PROCEEDINGS OF SCIENCE

MoMoTarO-ISS feasibility studies of neutron measurements

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We have developed a compact neutron and gamma-ray detector, Moon Moisture Targeting Observatory (MoMoTarO). The MoMoTarO project aims to utilize neutrons leaking from the lunar surface for water resource exploration, measure the neutron lifetime, and improve the localization accuracy of gamma-ray burst observations. The MoMoTarO is planned to be installed in the external experiment site on the International Space Station (ISS) for six months in 2026 (MoMoTarO-ISS). The MoMoTarO-ISS will operate in space to evaluate its performance and demonstrate its technology readiness level, simultaneously providing scientific observations, for example, of solar neutrons and orbital neutrons.
Particle acceleration in stellar flares and supernova remnants remains unresolved, even solar flares, which are familiar to us, are still in mystery. Especially, hadrons acceleration in solar flares also has not been fully understood. It is difficult to constrain the generation time and the particle's initial energy of the charged particles because magnetic fields distributed unevenly in space disturb charged particles. On the other hand, the hadrons interact with the solar atmosphere and produce neutrons, solar neutrons. We can study the hadron acceleration effectively by observing the solar neutrons, which reach the Earth directly. In 2026, we expect high solar neutron fluxes around the Earth because solar activity is expected to be still active. The MoMoTarO can detect solar neutrons of X-class solar flares and we expect 5-10 X-class solar flares during the 6-month operation. There are few observed cases of solar neutrons, so the MoMoTarO-ISS holds the potential for new discoveries. Additionally, it is possible to monitor thermal neutrons, epithermal neutrons, and fast neutrons outside the ISS, which enables a deeper understanding of the neutron environment in space.
We have environmental tests to evaluate the detector performance towards the launch of the MoMoTarO-ISS in 2026. We conducted proton irradiation tests and Geant4 simulations to study the radiation background and damage on the ISS orbit. We irradiated scintillators with 200 MeV protons and verified possible performance degradation due to radiation damage. As a result, the degradation in energy resolution and light output of scintillators was at most around 20% with the proton irradiation equivalent to 0.1-year exposure. The performance degradation of scintillators can be negligible because it is minimal and recovers over time. We simulated the orbital radiation environment of the MoMoTarO-ISS to confirm whether solar neutrons are observable in comparison to the background. We constructed the MoMoTarO-ISS geometry and ISS experiment site in Geant4 simulation and irradiated them with background particles at the ISS altitude (Cumani et al. 2019) and solar neutrons, the neutron energy spectrum detected in November 2003 was used (Watanabe et al. 2006). When comparing the typical energy range of solar neutrons deposited in the scintillator ($\geq$10 MeV) with the background, solar neutron detection is feasible with the MoMoTarO-ISS because solar neutrons and the background are at similar levels. In this presentation, we report an overview of the MoMoTarO-ISS, the results of these environmental experiments, simulations, and the examination of various space observations with the MoMoTarO-ISS.

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1. Introduction

We have developed a compact neutron and gamma-ray detector, Moon Moisture Targeting Observatory (MoMoTarO)[1]. The MoMoTarO has three purposes;

- Lunar water resource exploration using Galactic cosmic rays (Figure 1).
- Measurement of neutron lifetime using a lunar orbiter.
- Localization of gamma-ray bursts using the difference in arrival times between the Earth and the Moon.

The MoMoTarO is the CubeSat 1.5 U size detector, where the weight is approximately 2 kg, with a power consumption of about 2.5 W. It installs two types of scintillators; ^{6}Li–loaded plastic scintillators (EJ-270) for neutrons and a GAGG (Gadolinium Aluminium Gallium Garnet, $Gd_3Al_2Ga_3O_{12}$) scintillator for gamma rays.

We will install The MoMoTarO on the International Space Station (ISS) in FY2026 (MoMoTarO-ISS). At the same time, we also aim for scientific observations, for example, gamma-ray bursts, earth-albedo neutrons, and solar flares. The solar activity is expected to be still active in FY2026, so it is a favorable opportunity for observing solar flares.

Charged particles (e.g. protons) are accelerated during solar flares, but the detailed mechanism remains unclear. This is because protons are deflected by interplanetary magnetic fields (IMF) and lose their original information. Solar neutrons and solar gamma rays are produced when protons accelerated by a flare collide with atomic nuclei such as helium in the solar atmosphere. In particular, solar neutrons are produced only through hadronic interactions and electrically neutral. Since they are not affected by the IMF and travel straight to the Earth (Figure 2). Moreover, solar neutrons are attenuated to less than 1/1000 in the Earth's atmosphere, and it is essential to make observations in space. Therefore, observing solar neutrons in space is effective in understanding the acceleration mechanisms of ions.

