DMICA: exploring Dark Matter in natural muscovite MICA

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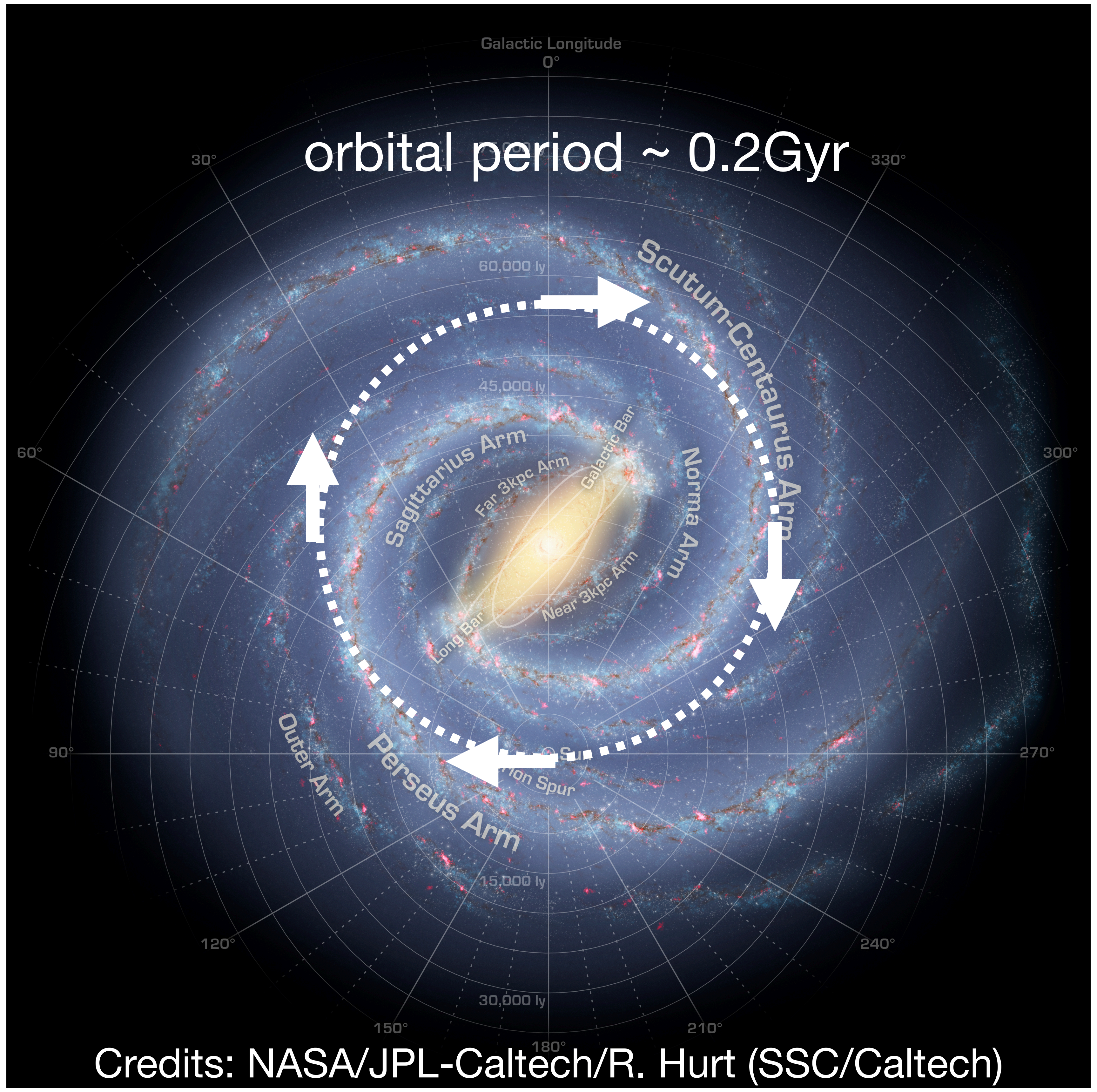
Natural minerals: the only tool for exploring “past-Gyr” DM events

- Conducting a galactic-wide DM survey

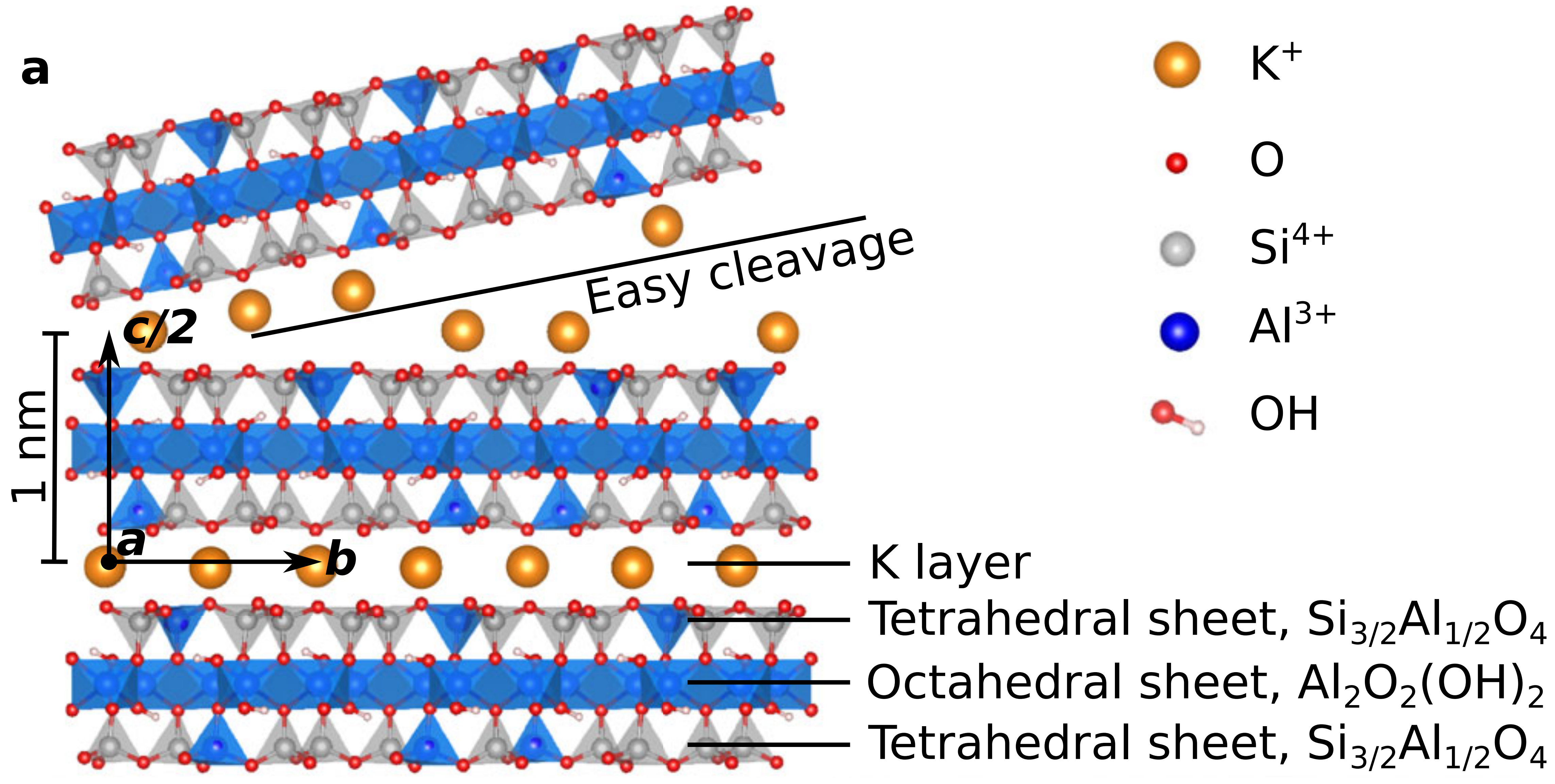


- Small target mass can achieve large exposure due to long age (e.g., 1 mg x 1 Gyr = 1 ton-year)

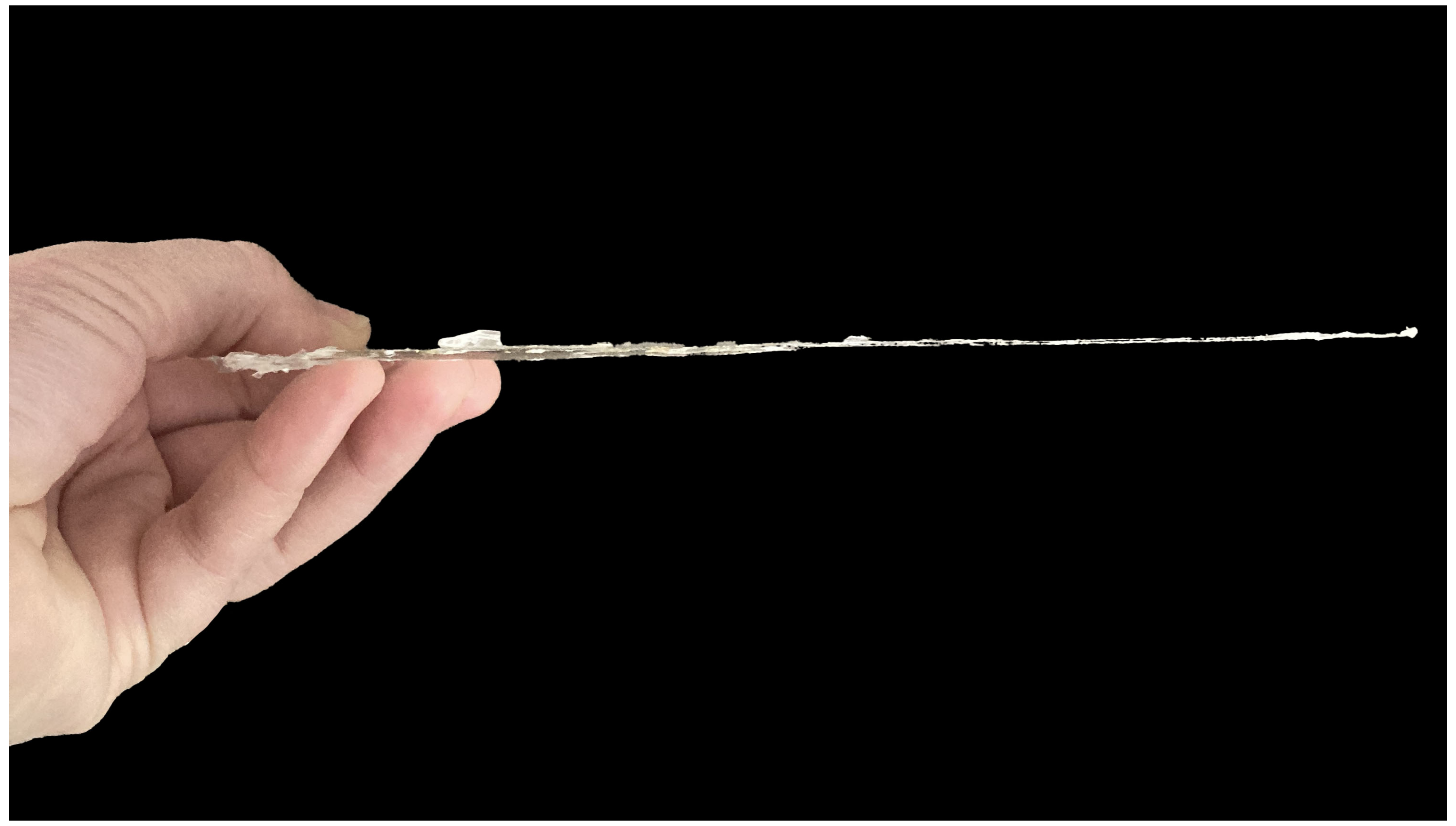
https://www.danspapers.com/2022/05/olivine-beach-replenishment-questions/

