Improved Hydrogen Maps of the Lunar South Pole by the Lunar Polar Hydrogen Mapper (LunaH-Map) CubeSat

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Overview

The Lunar Polar Hydrogen Mapper (LunaH-Map) mission is a planetary science cubesat mission designed to address the abundance and nature of lunar polar volatiles. LunaH-Map will orbit the Moon and map water-ice within regions of permanent shadow at the Moon's south pole. LunaH-Map is a pathfinder mission for the development of small, science-driven, high-risk, high-reward planetary science missions. For these types of missions, the overall project profile (e.g. lower budgets, tighter schedules) can accept a greater level of risk, however, the types of destinations for these missions may be more limited to Earth, the Moon and Mars as there are more regular and repeated launch opportunities. Looking forward, small spacecraft missions for planetary science that are much smaller in scope than Discovery or New Frontiers will provide benefits to both NASA and prospective PIs. These missions are well-positioned to complement the science of larger missions. Here we describe the LunaH-Map spacecraft subsystems, mission profile and present the scientific capabilities of this novel mission. To date, LunaH-Map has met all mission milestones, passed all design reviews, and is currently in integration and test.

Mission Background & Objectives

- LunaH-Map was selected by the Small Innovative Missions for PLanetary Exploration (SIMPLEx) program in late 2015 and is co-manifested on SLS along with twelve other 6U-sized spacecraft conducting their own independent investigations and technology demonstrations.
- LunaH-Map will deploy from the Space Launch System (SLS) Artemis-1 and maneuver into an elliptical orbit around the Moon to make maps of hydrogen (e.g. water-ice) enrichments within permanently shadowed regions (PSRs) at the lunar South Pole.

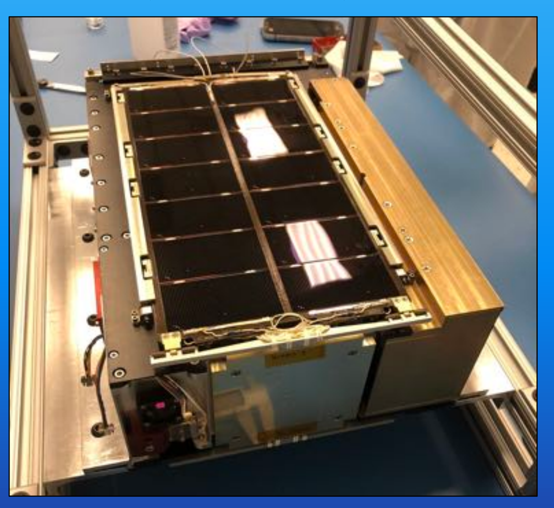

Fig. 1: The LunaH-Map flight spacecraft during fit-check assembly in Nov 2019.

- During the science phase, the miniature neutron spectrometer (Mini-NS) will measure epithermal neutron counts about the perilune of each orbit to map hydrogen enrichments at spatial scales of less than 20 km^2.
- **Science Objective:** Map hydrogen enrichments within PSRs at the lunar south pole at spatial scales <20 km^2.
- **Tech Objectives:** Deep space navigation, operations and planetary neutron spectroscopy using ion propulsion on a small sat.

Science Payload: Mini-NS

- The neutron spectrometer (called the Mini-NS) is a Cs_2LiYCl_6:Ce (CLYC) based scintillation detector shown in Figs. 2 & 3 [1, 2]. The $^6Li(n,\alpha)t$ reaction in CLYC allows the Mini-NS to detect neutrons [2].
- Eight Gd-shielded CLYC modules (Figs. 4 & 5) make up the full 2x4 Mini-NS detector array.
- A technique called Pulse Shape Discrimination (PSD) is used to distinguish between neutron and gamma-ray events (Figs. 6 & 7).
- The Mini-NS is located on the nadir face of the LunaH-Map spacecraft.
- The Mini-NS was calibrated at the Los Alamos National Laboratory Neutron Free In-Air Facility in December of 2018.

