Paleo-detectors for cosmic rays

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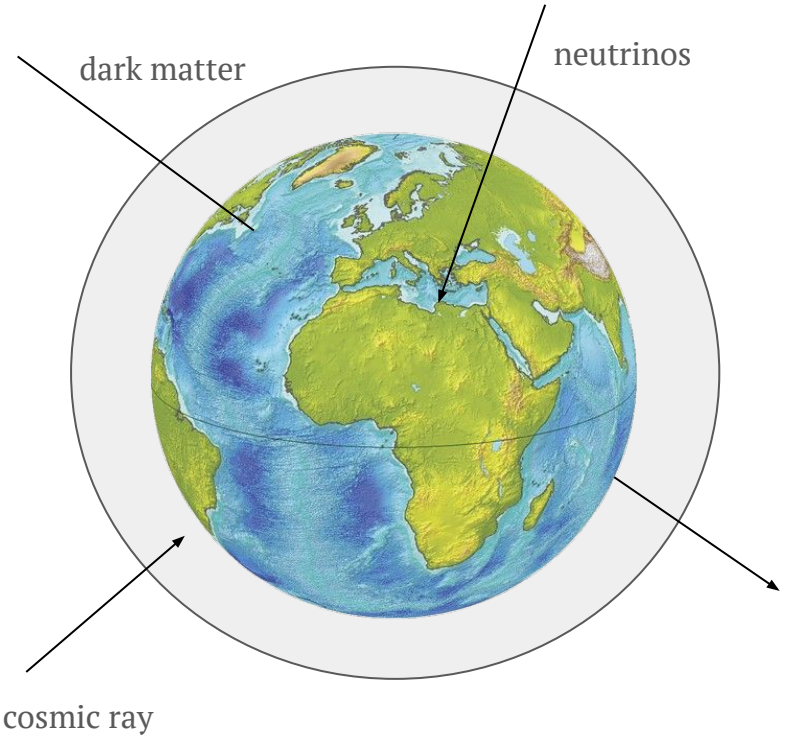
17th Marcell Grossmann Meeting - 12/07/2024 - **Mineral Detection of Neutrinos and Dark Matter**

Mineral detection of neutrinos and Dark Matter?

- The Earth is continually passed by a large amount of astroparticles.



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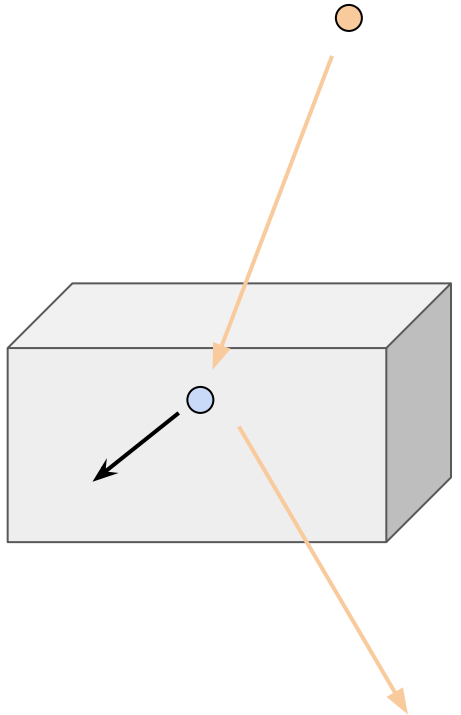

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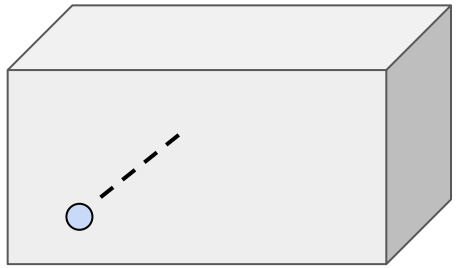

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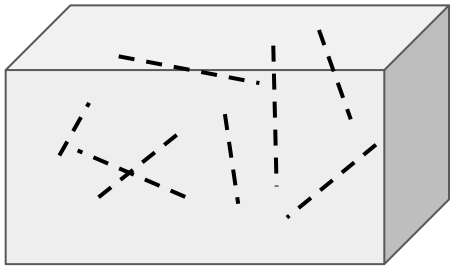