Muscovite mica is well-established as a solid state track detector in geology

Muscovite mica $KAl_3Si_3O_{10}(OH)_2$



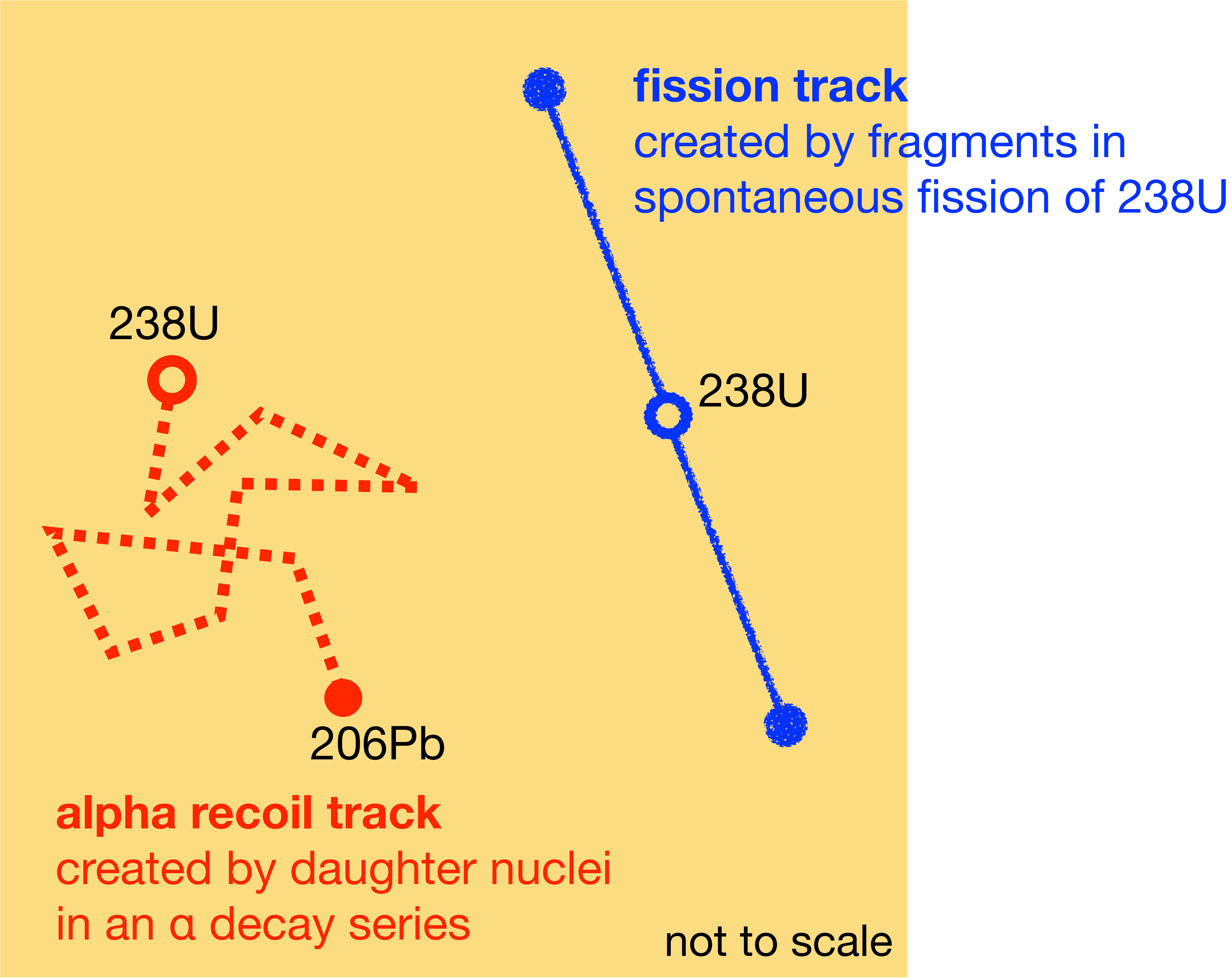
Franceschi+ 2023

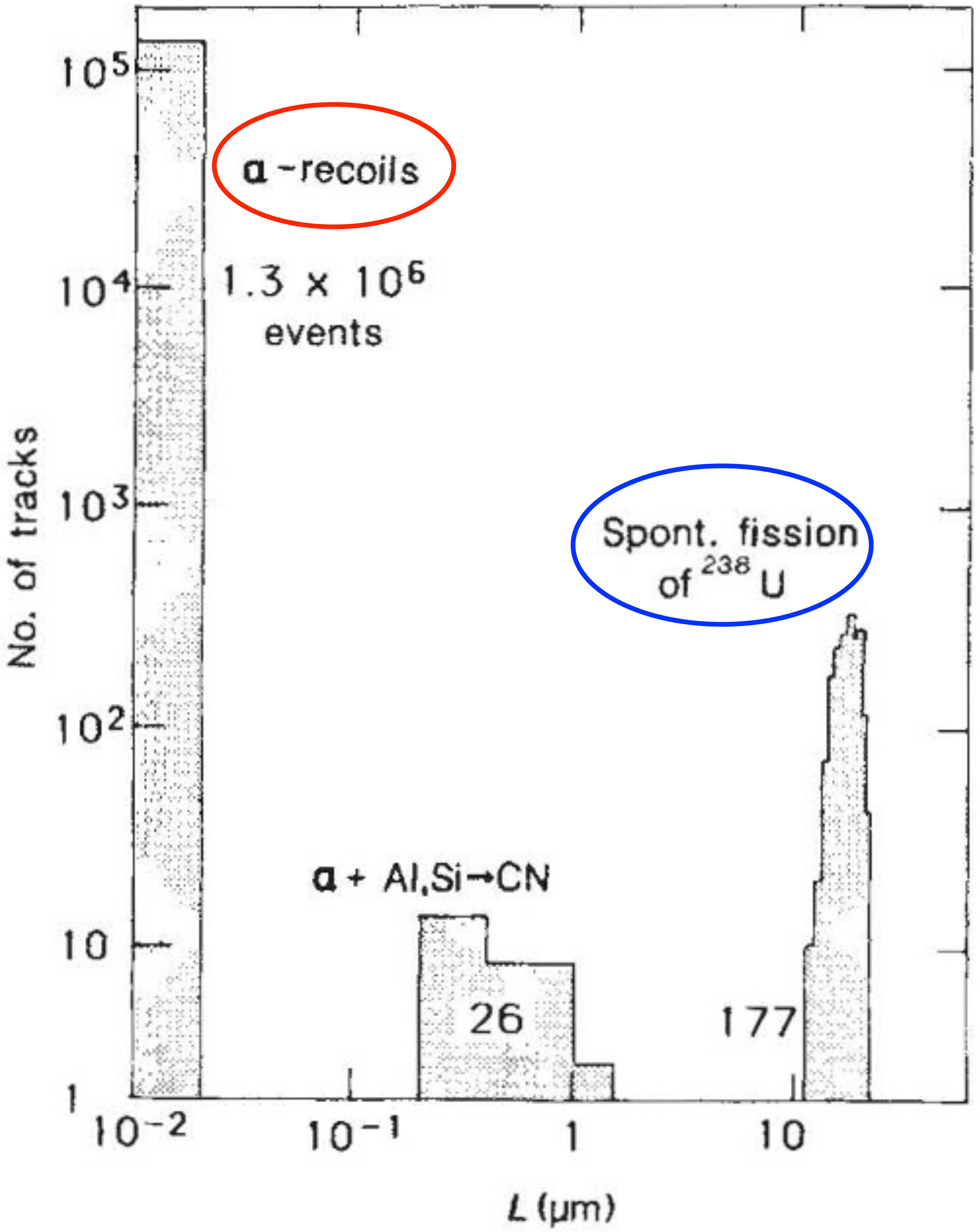


- Cleavage at a potassium layer allows easy access to the crystal's interior.

https://www.museums.msstate.edu/specimen-of-the-month/december-2023-muscovite-mica

