Paleo Detectors
For Dark Matter and Neutrino Detection

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Oskar Klein Centre (2107.02812, 2004.08394, 1906.05800, 1811.10549, 1806.05991)
Overview:

1. Paleo-Detector Basics
2. Probing Dark Matter, Neutrinos, and Time-Varying Signals
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Paleo-Detector Basics

Paleo-detectors are minerals from far below the Earths surface (5-10 km).

Instead of phonons, charge, and light, paleo-detectors look for permanent damage track features in the structure of the mineral.

Recoil Rate $\propto$ Target Mass $\times$ Observation Time

- Smaller Targets
- Huge Observation Time
Paino-Detector Basics: Tracks

Damage tracks are caused by recoiling nuclei depositing energy through multiple scatters. The detailed mechanism is unknown.

Annealing timescales are extremely long compared to the age of the mineral.

High track length resolution allows us to probe low energy recoils - We are therefore sensitive to lighter dark matter.
Paleo-Detector Basics: Background neutrinos

$p + p \rightarrow d + e^+ + \nu_e$

Epsomite; $C_{238} = 0.01$ ppb

$\frac{dR}{dx} [\text{nm}^{-1} \text{kg}^{-1} \text{Myr}^{-1}]$

$10^6$

$10^4$

$10^2$

$10^0$

$10^{-2}$

$10^{-4}$

$x [\text{nm}]$

$10^1$

$10^2$

$10^3$
Paleo-Detector Basics: Radioactivity

Epsomite; $C_{238} = 0.01$ ppb

Uranium-238 Concentration $\sim 0.01$ ppb
Paleo-Detector Basics: Cosmic Rays

Depth [km] | 2 | 5 | 7.5 | 10
Neutron Flux [1/cm²/Gpc] | $10^3$ | $10^1$ | $10^{-4}$ | $10^{-8}$
Paleo-Detector Basics: Readout

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[Holler et. al. 14]
Paleo-Detector Basics: Readout

Able to reach < 1nm resolution

To take measurements efficiently, must remove layers and scan repeatedly
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Dark Matter Sensitivity

Using the faster scanning method we can probe WIMP DM well below current experimental limits > 1 GeV.

More precision allows us to probe lighter DM masses.

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[Baum, TE et. al: 2106.06559]
Galactic Supernova Neutrinos

Signal from galactic supernova is much larger than DSNB

Galactic SN spectrum peaks at different energy due to redshift
3-sigma detection if we achieve low enough concentrations of Uranium-238.

Here we assume a constant rate of SNe throughout the history of the galaxy.
Time Varying Signals

![Graph showing the number of recorded tracks over age. The graph includes three categories: MW Halo, Subhalo, and Dark Disk. Each category is represented by different markers and colors: green circles for MW Halo, orange diamonds for Subhalo, and purple squares for Dark Disk. The x-axis represents age in Myr, ranging from 0 to 200, and the y-axis represents the number of recorded tracks per g, ranging from 0 to 600.](attachment:image.png)
Tracking Star Formation

Estimate of the Milky Way SFR from Gaia

Baseline case can rule out constant rate at 2 sigma depending on model

Mor et al. SFR (1901.07564)
Cosmological SFR (1403.0007)

Look-back Time [Gyr]

Uranium-238 Concentration [ppb]

SFR, $\psi(t_*)/\psi(0)$

Discrimination Significance [$\sigma$]

Estimate of the Milky Way SFR from Gaia

Baseline case can rule out constant rate at 2 sigma depending on model

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Cosmological SFR (1403.0007)
Dark Matter Substructure

Dark Disks

SubHalos

halo (dark matter)
spiral disk (visible stars)
subhalos (dark matter)

32 Myr
Conclusions

1. Paleo-Detectors represent a novel detection strategy for rare event searches

2. Paleo-Detectors have the unique ability to see into the past, and probe time varying signals