

Towards the lightest Dark Matter in direct searches

Deutsche Physikerinnentagung, Karlsruhe, 27.11.2022

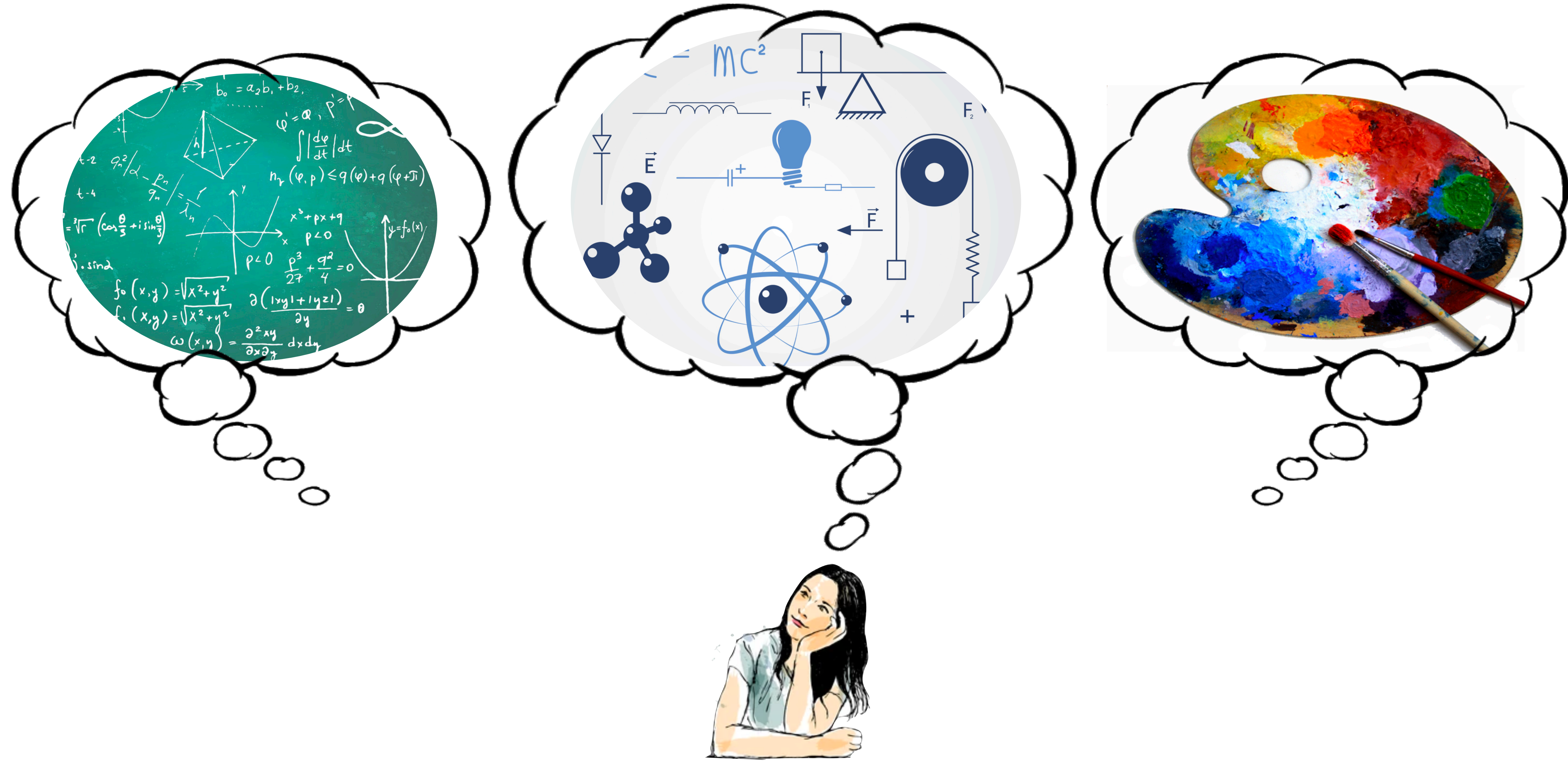
Belina von Krosigk (belina.krosigk@kit.edu)

Institut für Astroteilchenphysik (IAP)

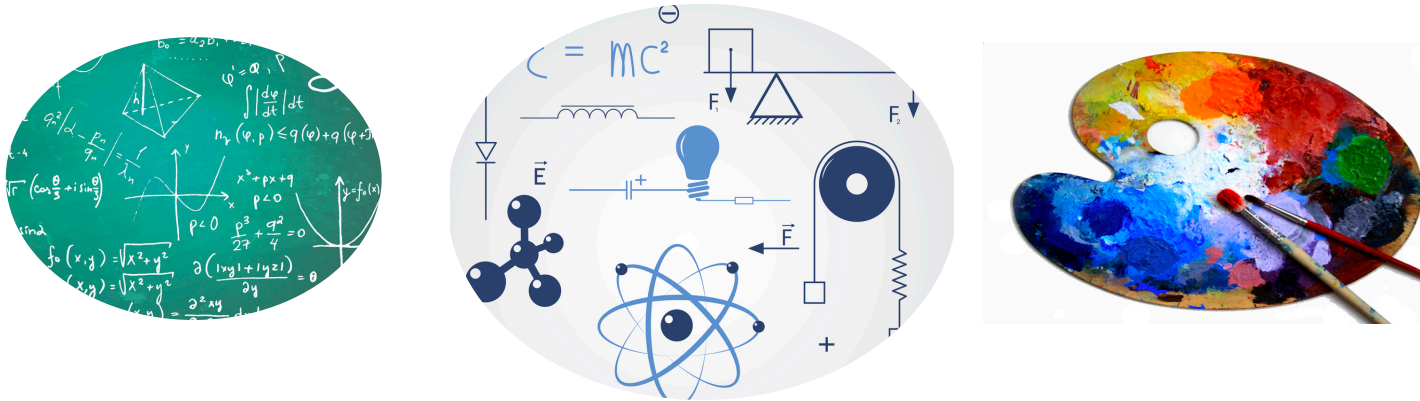


Credit: Swinburne Astronomy Productions - J. Josephides

A not so straight way to become Dark Matter spotter



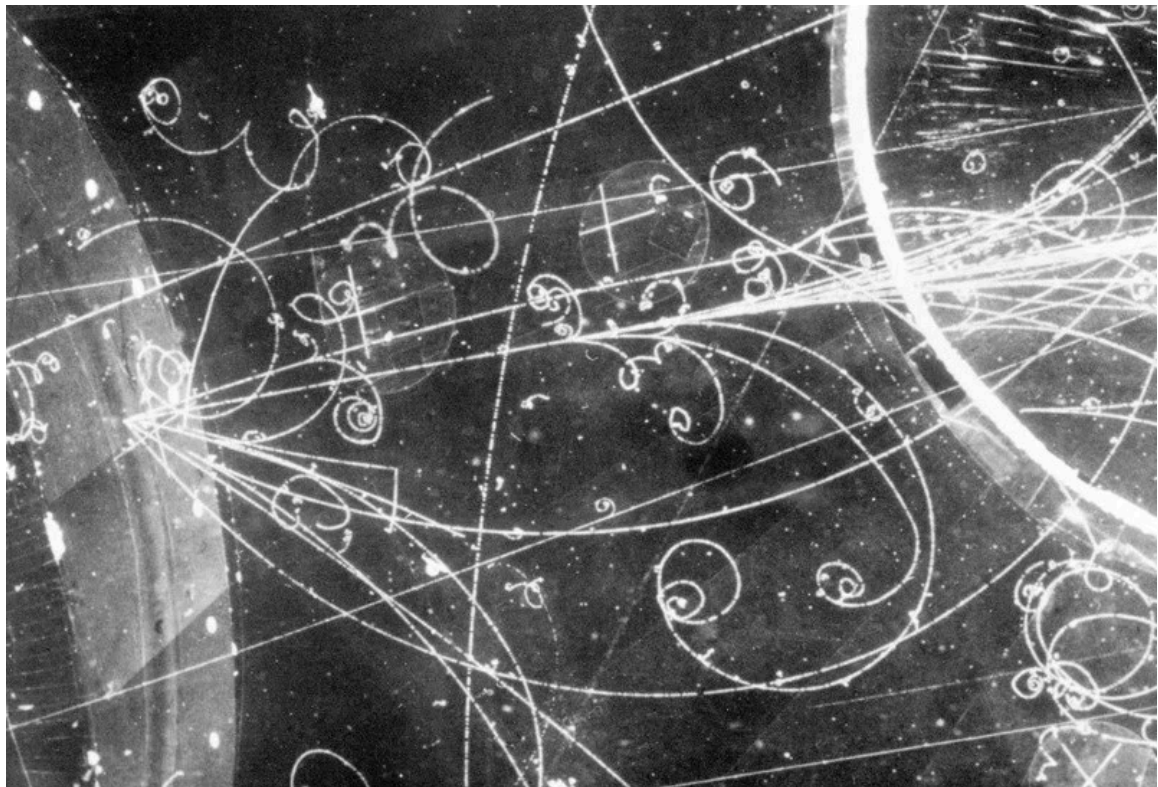
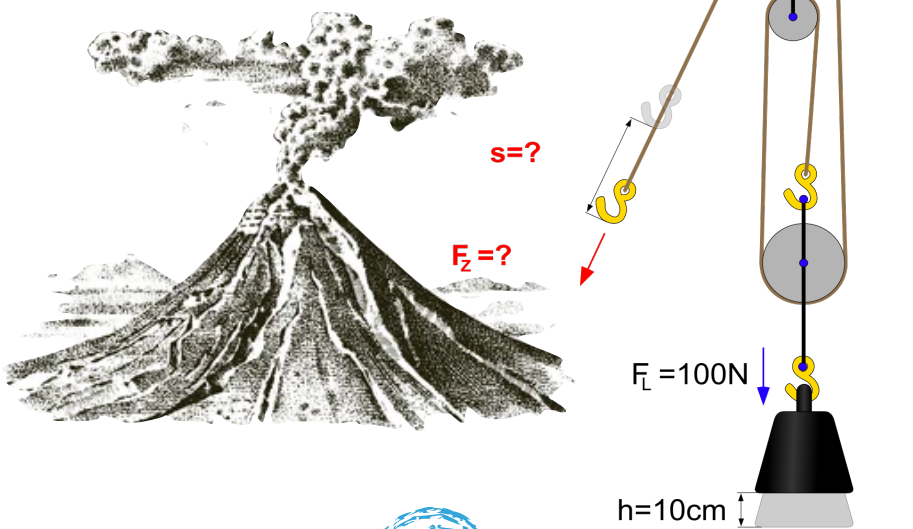
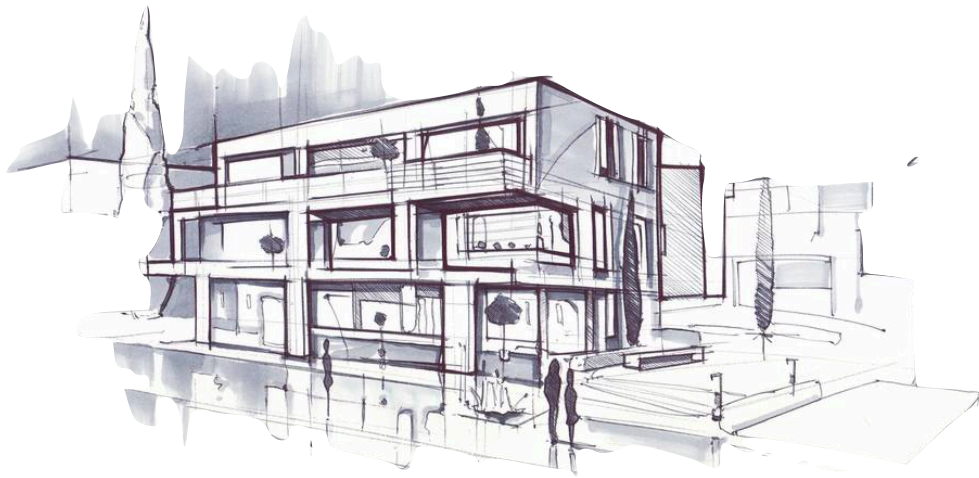
A not so straight way to become Dark Matter spotter



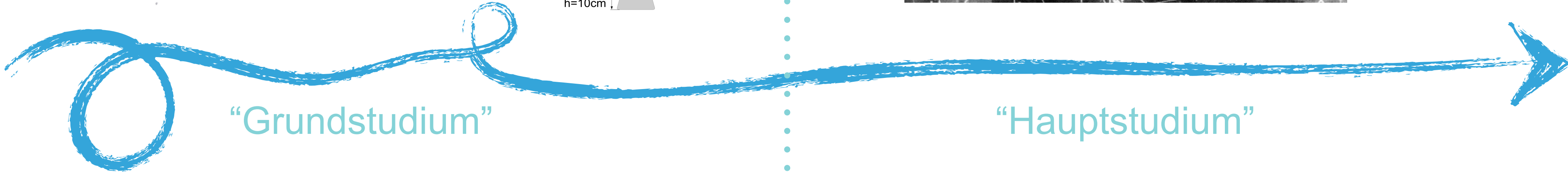
Architecture

Geophysics → Physics

Physics



Particle and
Astroparticle
Physics



“Grundstudium”

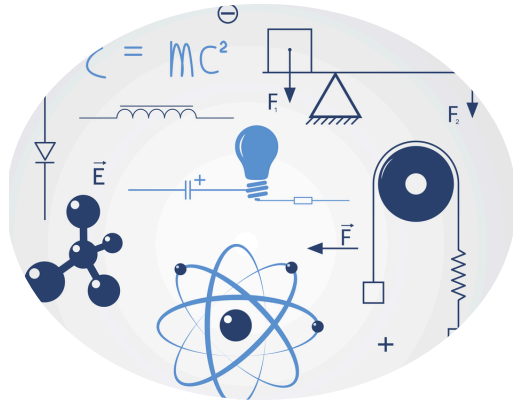
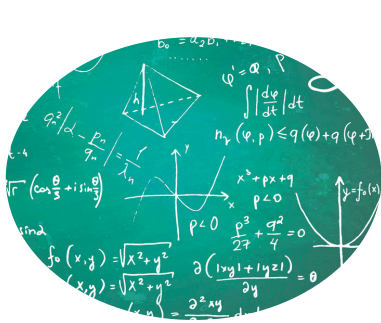
“Hauptstudium”

H F B K
University of Fine Arts
Hamburg

U+H
Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

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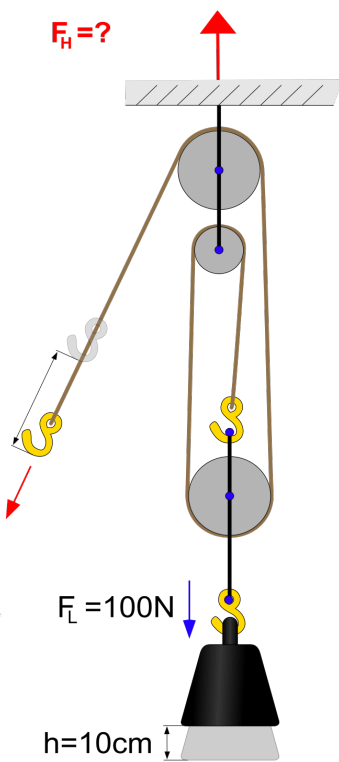
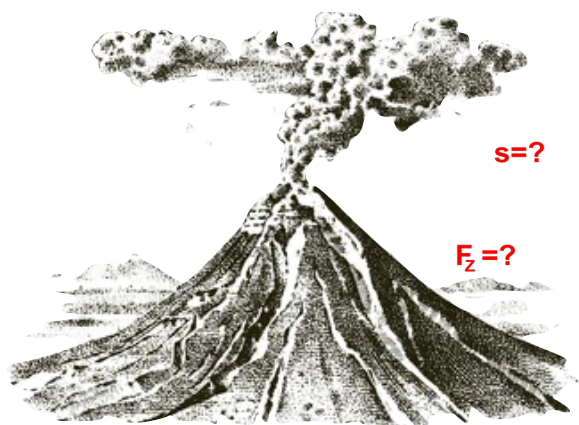
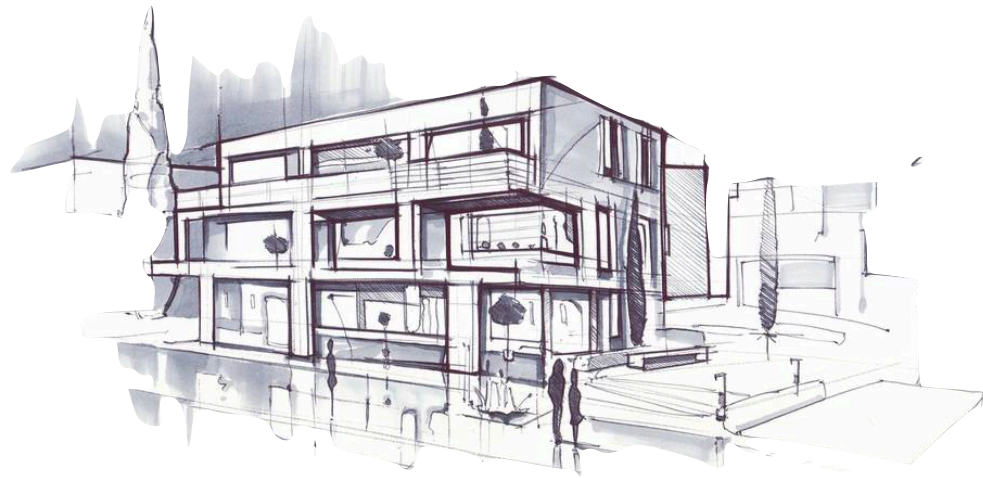
A not so straight way to become Dark Matter spotter



Architecture

Geophysics → Physics

Physics



Credit: CERN

Particle and
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Physics



“Grundstudium”

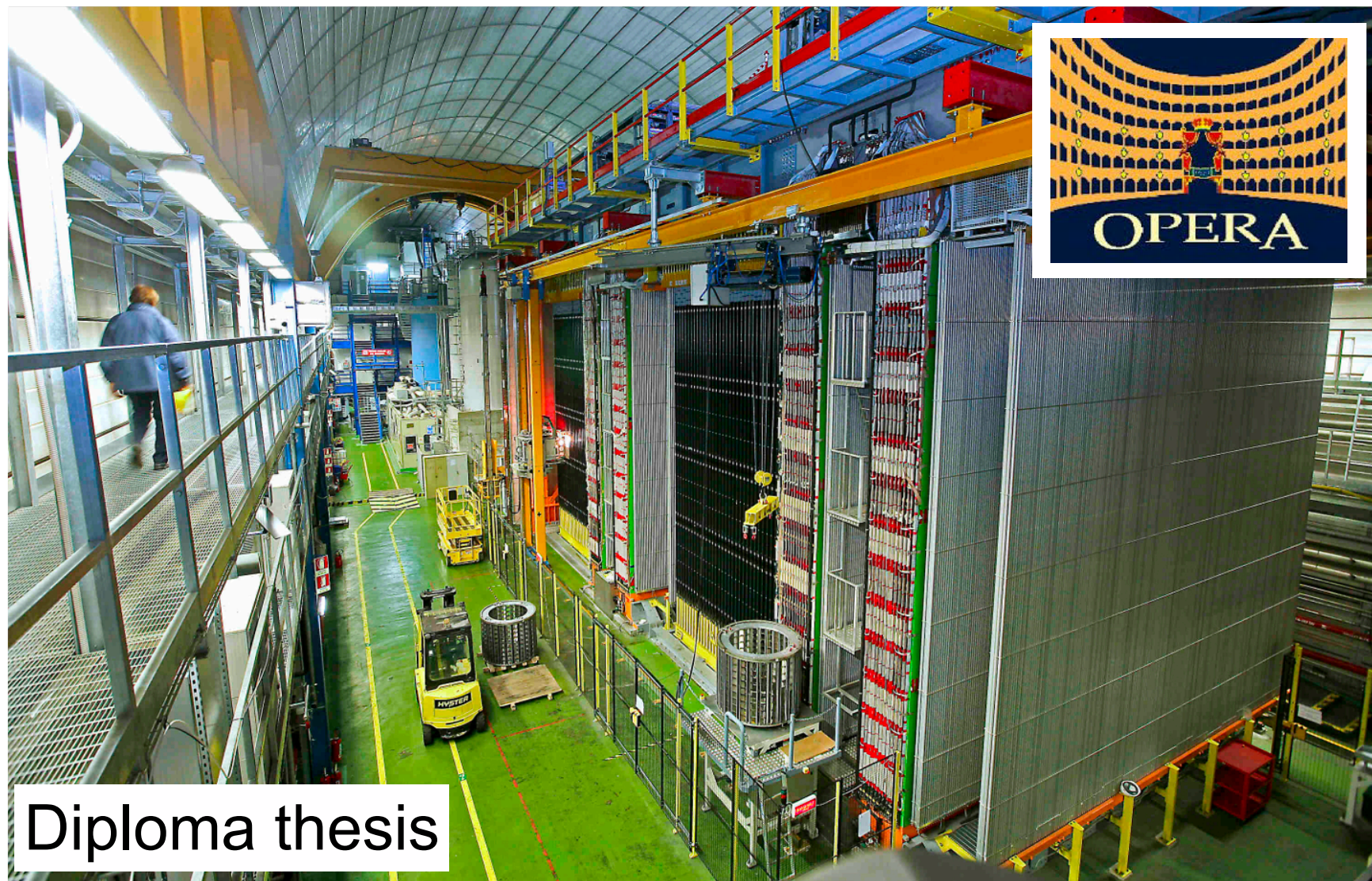
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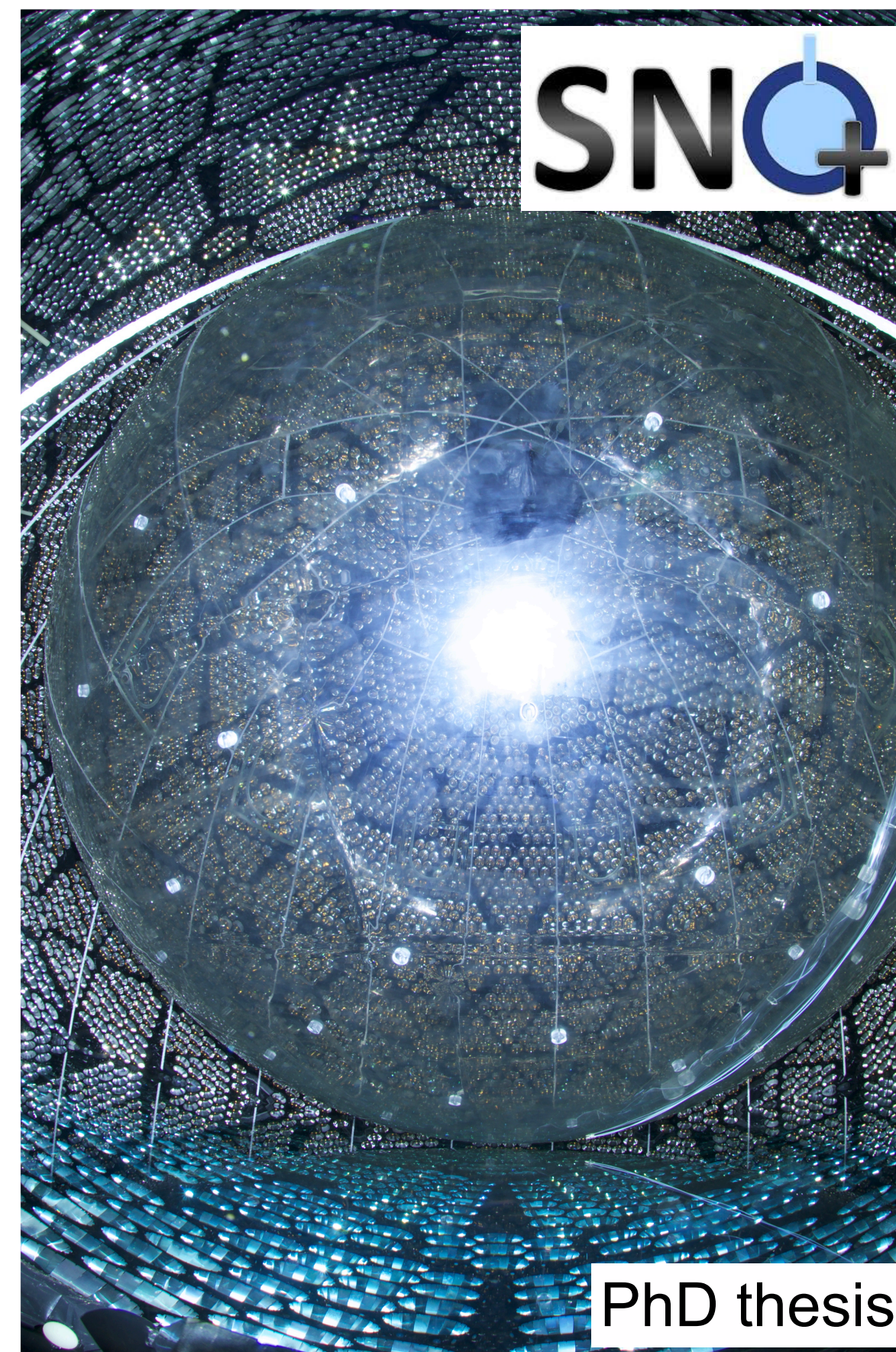
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A not so straight way to become Dark Matter spotter