Table 1: Mini-NS flight instrument specifications

Detector	2x4 array of 4.0cm x 6.3cm x 2cm CLYC Detectors
Sensitivities	Epithermal (E>0.3 eV) neutrons; Gd shield
Dimensions	25cm x 10cm x 8cm
Mass	3.2kg (measured)
Power	3.5W (AVG standby for 2 detectors), 15W (AVG nominal for 2 detectors)
Data Ac Times	Counts binned every 1 second
Data Rate	14 Bytes/Sec (50 kB/sec stored locally)

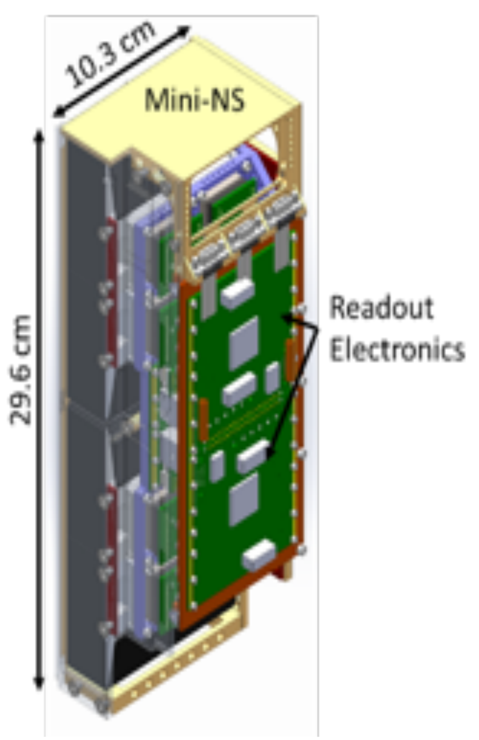

Fig. 2: Mini-NS instrument CAD model

Fig. 3: Photograph of the Mini-NS flight instrument

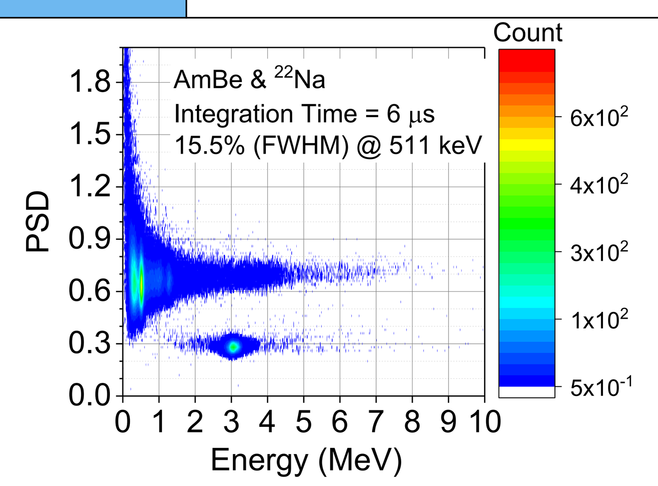

Fig 6: Plot of the pulse shape discrimination (PSD) ratio verses the energy deposited in equivalent electrons (gamma ray) energy. The energy spectrum shows the neutron peak at ~3 MeV.

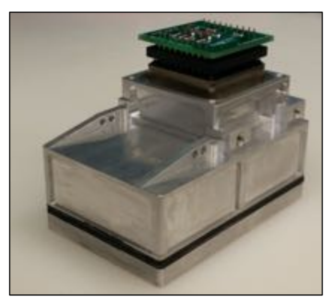

Fig. 4: One Mini-NS detector module. The mechanical housing is shown with a mounted Hamamatsu R11265 photomultiplier tube (PMT).

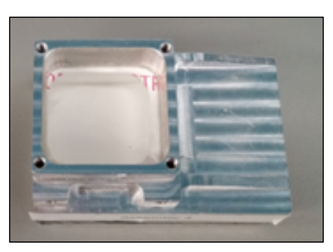

Figure 5: Photograph of the packaged crystal module. The open quartz window shows the inside of the package and is the spot where the PMT will optically-coupled to the module.

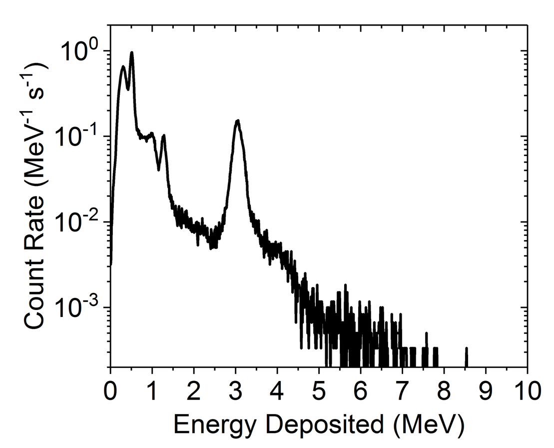

Fig. 7: Gamma-ray and neutron energy spectrum with a Mini-NS module.

