Searching Dark Matter with Muscovite Mica

[Based on 2604.xxxxx]

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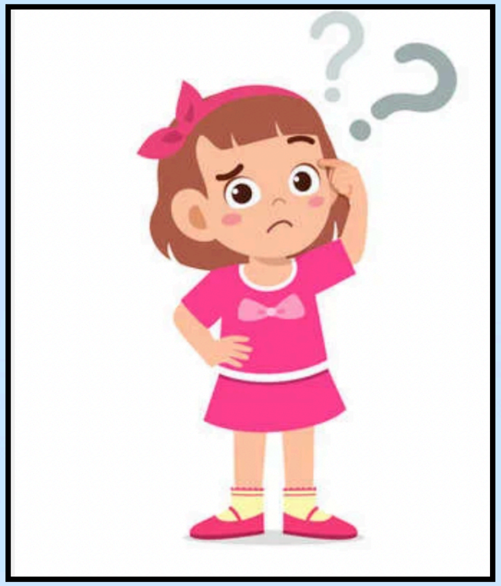
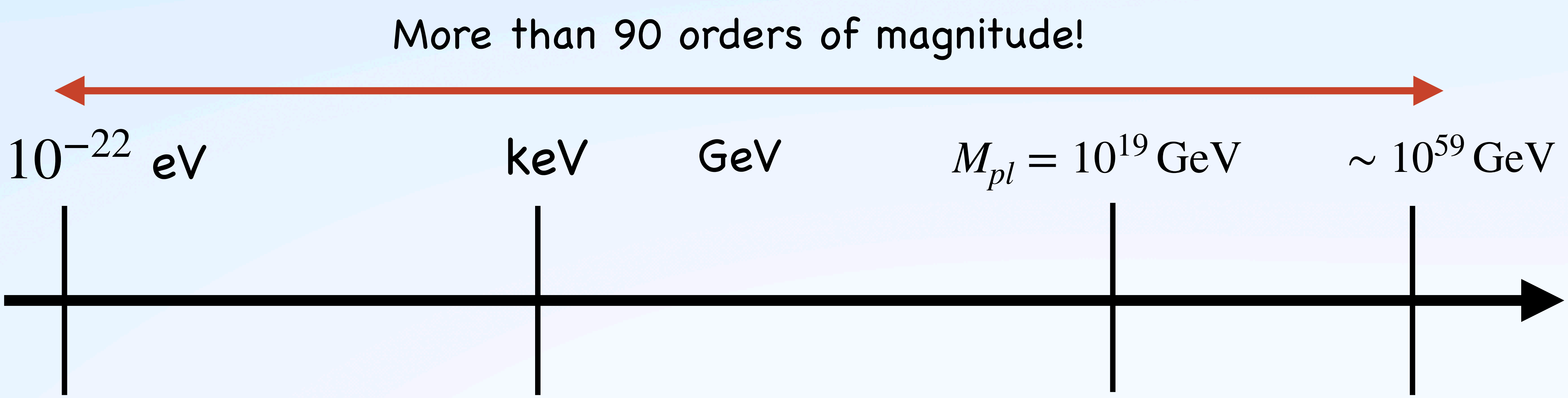
Dark Matter



- DM mass?
- DM interactions?

Cost-effectiveness is crucial.



Mineral Detection

- Not only cost-effective but also probes unreachable DM parameter space.

Assume:

$m_{\rm DM} = 10^{22}$ GeV

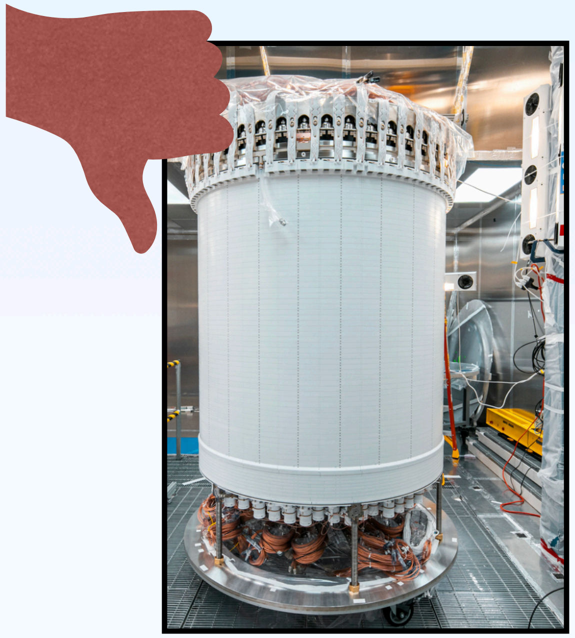
You have a $1.5 \times 1.5\, m^2$ detector

It detects all DM particles that passes through.

# of detection

5 events in 10,000 years!

Impossible by Direct detection



Mineral Detection

- Mineral detection is the way to go!

Assume:

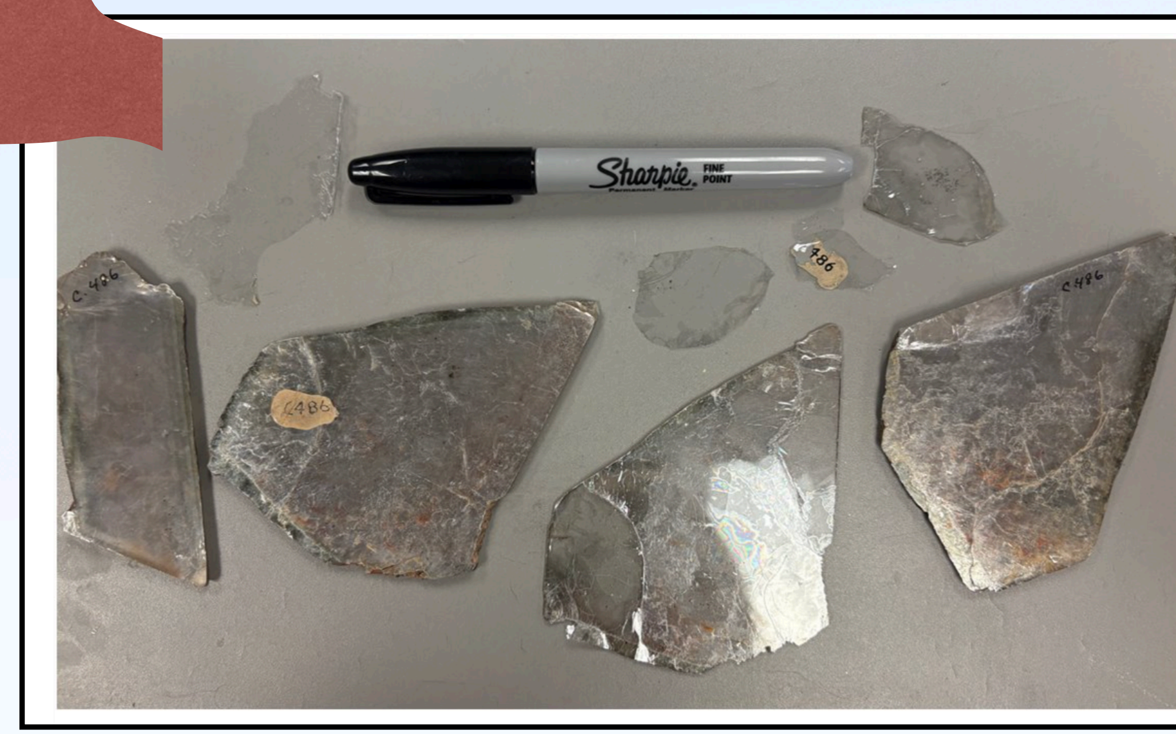
$m_{\mathrm{DM}} = 10^{22}$ GeV

You have a $1.5 \times 1.5\, m^2$ mineral sample of age 1 Gyr

It detects all DM particles that passes through.

# of detection

500,000 events!



