NEUTRON MEASUREMENTS AT THE LUNAR SURFACE (NMLS)

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Overview

The Neutron Measurement System (NMS-Lunar) is an instrument payload manifested on Astrobotic's Peregrine Mission One (M1). Astrobotic Mission One will land at Lacus Mortis (~44ºN, 254ºE). Astrobotic will fly up to fourteen NASA payloads to the lunar surface in addition to other payload customers on M1. NMS-Lunar is a re-design of the MSFC Fast Neutron Spectrometer (FNS) currently operating on the ISS. The design of NMS-Lunar enables operation on the lunar surface, integration onto the Peregrine lander, and measurement of thermal neutron count rates on the lunar surface. The primary science objectives for NMS-Lunar is to provide ground truth of mapped neutron data from the Lunar Reconnaissance Orbiter and Lunar Prospector missions. Neutrons are created when galactic cosmic rays interact with the lunar regolith, and can provide valuable elemental composition information.

Background & Motivation

Figure 1. Payloads on board Commercial Lunar Payload Services (CLPS) landers will provide early opportunities to conduct lunar science in support of the Artemis program [1].

- CLPS payloads provide science at the surface of the Moon in support of the Artemis program.
- NMS-Lunar is selected for flight on Astrobotic Mission 1 to Lacus Mortis (~44ºN, 254ºE) for ~7 earth days of operation on the lunar surface, (see Figures 4 & 10).
- NMS-Lunar fits in a small volume and requires minimal spacecraft resources.
- NMS-Lunar will provide high science return including elemental composition constraints at the landing site.
- Fig. 2,3: NMS is a derivation of MSFC's larger and more complex FNS that is currently operating on the ISS and is also in development for Gateway. The smaller form factor operates with a higher absorption efficiency than traditional neutron detectors. Coated cadmium shielding is incorporated to discriminate neutron energies and to minimize the sensors' view of the neutron contaminating fuel.

Figure 2. Astrobotic Peregrine lander. [2]

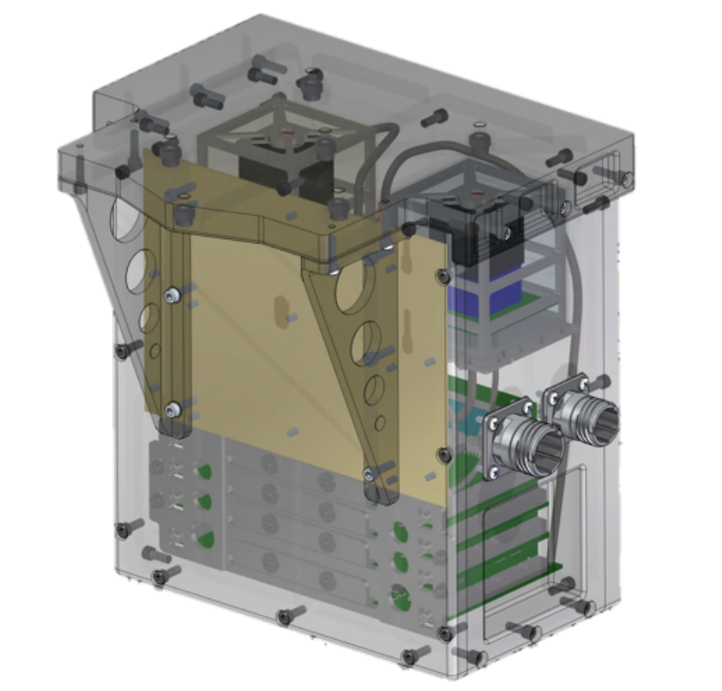

Figure 3. Backside of NMS CAD model showing additional supports and cadmium shielding minimizing the sensors view of the fuel tanks.

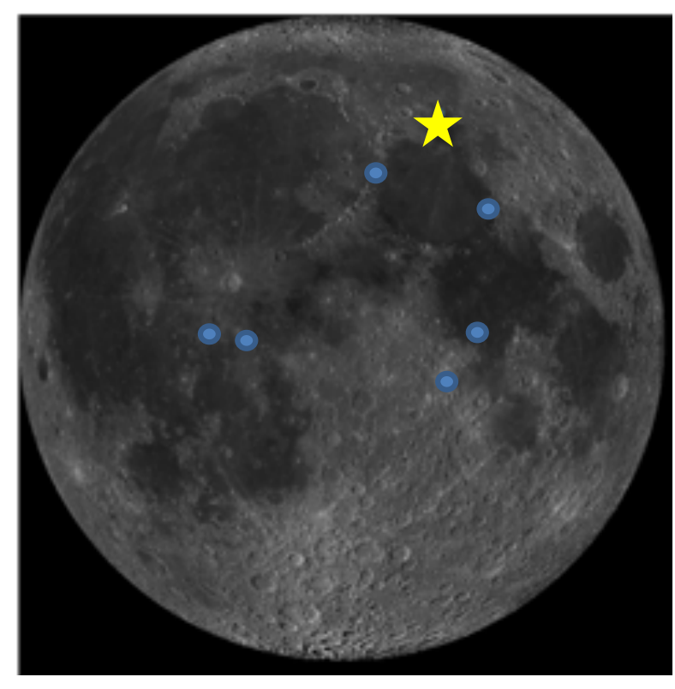

Figure 4a. The landing site (star) at Astrobotic M1 in relation to Apollo sites (blue) [3].

