Imaging Volcanoes with Cosmic Particles

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What is Muography?

Muography uses high-energy muons to image subsurface structures by detecting density variations

Muons are…

- Elementary particles originating from high-energy cosmic ray collisions in the upper atmosphere
- Either negatively or positively charged with a mass 207x greater than an electron
- Muon flux is ~90 1/m²/sr/s at sea level (Oláh et al., 2022)
- Travel close to the speed of light
- High-energy muons can penetrate kilometers of rock

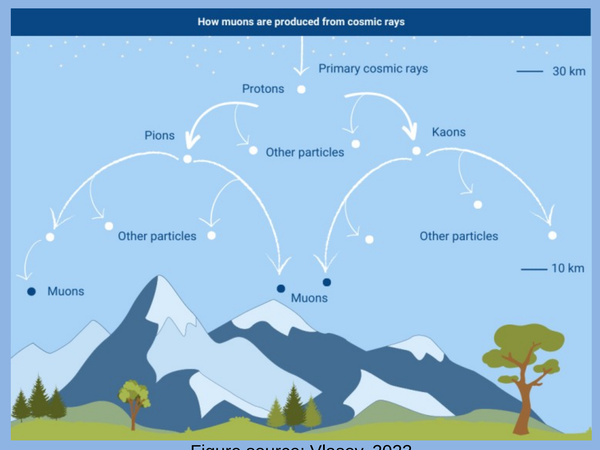


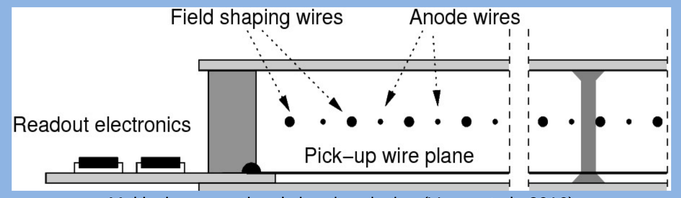
Figure source: Vlasov, 2023

Muography can passively ”X-ray” the Earth with resolution of a few meters

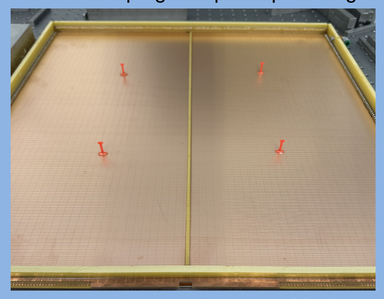
Detector Construction

Multi-wire proportional chamber construction:

- $ArCO_2$ gas mixture
- Two perpendicular wire planes spaced 12 mm with 4 mm 2D position resolution
- Multiple detectors are used for 3D positioning
- 1700 V applied on the anode wires for signal amplification
- Field-shaping and pick-up wires grounded



Multi-wire proportional chamber design (Varga et al., 2016)



An open 50 cm x 50 cm multi-wire proportional chamber

Detecting Steps

1. Muon enters detector
2. Ionization of gas
3. Gas Amplification
4. Position Measurement
5. Data Acquisition

Soldering channel readouts

Imaging Volcanoes

Why measure volcanoes?

- Muography is a non-destructive technique with meter-scale spatial resolution from kilometers away
- Volcanoes have high density contrasts
- Temporal range can investigate subsurface changes
- 800 million people live within 100 km of an active volcano (Brown et al., 2015)

Imaging the interior of a volcano using muography can help predict future eruptions, as changes in muon flux offer valuable insights into internal magma movement.

Sakurajima Volcano

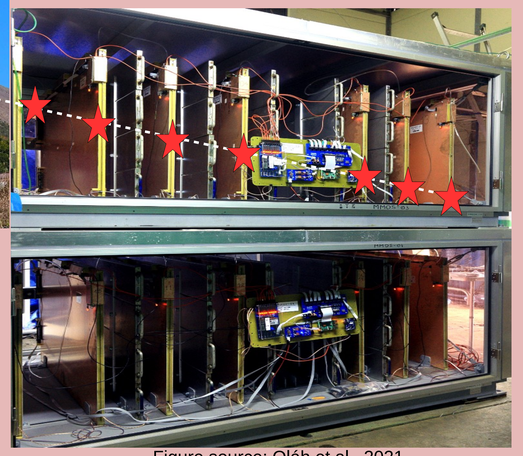
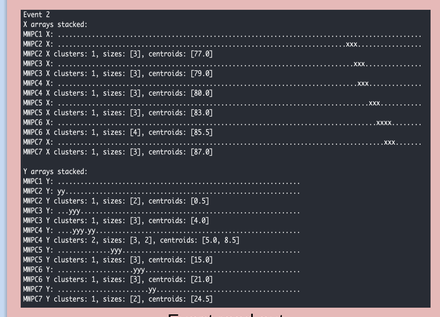


Figure source: Oláh et al., 2021

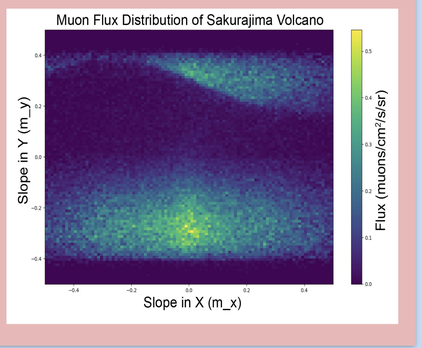
- Active stratovolcano in Kyushu, Japan
- Two eruptive craters
- Next large eruption is expected in 25 years
- University of Tokyo and Wigner Research Center for Physics have conducted muography here since 2017 (Oláh et al., 2018)



Event read out

What do we record?

- Time of event
- Channels hit
- Slope of muon trajectory
- Number of events per bin



Measuring the muon flux over time reveals areas with internal density variations within the volcano.

Future perspectives

- Enhancing image reconstruction techniques for greater clarity and precision
- Integrating machine learning for eruption prediction

Muography can be used on a variety of Earth structures including caves, hurricanes, glaciers, and archaeological sites.

Citations

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