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Do minerals know about supernovae?

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Abstract

Knowing the evolution of our Galaxy is a difficult task, but we can take advantage of what has been captured by the Earth. Some information can be extrapolated by analyzing concentrations of radionuclides in layers of material inside the Crust, but this could give us hints just on the evolution of the Solar System and its neighborhood.
We propose instead the use of **long-aged minerals**, called paleo-detectors, as **solid state track detectors**. Neutrinos and other astroparticles passing through paleo-detectors could generate nuclear recoils that lead to the formation of defects, defined as **tracks**, still visible inside the mineral. By counting the number of tracks and measuring their lengths, we obtain information on the flux of astroparticles that passed through the mineral. With this work, we analyze the discovery potential of paleo-detectors to the neutrinos and cosmic-rays emitted by past Supernovae.

Paleo-detectors

Minerals can be used as **particle detectors**

Astroparticles passing by the mineral can interact with the nuclei → the nucleus are shifted from their original position → the shift produce permanent damages inside the mineral called **tracks**

WHY USE PALEO-DETECTORS?

Have a **large effective exposure:** 100 g of a 10 Myr mineral are equal to 10^5 kg of material exposed for 10 yr

Useful for **dark matte**r studies

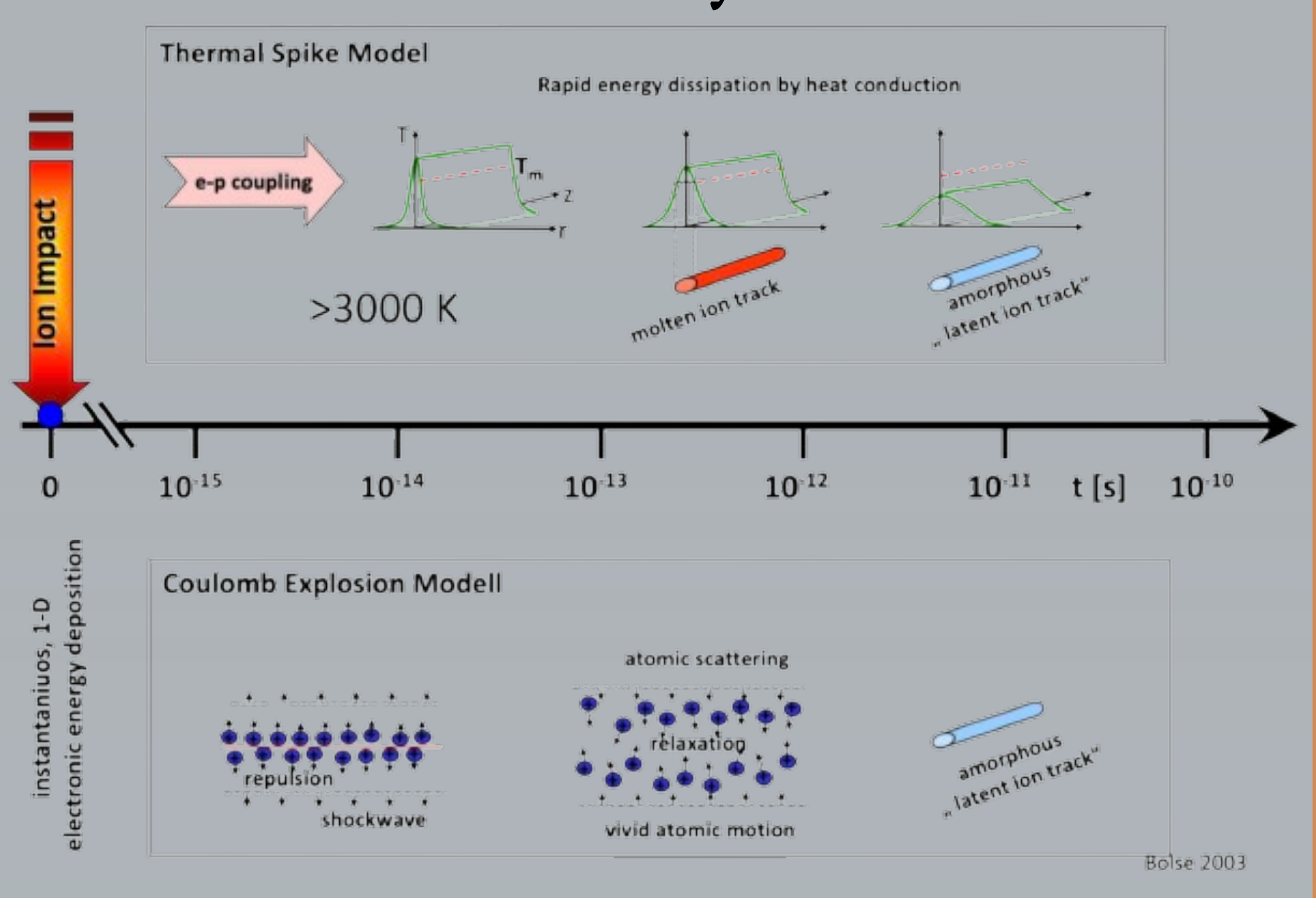
Get information on the **past fluxes of astroparticles** and study the of the neighborhood of the Solar System

