MWPC-based Muographic Observation System for remote monitoring of active volcanoes

László Oláh[1], Szabolcs József Balogh[2], Gergő Hamar[2], Gábor Nyitrai[2], Hiroyuki K. M. Tanaka[1], Dezső Varga[2]

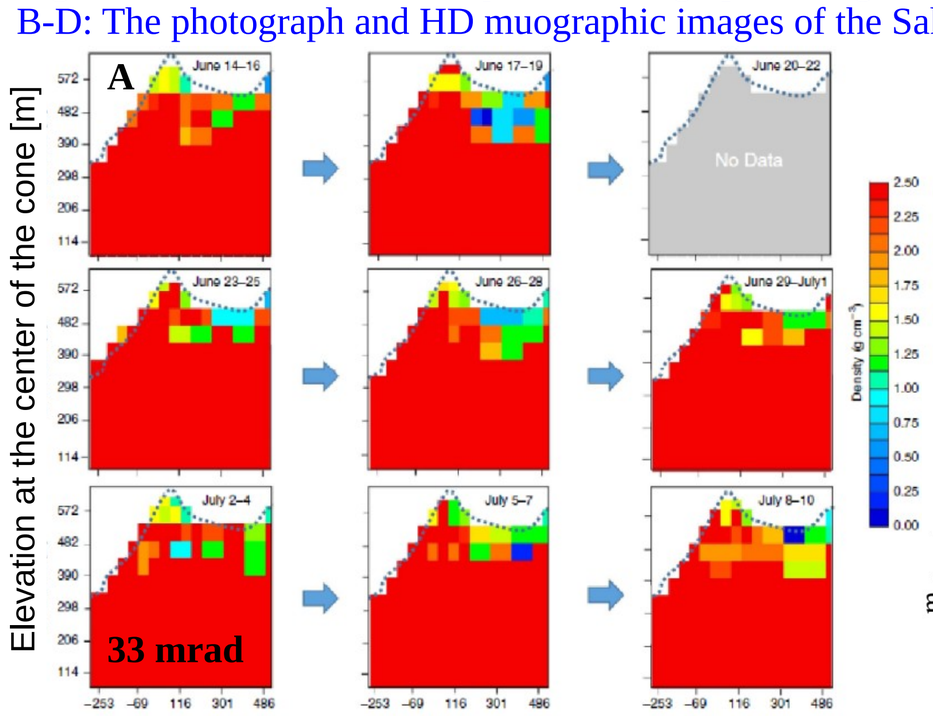
[1]Earthquake Research Institute, The University of Tokyo

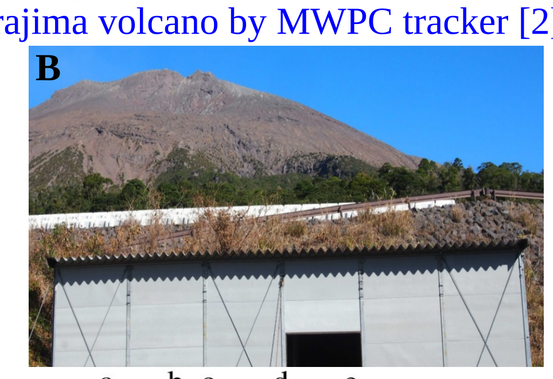
[2]Wigner Research Centre for Physics of the Hungarian Academy of Sciences

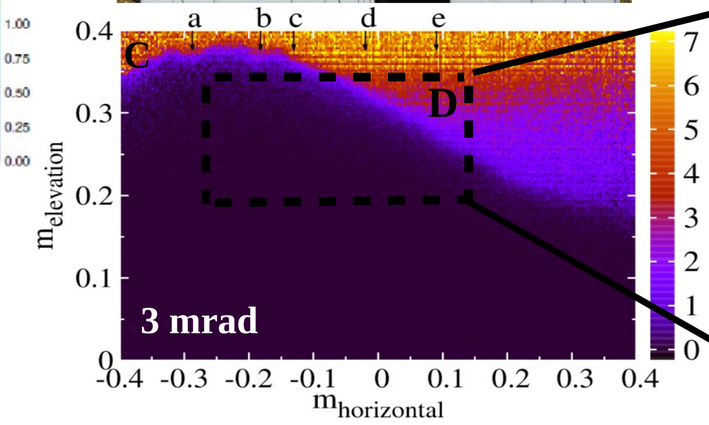
Motivation for imaging of the interior of active volcanoes with cosmic-ray muon tracking