Radiative tracks (crystal defects) occurring in natural mica

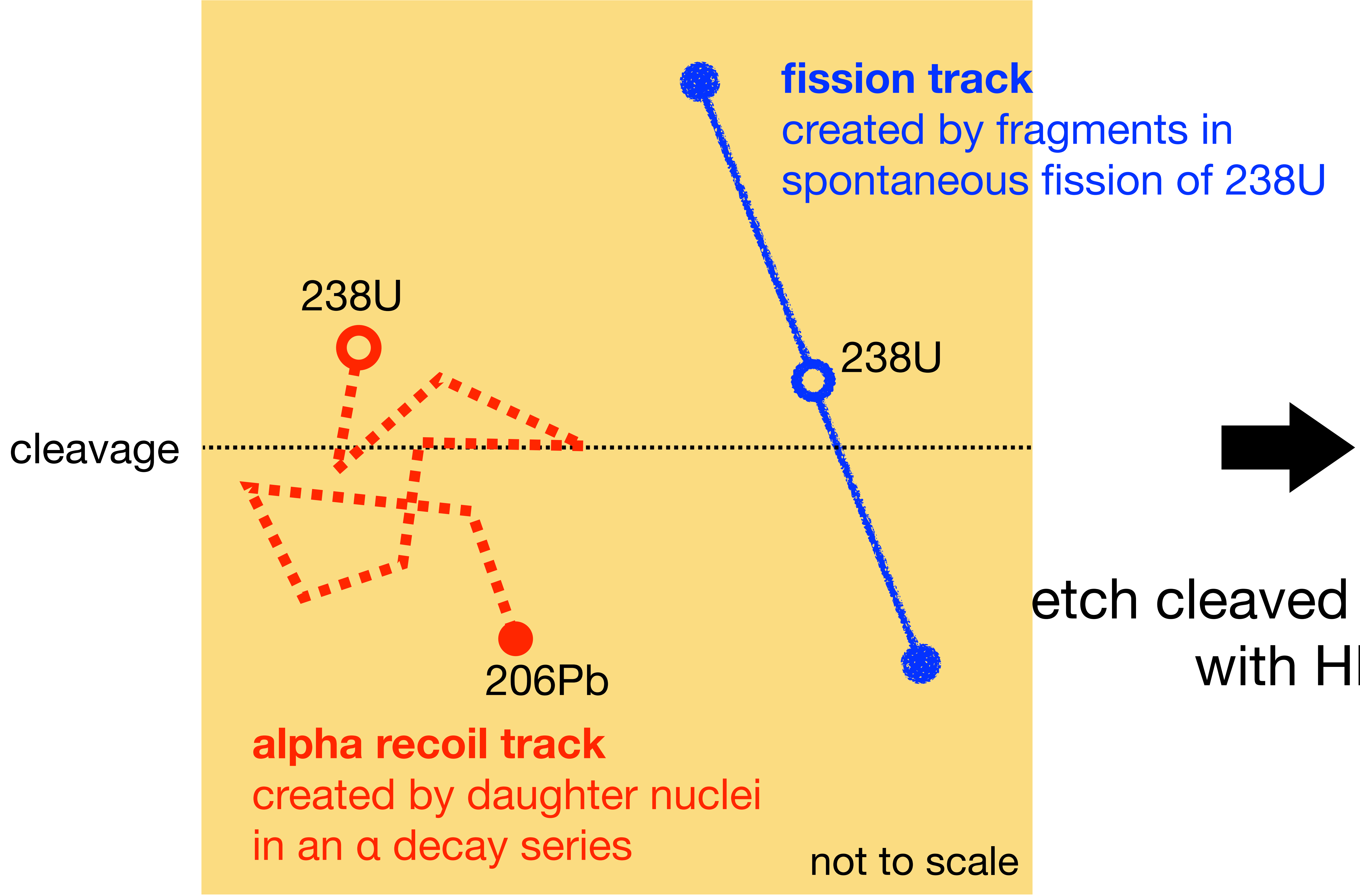




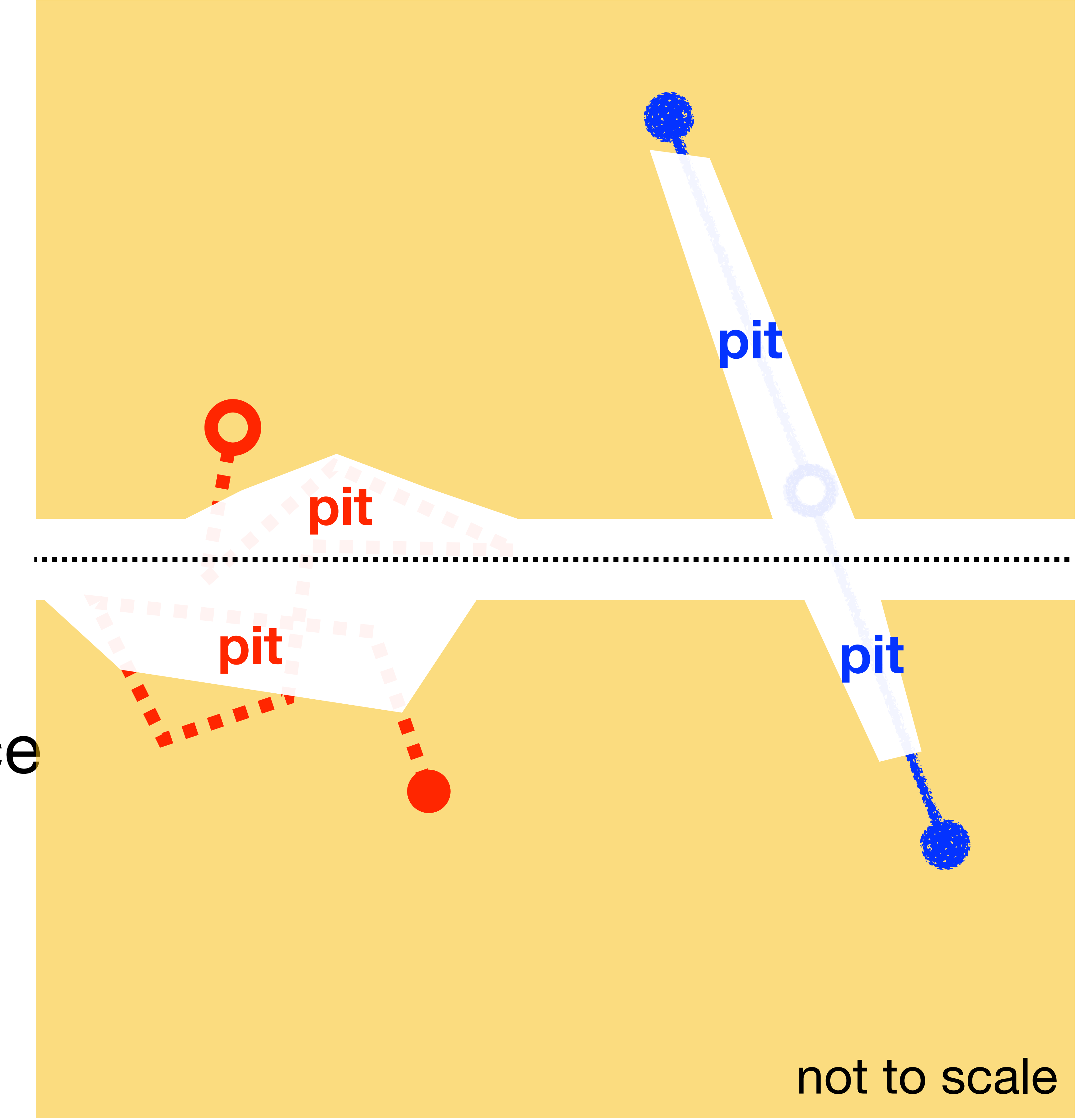
Frequency of naturally occurring tracks in muscovite mica (Price & Salamon 1986)

- Typical concentration of ^{238}U ~ O(0.1) ppb.
- α recoil tracks are most common.

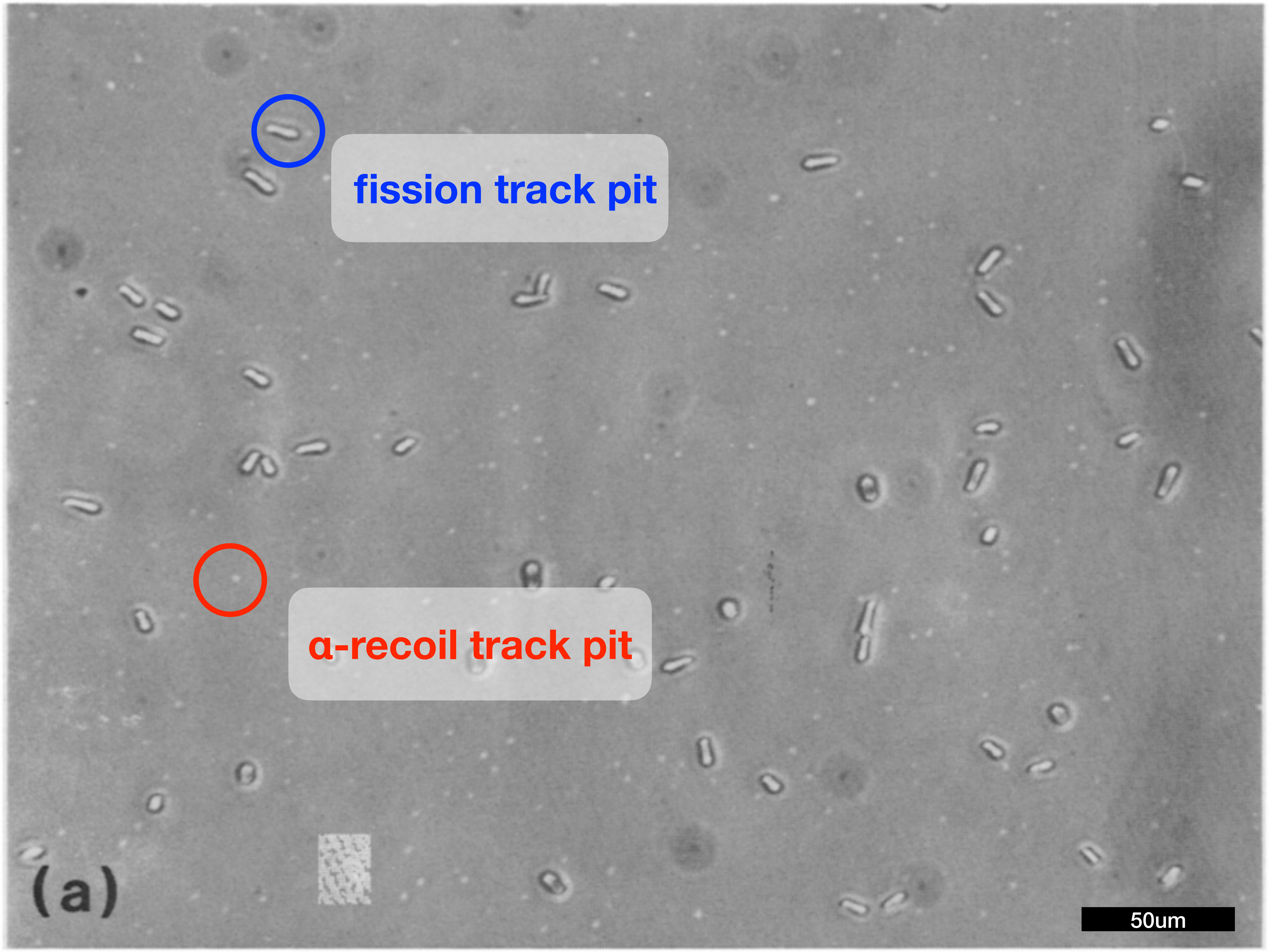
“Latent” tracks are revealed as pits through chemical etching



etch cleaved surface
with HF



Observation of etch pits of radiation tracks with microscopes



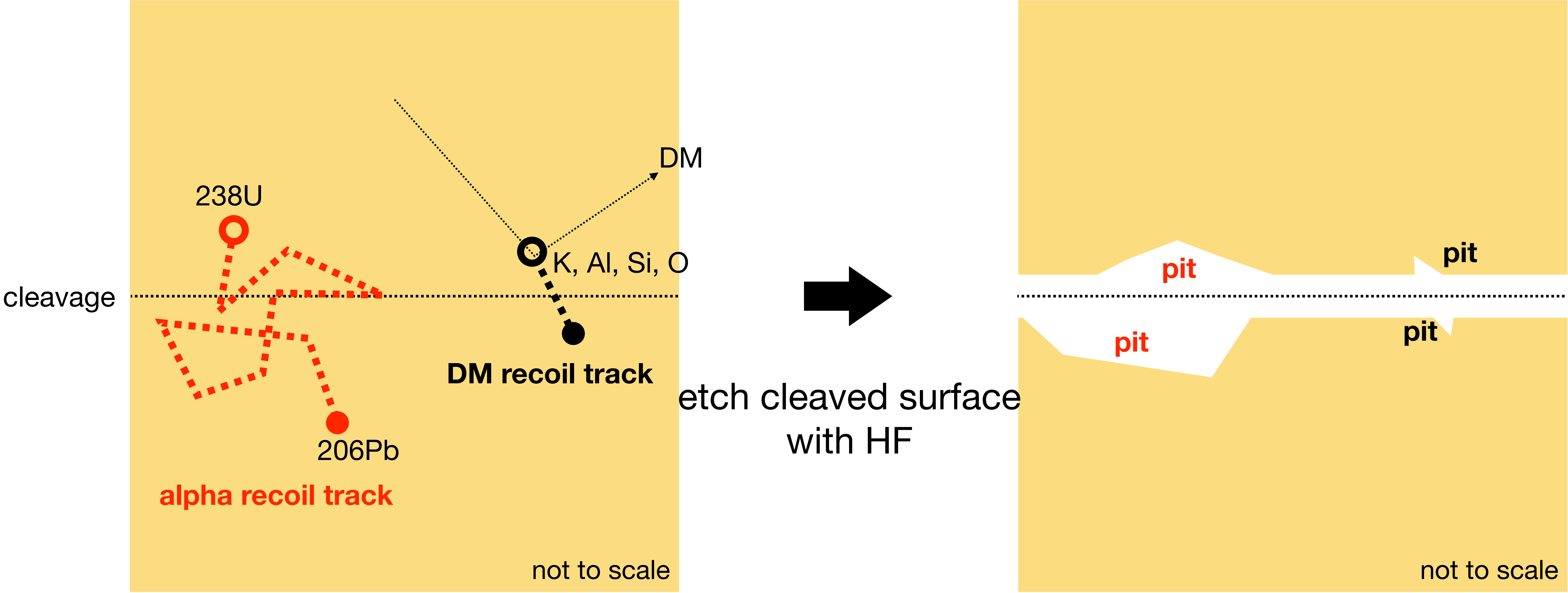
Phase contrast microscopic photograph of *induced* alpha-recoil and fission tracks on the etched surface of mica (Hashimoto et al. 1980)