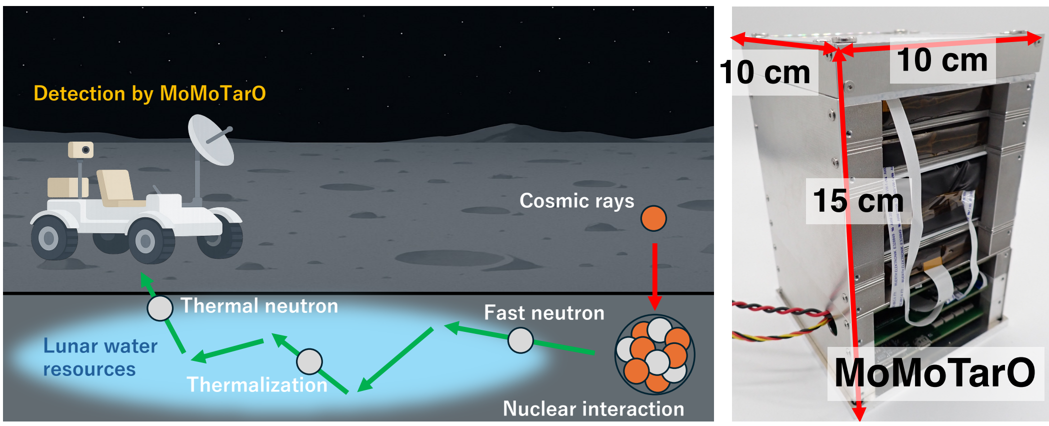

Figure 1: (Left) A method for detecting water resources on the Moon using the Galactic cosmic rays. When cosmic rays strike the lunar surface, they produce fast neutrons. If water resources are present, these fast neutrons are thermalized and thermal neutrons will be detected. (Right) The detector design of the MoMoTarO.

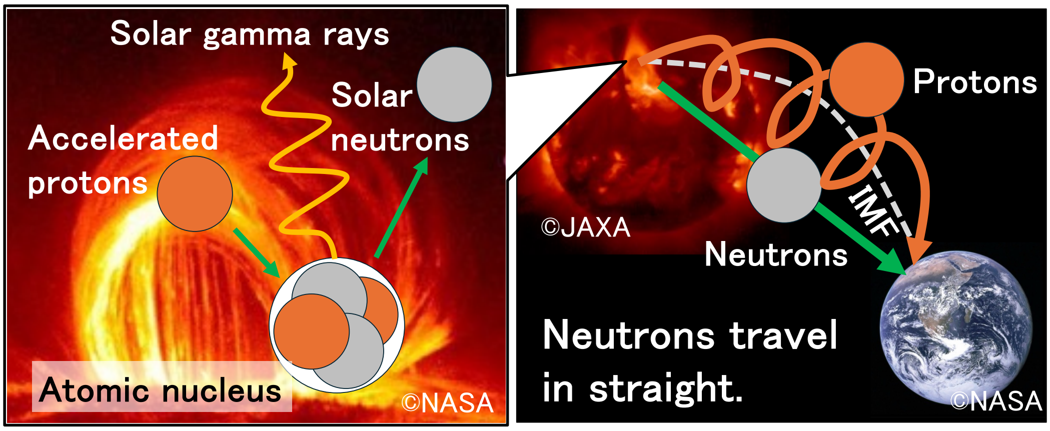

Figure 2: The process of neutrons generation in solar flares.

2. Space environment experiment

We conducted various environmental verification experiments in preparation for installing the MoMoTarO on the ISS. A vibration experiment was conducted to verify the resistance to vibrations of the launch. A random vibration experiment was conducted in the X, Y, and Z directions, each with a target acceleration of 6.08 G_{rms} and a vibration duration of 3 minutes. In addition, modal surveys were conducted in the 20–2000 Hz range before and after the random vibration experiments to confirm that no deformation of the MoMoTarO enclosure or failures in the electrical system occurred. The vibration experiments were performed with the enclosure wrapped in cushioning material to simulate the actual soft-bag launch conditions (Figure 3). Our MoMoTarO Engineering Model (EM) passed the test without any significant damage.