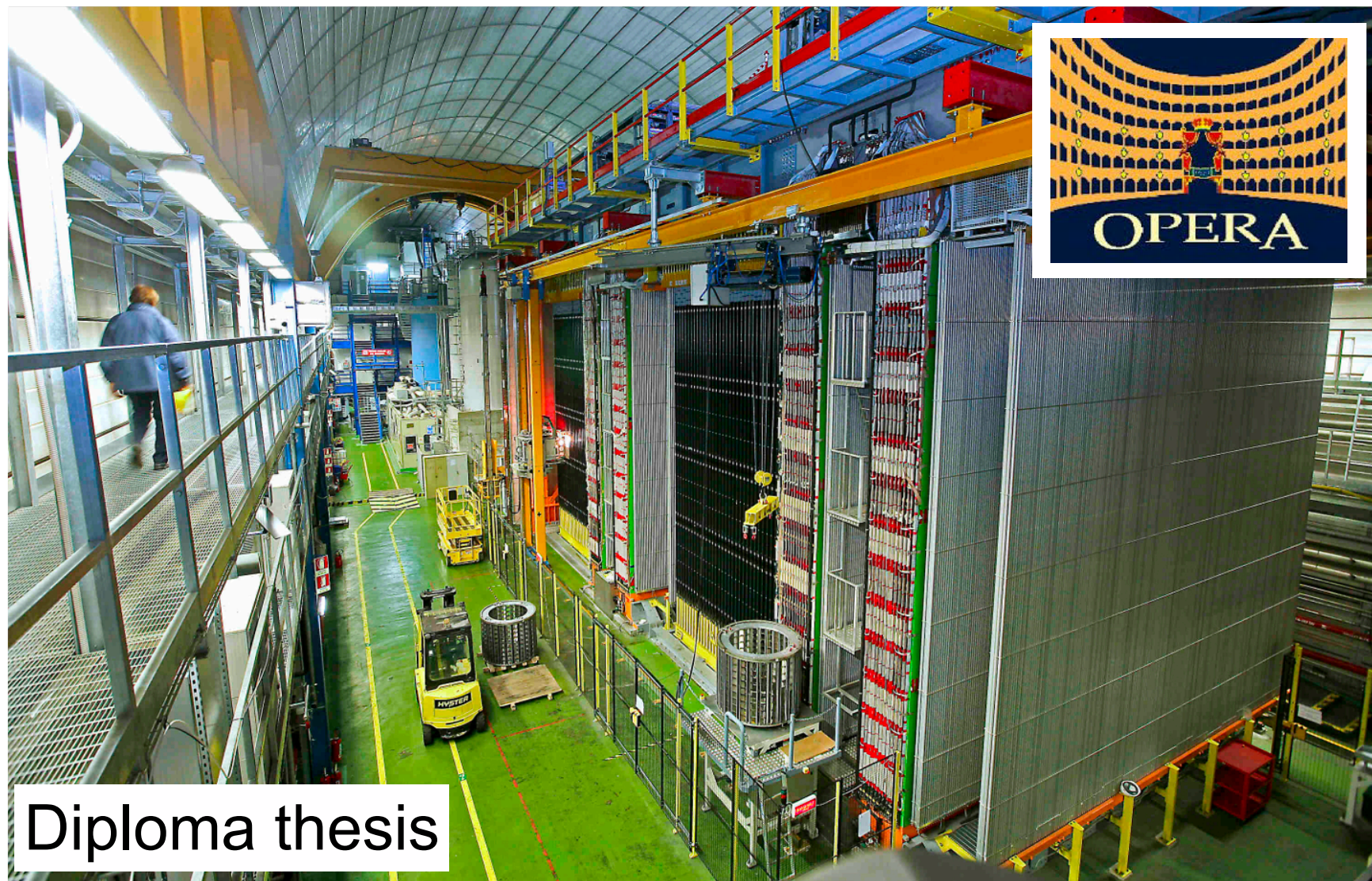
- Long-baseline **neutrinos**
- **Gran Sasso** Underground Laboratory, Italy

- Solar and supernova **neutrinos**
- **SNOLAB** Underground Laboratory, Canada



- Galactic **Dark Matter**
- **SNOLAB** Underground Laboratory, Canada

A not so straight way to become Dark Matter spotter



- Long-baseline **neutrinos**
- **Gran Sasso** Underground Laboratory, Italy

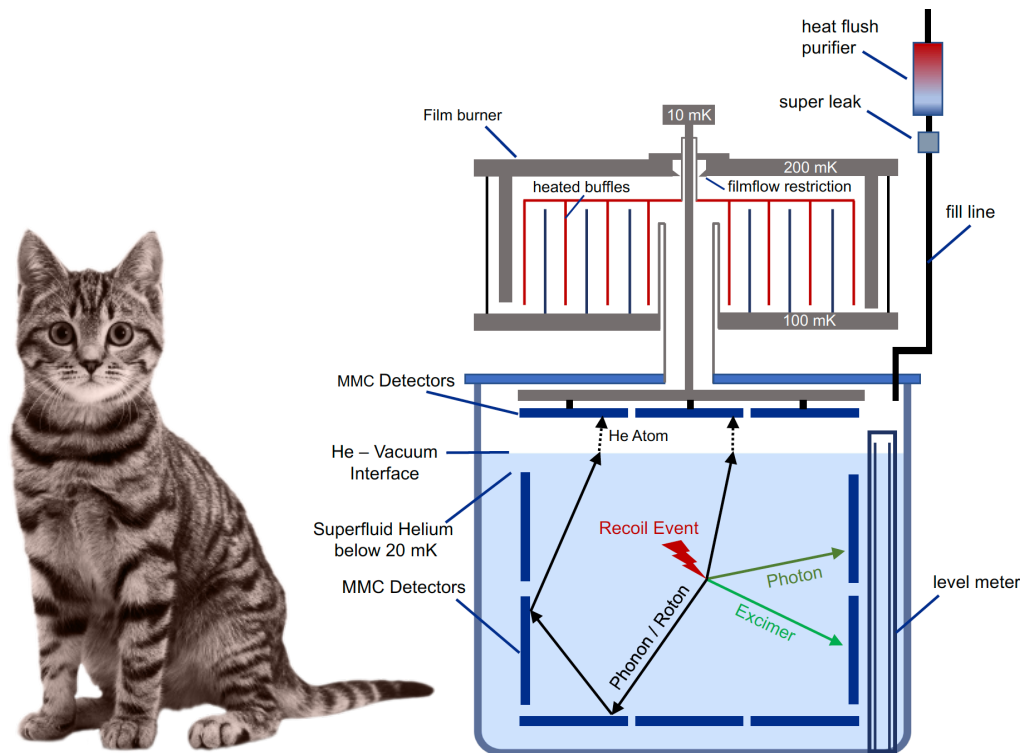
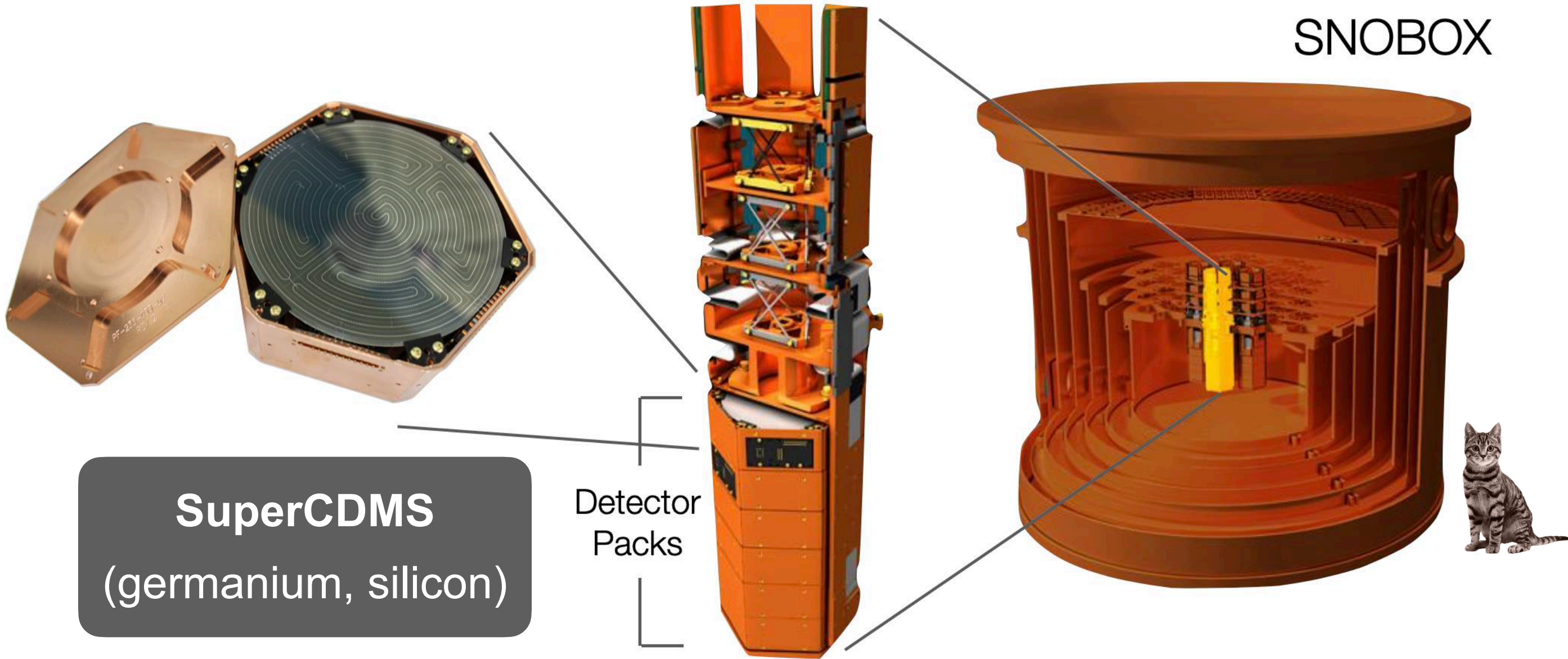
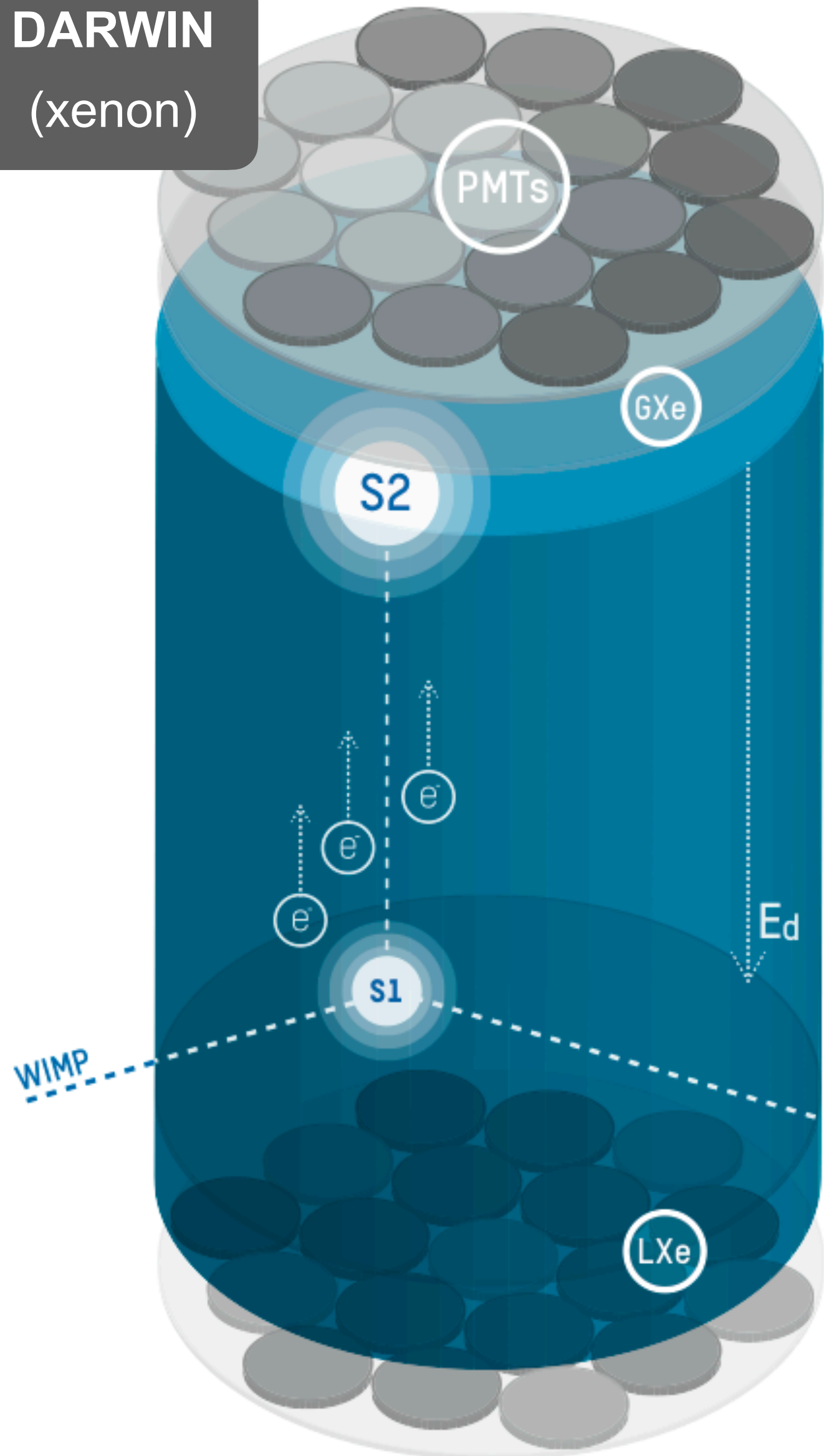
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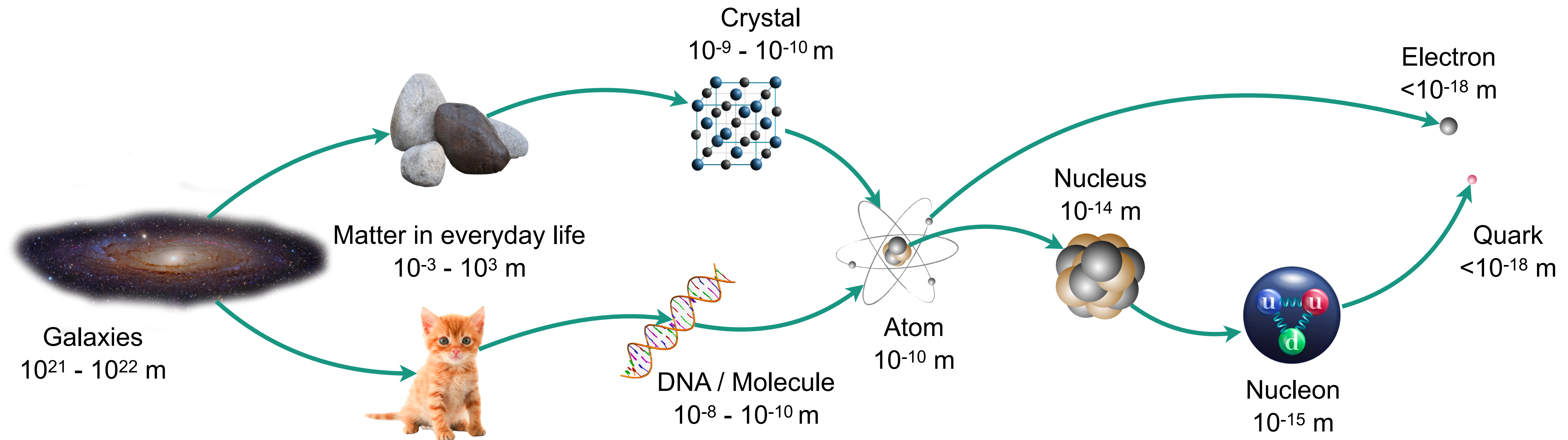
DARWIN
(xenon)



DELight
(helium)

**What's the excitement about
Dark Matter?**

Visible (“normal”) matter and mass



- “Normal” matter
 - is made from elementary particles
 - is visible via photon emission
 - is extremely well understood

“Normal” matter in the Universe



- Telescopes, like the “James Webb” Space Telescope, allow the observation of visible matter in the Universe

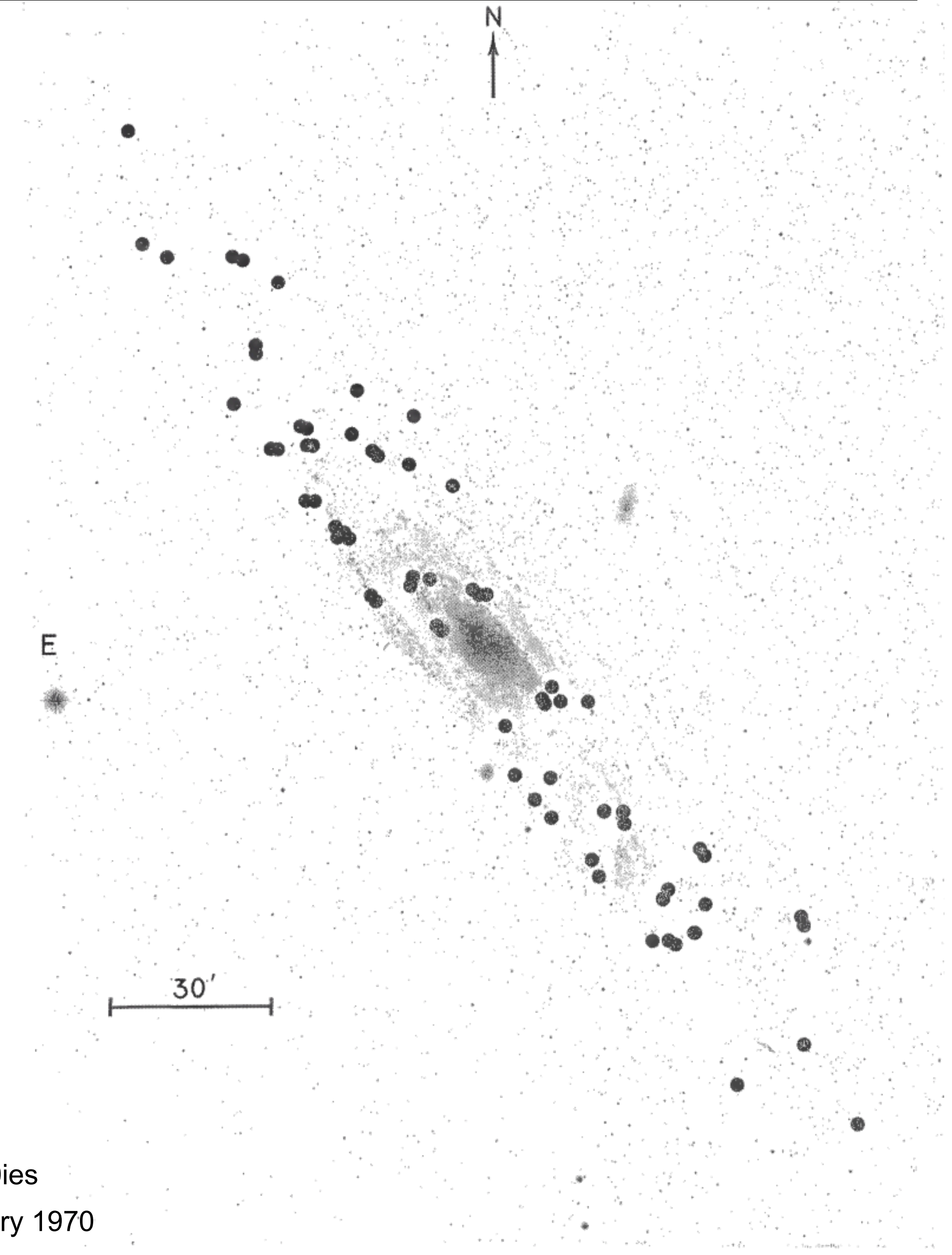


Galactic rotation curves

Vera Rubin (*1928 - †2016)