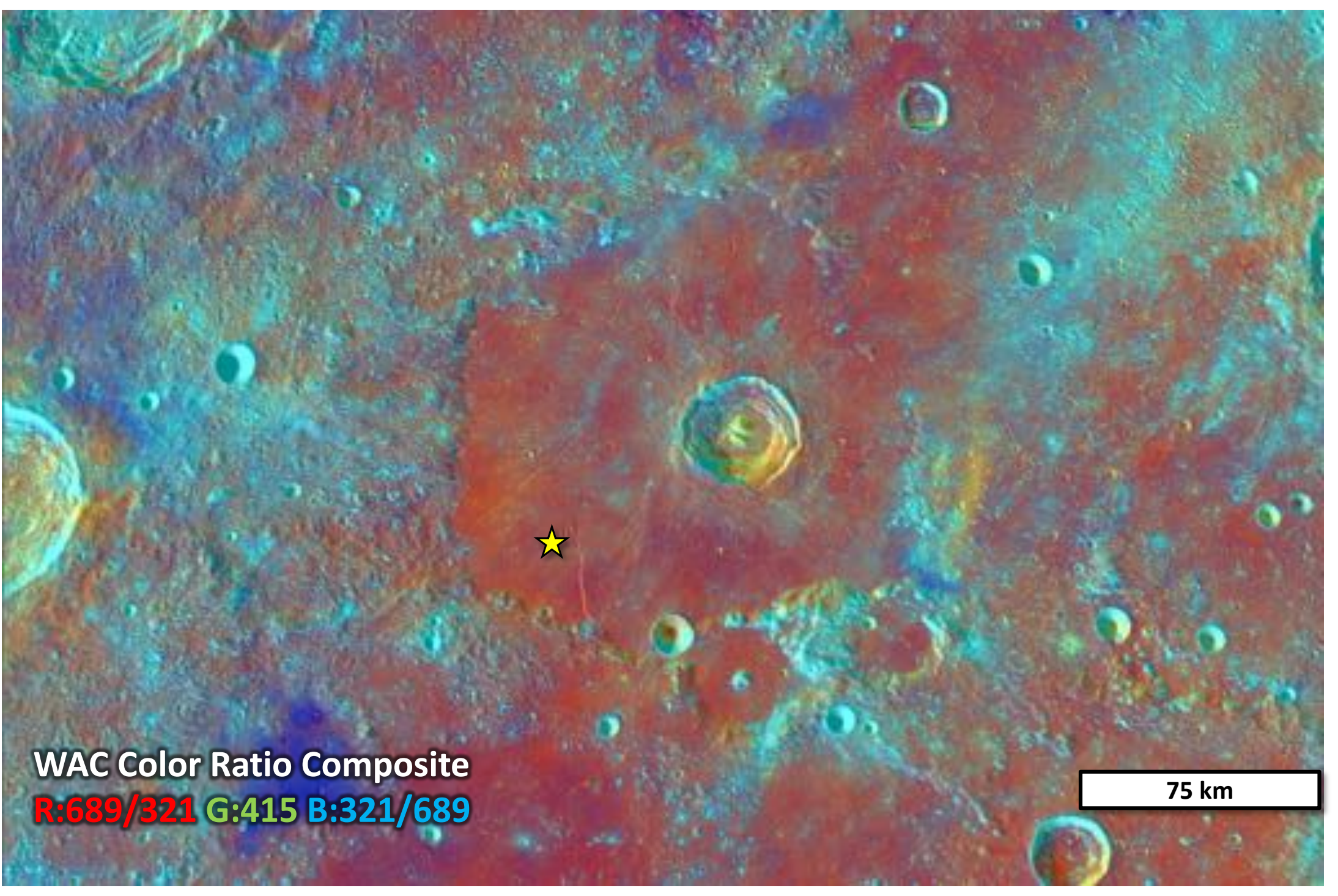

Figure 4b. The landing site (star) at Astrobotic M1 is a geologically diverse mix of highland and mare materials. Crater Bürg (center) is ~40 km diameter. Reds and oranges are mare material (high Fe). Light blues are highlands (low Fe). [3]