	Z_{recoil}	v_{recoil} / c	dE/dx GeVcm^{2}g^{-1}	pit depth um
fission track	~38 and ~52	0.031~ 0.046	~25 electronic stopping	~20
α-recoil track	82 ~ 90	0.0013	~15 nuclear stopping	0.01~ 0.03

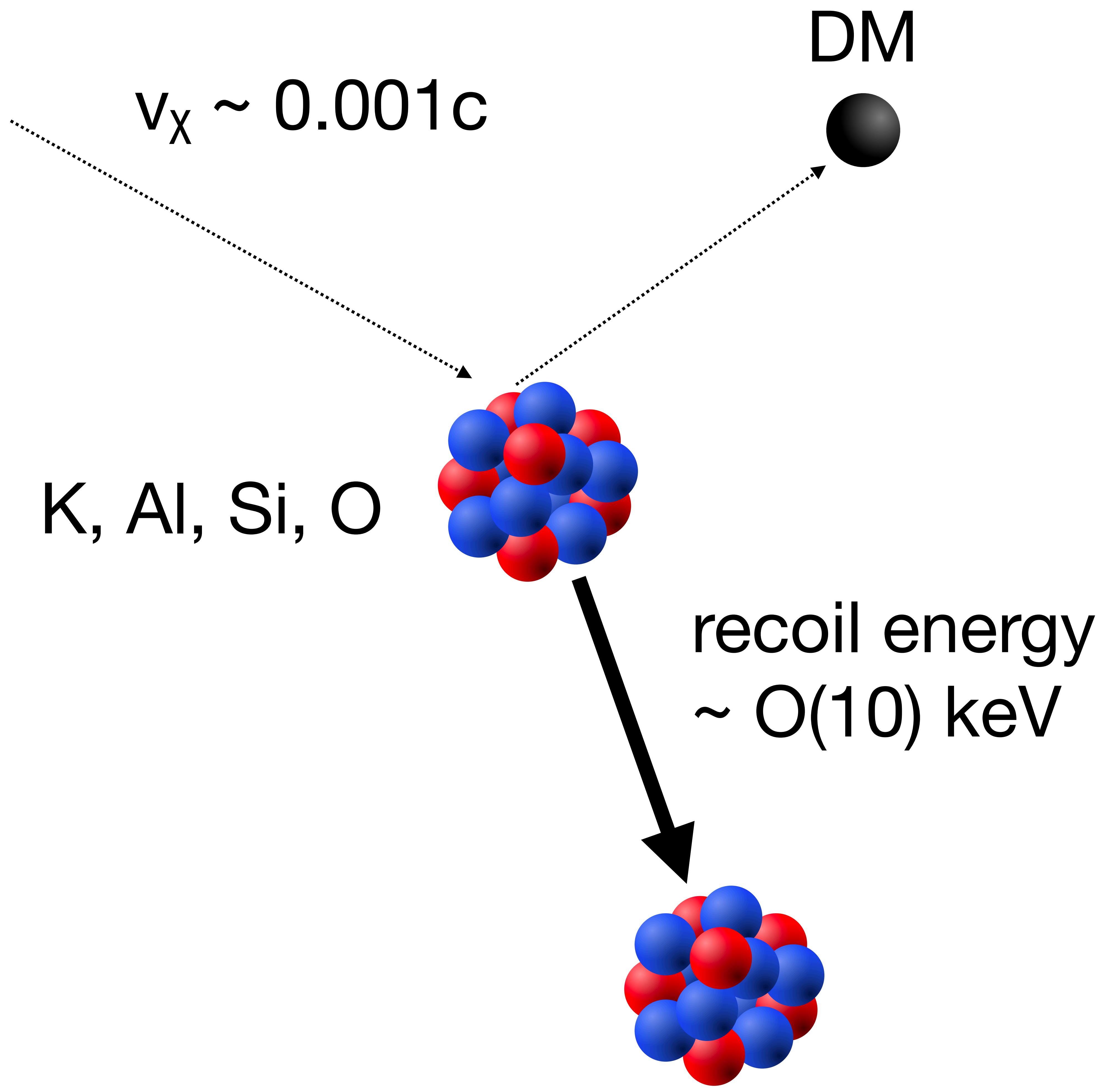
Comparison of natural radiation tracks (from Price & Salamon 1986 with modifications)

Can we readout DM nuclear recoil tracks within mica if they exist?

What track pit can we expect for DM nuclear recoil using the cleave-and-etch method?



Comparison between radiative and DM recoil tracks

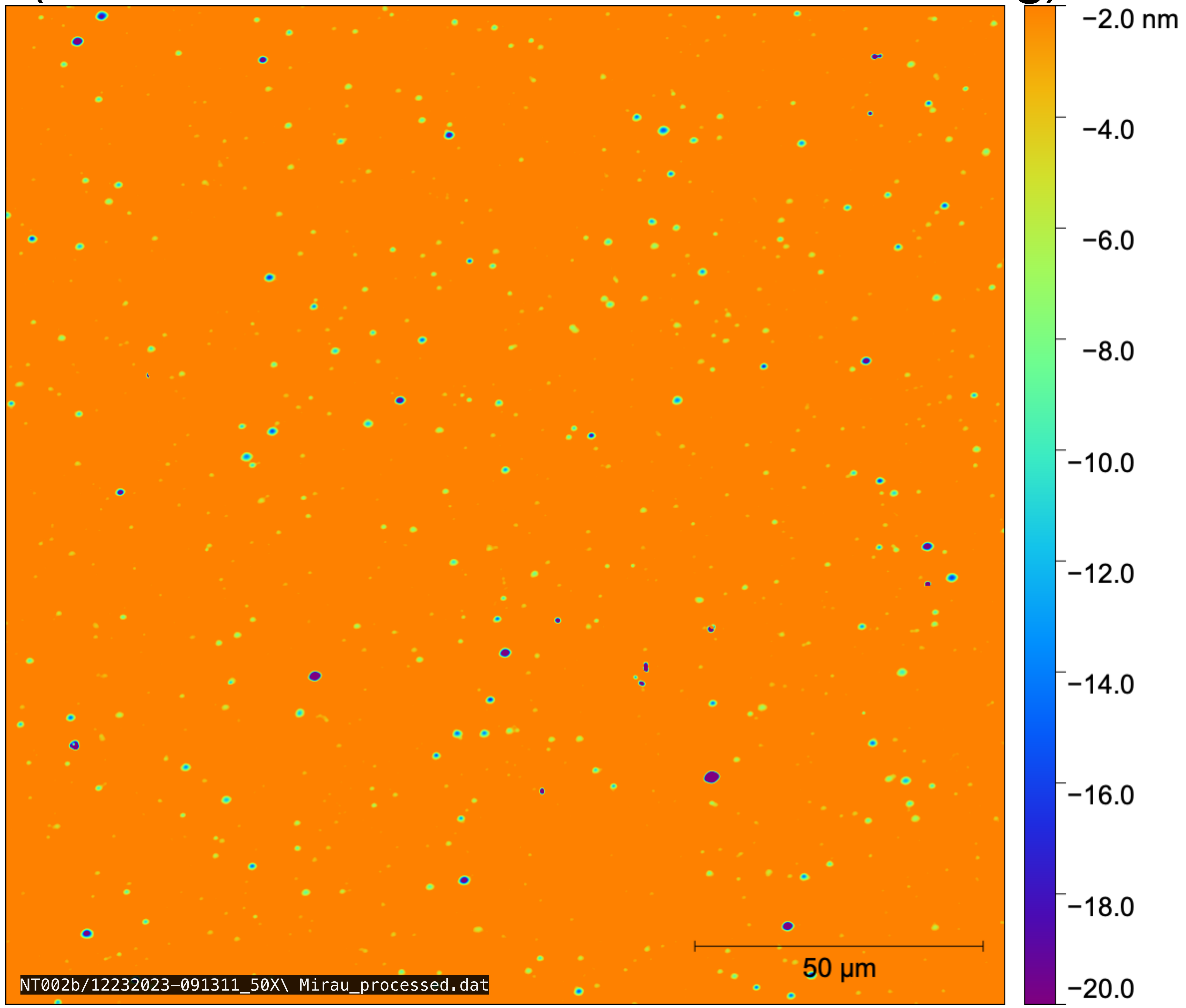


	Z_{recoil}	v_{recoil} / c	dE/dx GeVcm^{2}g^{-1}	pit depth um
fission track	~38 and ~52	0.031~ 0.046	~25 electronic stopping	~20
alpha recoil track	82 ~ 90	0.0013	~15 nuclear stopping	0.01~ 0.03
DM recoil track	8 ~ 19 (K, Al, Si, O)	~ 0.001	~O(1) nuclear stopping	**?**

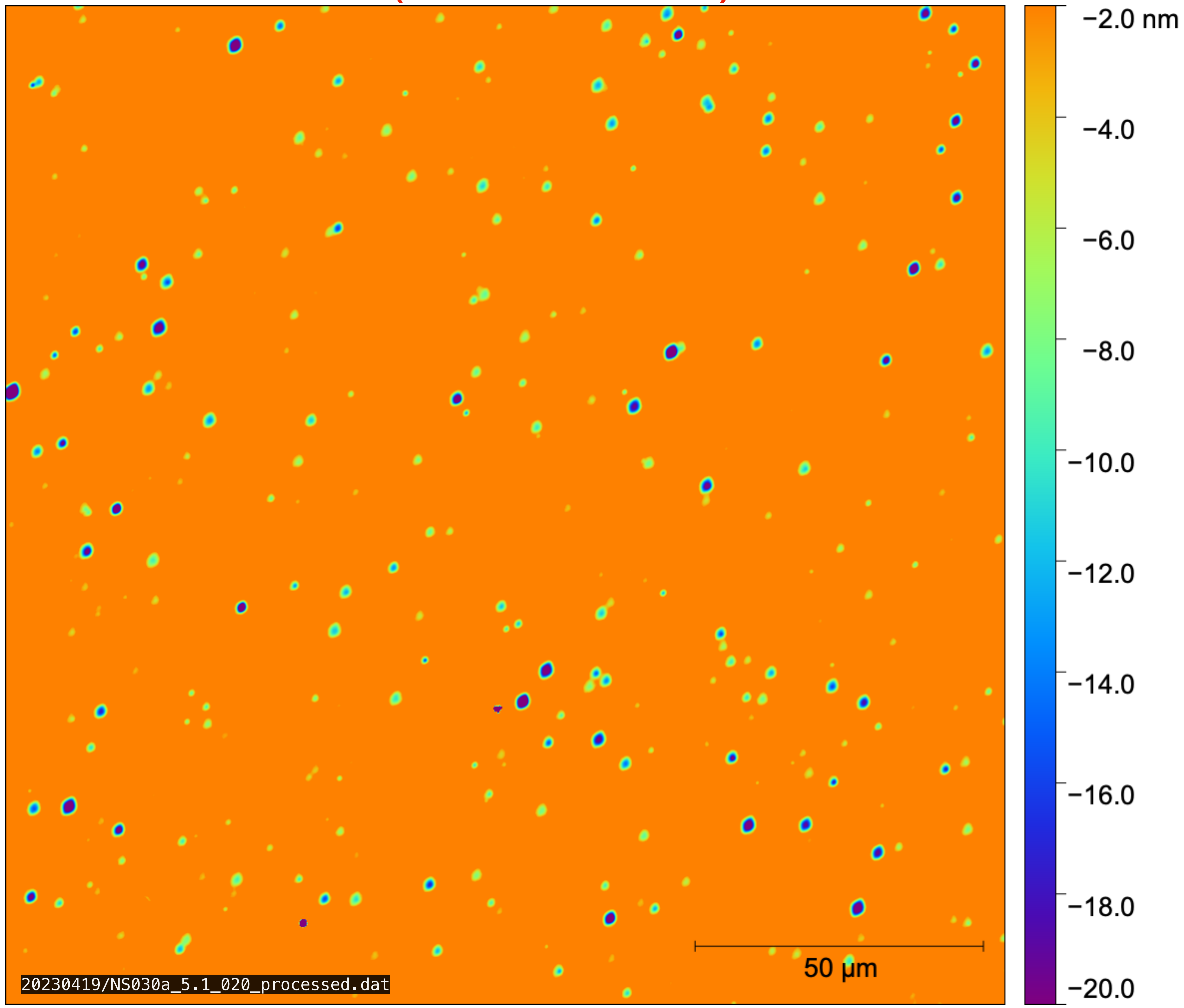
- Fast neutrons (~ MeV) mimic DM nuclear recoil (, which means they are genuine backgrounds).

