Workshop on Recent Advances in Muography

Muography of Samail ophiolite: preliminary results and future perspectives of studying oceanic lithosphere

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3 Geological Survey of Japan, Japan
4 Ministry of Energy and Minerals, Oman
5 The University of Tokyo, Japan
6 International Virtual Muography Institute (VMI), Global

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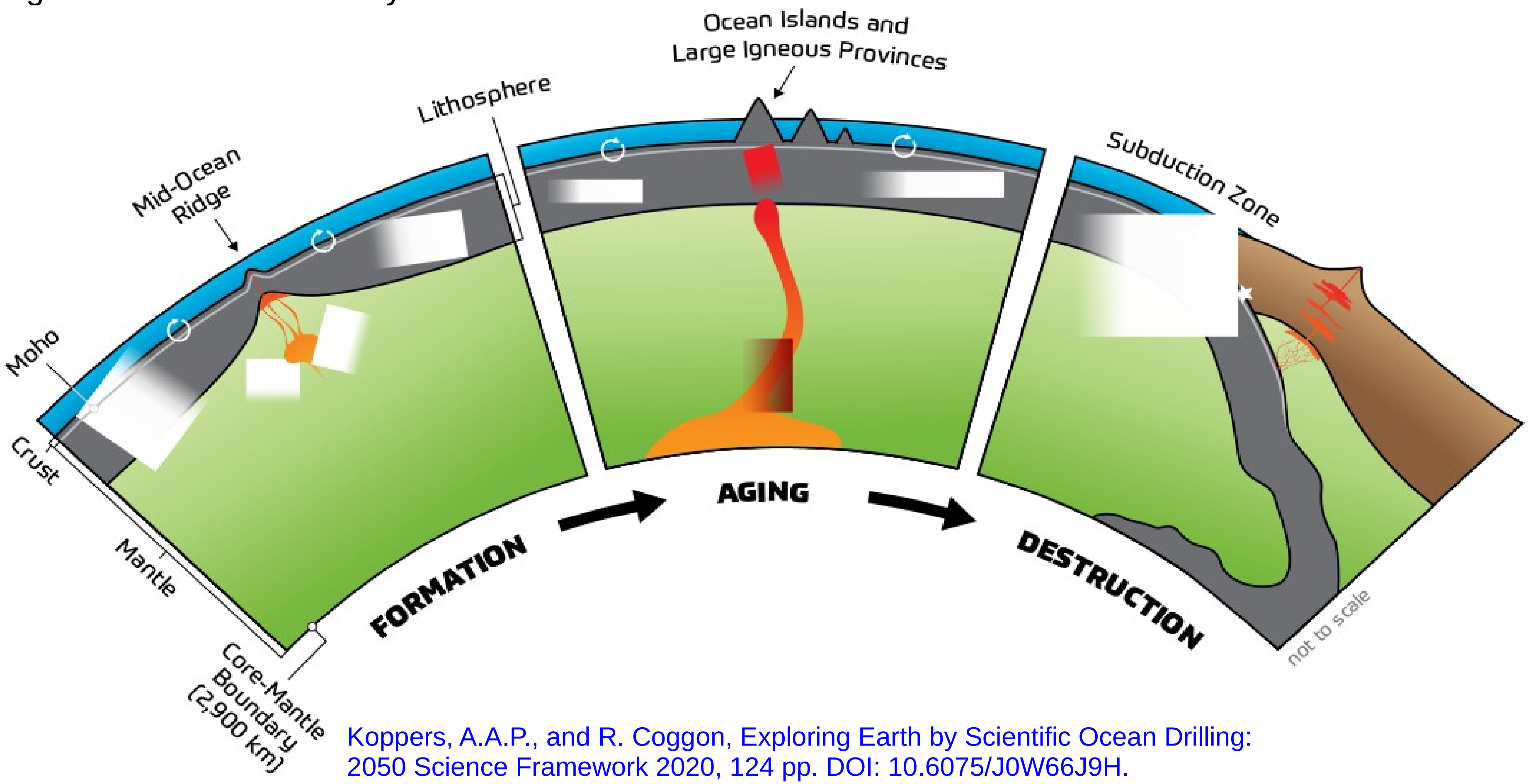
Outline

I. Introduction

- **Oceanic litosphere (crust and upper solid mantle) cycle (1. formation, 2. evolution and 3. desctruction)** occurs over tens to hundreds of million years.

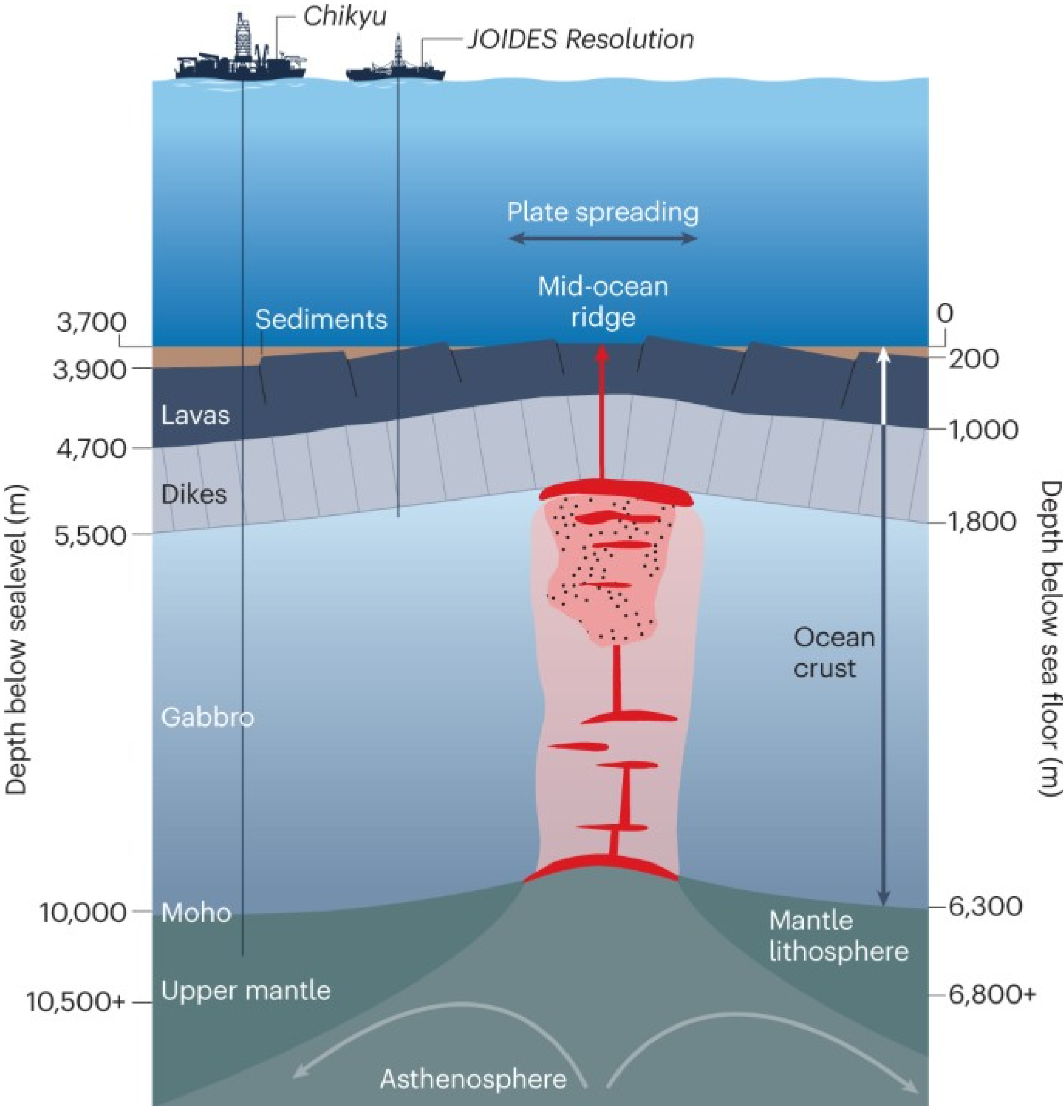
- **Cycle of matter and energy**
  produces critical resources to economy,
  governs the occurrence various natural hazards from earthquakes to volcanic eruptions and
  regulates Earth's climate system.



Koppers, A.A.P., and R. Coggon, Exploring Earth by Scientific Ocean Drilling: 2050 Science Framework 2020, 124 pp. DOI: 10.6075/J0W66J9H.