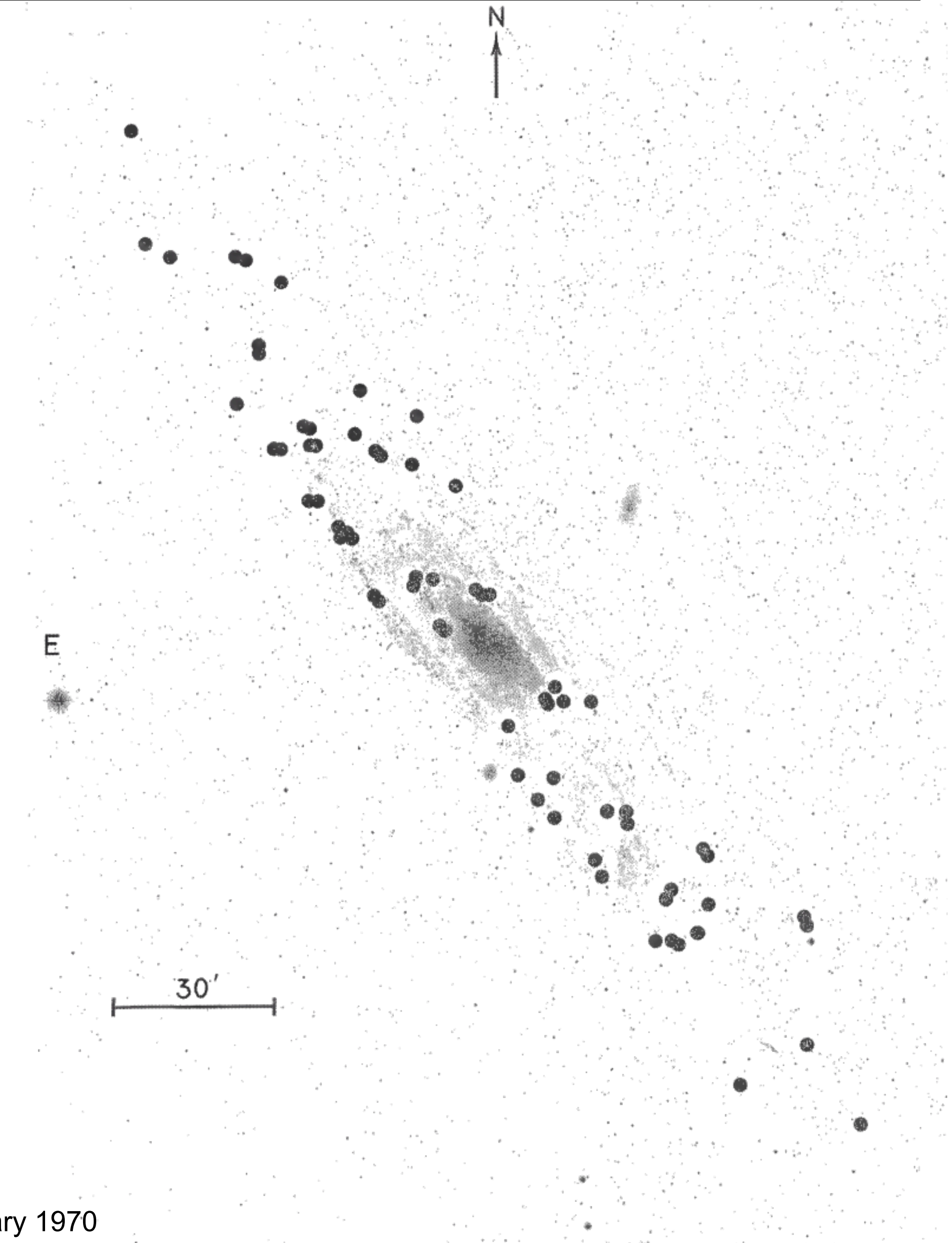
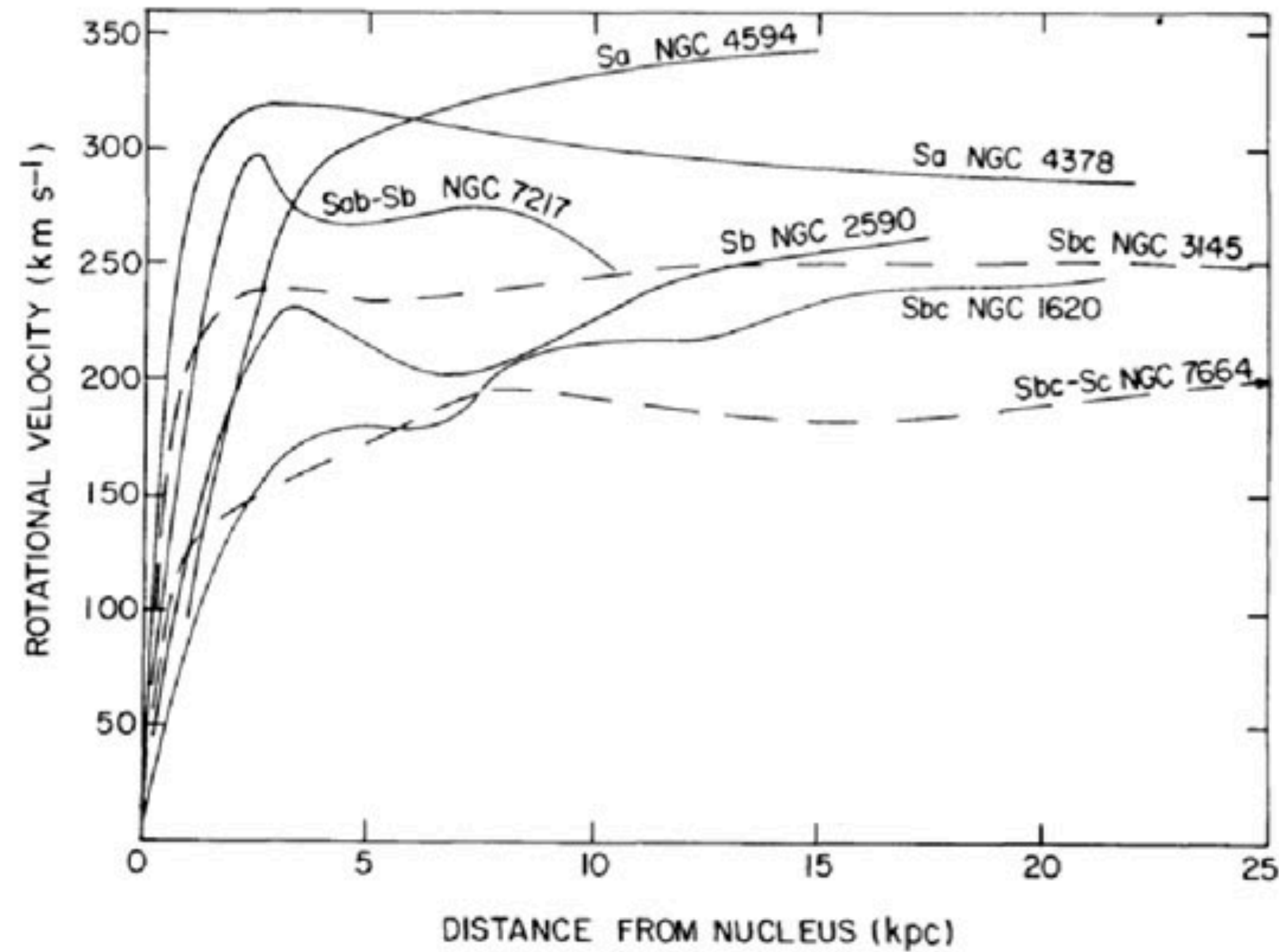


Credit (left): Carnegie Institution of Washington, 1970ies
Credit (right): The Astrophysical Journal, Vol. 159, February 1970



Galactic rotation curves

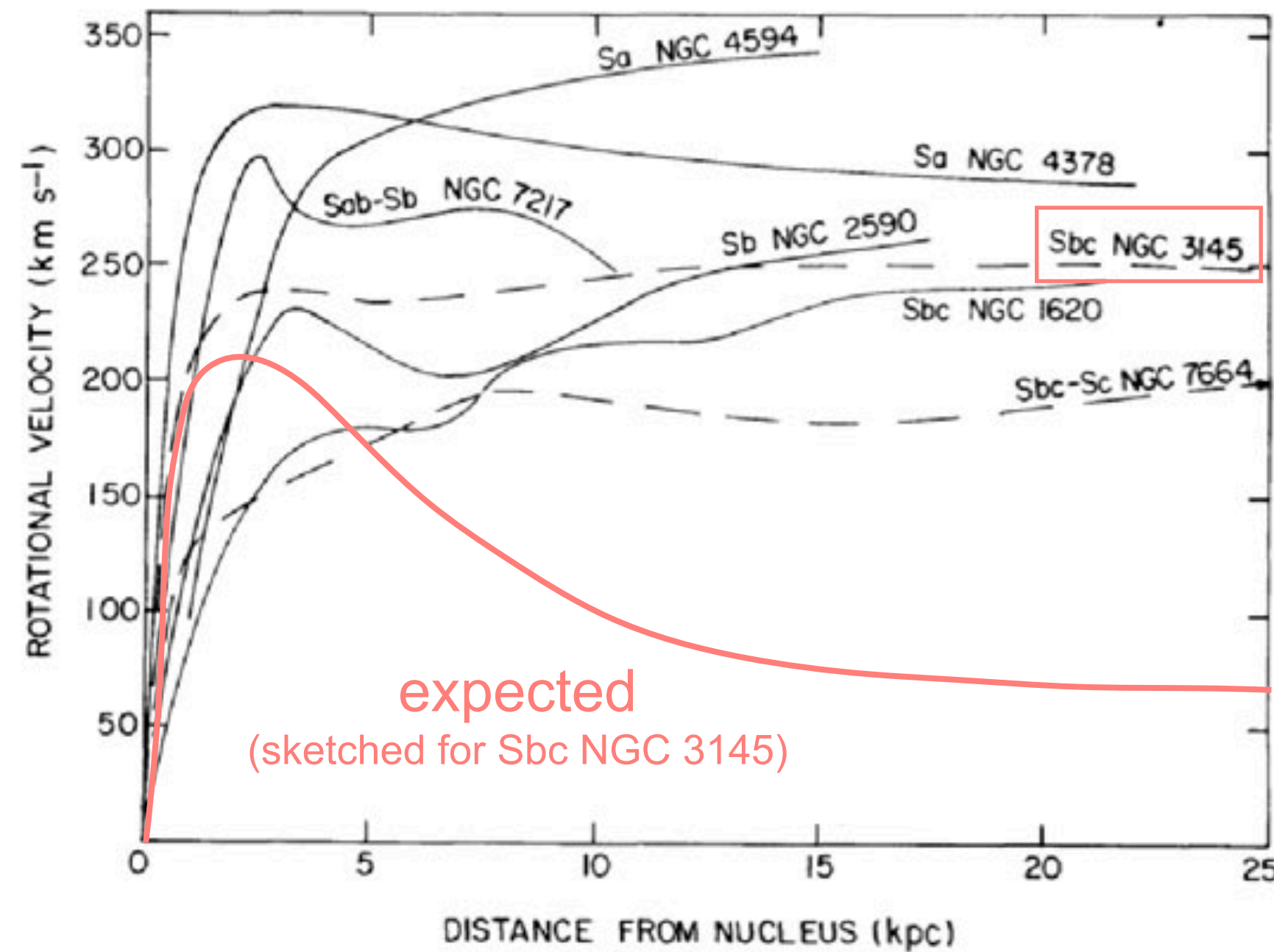
Vera Rubin (*1928 - †2016)



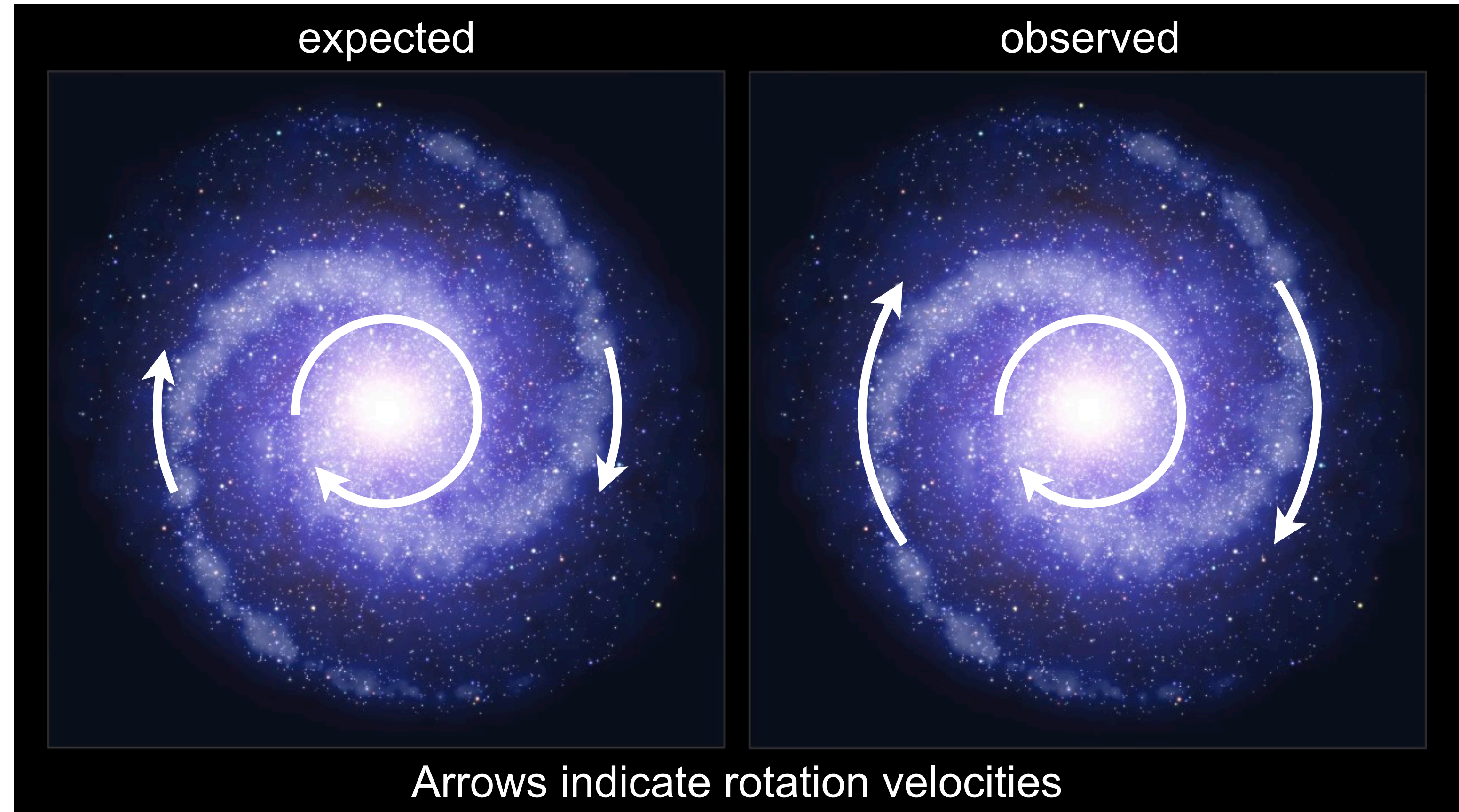
Credit (left): Rubin et al. / ApJL 1978

Credit (right): The Astrophysical Journal, Vol. 159, February 1970

Galactic rotation curves hinting towards Dark Matter



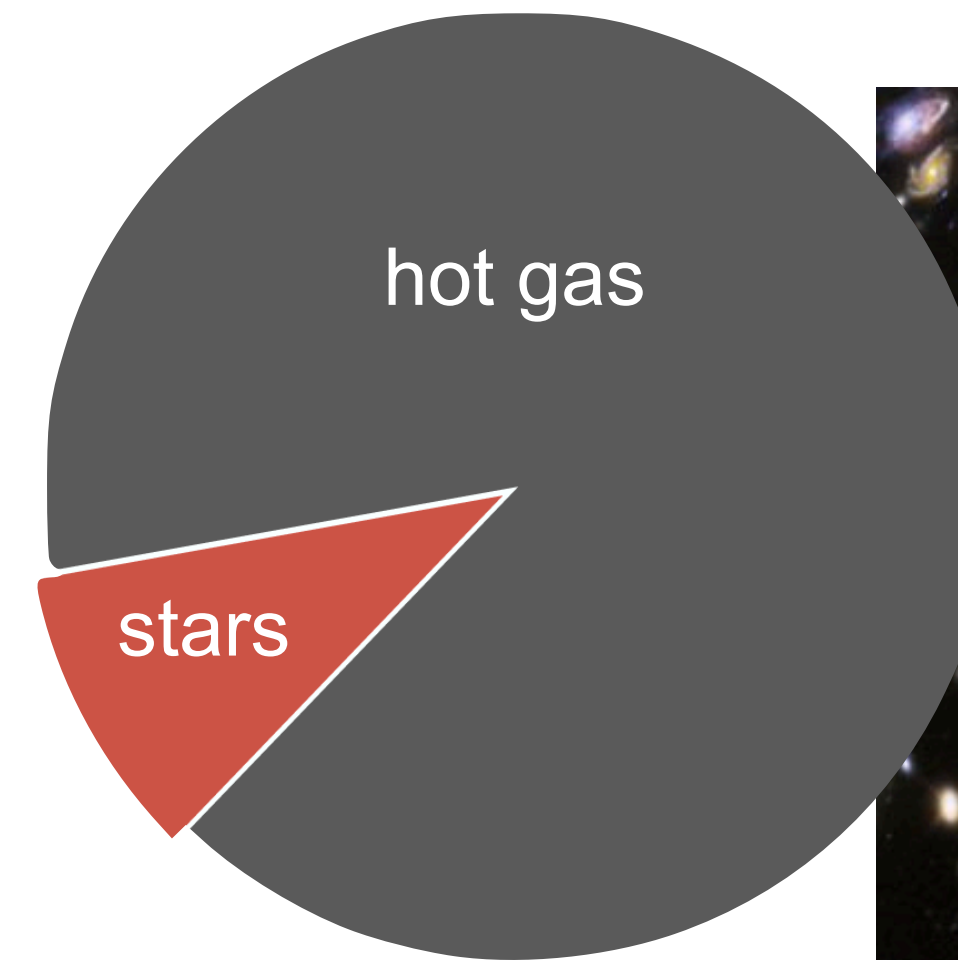
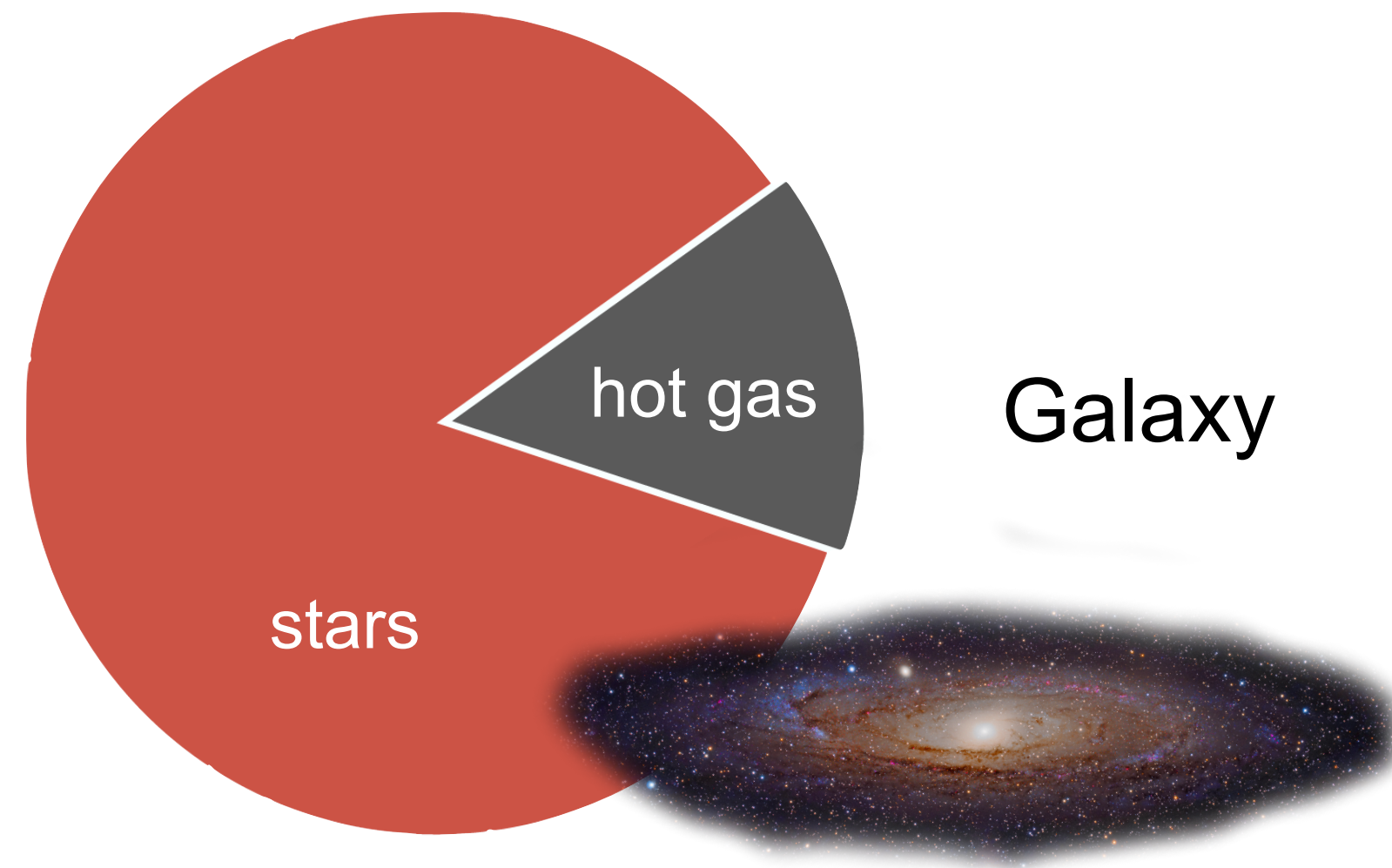
- Explaining the high velocities at large radii requires additional, invisible matter aka. Dark Matter (DM).



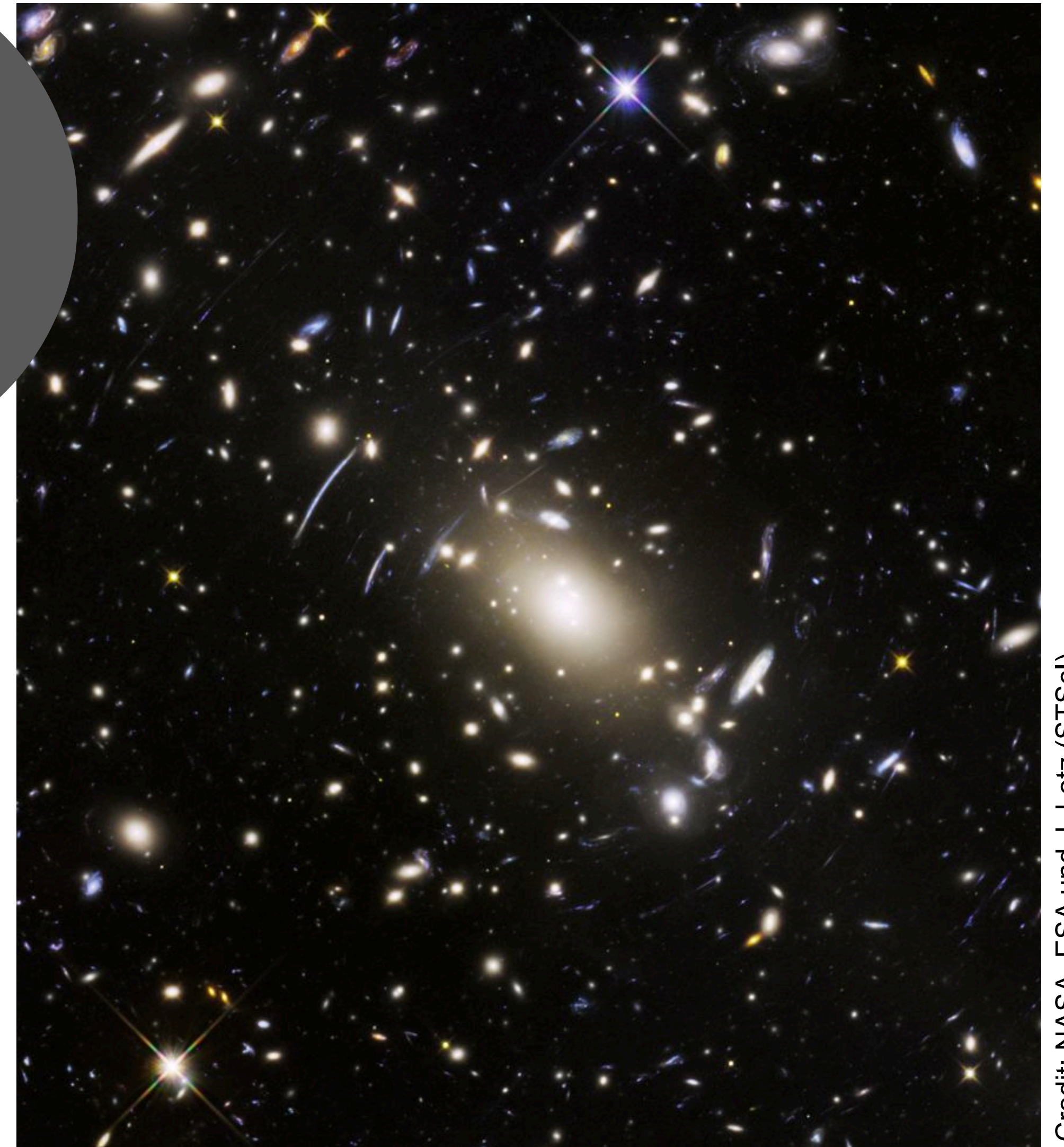
Credit (left): Rubin et al. / ApJL 1978

Credit (right): ESO

Galaxy clusters



Galaxy cluster: Abell S1063
(observed with the “Hubble” Space Telescope)

