LUNAR POLAR HYDROGEN MAPPER (LUNAH-MAP) CUBESAT MISSION LAUNCH, EARLY OPERATIONS AND LUNAR FLYBY NEUTRON DATA COLLECTION. C. Hardgrove[1], L. Heffern[2], T. Prettyman[3], R. Starr[4], I. Lazbin[5], E. Johnson[6], B. Roebuck[5], J. DuBois[1], N. Struebel[5], A. Colaprete[7], P. Hailey[8], K. Poetsch[8], T. O'Brien[8], S. Burgwell[8], S. Hoang[8], S. Larriva[1], E. Klaseen[8], D. Nelson[9], J. Knittel[9], B. Williams[9], M. Tsay[10], A. Babuscia[11], A. Klesh[11], S. Stem[12], [1]Arizona State University (chardgro@asu.edu), [2]Southwest Research Institute, [3]Planetary Science Institute, [4]Catholic University of America, [5]AZ Space Technologies, [6]Radiation Monitoring Devices, [7]NASA Ames Research Center, [8]Qwaltec, [9]KinetX Aerospace, [10]Busek Space Propulsion, [11]NASA Jet Propulsion Laboratory, [12]Blue Canyon Technologies, LLC.

Introduction: The LunaH-Map spacecraft was delivered to NASA Kennedy Space Center (KSC) for integration onto the Space Launch System (SLS) Artemis-1 mission in July 2021. LunaH-Map was one of ten 6U cubesats manifested as secondary payloads on the Artemis-1 mission, which successfully launched on November 16th, 2022 at 6:47:44 UTC (1:47:44 EST). The primary science goal of the LunaH-Map mission is to spatially resolve hydrogen enrichments to tens of centimeters depth across the lunar South Pole. LunaH-Map carries a 2U neutron spectrometer, which can measure epithermal neutrons that scatter and leak from the Moon's upper meter of regolith. The spacecraft uses a suite of subsystems including the JPL Iris deep space transponder, an eHawk+ solar array from MMA Designs, an XB1-50, XEPS power system, and ADCS from Blue Canyon Technologies. Spacecraft propulsion would be provided by the low-thrust BIT-3 low-thrust propulsion system from Busek. The spacecraft Mission Operations Center (MOC) is located in ISTB4 at Arizona State University (ASU). The MOC was developed in a partnership between a small business, Qwaltec, and ASU [1].

Early Operations: LunaH-Map successfully deployed from the SLS Orion Stage Adapter (OSA) approximately 5 and a half hours after launch, and a signal from LunaH-Map's Iris radio was received by the Deep Space Network (DSN) Open Loop Receiver at 8:07AM EST on November 16th. The MOC established contact with LunaH-Map at 9:40AM Eastern on Nov 16th and successfully transitioned the spacecraft out of beacon mode and into nominal communication pointing for the commissioning of all spacecraft subsystems. Telemetry received indicated that all subsystems were performing nominally, the spacecraft was in a low momentum state, and was power positive with solar arrays tracking the Sun. Telemetry indicated the LunaH-Map spacecraft batteries were charged to 70% upon deployment.

The deployment trajectory put the spacecraft on a course for a lunar flyby from approximately 1,300km altitude on November 21st. The ballistic trajectory takes the spacecraft beyond the Moon and into a heliocentric orbit, returning to the Earth-Moon system in 2039. Pre-launch and post-launch navigation solutions provided by KinetX required a series of propulsive maneuvers prior to the lunar flyby that would raise the flyby altitude and would target the weak stability boundary for an eventual return to lunar orbit [2]. Initial navigation and operations plans were to enter a highly elliptical lunar orbit, which requires a low altitude perilune (~12km), however, as of January 10th, 2023 the propulsion system had yet to provide significant thrust. Preliminary telemetry from the spacecraft indicates this is likely due to a stuck valve from extended storage of the spacecraft (>1 year). Based on data from Busek, the stuck valve was not unexpected given the long wait from spacecraft delivery to launch. New valve and tank designs may now exist that are not subject to iodine corrosion, however, they require additional testing and were not

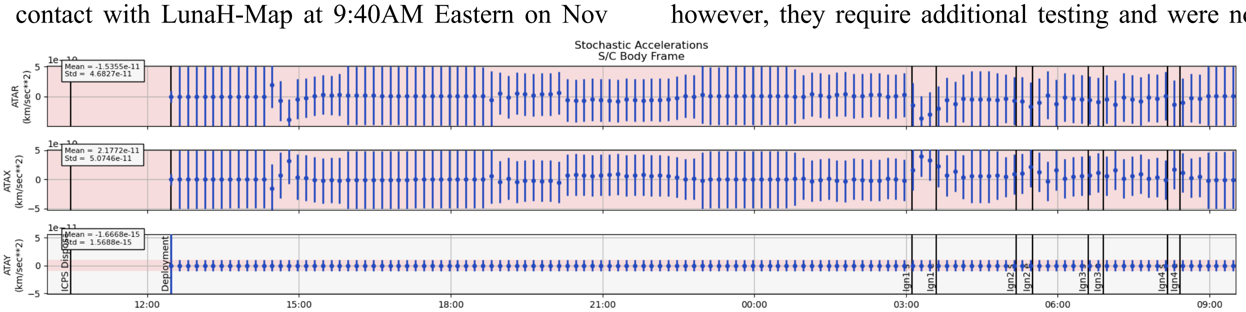

Figure 1: Small changes in the X and Z spacecraft accelerations were observed on the order of ~1^{-10} km/s^2 for all ignition attempts (black vertical lines) for which coincident real-time Doppler data were collected. The largest measured acceleration was ~4^{-10} km/s^2 for the first ignition attempt. These accelerations may not be due (only) to ΔV imparted by the thruster and could be caused by any spacecraft activity that would cause an acceleration, however, there were no other commanded changes in spacecraft attitude during these thrust attempts.