Scientific Ocean Drilling: Mohole 2 Mantle (M2M)

- Combining the geophysical surveying of ocean basins and petrological studies via in situ sampling of the segments of oceanic lithosphere in different tectonic environments is expected to advance the understanding of the nature of oceanic lithosphere
- Scientific ocean drilling aims to collect fundamental data on the plate tectonic cycle since 1960s
- Oceanic drilling has already revealed critical pieces of evidences about plate tectonics, break up of continents, etc.
- Recently, Integrated Ocean Discovery Program's (IODP) MoHole to Mantle (M2M) drilling proposal aims to reach the Moho and the underlying mantle at three candidate sites including the Hawaiian arch and on the Cocos Plate



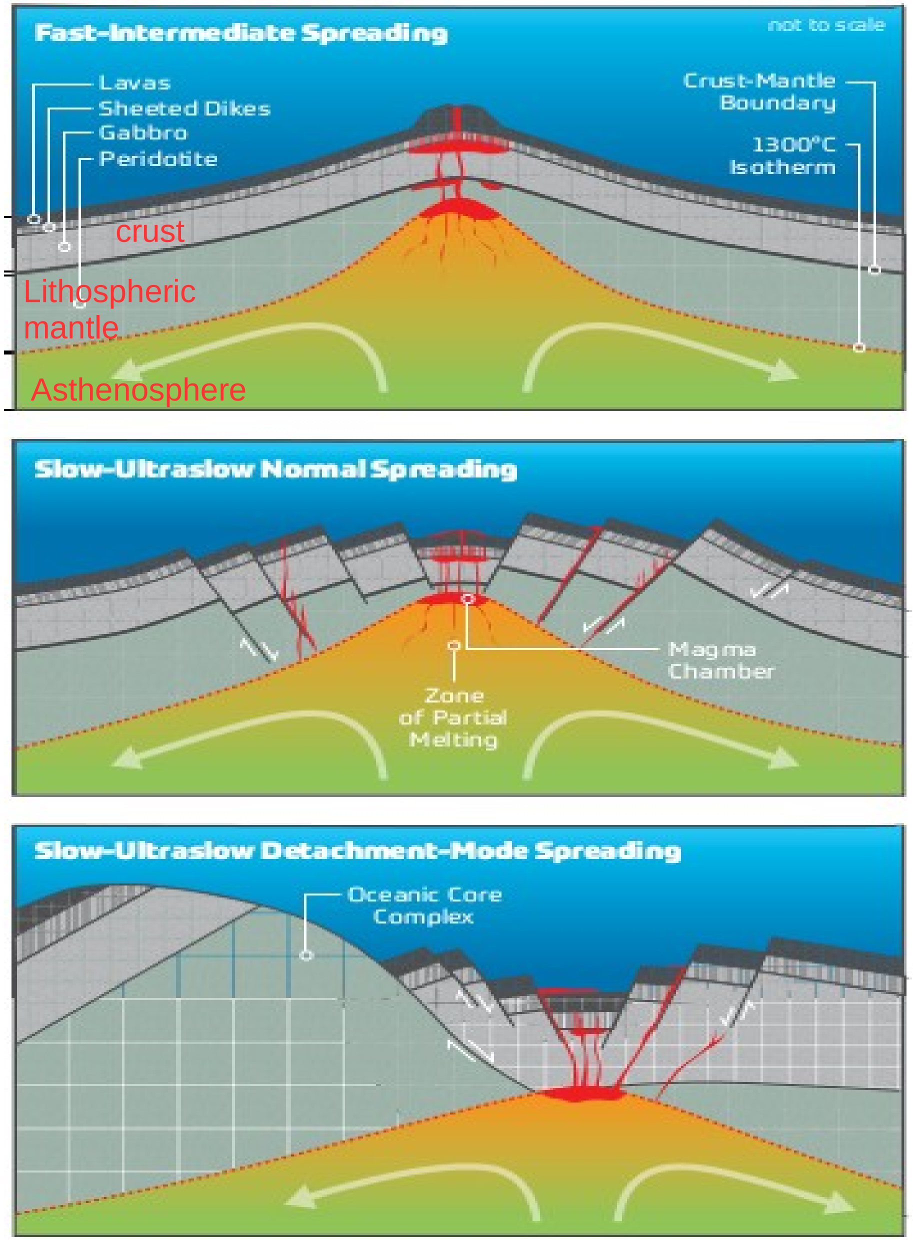
Teagle, D.A.H. Re-energizing the quest of drilling to the mantle. Nat Rev Earth Environ 4, 207–208 (2023). https://doi.org/10.1038/s43017-023-00413-0

Actual Knowledge and Scientific Questions

- **Volume, composition and architecture of crust depends on the seafloor spreading rate and the nature of underlying mantle (1967)**
    - fast spreading →
      tectonic extension dominates that is leading to heterogenous crust
    - Ultra slow spreading →
      low angle detachment faulting that result in exposure of mantle rocks (periodites, pyroxenites)
- Magma chamber depth negatively correlated with fast spreading rate → shallower magma chamber has higher magma supply rate

  (see Prof. Umino's talk at Muographers 2022 GA)

- **Questions:**
    - **Why and how does the crustal structure (layer 2/3) depend on spreding rate?**
    - **What is the geological nature of Moho?**



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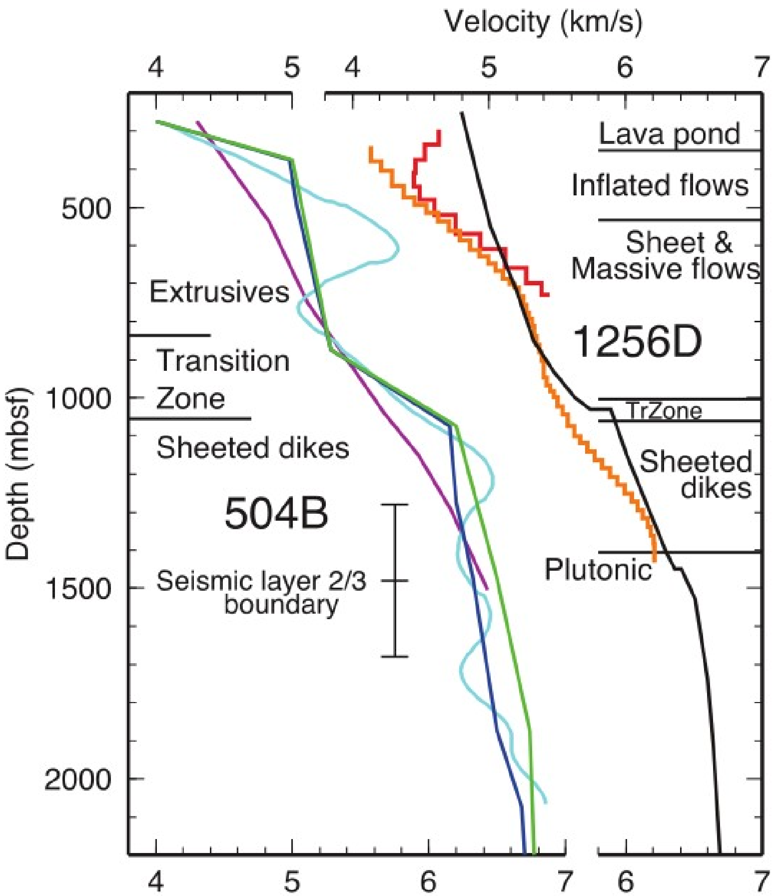
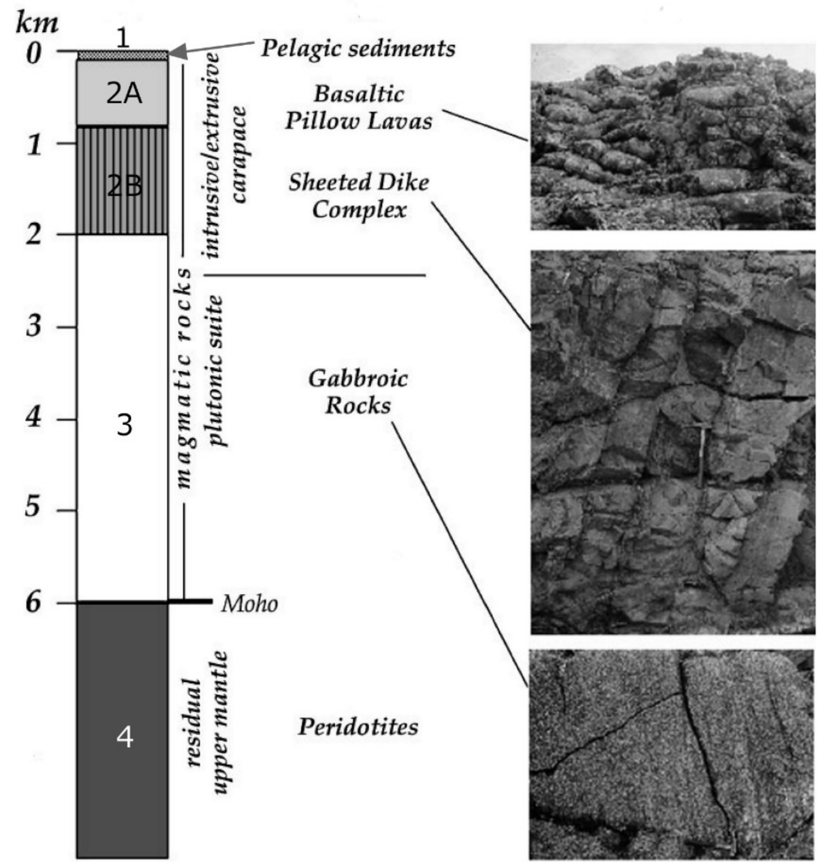
Oceanic lithosphere in Ophiolites