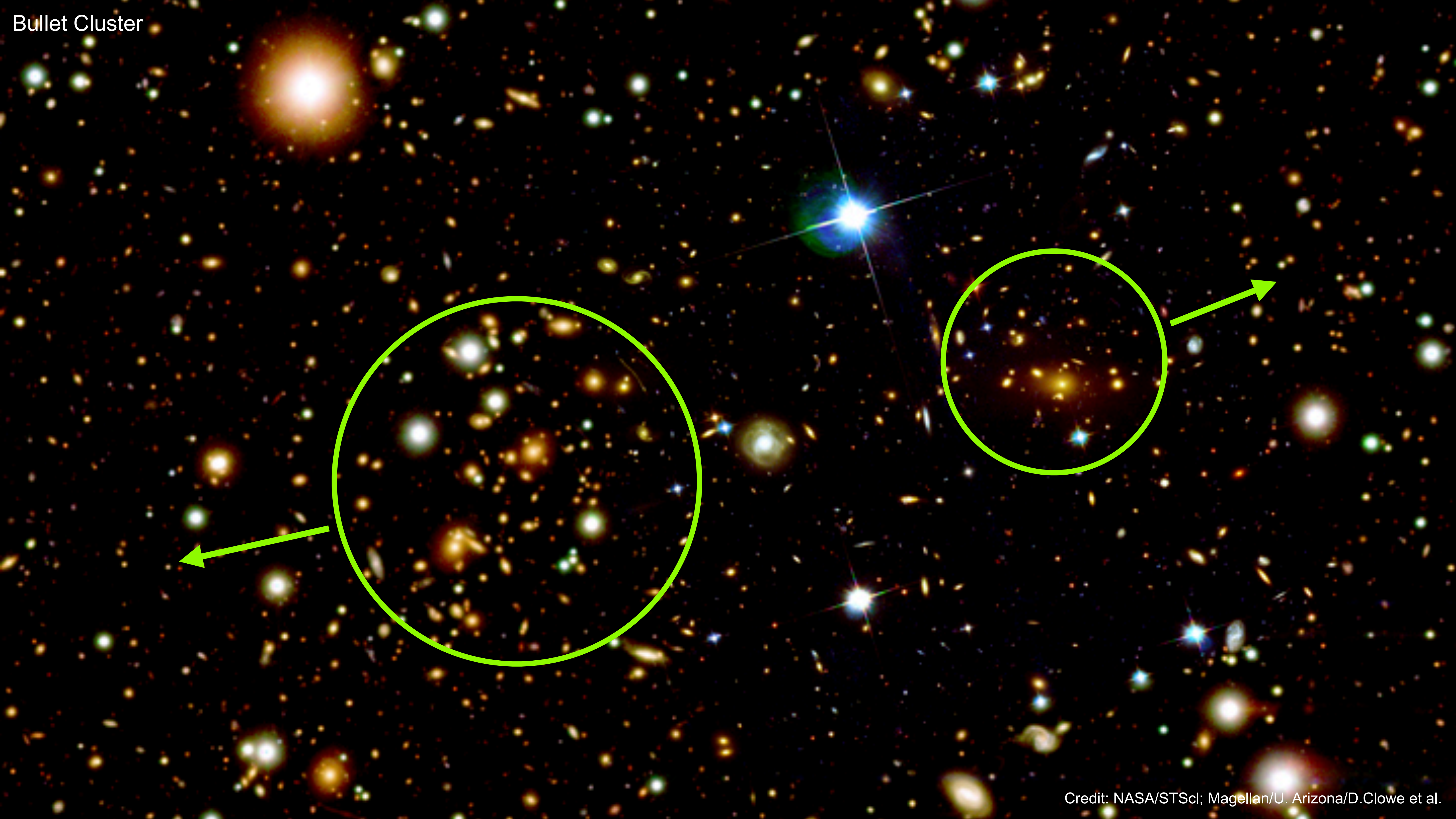


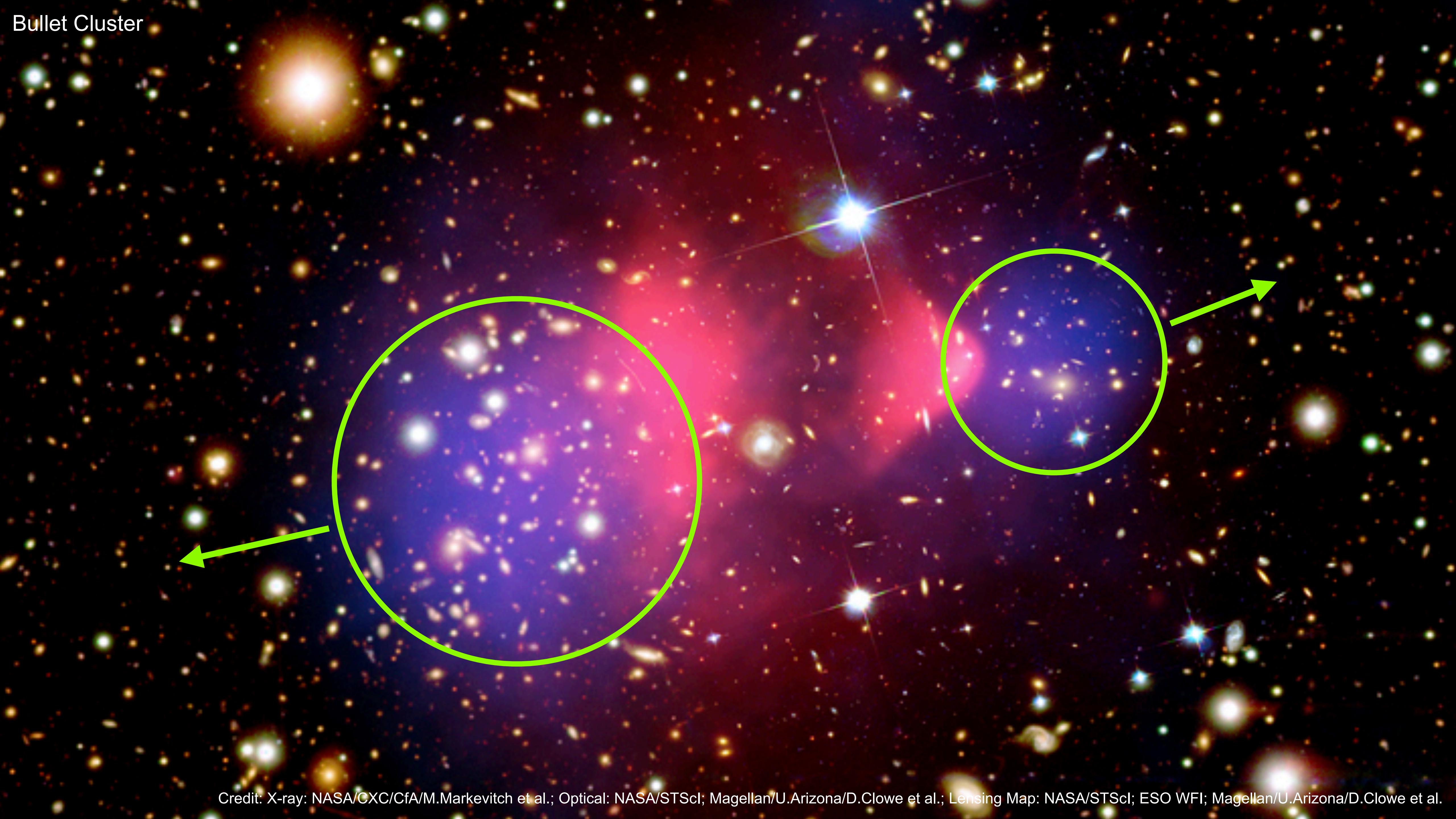
- Galaxy clusters consist of about 1000 galaxies and are mostly “**empty**”.



Bullet Cluster

Bullet Cluster





Bullet Cluster



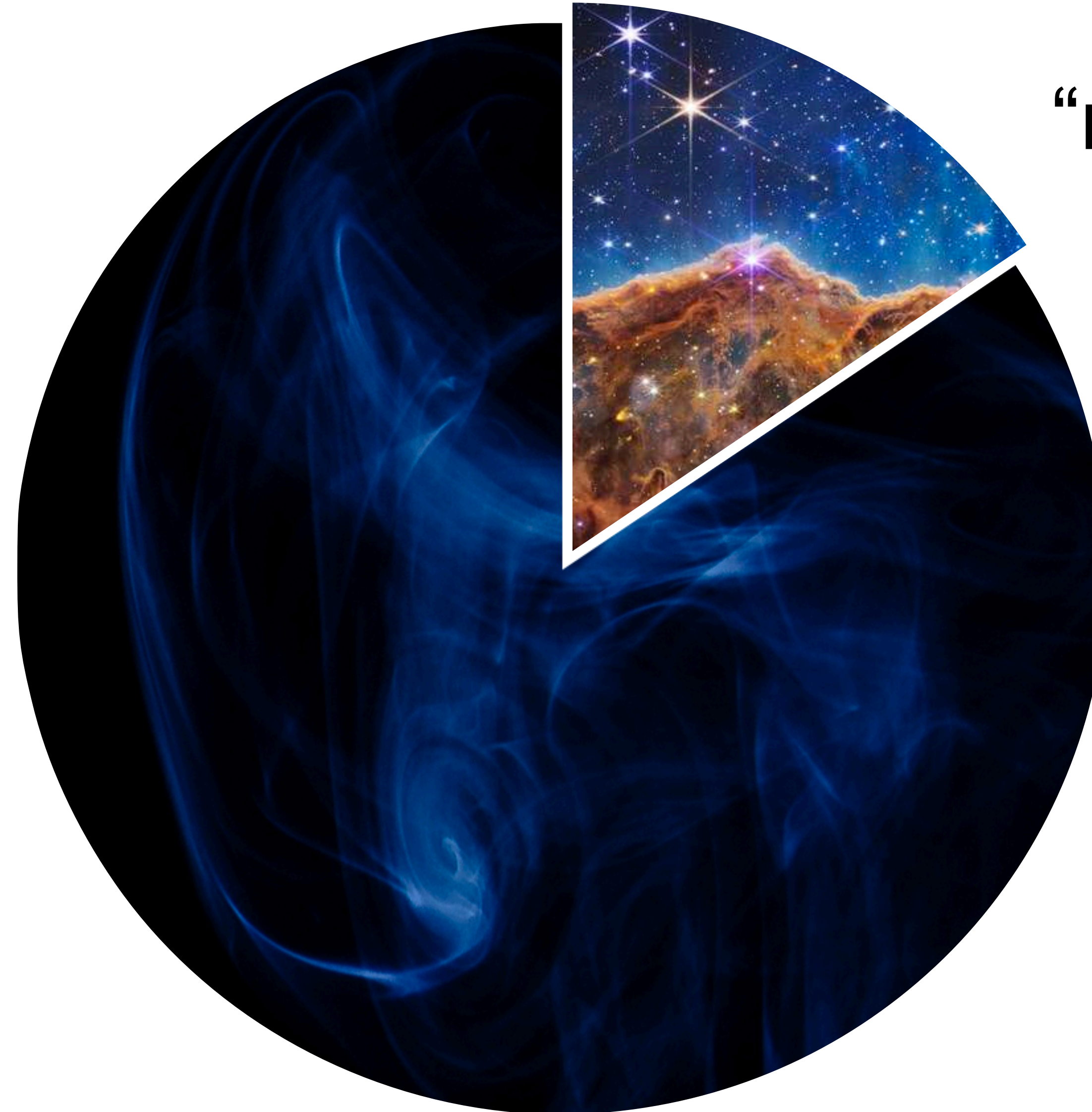
most “normal” matter

most
mass

most
mass

How much Dark Matter is there?

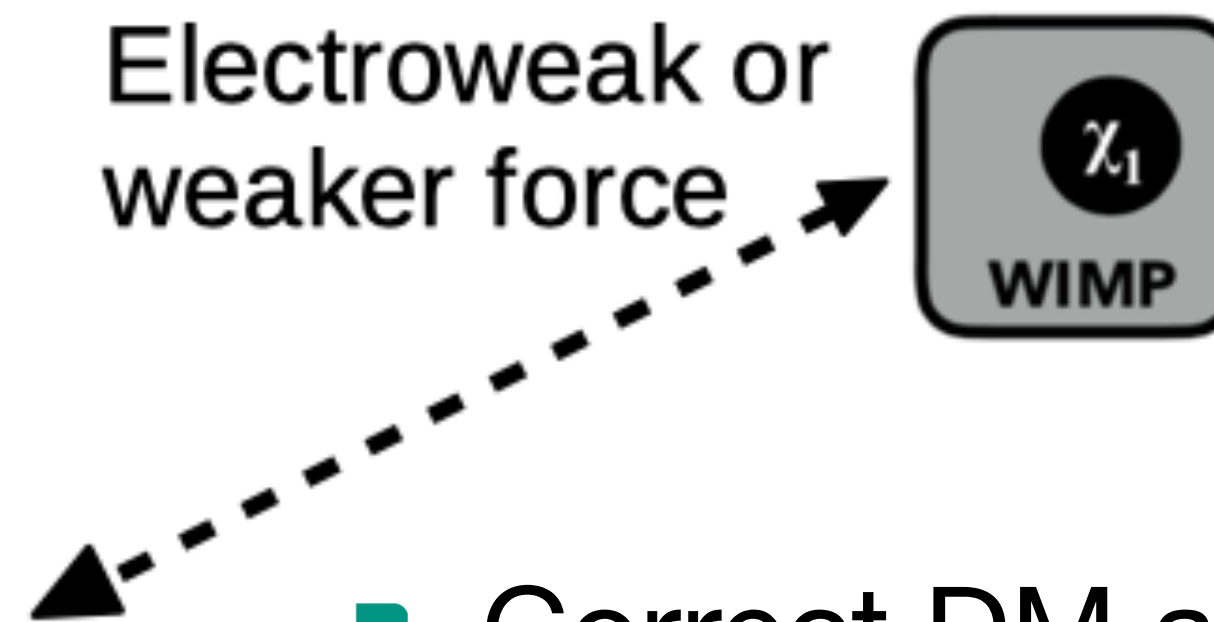
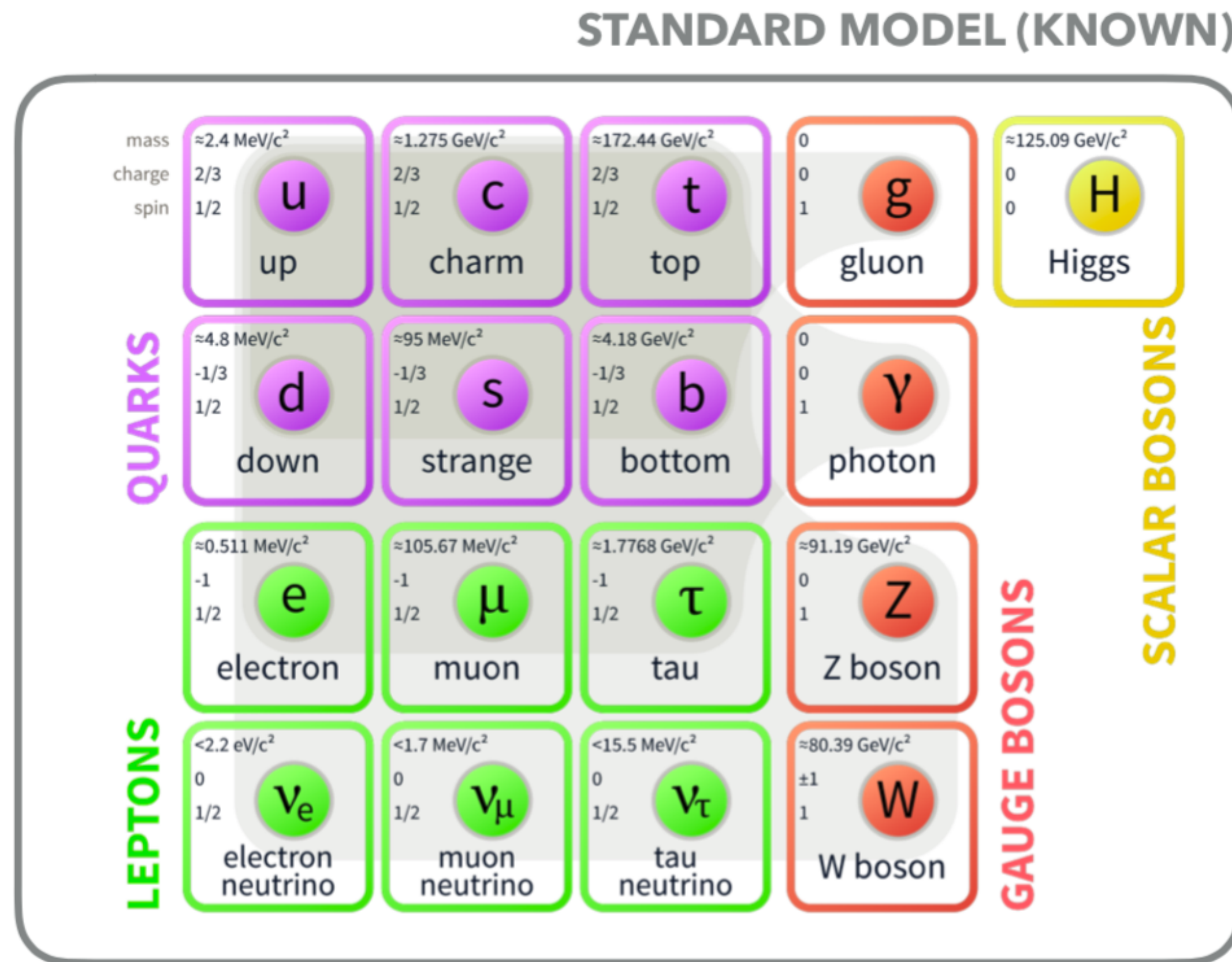
Dark Matter
(~ 85%)



“normal” matter
(~ 15%)

What constitutes Dark Matter?

WIMP: Weakly Interacting Massive Particle

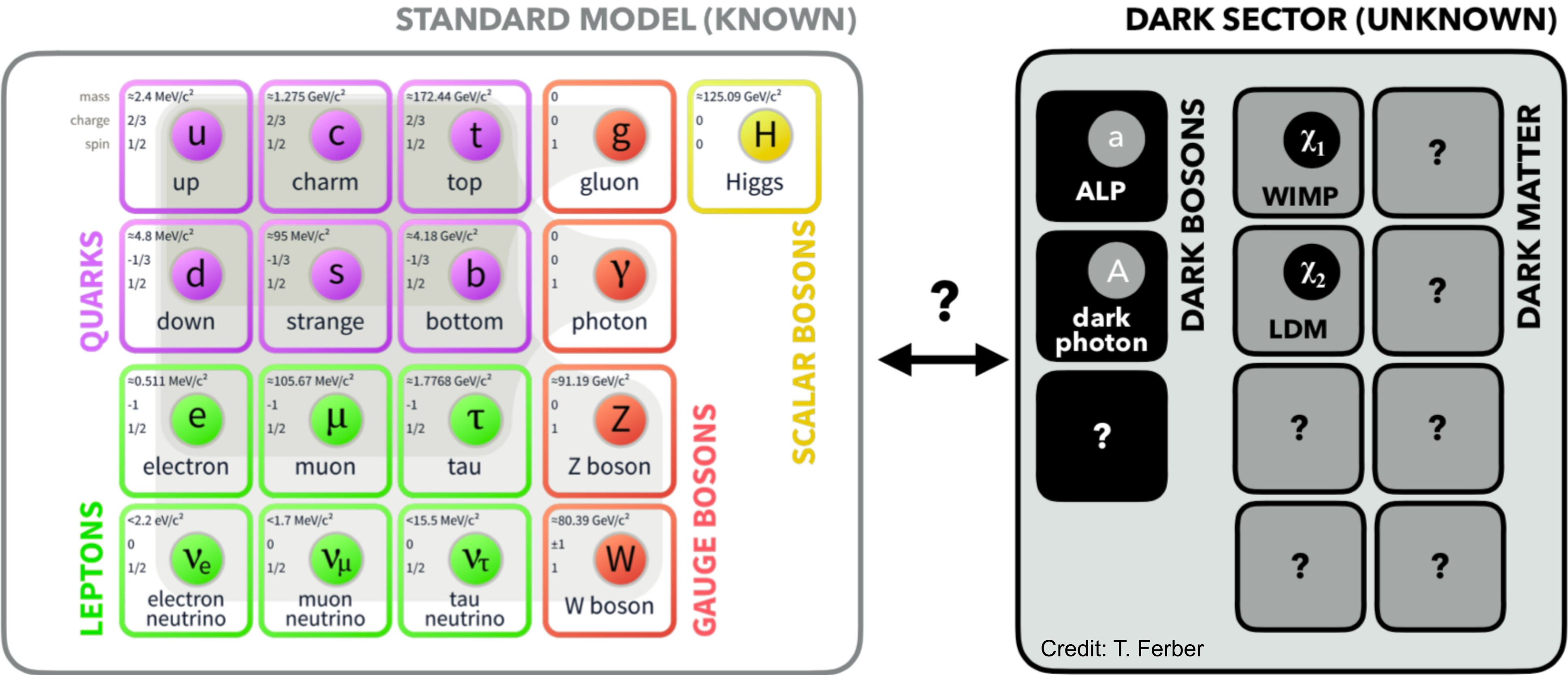


- Correct DM abundance today requires $\langle \sigma v \rangle \sim 3 \times 10^{-26} \text{cm}^3 \text{s}^{-1}$
- Expected for weak scale particle interacting weakly
- Other theories like SUSY readily predicts such a particle

“WIMP miracle”

What constitutes Dark Matter?

