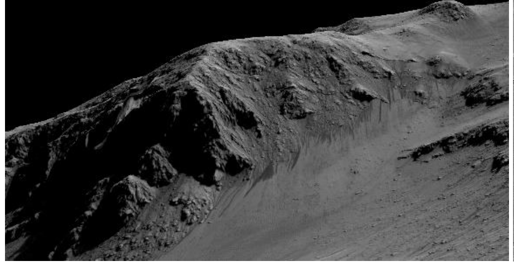
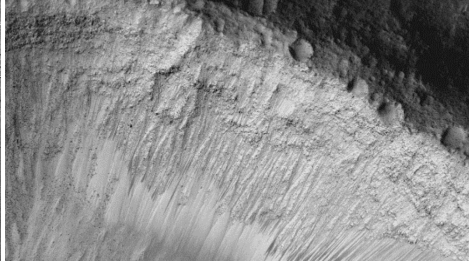
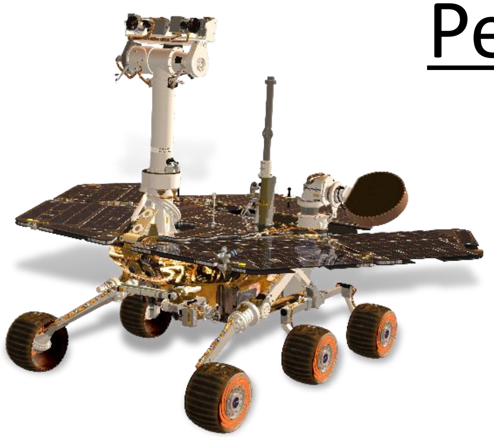




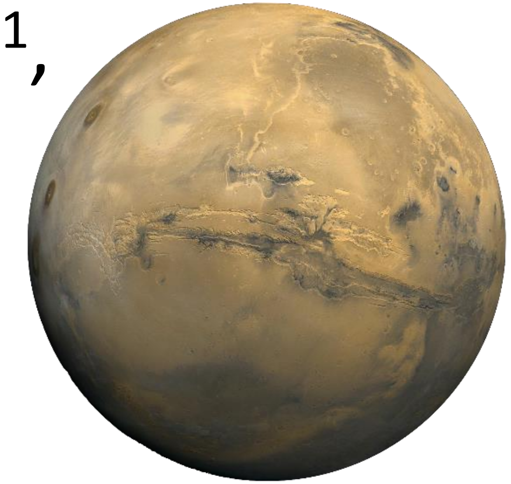
Muography for Future Mars Mission



Peng Hong[1]*, Yukito Koike[1], Hiroyuki Tanaka[1], Hideaki Miyamoto[1,2], Masanobu Ozaki[2]