Neutron (pseudo DM) recoil pits are shallower but observable

neutron-recoil track pits
(neutron-irradiated mica after annealing)



alpha-recoil track pits
(natural mica)



Surface topography measured by optical profiler (preliminary results)

Pioneering DM search using muscovite mica by Snowden-Ifft et al. 1995

Pioneering DM search using muscovite mica by Snowden-Ifft et al. 1995 (SI95)

VOLUME 74, NUMBER 21 PHYSICAL REVIEW LETTERS 22 MAY 1995

Limits on Dark Matter Using Ancient Mica

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(Received 20 September 1994)

The combination of the track etching method and atomic force microscopy allows us to search for weakly interacting massive particles (WIMPs) in our Galaxy. A survey of 80 720 μm^2 of 0.5 Gyr old muscovite mica found no evidence of WIMP-recoil tracks. This enables us to set limits on WIMPs which are about an order of magnitude weaker than the best spin-dependent WIMP limits. Unlike other detectors, however, the mica method is, at present, not background limited. We argue that a background may not appear until we have pushed our current limits down by several orders of magnitude.

PACS numbers: 95.35.+d, 14.80.Ly, 29.40.Ym, 61.72.Ff

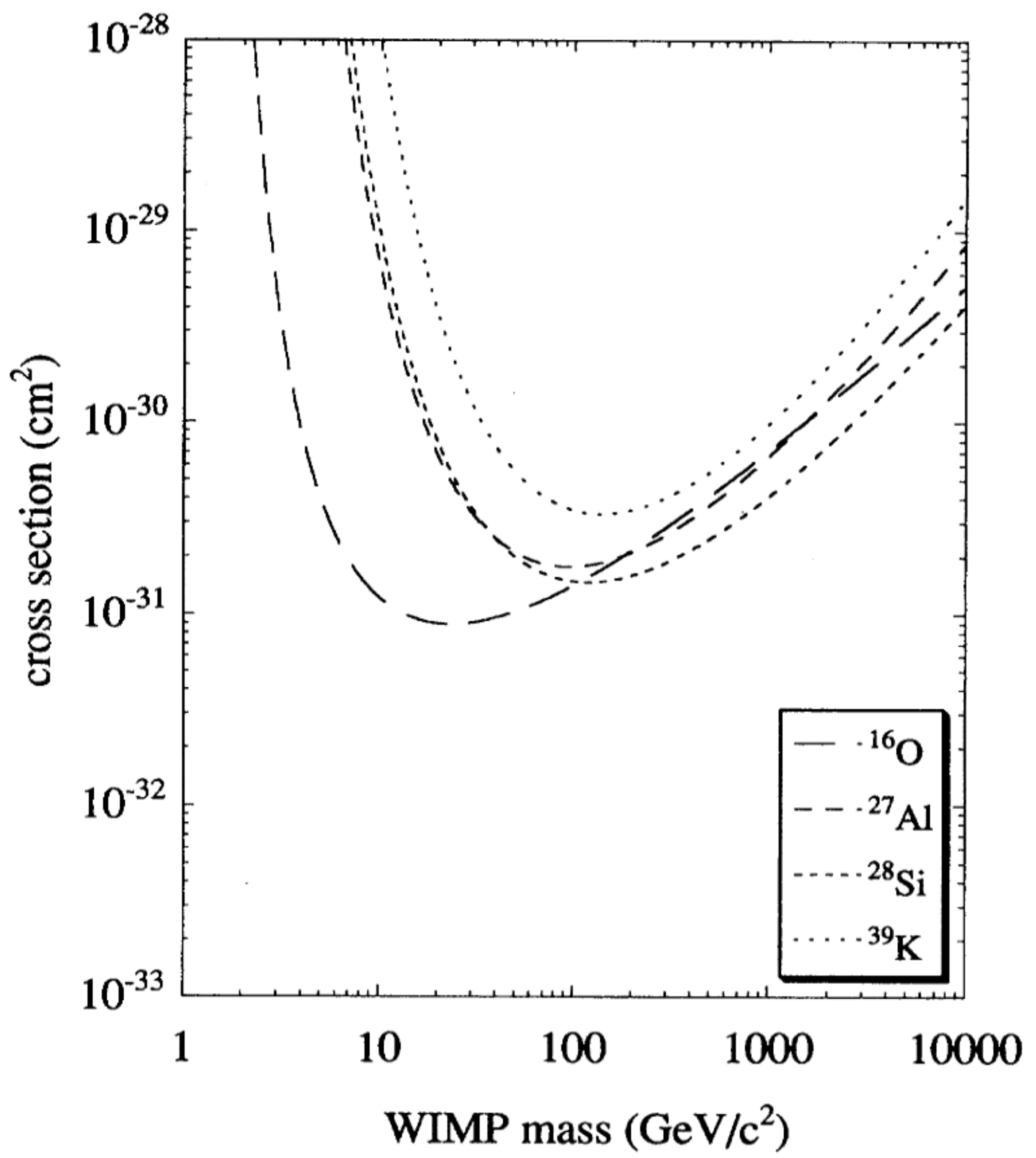
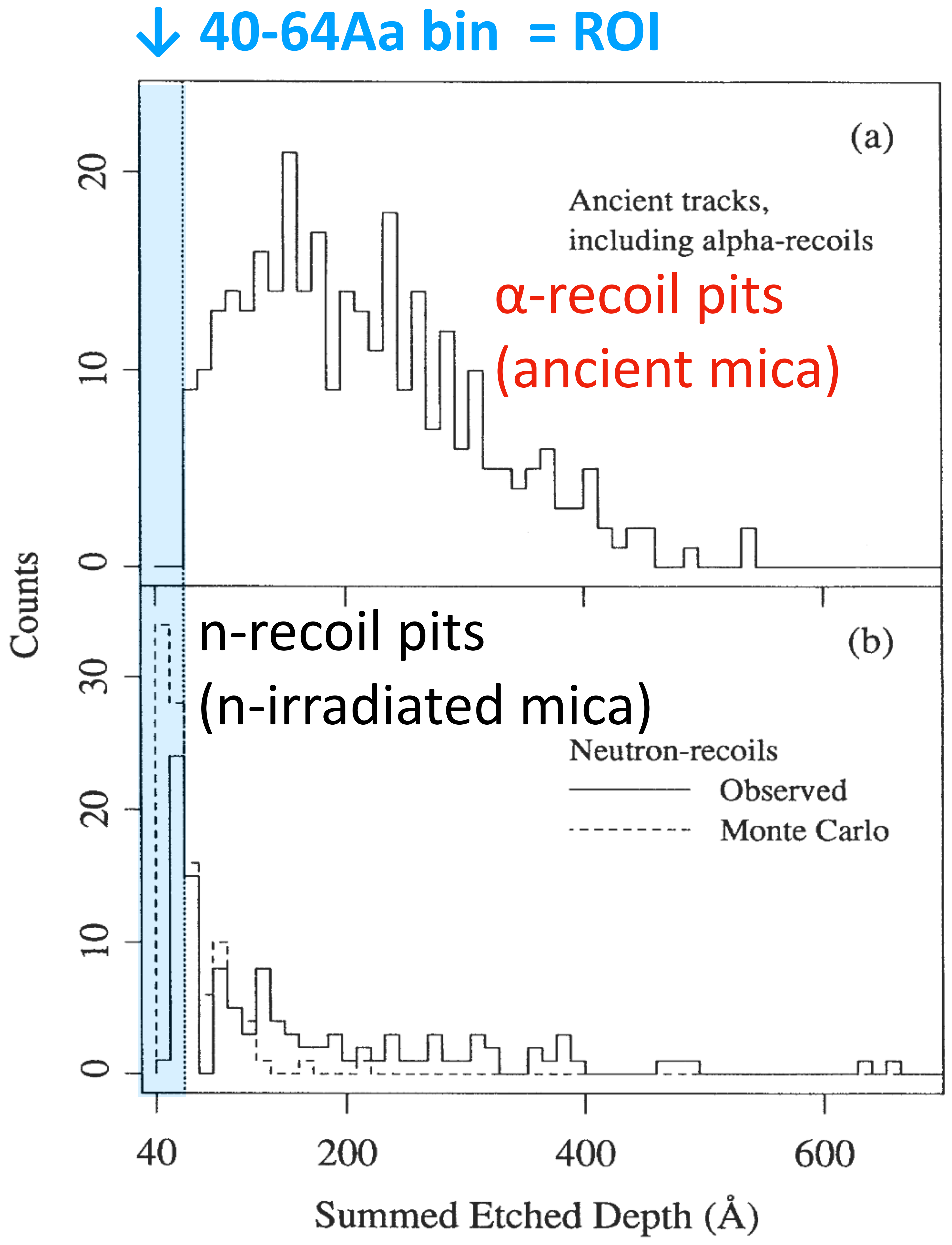


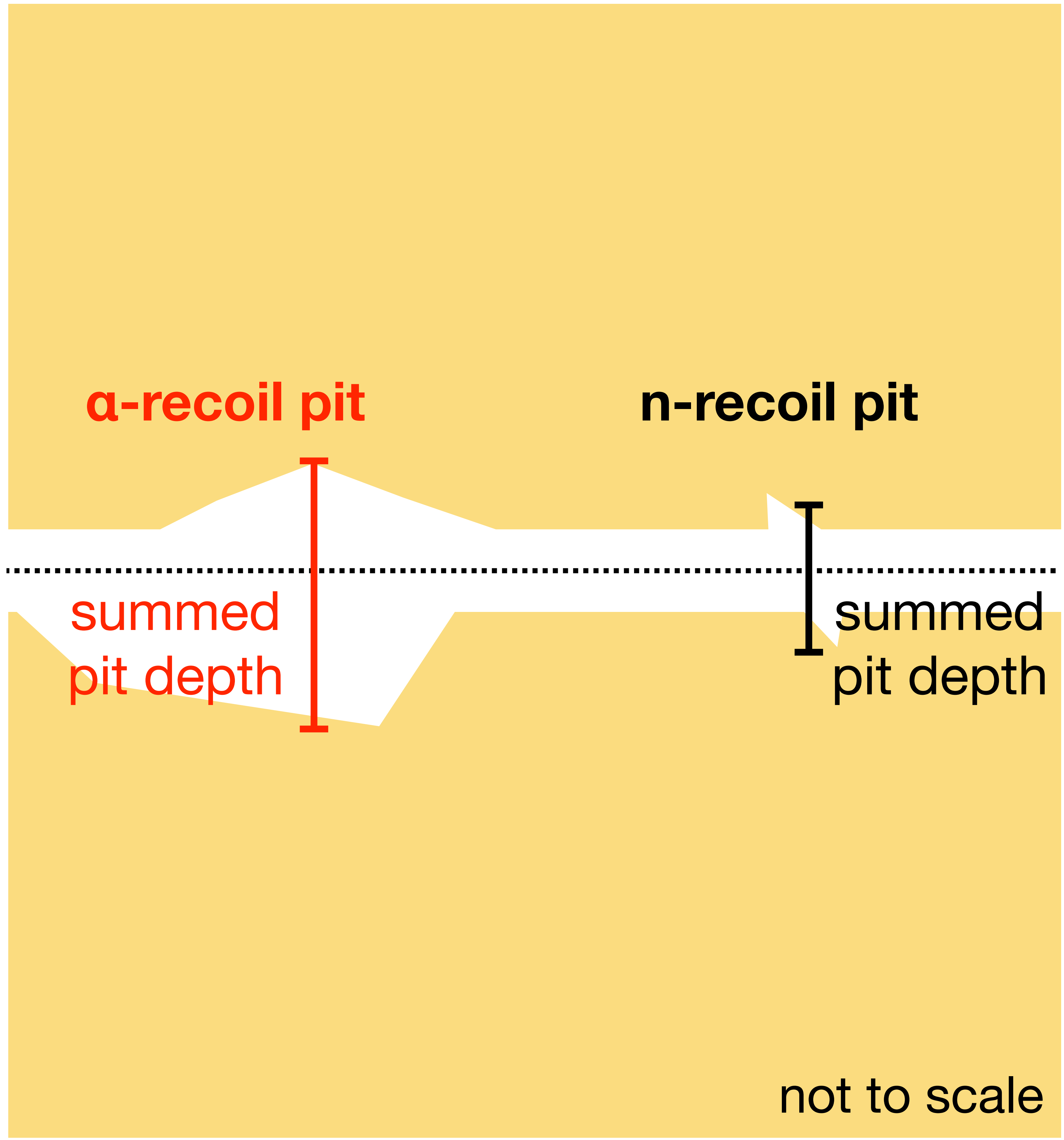
FIG. 4. Exclusion curves for each of the main constituent nuclei of mica. For a given mass, WIMPs with cross sections above these curves are ruled out at the 90% confidence level.

