PROCEEDINGS OF SCIENCE

Moon Moisture Targeting Observatory (MoMoTarO) for basic science application to neutron lifetime measurement

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With the international trend of the lunar exploration including the ARTTEMIS Plan, we are focusing on the lunar water resource exploration and the neutron lifetime measurement around the Moon by the radiation measurement of neutrons. We are developing a radiation monitor for neutrons and gamma rays, the Moon Moisture Targeting Observatory (MoMoTarO), which is mounted on a lunar rover or a lunar orbiter. The non-contact water exploration without excavation can be realized by measuring the difference in the number of thermal or epi-thermal neutrons depending on water content. The MoMoTarO can also challenge the measurement of the neutron lifetime and the gamma-ray bursts around the Moon. The MoMoTarO is in the process of developing a laboratory model and designing a space-environment model.

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1. Introduction

Since the water on the Moon has been discovered [1], the human exploration of the Moon is becoming the major trends of the space exploration, including the ARTEMIS Project [2]. We are planning a new project, the Moon Moisture Targeting Observatory (MoMoTarO), a radiation detector for neutrons and gamma rays to be mounted on a lunar orbiter or rover. The MoMoTarO aims to explore and discover water resources on the lunar surface, to derive the neutron lifetime by a new method, and to pioneer the lunar astronomy by the gamma-ray burst observation.

On the lunar surface, fast neutrons are produced by nuclear reactions with galactic cosmic rays, as shown in Figure 1 left. As the generated neutrons go through the lunar soil, they are scattered mainly by light elements and lose energy to become thermal or epi-thermal neutrons. Since this process is sensitive to the presence of water (hydrogen), it has attracted attention as a non-contact method to explore water resources on the lunar surface, and several projects are being planned. The MoMoTarO project will take advantage of this trend of the lunar exploration.

The neutron lifetime is a key parameter for solving the problems in astrophysics and particle physics. It is being measured around the world. However, there is a large difference in the neutron lifetime of about 8.6 s(4σ) between the present two methods [3], the beam method [4] and the bottle method [5]. The cause of the difference is not yet understood. This is one of the big unsolved problems in physics. Apart from these measurement methods, a new measurement method using planetary exploration satellites has been devised. The Lunar Prospector has measured the number of neutrons in an elliptical orbit around the Moon and derived the neutron lifetime of 900 ± 17 s [6]. However, because this was not the main objective for the Lunar Prospector, the statistical accuracy was limited by the size of the detector and the measurement time.

In the MoMoTarO project, thermal neutrons leaking from the lunar surface are measured via satellites orbiting the Moon, and the neutron lifetime is determined from the flux at each altitude. As shown in Figure 1 right, when the detector is operated in an elliptical orbit around the moon, the flux is high at low altitudes because the thermal neutrons do not decay and arrive directly, but at high altitudes, the flux becomes low because the neutrons decay. The lifetime is calculated from the decay rate of the thermal neutrons. Fast neutrons are also emitted from the lunar surface, but they are not suitable for the lifetime measurement because they are fast and reach sufficiently far.

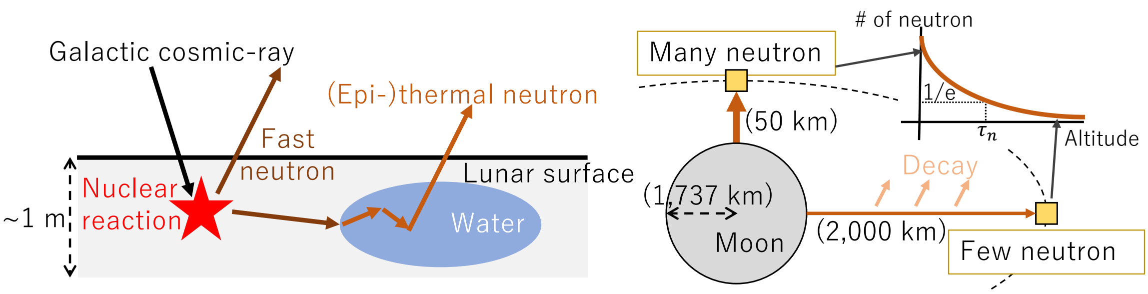

Figure 1: (Left) Thermal and epi-thermal neutrons leaking from the lunar surface. (Right) Neutron lifetime measurement using a lunar elliptical orbit.

The directional sensitivity of the gravitational wave interferometer is usually poor, and it estimates the direction from the time difference between multiple interferometers. Since the Moon is separated from the Earth's vicinity by an order of magnitude, the accuracy of direction determination can also be improved by an order of magnitude. The MoMoTarO aims to alert the gamma-ray burst around the Moon.

