The Deep Space Radiation Probe: Development and Results from a First Lunar Science Payload for Space Environment Studies and Capacity Building

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摘　要

低地球軌道（LEO，高度約2000公里以上）之外的區域被歸類為「深太空」，包括中地球軌道（MEO）、同步軌道（GEO），以及地月空間和月球空間。深太空環境對有人和無人太空探索產生了很多挑戰，包括更強的游離輻射通量、更極端的溫度變化，以及有限的數據回傳大小。隨著政府與商業月球任務中共乘酬載飛行機會的增加，未來十年在此環境中設計與實現酬載及其他太空電子系統的能力變得愈加重要。

國立中央大學（NCU）利用商業登月任務供應商日益增長的共乘機會，快速研發完成了台灣首個用於登月小艇的科學酬載，並於2025年1月15日搭乘 ispace 公司之 Hakuto-R Mission 2 的 Resilience 號登月小艇發射升空，並於發射後檢查完成後即開始運作進行科學觀測。該深太空輻射探測儀（Deep Space Radiation Probe, DSRP）在兩次半高離心率的月球擺動軌道、低能量轉換軌道及月球軌道期間，進行了為期五個月的輻射劑量、劑量率與單粒子翻轉率（SEU）的量測。DSRP 酬載由學生團隊開發，並由 ispace 登月小艇團隊的資深工程師提供諮詢與協助。

我們將報告DSRP計畫的目標、操作構想、設計、實現與結果。DSRP所提供的輻射數據涵蓋了高太陽活動期間，其劑量率明顯高於太陽活動低潮期間的任務，任務期間亦包含數次太陽粒子事件、地磁風暴及穿越范艾倫輻射帶。這些數據將有助於未來深太空宰句航電系統以及載人任務的發展，同時也建立了國立中央大學於深太空載具與酬載開發方面的能力。該酬載亦根據從 Hakuto-R M2 飛行中獲得的經驗教訓，進行精進與改良，以應用於未來的太空任務。

關鍵字：游離輻射、太空環境、輻射帶、宇宙射線、太陽粒子事件、單粒子事件

Abstract

Regions outside of Low Earth Orbit (LEO, altitudes above approximately 2000 km) are classified as “deep space”, including Medium Earth Orbit (MEO), geostationary orbit (GEO), as well as cislunar and lunar space. The deep space environment poses many challenges for human and robotic exploration, including stronger ionizing radiation fluxes, more extreme temperature variations, as well as limited data downlink volume. With the growth of the rideshare and hosted payload model aboard government and commercial lunar missions, developing the capacity to design and implement payloads and other space avionics for this environment is of increased importance this decade. Utilizing one of the growing number of rideshare opportunities offered by commercial lunar mission providers, National Central University (NCU) has completed the rapid development of Taiwan’s first scientific payload for lunar lander use, which was launched aboard the Hakuto-R Mission 2 (M2) *Resilience* lander from ispace,

inc. on Janaury 15, 2025, immediately commencing operations following post launch checkout. This Deep Space Radiation Probe (DSRP) provided 5 months of measurements of radiation dose, dose rate, and single event upset (SEU) rate during two and a half lunar swing by orbits, the low energy lunar transfer transit, and in lunar orbit. DSRP was developed by a student team, in consultation with experienced engineers from the ispace lunar lander team. We report on the objectives, concept of operation, design, implementation, and results of the DSRP project. The radiation data provided by DSRP covers a period of high solar activity, with dose rates considerably higher than on missions during lower solar activity, including several solar particle events, geomagnetic storms, and transit through the Van Allen radiation belts. The data will be beneficial for the development of future deep space spacecraft avionics, as well as crewed missions, and has also served to build the capacity for deep space spacecraft and payload development at NCU. The payload itself is also being modified for future missions based on lessons learned from the Hakuto-R M2 flight.

Key words : Ionizing radiation, space environment, radiation belts, galactic cosmic rays, solar energetic particles, single event effects.