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A physicist's noise is a geologist's signal: mutual benefits of palaeodetector research for particle physics and geochronology

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The 2017 discovery of coherent elastic neutrino-nucleus scattering (CEνNS) confirmed experimentally for the first time the process that gives rise to palaeo-neutrino damage tracks. By increasing the exposure time of neutrino detectors from human to geological timescales, it is possible to shrink their physical size from thousands of tonnes to mere kilograms. Realising palaeo-detection (the "signal") requires geological background rates from cosmic radiation and natural radioactivity (the "noise") to be both low and precisely quantified. The search for suitable materials and readout techniques offers mutual benefits to particle physicists and geologists:

1) Geological settings with low background levels are attractive for fundamental physics. With nanometre-scale resolution and sufficient exposure, palaeo-detectors can probe unexplored dark-matter phase space. At micron-scale resolution, they may also record integrated signals from higher-energy supernova neutrinos over geological timescales. Reconstructing fossil tracks further provides the only direct archive of Earth's long-term cosmic-ray history.

2) Materials with high background levels are well suited for geochronology. Recoil-track dating could fill the gap between radiocarbon dating (<50 kyr) and conventional radiometric methods (>1 Myr). This interval spans critical phases of human evolution and Quaternary climate change.

A major source of geological background noise arises from cosmic-ray neutrons and muons. Their interaction with near-surface rocks produces spallation products, cosmogenic nuclides, and cosmic-ray tracks (CRTs). For physicists, CRTs represent an unwanted background that must be quantified and minimised. Neutron-induced tracks attenuate rapidly and are suppressed by a few metres of overburden, whereas muons penetrate hundreds of metres, requiring deep underground settings. Accurate characterisation of cosmogenic backgrounds is therefore essential for selecting suitable mineral targets and subtracting residual tracks.

For geologists, cosmogenic nuclides are powerful tracers of Earth surface processes. If the production rate of a nuclide such as ^{21}Ne is known and its concentration measured, exposure ages and erosion rates can be determined over millennial timescales. Extending this principle to CRTs would enable a new form of exposure dating. Owing to minimal sample-size requirements, CRT dating could be applied to individual sediment grains, allowing probability distributions of exposure ages to be used to reconstruct spatial and temporal variations in erosion.

A second important background source is α-recoil tracks (ARTs) produced by the decay of ^{238}U, ^{235}U, and ^{232}Th. Recoil of daughter nuclei damages the crystal lattice, generating tracks initially ~100 nm in size. Partial annealing at elevated temperatures may reduce track sizes, potentially causing overlap between ART and neutrino-track size distributions.

Minimising confusion between ARTs and neutrino tracks requires that ARTs are both minimised and well characterised. Mica minerals are ideal for this purpose due to their strongly anisotropic sheet structure, which enables efficient nuclear track detection by acid etching. Micas are routinely used in geochronology as detectors for induced fission of ^{235}U. The most important members are muscovite ("white mica") and biotite ("dark mica"). Muscovite typically contains ppt—ppb levels of U and Th, making it well suited for neutrino detection. Biotite, relatively enriched in U and Th, is unsuitable for palaeo-detection but ideal for ART-based geochronology.

Despite being proposed nearly 60 years ago, ART dating remains underdeveloped due to difficulties in determining track *densities* and U—Th *concentrations* using acid-etching methods, particularly in compositionally zoned minerals. Emerging palaeo-particle readout techniques offer a solution by enabling (1) direct counting of total recoil tracks *numbers* using 3D imaging, and (2) precise determination of parent-nuclide *amounts* by isotope dilution mass spectrometry. This new approach can be validated using geochronological reference materials of known age. Following validation, the method will be ready for broad application in geology and archaeology, while also providing training data for machine-learning algorithms to distinguish ARTs from other forms of crystal damage.

By joining forces, physicists and geochronologists can significantly reduce the risk-to-reward ratio of their research efforts.

Do you plan to give the talk in person?

Yes

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