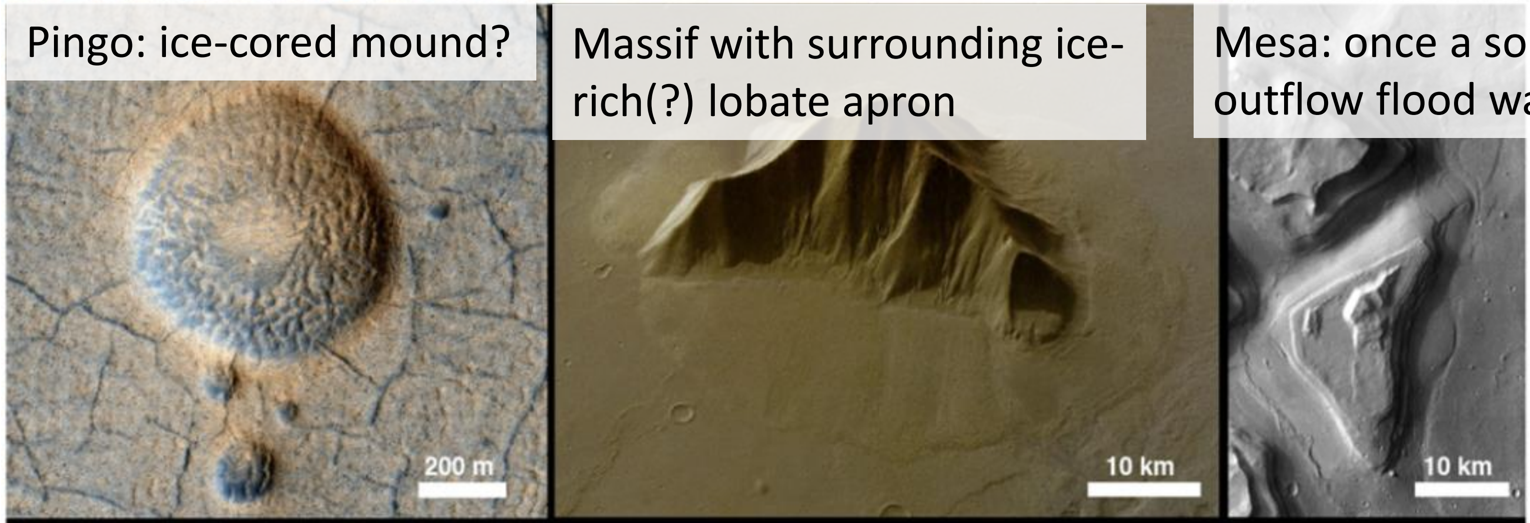
[1]The University of Tokyo

[2]Japan Aerospace Exploration Agency

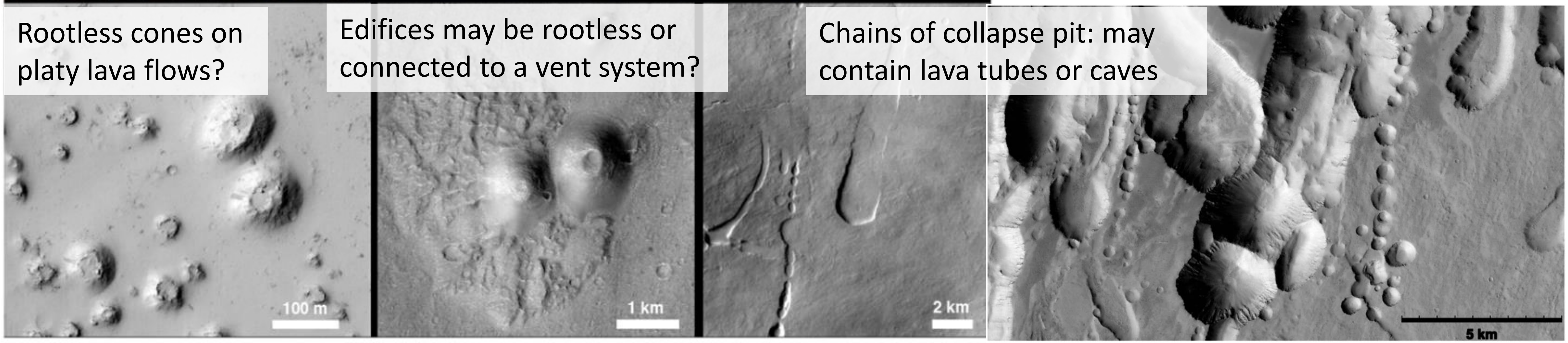


MUOGRAPHERS 2017 General Assembly at the Embassy of France, Tokyo (October 2nd, 2017)

Interesting Martian Geological Features



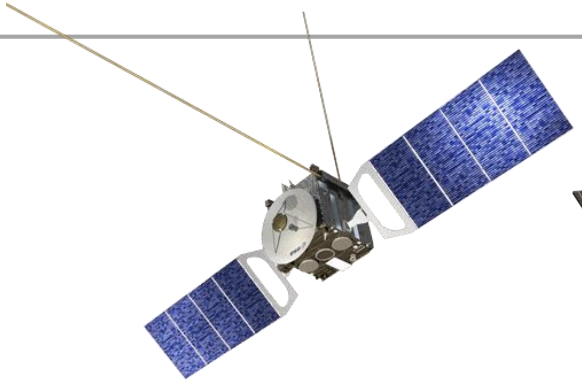
- Indication of persistent aqueous activities
- Important for planetary science and astrobiology

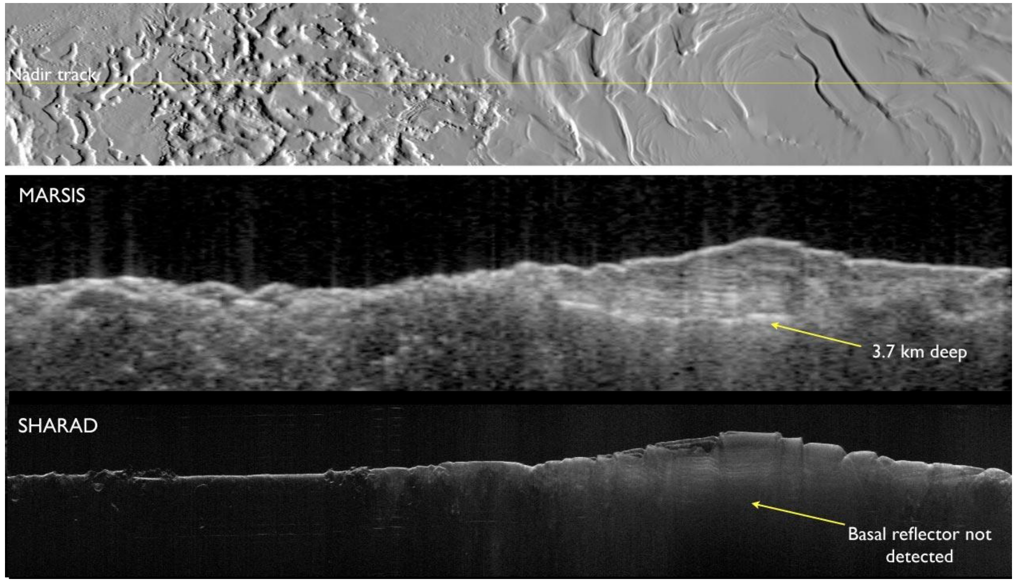


(Kedar et al., 2013)

Previous Observations of Martian Subsurface Structures

- Seismic tomography
  - Few seismic events on Mars
  - Low spatial resolution
- Ground penetrating radar
  - Requiring a large antenna and power source for observation of rocks
- Microgravimetry surveying and Magnetic surveying
  - Requiring detector being physically near the target



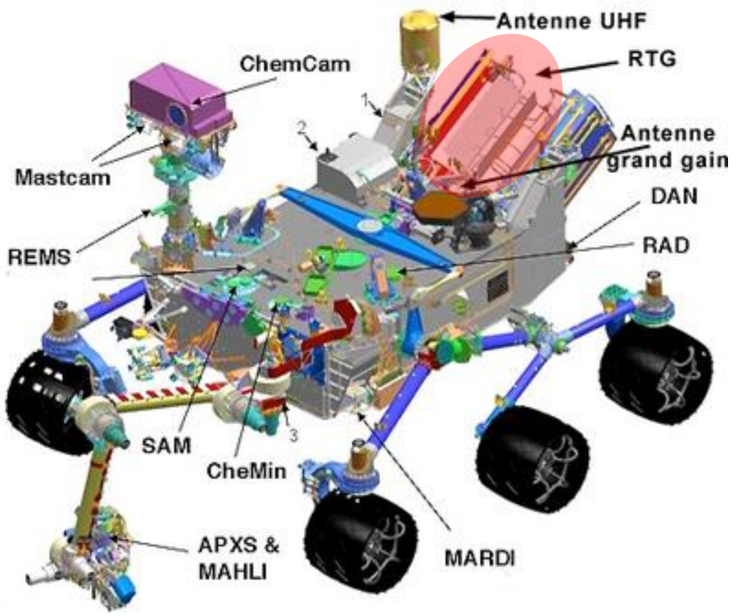


South polar layered deposits on Mars explored by two different ground penetrating radar sounders