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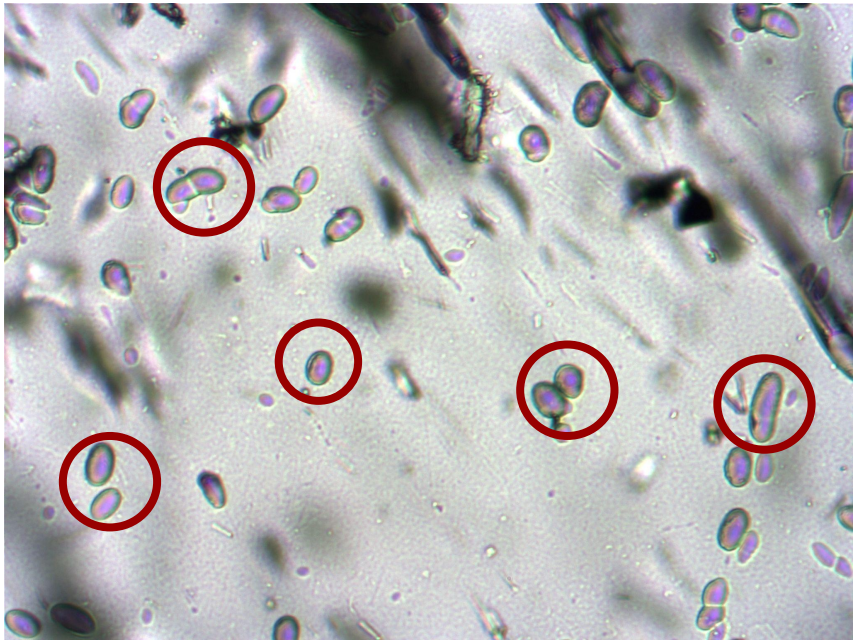

Mineral detection of neutrinos and Dark Matter?

WHY?!

WHAT IS THE TRADE-OFF?

Mineral detection of neutrinos and Dark Matter?

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- Enormous exposure $10\ \mathrm{g} \times 10^6\ \mathrm{yr} = 1000\ \mathrm{kg} \times 10\ \mathrm{yr}$
- Retain information about past flux of astroparticles

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WHAT IS THE TRADE-OFF?

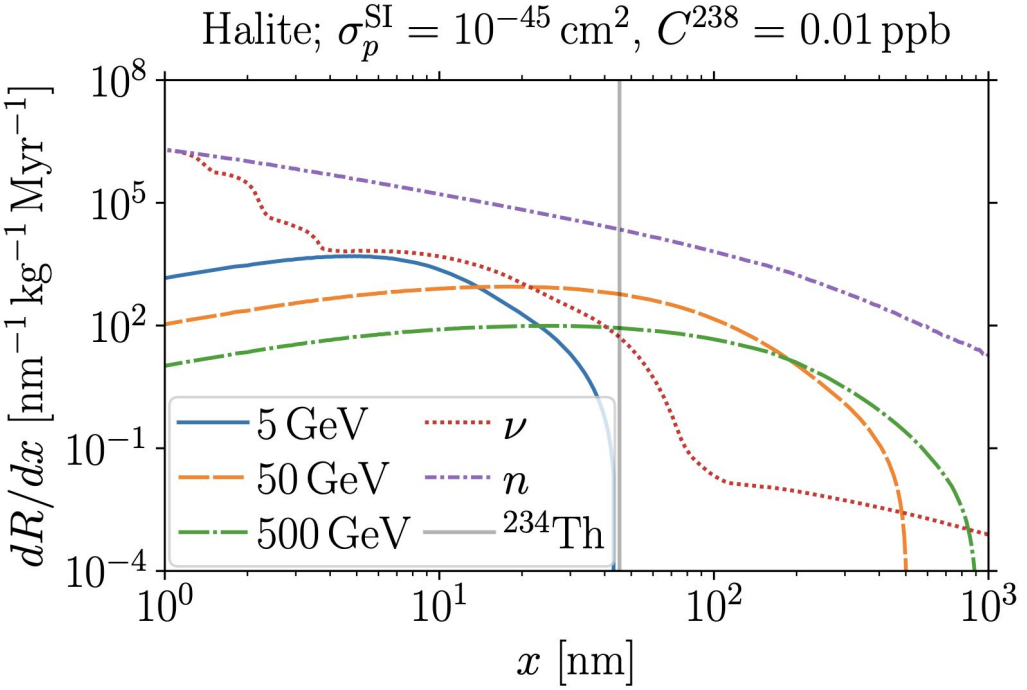
Minerals live in an uncontrolled environment, using them will lead us to a significant problem of the background

Background

Signal
dark matter

Background
- α-decay in ^{238}U chain (only the nuclei decaying one time)
- neutrons generated in (α,N) interactions
- neutrinos

A. K. Drukier, S. Baum, K. Freese, M. Gorski and P. Stengel, Paleo-detectors: Searching for dark matter with ancient minerals, Physical Review D 99 (Feb., 2019).



