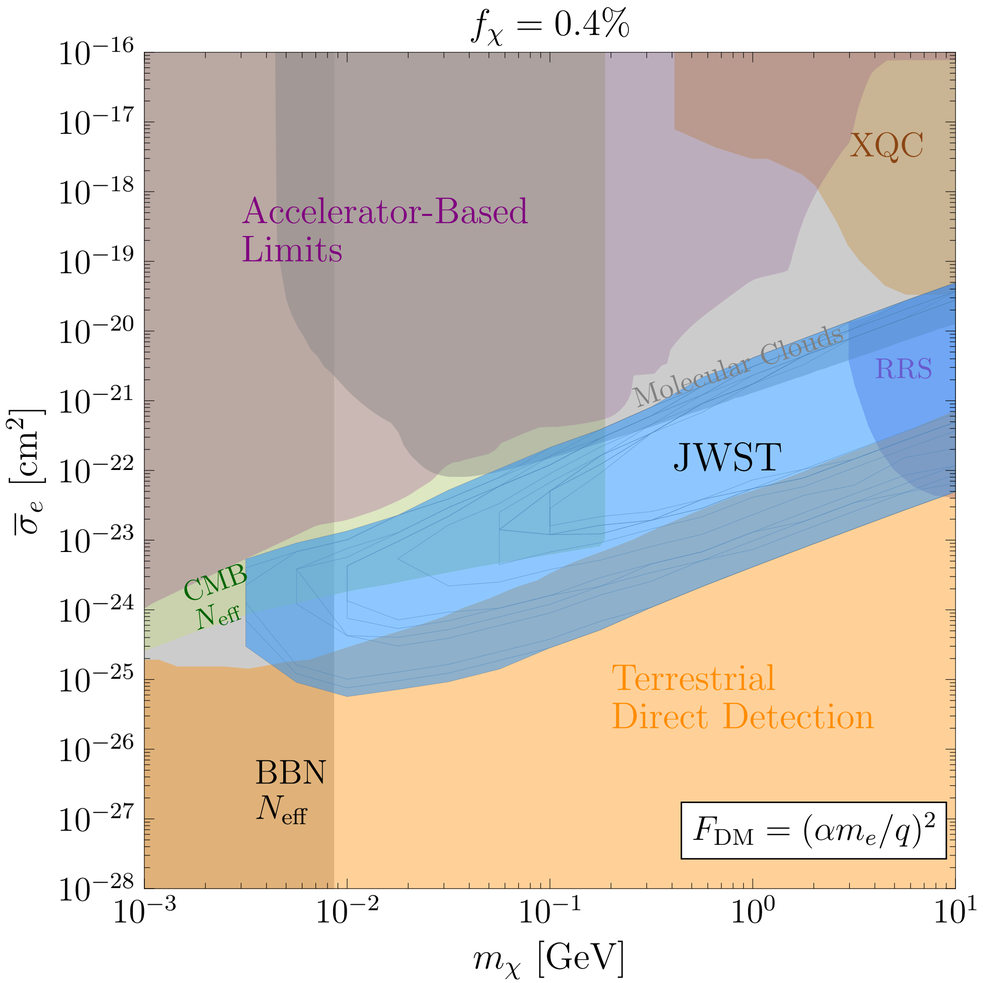
  $m_\chi = 1\,\mathrm{GeV}$