We also conducted a thermal vacuum chamber experiment. The temperature cycling was between 10°C–60°C. 16°C–34°C is the typical temperature range on the ISS and the others are the

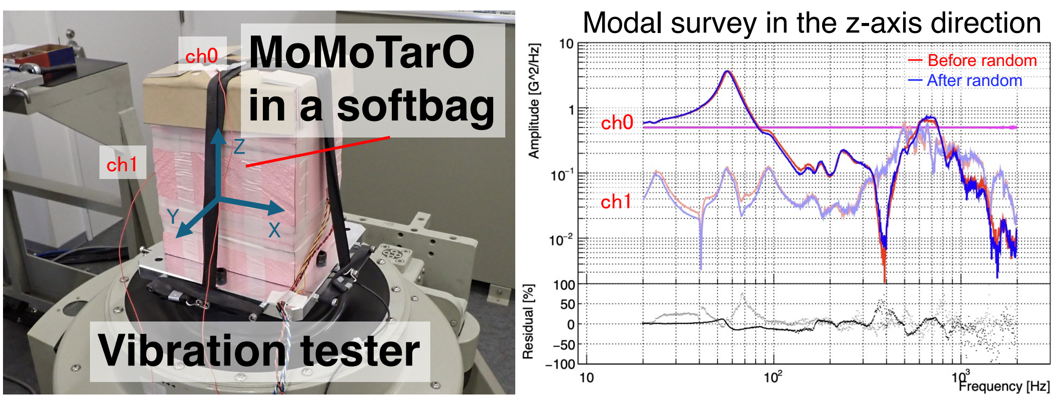

Figure 3: (Left) The configuration of the MoMoTarO vibration experiment. The MoMoTarO was wrapped with the softbag, and accelerometer were attached to the top and side surfaces. (Right) The results of the modal surveys in the z-axis (ch0) and x-axis (ch1) direction. The red line and blue line are the results before and after the ramdom vibration experiment, respectively.

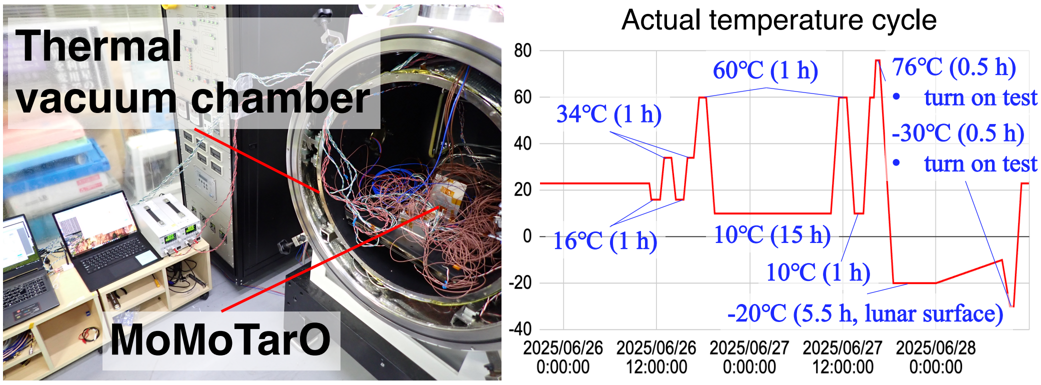

Figure 4: (Left) The configuration of the MoMoTarO thermal vacuum experiment. (Right) The temperature cycle conducted in the experiment.

hardest temperatures (defined as "survival condition" on the ISS) respectively (Figure 4). When the power was turned on at -20℃, some components were damaged. Therefore, the components will be replaced with different ones. We will further improve the thermal design adding new thermal paths. These experiments will be also conducted for the Flight Model.

3. Geant4 simulation of solar flare obsevation on the ISS

We conducted Geant4 simulations for the MoMoTarO-ISS to evaluate the possibility of the solar neutron observations. Geant4 is a Monte Carlo simulation tool provided by CERN that reproduces interactions between particles. The configuration of this simulation is shown in Figure 5. In this simulation, the scintillator section of MoMoTarO and the ISS were modeled. The ISS was approximated as an Al box. Using this configuration, solar neutrons and each background component were irradiated separately to assess how effectively solar neutrons could be detected compared to the background. Solar neutrons were irradiated based on the energy spectrum observed during the X28-class solar flare on November 4, 2003 (the largest recorded flare to date, [2]). For the background, models created from past observations were used [3]. The simulation was performed over a duration of 100 s, which corresponds to the typical duration of a solar neutron event.

The result is shown in Figure 6. Using an anti-coincidence method using multiple EJ-270s, the hadronic background can be suppressed to about 1046 ± 32 cps in the 0.1–1000 MeV energy deposit. It is found that solar neutrons from an X28-class flare can be detected at 298 ± 17 cps after performing the same procedure, so it provides a 9.2σ statistical significance within 1 s and a $> 10\sigma$ significance was achieved over the entire duration of the flare (about 900 s). Therefore,we can detect the solar neutrons with enough statistical significance if the X-class solar flare occurs. In the future, we will explore more suitable energy thresholds to improve the signal-to-noise ratio (S/N). We will also consider observing solar gamma rays with the GAGG.