Background

ONLY VALID IF WE ARE AVOIDING THE COSMIC RAYS BACKGROUND TAKING MINERALS DEEP UNDERGROUND

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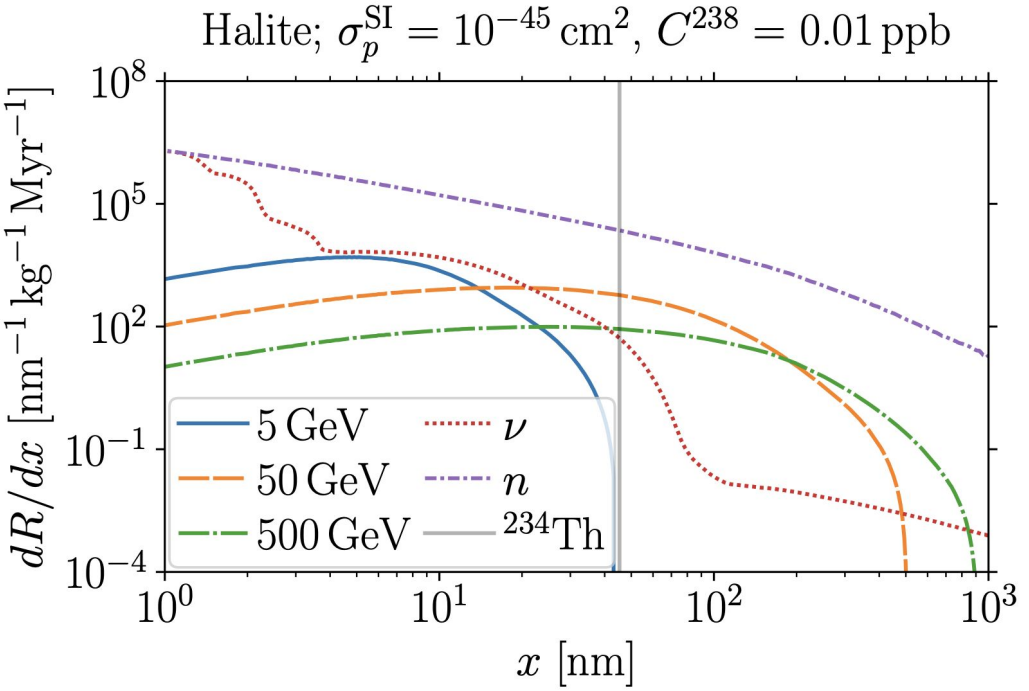

USE PALEO-DETECTORS TO STUDY COSMIC RAYS

to take advantage of the large exposure of this technique

to obtain information on the cosmic ray flux in the past

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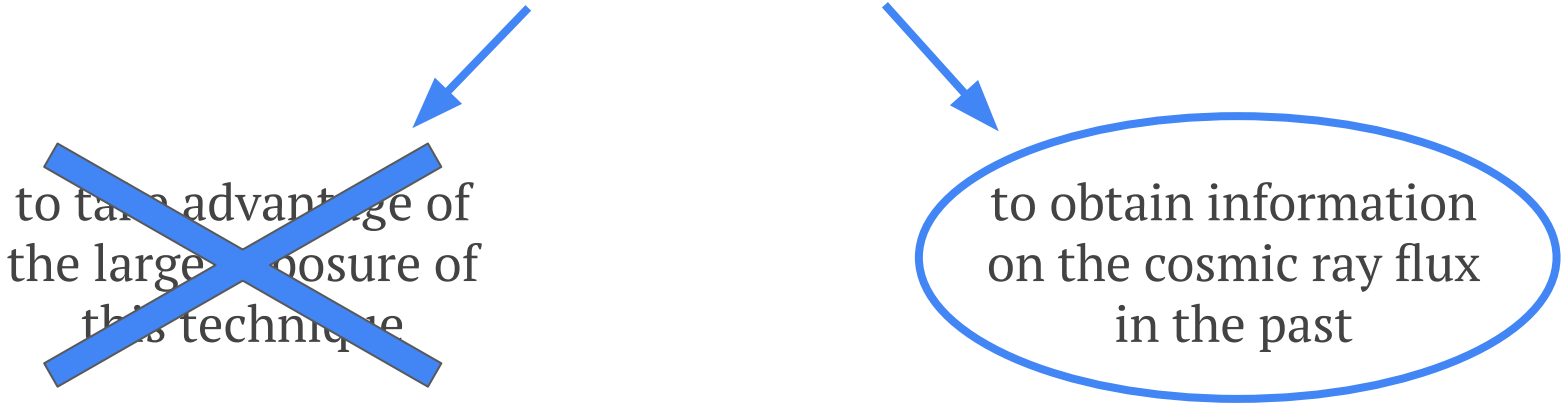
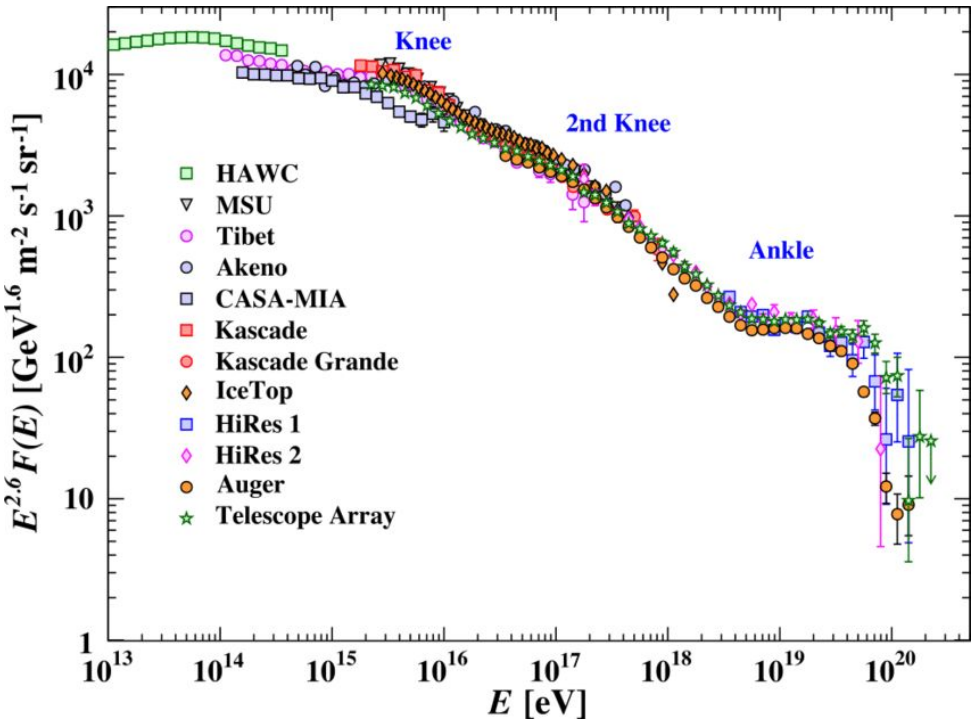