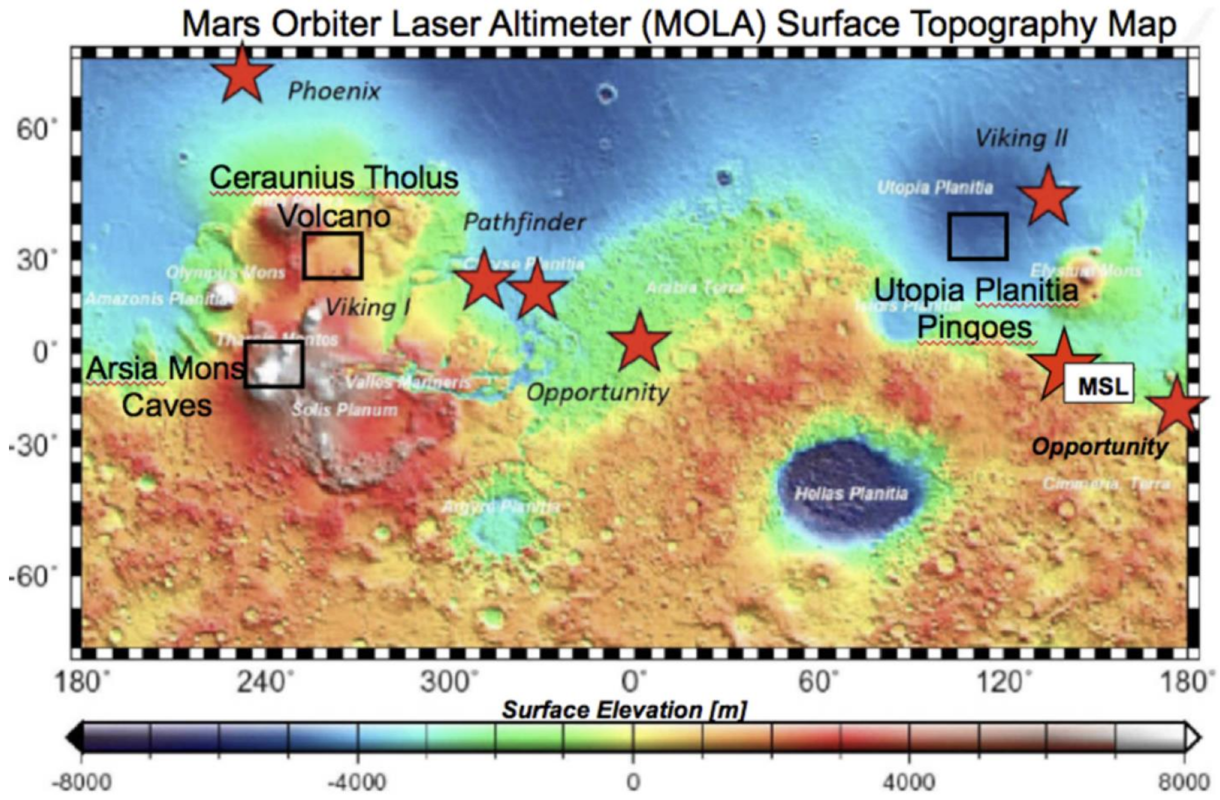
Image credit: NASA/ESA/JPL-Caltech/University of Rome/Washington Universtiy in St. Louis

Advantages of Muography on Mars (Kedar et al., 2013)

- Low power consumption (e.g., Tanaka, 2012)
  - muography: 2-3 W
  - Mars Science Laboratory Radioisotope Thermoelectric Generator power production: 110 W
- Extremely low data rate for transmission
  - A density profile: a few kilobytes
- Flexible implementation
  - Passive detector with no moving parts
  - Weak pointing requirements
  - Relatively low computational and processing requirements

