**THE MEV (MUOGRAPHY OF ETNA VOLCANO) PROJECT AND ITS FUTURE APPLICATIONS TO THE EARTH AND MARS.** D. Lo Presti[1,2], G. Gallo[1,3], D.L. Bonanno[2], G. Bonanno[4], D.G. Bongiovanni[3], D. Carbone[5], C. Ferlito[6], J. Immè[1], P. La Rocca[1,2], F. Longhitano[2], A. Messina[5], S. Reito[2], F. Riggi[1,2], G. Russo[1,2], L. Zuccarello[7,5], G. Leone[8], M. Barbieri[8], G. Romeo[4], S. Garozzo[4] and S. Riggi[4], [1]Department of Physics and Astronomy, University of Catania, Italy; [2]Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Catania, Catania, Italy; [3]INFN, Laboratori Nazionali del Sud, Catania, Italy; [4]Istituto Nazionale di Astrofisica (INAF), Osservatorio Astrofisico di Catania, Italy; [5]Istituto Nazionale di Geofica e Vulcanologia (INGV), Sezione di Catania - Osservatorio Etneo, Catania, Italy; [6]Department of Biological, Geological and Environmental Sciences, University of Catania, Italy; [7]Universidad de Granada, Dpto. de Teorìa de la Señal, Telemàtica y Comunicaciones ETSI Informàtica y de Telecomunicaciòn Universidad de Granada, Spain; [8]Universidad de Atacama, Instituto de Astronomia y Ciencias Planetarias, Copiapó, Chile.

**Introduction:** The MEV project [1] aimed at developing a muon telescope expressly designed for the muography of the top of Etna Volcano. The project is leaded by a team of physicists and engineers from Department of Physics and Astronomy of the University of Catania and INFN in collaboration with volcanologists from INGV and the Department of Biological, Geological and Environmental Sciences of the University of Catania.

The MEV telescope was built in 2016 at the Department of Physics of the University of Catania and was funded by FIR2014 (Future in Research) and strongly supported by the “Parco dell'Etna” authority. The muon telescope, custom designed for the application of high resolution muography of Etna volcano, is a tracker based on extruded scintillating bars with WLS fibres and featuring an innovative read-out architecture, developed for the minimization of the overall power consumption. A special effort concerned the design of mechanics and electronics in order to meet the requirements of a detector capable to work in a completely autonomous way in a hostile environment such as the top of a tall volcano, far away from any facility.

The telescope was installed at about 3100 m a.s.l. south oriented towards the North-Est crater of Etna volcano in August 2017. The detector acquired data for about 56 days in 2017 and after several months of snow coverage was successfully restored and set back in measurement in August 2018. In December 2017 an important event regarding the collapse of the NE crater roof, sealed before, was registered. The influence of bad reconstructed tracks near the horizon is one of the most important limits in the measurement. TOF data analysis is still running but the preliminary results confirm the need for a TOF measurement correlated to the tracking of muons. In order to address background noise issue, a Time of Flight (TOF) module to measure the TOF of the particle between the external planes was installed inside the telescope in October 2018. A new measurement campaign was conducted for about 96 days. The comparison between the muographies acquired in 2017 and 2018 shows the capability of the telescope to image the top interior of the crater and the potentiality of the technique to provide information on the internal dynamics of an otherwise inaccessible geophysical object.

**Detailed description of the MEV telescope:** The detector is based on three XY position-sensitive (PS) planes, with a sensitive area of $1m^2$. The angular resolution does not exceed 0,4 msr and the total angular aperture is about ±45°. The sensitive modules are enclosed in a cubic box with external side of about 1,5 m, made with panels with double metallic cover and an inner isolating filling of polyurethane. Two solar panels are mounted on the upper side of the box and charge two suitable batteries housed inside the box. The box is mounted on a modular frame made with scaffolding pipes which facilitate the transportation of the structure using a truck with a mechanical arm. This allows to transport the telescope already mounted to the measurement site. However, the internal aluminium structure which holds the PS planes is modular and can be assembled in the field. The frame lies on adjustable legs to cope with uneven terrain. The mechanical structure that contains the three sensitive planes proved to be relatively light and water tight. The telescope, in acquisition mode, sends data every five minutes directly to data storage through a mobile connection. The muographic images of a geophysical object was acquired with a promising quality. In order to address background noise issue, we installed a module to measure the TOF of the particle between the external planes by means of picosecond resolution TDC. This information helps in reducing the influence of bad reconstructed tracks near the horizon. The scattering due to the target object itself is practically unavoidable. Other projects, have employed planes of high Z material, mainly lead, in order to suppress the tracks due to low energy particles and consider only muons that go straight through the structure to be imaged. However, this approach is not feasible in the summit zone of a tall volcano like Etna, where limited access due to harsh conditions prevents the use of heavy equipment.