Not useful!
We can observe cosmic rays easily with large detectors

Very useful!
This can be one of the few techniques to obtain this kind of information

Cosmic rays

- Cosmic rays spectrum ranges from few to O(100) EeV (1 EeV = 10^{18} ev)
- When cosmic rays enter the atmosphere they interact and generate **shower of secondary particles.**
- As primary cosmic rays are deflected by galactic and extra-galactic magnetic fields the **arrival directions do not point to the sources**.
- In TeV-PeV cosmic rays are associated with **SNR**, at higher energies they may be accelerated by **compact objects**.
- Above few EeV the origin is mainly **extra-galactic**

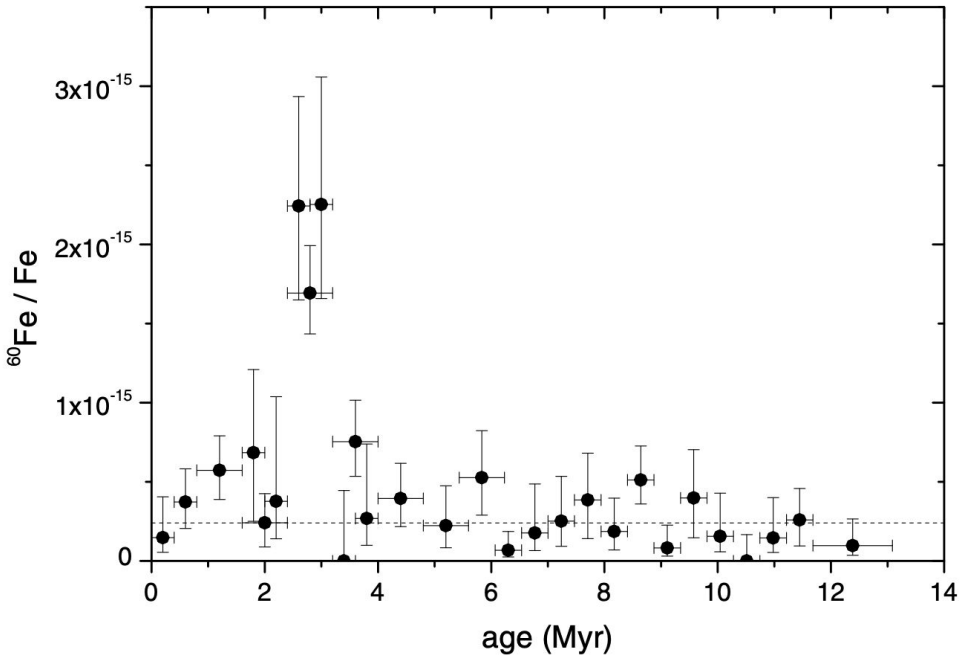


Cosmic rays in the past

What do we know?

- Knowledge of past flux of cosmic rays limited to **radionuclides**.
- Excess on the amount of ^{60}Fe identified as trace of close (O(10) pc) recent (few Myr) supernova

K. Knie, G. Korschinek, T. Faestermann, E. A. Dorfi, G. Rugel and A. Wallner, ^{60}Fe anomaly in a deep-sea manganese crust and implications for a nearby supernova source, Phys. Rev. Lett. 93 (Oct, 2004) 171103.