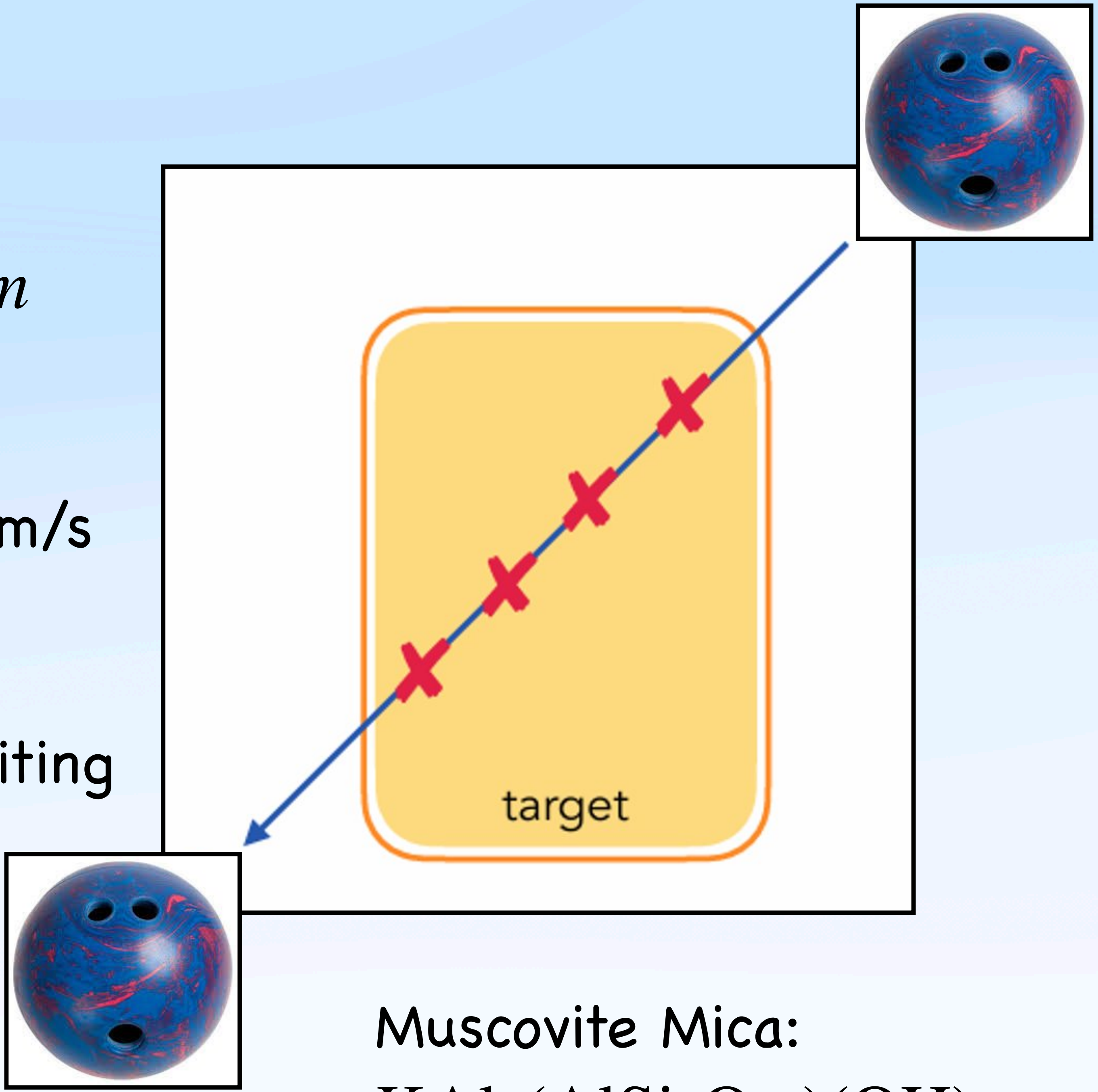
Mineral Detection: Observables

- Observable in Mica sample:

Consider a composite DM of
$m_{\rm DM} = 10^{22}$ GeV & $R_{\rm DM} = 0.1\mu m$

Transits through the Mica at 220 km/s

Scatter with the nuclei while transiting



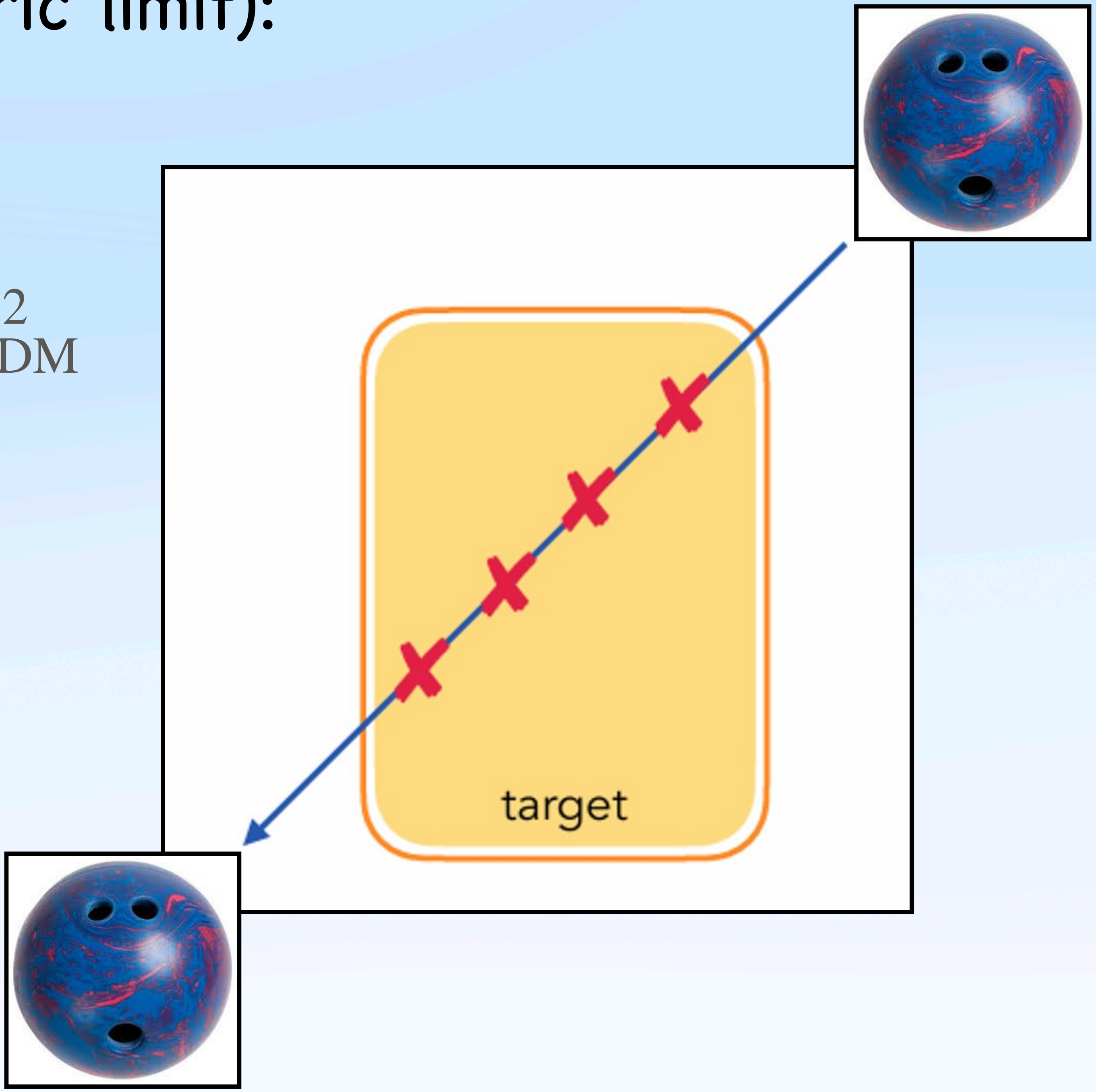
Muscovite Mica:
$KAl_2(AlSi_3O_{10})(OH)_2$

Mineral Detection: Observables

- Energy deposition (Geometric limit):

$$dE_{\rm dep}/dx = \rho_{\rm Mica} \times \pi R_{\rm DM}^2 \times v_{\rm DM}^2$$

= 3×10^8 GeV/cm



Energy deposition in Mica happens via many many collisions.

Mineral Detection: Observables

- Deposited energy is NOT diffused away

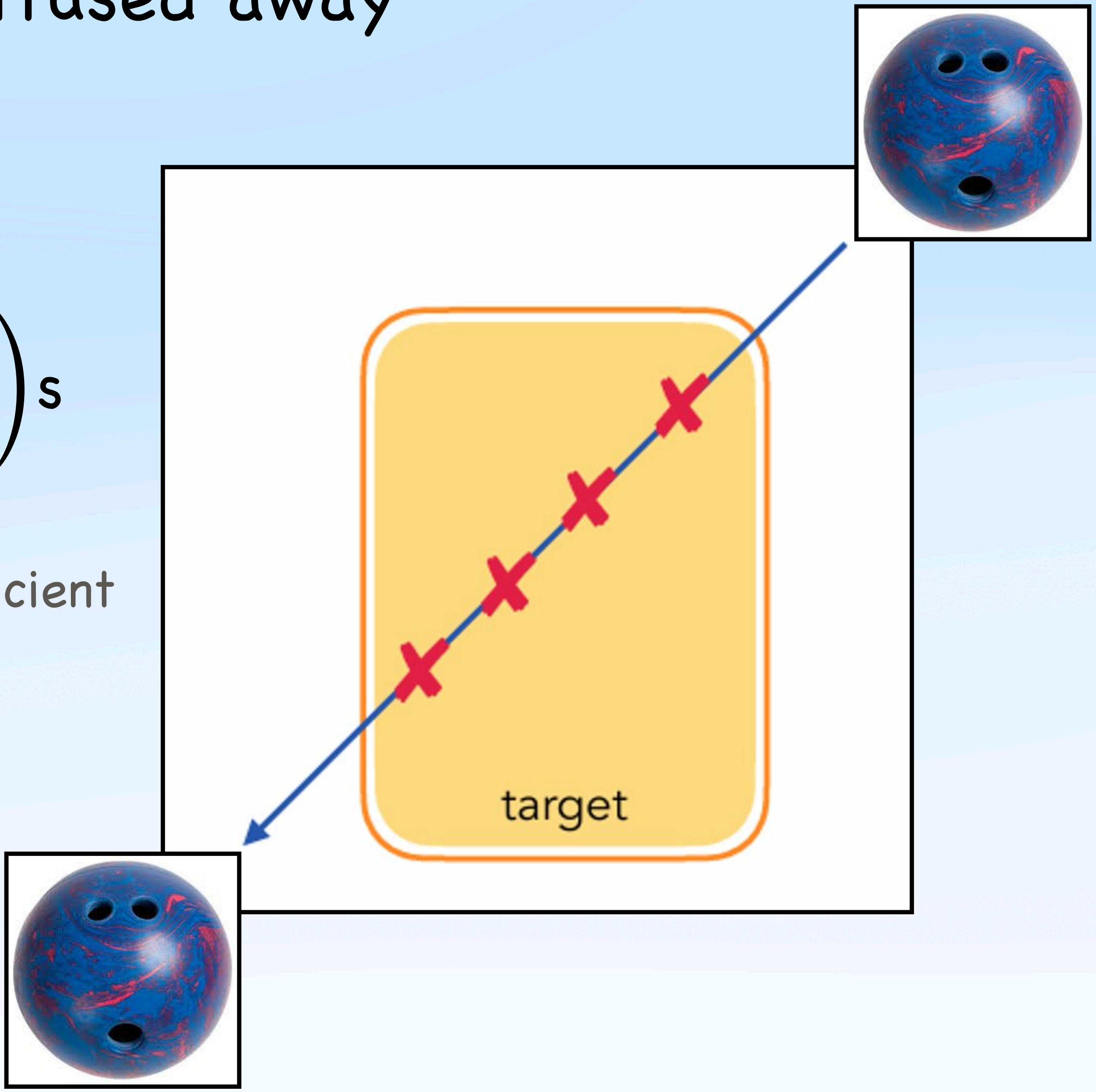
$$\tau_{\rm dep} = b_{\rm mica}/v_{\rm DM}$$

