Snowmass2021-Letter of Interest
Ocean Bottom Detector

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ABSTRACT

Anti-neutrinos emitted from radioactive isotopes inside the Earth, geoneutrinos, bring unique and direct information on the Earth's composition and yield insights into its heat balance and thermal evolution. KamLAND and Borexino experiments show that geoneutrino measurements can be translated into useful geoscientific insights, although their latest results are in tension, leaving a question of the mantle's contribution to the global signal. Distinguishing the mantle flux by current detectors, which are all located on the continents, is challenging, since the crustal signal is about 70 % of the total flux. Given the oceanic crust is thin, simple, and has low Th and U abundances, remotely placing a geoneutrino detector on the seafloor provides the ideal location for identifying those geoneutrinos originating from Earth's mantle. Since 2019, a Japanese collaboration, involving physics, geoscience and ocean engineering, has been developing a 20 kg prototype liquid scintillator detector. This detector will undergo operation deployment tests at 1 km depth, on the seafloor, starting in 2022. Since geoneutrinos constitute am irremovable background below 3.27 MeV for reactor neutrino measurements, geoneutrinos studies contribute to precise reactor spectrum observations.

Introduction

Great progress over the last several decades have been made in our understanding of the fundamental properties of neutrinos. Although the elusive neutrino is a challenge to detect, the particle can now be used as a tool to understand astronomical objects, such as the Earth. Detecting geoneutrinos, electron anti-neutrinos emitted by heat-producing, radioactive isotopes inside the Earth, are now transforming our concepts of the power driving the Earth's engine. Geoneutrinos from ^{238}U and ^{232}Th decay chains are being measured with liquid scintillator (LS) detectors via inverse-β reaction ($\bar{\nu}_e + p \rightarrow e^+ + n$). Unfortunately, a new technique is needed to detect ^{40}K geoneutrinos, because its energy is below the reaction threshold, 1.8 MeV. The number of detected geoneutrinos can be translated into the abundances of U and Th in the Earth using geoscientific knowledge.

The Earth interior remains a mystery. It's surface heat flux is 47±2 TW[1], based on multi-point measurements and geological modeling. However, for two centuries debate continues regarding the Earth's relative contributions of primordial versus radiogenic power, with current estimates predicting 10-30 TW of radiogenic heat. Despite negligible quantities of U and Th in the core and detailed geological models of the Earth's crustal structure and composition, questions remain regarding the power driving plate tectonics, mantle convection and volcanism. Despite significant advances by geological studies, geoneutrino measurements represent the exclusive method to measure "directly" the amount of radioactive power in the Earth.

The KamLAND experiment has been stably observing geoneutrinos, with highest sensitivity, since it made the world's first observation in 2005[2]. To date, limits on the global flux of geoneutrino have been set, which constrains the range of acceptable compositional models. At KamLAND, as well as all land-based detectors, the mantle's flux of geoneutrino is ∼30 % of the signal because of the 1000 times greater crustal abundances of Th & U and the detector's $1/r^2$ sensitivity. The thin 7 km oceanic crust (cf., Cont. crust 35 km thick), and order of magnitude lower Th & U content, make a detector sited in the middle of the ocean ideally sensitive to identifying geoneutrinos originating from the Earth's mantle. As shown in Figure 1, an Ocean Bottom Detector (OBD) has a much higher mantle contribution as compared with land-based detectors. OBD represents a breakthrough, which goes beyond the modern land-based detector, providing transformative insights into the deep Earth.

OBD: Ocean Bottom Detector

Fifteen years ago the "Hanohano" experiment[3] recommended placing an anti-neutrino detector in the deep ocean. The group at University of Hawaii, together with Makai Ocean Engineering[4], reported on technological developments and a detailed detector design. The idea had became common and was expected to be achieved, however, funding for the project was not realized.

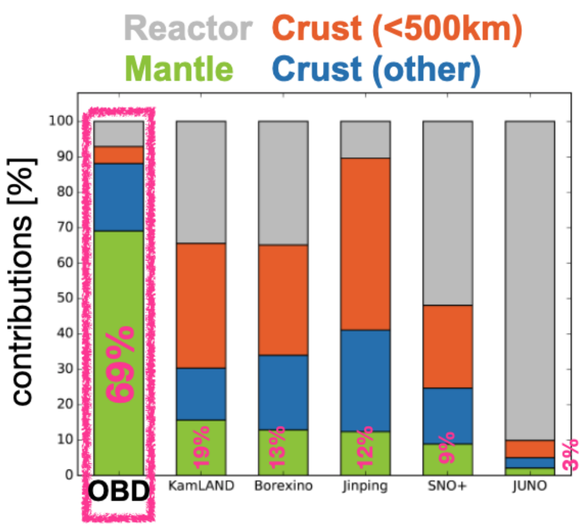

Figure 1. Contributions to total expected anti-neutrino flux. The figure was modified by Šrámek, O[6].

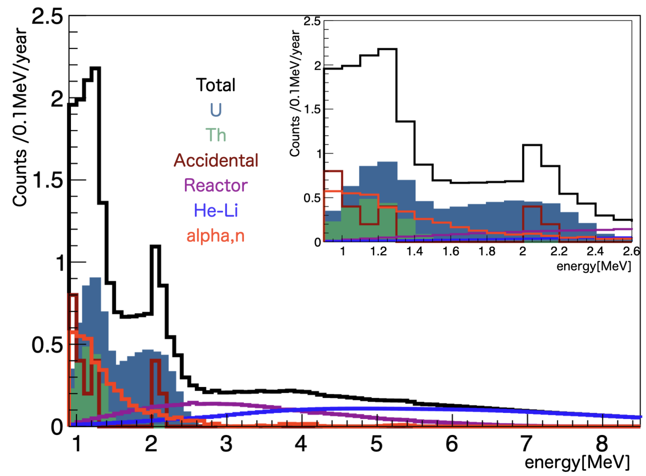

Figure 2. Expected energy spectrum of 1.5 kt OBD estimated by Geant4 simulation. Right top panel focuses on geoneutrino energy range. 70 cm fiducial volume cut was applied to reduce backgrounds from detector contamination.

Today in Japan an ongoing collaboration between Tohoku University (KamLAND team) and JAMSTEC (Japan Agency for Marine-Earth Science and Technology) has reinvigorated this idea with OBD (Ocean Bottom Detector). Kick-off workshop held in July 2019 put forth their strategy and a JSPS grant has supported:

- ~20 kg detector: Technical test and world's first measurement in the ocean with a liquid scintillator detector.
  - The detector will be installed at the Hatsushima Observatory[5] located in the ocean at 1 km depth in 2022.
  - Technical developments are in progress: Low-impurity PMT shield, LS optimization for seafloor environment, DAQ system & power supply, procedure design for deployment, recovery, maintenance and redeployment
- One ~10 t detector: Technical demonstration and environment measurement in the seafloor
- A ~1.5 kt detector deployed: First clear mantle signal [Detector simulation study results (Figure 2)]
  - Backgrounds estimated assuming radioactive contamination in the detector components.
  - Number of events in geoneutrino energy region (1 year):
    Background: 8.1 events, Geoneutrino: 9.2 events (mantle geoneutrino: 6.9 events)
  - Expected sensitivity for mantle geoneutrino: 1.7 σ (1 year), 2.5 σ (2 years)
- A 10 to 50 kt detector: Maturity of science

Conclusion

OBD project broadens our perspective and works across the disciplinary boundaries of particle physics, applied anti-neutrino science, geoscience, and ocean engineering. The kt scale detector will be a breakthrough in the interdisciplinary community.

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