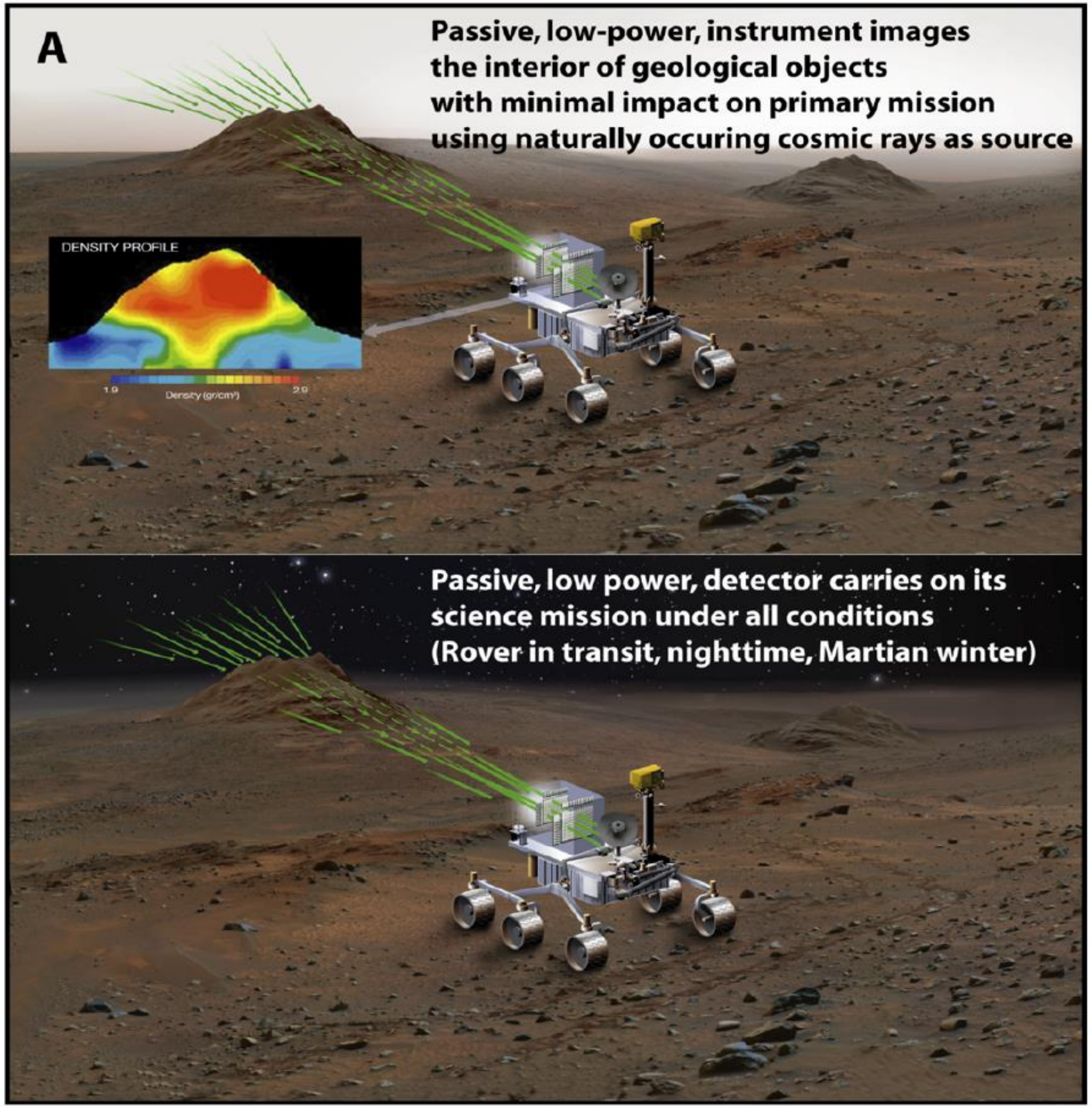


Concept of Muography for Future Mars Mission



Black rectangles show geological regions of interest for future Mars muography mission

(Kedar et al., 2013)

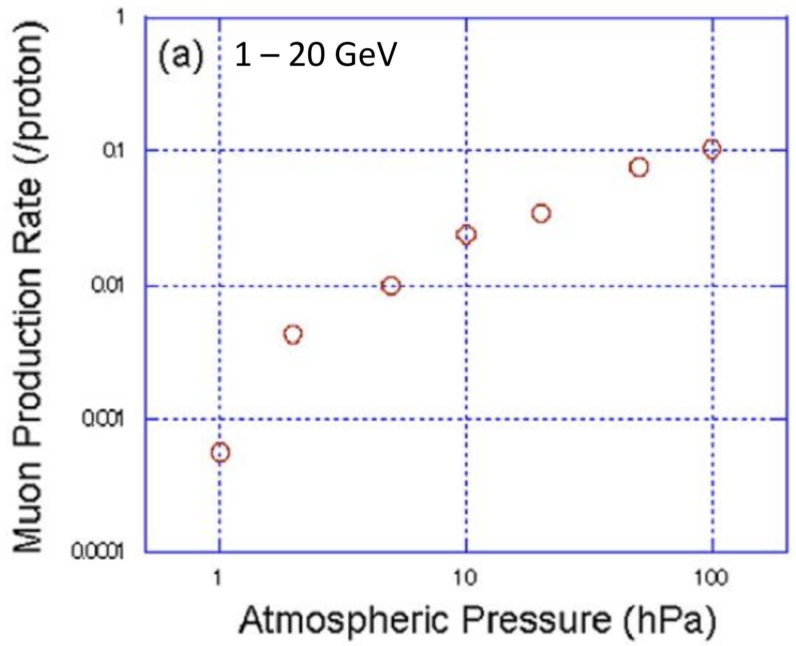


(Kedar et al., 2013)

Obstacles for Muography on Mars

- Less production rate of muon due to the thin atmosphere
  - Mars: ~ 7.6 hPa, Earth: ~ 1000 hPa
- Significant noises due to protons and other cosmic rays on martian surface
- Small sensitive area of detection system resulting in low count rate

Feasibility assessment is required



(Tanaka, 2007)

Depth (hPa)	7	100	200
Proton ($m^{-2}s^{-1}sr^{-1}$)	9000	5000	2000
$\pi^{+/-}$ ($m^{-2}s^{-1}sr^{-1}$)	2	10	8
$\mu^{+/-}$ ($m^{-2}s^{-1}sr^{-1}$)	40	200	300