$$= 9 \times 10^{-10} \left(\frac{b_{\rm mica}}{200\,\mu m}\right) \text{s}$$

Thermal diffusion co-efficient

$$\tau_{\rm diff} = b^2_{\rm mica}/D_{\rm diff}$$

$$= 0.25 \left(\frac{b_{\rm mica}}{200\,\mu m}\right)^2 \text{s}$$



Adiabatic Energy Injection

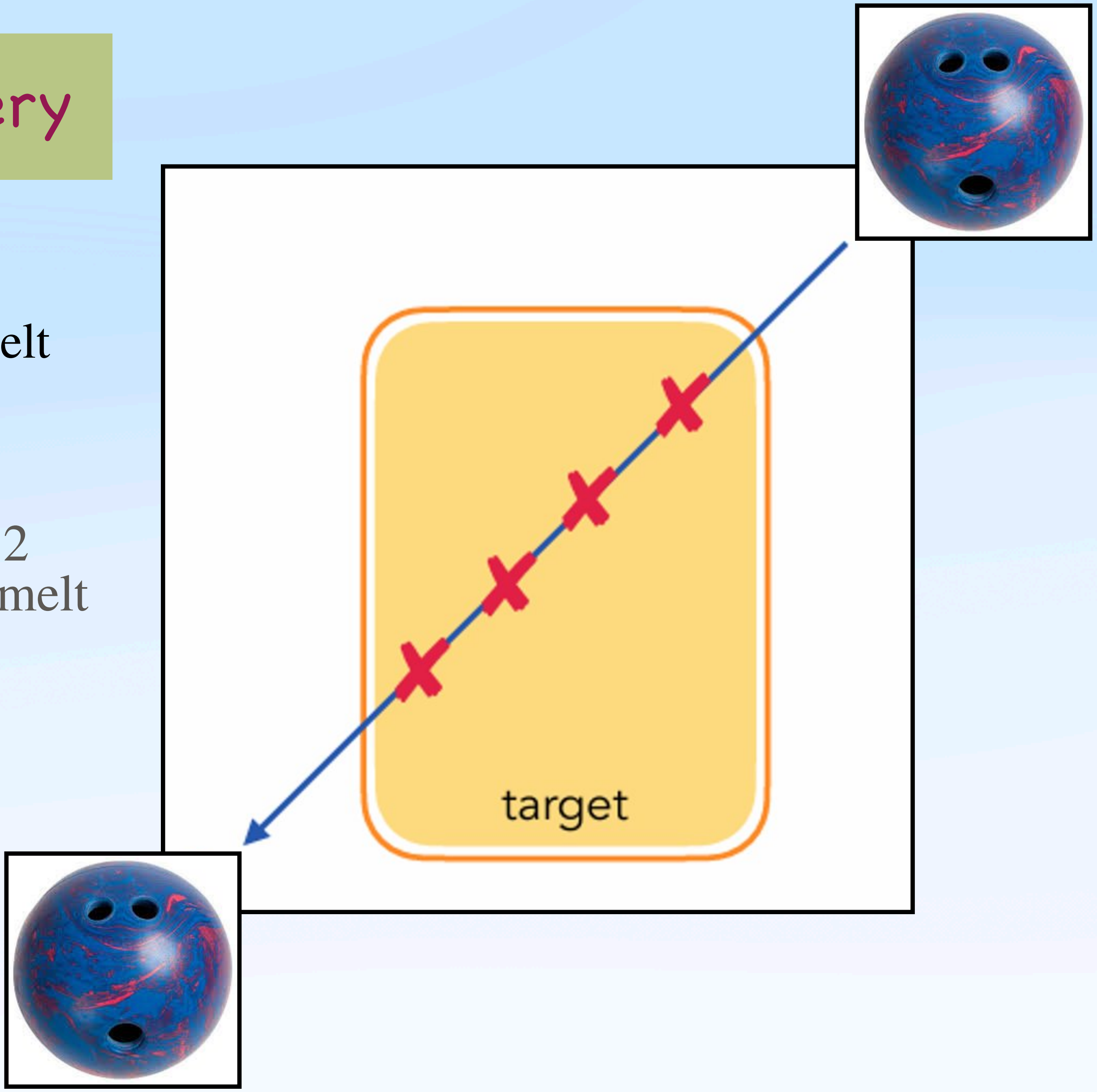
Mineral Detection: Observables

- Creates a unique/distinctive melt-track signature.

Potential DM Discovery

Forming a melt track of radius R_{melt} requires an energy-deposition

$$dE_{\text{req}}/dx = \rho_{\text{Mica}}(C_p \Delta T + H_f)\pi R_{\text{melt}}^2$$



First term: Req. energy to raise the temp to Mica's melting point

Second term: Latent heat for melting

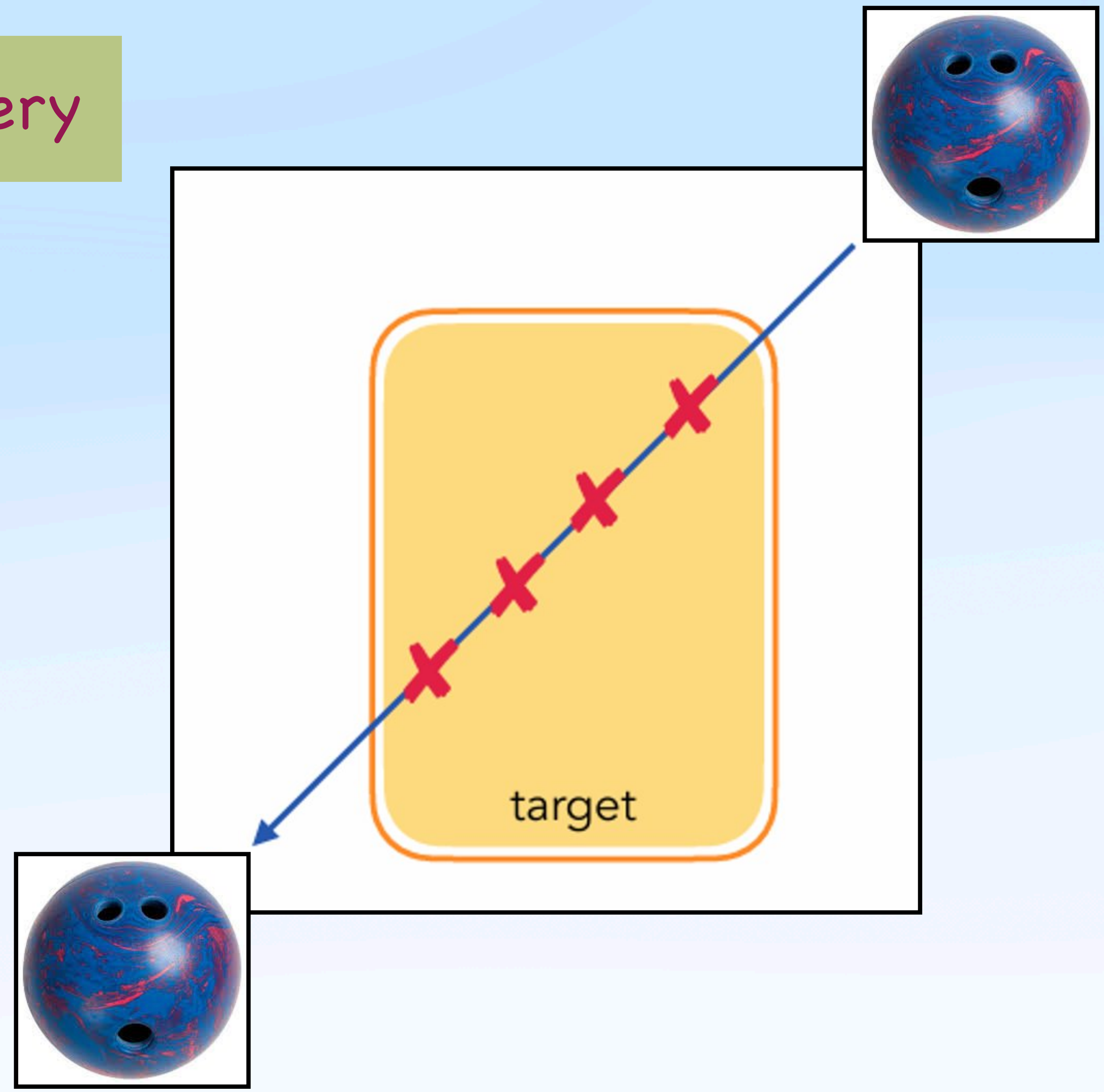
Mineral Detection: Observables

- Creates a unique/distinctive melt-track signature.