- Only one vertical seismic profile reached seismic layer 2/3 boundary and **Moho has not yet been reached** → geological nature is not yet well understood
- Sampling is available but sampling density is low → seismic velocities are different
- **Different seismic layers (layer 2/3 boundary and Moho) are exposed above ground in ophiolites**

→ **Ophiolites help to understand the correlation between oceanic structure and geology**



Swift, et al. 2008. Velocity structure of upper ocean crust at Ocean Drilling Program Site 1256. Geochim. Geophys. Geosys., 9, Q10O13, DOI:10.1029/2008GC002188



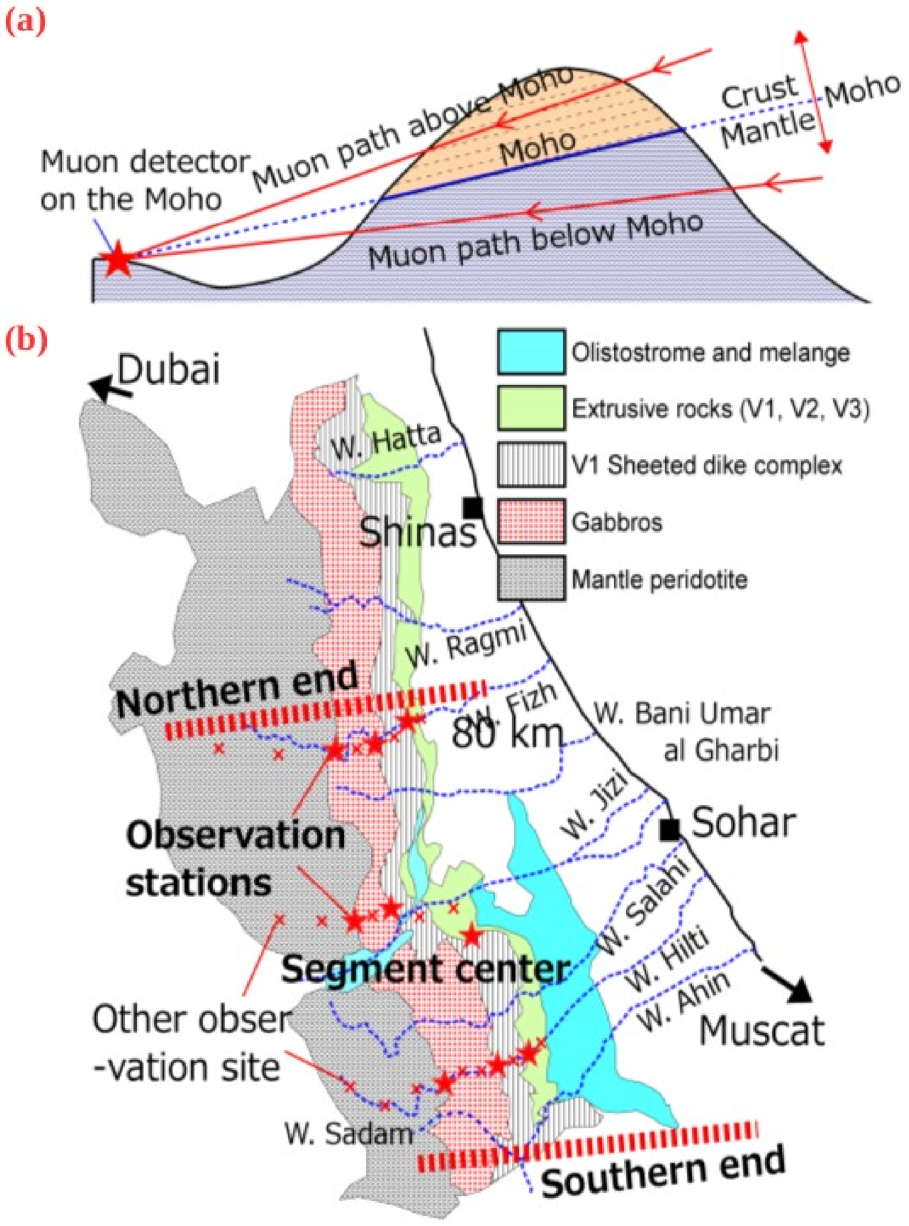
Karson, J.A., Geological structure of the uppermost oceanic crust created at fast- to intermediate-rate spreading centers. *Annu. Rev. Earth Planet. Sci.* **2002**, 30, 347. DOI: 10.1146/annurev.earth.30.091201.141132.

II. Muography of Samail Ophiolite

Muography of Samail Ophiolite

- **Objective: better understand the geologic nature of the crust/mantle (Moho) and upper/lower crustal boundaries of the Oman Ophiolites**
- Muographic images of the bulk density structure can be compared to the seismic data of the ocean floor
- The Samail ophiolite is the largest and best preserved fragment of oceanic lithosphere in the world, extending 80 km × 500 km
- **Oman ophiolites oceanic crustal structure is similar to the structure of East Pacific Rise**

  → data can be compared with the structure of the Pacific Plate, the target of the IODP-805 MoHole to Mantle (M2M) Proposal