Evaluate the evolution of the rate of tracks left by **neutrinos and cosmic rays**

Two possible track formation mechanism unknown

THERMAL SPIKE MODEL

COULOMB EXPLOSION MODEL



Multiple possible readout techniques on nm-scale

- laboratory-based X-ray techniques such as micro- and nano computer tomography
- hard X-ray imaging techniques at synchrotron,
- electron and focused He-ion beam microscopes

SN neutrinos tracks

Tracks in paleo-detectors overwhelmed by muon tracks → **find minerals deep underground where the muon flux is negligible**

Neutrinos can leave tacks recoiling with the nuclei
- **solar neutrinos**
- **atmospheric neutrinos**
- **DSNB neutrinos**
- **SN neutrinos**

other tracks can be left by
- **neutrons** generated in (α,N) reactions
- U nuclei decaying in **Th**

The total number of tracks (N) in a sample is

$$\mathrm{N} = \mathrm{p_{solar}N^t_{solar} + p_{geo}N^t_{geo} + p_U[N^t_{Th} + (1 + p_{neut}N^t_{neut})] + p_{SN}N^{1987A}_{SN}}$$

$\mathrm{N^t_i} =$ number of tracks in the mineral per unit of time and mass produced by i

$\mathrm{N^{1987A}_{SN}} =$ number of tracks in the mineral per unit of time and mass produced by SN1987A