Potential DM Discovery

$$R_{\text{melt}} = R_{\text{DM}} \sqrt{\frac{\eta v_{\text{DM}}^2}{C_p \Delta T + H_f}}$$

$$\approx 200\, R_{\text{DM}} \;\; = 20\, \mu m$$

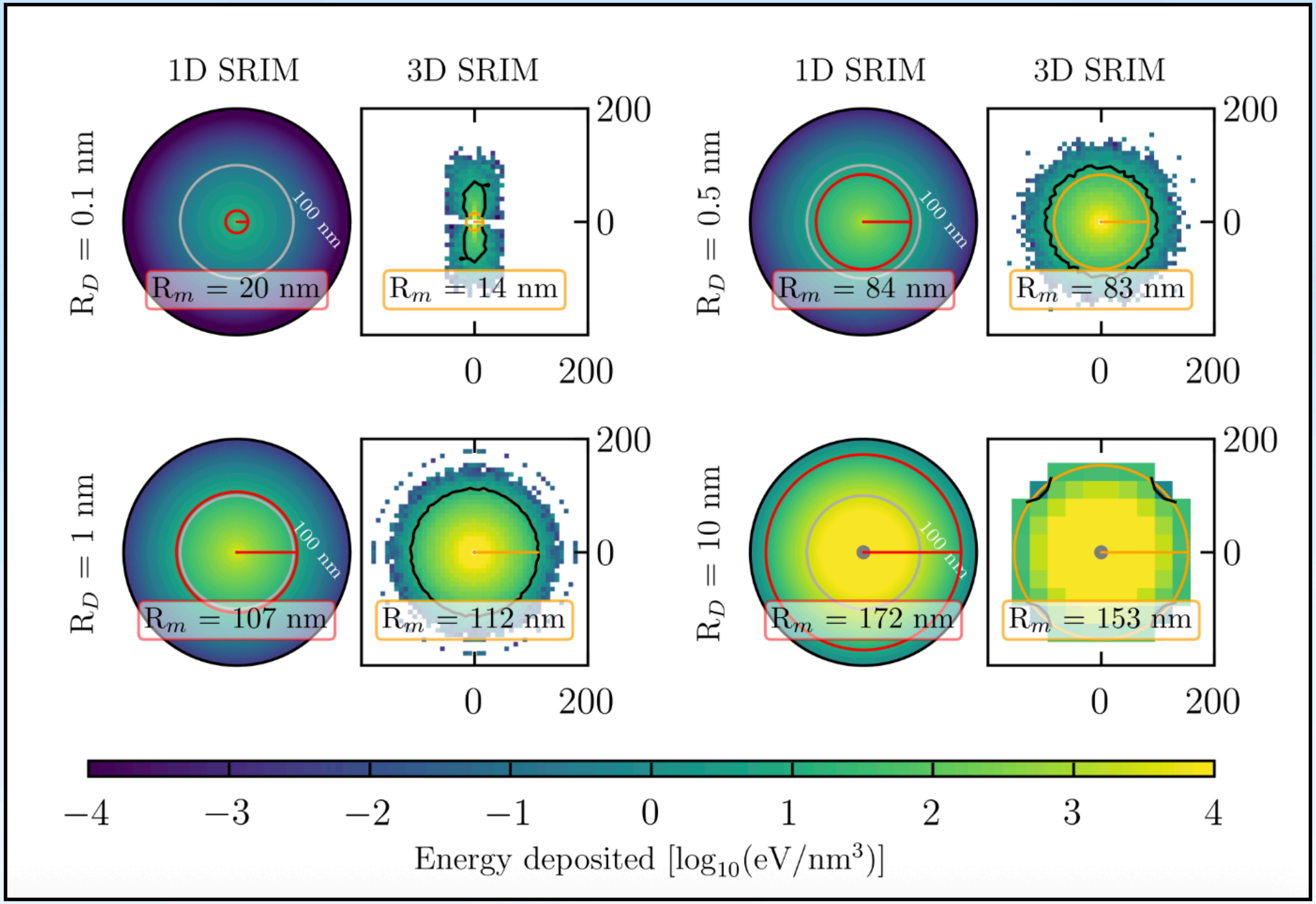


Search melt tracks/holes in Ancient Mica

Morphology: Very very straight → $\theta_{\text{DM}} \sim m_N / m_{\text{DM}}$

Checking with SRIM

Boukhtouchen et al (2604.xxxxx)

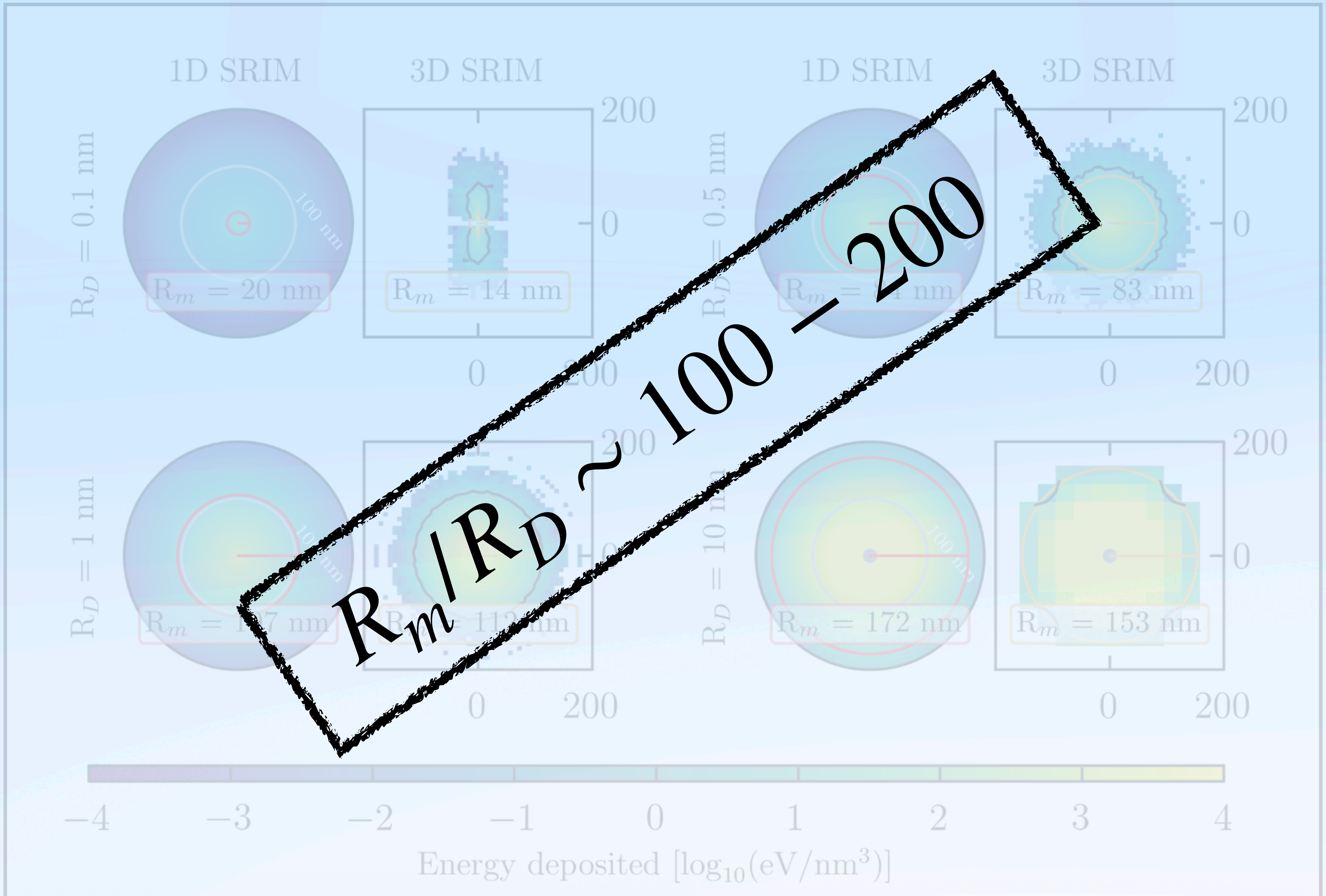


From: SRIM (Stopping and Range of Ions in Matter) simulation

http://www.srim.org/

Checking with SRIM

Boukhtouchen et al (2604.xxxxx)



$R_m / R_D \sim 100 - 200$

From: SRIM (Stopping and Range of Ions in Matter) simulation

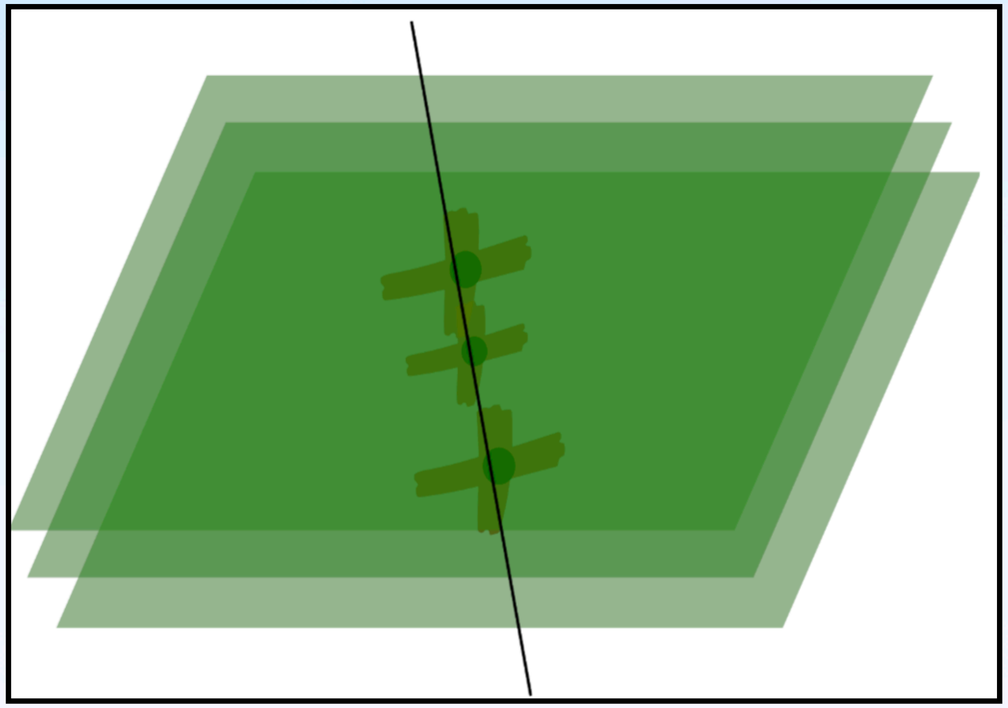
http://www.srim.org/

Experimental Readout

- What are we looking for in Mica?