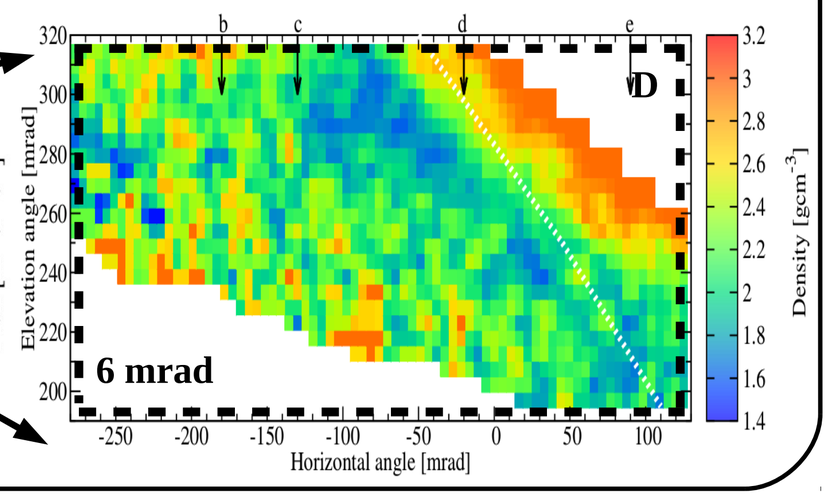
Muography resolves the spatial distribution of large-sized objects with cosmic-ray muons by deriving the amount of material along their path through the target objects.

Figure 1. A: The first time-sequential muographic images of an erupting volcano by scintillators [1]. B-D: The photograph and HD muographic images of the Sakurajima volcano by MWPC tracker [2].









Feasibilities and limits of muography of volcanoes:

- ✔ Shallow (< 3 km) regions of the volcano can be imaged.
- ✔ Monitoring of density variation inside the volcano can be performed from safety (> 1 km) distance.
- ✔ High resolution (< 10 mrad) imaging makes visible magma conduits with the diameter of few 10 meters.
- ✗ Limited muon flux (10^{-1}-10^{-4} $m^{-2}sr^{-1}s^{-1}$):
  → large-sized (>10 m^{2}) monitoring system for imaging with the time resolution of few hours,
  → suppression of hadronic and scattered particles.

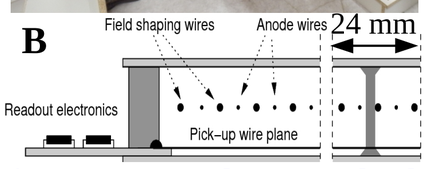
The MWPC-based Muographic Observation System (MMOS) for monitoring of volcanoes

New variant of MWPC detectors:

- MWPCs are localizing the electron avalanche created by penetrated charged particles in gas medium with perpendicular wire planes.
- MWPCs are optimized for field operation with its robust structure, size of 0.9 m^2, and weight of 15 kg per detector.
- The MWPCs provide positional resolution of 4 mm.
- Non-flammable, non-toxic Ar-CO_2 (80%-20%) gas mixture is flushed across MWPCs with the typical flow of 1 L/h.
- The high-voltage of about 1750 V is applied on the anode wires to achieve the reasonable tracking efficiency of above 95 % and trigger efficiency of above 90 %.

MWPC-based tracking system:

- 2 meter-length tracking system consists of at least five MWPCs and five 2-cm thick lead shielding plates for the deflection of background particles.
- Angular resolution of 3 mrad allows imaging resolution of 10 m from 3 km.
- Data taking is triggered by coincidence of MWPCs. Raspberry Pi-based DAQ system allows remote control. The total power consumption of MMOS is 10 W.



