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The feasibility of geophysical imaging using cosmic-ray muons. An application to Etna volcano (Italy).

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Volcanic activity involves phenomena which result from complex interactions of conduit geometry with gas-liquid flows. Hence, the capability to mitigate volcanic hazards requires the quantitative characterization of conduit geometry. The more established geophysical imaging techniques often suffer from inherent ambiguity, may require dense measurements in active areas and may not provide sufficient spatial resolution. Hence, there is the need to adopt new imaging techniques, allowing a better spatial resolution of a volcano's upper feeding system, with reduced ambiguity and a low level of risk for operators during field work.
Recent studies have demonstrated that muon particles, produced by the interaction of cosmic rays with the Earth's atmosphere, can be utilized to image the internal density distribution of volcanic structures. Muon imaging works similarly to X-rays imaging, the main difference being the use of muons instead of photons. Differential attenuation, due to the inhomogeneous density distribution inside the target object, is exploited to attain a quasi-direct information about its inner structure.
Here, with a view to optimizing the signal-to-noise ratio in muon imaging, we address issues concerning (i) the energy spectrum for muons arriving at different zenith angles, (ii) the muon propagation through matter and (iii) the characteristics of the muon detector. We eventually define a feasibility equation, relating the geometrical characteristics of the detector and the duration of the experiment to the expected density resolution, in turn a function of the geometrical characteristics of the target structure. This relation allows to define the applicability domain of muon radiography.
We apply our feasibility equation to test the suitability of the method to investigate the density distribution inside the Southeast Crater of Mt Etna (Italy). Results indicate that, if the acquisition period is 150 days (the average yearly period without snow on the summit of the volcano), inner structures, with size exceeding the space resolution of the telescope (about 10 m for the expected conditions), could be recognized, if the density contrast is at least 0.5 g/cmˆ3.
During the summer of 2010, we installed a muon detector on the summit zone of Etna, to perform a muon radiography of the Southeast Crater. Unfortunately, some technical issues limited the acquisition time to only one month, i.e. not enough to reach the required signal-to-noise ratio. Anyway, even though a clear picture of the internal density structure of the Southeast Crater cannot be assessed using this dataset, the experiment we performed gave precious information on the standards needed to withstand the harsh environment in the summit zone of an active large-sized volcano, like Etna. This experience will inform further experiments of muon imaging, towards maximization of the acquisition time, hence of the signal-to-noise ratio.
During the summer of 2010, we also performed gravity measurements on Etna's Southeast Crater. Analyses are ongoing, to try the first integration of muon imaging with gravity data.