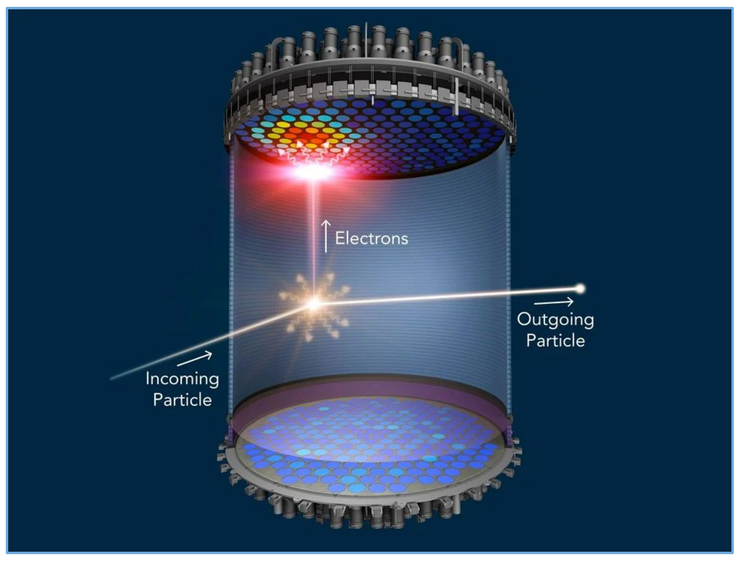
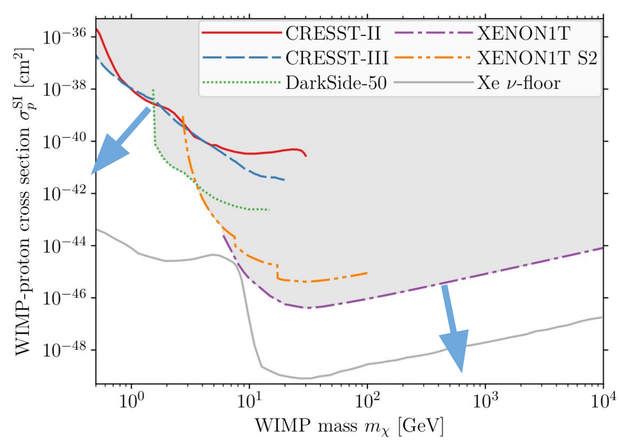
Paleo Detectors for Dark Matter, Neutrinos, and stories about our Galaxy's past

Sebastian Baum
Stanford Institute for Theoretical Physics

What if instead of looking for dark matter in a big detector in the lab, one could use billion years old rocks as detectors?





Conventional direct detection experiments

- Build the largest detector possible (current generation of liquid Xe detectors reaching a few tonnes)
- Instrument to detect nuclear recoils in real time with as low threshold as possible
- Observe for at most a few years

Paleo Detectors

- Natural minerals formed on Earth as long as a billion years ago can record damage tracks from nuclear recoils
- Once created, damage tracks can be preserved for $\gg 10^9$ years!
- Modern microscopy technology should allow one to read out small mineral sample with nanometer-scale resolution!

Exposure through time

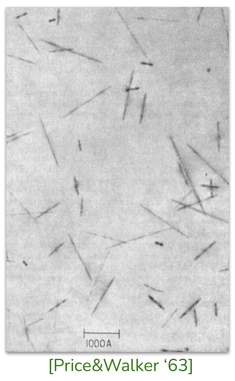
100 g × 1 Gyr = 10 kt × 10 yr

Track length corresponds to energy

$\lesssim$ keV recoil energy thresholds

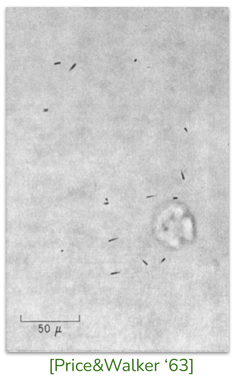
Natural Solid State Track Detectors

Fission fragment tracks in synthetic Mica, TEM



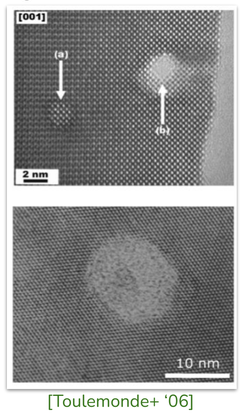
[Price&Walker '63]

Fossil Tracks in Phlogopite; optical microscopy after chemical etching.



[Price&Walker '63]

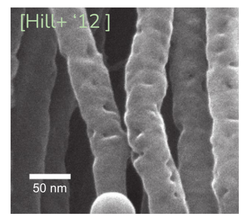
High-resolution TEM of high-Z ion tracks

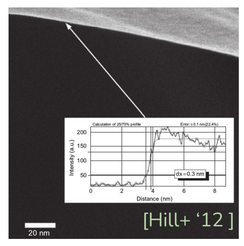


[Toulemonde+ '06]

Examples of modern read-out techniques [1,2,4]