Spacecraft Information

The LunaH-Map spacecraft is equipped with [3, 4]:

- Gimbaled solar arrays (MMA Designs)
- 3 reaction wheels (Blue Canyon Technologies)
- Star tracker (Blue Canyon Technologies)
- X-Band Iris radio (JPL)
- Command and data handling system (Blue Canyon Technologies)
- Power control system (Blue Canyon Technologies)
- Neutron spectrometer array (RMD, Catholic U, ASU)
- Low-thrust ion propulsion system (Busek)

Table 2: LunaH-Map spacecraft specifications

Dimensions: (stowed)	12 x 24 x 37 cm (to fit within Planetary Systems Corporation 6U+ dispenser)
Mass	14 kg
Power	151.2 W-hr max Battery
Propulsion	Busek BIT-3 Ion Thruster
Comm.	JPL Iris Deep Space Transponder
C&DH / GN&C	BCT XB1-50

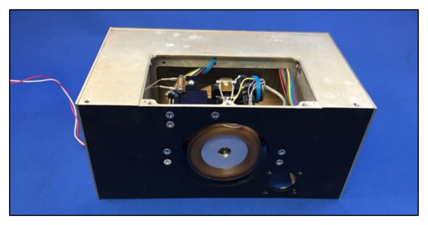

Fig. 8: Busek ion prop system

Fig. 9: Flight IRIS radio

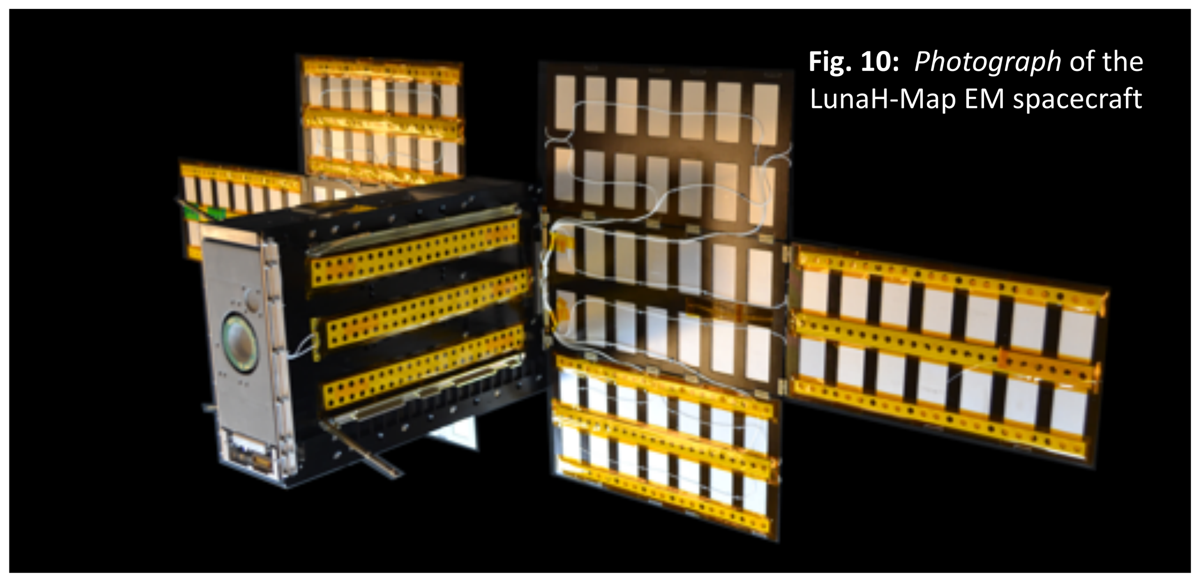

Fig. 10: *Photograph* of the LunaH-Map EM spacecraft

Flight operations

- After deployment from SLS, LunaH-Map will maneuver using a low-thrust ion propulsion system to perform a lunar flyby targeting L2 [5, 6].
- Once captured, LunaH-Map will spiral down to an elliptical low-altitude science orbit with perilune above the lunar South Pole (10-20 km altitude).