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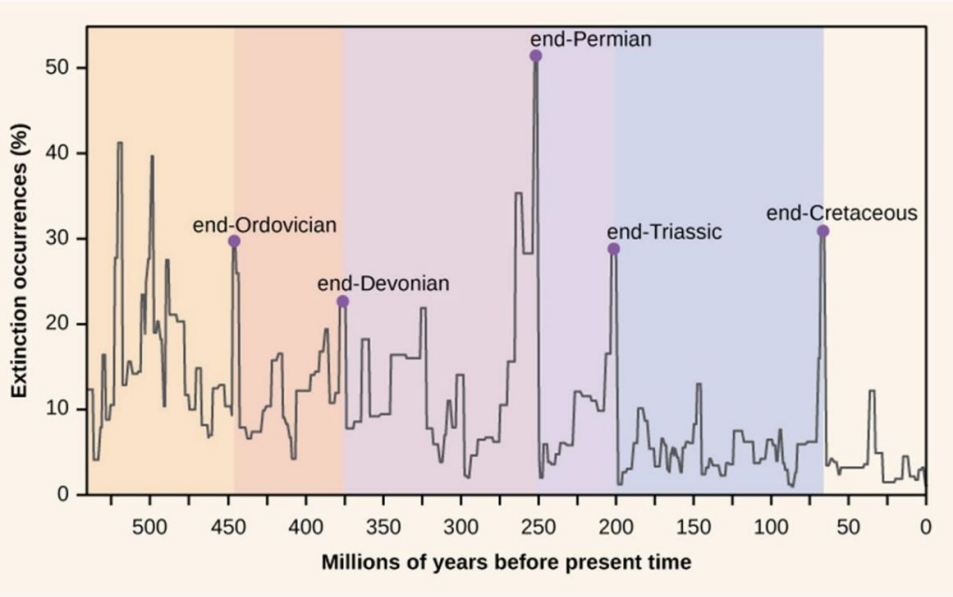
Why?

- Evolution of cosmic rays strongly linked to the e**volution of the Solar System** and the Earth.
- The evolution of the flux of cosmic rays have been suggested as a cause of various **mass extinctions**.



Paleo-detectors for cosmic rays

The cosmic ray flux can be studied through the **secondary particles** present in the **Extensive Air Shower**

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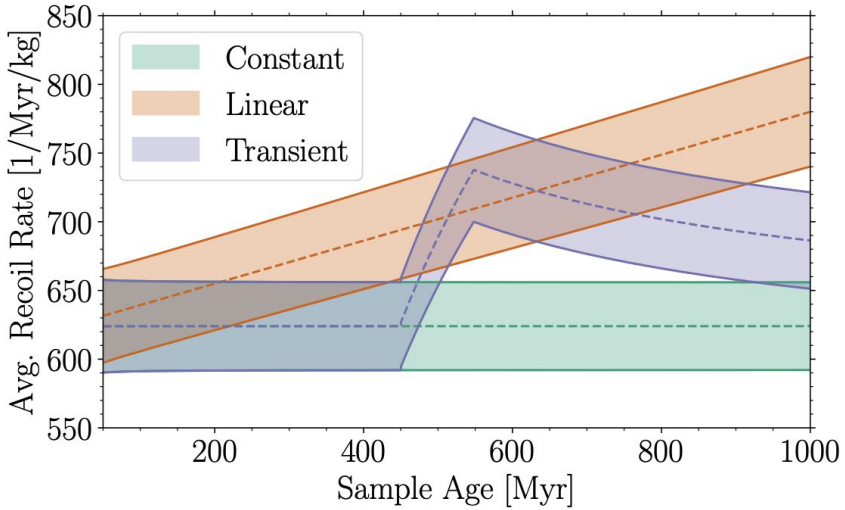
Atmospheric neutrinos

J. R. Jordan, S. Baum, P. Stengel, A. Ferrari, M. C. Morone, P. Sala and J. Spitz, «Measuring Changes in the Atmospheric Neutrino Rate over Gigayear Timescales,» Phys. Rev. Lett., vol. 125, n. 23, p. 231802, 2020



Optimal for long transients!