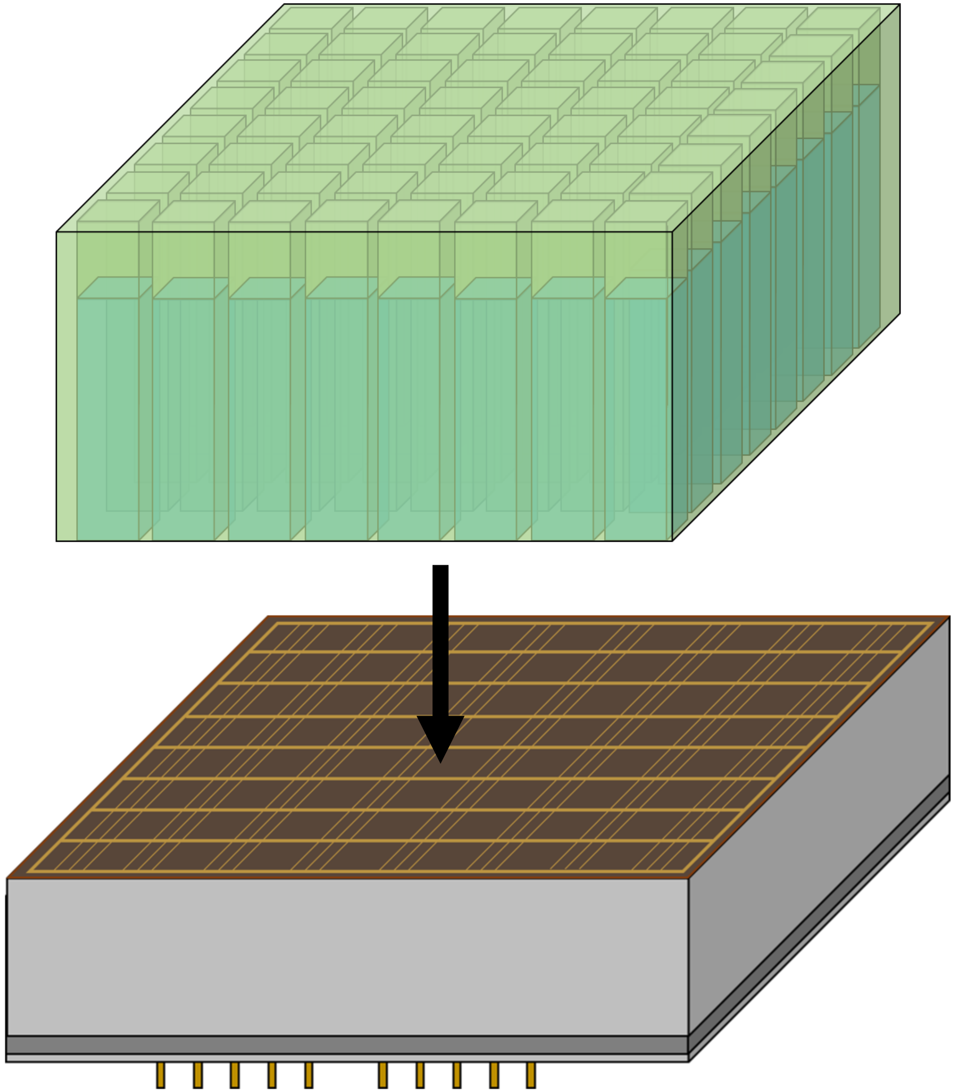
Vertical flux of particles on the surface of Mars

(Keder et al., 2013)

Objectives of Our Study

- Testing the feasibility of ultra-small muography system for future Mars mission
  - Building laboratory system to test the feasibility
  - Simulating operation on Martian surface using the developed ultra-small muography system
- Application of such ultra-small muography system would not be limited only for Mars
  - Can be used for other planetary missions (e.g., asteroids (Prettyman et al., 2013), Phobos (Miyamoto et al., 2016)) and terrestrial subsurface exploration

Building Small Muography System



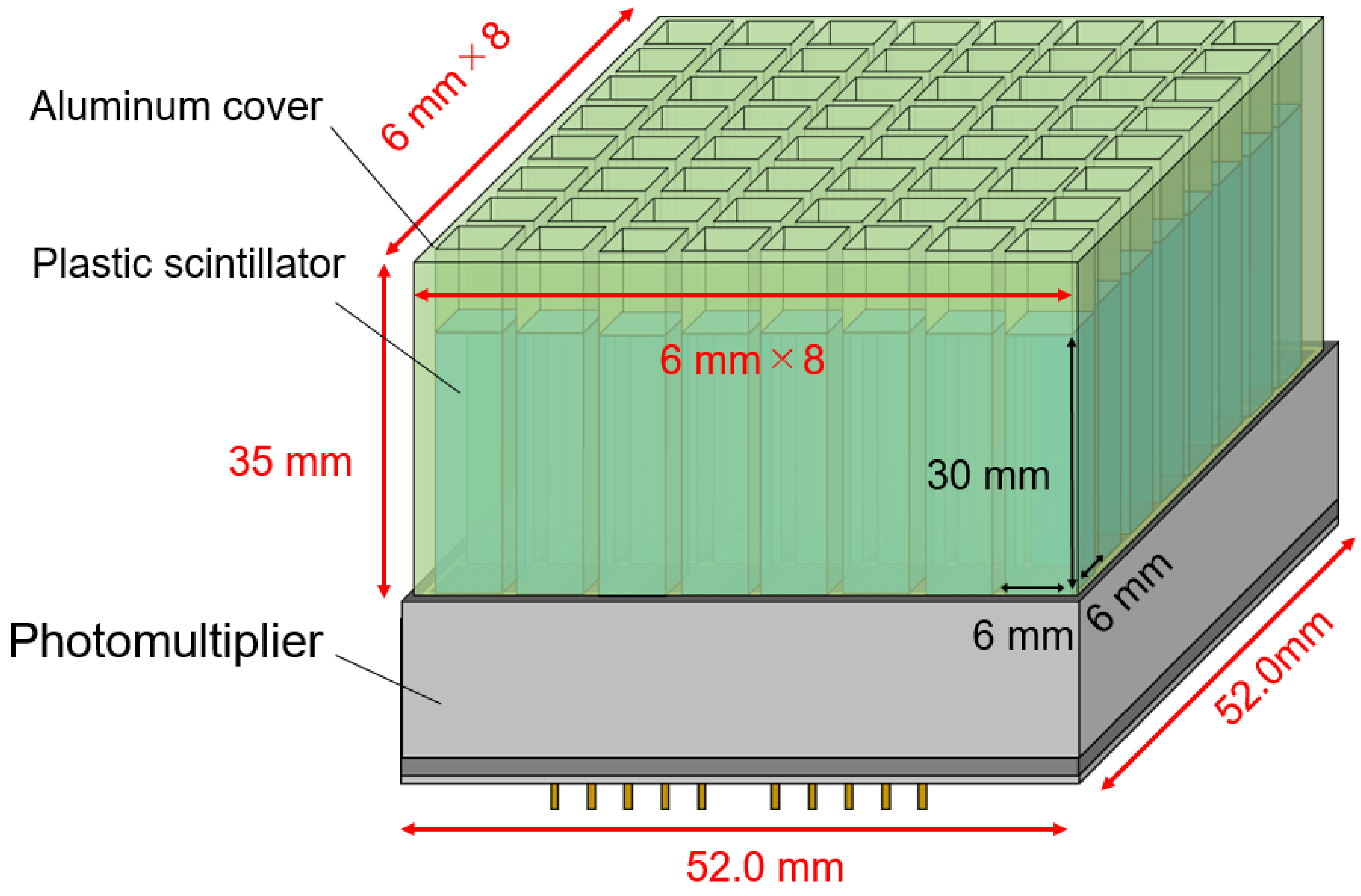
Plastic scintillator
(ELJEN EJ-200)

