COSMIC RAY SIGNATURES IN PALEO-DETECTORS TO INVESTIGATE THE PAST ACTIVITY OF OUR GALAXY

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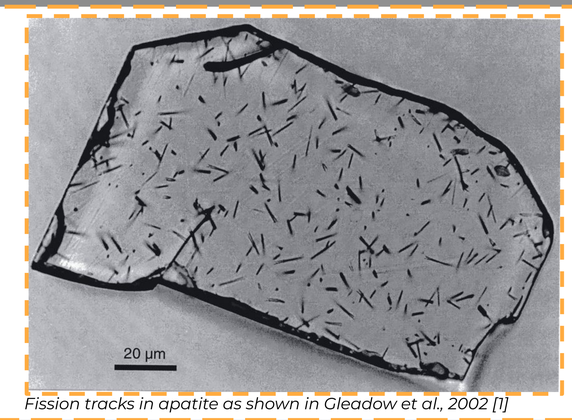
ION TRACKS

Energetic particles passing through a solid can interact elastically with the atoms in the lattice of the material: the recoiling ions leave **PERMANENT TRACKS**. The length and abundance of the tracks vary depending on incident particle energy, flux and species.



Fission tracks in apatite as shown in Gleadow et al., 2002 [1]

READING THE TRACKS

Tracks range from the nm to several μm in length. They can be etched or left in their natural state.

Automated optical microscope | Scanning electron microscope | Helium ion microscope | Xray scattering

WHAT IS A PALEO-DETECTOR?

Astrophysical messengers leave their traces in natural minerals which act as flux integrators from their formation to now

- Muons & secondary hadrons from EAS
- Atmospherical, astrophysical and solar ν
- WIMP Dark Matter

Information about the flux in the past remains frozen in the lattice structure
From this property the name **PALEO-DETECTOR**

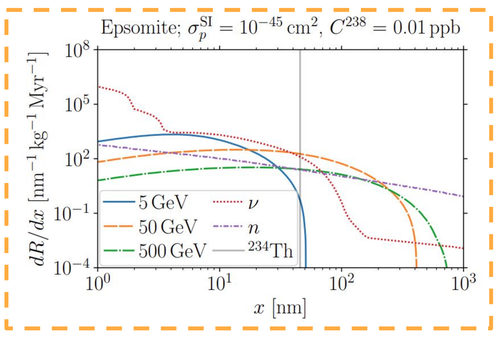
THE BACKGROUNDS

The main background for astrophyisical messengers is natural radioactivity.
-α particles from the decay chain of U and Th -> can be reduced looking for multiple tracks (if imaging is available)
-neutrons from (α, N) reactions and spontaneous fission

Messengers act as background for each other. Muons and hadron tracks are much more prevalent than neutrinos.

CHOOSING THE MINERAL

Main selection criteria are **COMPOSITION** and **GEOLOGICAL HISTORY**
-Composition determines the sensitivity to certain backgrounds
-Geological history is important to to highlight certain messengers/time periods and block others
e.g. To study neutrinos the mineral has to be shielded from cosmic rays that leave much more tracks: samples from the deep crust.



Tracks in Epsomite as shown in Drukier et al., 2020 [2] for the search of WIMPs

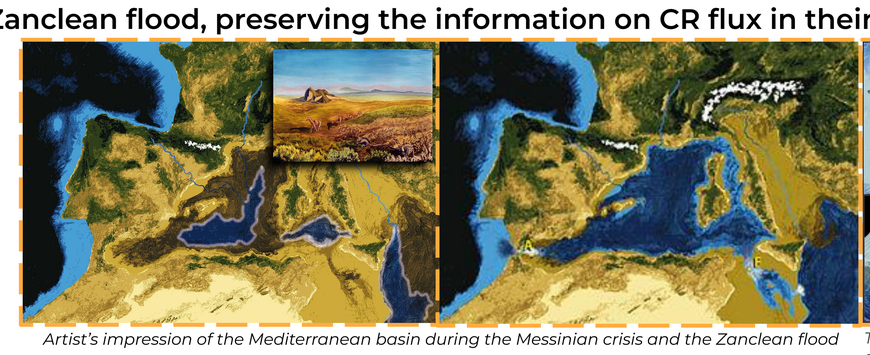
THE FERMI BUBBLES AND THE MESSINIAN SALINITY CRISIS

The Fermi Bubbles seen in gamma and Xrays could be the remnants of a past activity near the Galactic Center: they are estimated to be 6Myr old