4. Conclusion

We are developing a compact neutron and gamma-ray detector, the MoMoTarO, which is planned to be installed on the ISS in 2026. We conducted some environmental experiments

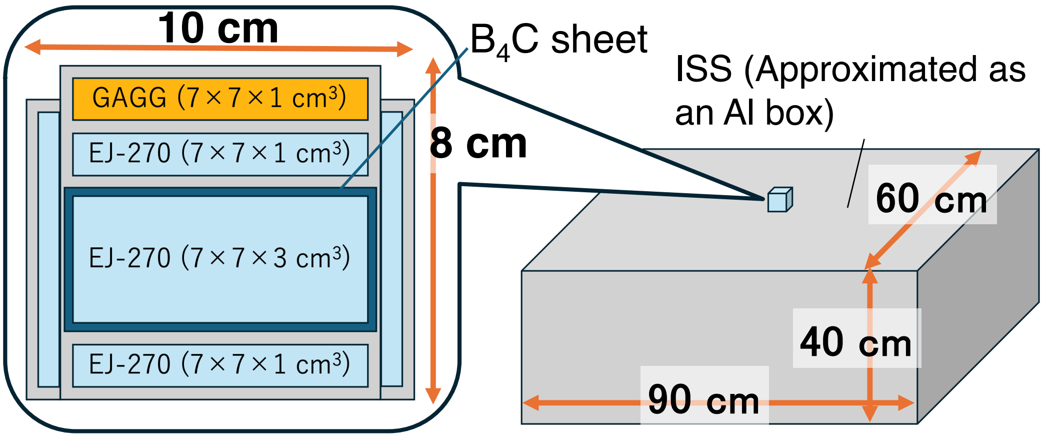

Figure 5: The Geant4 configuration. The B_4C sheet is used as a thermal neutron shield. All particles were isotropically irradiated from entire sky assuming the solar neutrons and cosmic-ray spectra.

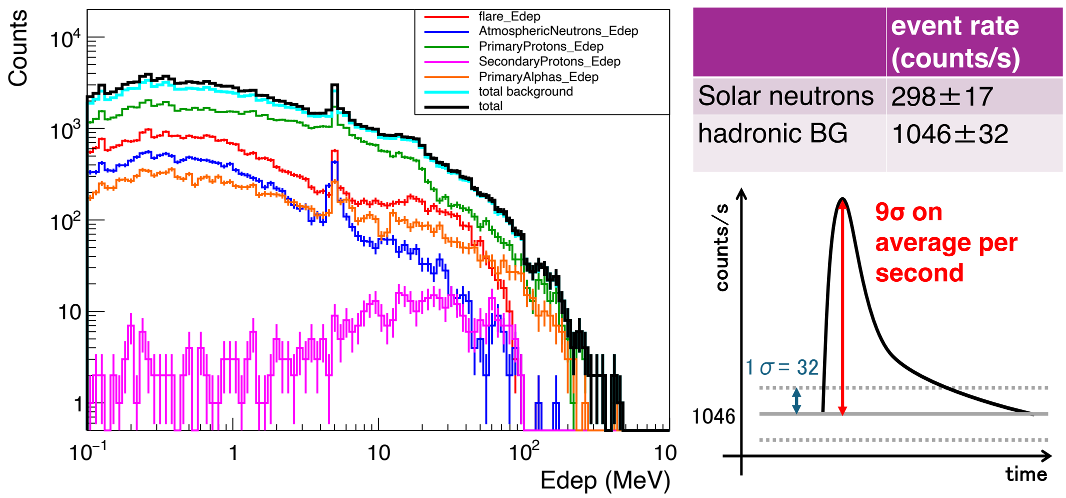

Figure 6: (Left) The horizontal axis represents the energy deposited in the all EJ-270 scintillators, and the vertical axis represents the counts integrated over 100 s. The red line represents solar neutrons, the blue line represents albedo neutrons, the green line represents primary cosmic rays (protons), the magenta line represents secondary cosmic rays (protons), and the orange line represents primary cosmic rays (alpha particles). The cyan line shows the sum of all background components excluding solar neutrons. (Right) The solar neutrons and background count rates of this simulation and the light curve expected from the simulation results. When a solar flare occurs, solar neutrons are observed as an addition to the background counts.

to assess its resistance in the space environment, and our MoMoTarO EM passed the experiments without any significant damage. Furthermore, we conducted a simulation to model the solar neutron observation using the MoMoTarO-ISS and we conclude that there is the possibility of detecting solar neutrons with enough statistical significance. In the future, we will explore more suitable energy thresholds and consider other methods of background rejection.

Acknowledgments

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References

[1] Tsuji, N. et al. 2024, PoS SPIE2024

[2] Watanabe, K. et al. 2006, *Adv. Space Res*, 38, 425

[3] Cumani, P. et al. 2019, *Experimental Astronomy*, 47, 273