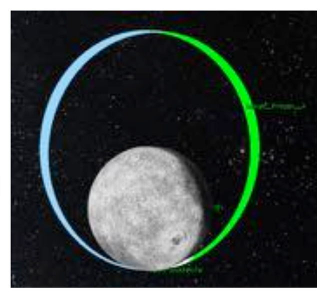

Fig 11: LunaH-Map Science Phase [6]

Table 3: LunaH-Map science phase specifications [6]

Orbital Period	4.76 hour
Aposelene Altitude	3150 km
Periselene Altitude	Right angle of ascending node dependent, 5-25 km
Total number of orbits	282
Inclination	90°
Argument of Periselene	273.5°

Table 4: LunaH-Map Avionics performance specifications [6]

	Parameter	Performance/Metric
General	Mass / Volume for Avionics	1.5 kg / 10 x 10 x 13 cm
	Nominal Power	XB1-50 < 6.8W
	Orbit Altitude / Orbit Lifetime	Deep Space & Lunar / 3 years
Guidance, Navigation, & Control Subsystem	Pointing Accuracy	±0.016° (1-sigma), 3 axes, 1 Trackers
	Pointing Stability	1 arc-sec/ 1-sec
	Maneuver rate	12 deg/sec
	Orbit Determination	Chebyshev Polynomial, SGP4, J2
Command & Data Handling Subsystem	Data Interfaces	Serial: LVDS, UART or SPI available
	Onboard Data Processing	Configurable via user loadable software
	Telemetry Acquisition	6 12bit Analog, 6 discrete inputs
	Commands	Real-time, stored, macro
	Onboard Data Storage	Redundant 8 Gbyte SD Cards (cold spare)
Electrical Power System	System Bus Voltage	5V, 12V and 28V bus supplies
	Energy Storage	12-Cell (3s4p) Li-Ion Battery with High and Low Side Inhibits
Misc.	SADA Interface	Avionics Autonomously Drive SADA to Optimize Power
	Propulsion	Busek BIT-3 propulsion system with gimbaled thruster provides angular and linear ΔV. C&DH provides momentum management via autonomous gimbal control during maneuvers

Prospective study

End-to-end modeling of time-series counting data acquired by the Mini-NS supports design of orbital operations and optimization of methods for hydrogen mapping (see [7-9] for methods). Simulations consider a range of prospective orbital trajectories and trial distributions of sub-surface hydrogen. Here we show example results assuming hydrogen is distributed uniformly within permanently shadowed regions (PSRs) based on illumination modeling [10] (Fig. 12 **A**, below).

The prospective orbits dip well below Lunar Prospector's nominally 30-km orbital altitude [11], enabling high-spatial resolution measurements of hydrogen near the south pole. See example orbits (red and blue) in **A** and **B** and mapped orbital altitudes in **C**. Contributions of PSRs to the response of the Mini-NS – assuming uniform surface composition - show that large PSRs can be resolved (**B** and **D**). The maps of corrected epithermal neutron counts in **E** and **F** include counting statistics and assume the PSRs contains 1000 μg/g hydrogen [H] [cf. 12, 13]. Regions with decreased counts indicating elevated [H] correspond to large PSRs (e.g. Shoemaker) and clusters (e.g. Cabeus) (arrows). Work is underway to assess candidate mapping/analysis procedures to maximize hydrogen sensitivity.

