

Development of an ultra-small Muography instrument prototype for future planetary missions

*Yukito Koike¹, Peng Hong¹, Hiroyuki Tanaka¹, Hideaki Miyamoto¹

1. Tokyo University

"Muography" is a technique for visualizing the density distribution of massive objects using elementary particle muons generated by the interaction between cosmic rays and atmosphere's gas molecules. Muography has been used for the exploration of internal structures such as terrestrial volcanoes, caves (Tanaka et al., 2007), nuclear reactors (Normile, D. 2015), and pyramids (Morishima et al., 2017). In principle muography can be used anywhere if there is an environment where muons are produced. Several targets have been proposed for planetary missions including martian surface (Kedar et al., 2013), small bodies (Prettyman et al., 2014), and martian satellites (Miyamoto et al., 2016). Exploring the structure of the shallow subsurface of small bodies is necessary to understand the origin and evolution. However, conventional methods such as ground penetrating radar and seismic tomography have constraints on targets and there is a tendency for the instruments to become huge and complicated. Compared with those conventional methods, muography has several advantages such as low power consumption, small and light instruments, low data rate for transmission, and passive detector with no moving parts (Tanaka, 2012; Kedar et al., 2013).

In order to perform muography observation in solar system exploration, miniaturization of devices is necessary for the instruments to be on board spacecraft. However, as the device is downsized, light receiving area of the detector becomes small, so detection efficiency of muon decreases. Because of this obstacle, an ultra-small muography device designed for a future planetary mission has not been developed thus far. In this study, based on the recent technological advancement in terrestrial muography observations, we designed and developed an ultra-small muography instrument prototype for future planetary missions.

A detection device for the small muography instrument consists of a 64-channel multi-anode photomultiplier tube, plastic scintillators, and a high-voltage power supply unit. Incident muons react with the scintillator to emit weak light and the light is amplified by the photomultiplier and read out with an oscilloscope. The size of the detector developed is 4 cm × 4 cm × 7 cm, and its weight is about 500 g. The detection unit was performed with -0.8 kV of supply voltage and 35.0 μ A of current, resulting in a power consumption of 0.03 W.

We operated a prototype with the trigger level of oscilloscope being -60 mV and performed four cases of experiments, changing the direction and distance of the two detectors as well as shielding effect by a lead plate. the experiment in used detectors installed vertically with a narrow spacing which is a similar setup with the planned muography observation on martian surface. We detect 11 particles using one pixel of 64 pixels of the detectors. The signal peak obtained was -500 to -150 mV. Therefore the detection rate of particles that would be obtained by the whole device (64 pix) is 138.24 ± 41.60 / day, which is consistent with the vertical muon intensity on the ground (7.3 ± 0.1) / cm² / day / sr (S.Fukui et al., 1976). By inserting a lead plate between the two detectors, signal count rate decreases to 70 % , which is consistent with expected muon detection rate with a lead shield 75 % (Chronological Scientific Tables, 2014). Based on these results, we confirmed that the ultra-small muography developed by this study can actually detect muons.

We also performed theoretical calculations in order to evaluate whether the developed device can detect a density difference of rocks within a realistic time period under martian surface. We assumed a 100 m size rock with an average elemental composition of martian rocks (Gellert et al., 2004). We changed the

density of one side half of the rock from 1.0 to 5.0 g / cm³. We found that the minimum muon energy required to penetrate the rock is 46.0 ~ 88.0 GeV. This suggests that assuming a Poisson distribution for the dispersion of muon detection rate, the ultra-small muography device developed in this study could detect the density difference of 0.1 ~ 2.0 g/cm³ within an observation time between 0.5 to 16 days on martian surface.

Keywords: muography, Mars, muon, planetary mission