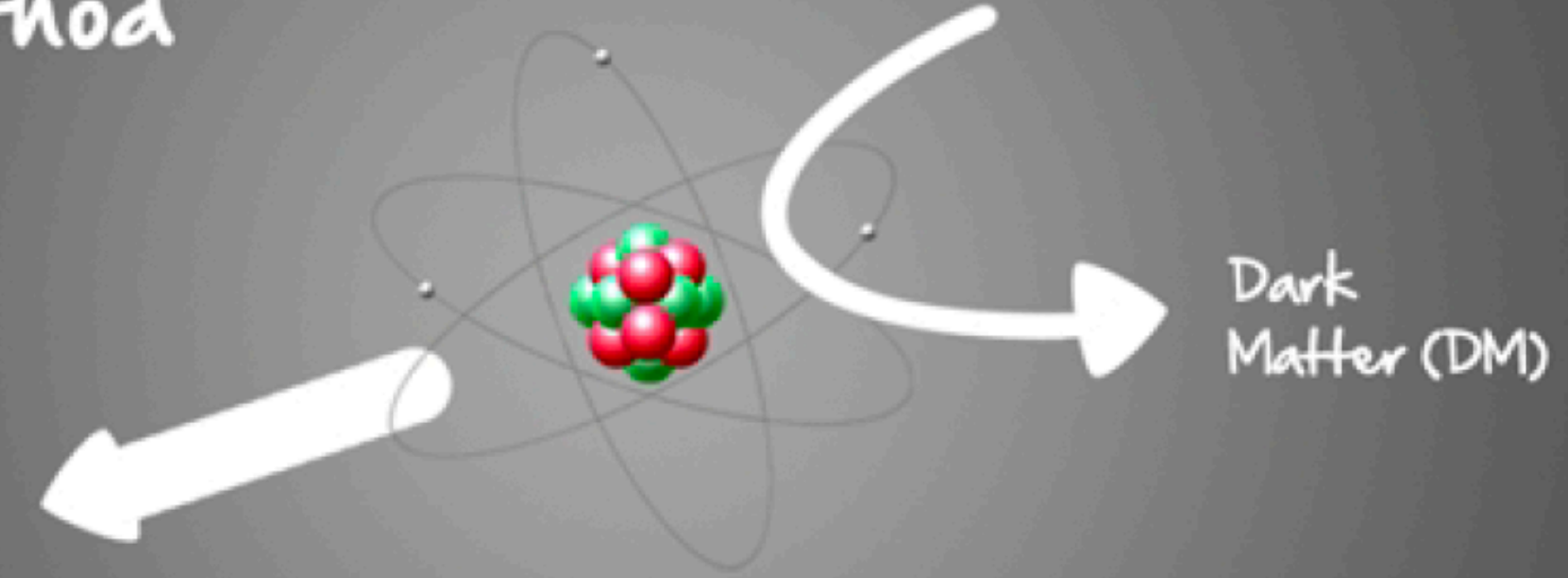
WIMP: Weakly Interacting Massive Particle
LDM: Light Dark Matter
ALP: Axion-Like Particle



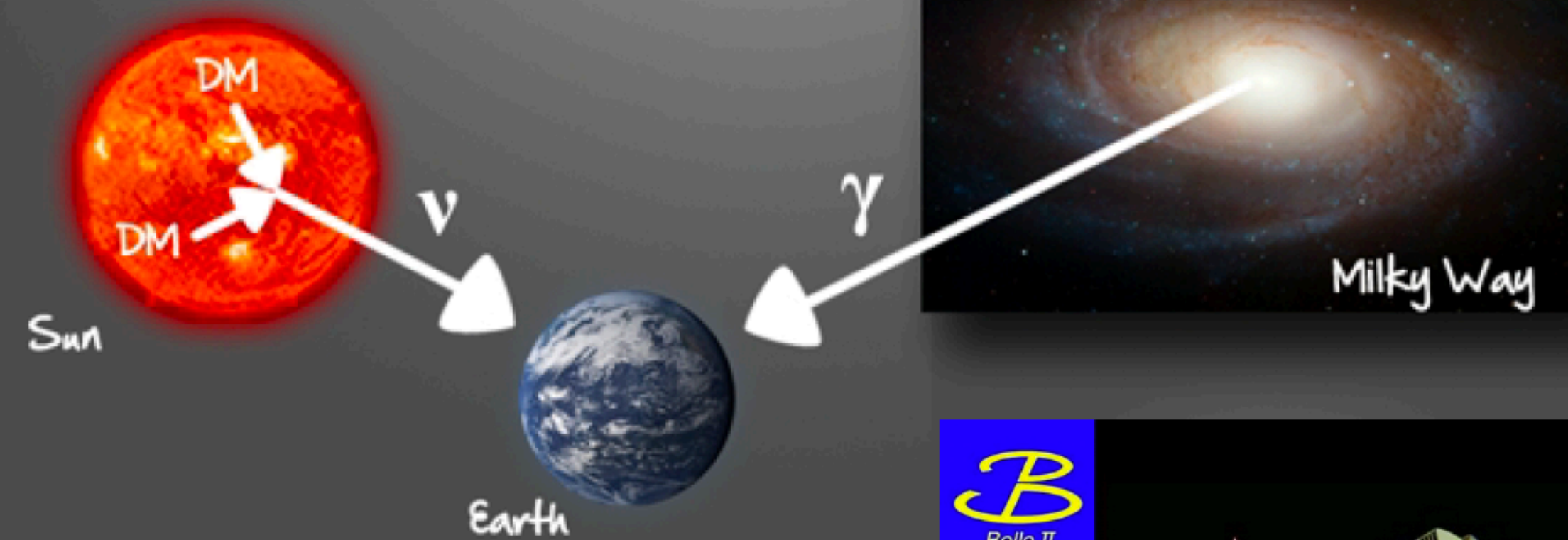
Searching for Dark Matter

Experimental approaches to search for Dark Matter

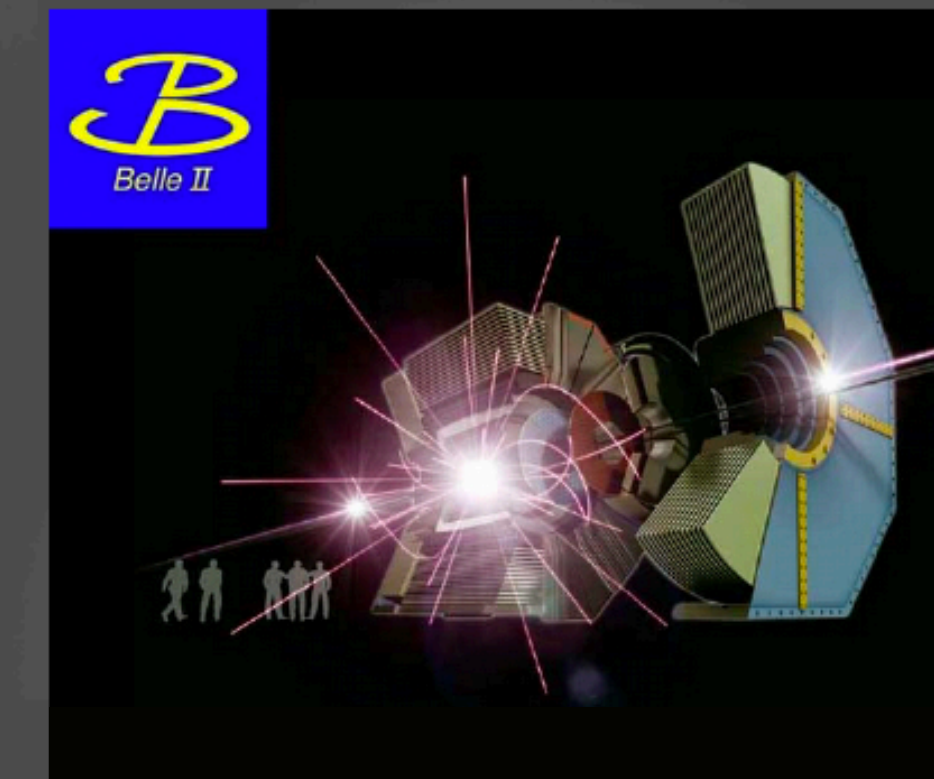
Direct Method



Indirect Method



Production
at Colliders



Experimental approaches to search for Dark Matter

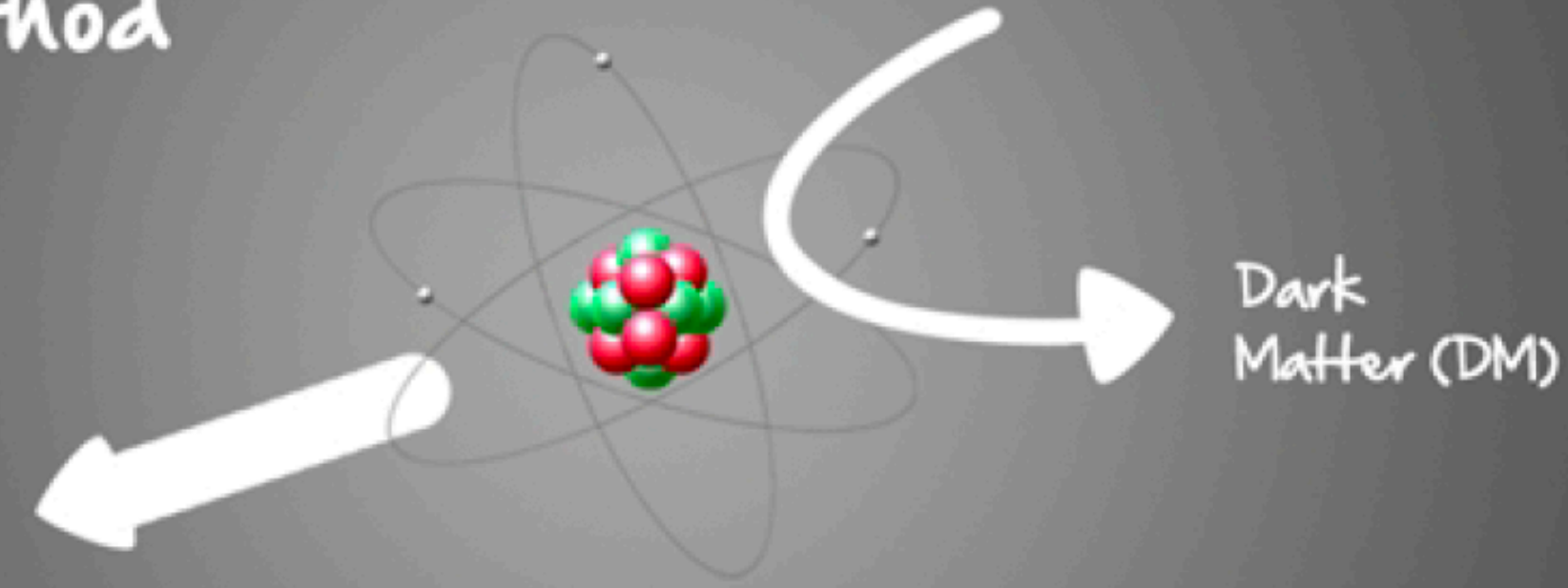
■ Basic idea:

- DM is made of particles which directly interact with the atoms of the detector material.
- The source of DM particles is our galactic DM halo.

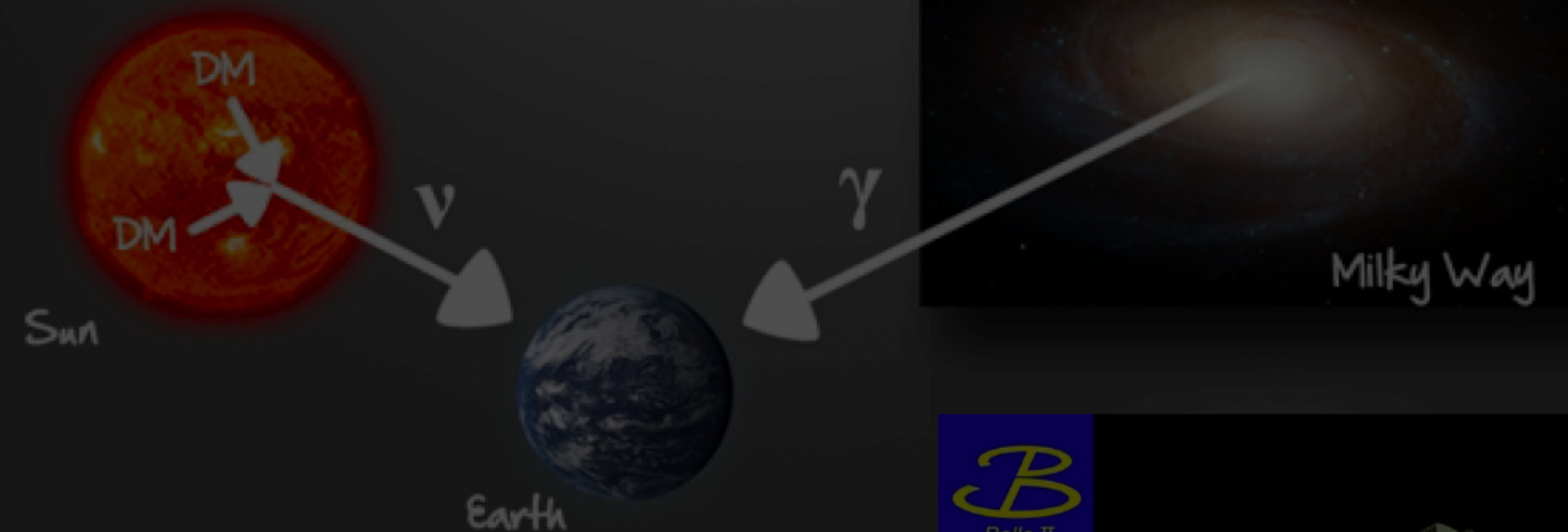


Artist's impression of a spiral galaxy
embedded in a Dark Matter halo
(Credit: ESO / L. Calçada)

Direct Method



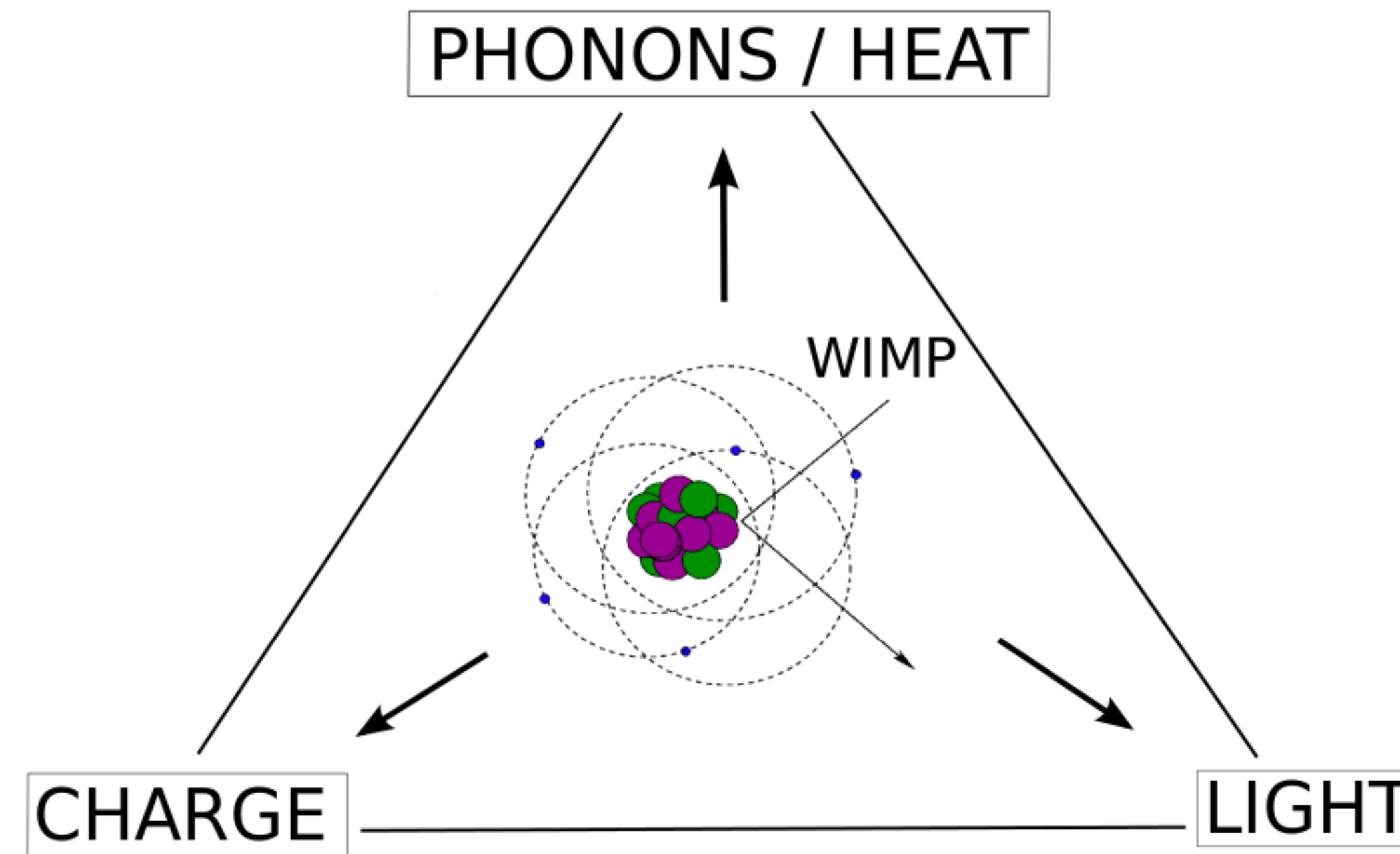
Indirect Method



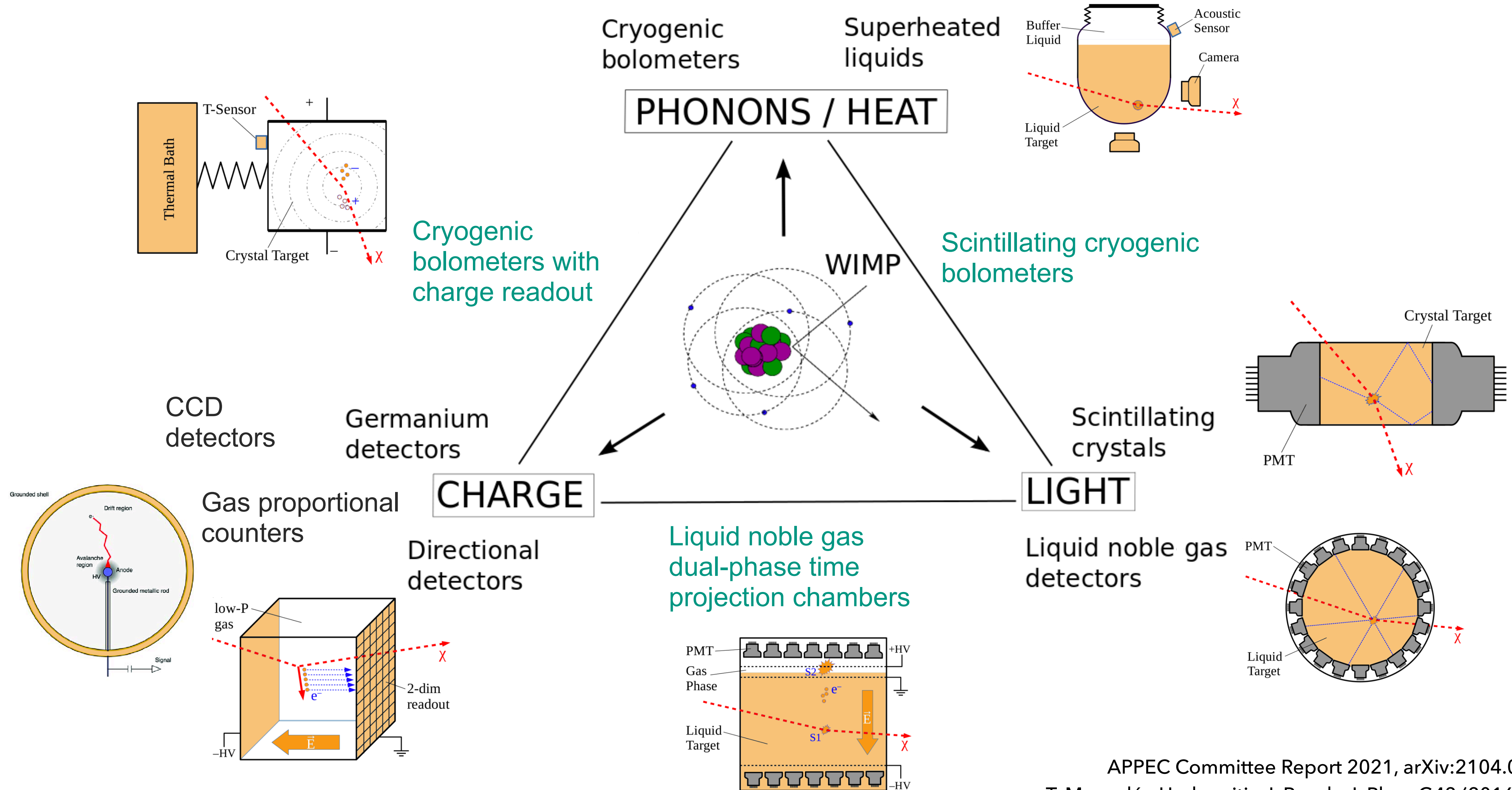
Production at Colliders



Basic concepts for direct detection



Basic concepts for direct detection



Dark Matter-nucleon scattering

Expected
interaction
rate

$$\frac{dR}{dE_R}$$

Particle
theory

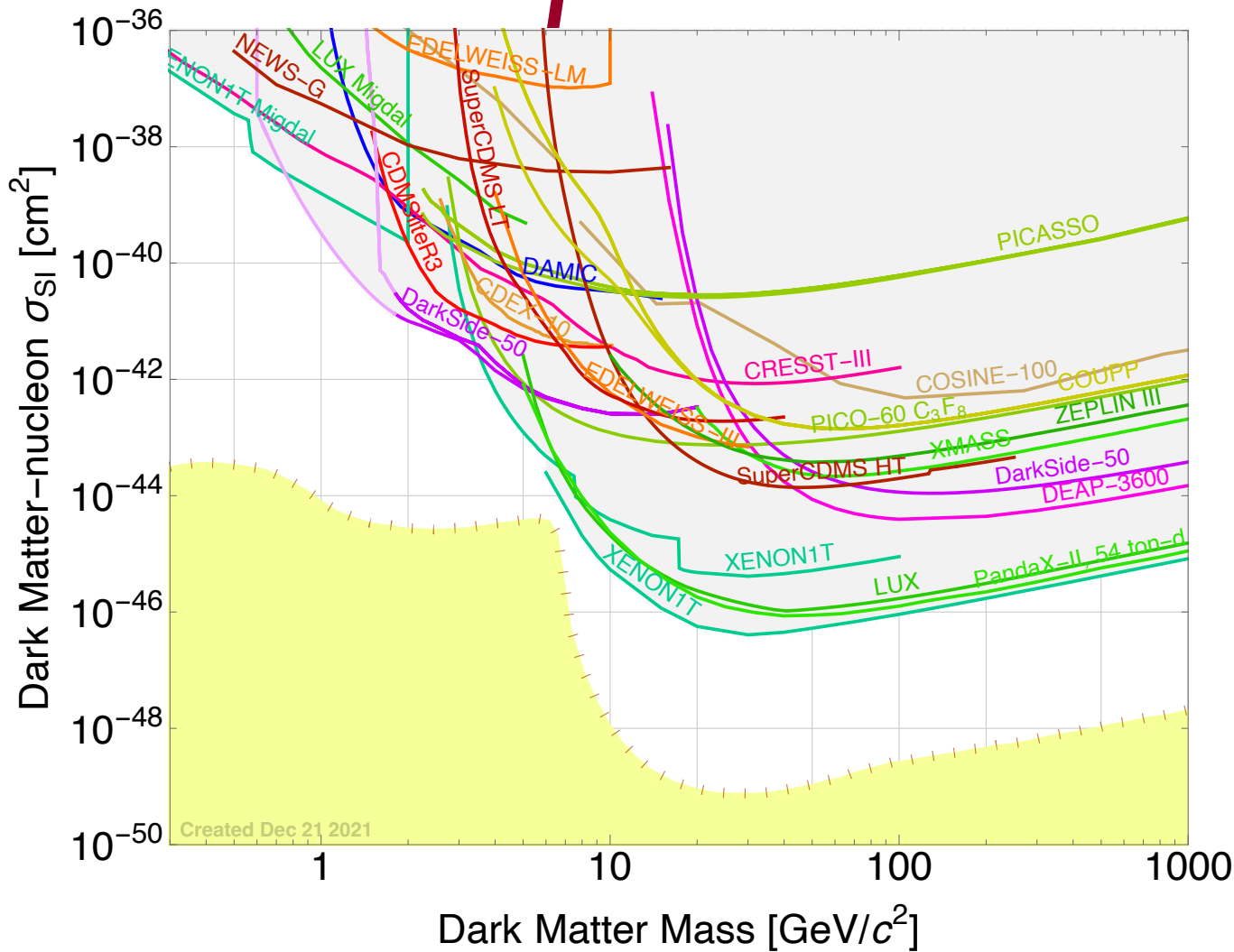
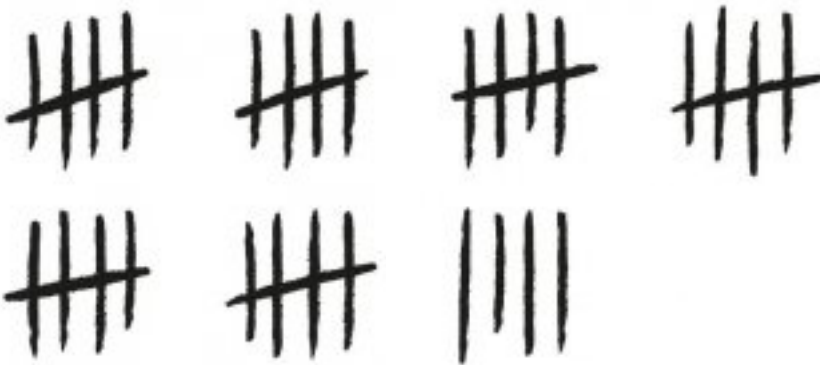
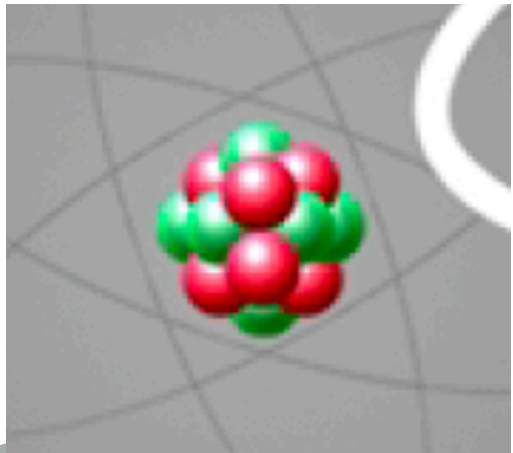
$$\frac{\sigma_n}{m_{\text{DM}}}$$