perfect minerals need

large hydrogen content to moderare the neutrons

low U content to limitate the background

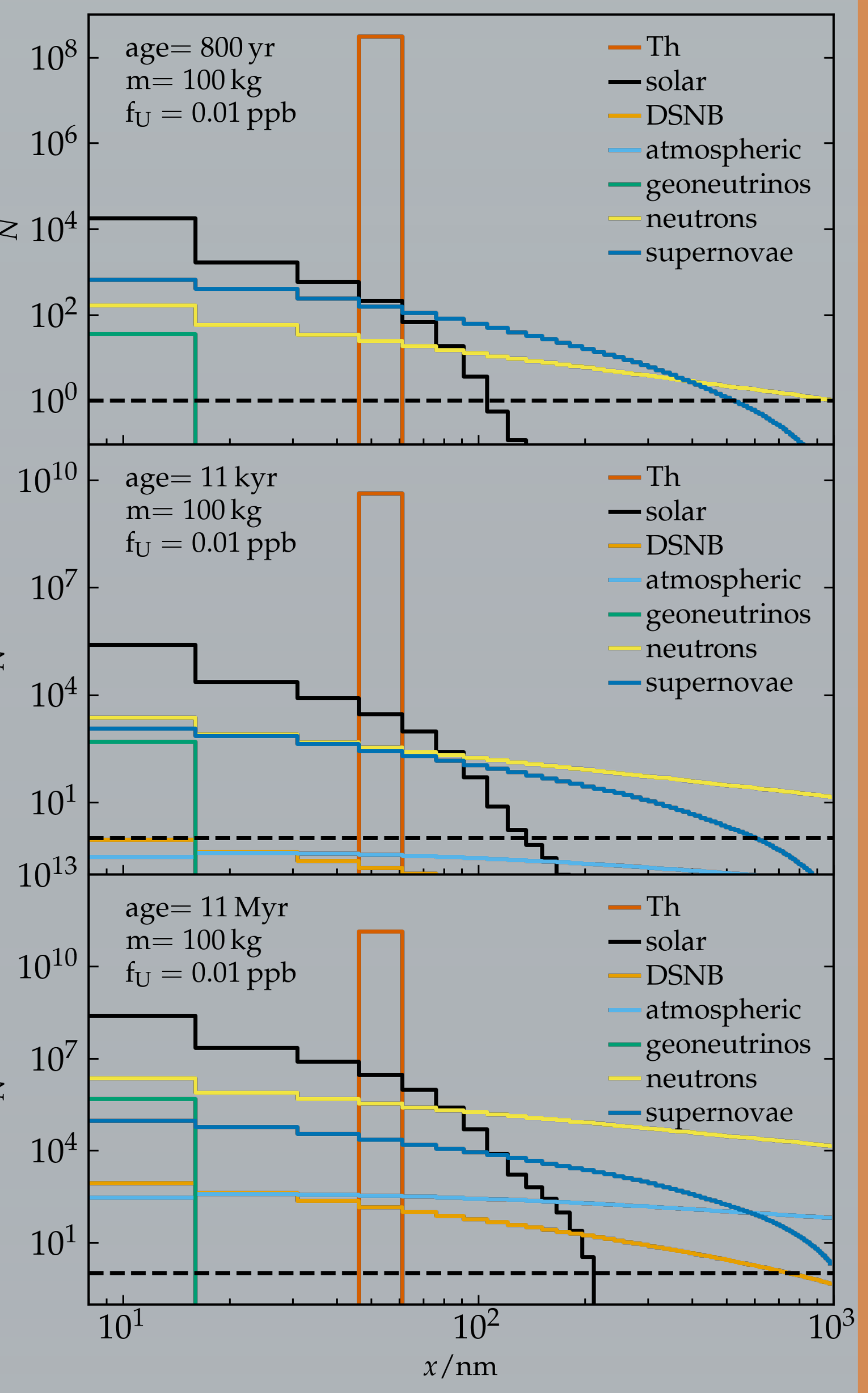
Epsomite ($MgSO_4$ 7(H_2O)) is a perfect candidate

