Imaging and probing the Inner Earth
with the new generation of atmospheric neutrino detectors

Contacts:

Véronique Van Elewyck (APC) – elewyck@apc.in2p3.fr
Nobuaki Fuji (IPGP) – nobuaki@ipgp.fr

Several large-scale neutrino detectors, based either on the Liquid Argon technology (DUNE) or the water-Cherenkov approach (KM3NeT, HyperKamiokande, IceCube Upgrade,...) are currently under construction and on the verge of providing unprecedented statistics and sensitivity for neutrinos created in the interactions of cosmic rays with the Earth's atmosphere. Because of their weak interactions, most such atmospheric neutrinos can traverse large amounts of matter, and even the entire Earth, thereby offering an alternative way of probing its structure and composition.

Much has been learned about the deep Earth through a combination of geophysical constraints, theories of Earth's formation, and seismic measurements. However, such methods alone cannot directly resolve the full structure of the inner Earth, in terms of matter density, composition and temperature distributions. Open questions in this realm concern e.g. the presence and abundance of light elements (such as Hydrogen) in the core and lower mantle, and the nature and composition of two large-scale heterogeneities revealed by 3D seismology and known as large low-shear-velocity provinces (or LLVPs), that are located at the base of the mantle beneath the Pacific and Africa.

Atmospheric neutrinos are particularly appealing for Earth tomography studies as they span a wide range of energies and path lengths across the Earth. Two different methodological approaches can be explored, both based on the study of the energy and angular distributions of neutrinos that reach the detectors after traversing the Earth: oscillation and absorption tomography.

This PhD project aims at evaluating and developing the potential of current and upcoming atmospheric neutrino detectors for neutrino tomography, as an alternative method to constrain the Earth composition and matter content. Detailed sensitivity studies for different neutrino detectors will be conducted using (and refining) the EarthProbe software suite developed by the APC group for tomography studies [1]. Desirable improvements include the possibility to use fully tridimensional Earth density profiles (of prime importance to study localized heterogeneities such as the LLVPs) and to combine data from multiple detectors at different locations on the Earth. Such a study will increase the physics reach of neutrino experiments and provide new synergies between neutrino physics and Earth sciences. Guided by the preliminary sensitivity studies and first data analysis, the project will also pave the way to future progress in the field, studying and proposing alternative neutrino detector configurations that would be fully optimized for Earth tomography studies.

The successful candidate will be based at APC and integrated into the KM3NeT team under the supervision of Dr. V. Van Elewyck. The KM3NeT group at APC, one of the largest ones in the collaboration, is strongly involved in the analysis of neutrino oscillation data, as well as in astrophysical neutrinos searches with KM3NeT detectors ORCA and ARCA. Close collaboration is also expected with Dr. N. Fuji (IPGP), who will provide guidance on current open questions regarding the structure and composition of the deep Earth. Building on this dual expertise and long-standing interdisciplinary collaboration, the candidate will be in an ideal position to steer the sensitivity studies and the interpretation of initial KM3NeT data towards addressing the most pertinent geophysical questions.

Frequent interaction with the KM3NeT Collaboration is expected, including regular meetings (3-4 per year), and contributing to the operation and maintenance of the detectors, as well as to aspects of data processing, calibration and monitoring. A high level of motivation, strong teamwork skills, and effective communication abilities are essential in the context of this interdisciplinary project. Familiarity with C++ and Python programming, computational tools, particle physics data analysis (e.g., using ROOT), and statistical methods will be considered a valuable asset.

[1] https://gitlab.in2p3.fr/apc-tomography/earthprobe