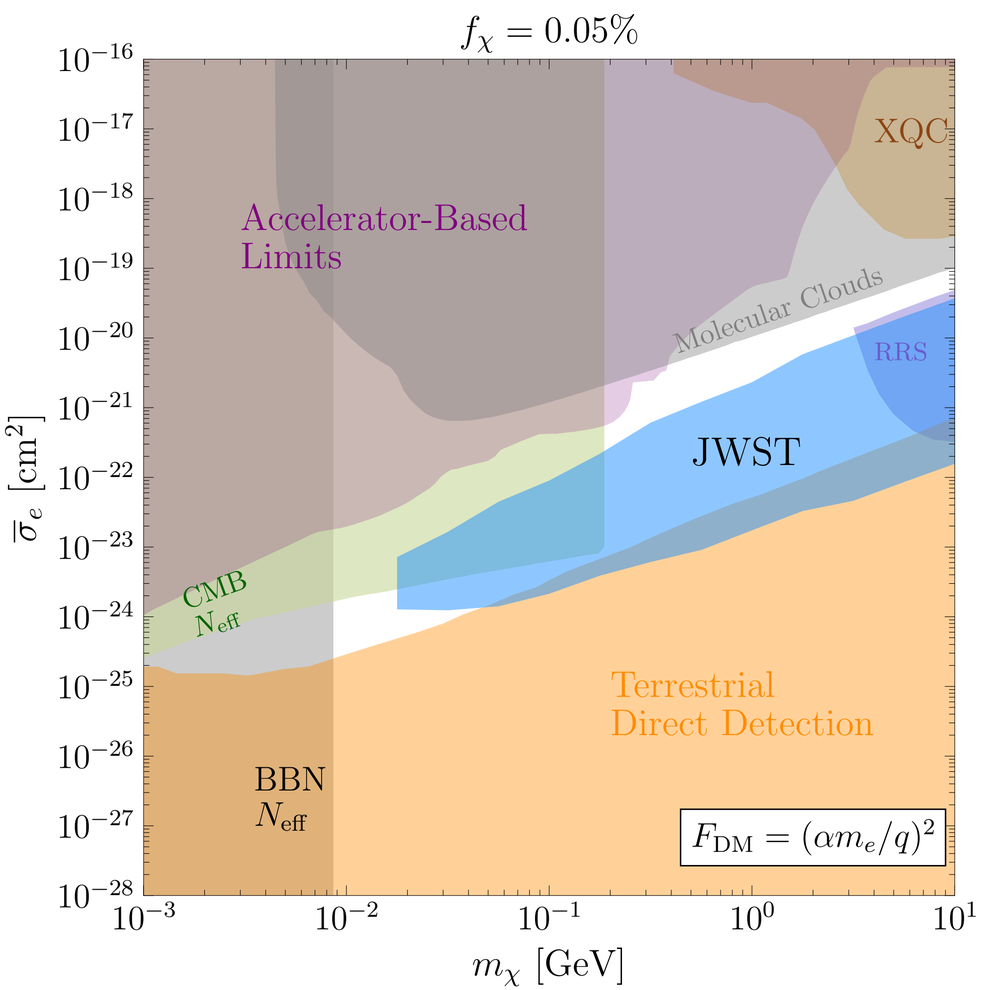
  $\bar{\sigma}_e = 3.09 \times 10^{-22}\mathrm{cm}^2$