Local
properties of
DM halo

$$\frac{\rho_{\text{DM}} T(E_R)}{v_{\text{DM}} \sqrt{\pi}}$$

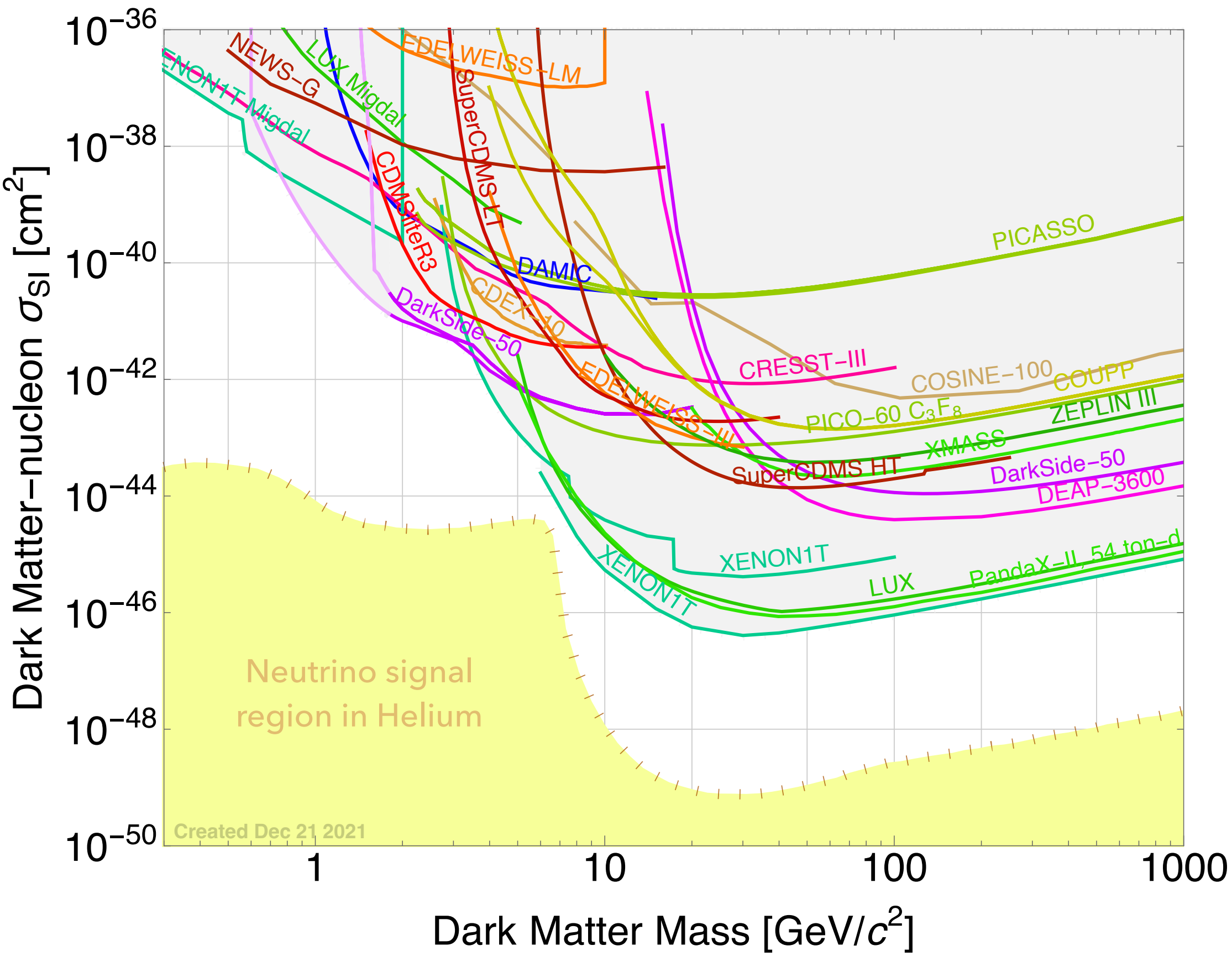
Nuclear
structure

$$\frac{F^2(E_R)}{\mu_n^2}$$

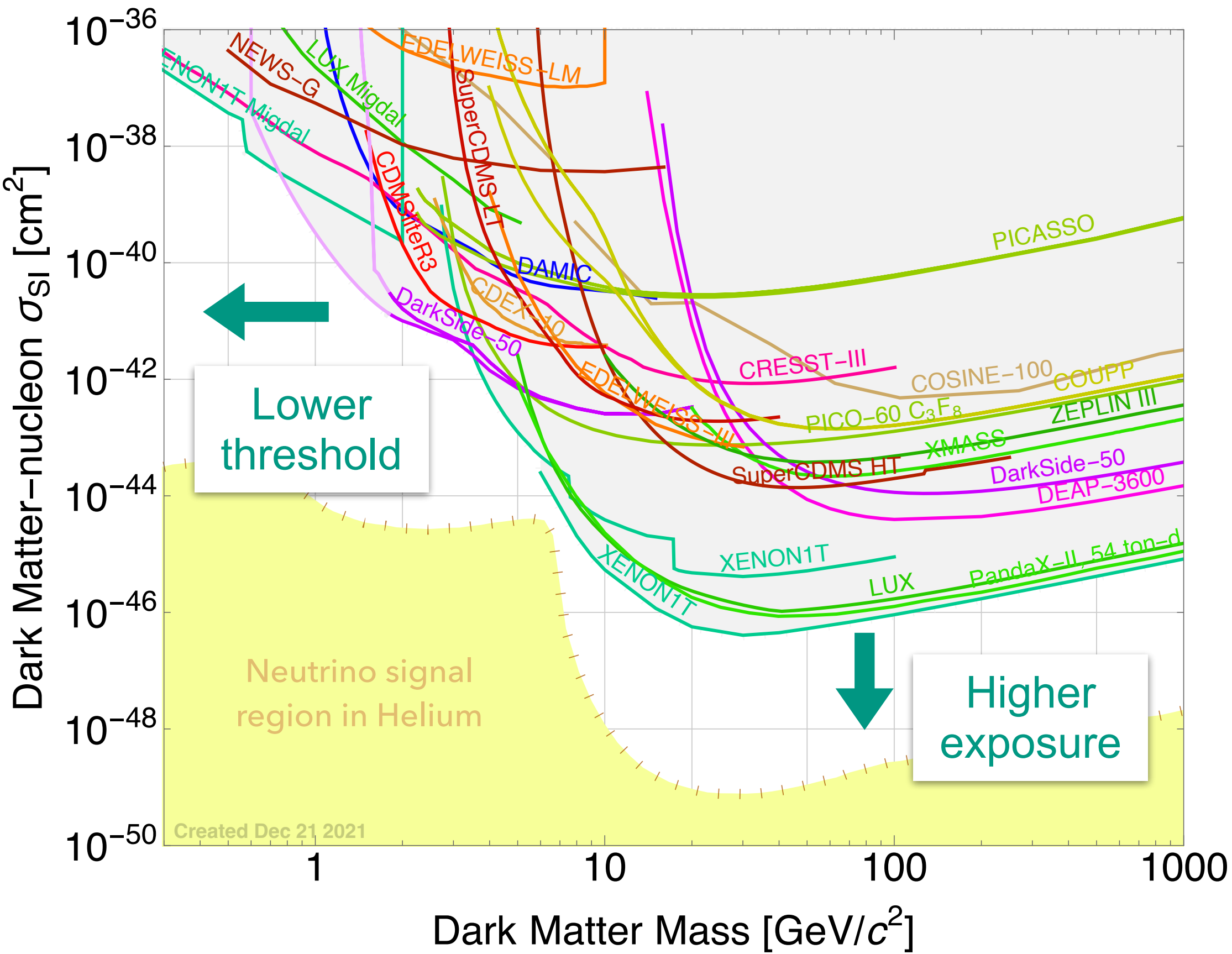


Credit: ESO / L. Calçada

Dark Matter-nucleon scattering



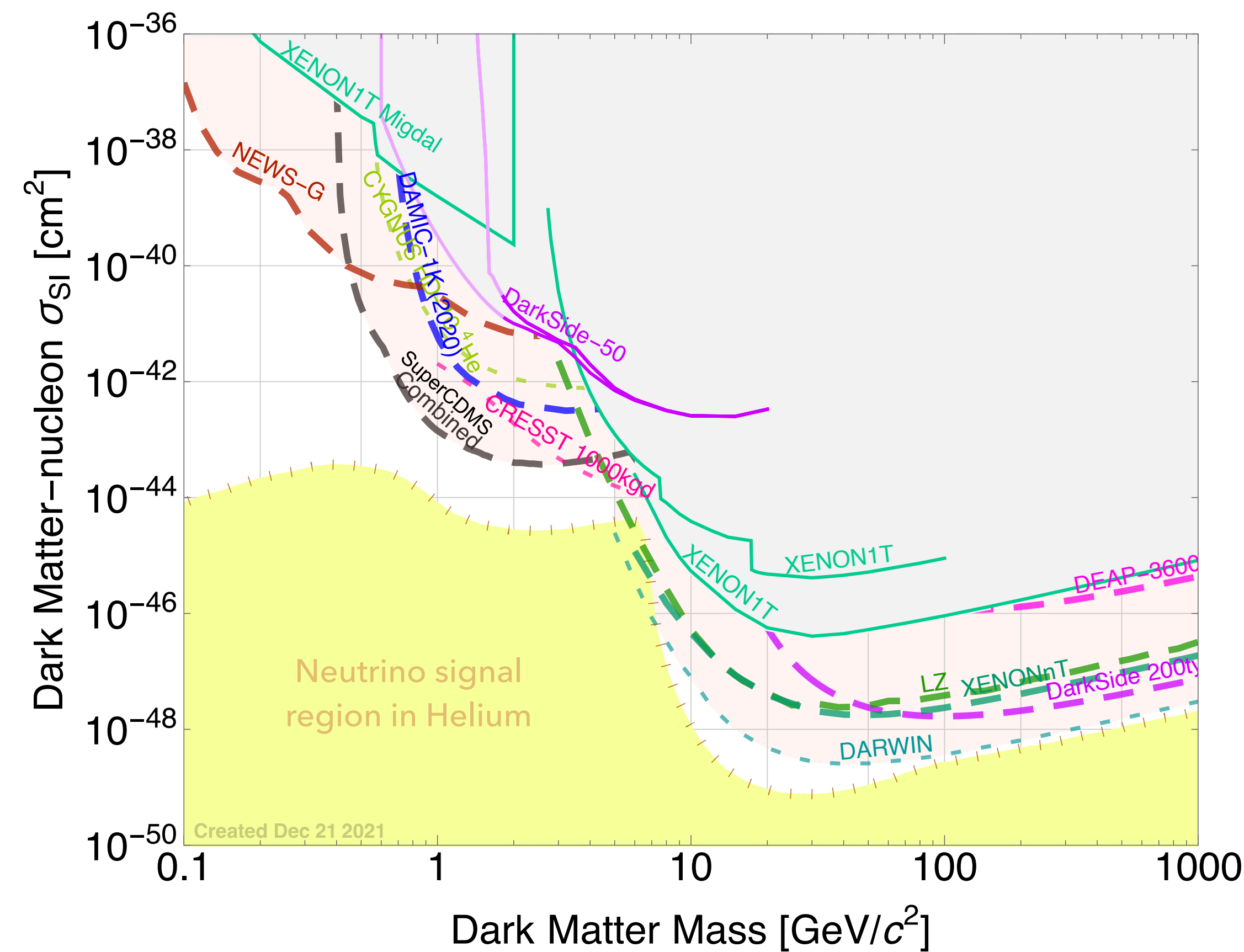
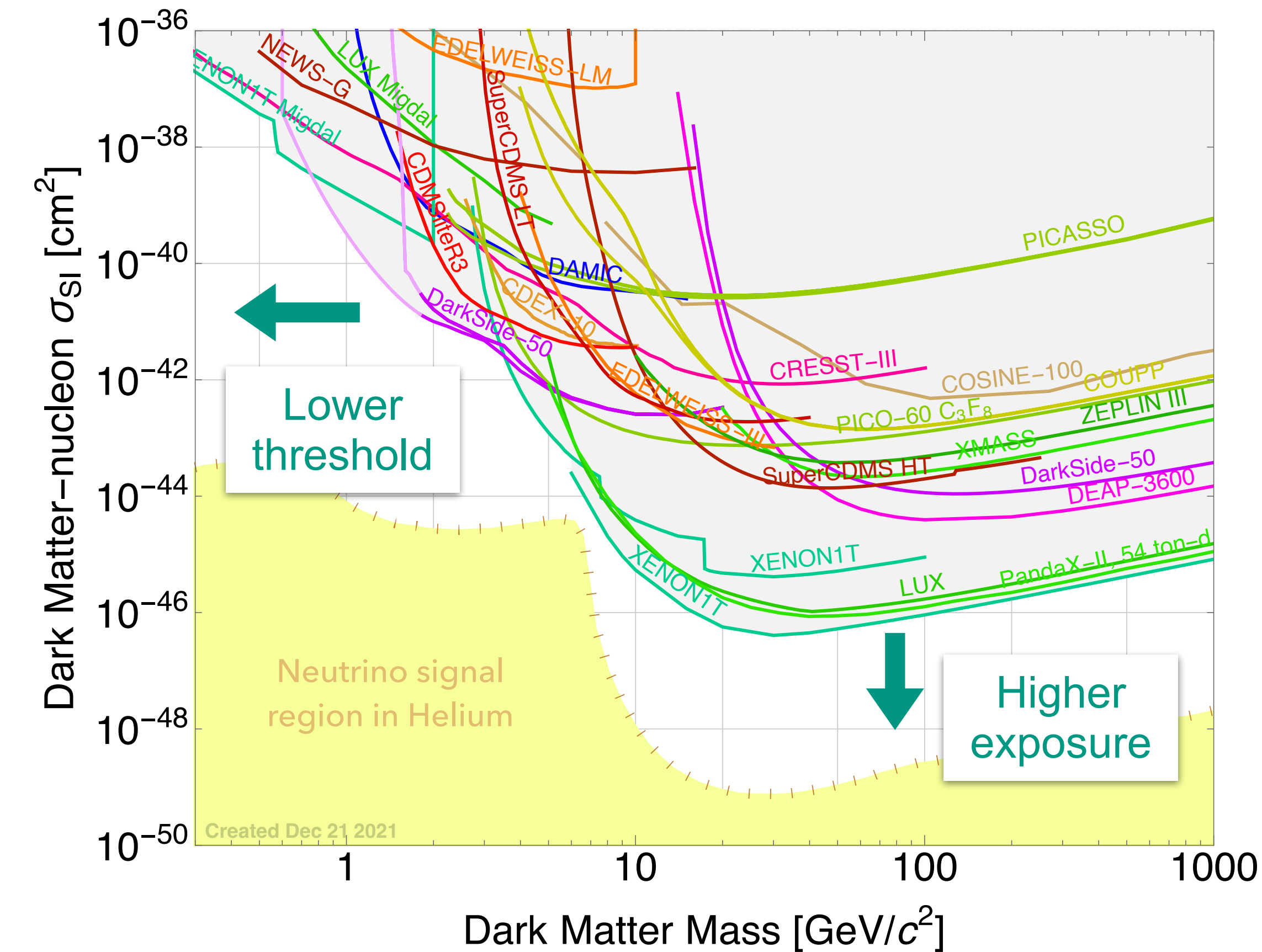
Dark Matter-nucleon scattering



Lighter elements
(typically crystals)

Easier scalable elements
(typically liquid noble gases)

Dark Matter-nucleon scattering

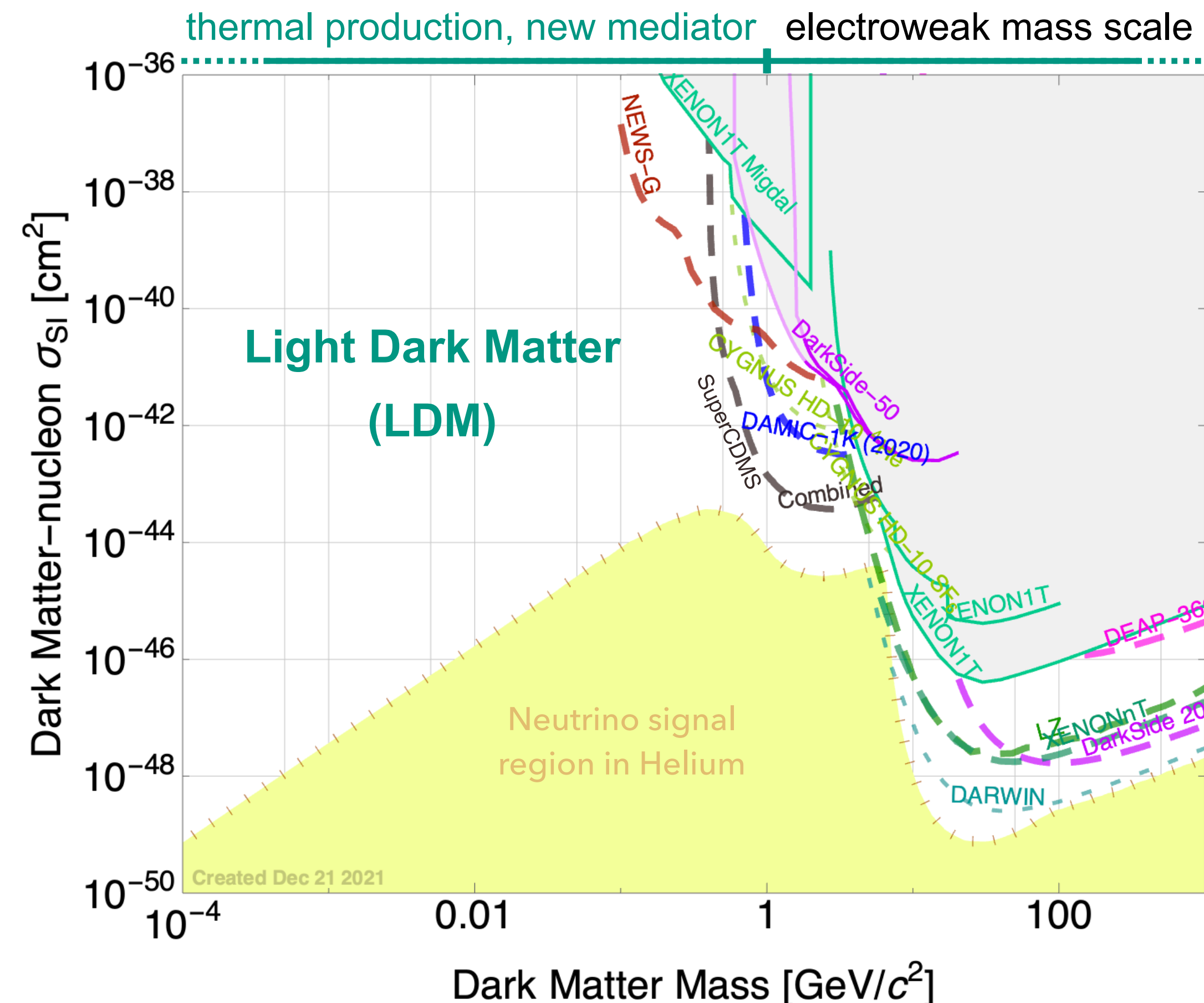
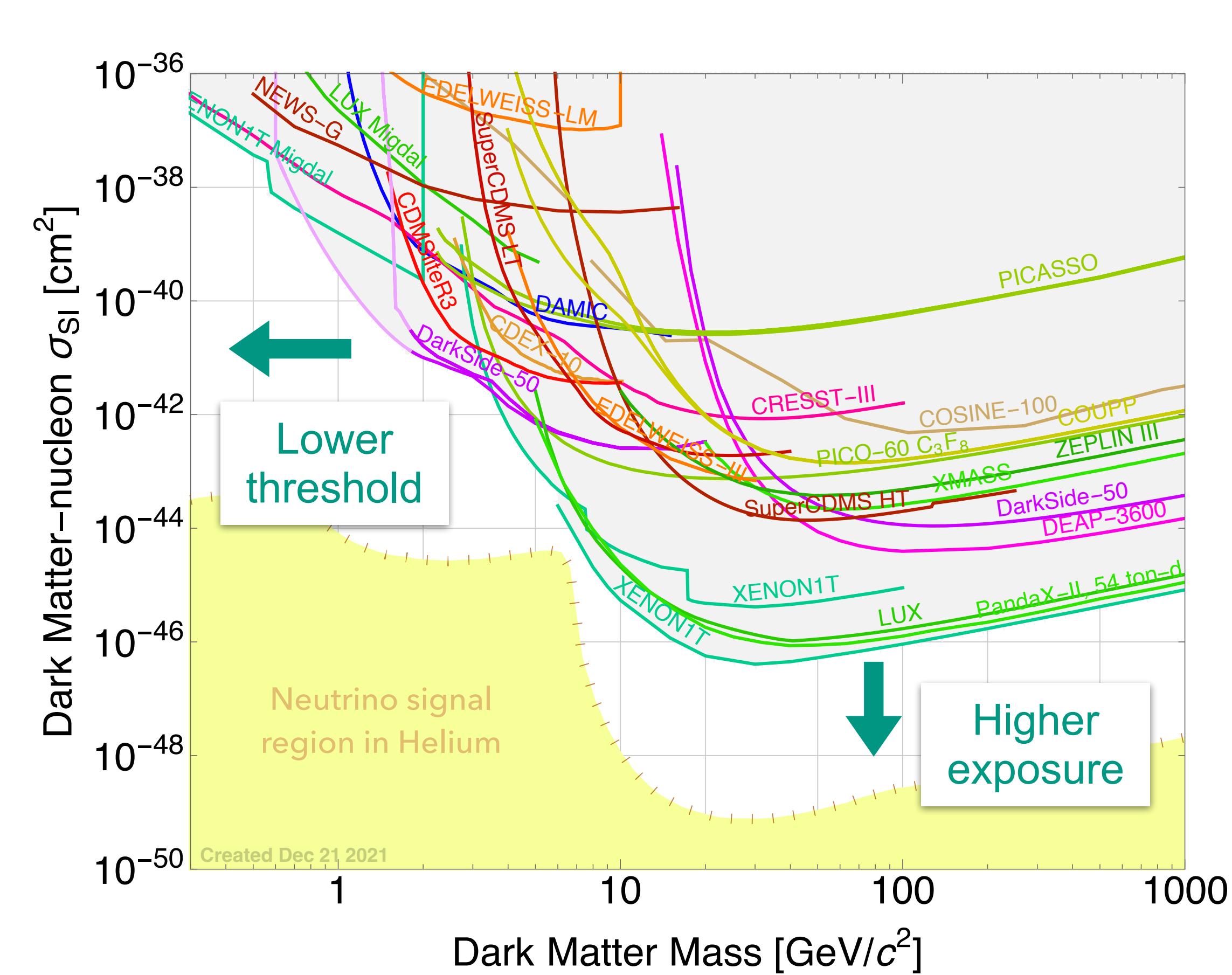


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Dark Matter-nucleon scattering