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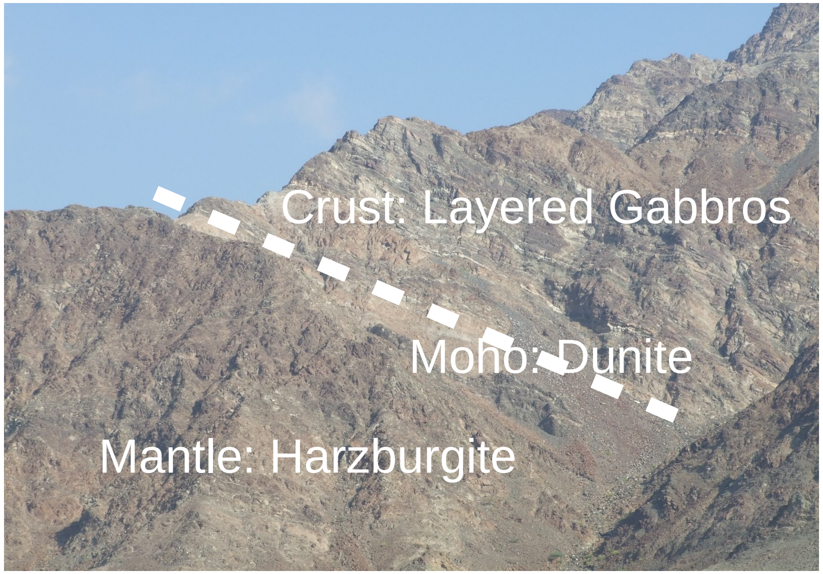
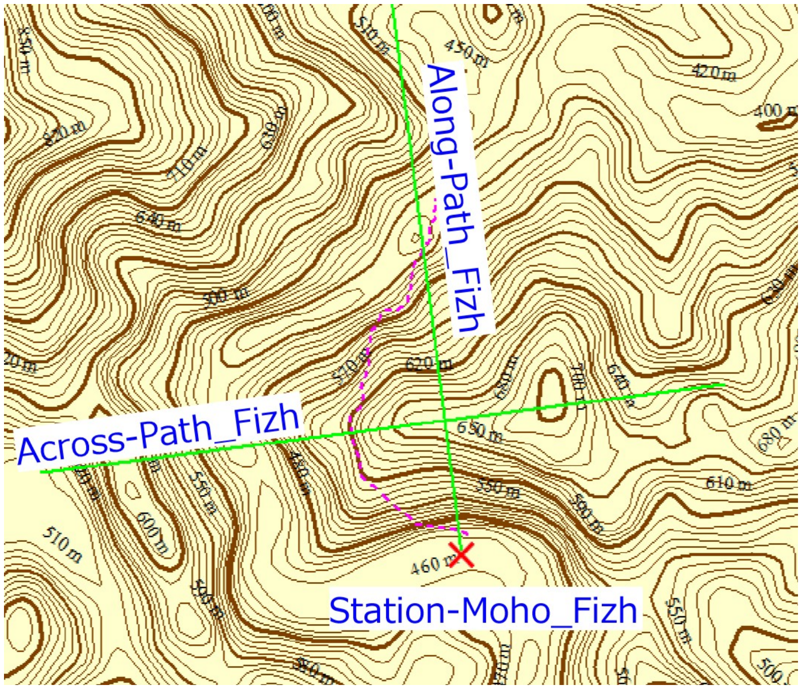
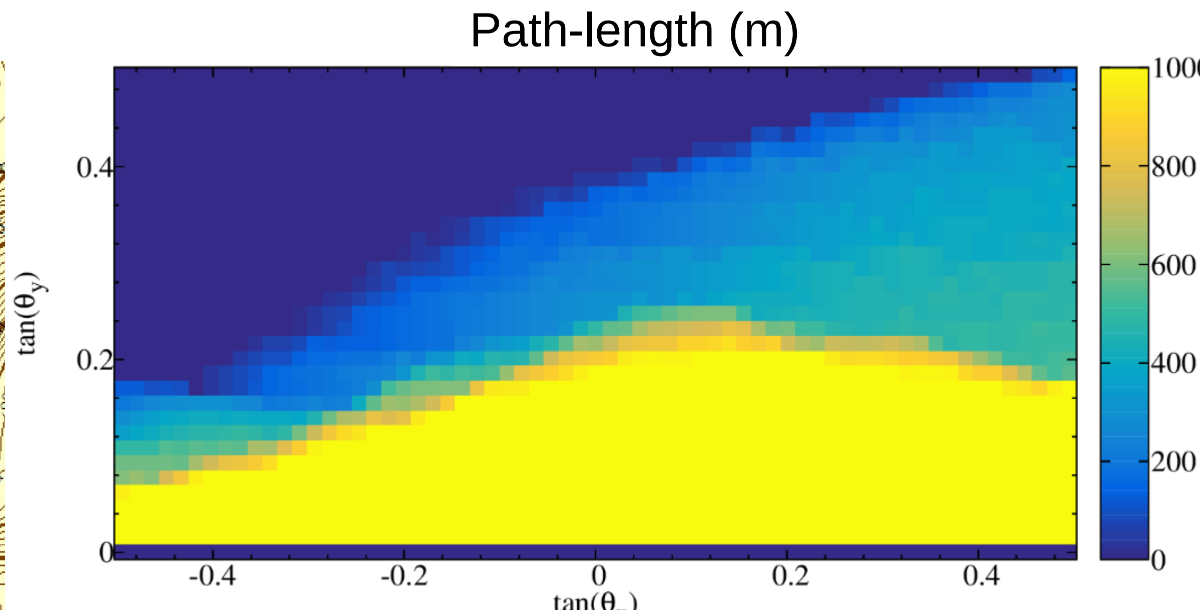


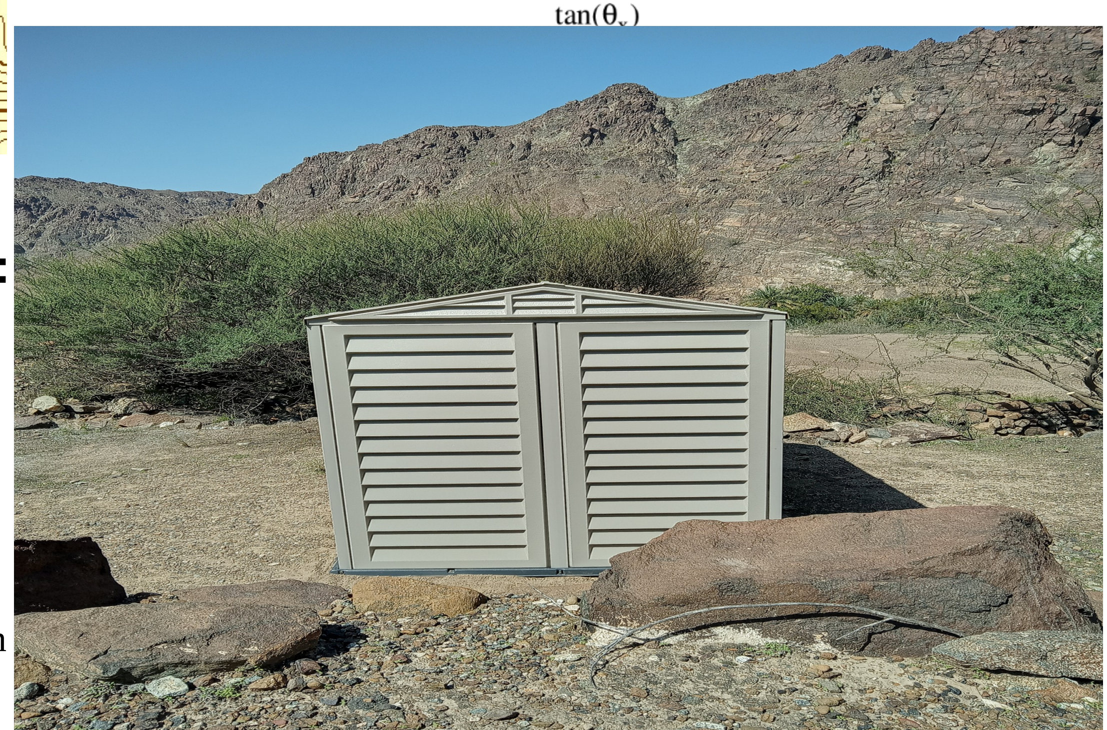
Photos provided by Prof. Umino

The first target: a Moho at Wadi Fizh





Observation location & orientation:
Lattitude: 24.45655 deg
Longitude: 56.29703 deg
298 deg from north