2. Detector design

The MoMoTarO detector is modularized as the CubeSat 1U size to increase the mounting opportunities and expandability. The detector consists of scintillator-based neutron and gamma-ray detectors. ^{3}He detectors have been the mainstay of the neutron detection, but they are expensive and vulnerable to vibration. We are developing the new technique to use a lithium-doped plastic scintillator EJ-270 readout by the Silicon PhotoMultiplier (SiPM).

The EJ-270 can discriminate the thermal neutrons, fast neutrons, and gamma rays using the pulse shape due to the difference of the reaction in the scintillator. As shown in Figure 2 left, the fast neutrons lose energy mainly by the elastic scattering with protons, that is hydrogen nuclei, then lose enough energy to be thermalized and captured by ^{6}Li. Thermal neutrons are captured by ^{6}Li, and α-particle and ^{3}He are emitted by the (n,α) reaction. Gamma rays are scattered by the compton scattering.

As shown in Figure 2 right, the MoMoTarO detector consists of 3 units, and 1 unit consists of a scintillator readout by 8 pieces of SiPMs. 2 kinds of EJ-270 scintillators, one with 10 mm and the other with 30 mm and thermal neutron shielding, are located on the lunar surface side to discriminate the thermal and epi-thermal neutrons. A GAGG scintillator is located on the deep space side to measure the gamma-ray bursts.

3. Experimental test

The MoMoTarO is in the process of developing a laboratory model and designing a space-environment model. The pulse shape discrimination of the fast neutrons, thermal neutrons, and

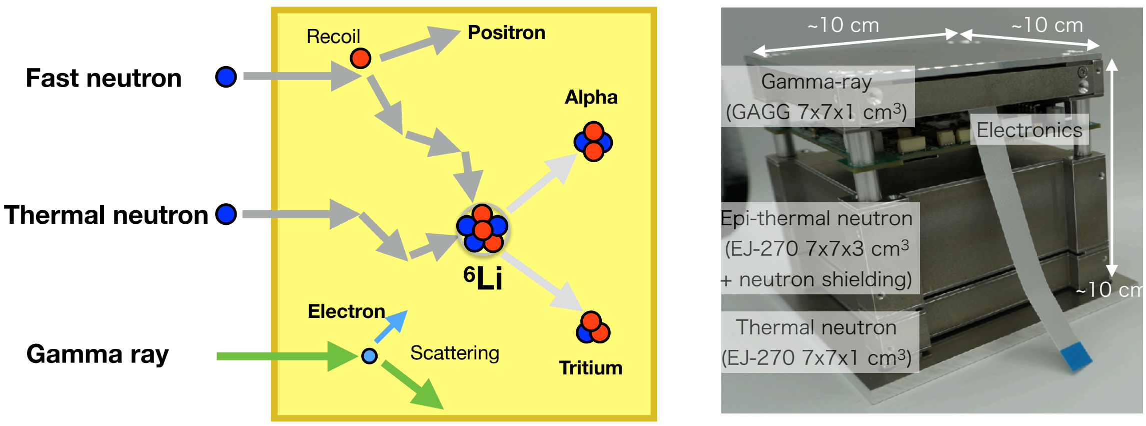

Figure 2: (Left) Structure of 1 unit with a scintillator and SiPMs. (Right) Structure of the MoMoTarO detector.

gamma rays is evaluated using the EJ-270 and the dedicated circuit board. The neutrons and gamma rays are well discriminated, but it remains an issue in discriminating between thermal and fast neutrons. We are updating the circuit board for the more accurate discrimination. Futhermore, scintillators and circuit elements are irradiated with gamma rays and protons to check their resistance.

The prototype model MoMoTarO was lifted to an altitude of 30 km on a balloon to conduct a demonstration test in a near-space environment. A balloon carrying the MoMoTarO prototype was flown to the stratosphere to observe secondary cosmic rays. The results will be used as feedback for the detector design.

4. Conclusion

We are developing a radiation monitor, the MoMoTarO for the lunar exploration. The science objectives are the exploration of the water resources, measurement of the neutron lifetime, and detection of the gamma-ray burst. The MoMoTarO detector consists of the EJ-270 scintillator to measure the neutrons and GAGG scintillator to measure the gamma rays. The performance of the detector is demonstrated using the laboratory prototype, irradiation facilities, and balloon experiments. We are now designing the space-environment model.

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