NMS Instrument Overview

Mass: ~4 kg
Data rate: 10 bps
Ave Power: 4.8 W
Peak Power: 10 W

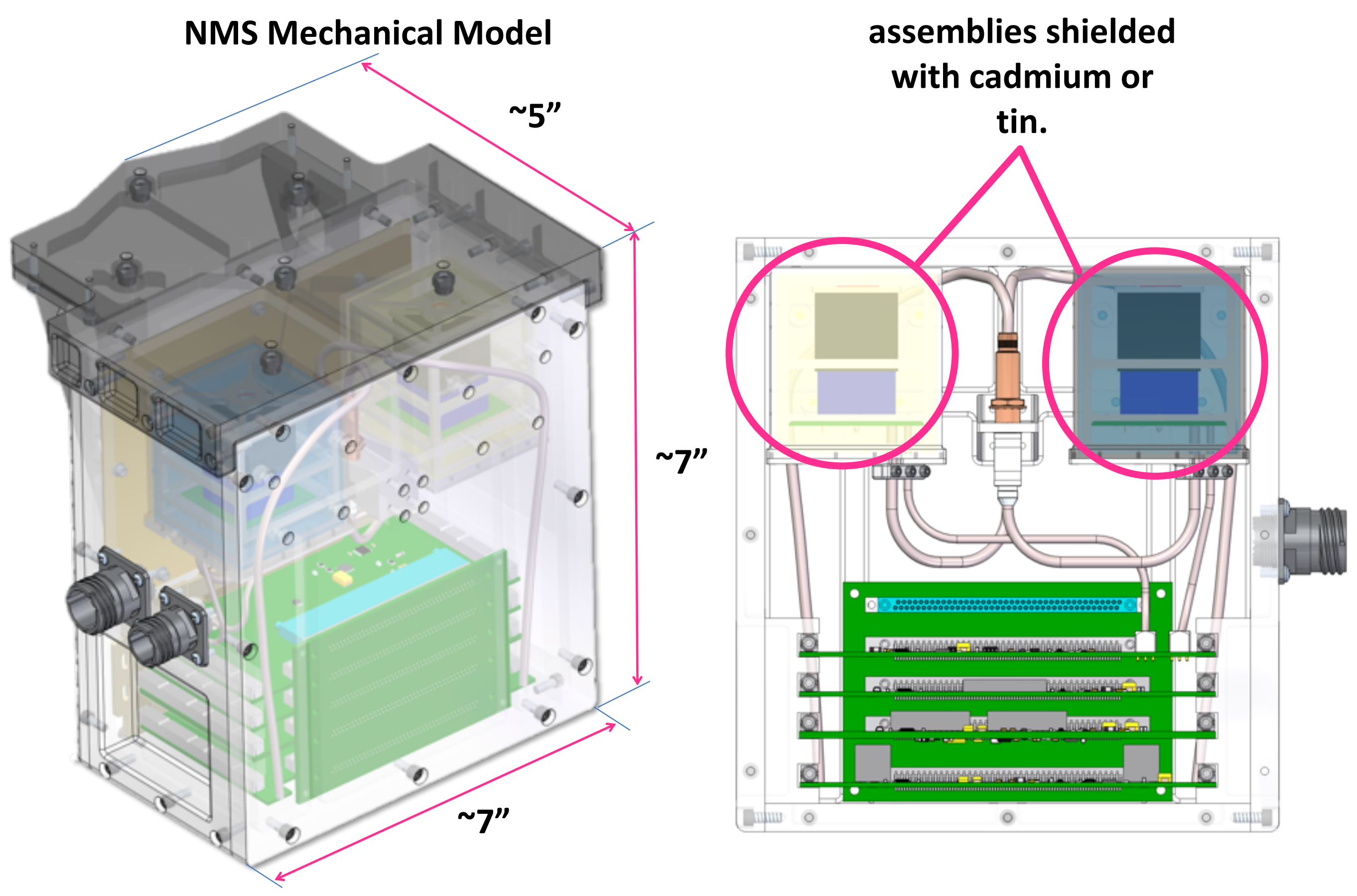

Figure 5. NMS mechanical model front (left) and planar (right) views. NMS offers high science reward for minimal spacecraft resources. Key sensor components are labeled above. Cd shielding absorbs all neutrons below ~0.4 eV preventing thermal neutrons from detection.

Mission Objectives:

1. Characterize the neutron radiation environment.
2. Provide in-situ ground truth for calibrating orbital data.
3. Provide constraints on composition (e.g., science & ISRU).
4. Monitor hydrogen cycle through lunar day.

Project Description:

- Provide neutron counts at the lunar surface.
  - Deliver thermal and epithermal neutron rate counters using ^{6}Li-doped scintillators.
  - Operate for ~7 Earth days, (~1/2 lunar day).

Funding:

- Lunar Discovery and Exploration Program (LDEP), NASA Provided Lunar Payloads (NPLP) Solicitation.