Muography Instrumentation

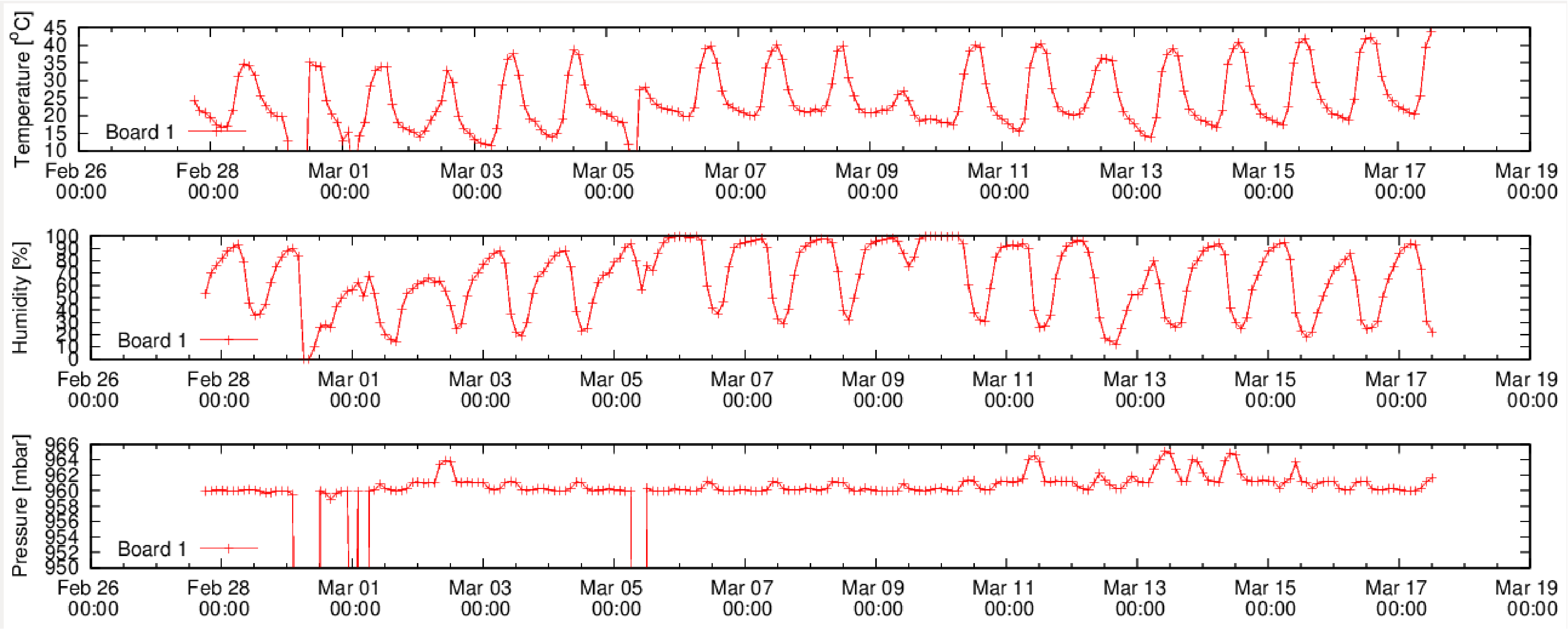
- **MWPC-based Muography Observation System (MMOS):**
  - Seven 80 cm by 80 cm sized Multi-Wire Proportional Chambers each with a spatial resolution of 4 mm, >95% trigger and >98% tracking efficiency,
  - Rasperry PI controlled DAQ with a deadtime of 100 microsec,
  - Total power consumption of about 6 W.
  - Power supply:
    110 V (60 Hz) AC & 100 W solar panel
  - Gas supply:
    Ar + CO_2 (80:20), flow of 1 L/h

D. Varga, L. Oláh, G. Hamar, H. K. M. Tanaka, T. Kusagaya:
Muographic Observation Instrument, WO2017187308A1
https://patents.google.com/patent/WO2017187308A1/en
D. Varga et al. Advances in High Energy Physics, 2016, 1962317 https://doi.org/10.1155/2016/1962317
L. Oláh et al. Scientific Reports, 8, 3207, 2018 https://doi.org/10.1038/s41598-018-21423-9

III. Preliminary Results

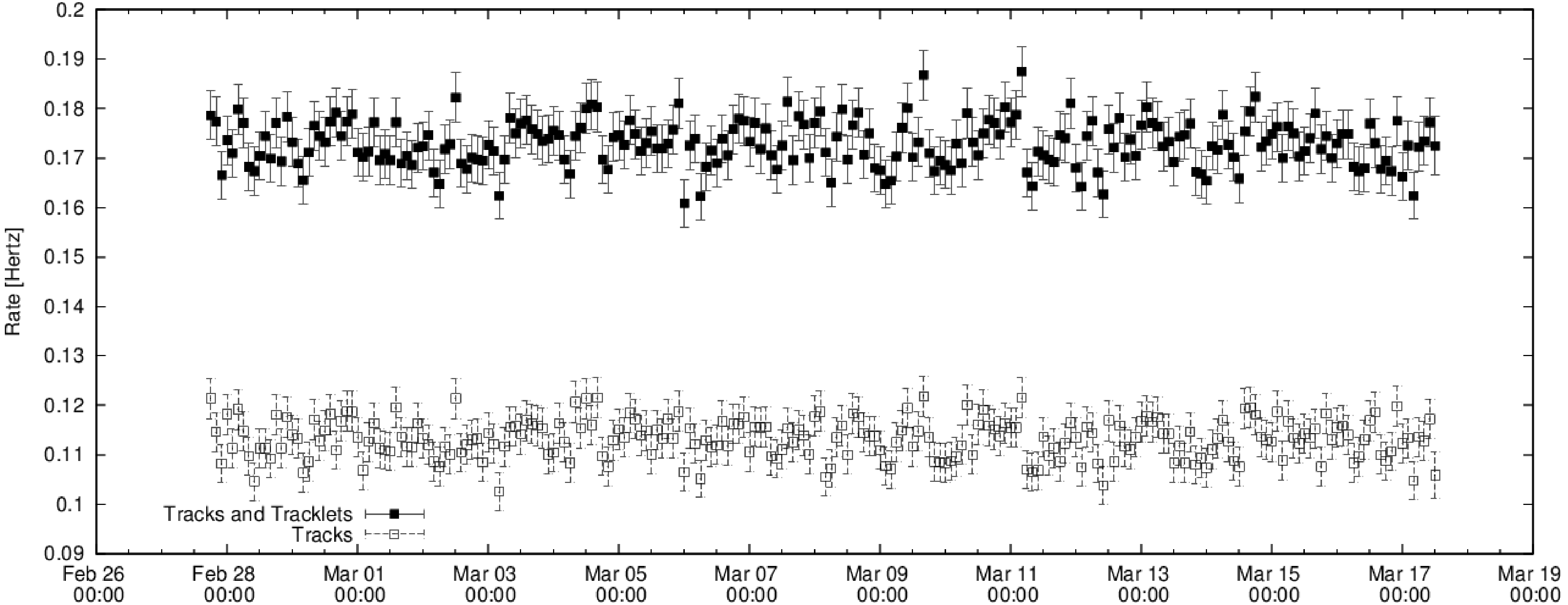
Operational Performance

- **MMOS is continuously operating since 27th February**
- Daily variations of temperature and humidity are significant

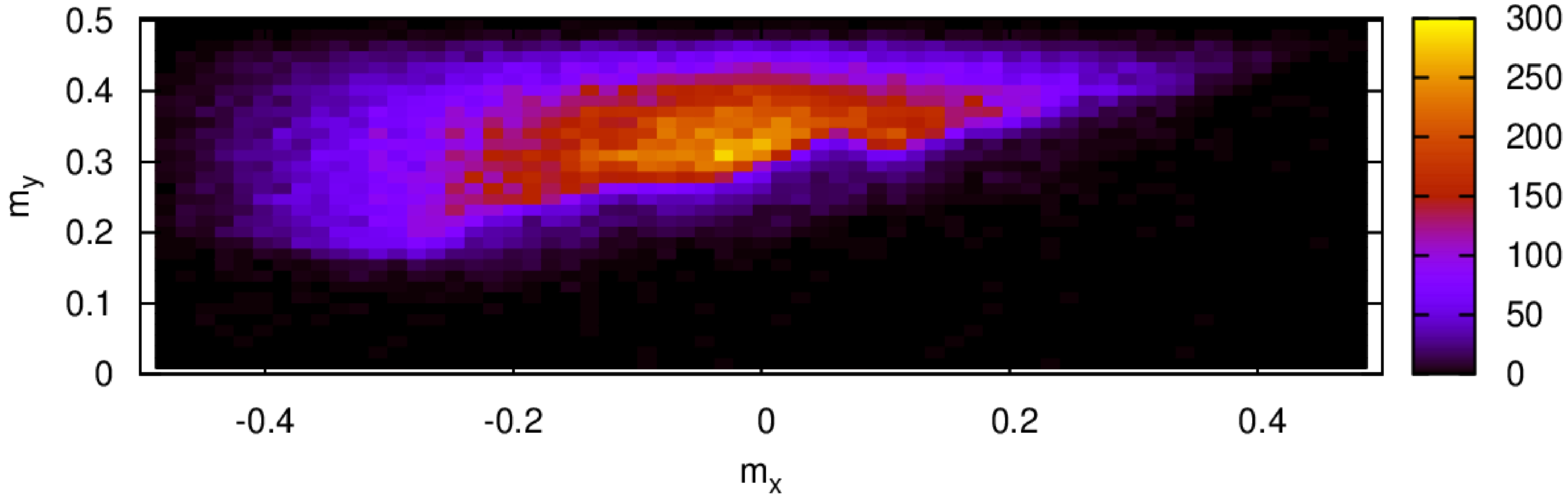


Operational Performance

- Trigger rate varies from 25-35 Hz (dead time < 0.4 %)
- Track rate is measured between 0.165-0.175 Hz (black rectangles)
- Trigger and tracking efficiencies are respectively measured above 93 % and 94 % for each MWPC