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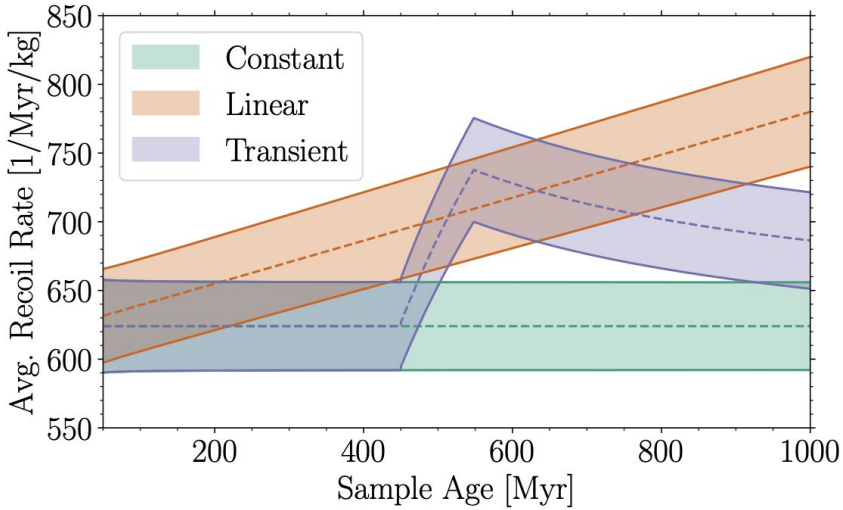
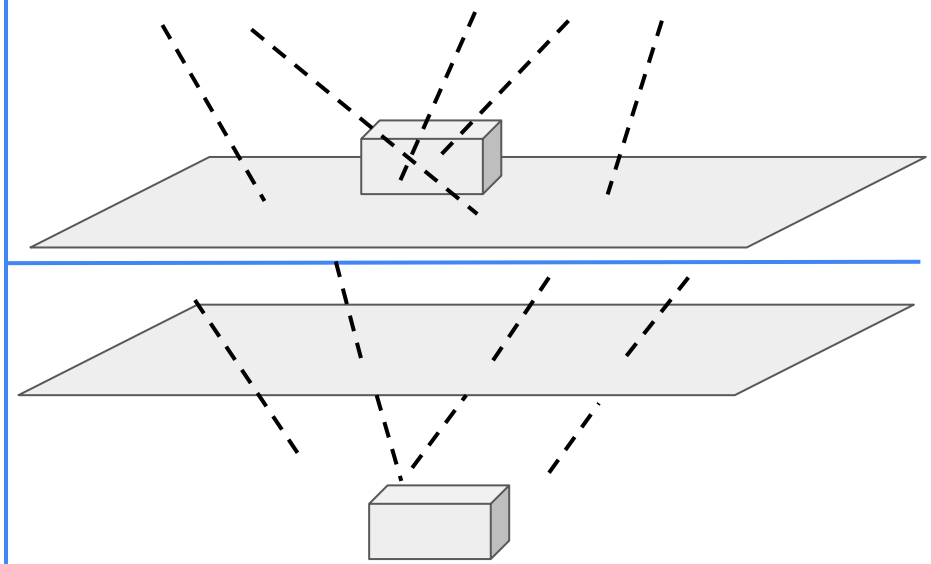


Optimal for long transients!

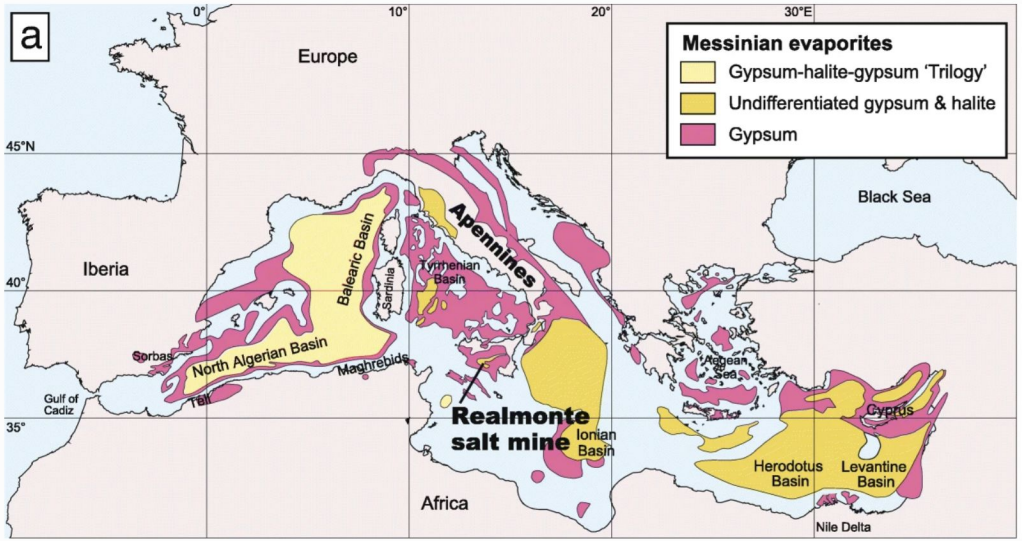
Muons using windows of exposure



Optimal for short transients!

The Messinian Salinity Crisis

- At the end of the Messinian age (~6 Myr ago) the **Strait of Gibraltar closed up**.
- Large part of the **Mediterranean Sea evaporated** in the following tens of kyr.
- A huge amount of **evaporites formed** (~5.6 Myr ago), mostly halite [NaCl] and gypsum [$CaSO_4 2(H_2O)$], and were exposed directly to secondary cosmic rays.
- The Gibraltar strait opened again after ~600 kyr and the evaporites were covered by ~1500 m of water