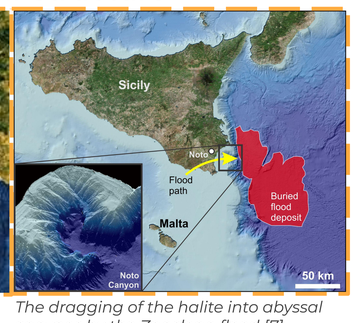
Active Galactic Nuclei are one of the prime candidates to accelerate cosmic rays to ultra-high energies.

Between 5.9 and 5.3 Myr ago the Mediterranean basin drained
The desiccation left crystals known as **EVAPORITES** among which **HALITE,** exposed to the cosmic ray flux

The minerals were then shielded from more interactions 5.3 Myr ago during the Zanclean flood, preserving the information on CR flux in their structure



Artist's impression of the Mediterranean basin during the Messinian crisis and the Zanclean flood

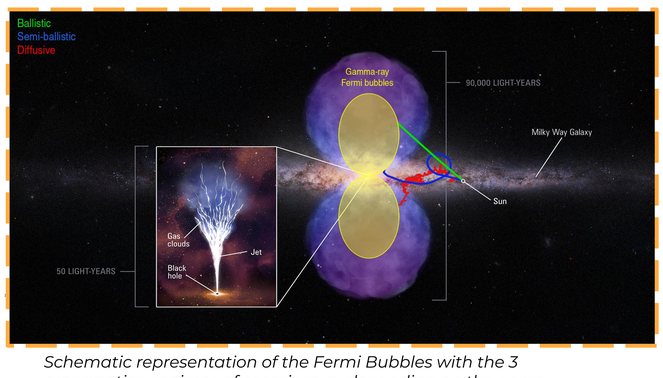


The dragging of the halite into abyssal canyons by the Zanclean flood [7]

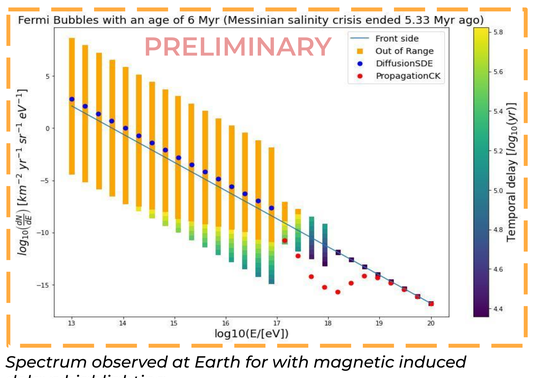
FLUX, PROPAGATION, SHOWER SIMULATIONS

Flux at source is estimated using the most recent results by Auger on the spectrum [3] and the hint of a CenA region excess [4] rescaled to FB-Earth distance

Particles are propagated in the GMF (JF12 [5]) using CRPropa [6] to obtain delays and flux at Earth in the MSC time window



Schematic representation of the Fermi Bubbles with the 3 propagation regimes of cosmic rays, depending on the energy