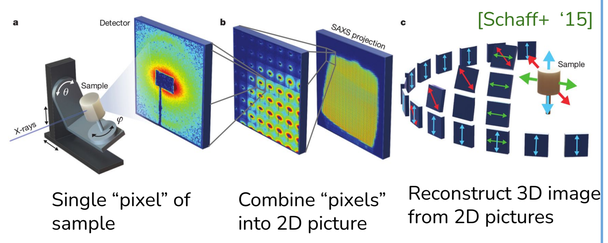
Helium Ion Beam Microscope



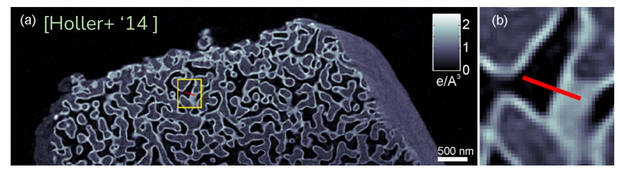


Commercially available

X-ray Ptychography



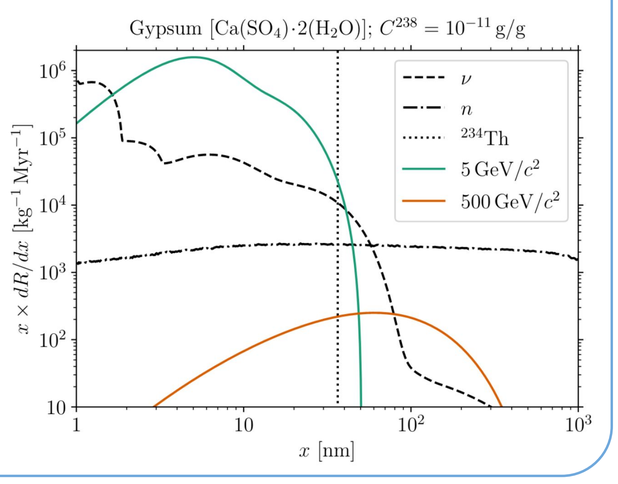
Single "pixel" of sample | Combine "pixels" into 2D picture | Reconstruct 3D image from 2D pictures



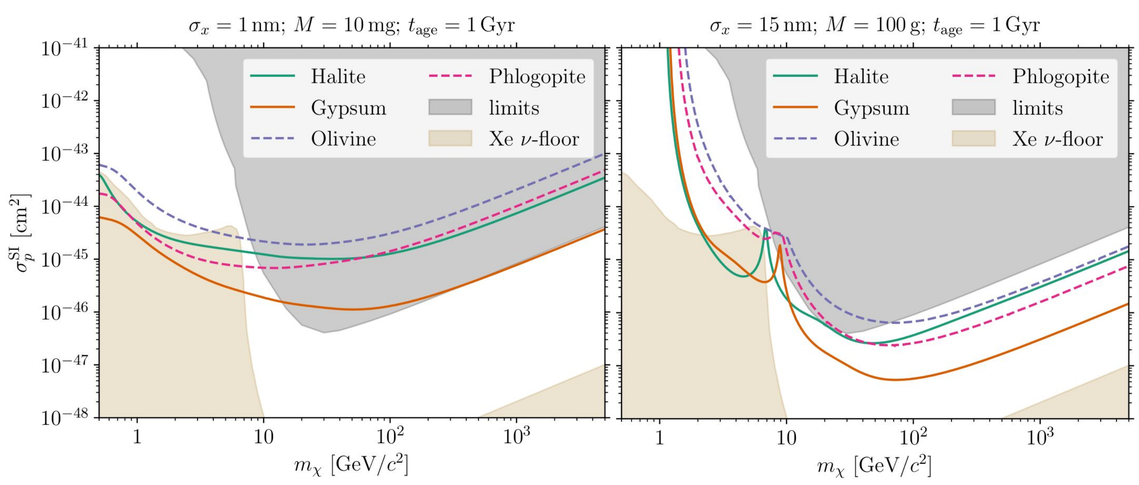
16 nm isotropic 3D resolution demonstrated!

Backgrounds, Backgrounds, Backgrounds [1,2,3,4,6]

- Natural Defects → no confusion with signal
- Cosmogenics → use minerals from deep underground (e.g., boreholes)
- Radioactivity → use radiopure minerals (e.g., ultra basic rocks)
- Neutrinos → Background or signal?



Dark Matter Sensitivity Projections [1,2,3,6]



- Halite -- NaCl
- Gypsum -- $Ca(SO_4)•2(H_2O)$
- Olivine -- $Mg_{1.6}Fe_{0.4}(SiO_4)$
- Phlogopite --$KMg_3AlSi_3O_{10}F(OH)$

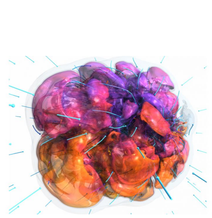
Do you want to know more?

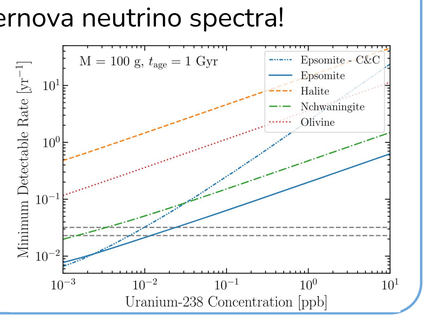
Find me, or read some of these papers:

[1] SB, A. K. Drukier, K. Freese, M. Górski and P. Stengel, 1806.05991 (PLB).
[2] A. K. Drukier, **SB**, K. Freese, M. Górski and P. Stengel, 1811.06844 (PRD).
[3] T. D. P. Edwards, **SB+**, 1811.10549 (PRD).
[4] SB+, 1906.05800 [astro-ph.GA] (PRD).
[5] J. R. Jordan, **SB+**, 2004.08394 (PRL).
[6] SB, T. D. P. Edwards, K. Freese and P. Stengel, 2106.06559 (Instruments).
[7] SB, W. DeRocco, T. D. P. Edwards and S. Kalia, 2107.02812 (PRD).
[8] SB, F. Capozzi and S. Horiuchi, 2203.12696.

Supernova Neutrinos [4,8]

Directly measure the Milky Way's supernova rate, star formation history over Gyrs, and get an all-flavor measurement of supernova neutrino spectra!





Atmospheric Neutrinos [5]

Could we learn about the rate of cosmic rays hitting Earth on Gyr timescales?

50% drop

100% enhancememt for 0.1 Gyr