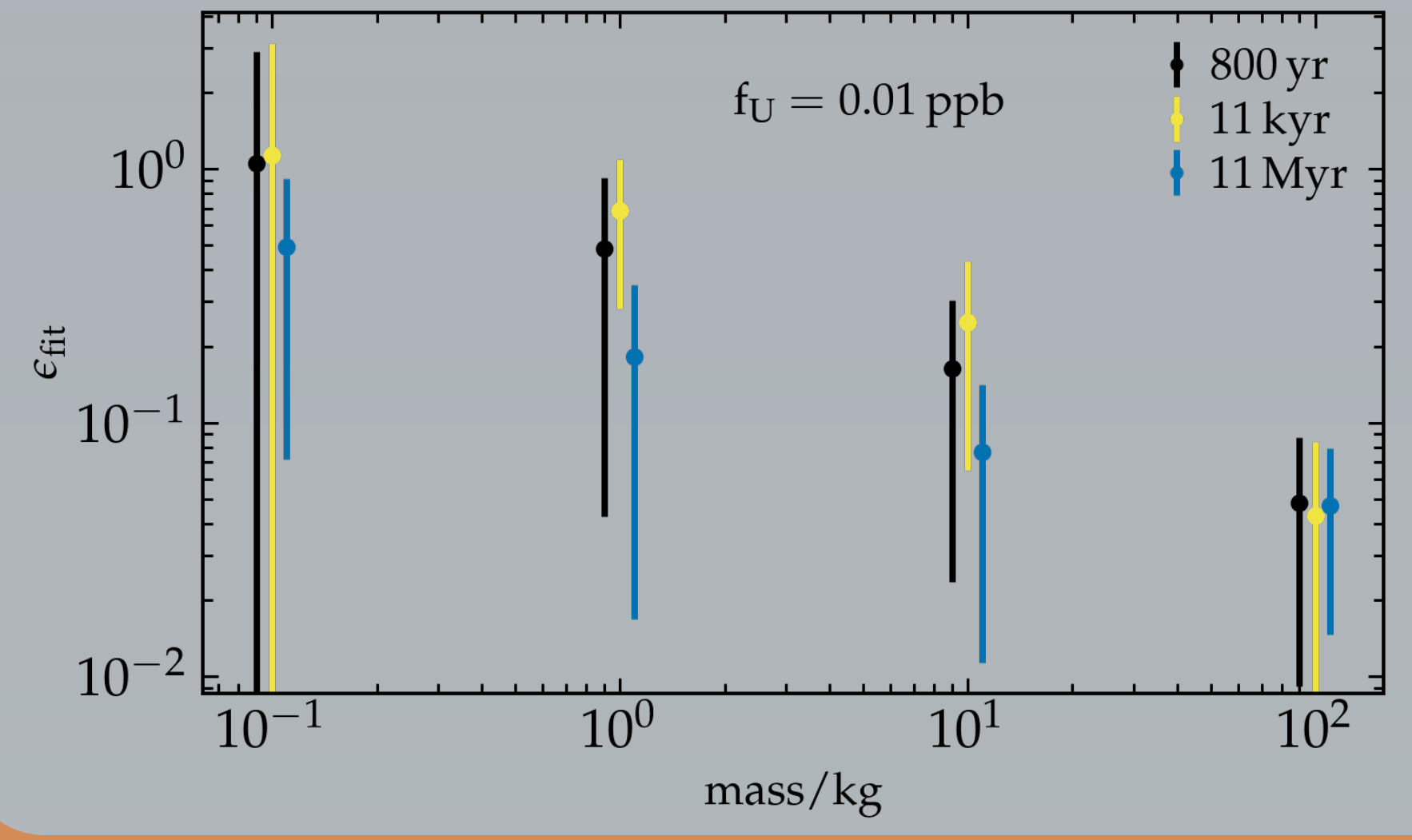
We considered several known SN and simulated the signal expected in Epsomite samples with U fraction (f_U) = 0.01 ppb