  $f_\chi = 0.4\%$

PD, Essig, Rauscher, Xu, *PRL,* 2025

JWST DM constraints

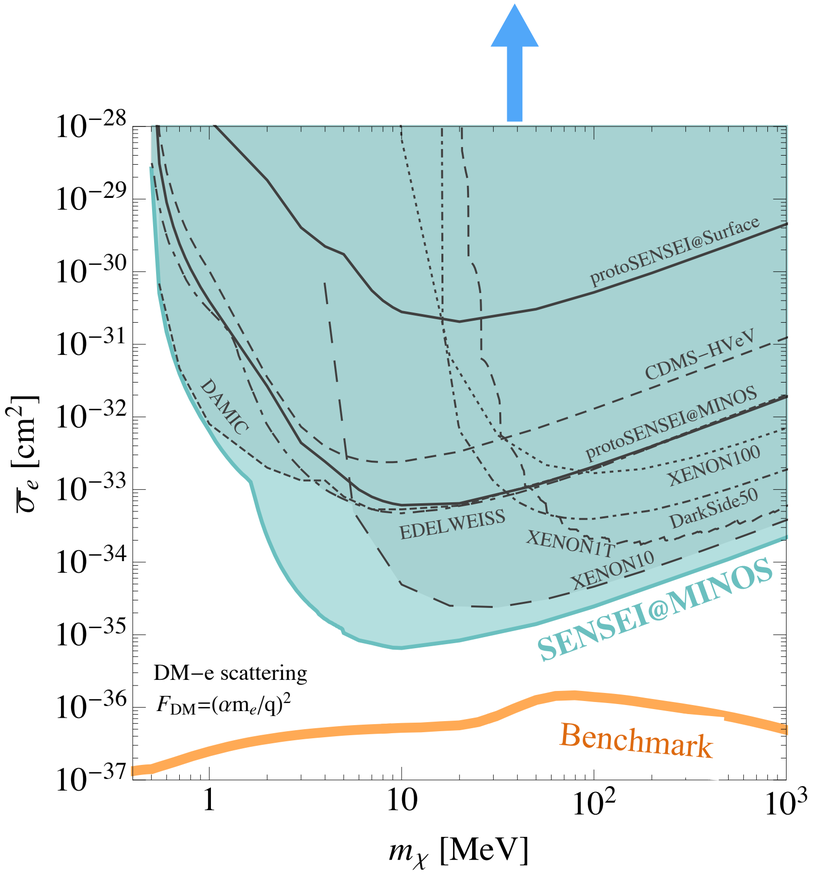




PD, Essig, Rauscher, Xu, *PRL*, 2025

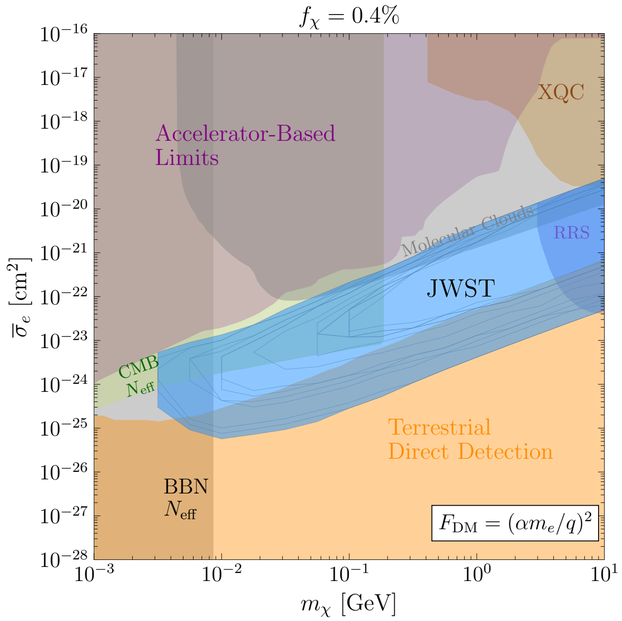
- Closing the window for 0.4% of interacting DM
- Future space detectors (e.g. DarkNESS) can further probe DM

Conclusions

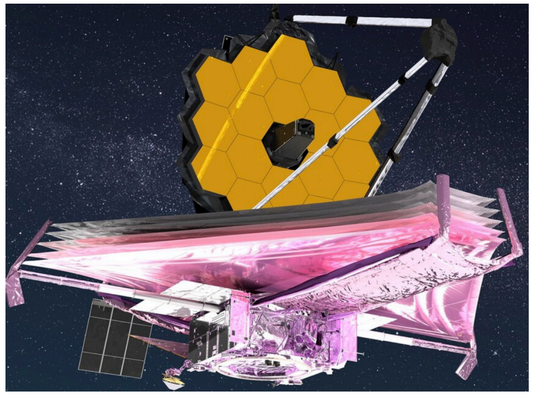


Direct Detection of Light DM

Space detectors can surpass the upper-limit of ground-based detectors in probing strongly interacting DM



Current JWST data can close the window for 0.4% of strongly interacting DM



Thank you!