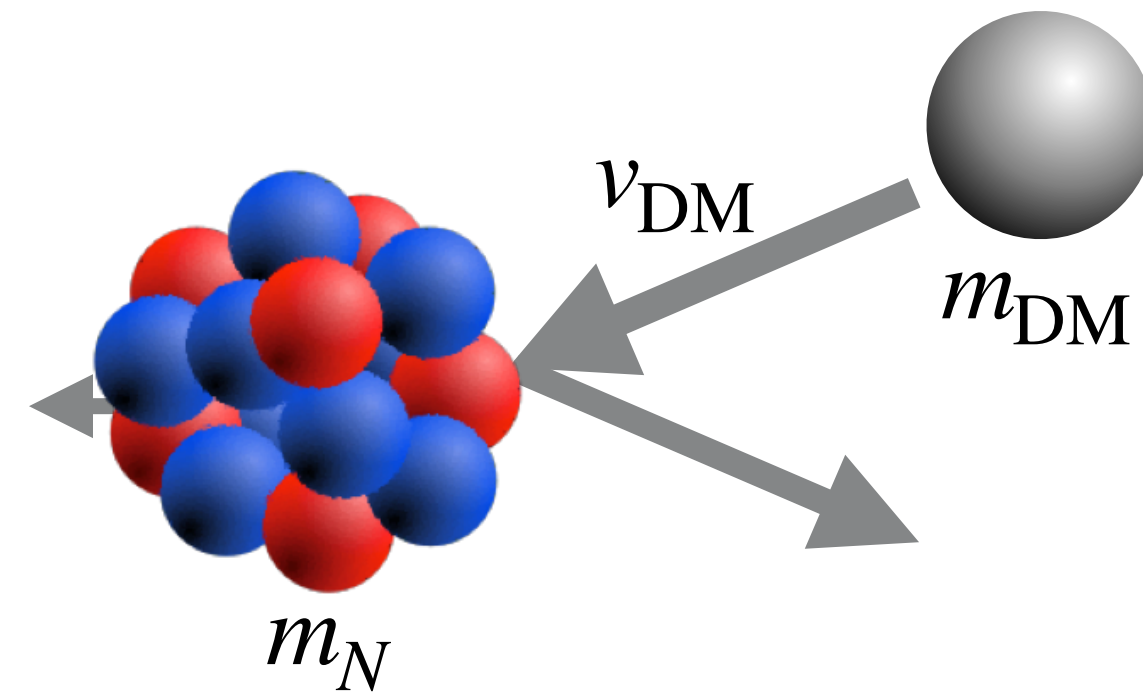
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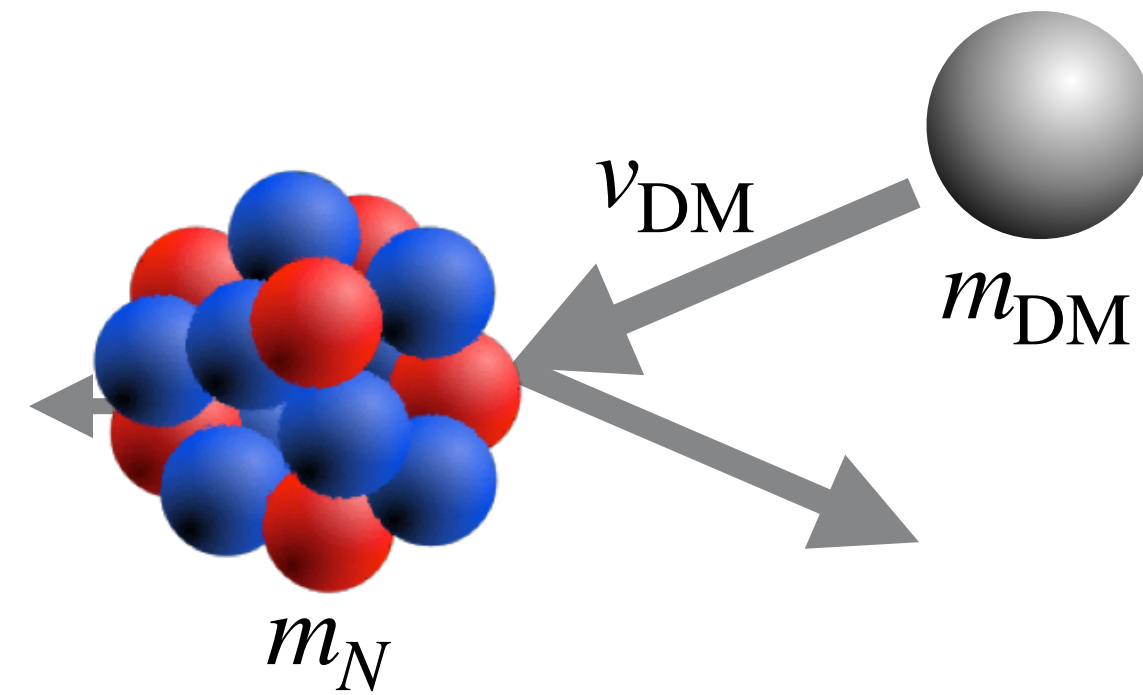
Dark Matter mass vs. nucleus mass

32

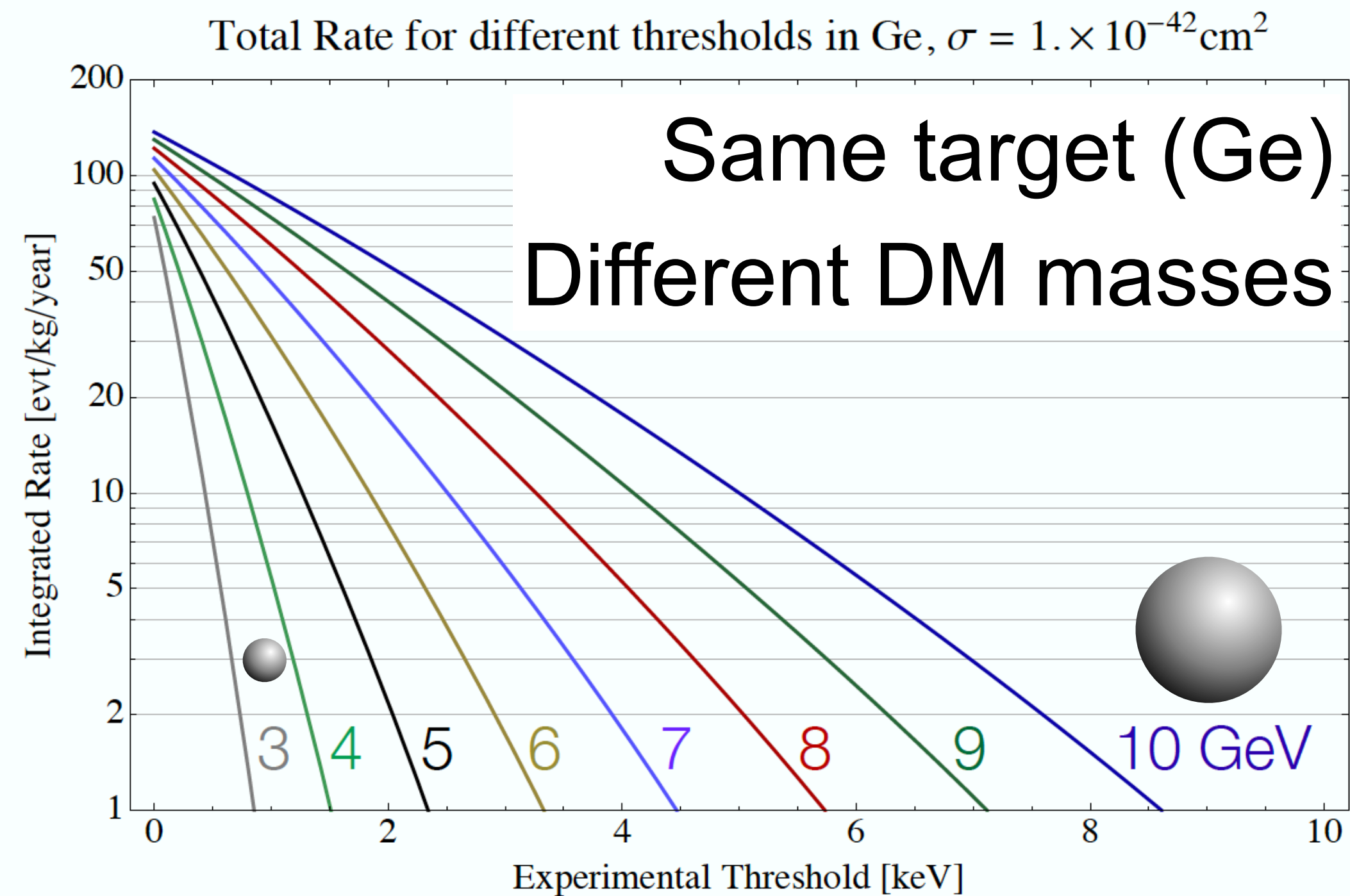


$$\Delta E = \frac{1}{2} \frac{\Delta p^2}{m_N} \simeq \frac{2 m_{DM}^2 v_{DM}^2}{m_N}$$

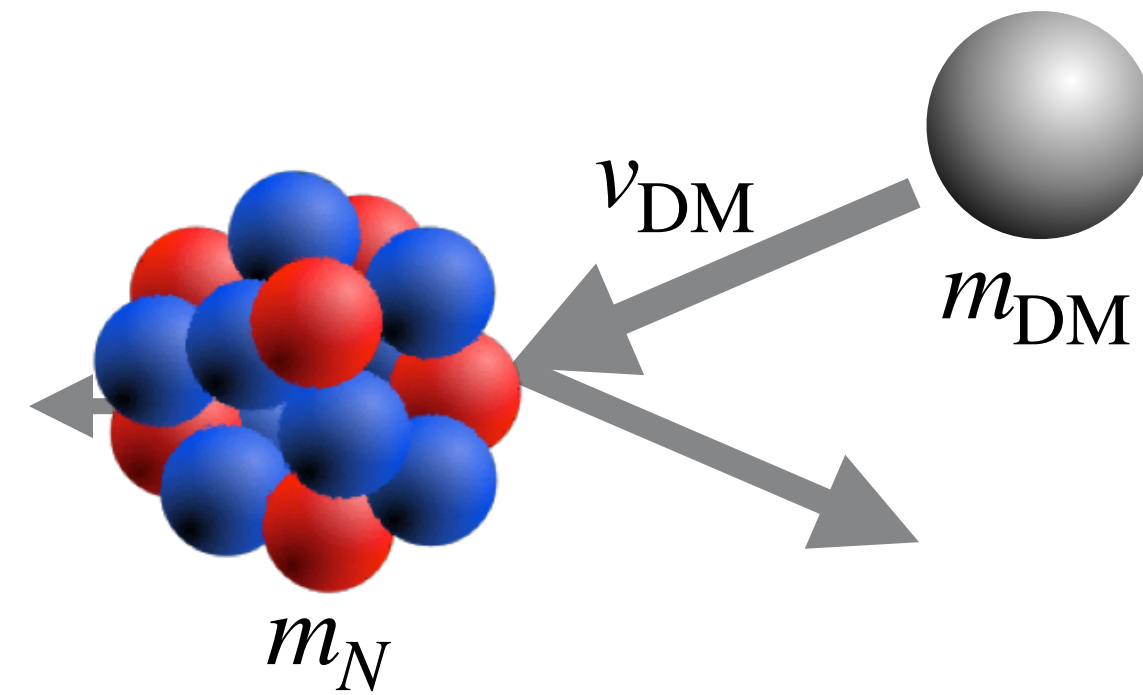
Dark Matter mass vs. nucleus mass



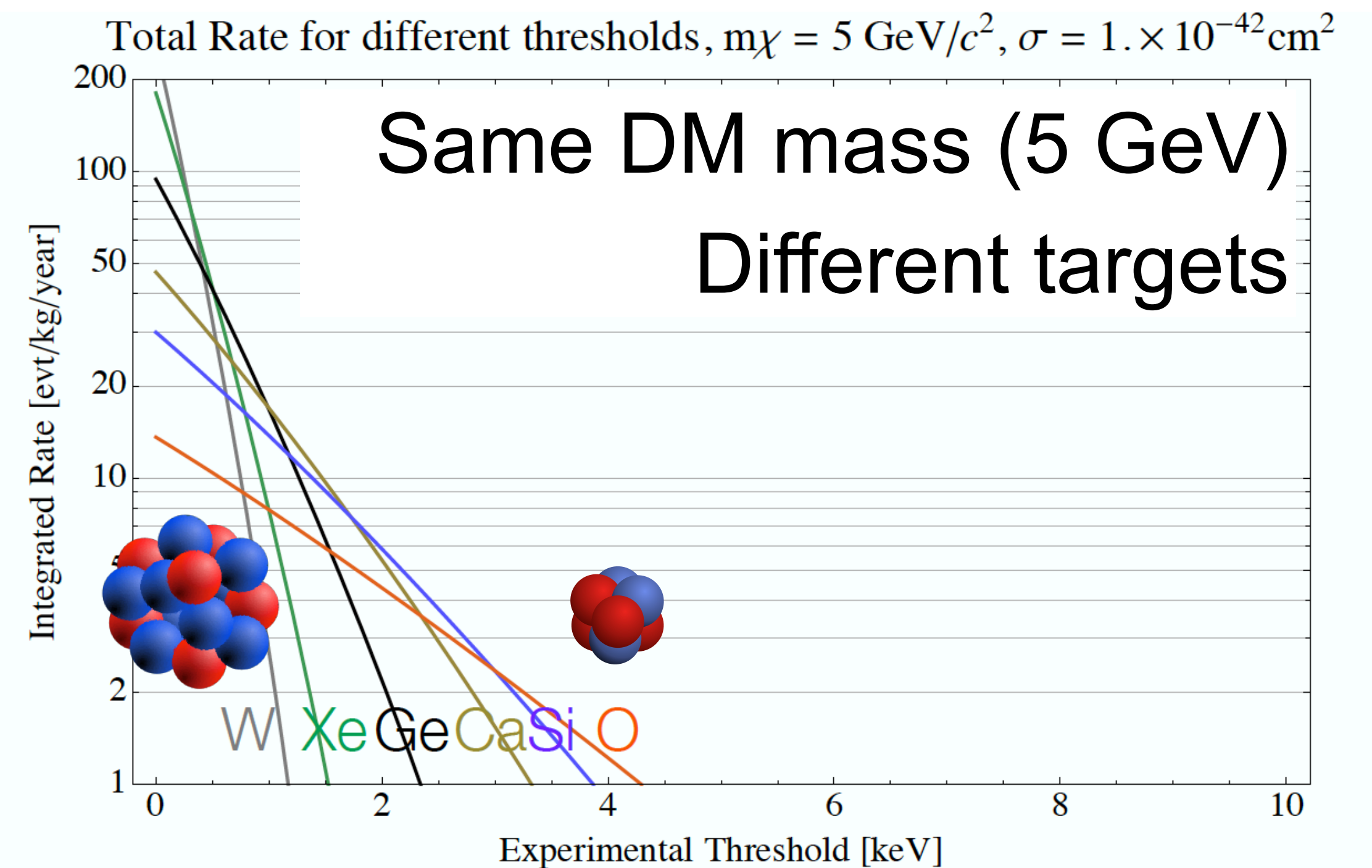
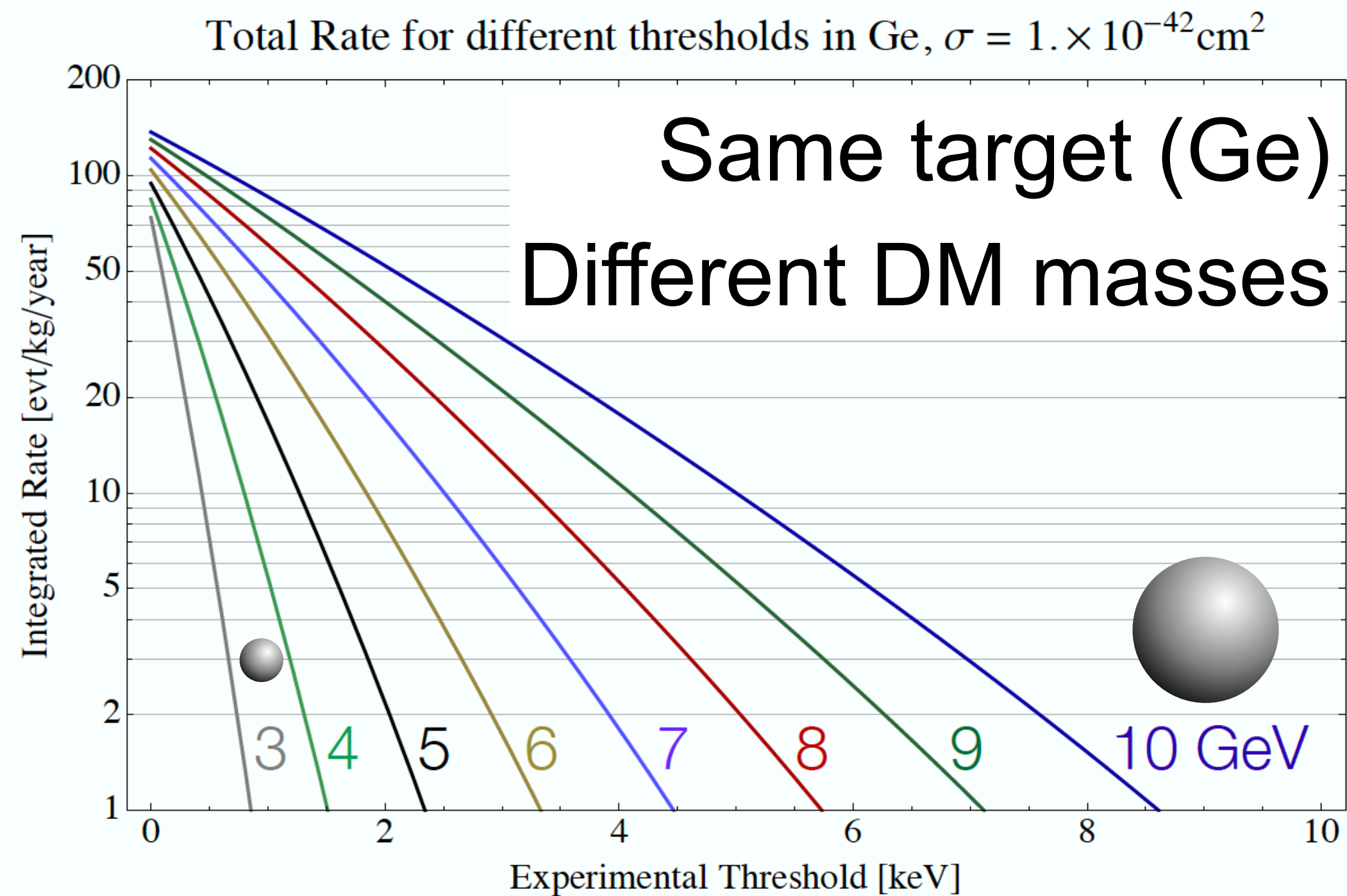
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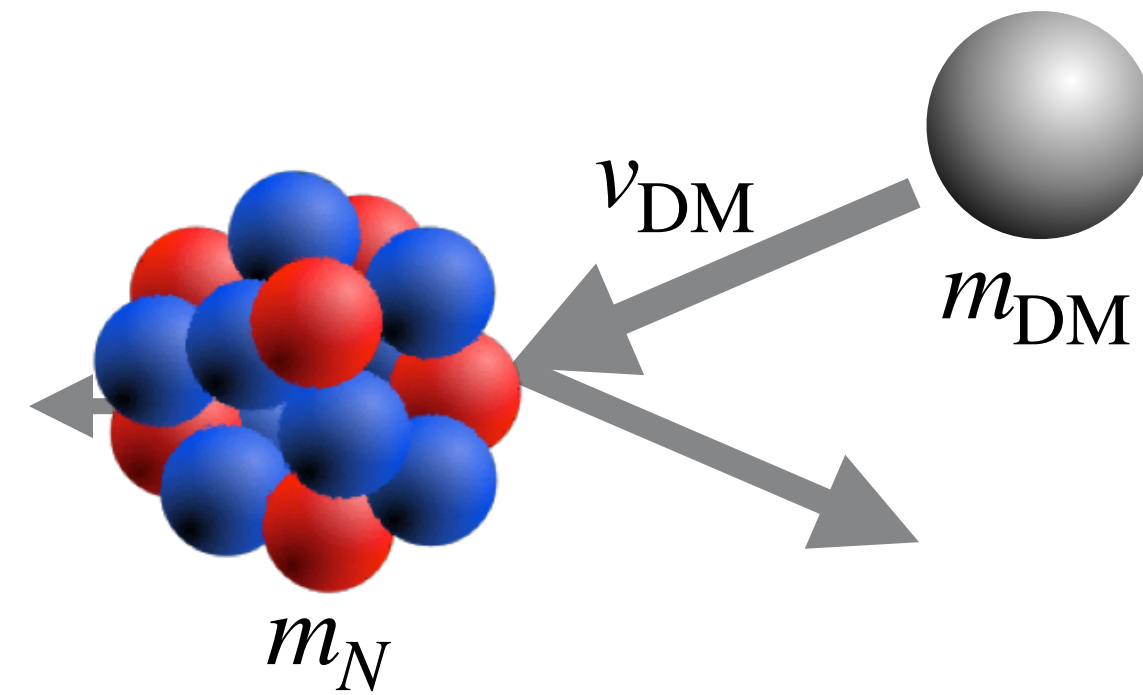
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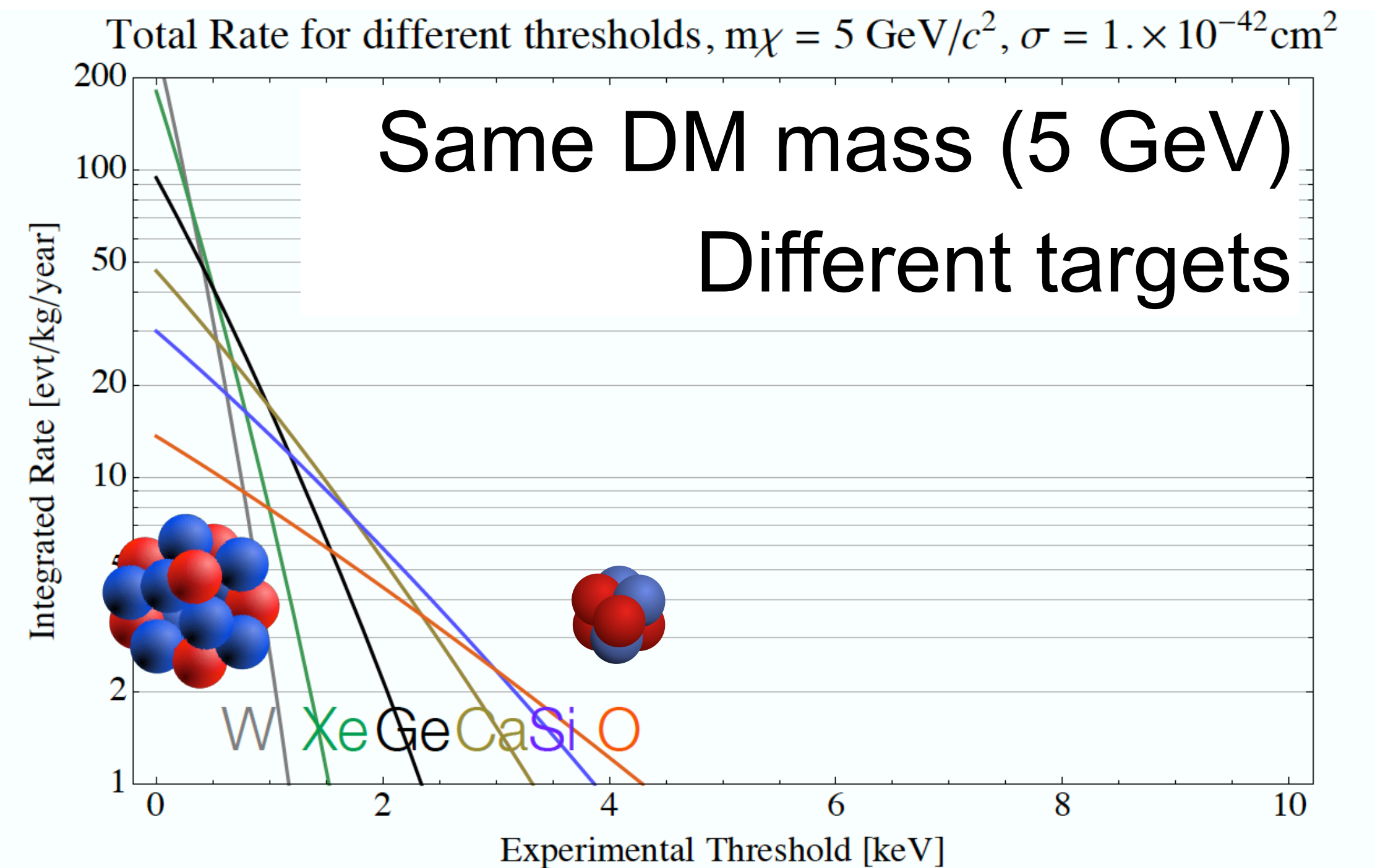
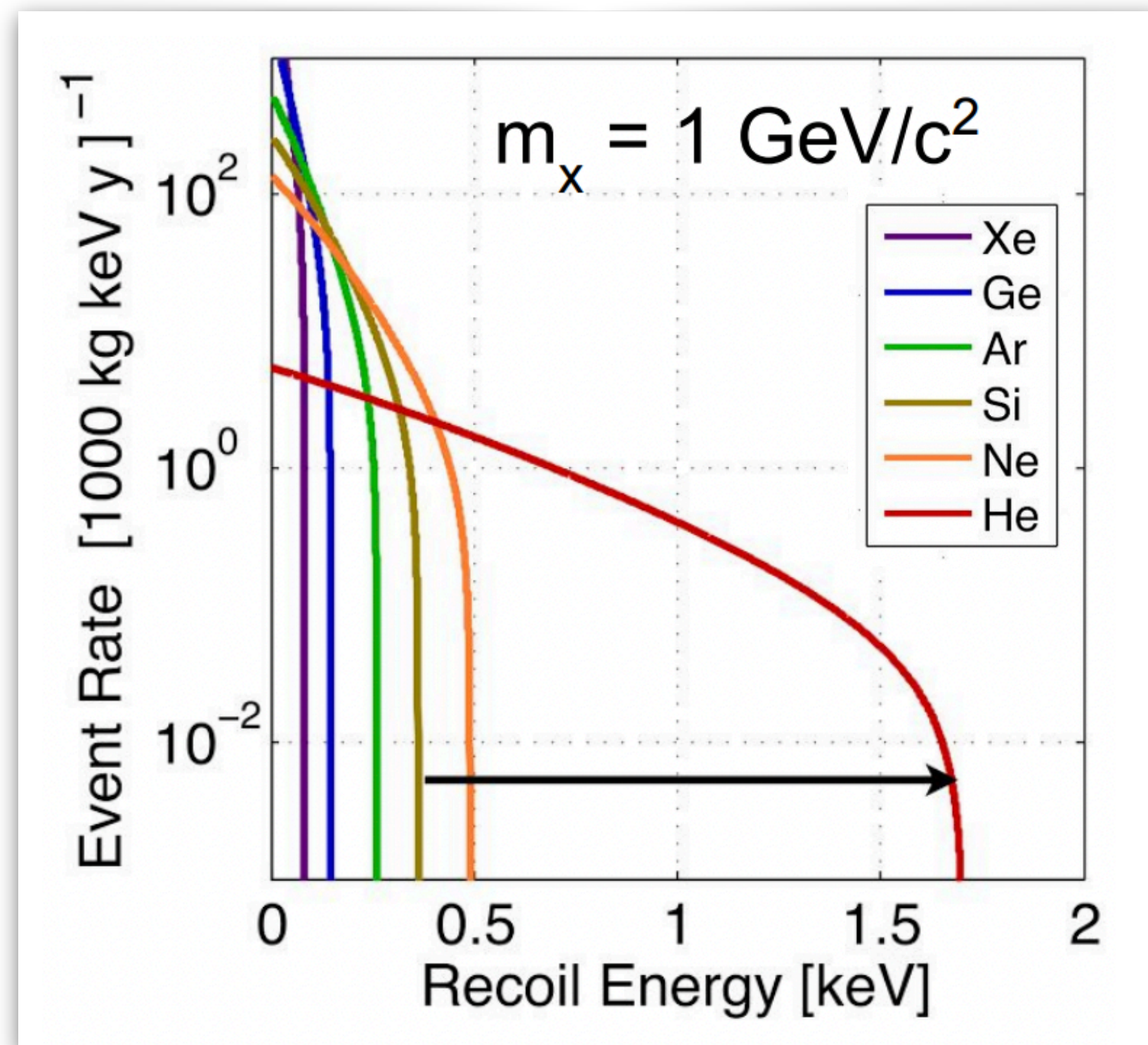
$$\Delta E = \frac{1}{2} \frac{\Delta p^2}{m_N} \simeq \frac{2 m_{\text{DM}}^2 v_{\text{DM}}^2}{m_N}$$