- Each scintillator is coated with Titanium reflector
- Top space is filled with black silicone rubber

Photomultiplier
(Hamamatsu H12700)

- 52 mm square
- Bialkali photocathode
- 10-state 8 × 8 multianode

Building Small Muography System



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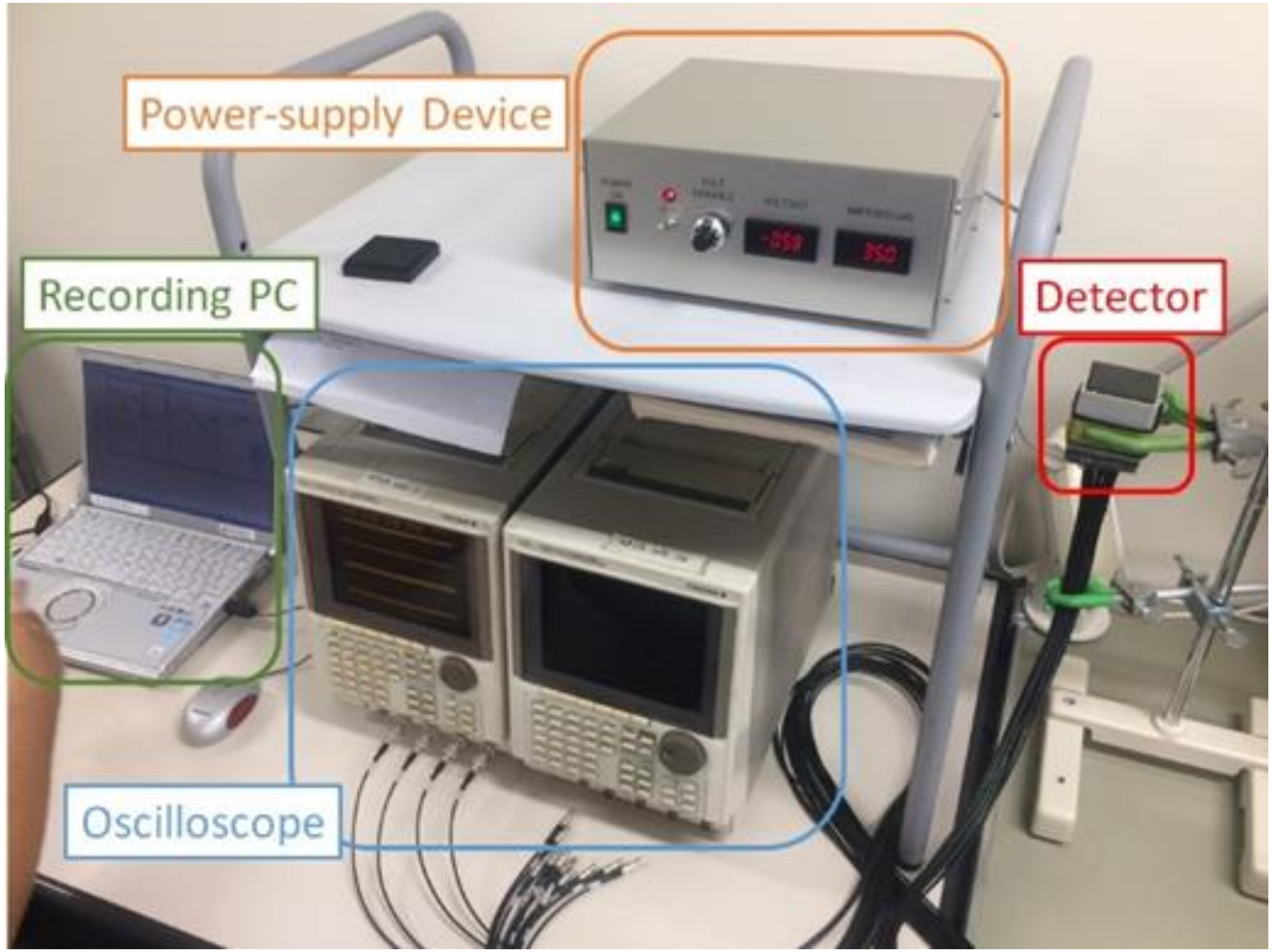
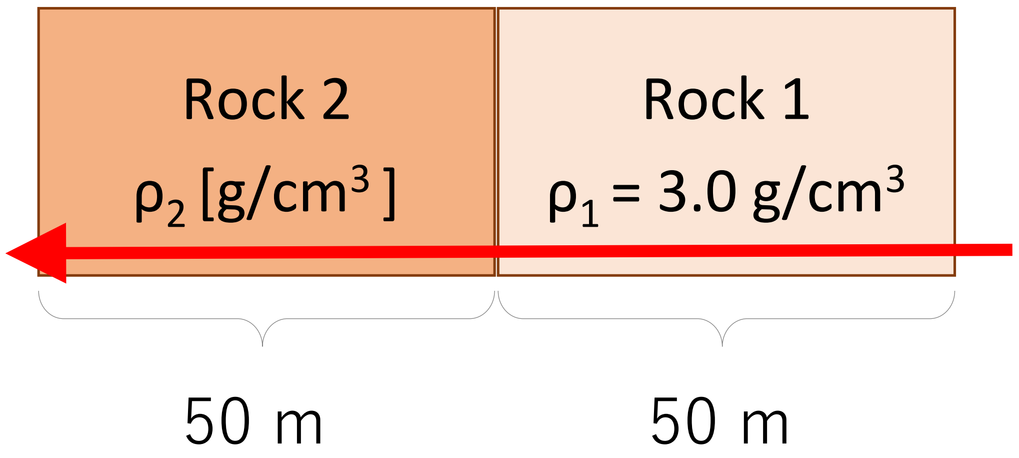
Current Status of Experimental System