- SI95 set one of the strictest limits on WIMPs cross section at that time, with an exposure of just 1e-6 ton-year.

Identified ROI in the pit-depth histogram with no α-recoil pits

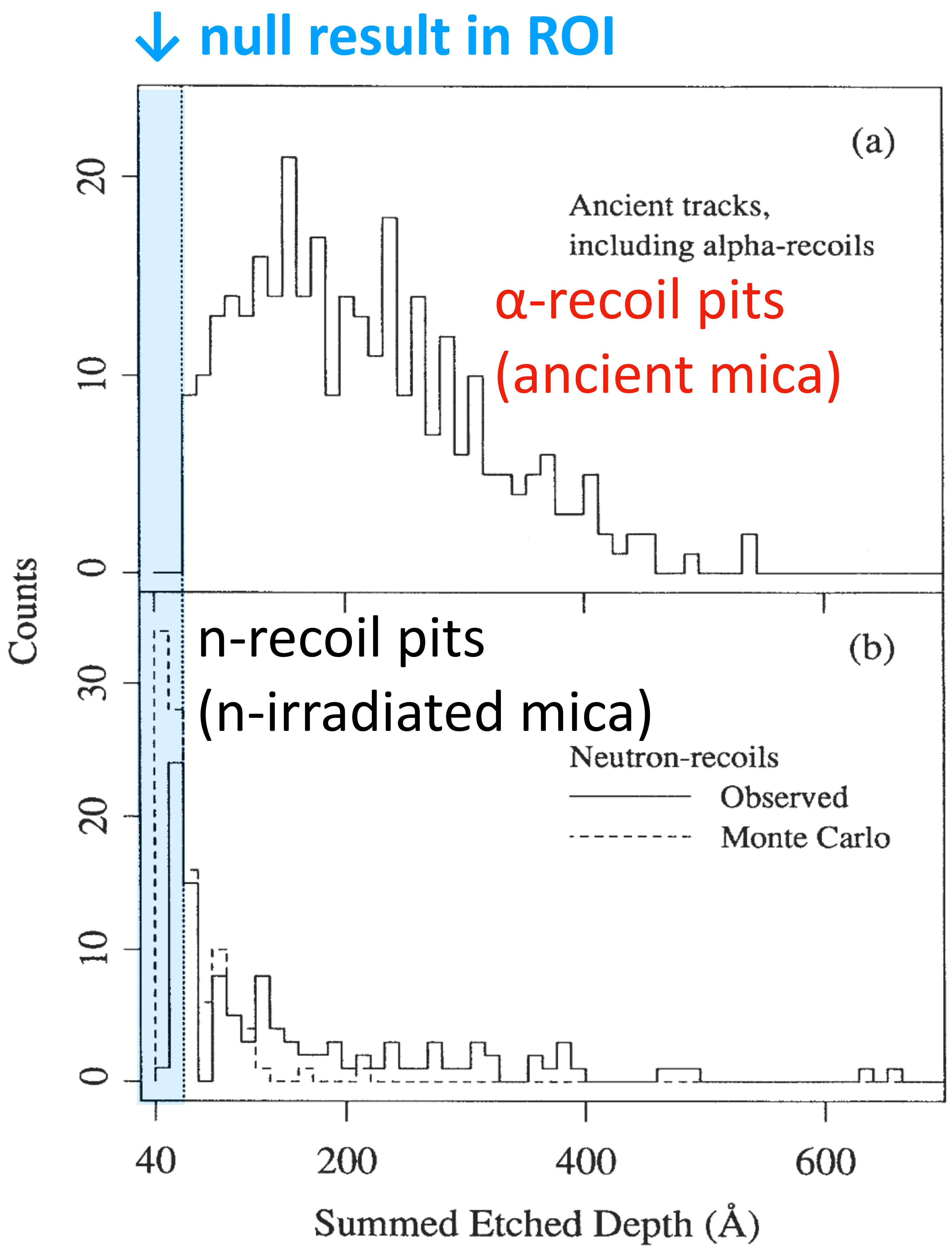


Snowden-Ifft et al. 1995



- SI95 found that the summed pit depth histogram showed null for α-recoil pits but a peak for n-recoil pits in the smallest (40-64Aa) bins.

Limits on dark matter from 80,720um² mica scan



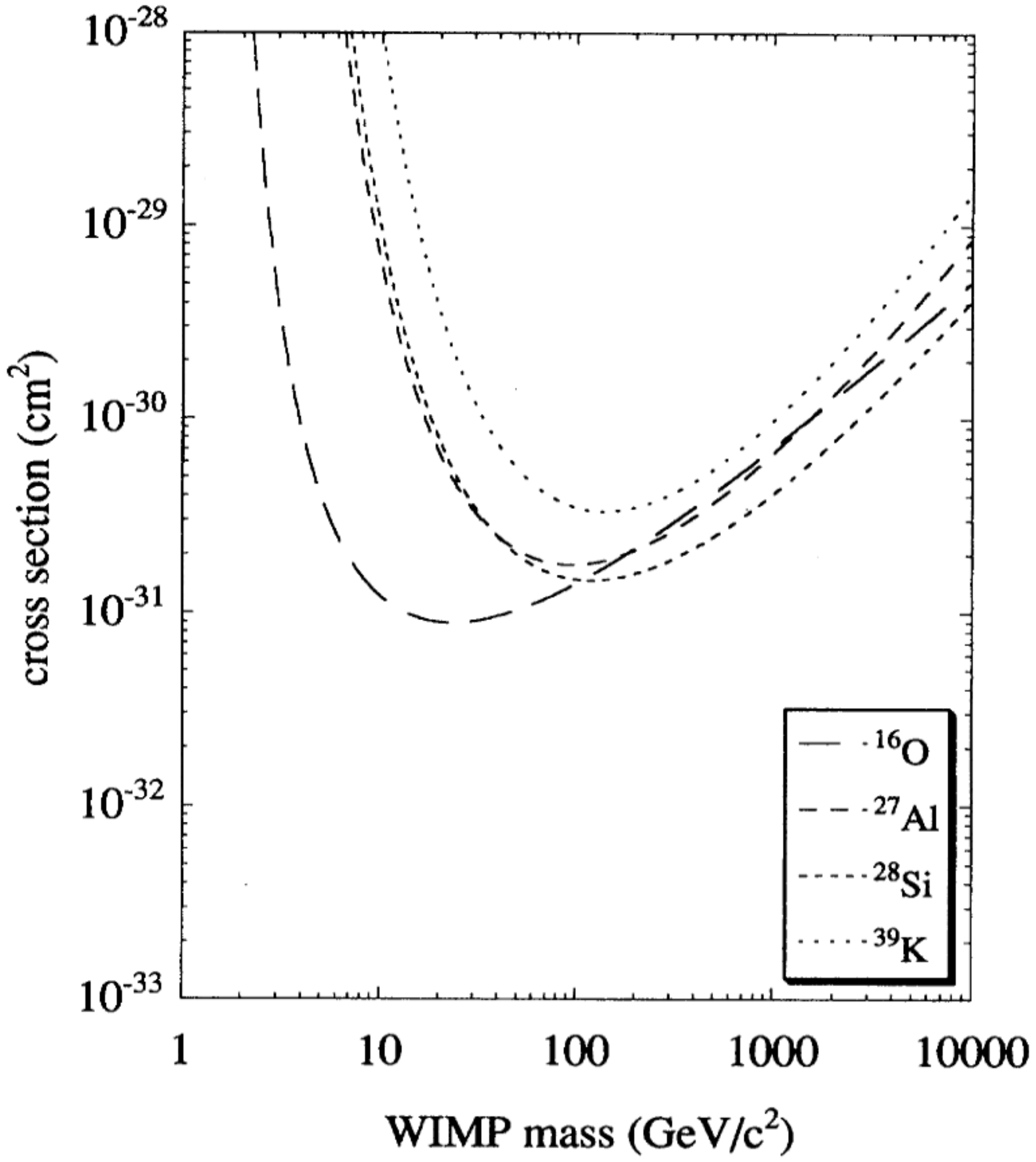
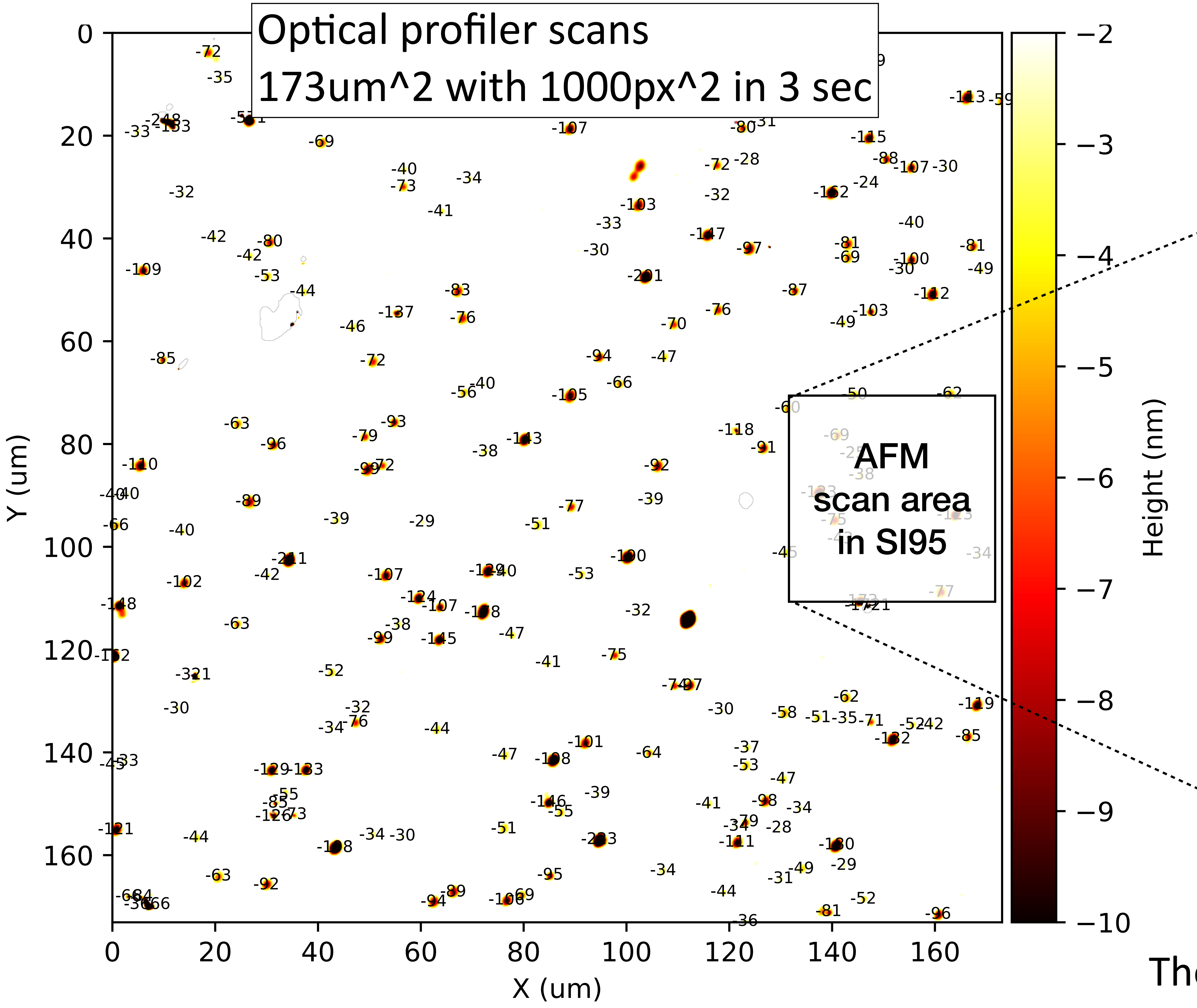