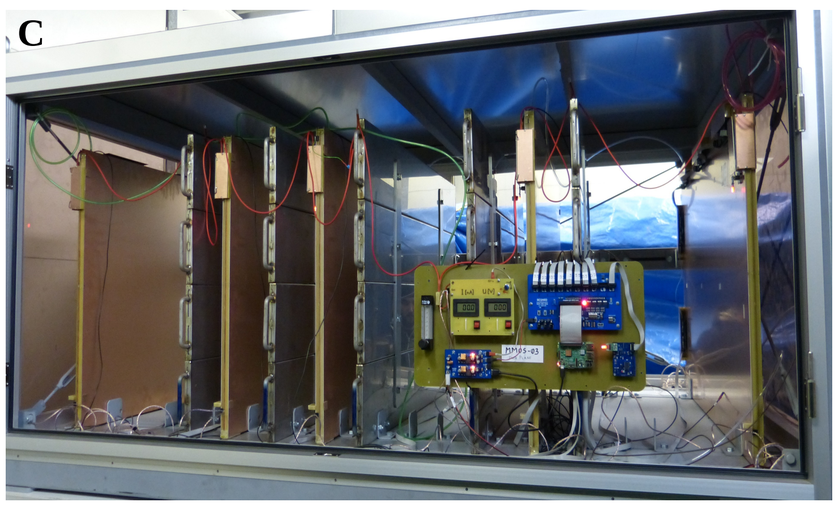


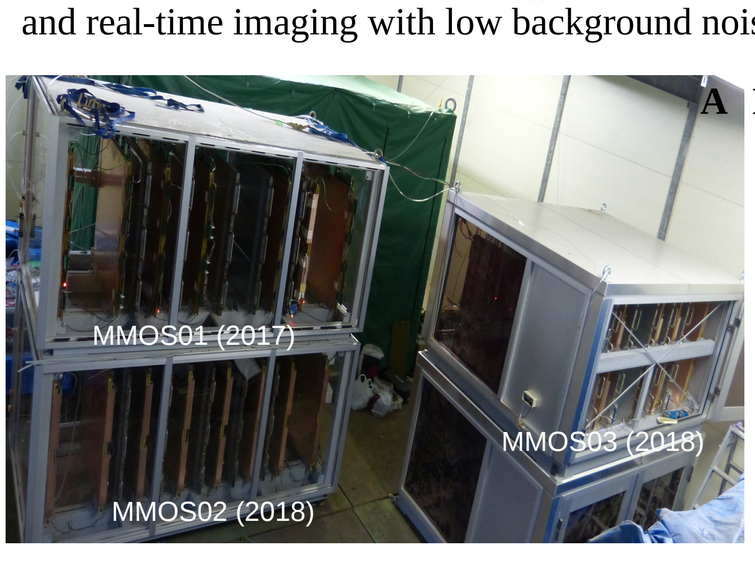
Figure 2. A: Photograph about the construction of MWPC. B: Schematic view of an MWPC [3]. C: Photograph of MWPC-based Muographic Observation System.

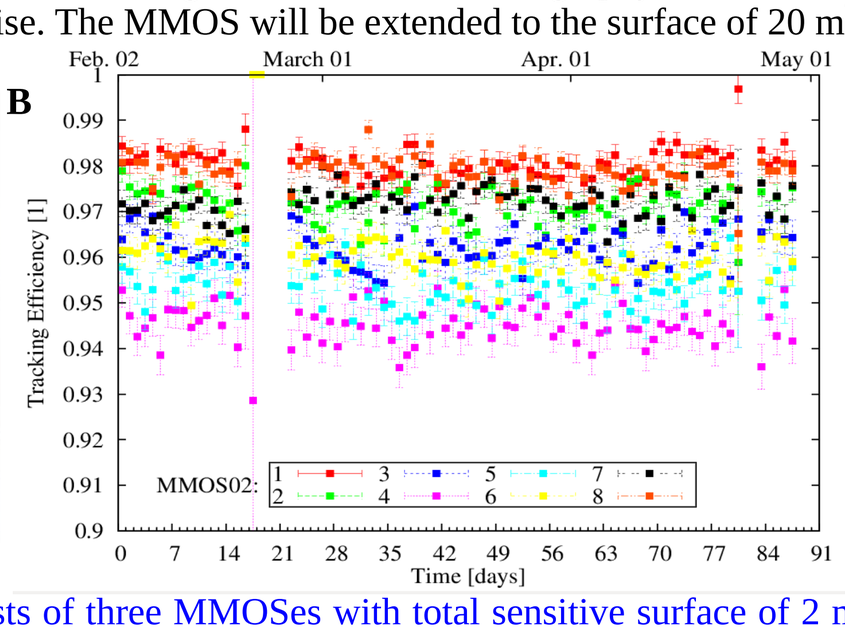
Real-time data acquisition and analysis for volcano monitoring:

- Compressed ASCII data files are automatically transferred from MMOS to remote server via VPN.
- High energy physics data analysis methods (cluster reconstruction, combinatorial tracking algorithm) are automatized for calculation of muon flux in real-time.
- Time-sequential track maps can be observed and analyzed by users via on-line monitoring system [4].
- Average density of Sakurajima volcano is deduced with the comparison of measured and expected fluxes using topographic data, muon spectra model.
- Development of density monitoring system is ongoing.