Dark Matter mass vs. nucleus mass



$$\Delta E = \frac{1}{2} \frac{\Delta p^2}{m_N} \approx \frac{2 m_{\text{DM}}^2 v_{\text{DM}}^2}{m_N}$$

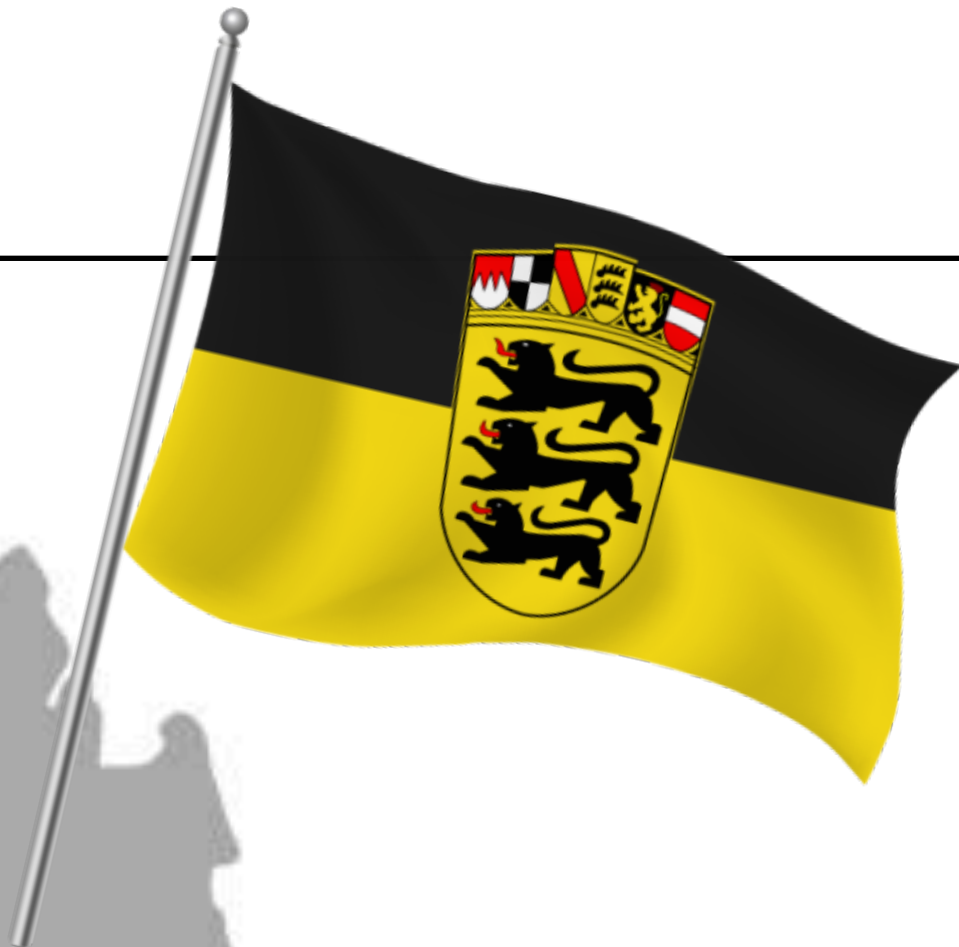
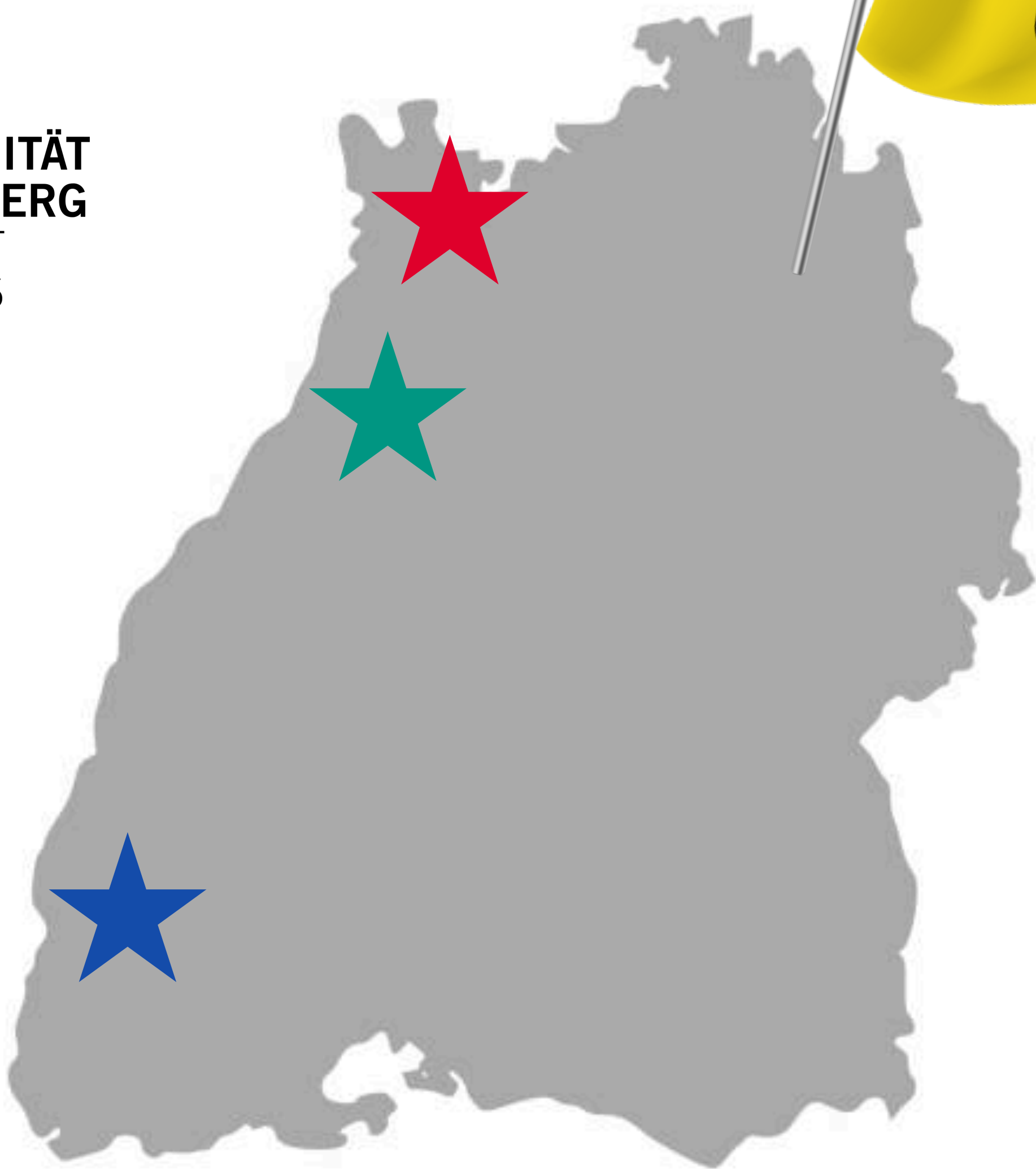


The DELight Experiment

(To be) Made in Baden-Württemberg



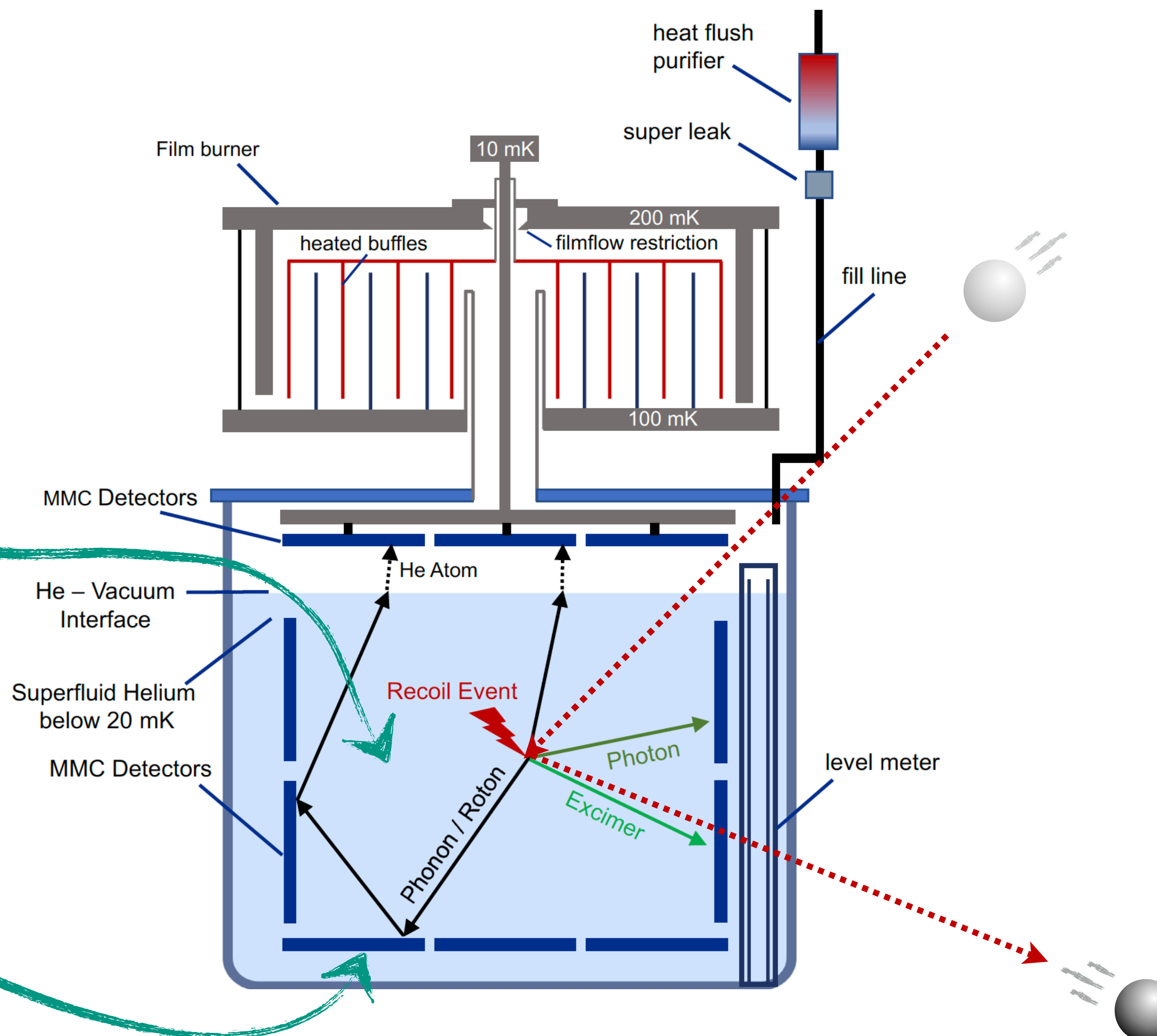
UNIVERSITÄT
HEIDELBERG
ZUKUNFT
SEIT 1386



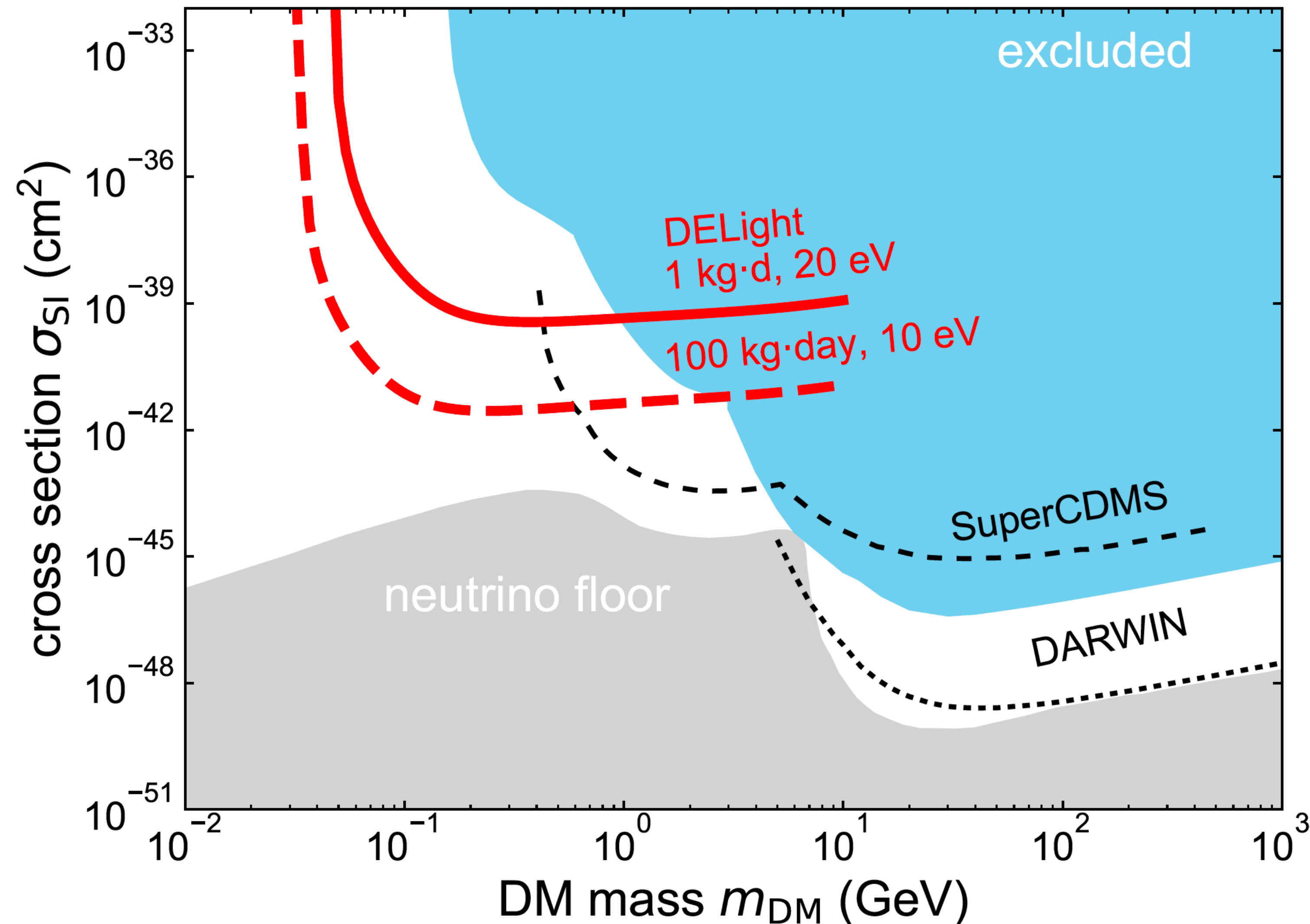
DELIGHT: a Direct search Experiment for Light dark matter

Superfluid ^4He
(~ 10 liters in phase-I)

Ultra-sensitive heat sensors
(Magnetic Micro-Calorimeters:
MMCs)



Towards Light Dark Matter with DELight



Phase-I:

- 10 L cell on surface or in shallow lab
- O(kg·d) exposure
- 20-30 eV threshold

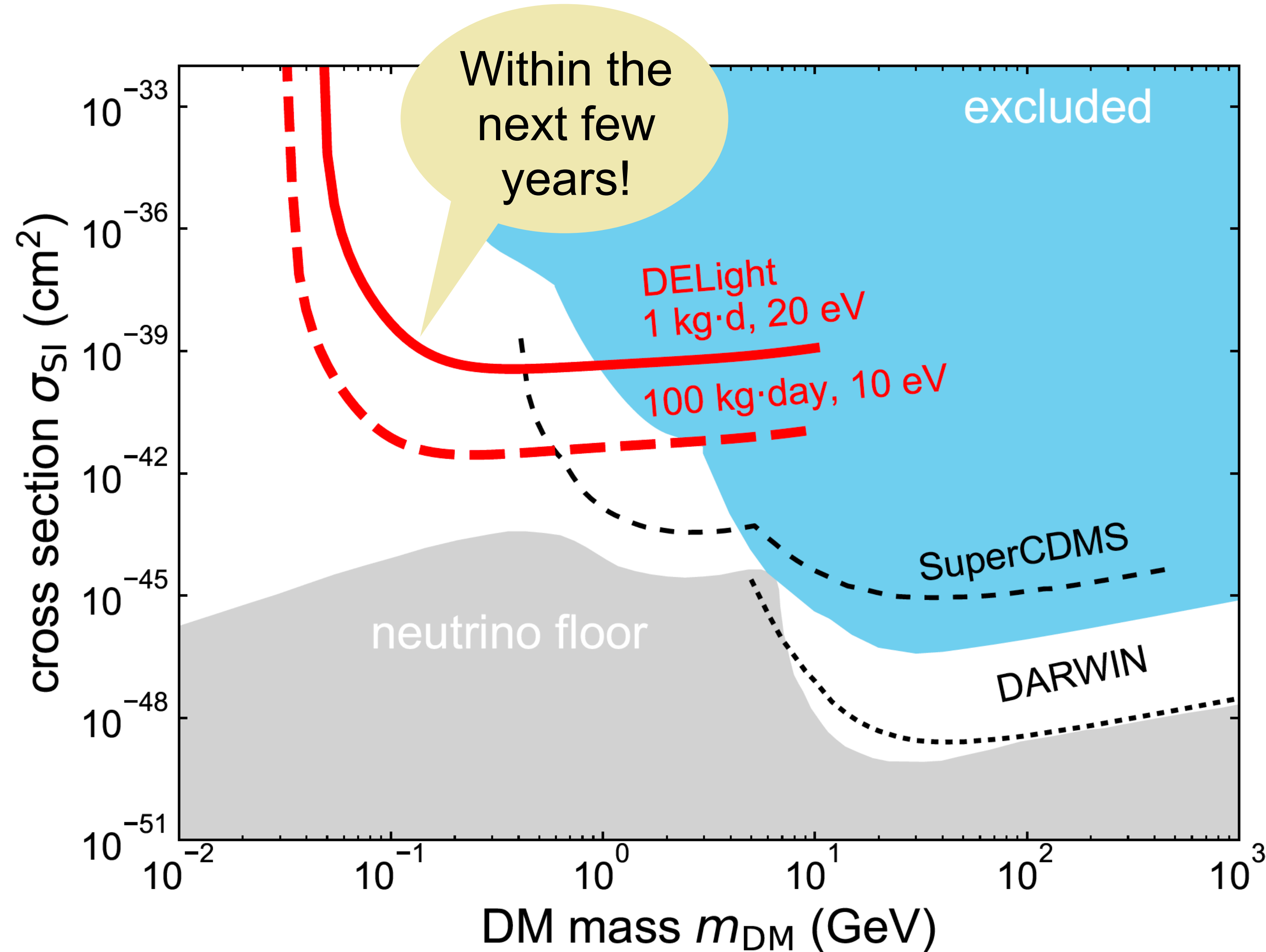
Phase-II:

- ~20 L low-background cell in shallow lab
- O(10-100 kg·d) exposure
- 10 eV threshold

Long range plan:

- Up to 200 L cell in underground lab
- O(kg·yr) exposure
- <10 eV threshold

Towards Light Dark Matter with DELight



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- O(kg·d) exposure
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