Heavy DM induced "Micron-scale" damaged holes.

Target area: $1 \times 1\, m^2$



- How are we looking for?

X-ray Fluorescence Mapping

Experimental Readout

X-ray Fluorescence Mapping

- We put the mica sample on a thin Cu-sheet.
- Mica sample is irradiated with high-energy photons produced by an X-ray tube.
- Undamaged part: efficiently absorbs the high-energy photons.
- Damaged part: high energy photons penetrate, knocks off inner-shell electrons of Cu and emit characteristics X-rays.

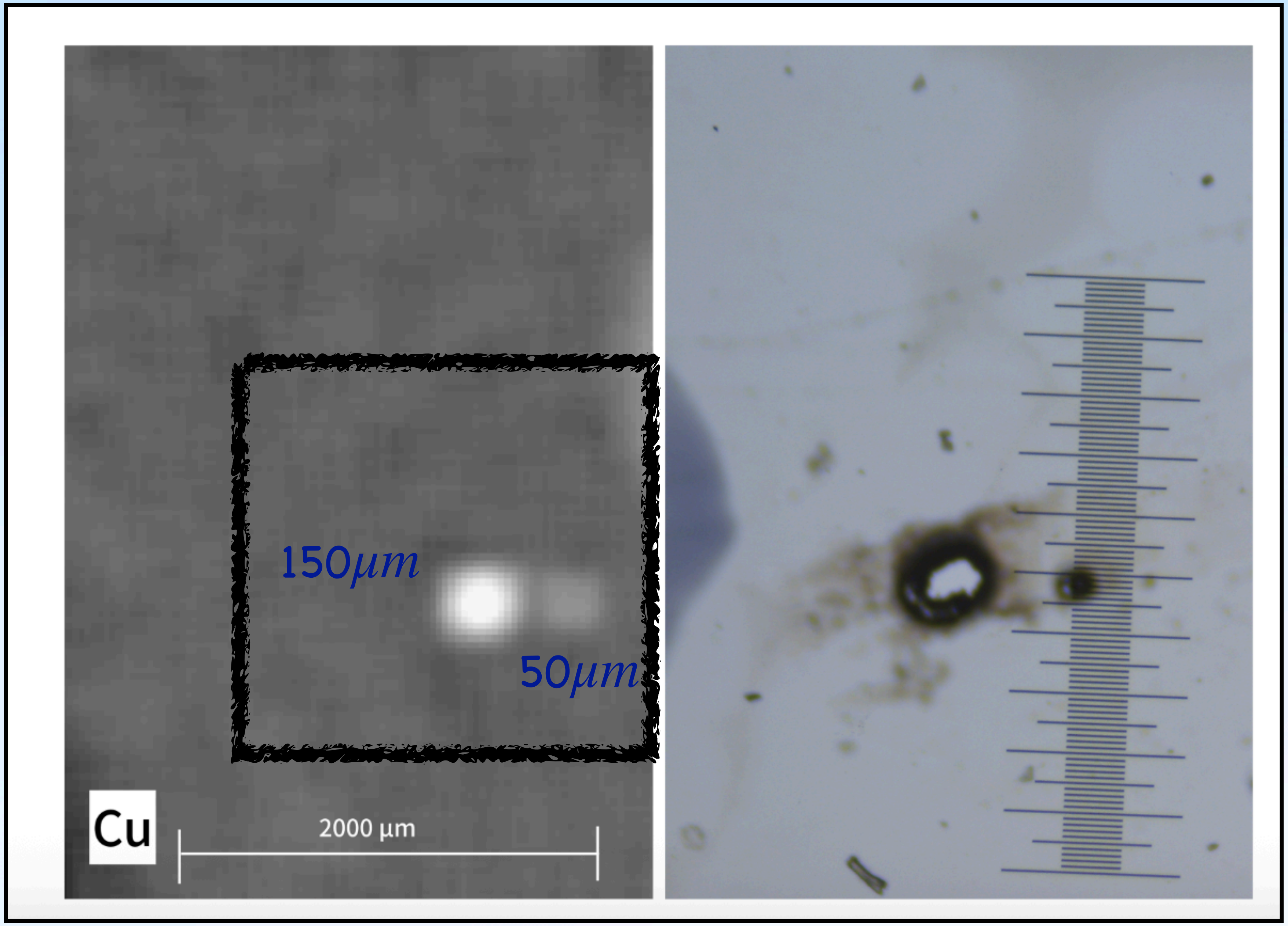
8 keV for Cu ($K\alpha$)

Experimental Readout

- We observe spatial variation in the XRF mapping.

Calibration result

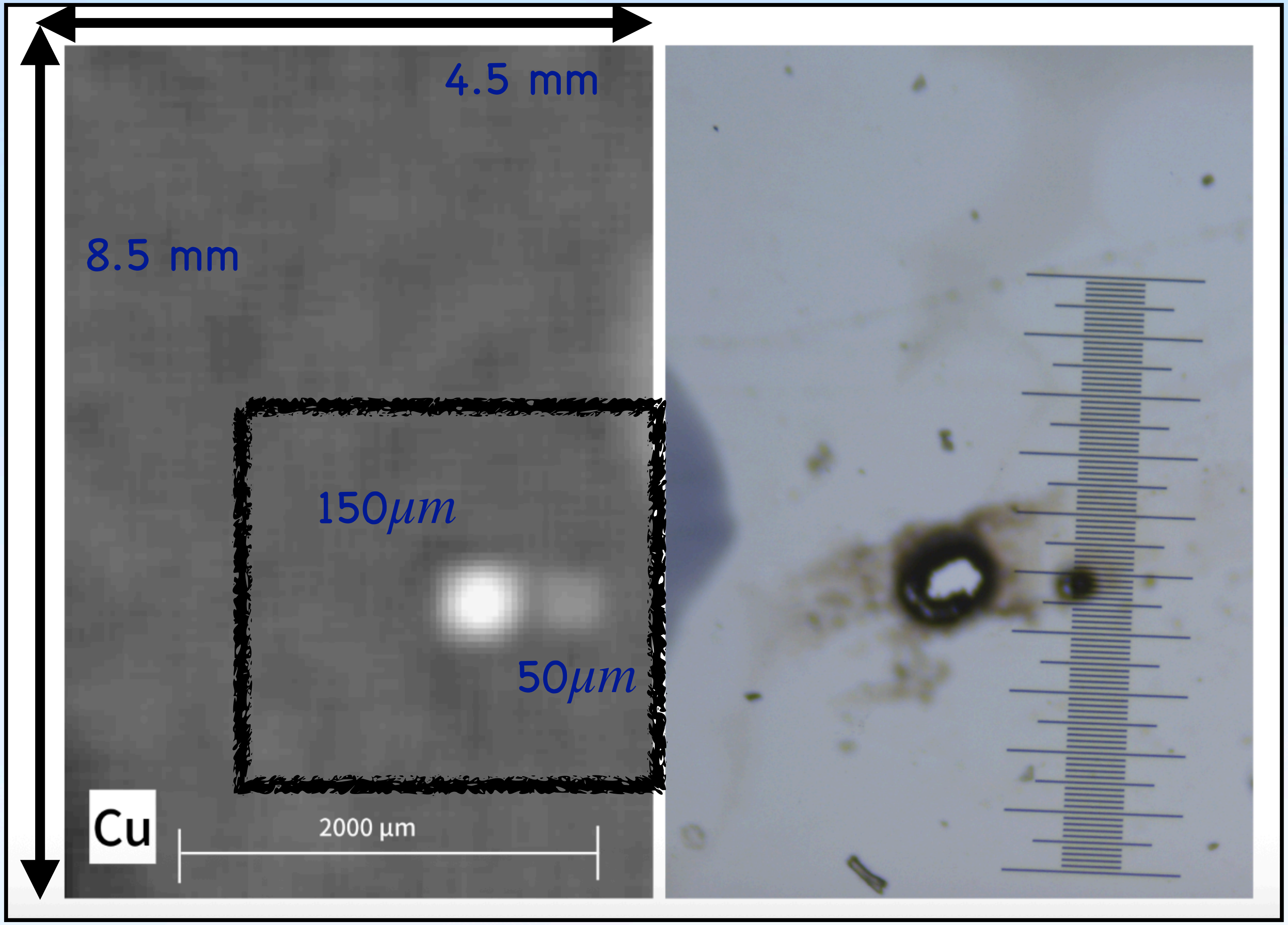
Boukhtouchen et al (2604.xxxxx)



The experimental signature of a damage track is essentially defined by the localized enhancement in the XRF map.

Experimental Readout

- We are currently sensitive to $\geq 25\,\mu m$ scale damage.



Boukhtouchen et al (2604.xxxxx)

Scan area: 8.5×4.5 mm^2

Step size: 30 μm

Scan time/pixel : 25 ms

Total scan time ≈ 18 min

Target area: $1 \times 1\, m^2$

≈ 300 days

Experimental Readout

- Why Cu?

Cu is naturally absent in Muscovite Mica.