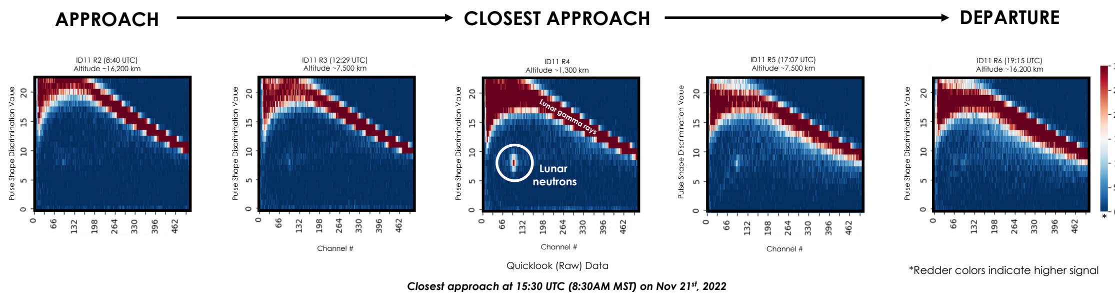

Figure 2: Spectra from the LunaH-Map Mini-NS acquired along the closest approach of the lunar flyby. The spectra clearly show lunar neutrons (white circle) at 1,300 km altitude and demonstrate that the instrument is capable of pulse shape discrimination and detection of both lunar neutrons and gamma-rays in the lunar environment (TRL-9).

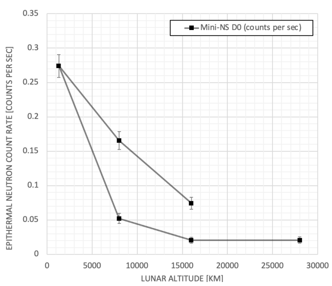

Figure 3: Mini-NS count rates during the lunar close-approach and flyby encounter.

available when LunaH-Map was selected in 2015. When SLS launch delays were announced after spacecraft delivery, in late 2021, access to the spacecraft was not possible and there was insufficient time to implement any design changes prior to the launch of Artemis-1. Despite not yet achieving ignition, spacecraft telemetry and radiometric tracking data acquired during pre-lunar flyby ignition attempts were consistent with minor amounts of iodine flow during ignition attempts, suggesting the valve may only be partially stuck (Fig 1). Post-flyby operations have focused on using heaters to condition the valve, tank, and feed lines. Navigation solutions exist to return LunaH-Map to the Earth-Moon system if ignition is achieved by early 2023. Beyond early 2023, propulsion could be used to target a near-Earth asteroid rendezvous or flyby. In-flight data has demonstrated that solar radiation pressure could provide approximately 5 m/s ΔV over the course of a year, which can change the trajectory by approximately 150,000 km.

Science Data Collection: Shortly after deployment on Nov 17th, LunaH-Map's Miniature Neutron Spectrometer (Mini-NS) was powered on and collected a five-minute commissioning dataset, which was used to assess the health and safety of the instrument and to set gain, offset and pulse shape discrimination parameters prior to the lunar flyby. Background counts were measured to be several times higher than modeled, however, this is likely due to increased solar activity during the launch period. Beginning at 8:40 UTC on Nov 21st, 2022, a lunar flyby dataset was acquired with the Mini-NS starting at a lunar distance of approximately 10 lunar radii from the Moon. The closest approach to the lunar surface occurred at 15:30 UTC on Nov 21st, 2022. Measurements were acquired at altitudes of 28,000, 16,000, 8,000, and 1,300 km on approach and again on departure (Figs. 2 and 3). The spacecraft orientation and attitude were fixed with the -Z antenna pointed towards Earth so that communications could be maintained throughout. Due to this geometry, the orientation of the Mini-NS with respect to the Moon changed throughout the flyby. The Mini-NS uses an array of four sensor heads arranged 2x2 on each detector, therefore, interpretation of the flyby data requires reconstructing each detector orientation and correcting for geometric and self-shielding factors of individual sensor heads. The raw data from a single sensor head, however, shows that neutron count rates increased by a factor of 10 between measurements acquired at 8,000 km altitude and 1,300 km altitude (Fig. 3). This flyby dataset demonstrates that the Mini-NS can detect neutrons and gamma-rays in the lunar environment, can accomplish the originally planned LunaH-Map science mission, and is TRL-9.

Technology Demonstrations: LunaH-Map has developed and demonstrated several new technologies for small spacecraft. A version of the LunaH-Map Mini-NS has been selected as a part of the Lunar VISE rover instrument suite [3]. On Dec. 2nd LunaH-Map successfully imaged Mars and Uranus, demonstrating autonomous optical navigation software routines. Optical navigation algorithms will be important for future small spacecraft to perform operations in deep space, given their minimal communications resources. In the coming months, LunaH-Map will also attempt a demonstration of a new type of radio ranging technique called Pseudo Noise Differential One Way Ranging (PN DOR). This would be a first-time demonstration of PN DOR and will enable better-ranging accuracy on future deep space CubeSats as well as larger missions.

References: [1] Hardgrove et al., (2020) IEEE LunaH-Map [2] Genova et al., (2017) *AAS 17-456*. [3] Donaldson et al., (2023) *54th LPSC this conf.*