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Revealing mantle heterogeneities with future directional geoneutrino detection

According to geophysical studies, the Earth's interior is highly heterogeneous, containing large-scale structures. One of the most prominent features is the Large Low Shear Velocity Province (LLSVP), imaged by seismic tomography as regions with anomalously slow S-wave velocities relative to the surrounding mantle. Two major LLSVPs have been identified: one beneath the Pacific Ocean and the other beneath Africa. Several hypotheses have been proposed to explain the origin of such mantle heterogeneities. For example, LLSVPs may result from anomalous chemical compositions enriched in U, Th, and other elements, while an alternative hypothesis suggests that they are formed by the accumulation of downwelling mantle heat.

Geoneutrino detection provides a promising approach to probe this problem. Geoneutrinos, generated by the beta decay of radioisotopes inside the Earth, can traverse the planet with little interaction and be detected at the surface. However, previous measurements lack angular resolution, preventing the identification of their source regions. Recent advances, such as gadolinium-doped liquid scintillators that enhance neutron tagging, and segmented detector designs that improve event reconstruction, may enable geoneutrino observations with angular resolution.

In this study, we present a hypothetical exploration of the potential of future geoneutrino detectors equipped with angular resolution. Specifically, we evaluate how precise the angular resolution would need to be in order to identify mantle heterogeneities and to constrain the distribution of heat-producing elements within LLSVPs. Our results suggest that the optimal location for such a detector is near Hawaii, directly above the central Pacific LLSVP, highlighting the strong potential of ongoing projects such as the Ocean Bottom Detector (OBD) to eventually achieve this goal.

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