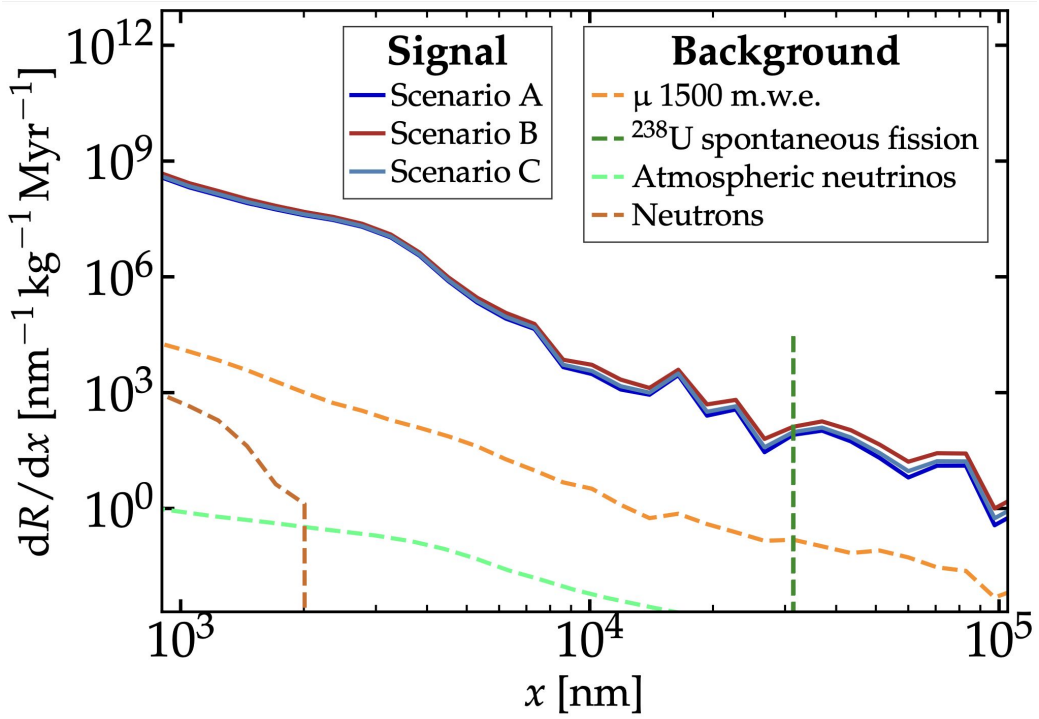


Isaji, Y., Yoshimura, T., Kuroda, J. et al. Biomarker records and mineral compositions of the Messinian halite and K–Mg salts from Sicily. Prog Earth Planet Sci 6, 60 (2019). https://doi.org/10.1186/s40645-019-0306-x

Simulating tracks

Considered a muon flux at sea level and a **halite** [NaCl] sample.
Pass the muon fluxes in a **Geant4** simulation and obtain the nuclear recoil.
Obtain the differential **rate of tracks**.

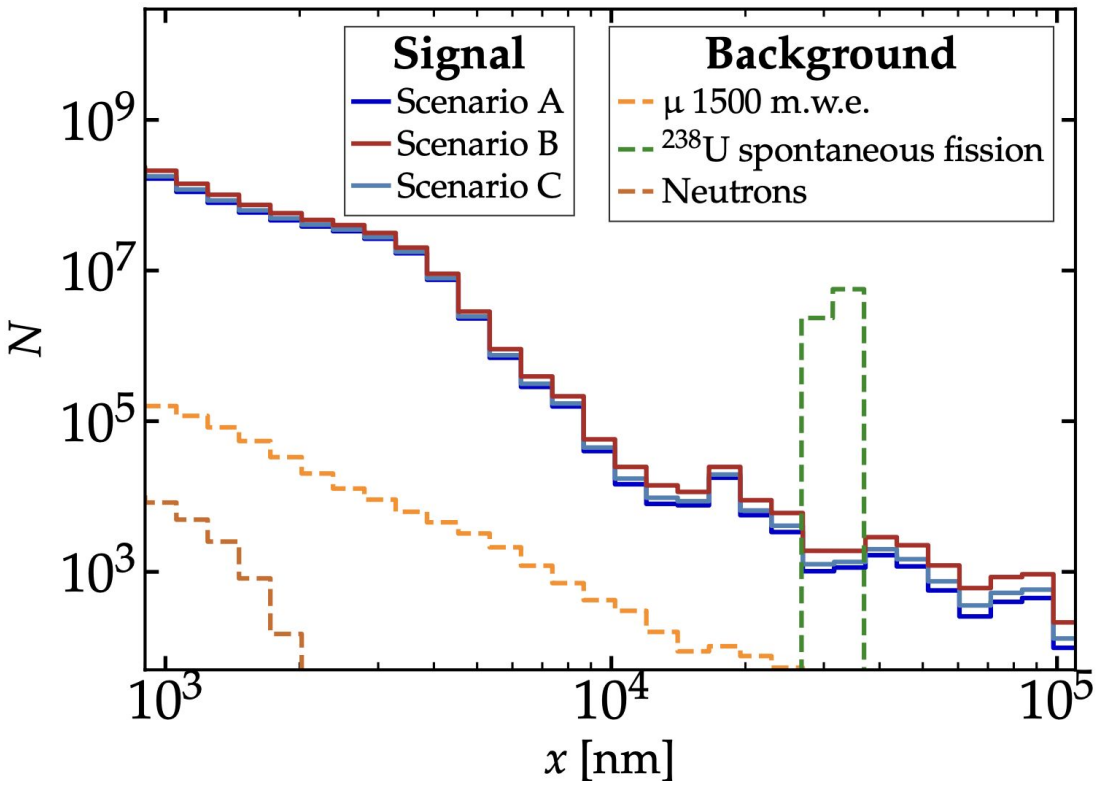
Scenario A: current muon flux
Scenario B: current muon flux + SN exploded at 20 pc
Scenario C: current muon flux + SN exploded at 100 pc



Simulating tracks

Integrate the signal expected over the exposure time.