FIG. 4. Exclusion curves for each of the main constituent nuclei of mica. For a given mass, WIMPs with cross sections above these curves are ruled out at the 90% confidence level.

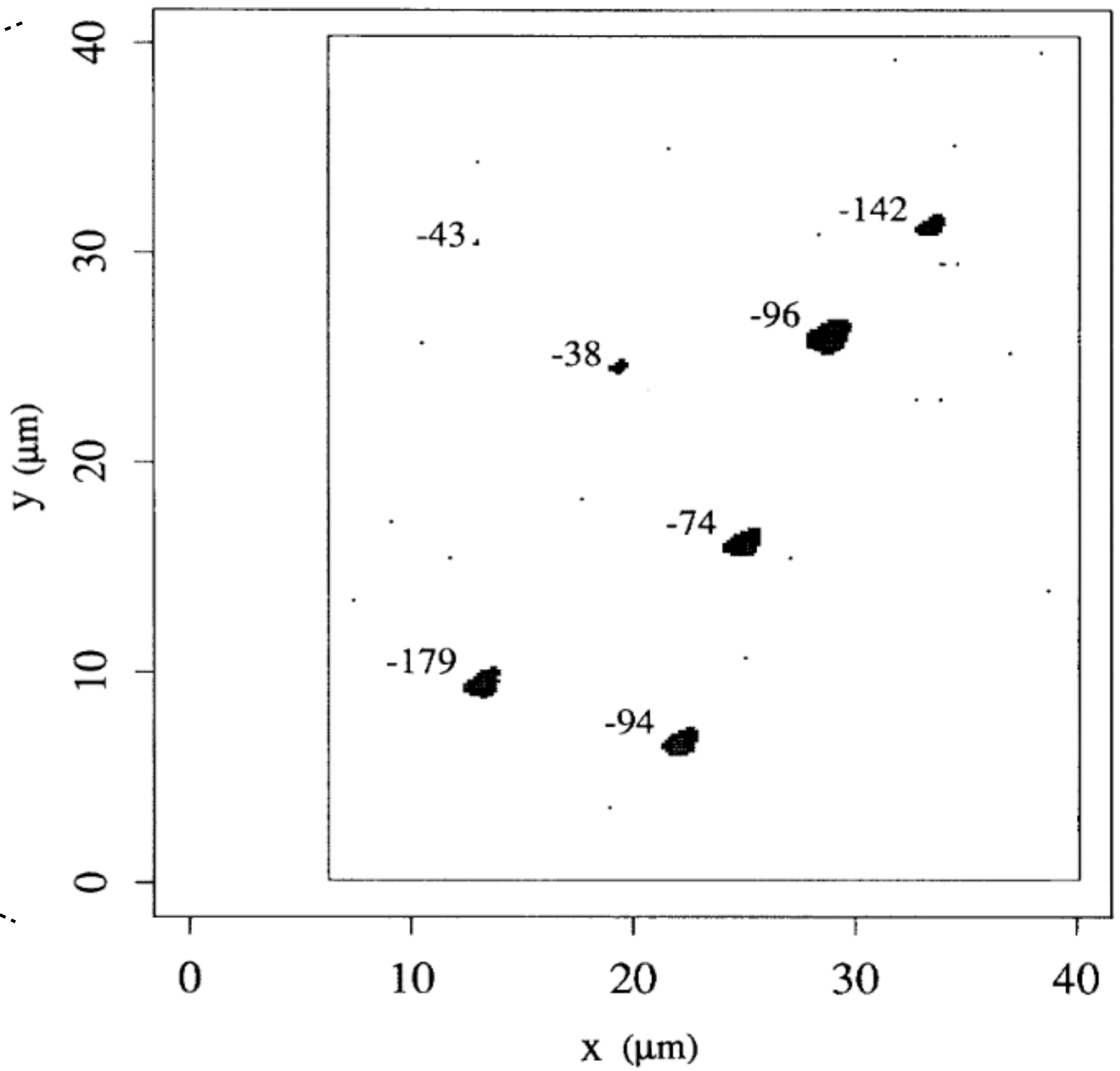
Snowden-Ifft et al. 1995

DMICA targets an exposure of 1 ton-year following the methodology established by Snowden-Ifft et al. 1995

Optical profiler scans mica much faster than AFM



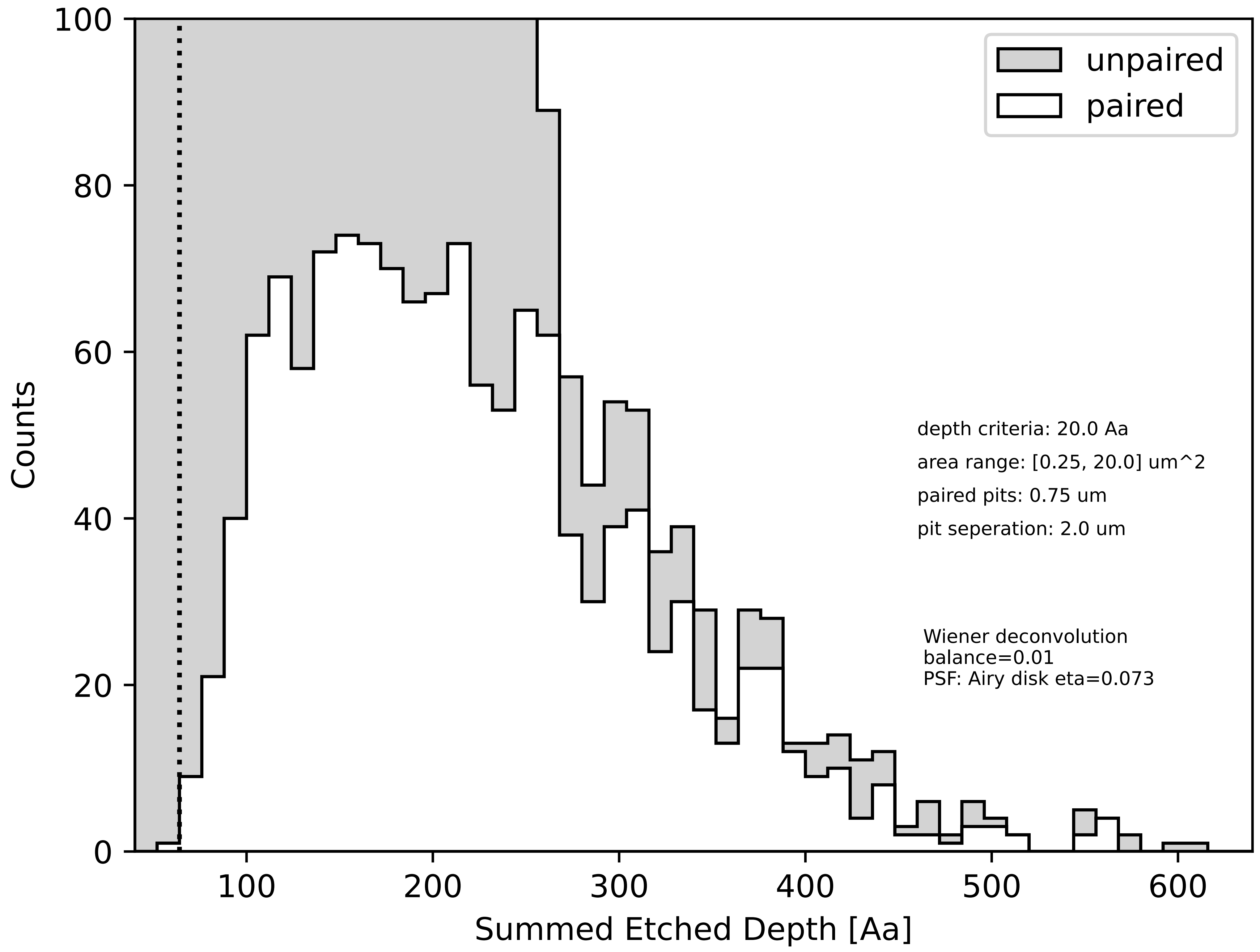
AFM scans
40um^2 with 256px^2 in several min