Scintillator Sensor Assembly Buildup

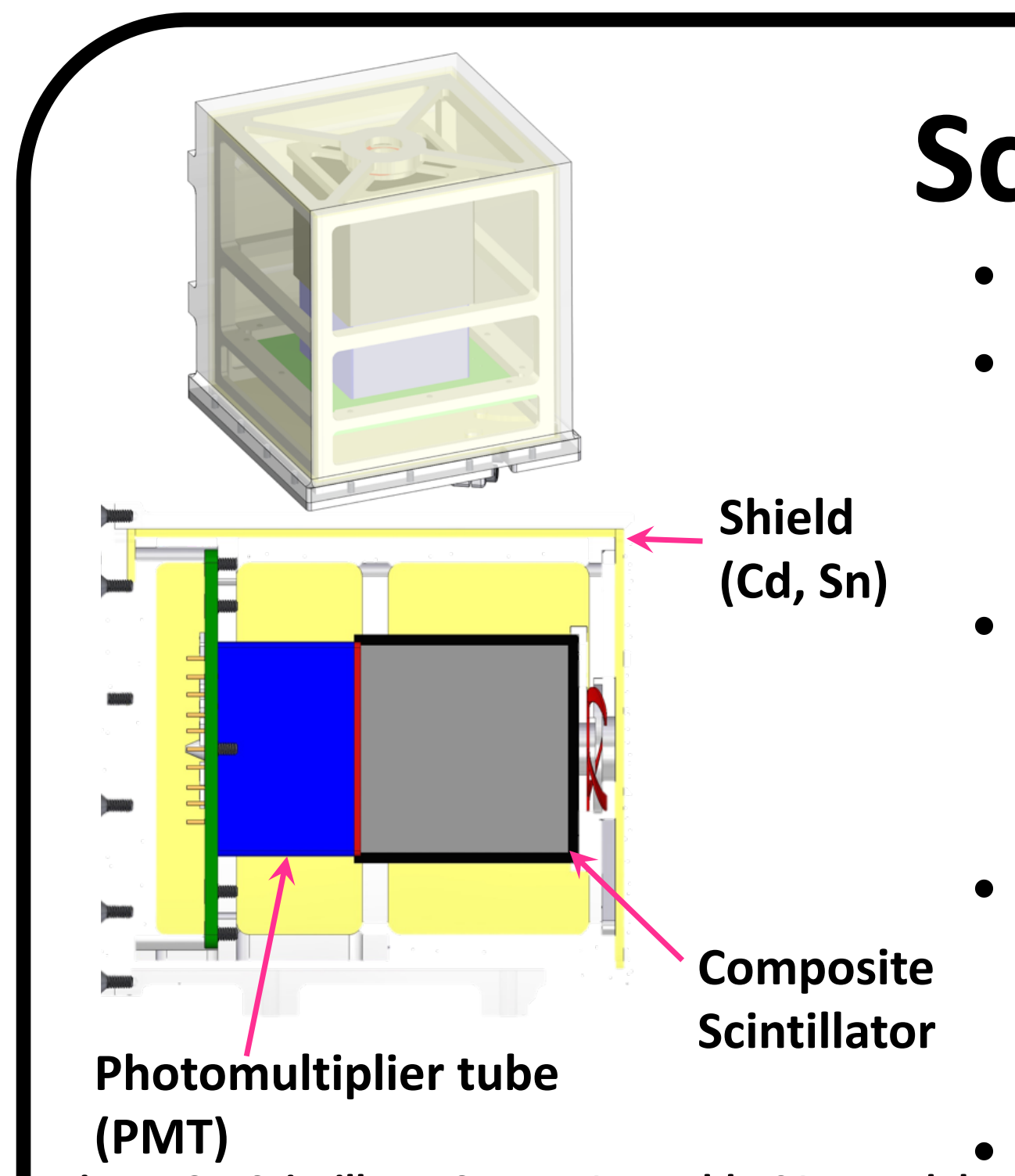

Figure 6a. Scintillator Sensor Assembly CAD model.

- ^{6}Li-doped glass fibers produce a distinctive signal for neutrons.
- 120-micron ^{6}Li-doped scintillating glass fibers are mounted, stacked, and assembled into bundles with epoxy ends, ~480 glass fibers in each bundle (Fig. 6b, 6c).
- Bundles are immersed in a liquid plastic scintillator (polyvinvyl toluene, PVT) using custom molds of AL and optically flat glass. ~4 weeks cure time (Fig. 6d).
- Two right square prisms of solid plastic scintillator, with ^{6}Li glass fibers embedded within, are cut into 1” cube detector volumes. These are wrapped in tape and coupled with a PMT.
- Counting rate is estimated to be 0.1 – 0.5 Hz.

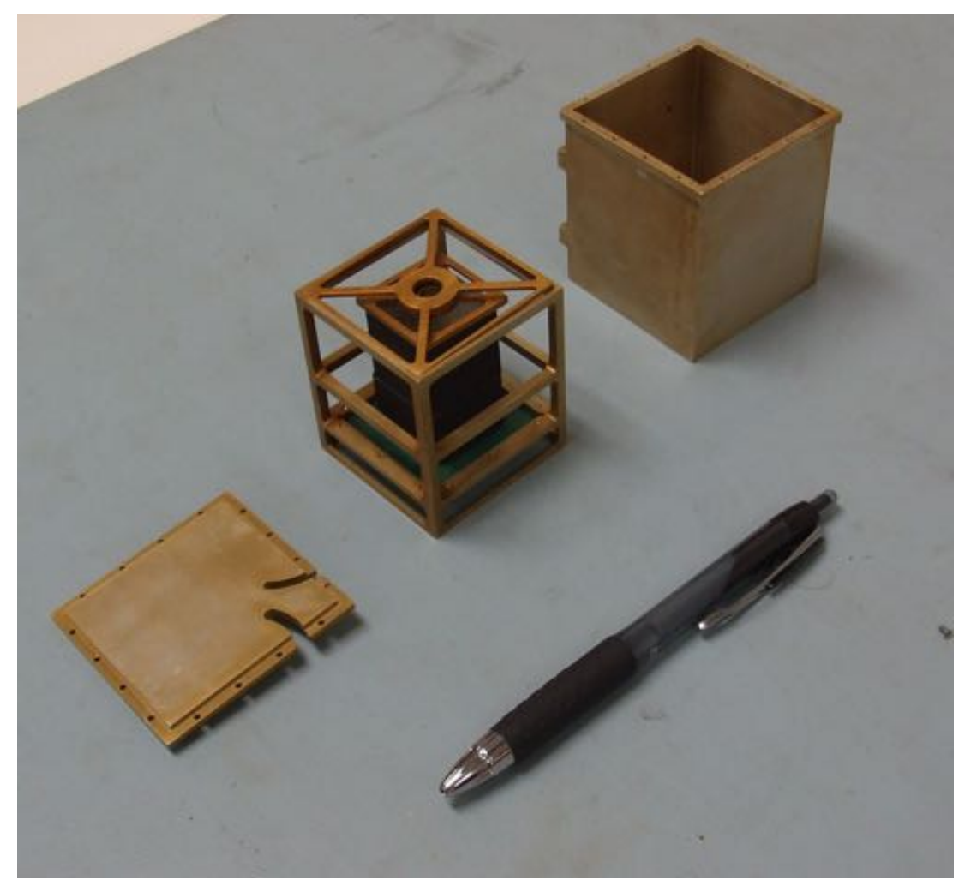

Figure 6f. Sensor assembly prototype for functional performance testing.