**Work in progress:** The use of the MEV telescope in other volcanic sites is possible with minor changes in the design. The increase in the altitude of the measurement site, for example, is not an issue. Low temperatures must be taken into account in the choice of the electronics and the batteries for the solar powering system. In lack of radio communication, a robust and smart storage system can be used. A fundamental preliminary study must be conducted regarding the choice of the installation site and the orientation of the telescope respect to the object to be imaged. The distance between the telescope and the crater must be as short as possible and the field of view must exclude as much as possible superimposed structures. These two parameters will impact the amount of background, the time needed for the measurement to reach optimal statistics and the maximum elevation angle (excessive cumulative depth). A high resolution DEM of the structure is fundamental for the evaluation of the muography in terms of density referred to standard rock density, for example. A preliminary survey was conducted on the volcano Lascar, Chile, which is still active and has several ways of easy access all over its flanks. This volcano has the above specified characteristics and, although frequently poses a threat to the nearby village of Cramar on the southern flank, it offers suitable conditions of observability in a quite dry climate.

**Study on the future application of muography on Mars:** Muography in an alien environment, like Mars, pones a quantity of additional constraints to the already challenging Earth volcano muography. Apart from the transportation of the telescope and the fail-safe design which is in charge of the space agency, two main considerations must be taken into account. First, the cosmic ray composition, angular distribution and their interaction mechanism with the alien volcano and the detector itself. The interaction of the primary cosmics with other planets and celestial bodies produces different results depending on the presence of an atmosphere around the solid structure of the body [2].

Monte Carlo calculations of the interaction of energetic particles with the detailed structure of these bodies should be carried out for any specific situation in order to understand their peculiarities. In case of Mars, where the atmospheric pressure near the surface is only 1/100 with respect to Earth, the development of air showers has been studied in some detail by Tanaka [3], allowing to understand how the proportion between primary protons and secondary pions or muons is very much different than on Earth. In particular, due to the reduced thickness of the Martian atmosphere, the vertical flux of muons is much smaller with respect to the values obtained on the Earth; however, for inclined muons, close to the horizontal, the situation is reversed, and a larger flux of muons would be observed. In any case, contamination from the primary protons is a challenge, and some way to discriminate between the two species should be devised. It is interesting that such concepts have been discussed with relation to realistic Martian exploration missions, trying to understand even the practical aspects and problems which would be required to solve to carry out tomographic measurements on the Red Planet [4], [5].

Another critical issue is the radiation damage level which set severe constraints on the design of the detector and the electronics. Once these issues will find a solution, there is a wealth of volcanoes that can be studied on Mars. Most of them have huge lava fields with slopes not much steep that would allow perfect conditions of observability within the parameters of security required by the space agencies. One of these could be Tyrrhenus Mons, a shield volcano located in the Hesperia region of Mars characterized by several episodes of magma withdrawal and pyroclastic activity, which shows a caldera on its summit and might also have a relatively shallow reservoir [6]. The target of the observation would be the main conduit connected to the calderas in the summit sector.

**References:** [1] Lo Presti D. et al. (2018) NIMA, 90, 904, 195-201 [2] La Rocca P., Lo Presti D. and Riggi F., (2018) IntechOpen “Cosmic Rays”, chapter 3 [3] Tanaka H. (2007) Icarus, 19, 603-615 [4] Kedar S et al. (2012), 1679, 4150. [5] Kedar S. et al. (2013) Geoscientific Instrumentation, Methods and Data Systems,2,157-164. [6] Greeley R., and Crown P., (1990), JGR 95, 7133-7149.