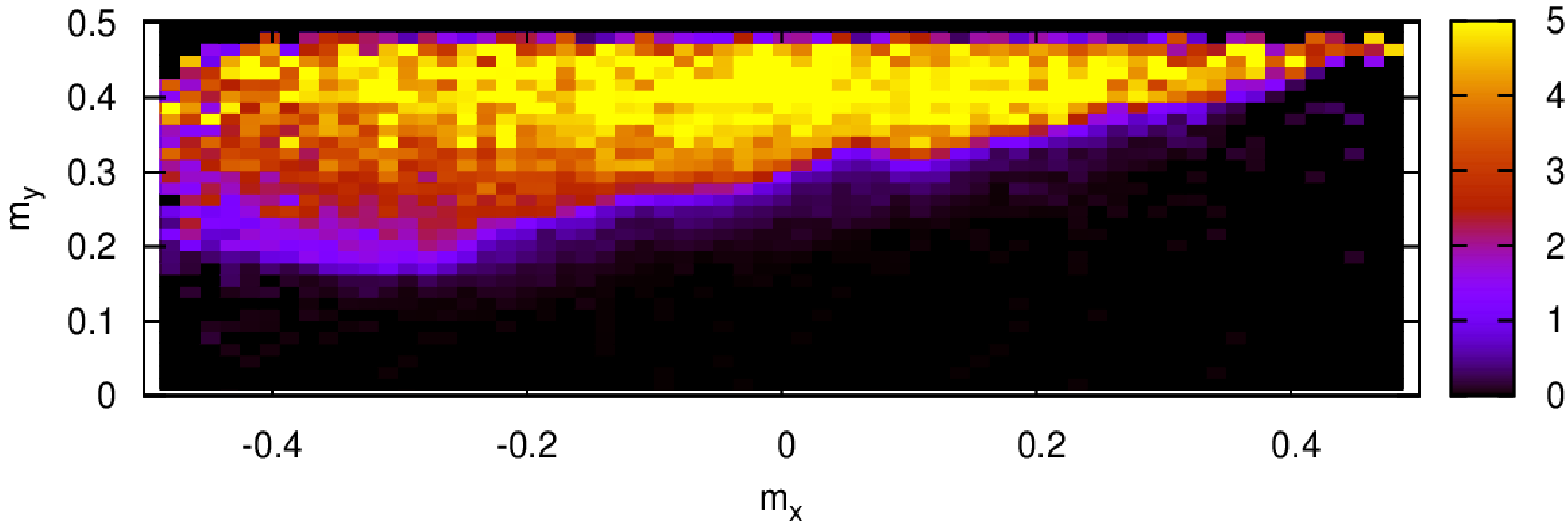
Muon Counts



- **Track selection:**
- ADC > 200
- Chi2/ndf < 1.5

- **Tracks visualize the ridge of the ophiolite with a slope binning of 15 mrad that corresponnds to 5 meters spatial resolution from a distance of 300 m**

Muon Flux



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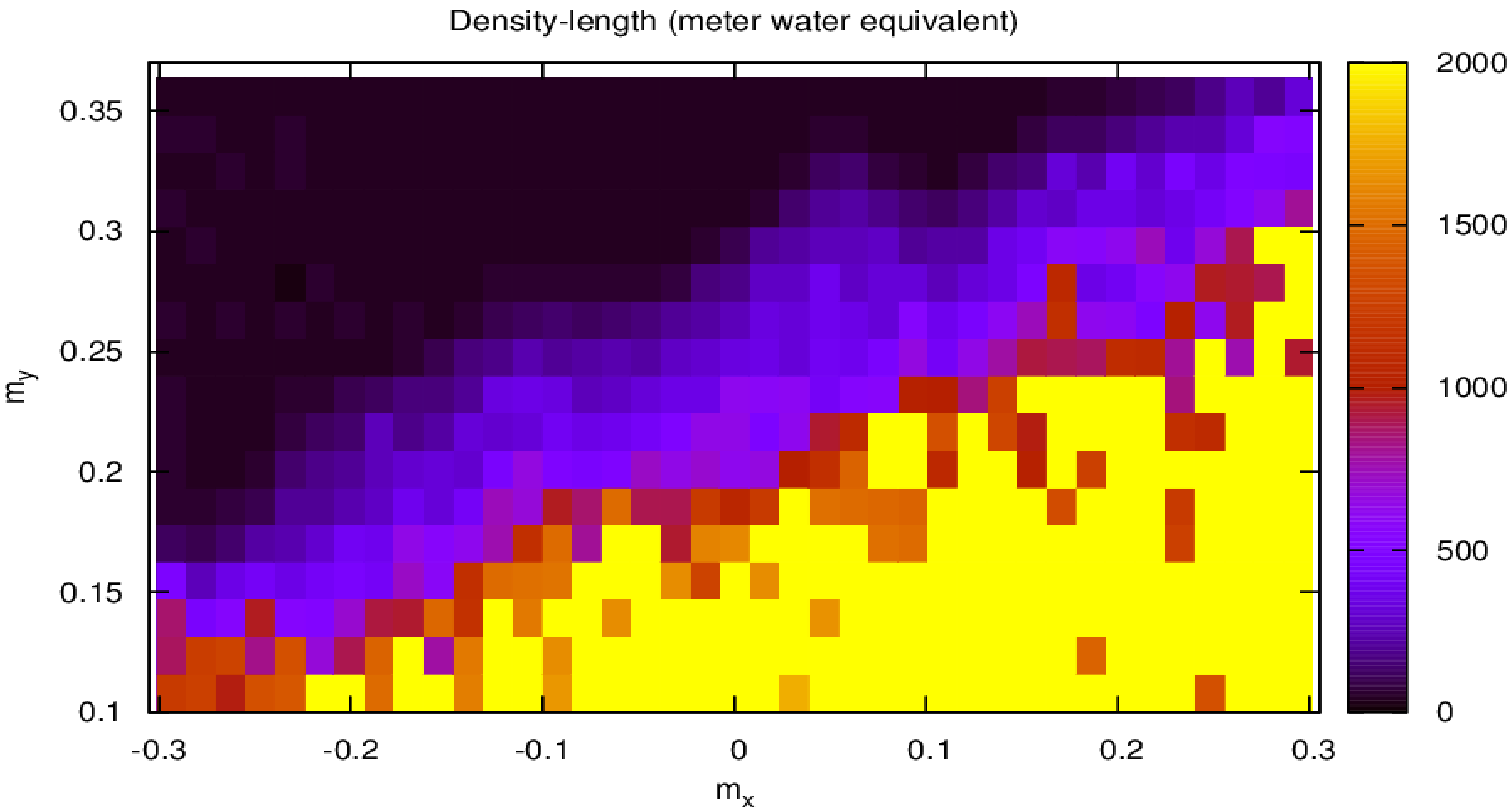
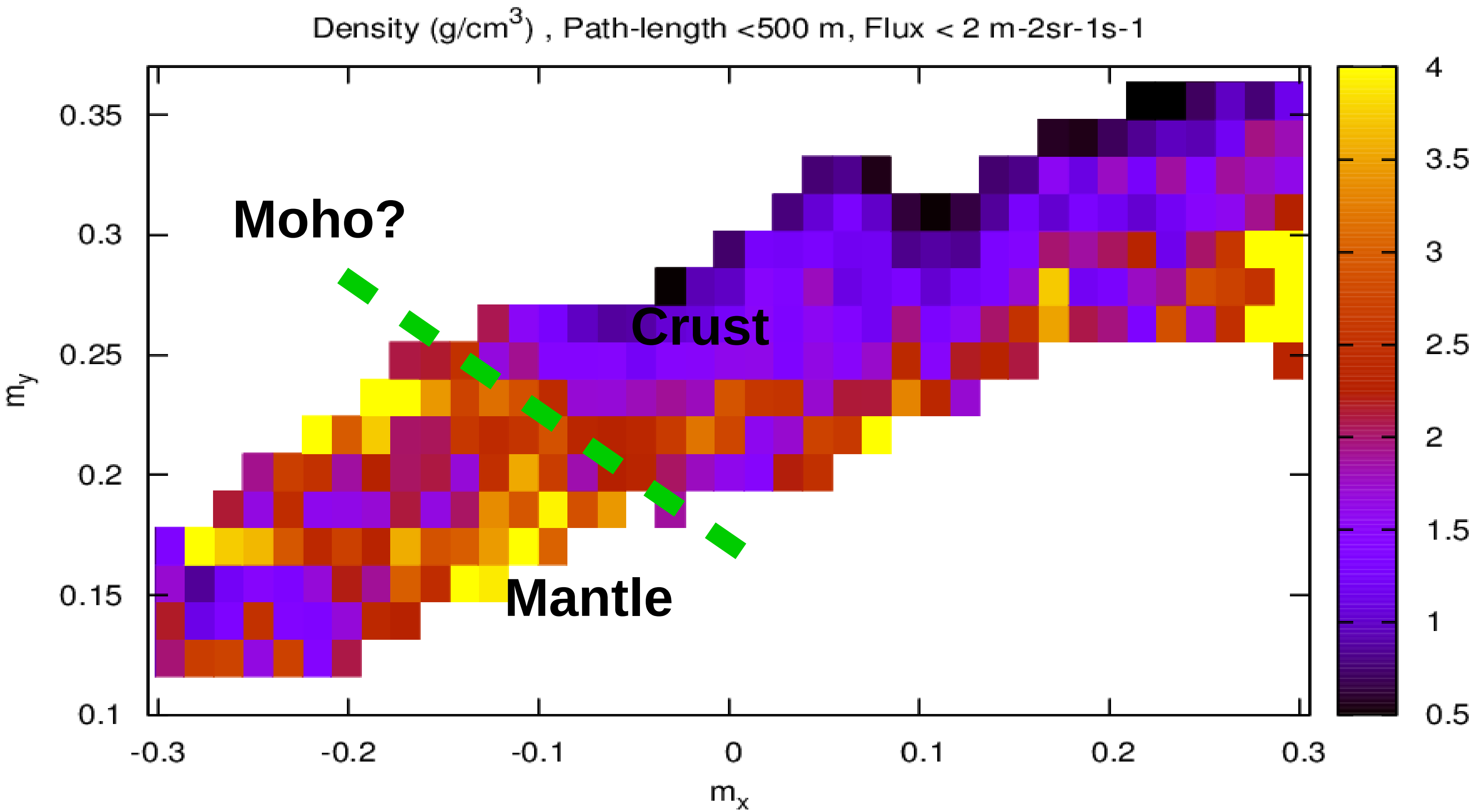
Density-Length Image