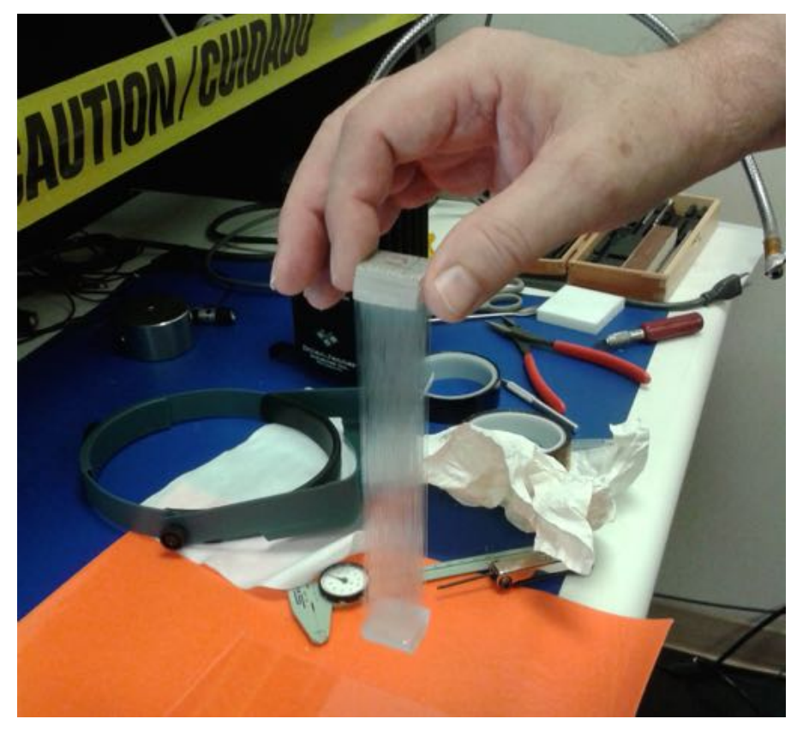

Figure 6b. ^{6}Li-doped glass fibers built up into bundle by hand.