$KAl_2(AlSi_3O_{10})(OH)_2$

Appearance of Cu fluorescence therefore provides an unambiguous tracer.

Because of higher Z of Cu, stronger fluorescent signals are generated → easier readout.

Experimental Readout

- XRF technique is excellent in Muscovite Mica + Cu sheet

From Beer-Lambert law

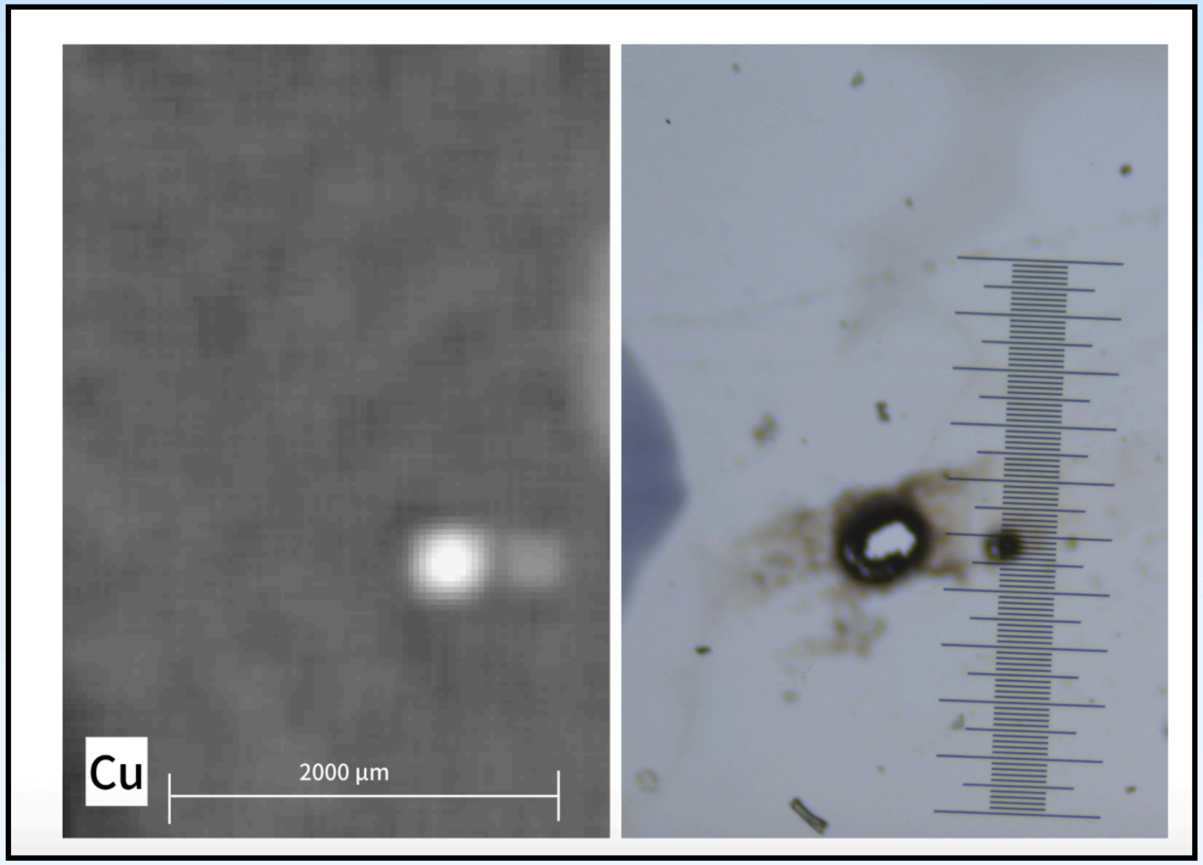
$$I = I_0 \exp[-\mu_{\text{Mica}} b_{\text{Mica}}]$$

(Linear attenuation co-efficient)

μ_{Mica} = 124.1 /cm at 8 keV [Cu (Kα)]

(Sample Thickness)

$b_{\text{Mica}} = 200\,\mu m$

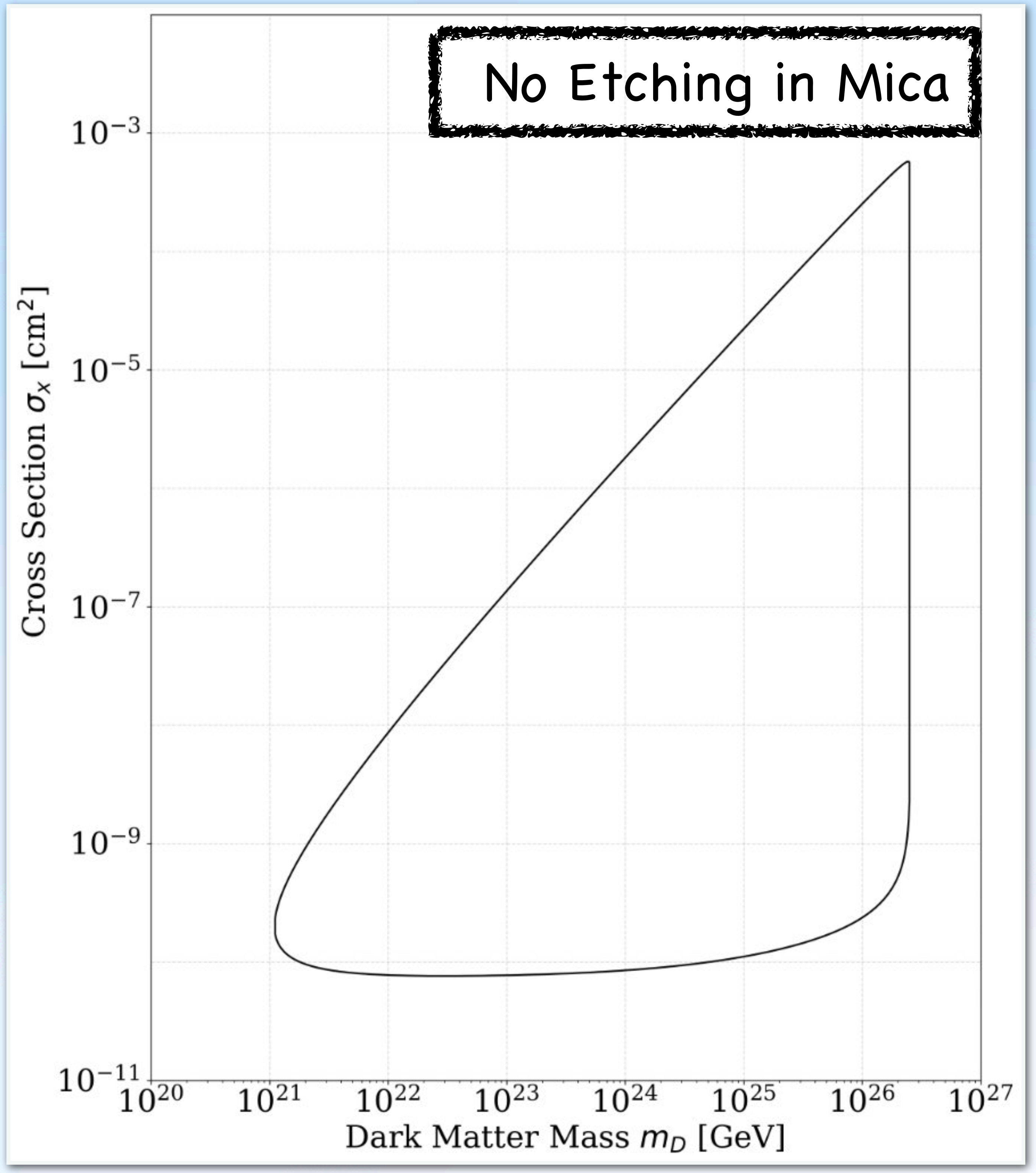


Void-to-intact signal enhancement = 12

Larger contrast → easier readout.

Results: Sensitivity Plot

- Assuming no "melt-track" in a 1×1 m^2 mica sample of age 1 Gyr



Mica sample is placed 20 km underground.