- Density-lengths determined by comparing measured and modelled (Modified Gaisser model) muon fluxes
- Mass densities = density-length / path-length



Very Preliminary
Mass Density Image

- Two regions can be distuinguished that may corresponds to mantle and crust



IV. Summary

- The geological nature of oceanic lithosphere is not fully understood
- Moho has not yet reached by ocean drilling → ophiolites can provide information
- Muography can extract density information from Ophiolites with a relatively good spatial resolution → comparison with seismic and later ocean drilling data will be possible
- Muographic exploration has been started at Wada Fizh in February 2024

L. Oláh, S. Umino, et al, “Plans for Muography of Samail Ophiolite”,
Journal of Advanced Instrumentation in Science, vol. 2024, no. 1, Feb. 2024.
http://journals.andromedapublisher.com/index.php/JAIS/article/view/499

Thank you for your attention!

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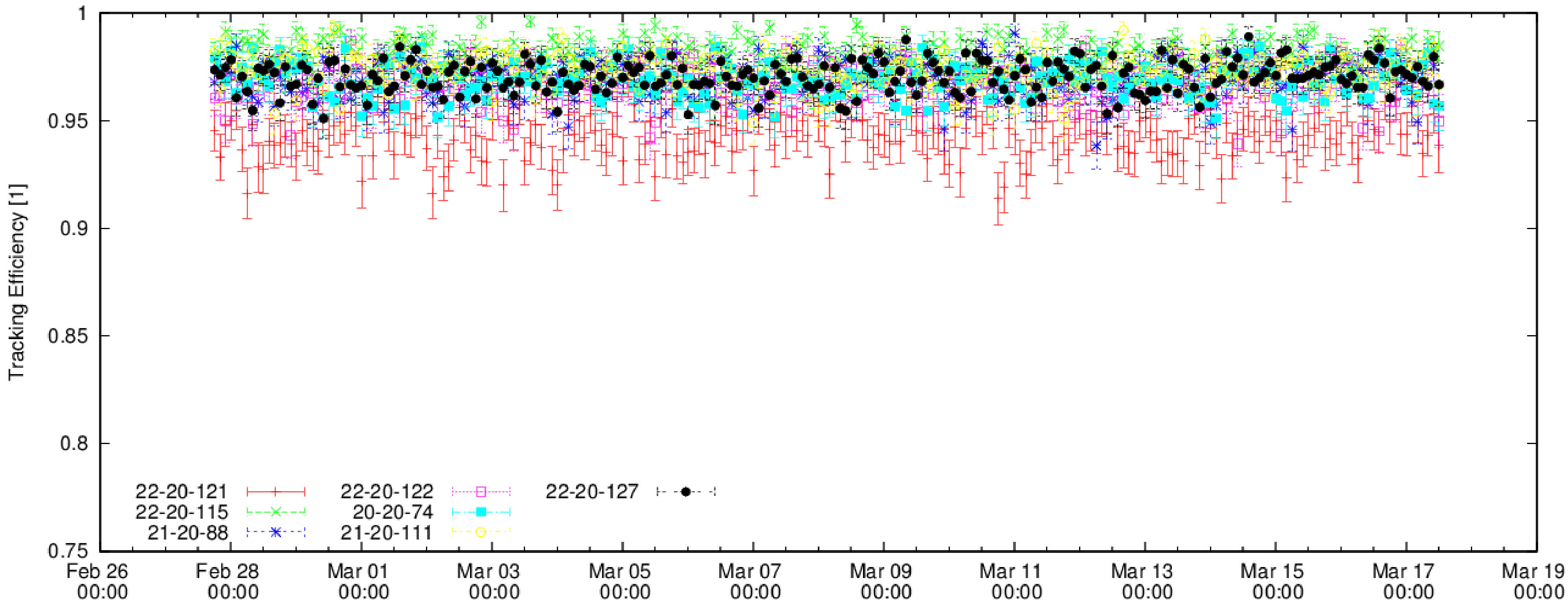
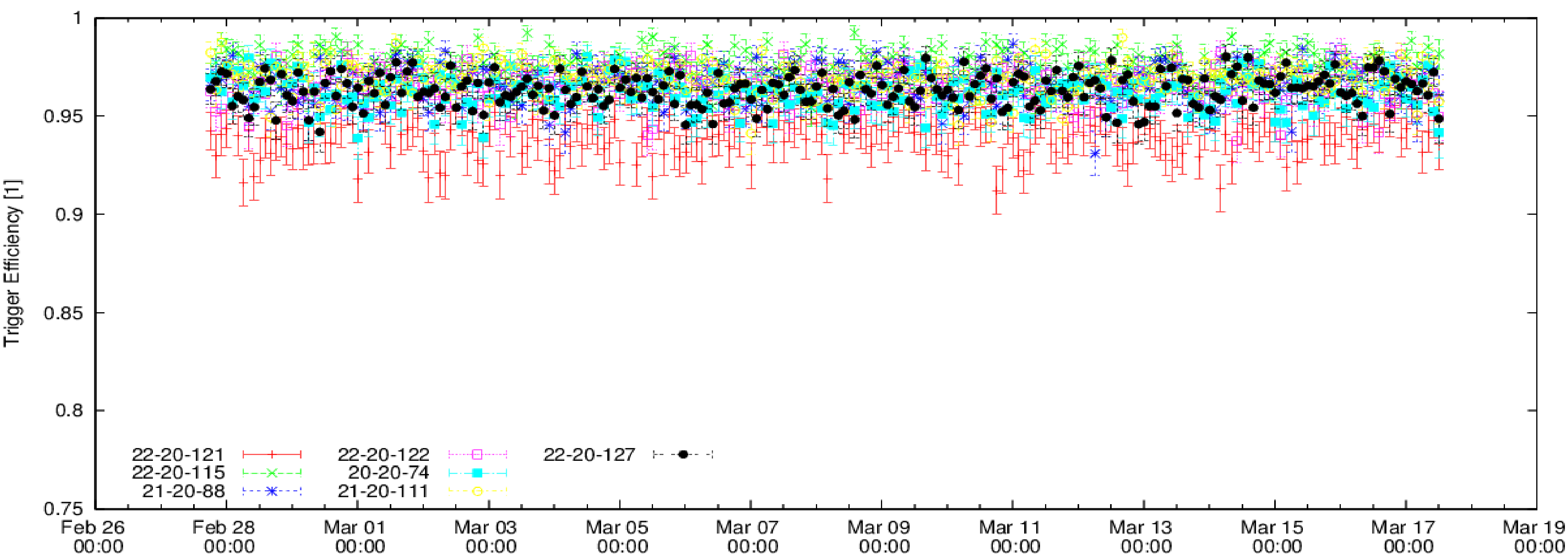
Backup slides