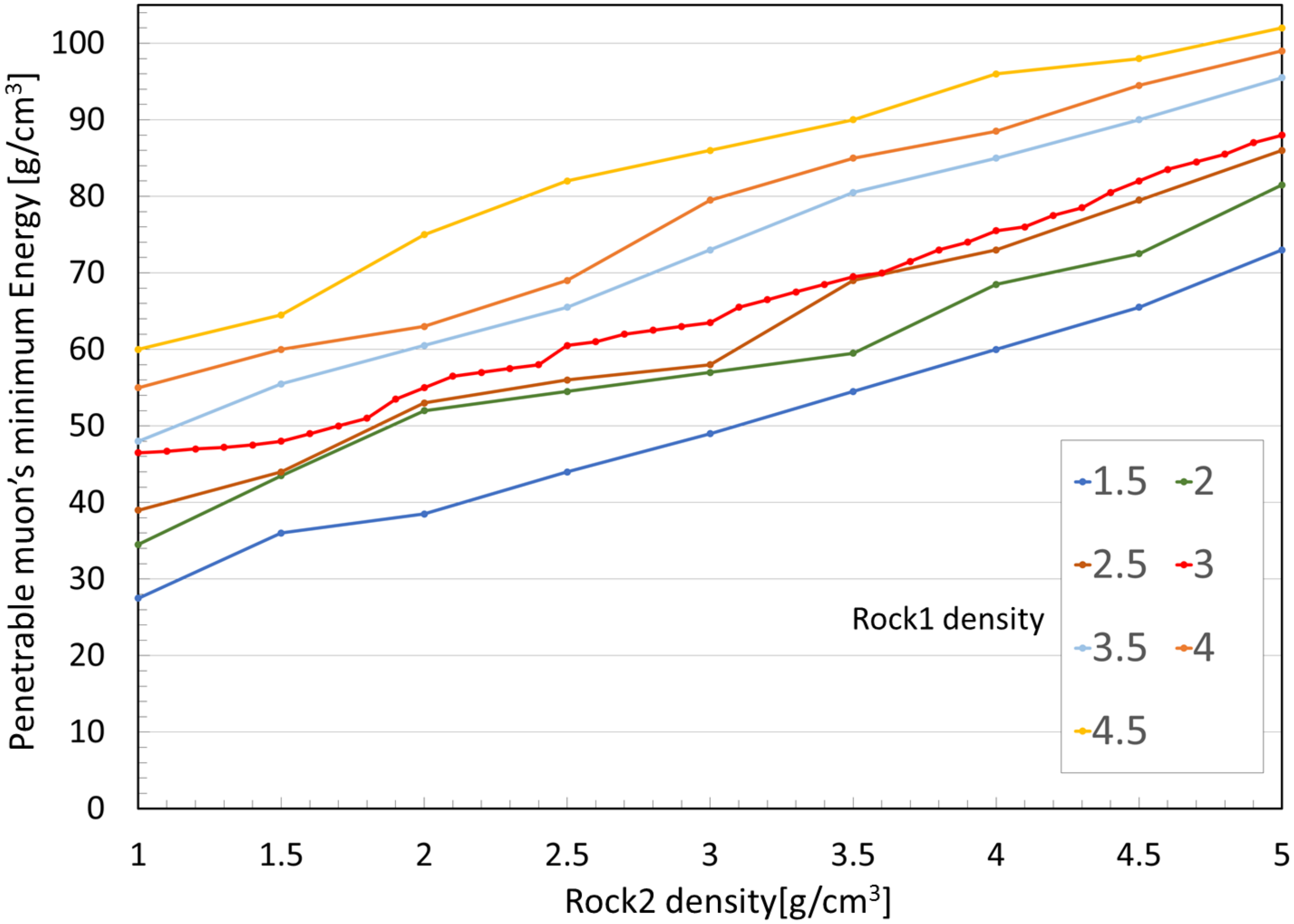
- The detector is very sensitive to surrounding magnetic field such as from HV power and human
  - We are planning to reduce the influence of surround magnetic field
- We have not detected muons yet, partially because oscilloscopes are too old
  - Frequency may not be sufficient to detect muon event
  - A new oscilloscope will be arrived tomorrow

Theoretical Calculation using Geant 4 Simulating Operation on Martian Surface

Calculating muon's energy loss processes passing through rocks



$$\frac{dE_\mu}{dX} = [\underbrace{1.88 + 0.077\ln\left(E_\mu/M\right)}_{\text{ionization loss}} + \underbrace{3.9E_\mu}_{\text{bremsstrahlung + direct pair production + photonuclear reaction}}] \times 10^{-6} \ \text{TeV / (g/cm}^2\text{)}$$