↓

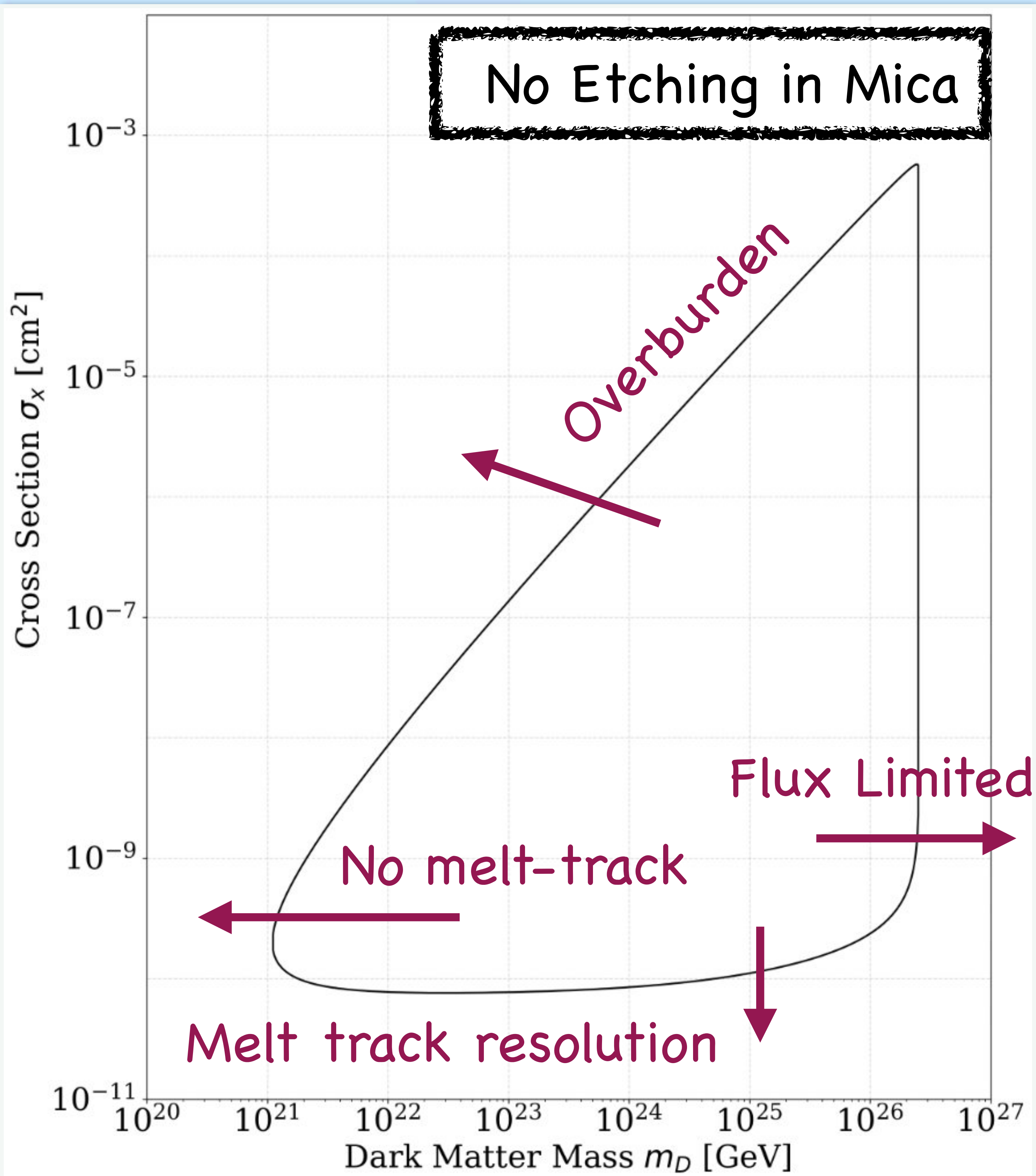
In this depth, temperature is low enough: melt tracks will not be thermally annealed.

Boukhtouchen et al (2604.xxxxx)

See also: Ebadi et al (Quarz+Electron Microscopy)

Results: Sensitivity Plot

- Assuming no "melt-track" in a 1×1 m^2 mica sample of age 1 Gyr.



Melt-track resolution is $\geq 25\,\mu m$ (from calibration)

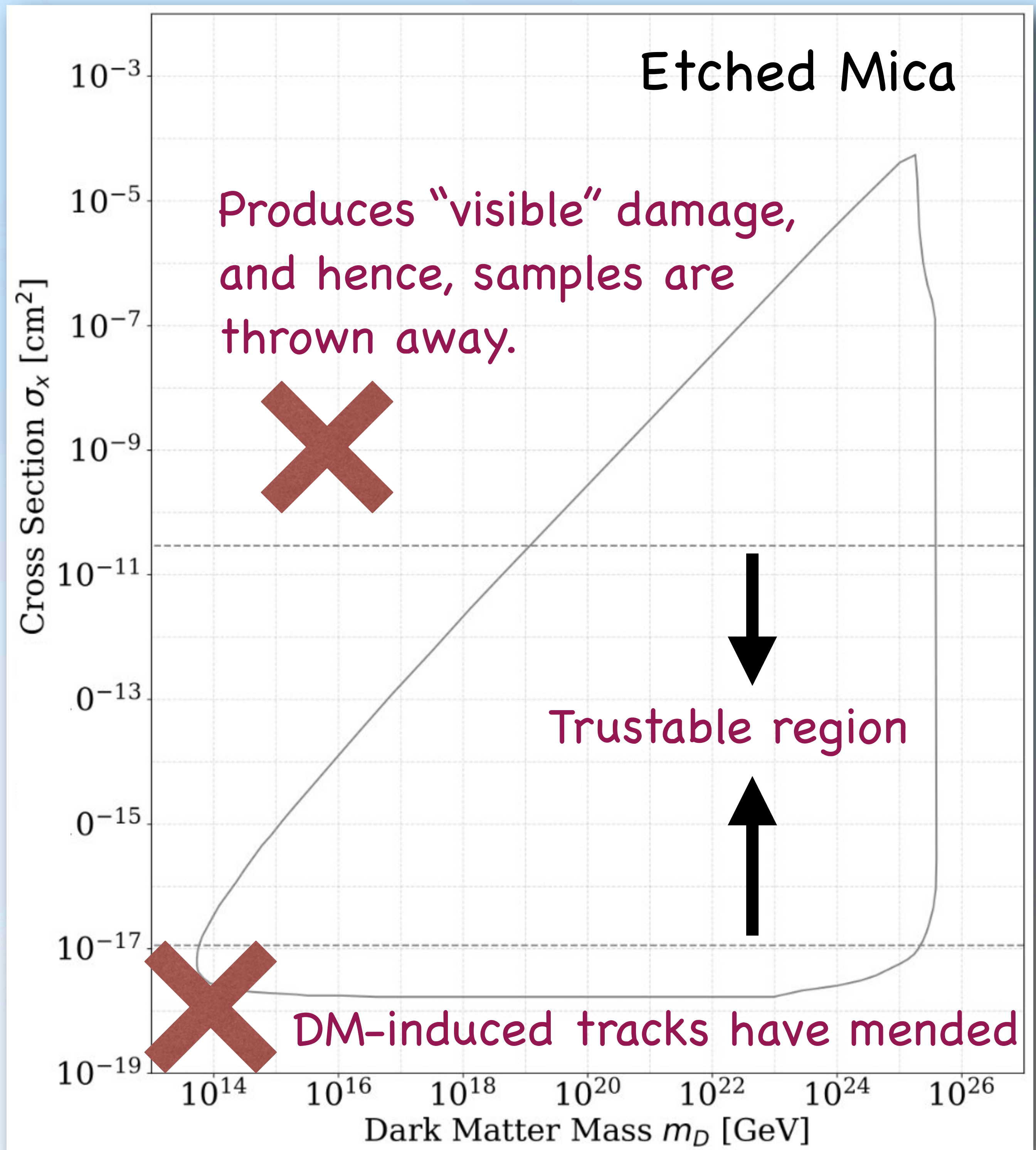
With $\geq 0.1\,\mu m$, much lower cross-section can be probed

Boukhtouchen et al (2604.xxxxx)

Prior Analysis with Mica

- Etched Mica sample has been used to set limits on DM interactions.

e.g., Acevedo, Bramante, Goodman (JCAP, 2023)

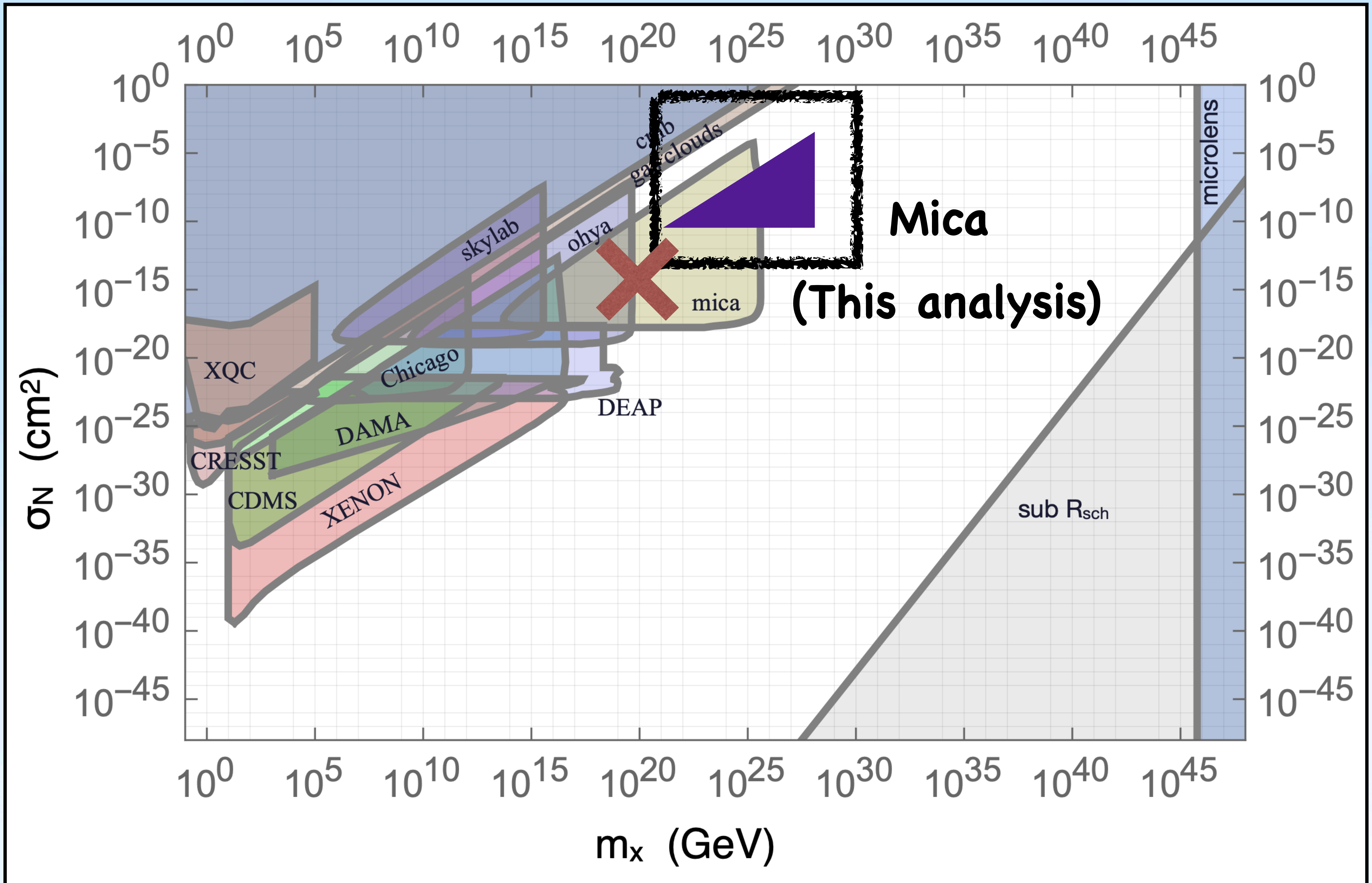


Prior Analysis:

i) $dE/dx \geq 7$ GeV/cm implies DM-induced tracks.

ii) Tracks are assumed to be retained forever.