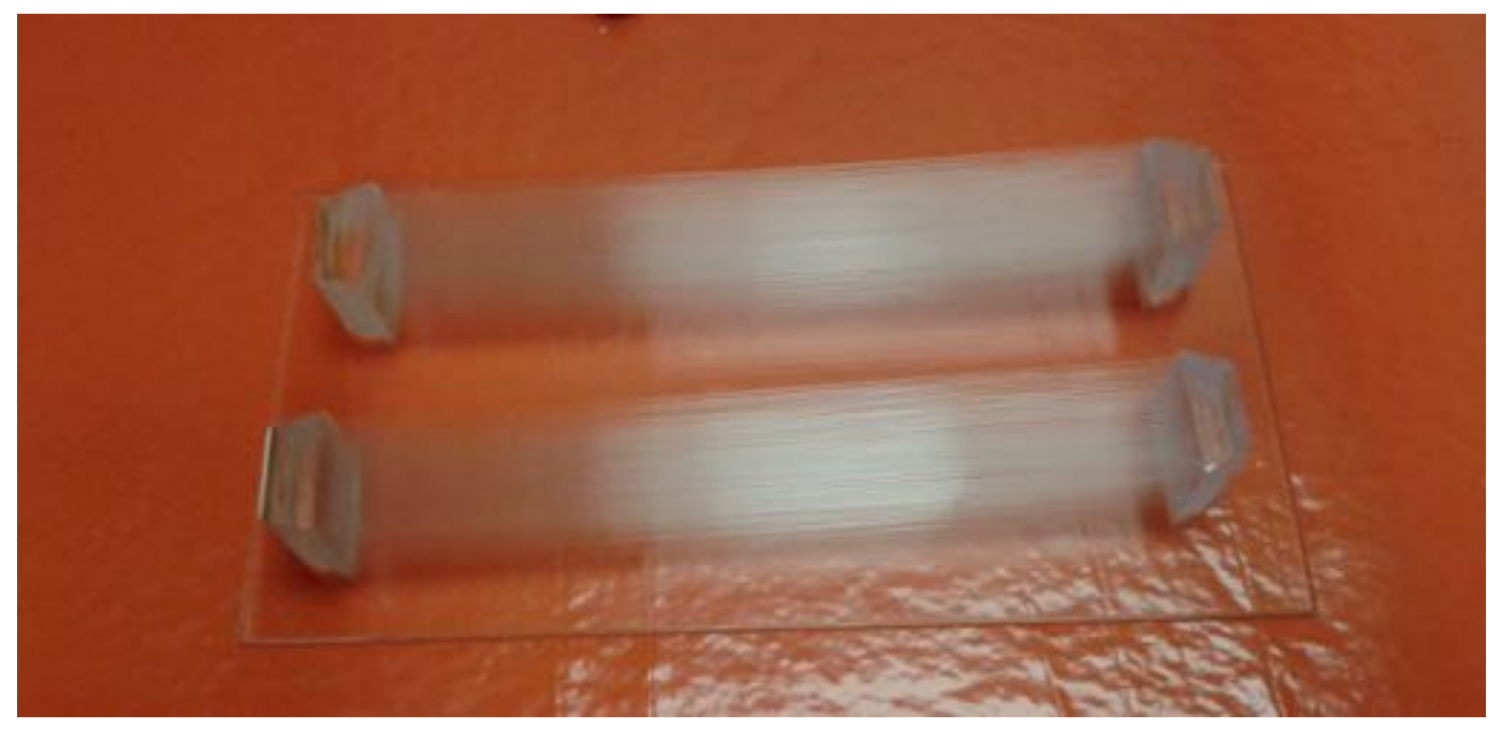

Figure 6c. Glass fiber bundles are ~0.8”x0.8”x7” with ~480 fibers each.

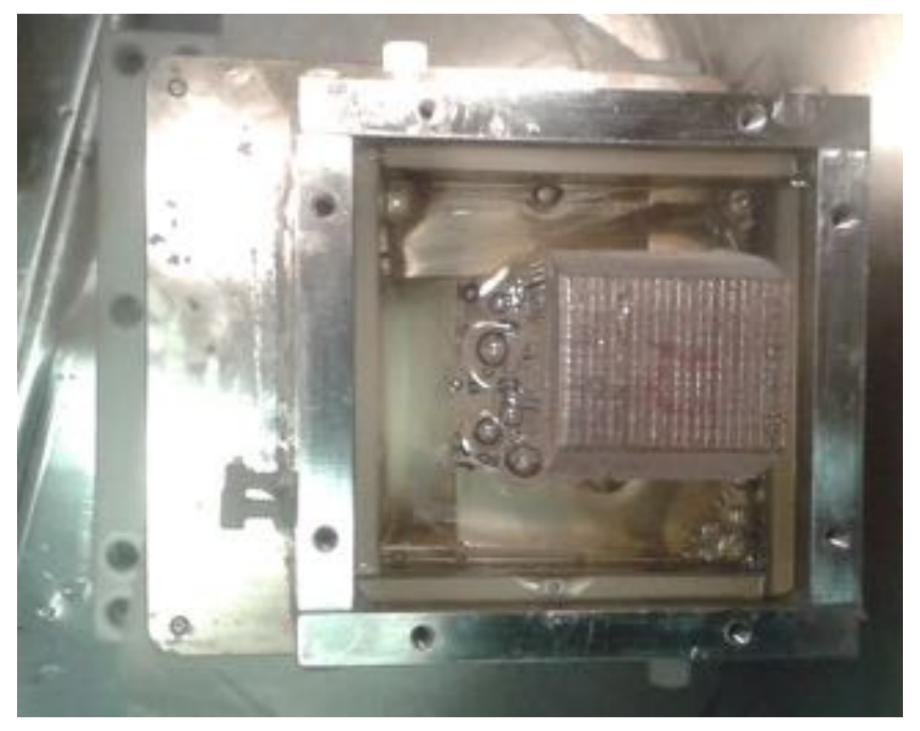

Figure 6d. Bundle is cast with BC-490 polyvinyl-toluene plastic scintillator.

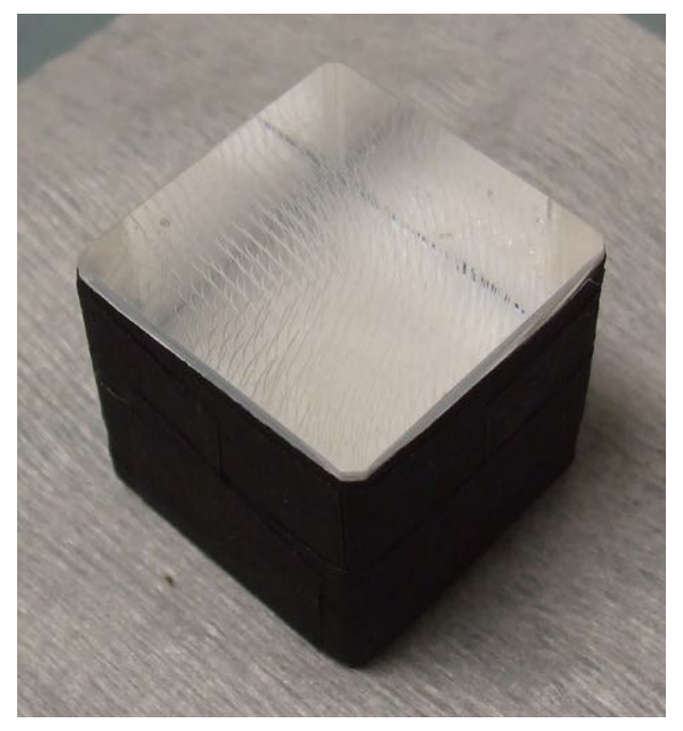

Figure 6e. 1” cube composite scintillator wrapped in black tape.