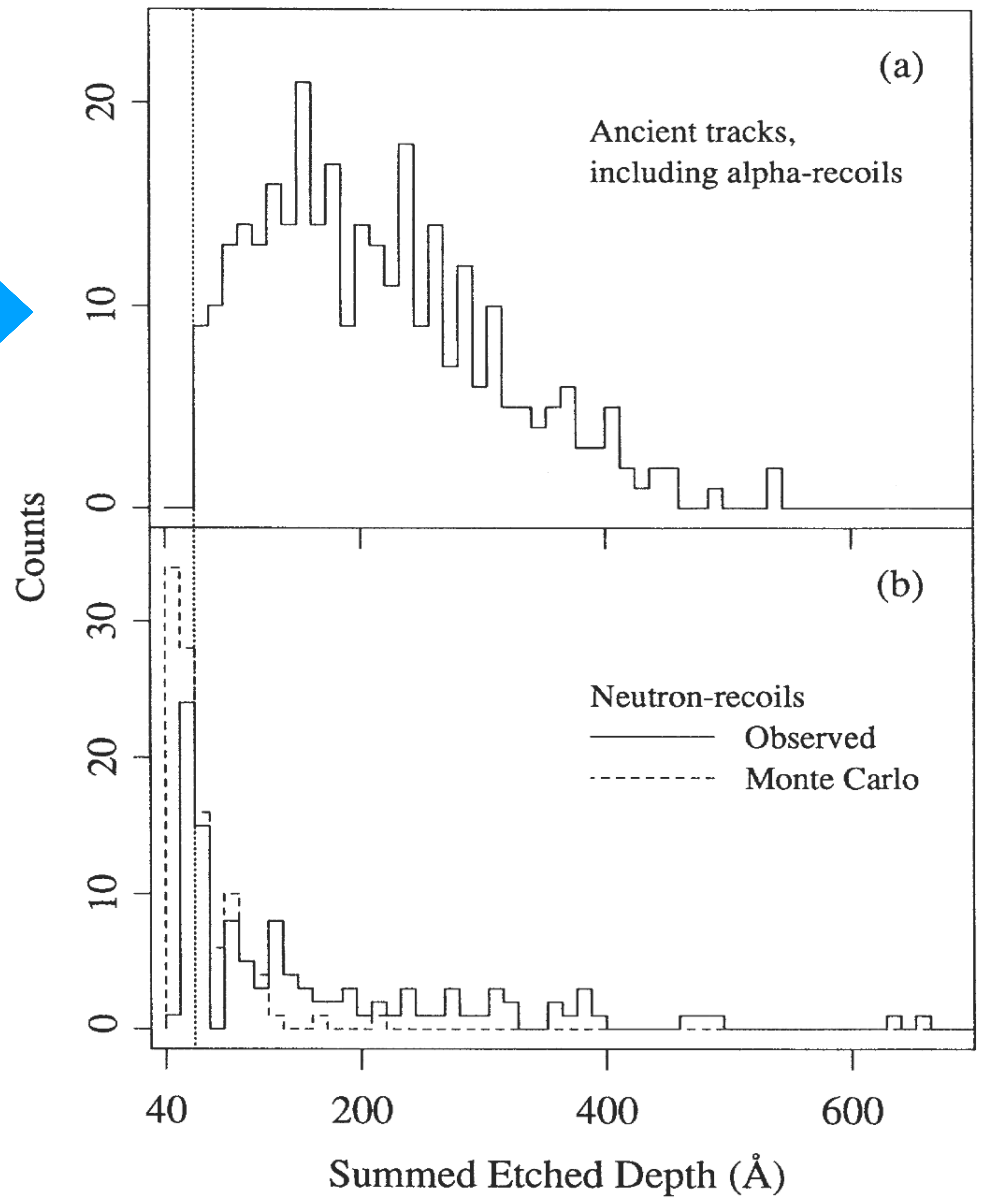
The numbers in the figures are depths of pits in Aa.

DMICA has tentatively processed mica of 524,765 um², 6.5x SI95

DMICA: 524,765 um²



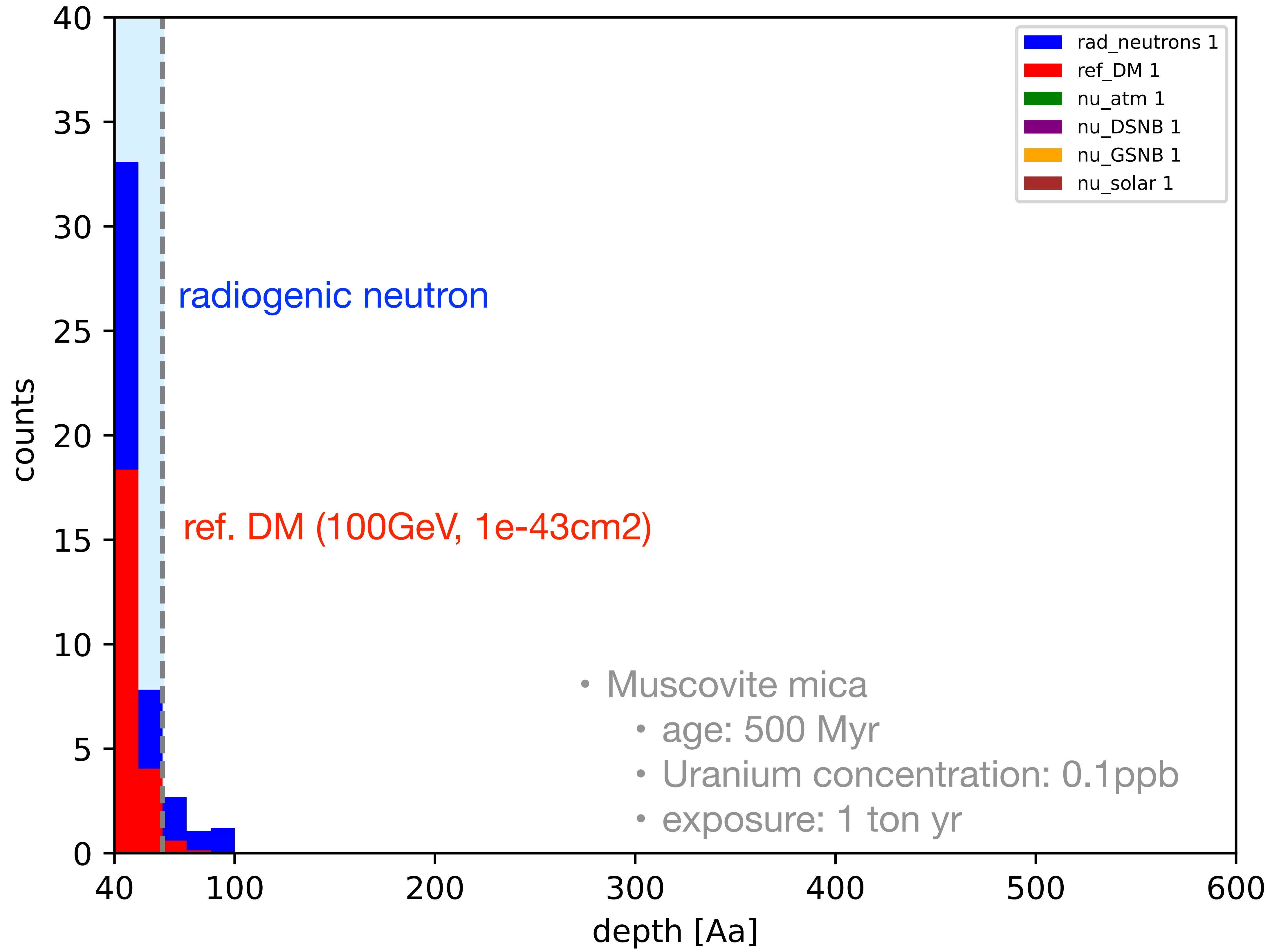
Snowden-Ifft et al. 1995: 80,720 um²



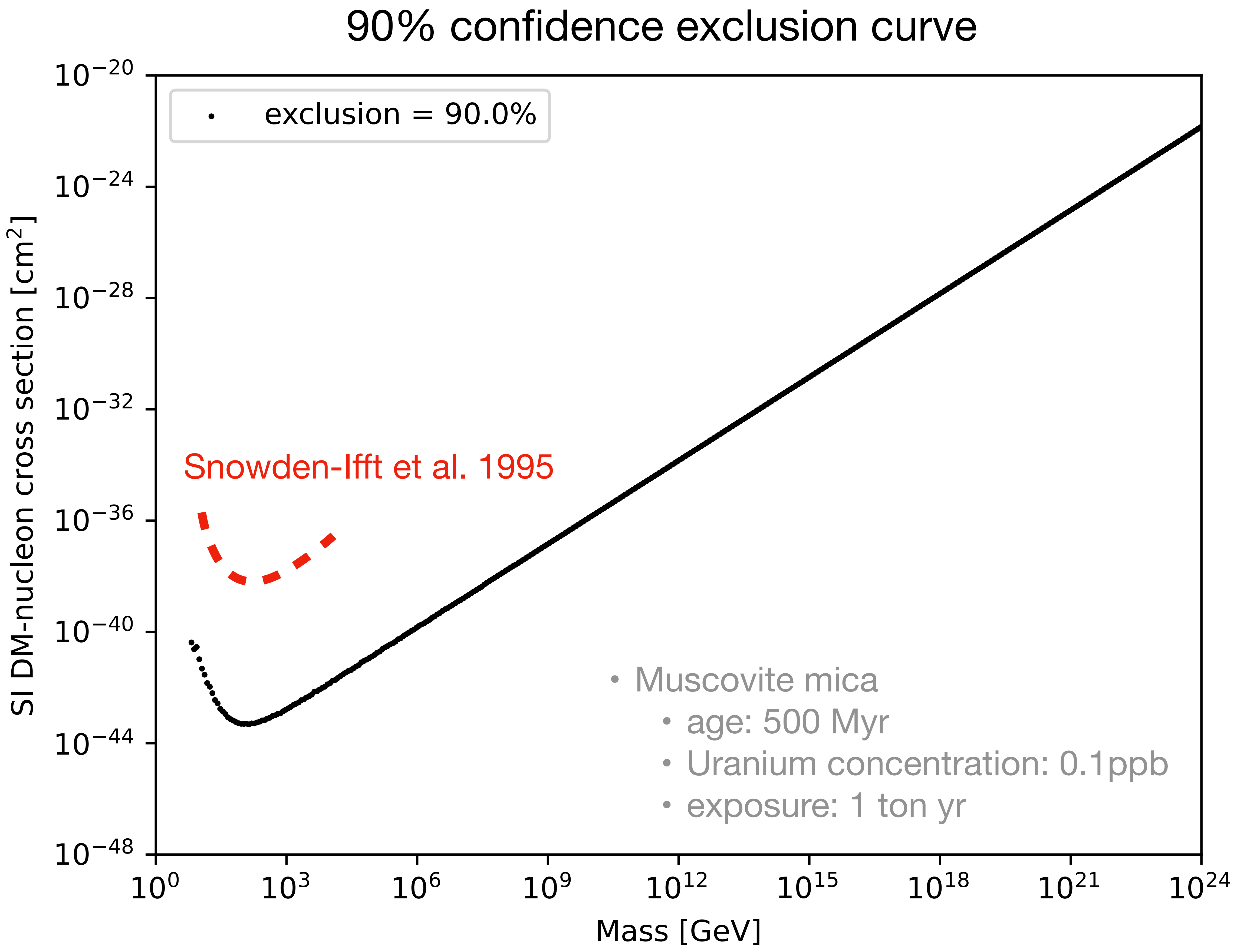
Comparison of DMICA with Snowden-Ifft et al. 1995

	Snowden-Ifft et al. 1995	**DMICA**
Exposure (Scan area)	1e-6 ton-year (80,000 um^2)	**1 ton-year** **(800 cm^2)**
Readout (Scan speed)	Atomic Force Microscopy (0.3 s/um^2)	**Optical profiler** **(0.0001 s/um^2)**
Nominal scan time	10 hours	**92 days**
Backgrounds in ROI	no background	**radiogenic fast neutrons**

Projected sensitivity for DMICA's target exposure of 1 ton-yr taking account of neutron background in ROI



predicted pit depth histogram
based on a pit-creation model (Snowden-Ifft and Chan 1995)



- Upper limit on detectable mass:

$$\left(\frac{m_\chi}{\mathrm{GeV}}\right) < 10^{26}\left(\frac{Mt}{1\mathrm{ton}\cdot\mathrm{yr}}\right)\left(\frac{A/V}{(10\mathrm{nm})^{-1}}\right)$$

Summary

- DMICA explores DM nuclear recoil events in natural mica.
  - natural minerals are the only tool for exploring "past-Gyr" DM events
  - huge surface-to-volume ratio of mica target allows detection of ultra-high mass DM
- DMICA uses an optical profiler instead of AFM to scan mica, enabling a 1 ton-year exposure, a six-order-of-magnitude jump from the previous study (SI95).
- DMICA is still in the R&D phase, but has demonstrated reproducing SI95 with 6.5 times larger exposure.
  - Obtaining samples with a low concentration of radiative impurities is crucial for the production phase.