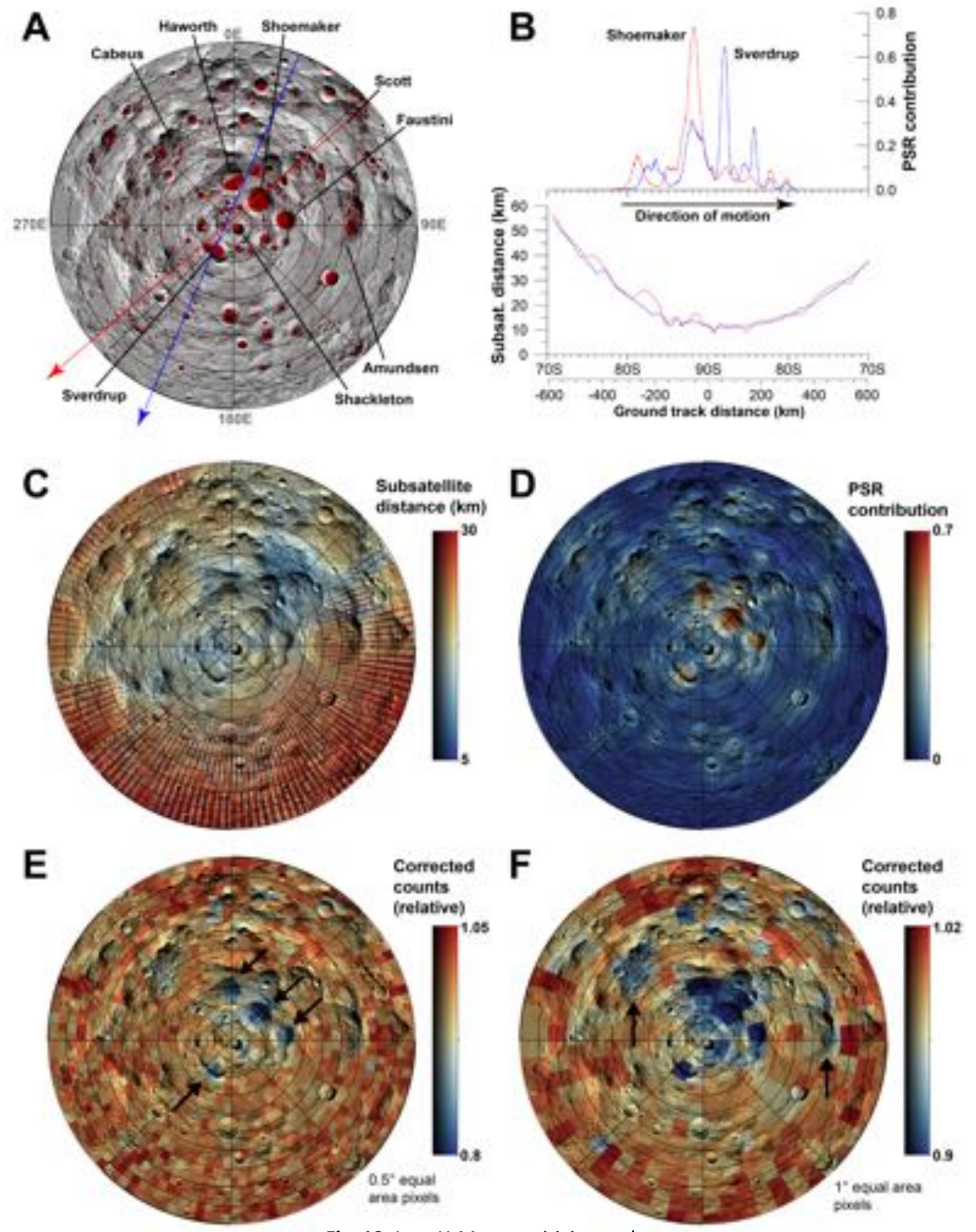

Fig. 12: LunaH-Map sensitivity study

Road to Launch

- Initial Accommodation Audit – completed on December 11, 2015
- System Requirements Review – completed on April 8, 2016
- Phase 1 Safety Review – completed on June 21, 2016
- Preliminary Design Review – completed on July 25, 2016
- Critical Design Review – completed June 29, 2017
- Phase 2 Safety Review – completed on November 9, 2017
- Systems Integration Workshop – completed on December 7, 2017
- Flight Instrument Delivery – November 8, 2018
- Flight Solar Array Delivery – February 22, 2019
- Flight Radio Delivery – March 20, 2019
- Enter Assembly, Integration, and Test – Q1 2019
  - AI&T Review/Workshop with review board – completed on December 7, 2017
- Flight GNC and C&DH System – September, 2019
- Phase 3 Safety Review –September 25, 2019
- Flight Propulsion Delivery – scheduled December, 2019
- **Environmental Testing in mid-2020**
- **Spacecraft Delivery to NASA in late July/early August 2020**
- **Launch-SLS EM-1 in ~TBD**

References

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