Performance of MMOS System during the data taking period of 2018

- The MMOS system has been enlarged with two more tracking systems to the sensitive surface of 2 m^2 at the Sakurajima volcano in February 2018.
- The MMOS system was operated reliably with tracking efficiency of above 98 % during the data taking period of 2018 except two technical stops because of the upgrade of gas system and extension of MMOS housing.
- The fluxes measured by the different tracking systems were found in agreement with the expected flux down to below 10^{-3} $m^{-2}sr^{-1}s^{-1}$ (7,000 m.w.e. depth).
- As conclusion, MWPC technology was demonstrated as a good candidate for muography of volcanoes thanks to its capability to perform high-definition and real-time imaging with low background noise. The MMOS will be extended to the surface of 20 m^2 to provide enough statistics for eruption prediction.





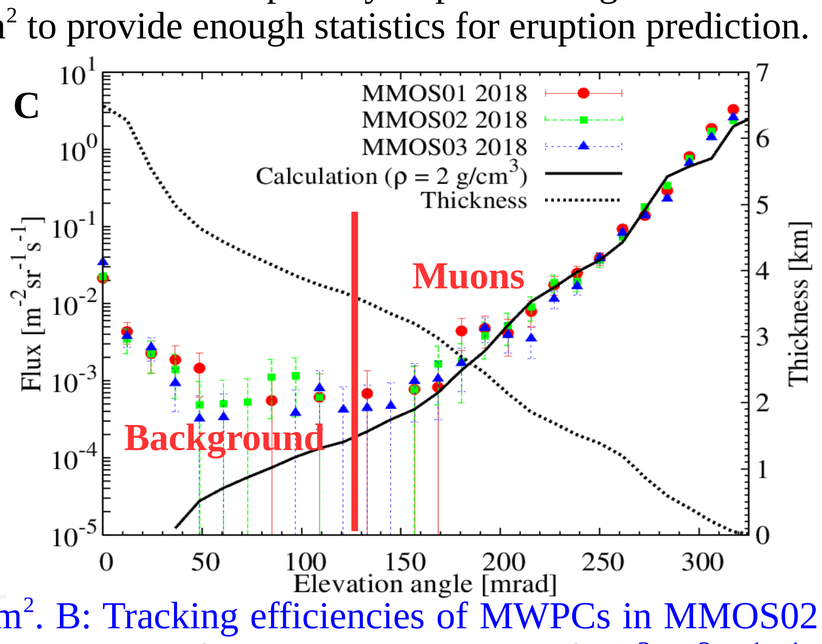


Figure 3. A: Photograph MMOS system consists of three MMOSes with total sensitive surface of 2 m^2. B: Tracking efficiencies of MWPCs in MMOS02 were found above 94 %. C: The fluxes measured by MMOSes are consistent with each other and with the expected flux down to the value of 10^{-3} $m^{-2}sr^{-1}s^{-1}$.

References:

[1] H. K. M. Tanaka *et al.*: Nature Communications 5:3381 (2014)
[2] L. Oláh *et al.*: Scientific Reports 8:3207 (2018)
[3] D. Varga *et al.*: Advances in High Energy Physics 1962317 (2016)
[4] Online Monitoring of Sakurajima: https://mmos.muographers.org/

Acknowledgement: This work is supported by Ministry of Education, Culture, Sports, Science and Technology, Japan (MEXT) Integrated Program for the Next Generation Volcano Research and Human Resource Development and Hungarian-Japanese Bilateral Research Fund For Science and Technology (TÉT_16-1-2016-0198).

Contacts: olah.laszlo@wigner.mta.hu, ht@eri.u-tokyo.ac.jp,varga.dezso@wigner.mta.hu