Science Overview

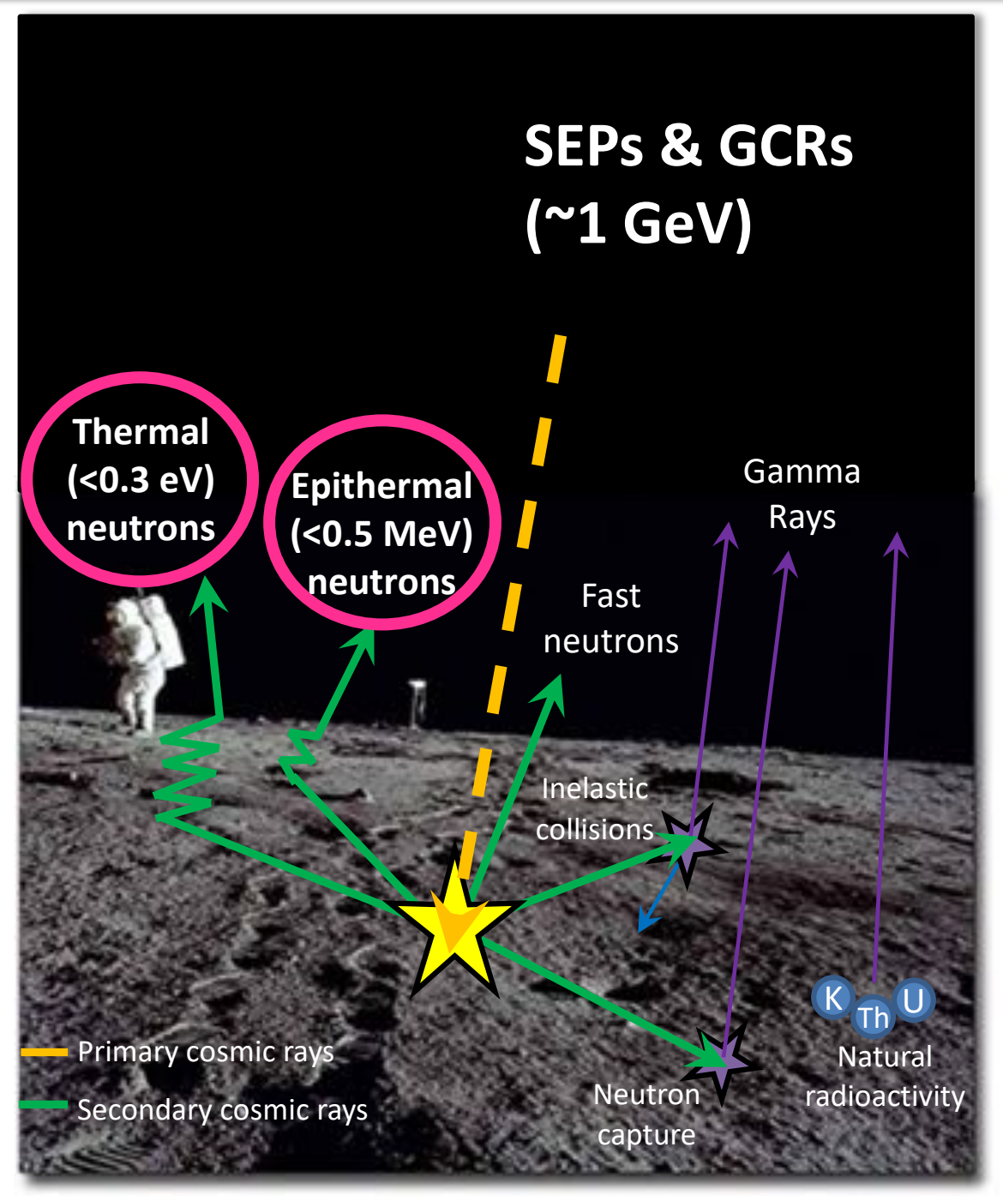

Figure 7. Nuclear spectroscopy at the lunar surface. High energy solar energetic particles (SEPs) and Galactic Cosmic Rays (GCRs) impact the lunar regolith producing neutrons. [4]