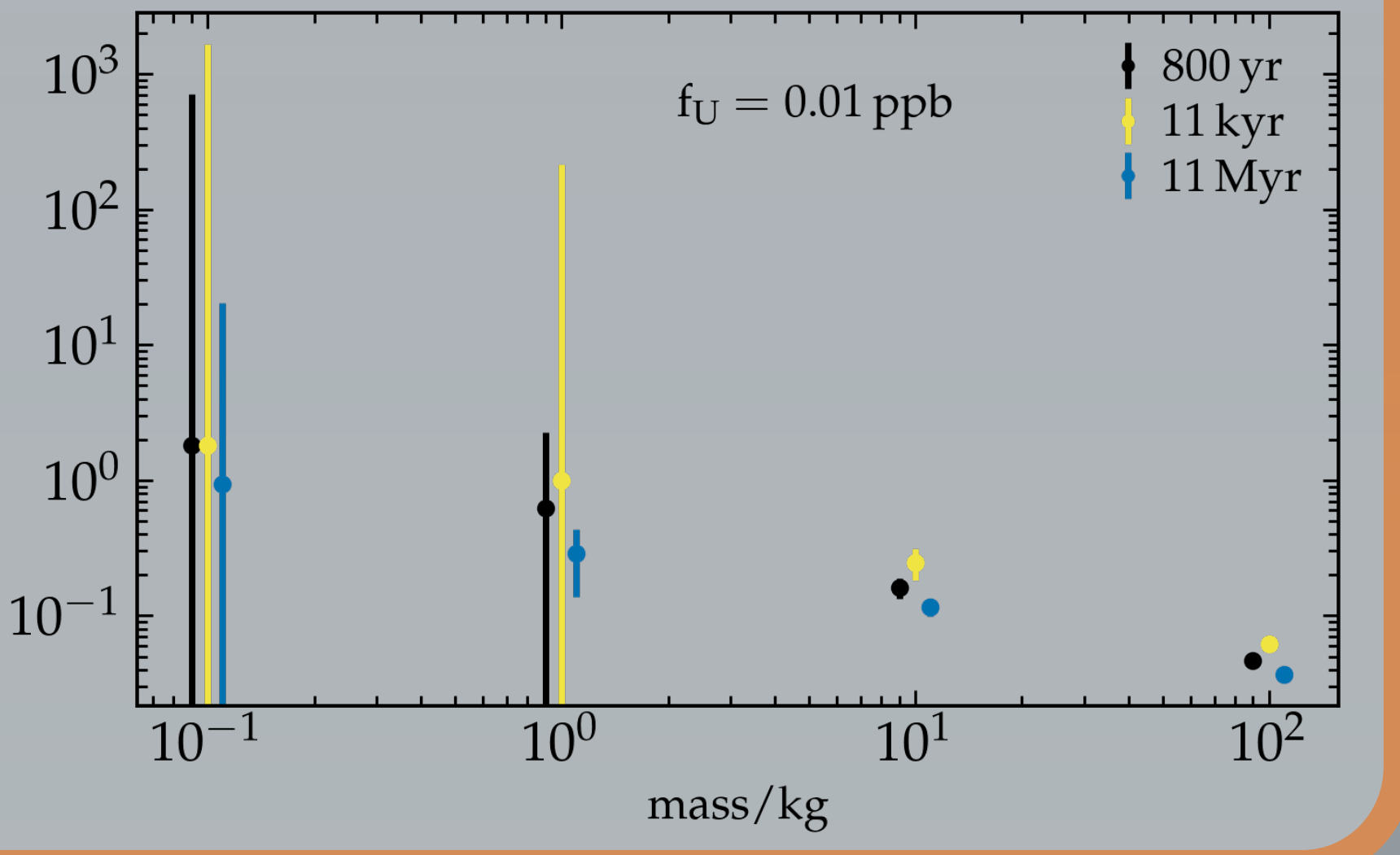
The three most important contributes are:
- **Vela jr** (~800 yr ago)
- **Vela** (~11 kyr ago)
- **multiple nearby SN** known from ^{60}Fe abundance in oceanic crust (~11 Myr ago)

We fitted the total N to reconstruct p_{SN} and evaluated

$$\epsilon_{\rm fit} = \frac{|p_{\rm SN} - p^{\rm MC}_{\rm SN}|}{p^{\rm MC}_{\rm SN}} \quad \Big| \quad \epsilon_{\rm rel} = \frac{\sigma_{p_{\rm SN}}}{p_{\rm SN}}$$







Cosmic-rays tracks

Cosmic-rays are more easibily shieldable respect to neutrinos → minerals can be exposed directly to muons for a limited time period, then shielded → from the expected number of tracks we can evaluate if during the esposure period there was a transient event

The Messinian Salinity Crisis is a potentially interesting time window

6 Myr ago the Strait of Gibraltrar closed and the Mediterranean Sea dessicated → lot of evaporites were formed, mostly Halite (NaCl) and Gypsum ($CaSO_4$ 2(H2O)) → the minerals were exposed directly to muons for around 500 kyr → the strait reopened during the Zanclean flood and the minerals were shielded to muons

To compute the expected number of tracks in a Halite sample formed during the Messinian Salinity Crisis we used GEANT4, SRIM and paleopy.
We defined three different signal scenarios and confronted them with the expected backgrounds.

SIGNAL

Scenario A: the flux of cosmic rays is as the one observed today
Scenario B: the flux of cosmic rays is as the one observed today and a SN exploded 20 pc away from the Earth
Scenario C: the flux of cosmic rays is as the one observed today and a SN exploded 100 pc away from the Earth

BACKGROUND

The background tracks are given by:
- **spontaneous fission of ^{238}U**, which gives tracks with the same length
- **neutrons** generated by (α,N) reactions
- **muons** reaching the minerals even when they are submerged by around 1500 m of water

We show the plot for the signal expected in a 100 g sample of Halite with a $f_U = 5\times10^{-6}$ g/g.
In the zoom we show that the three scenarios are significally separated considering a 10% error on the number of tracks.