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PhD Project Description

Journey to the Core-Mantle Boundary Region: Uncovering Earth's Hidden Structures through Seismology

Supervisors

Lead Supervisor: Asst. Prof. Doyeon Kim

Co-supervisor(s): TBD based on the specific focus of each PhD project

Research Group

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Project Summary

The Earth's lower mantle hosts a fascinating variety of enigmatic structures that remain among the least understood features of our planet's interior. At the largest scale, two continent-sized anomalies—known as Large Low-Velocity Provinces (LLVPs)—stand out consistently across global tomographic models. At smaller scales, ultralow-velocity zones (ULVZs) and mega-ULVZs mark regions of extreme seismic heterogeneity along the core–mantle boundary (CMB). These features, though often beyond the resolution of global tomography, can be probed through advanced waveform analyses that capture subtle signatures of scattering and multipathing.

Despite decades of study, the origin, composition, and dynamics of these deep-mantle structures remain open questions. Geochemical evidence hints that they may preserve primordial reservoirs of early Earth material, linking them to core–mantle interactions, plume generation, and possibly the long-term evolution of the mantle. Geodynamic models now offer testable predictions of their morphology and stability but discriminating between competing scenarios—whether LLVPs are vast, cohesive piles or networks of thermochemical upwellings—requires tighter seismological constraints and innovative analyses.

Two critical frontiers persist in current research: <LLVP margins and tops> While tomography captures overall LLVP geometry, it cannot resolve margin sharpness, boundary topography, or detailed wave-speed contrasts—key diagnostics for their physical state and stability. These features manifest in waveform broadening, delays, and scattering, which remain largely unmapped. <ULVZ morphology and distribution> Although targeted waveform studies have identified ULVZs locally, their broader geometry, physical properties, and relationships to surrounding structures are poorly constrained, partly due to model trade-offs and the computational cost of 3-D analyses.

Research Context and Objectives

Please contact Asst. Prof. Doyeon Kim (doyeon.kim@imperial.ac.uk) for details on specific objectives of each PhD project. Projects within this theme may include, but are not limited to, the following: (i) Data-driven discovery – Mine global seismic waveform archives to uncover previously unrecognized, "exotic" seismic phases associated with ULVZs and LLVPs, expanding our observational understanding of deep mantle heterogeneity; (ii) Numerical exploration – Perform systematic 3-D wavefield simulations informed by geodynamic models to predict the seismic signatures and waveform features of realistic deep-mantle structures;

(iiii) Seismic imaging and inversion – Apply adjoint methods and compute 3-D sensitivity kernels to invert for velocity perturbations, reconstructing the detailed 3-D morphology of ULVZs and LLVPs with unprecedented resolution.

Collaborators and partners on the project:

Collaborations and partnerships will be determined flexibly for each PhD project, depending on the specific research focus and objectives.

Further reading:

For applicants interested in learning more about the scientific background and recent developments related to this research theme, the following publications provide valuable insight:

Lekic, V., et al. (2012). Cluster analysis of global lower mantle tomography: A new class of structure and implications for chemical heterogeneity. *Earth and Planetary Science Letters*, 357, 68-77. https://doi.org/10.1016/j.epsl.2012.09.014

Li,et al. (2017). Compositionally-distinct ultra-low velocity zones on Earth's core-mantle boundary. *Nature Communications*, 8(1), 177. https://doi.org/10.1038/s41467-017-00219-x

Mundl, A., et al. (2017). Tungsten-182 heterogeneity in modern ocean island basalts. Science, 356(6333), 66-69. http://doi.org/10.1126/science.aal4179

Kim, et al. (2020). Sequencing seismograms: A panoptic view of scattering in the core-mantle boundary region. *Science*, 368(6496), 1223-1228. http://doi.org/10.1126/science.aba8972

Dannberg, et al. (2021). The morphology, evolution and seismic visibility of partial melt at the core–mantle boundary: Implications for ULVZs. *Geophysical Journal International*, 227(2), 1028-1059. https://doi.org/10.1093/gji/ggab242

Wolf, et al. (2025). Detection of lowermost mantle heterogeneity using seismic migration of diffracted S-waves. *Journal of Geophysical Research: Solid Earth*, 130(6), e2025JB031367. https://doi.org/10.1029/2025JB031367

Forthcoming article from our group:

Kim, et al. (2025). Seismic and Mineralogical Evidence for an Iron-Rich Mega-ULVZ Beneath Hawaii. *Science Advances*, in revision

Who are we looking for?

We are looking for motivated hard hard-working students with a strong background in earth and planetary sciences, seismology, physics, mathematics, or engineering, and a curiosity to explore how planets work from the inside out. A willingness to learn computational methods as needed. A willingness to learn and apply computational and numerical methods is essential.

Through these projects, candidates will develop advanced numerical modeling and data analysis skills, gain hands-on experience with cutting-edge planetary science tools, and build expertise at the intersection of geophysics and space exploration.

Candidates will be encouraged and supported to present their work at international conferences and publish in high-impact journals, fostering both scientific and professional growth. The projects also offer opportunities for collaboration with other research groups within and beyond ESE, creating a dynamic, interdisciplinary research environment.