Exposure time signal = 270 kyr
Exposure time background = 5.6 Myr
mass = 10 g
^{238}U concentration = 5 x 10^{-6} g/g



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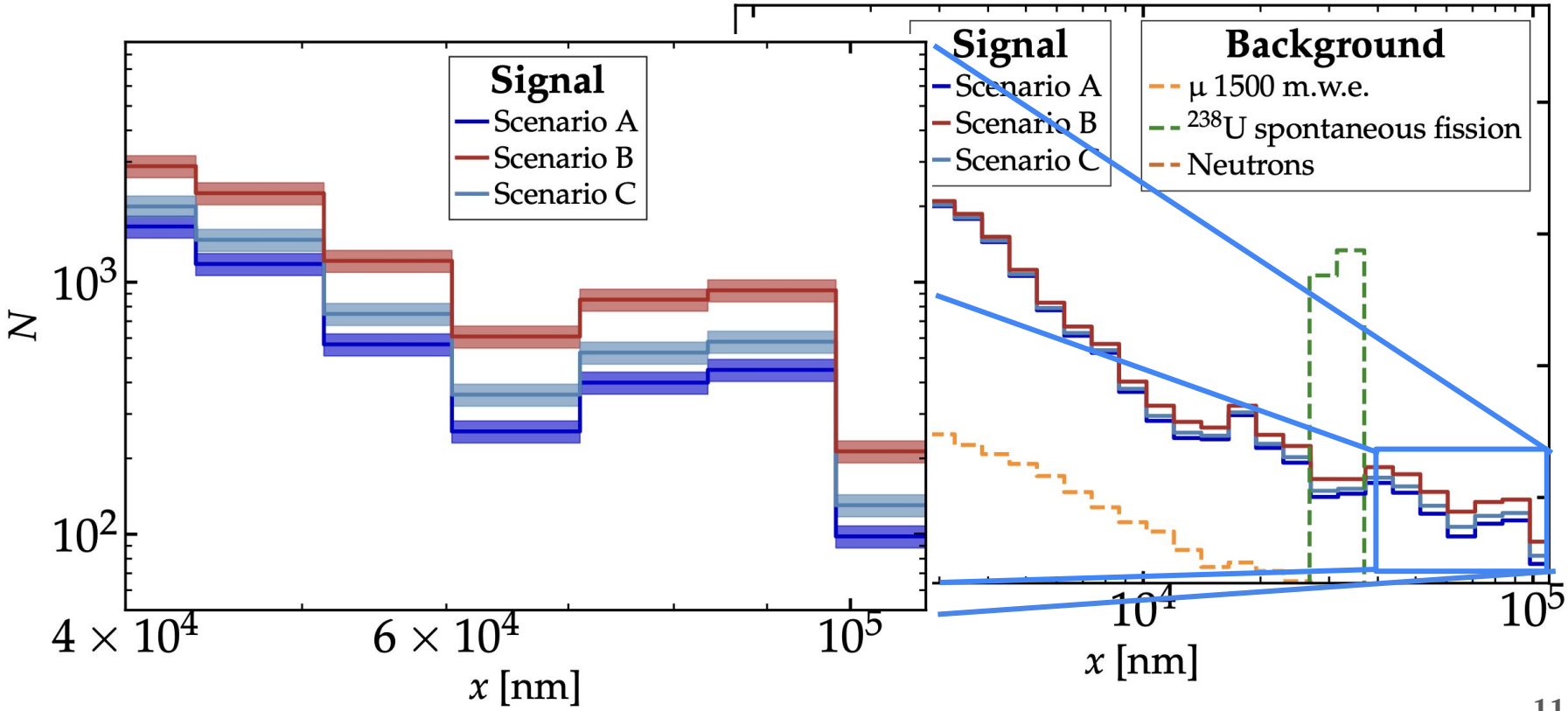

Conclusion

- Paleo-detectors are an interesting technique to study rare events taking advantage of the large exposure of minerals
- We have to select minerals with limited cosmic rays background
- We can use paleo-detectors to obtain information on the **past flux of cosmic rays**, which is related to the history of the neighborhood of our Solar System and our galaxy.
- Knowing the geological history of a mineral and taking advantage of cosmic rays being shieldable we can investigate specific time periods.
- An example is the **Messinian salinity crisis** and the study of halite produced during it contain a snapshot of the cosmic ray flux of that period.