Heavy DM: Full Landscape



e.g., Bramante (Annu. Rev. Nucl. Part. Sci., 2026)

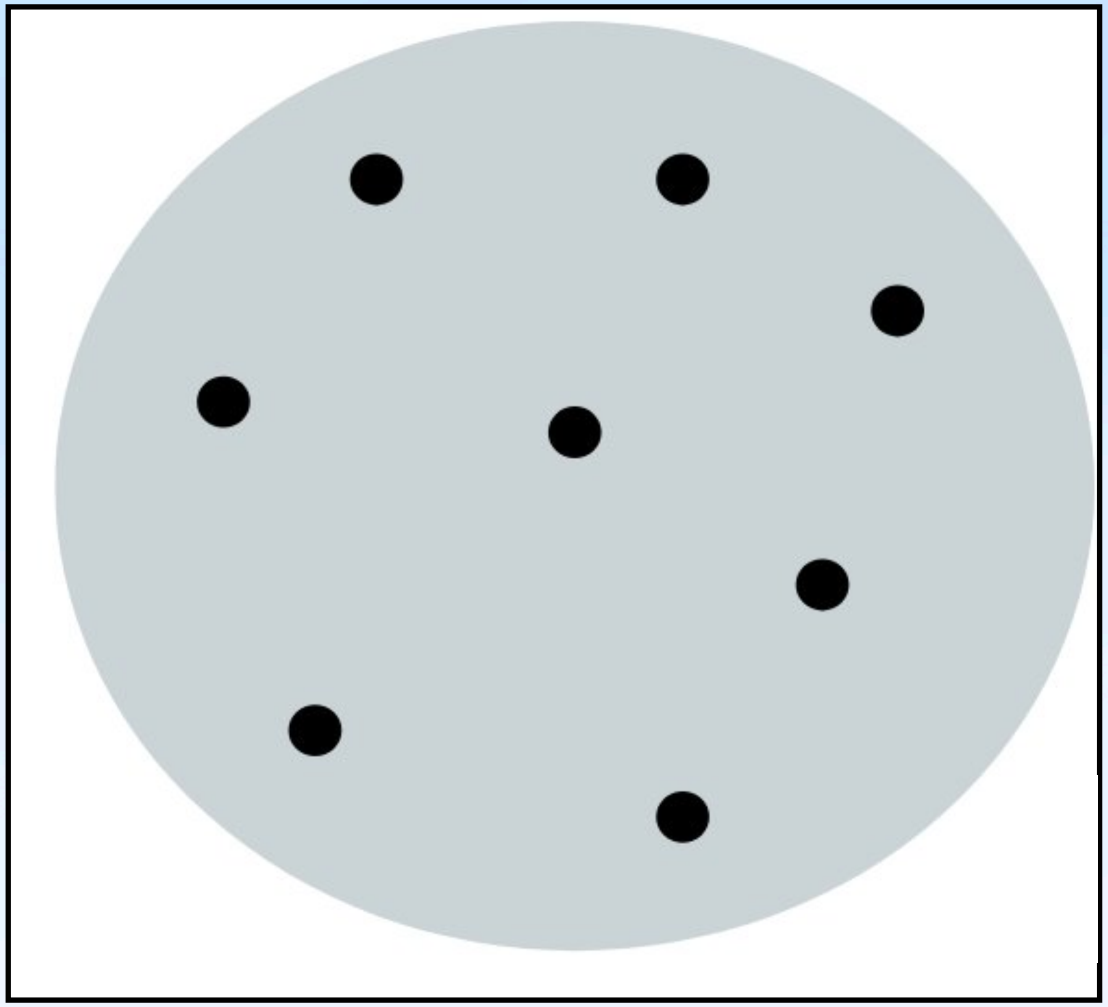
Heavy DM: Models

Composite Dark Matter

i) Very large number of asymmetric fermions.

ii) Attractive self-interactions

iii) Interacting via scalar mediator



Can easily generate such DM mass scales

e.g., Wise & Zhang (PRD, 2014), Bramante (Annu. Rev. Nucl. Part. Sci., 2026),++

Thanks!

MICA DM SEARCH AT QUEEN'S:

Boukhtouchen et al (2604.xxxxx)

Queen's UNIVERSITY

Yilda Boukhtouchen,

Joseph Bramante,

Andrew Buchanan,

Alex Hayes,

Matt Leybourne,

Jennika McIntosh,

Aaron Shugar.

Nuclear Geology

[Based on 26xx.xxxxx]

- $\mathrm{Ta}^{m,180}$ is a special isotope which stays in the nuclear excited state (9^-).

Nucelar Isomer

- Its decay to nuclear ground state (1^+) is hugely suppressed and never been observed.

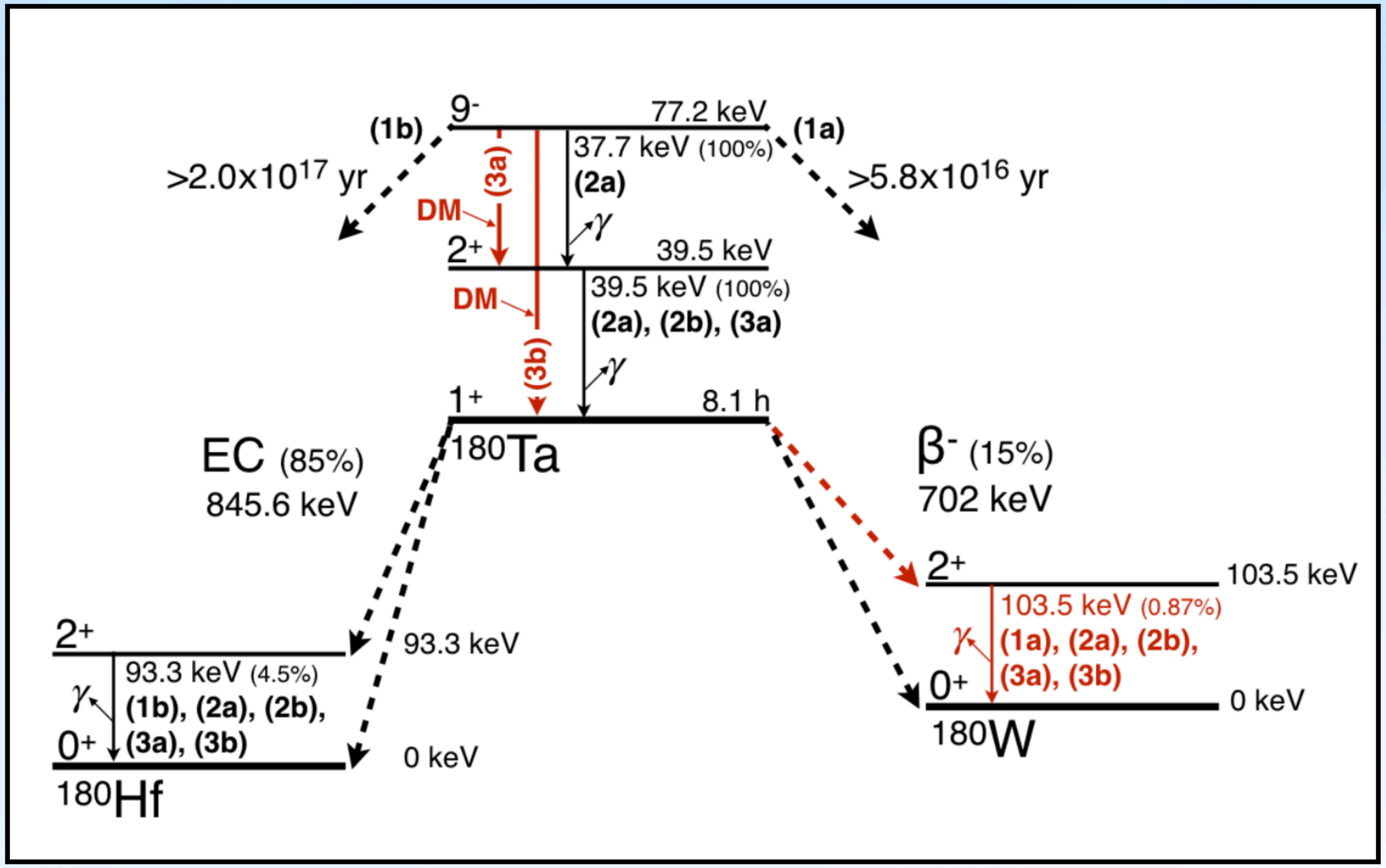
- $\mathrm{Ta}^{m,180}$ is naturally abundant in Tantalite minerals and can be used for heavy DM searches.

Source: Wiki

Nuclear Geology

[Based on 26xx.xxxxx]

- $Ta^{m,180}$ & ultra-heavy DM



Lehnert et al (PRL, 2020)

Source: Wiki

Thanks!