Development of a compact Muography instrument for future Mars exploration missions

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Muography is a technique that uses cosmic ray muons for visualizing the interior of large-scale structures in much the same way as standard X-ray radiography is used to image the interior of smaller objects. Muography has been successfully applied to explore the internal structure of geological targets on earth. Because exploring the inner structure of the shallow subsurface of celestial bodies is important to understand their origin and evolution, we are planning to operate muography instrument in the extraterrestrial environment, especially on the surface of Mars. Applying muography to planetary explorations has some advantages over conventional internal exploration methods: (1) it is able to observe the absolute linear density of objects; (2) the passive nature of the measurements provides low power consumption; (3) the instrument size is arbitral [1]. However, in order to mount muography instrument on a spacecraft, it is essential to downsize the instrument and investigate the radiation environment on the surface of the celestial body. In this study, we designed and developed a compact muography instrument based on the knowledge of compact gamma ray detectors for nuclear medicine imaging. At the same time, we theoretically estimated the muon production on Mars and evaluated the validity of using muography instrument on Mars.

The detection device of developing muography instrument consists of 64-channel silicon photomultipliers (SiPM), plastic scintillators, dynamic Time-Over-Threshold (dTOT) boards [2], data-acquisition (DAQ) board, and high-voltage power supply units. Incident muons react with the scintillator to emit weak light, and the light is amplified by SiPM attached to the both ends of the scintillator and read out with dTOT boards. The depth of interaction (DOI) in the scintillator is analyzed by measuring the pulse-height ratio of dual-sided readout. The size of the detector is 26.2 mm×26.2 mm×31.4 mm.

We first evaluated DOI resolution of this detector using a point beta-decay source of ^{90}Sr. The result indicates that the DOI resolution (FWHM) is 7.2 mm for the emitted beta rays with a spread of 2.2 mm. Then, we performed a Geant4 [3] simulation to examine the muon angular distribution that would be detected on the ground by this instrument. The result suggests that the structure of the detector makes the observation bias (Fig. 1). There are two solutions that can be considered to solve this problem: (1) developing one more detector and analyzing the coincident signals from dual-sided readout; (2) improving DOI resolution by performing accurate calibration.

We also performed a theoretical estimation to evaluate the muon production on Mars. Although the chemical composition and the density of Martian atmosphere are different from Earth's, the known muon flux in the upper earth atmosphere can be used for estimating the muon rates on Mars [4]. The result shows that the horizontal muon flux is greater than that on Earth (Fig. 2), which means that muography is more suitable for exploration of geological targets on Mars than on Earth.

In this presentation, we report the development status of the detection device and the concrete result of numerical calculation of radiation environment on Mars.

References
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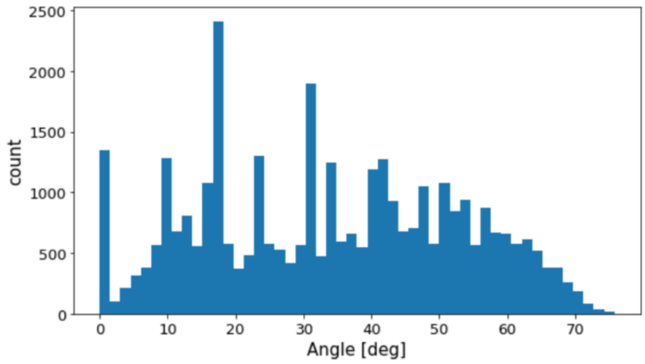

Fig. 1 The simulation result of muon zenith angular distribution that would be detected by developing instrument. The structure of detector makes the observation bias at 0°, 17° and 31°.

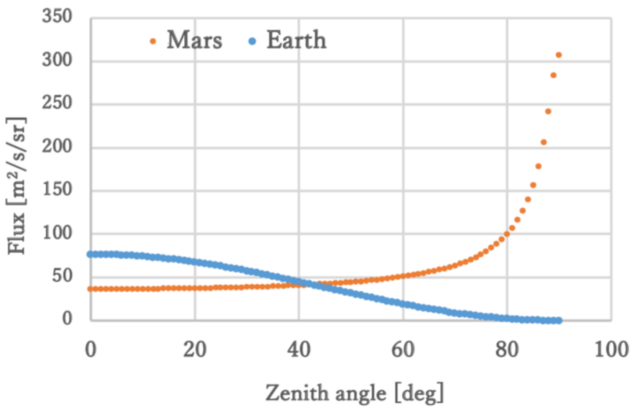

Fig. 2 Zenith angle dependence of muon flux on Mars and Earth. Horizontal muon flux on Mars is greater than that on Earth.