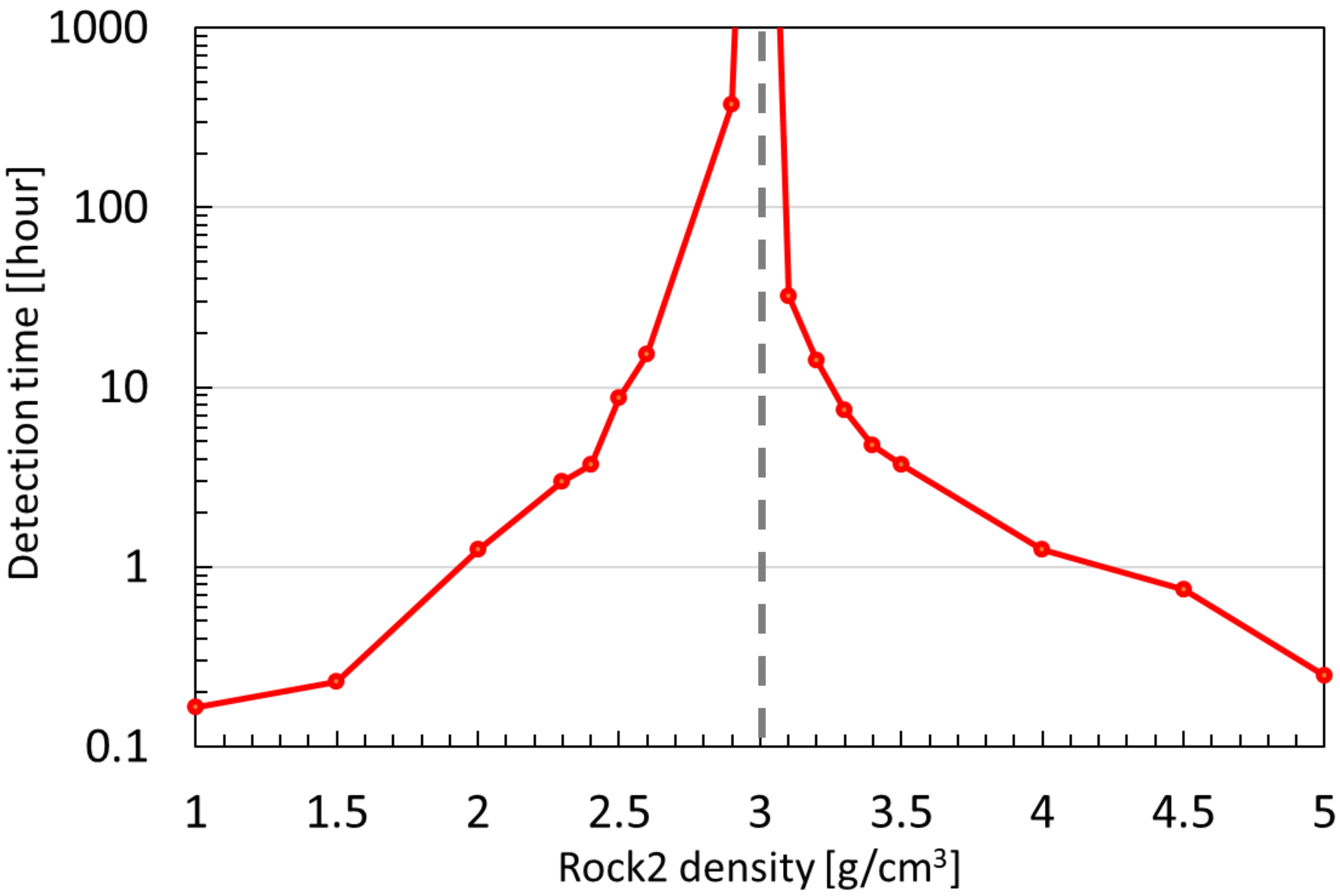
Muon's minimum energy required to penetrate rocks having an average elemental composition for martian rocks (Gellert et al., 2004)

Theoretical Calculation using Geant 4 Simulating Operation on Martian Surface

Preliminary calculations show that muography may be able to detect density distribution within two weeks of observation time for a 100 m size rock

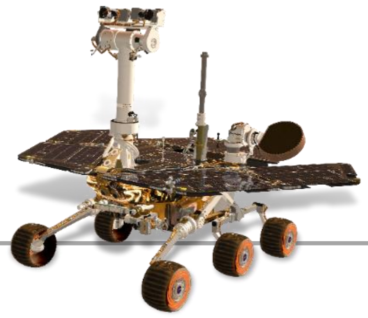
*Assumptions

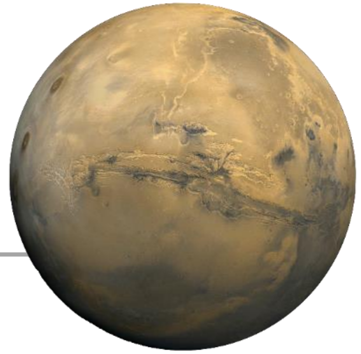
- No noise due to other cosmic rays
- Proton flux on Mars is similar to the Moon
- Dependency of muon production rate on incident proton energy is ignored



Detection time observing a 100 m size rock from a distance of about 60 m (solid angle 0.84 sr)

Summary





- Muography for future Mars missions have been proposed
- We are testing the feasibility of ultra-small muography system for future Mars mission
  - Building laboratory system
  - Simulating operation on Martian surface using the developed ultra-small muography system
- Preliminary calculations show that we may be able to detect density distribution within a realistic observation time using the ultra-small muography system