Density Imaging of Volcanoes
With Atmospheric Muons

Master 2 Research Internship at Laboratoire de Physique de Clermont Ferrand (LPC)

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Muography is an imaging technique that uses the attenuation of a natural radiation: the flux of atmospheric muons. It is particularly well suited to the study of large structures such as volcanoes. The integrated density map of the target [1] is inferred through an inversion procedure from the count of muons transmitted across a target. Building a 3D tomographic image from several radiographic maps is non-trivial because of the limited number of radiographies that can be taken. In other words, the tomographic problem is mathematically ill-posed because it is under-determined. Three-dimensional imaging is therefore inferred either through a regularisation procedure [2], or by combining muographic data with those obtained from standard geophysical measurements, such as gravimetry [3][4] or seismicity.

After imaging the puy de Dôme vulcano, the LPC's muography team is now studying an active hydrothermal system, Vulcano, in the Aeolian Islands, Italy. The 2D reconstruction algorithms developed for puy de Dôme need to be transposed to the study of this new target and optimised by considering its favourable characteristics (smaller size, presence of a well-defined crater allowing, in principle, good calibration of the muon telescope). The potential of measurements using two telescopes to identify substructures in the volcano needs to be quantified as a function of the duration of data collection and the performance of the telescopes (e.g. spatial resolution, background rejection power, effective detection area).

Another fundamental question that the Vulcano study should make it possible to answer concerns the length of time it takes to collect the data needed to highlight structural changes in the volcano, once its internal structure is known. Deep learning algorithms should significantly increase the speed of anomaly recognition in the data. The integration of muography into active volcano monitoring systems will depend on this speed of anomaly identification.

Advanced knowledge of particle physics is required for this internship. The muons used in muography undergo stochastic interactions as they propagate through the volcano and must be identified in a background that exceeds them by several orders of magnitude. The simulation, reconstruction and analysis chain in C/C++ is complex and relies on software such as PUMAS [5], GEANT4 [6] and ROOT [7]. A good knowledge of C/C++ and Python is required.

A successful internship can be continued be continued by a PhD.

[1] K. Vernet, « Imagerie densitométrique 3D des volcans par muographie », thèse de doctorat, décembre 2022

[2] F. Grill, « Reconstruction tomographique de la structure interne densitométrique du volcan du puy de Dôme par inversion des données muographiques », rapport de stage L3, août 2017.

[3] P.G. Lelièvre, A. Barnoud, V. Niess, C. Cârloganu, V. Cayol, C. G. Farquharson, "Joint inversion methods with relative data offset correction for muon tomography and gravity data, with application to volcano imaging", Geophys. J. Int., Oxford University Press (OUP), 2019, 218 (3), pp.1685-1701.

[4] A. Barnoud, V.Cayol, V. Niess, C. Cˆarloganu, P.Lelièvre, Ph. Labazuy, Eve Le Mén édeu, "Bayesian joint muographic and gravimetric inversion applied to volcanoes", Geophys. J. Int., Oxford University Press (OUP), 2019, 218 (3), pp.2179-2194.

[5] V. Niess, A. Barnoud, C. Cârloganu, E. Le Ménédeu, "Backward Monte-Carlo applied to muon transport", Comput.Phys.Commun. 229 (2018) 54-67 (2018-08), arXiv:1705.05636

[6] GEANT4, https://geant4.web.cern.ch
[7] ROOT, https://root.cern