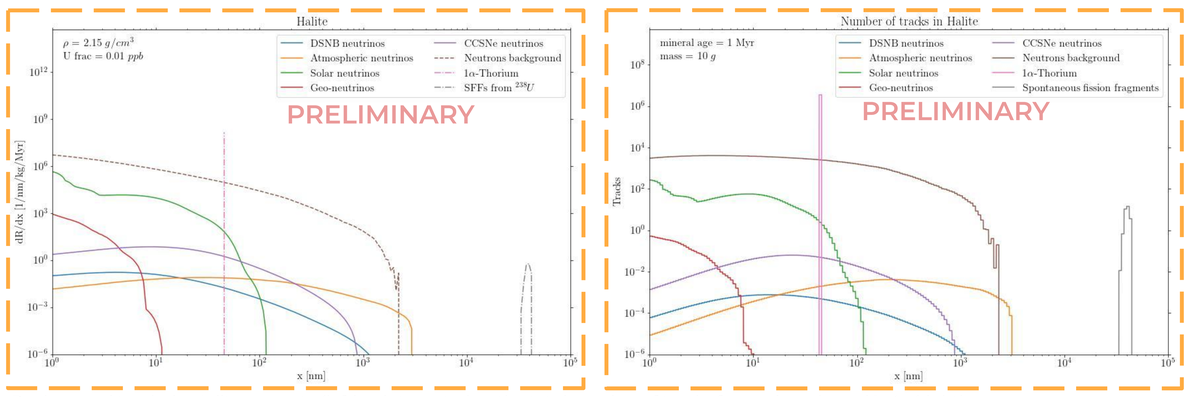


Spectrum observed at Earth for with magnetic induced delays highlighting

Flux of secondaries (muons) is obtained by convolution of primary flux with secondary productions from CORSIKA [8]

SIMULATIONS OF TRACK PRODUCTION

Tracks from signal and background are simulated using a combination of Geant4, SRIM, and the dedicated Python packages WIMPy [9] and paleopy [10]

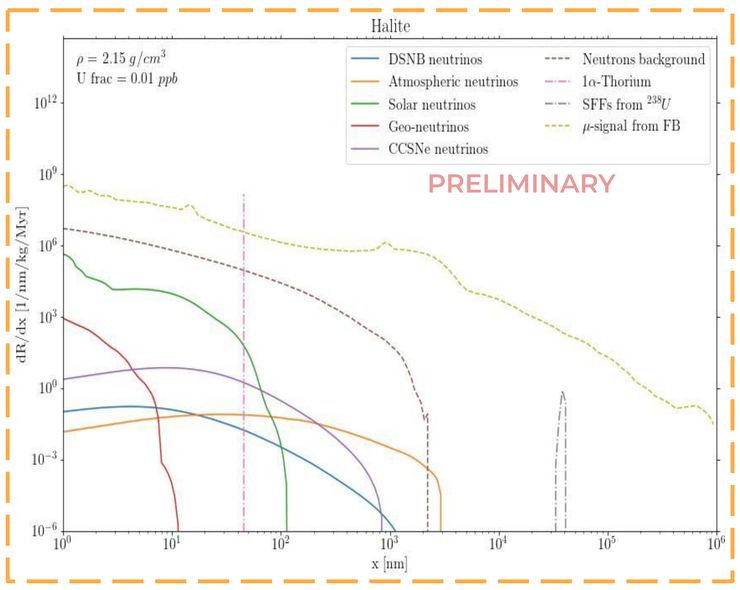


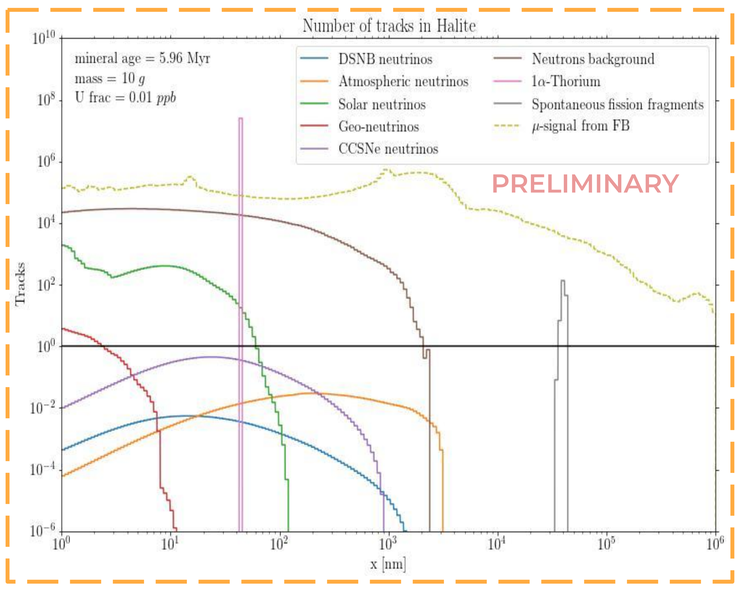
Background tracks in Halite as a rate (left) or integrated as the total number of tracks for a mineral aged 1 Myr(right)

CONCLUSION AND OUTLOOK

The >μm range of track size is promising for the detection of the signal left by the past activity of the Fermi Bubbles

The xray scattering technique could be efficient in scanning large volumes of material and counting tracks of the appropriate size





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[9]https://github.com/bradkav/WIMpy_NREFT

[10]https://github.com/tedwards2412/paleopy