Tracking Efficiency [1]
1
0.95
0.9
0.85
0.8
0.75
22-20-121
22-20-115
21-20-88
22-20-122
20-20-74
21-20-111
22-20-127
Feb 26 00:00
Feb 28 00:00
Mar 01 00:00
Mar 03 00:00
Mar 05 00:00
Mar 07 00:00
Mar 09 00:00
Mar 11 00:00
Mar 13 00:00
Mar 15 00:00
Mar 17 00:00
Mar 19 00:00



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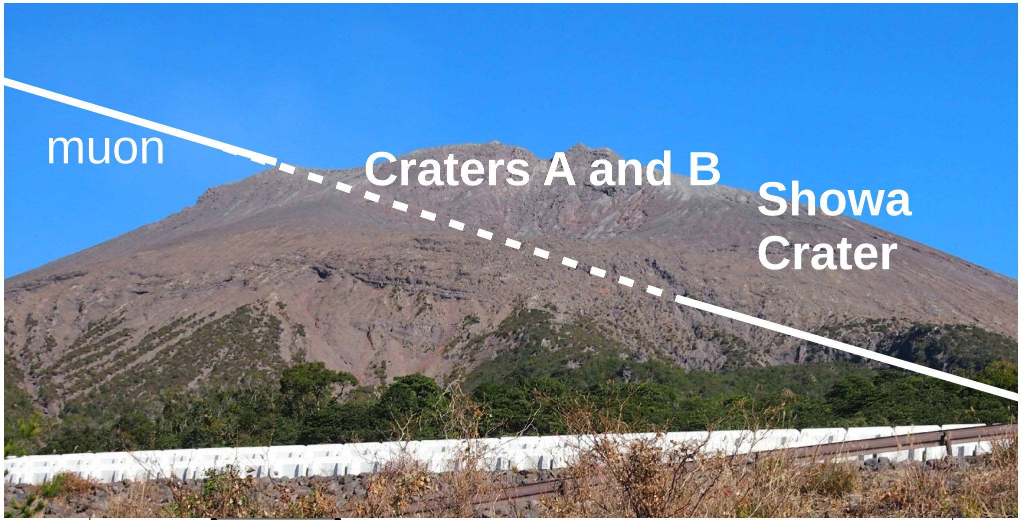
Mar 19 00:00

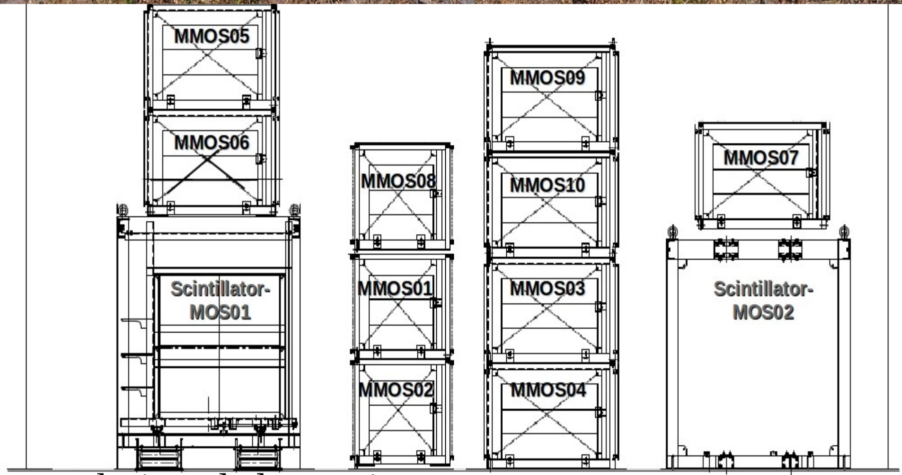
I. Research Infrastructures and Instrumentation

Vesztergombi High Energy Physics Laboratory (VLAB)
of HUN-REN Wigner RCP
→ Application oriented R&D of gaseous tracking detectors

International Virtual Muography Institute (VMI)
→ framework for data storage, monitoring and simulation

Muographic Observation Instrument (MOI)





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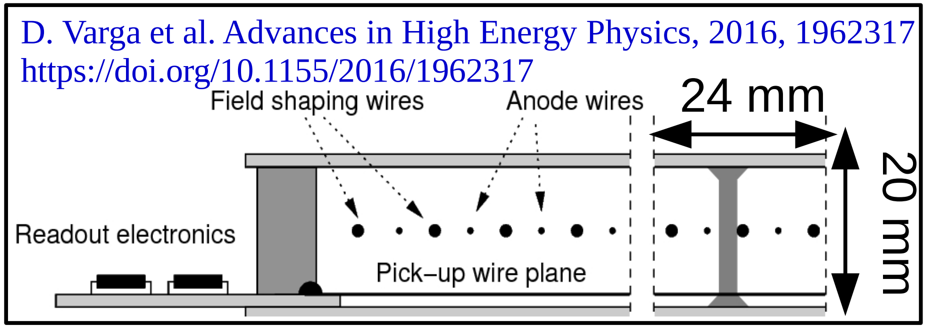

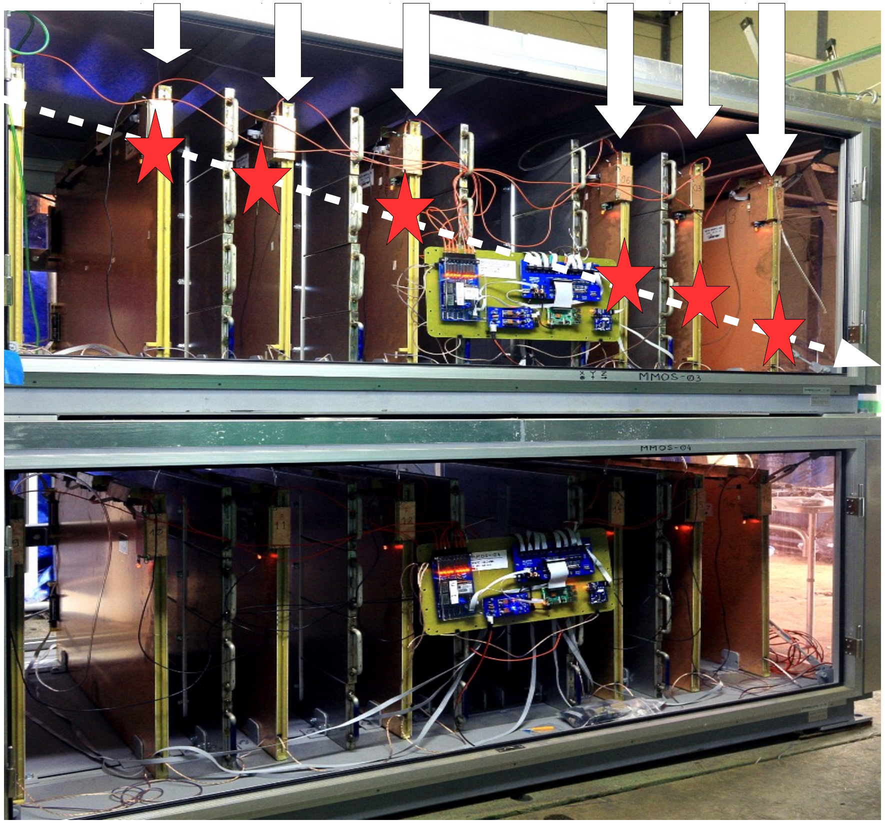

- Custom-designed electronics
- Micro-computer controlled
  → real-time DAQ & analysis
- Power consumption:
  ~ 6 W per MMOS

- **Modular infrastructure for volcano muography**
  (11 MWPC-based trackers cover10 sqm surface area)

L. Oláh et al. Scientific Reports, 8, 3207, 2018,
https://doi.org/10.1038/s41598-018-21423-9

Muograpic Observation Instrument WO2017187308
https://patentscope2.wipo.int/search/en/detail.jsf?docId=WO2017187308

D. Varga et al. Nucl. Instrum. Meth. A 958, 162236, 2020
https://doi.org/10.1016/j.nima.2019.05.077