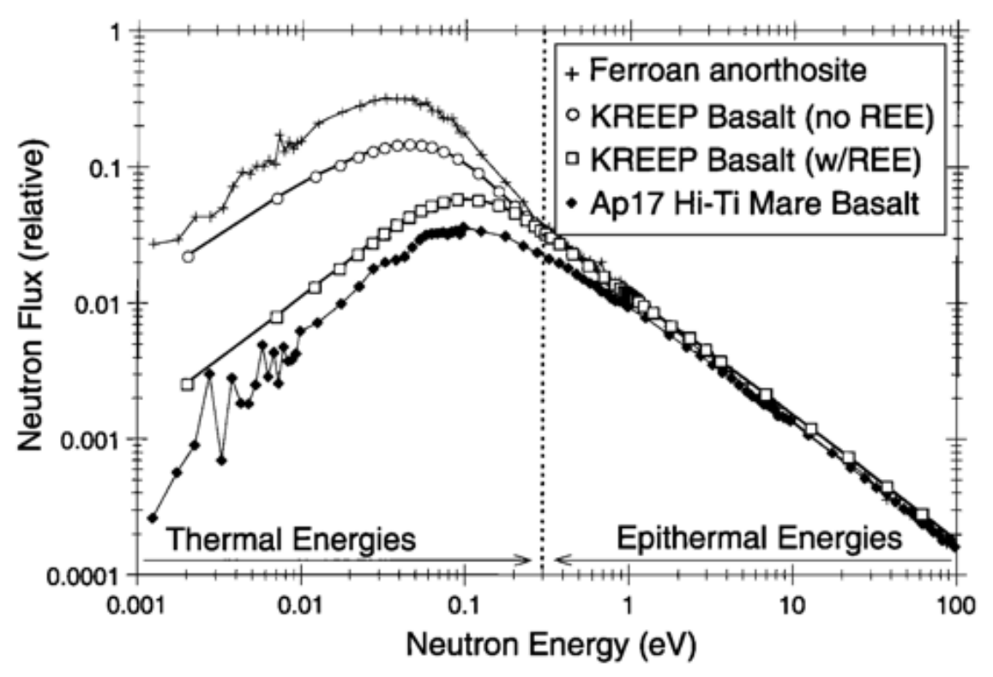

Figure 8. Simulated neutron energy demonstrating neutron flux sensitivity to lunar compositions in the thermal range [5].

- **“Epithermal neutrons”** (<~0.5 MeV)
  - ~constant for most lunar compositions (except H).
- **“Thermal neutrons”** (<~0.3 eV)
  - Neutron flux is highly composition dependent (flux is large for Fe, Ti, Fig. 8) and is greater in mafic materials (mare basalts, Mg or Fe-rich, of igneous/volcanic origin, dark in color, olivine, pyroxene) and smaller in the Fe-poor highlands (farside).
- MSFC scintillator technology effectively discriminates between pulse shapes and distinguishes between neutrons and other false triggers (Fig. 9).
- Elemental abundances are calculated including Th, Th is also proportional to the amount of Sm and Gd at the surface. Fe, Ti can be a marker of where Rare Earth Elements (REE).
- In-situ Resource Utilization (ISRU) applications.
- The Moon's water cycle varies over the course of a lunar day. This change in hydrogen concentration as a function of time will be detected with NMS.
- Dependent on data and power availability during lunar evening.

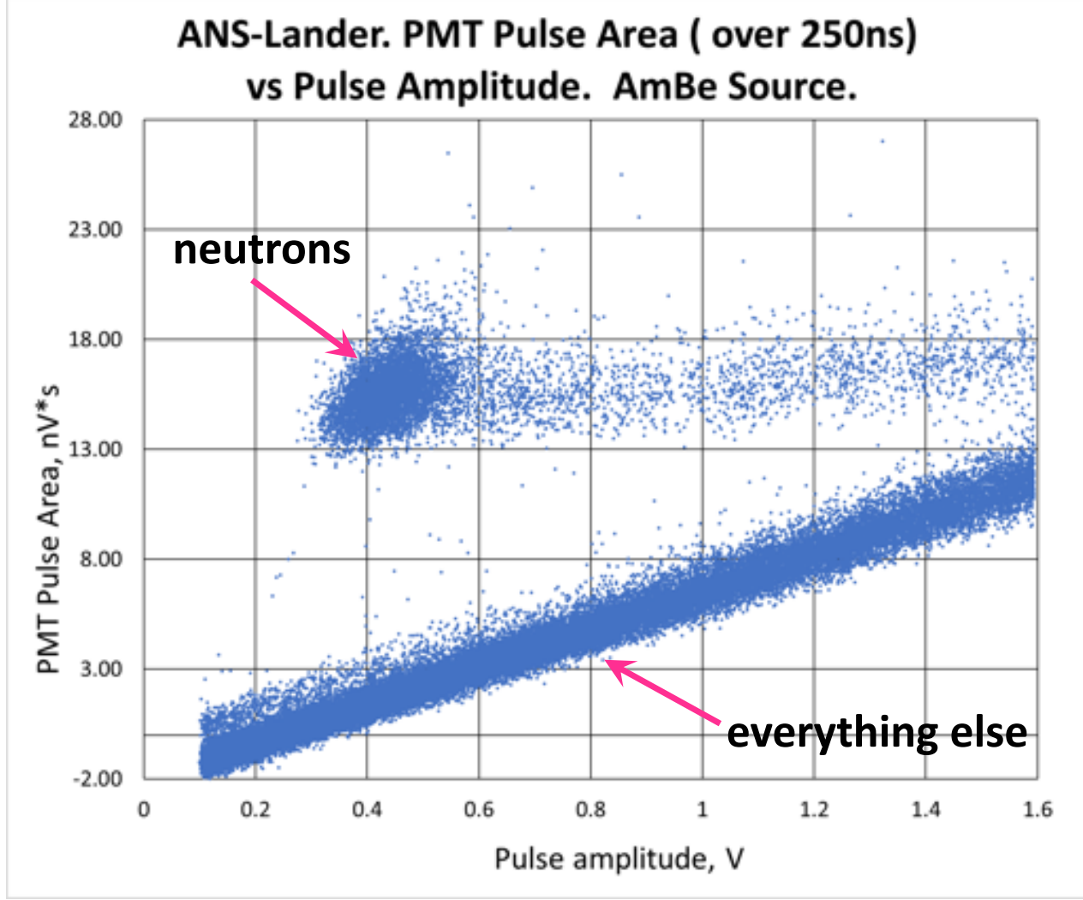

Figure 9. Composite scintillator technology effectively discriminates between pulse shapes and distinguishes between neutron and false triggers such as gamma rays.

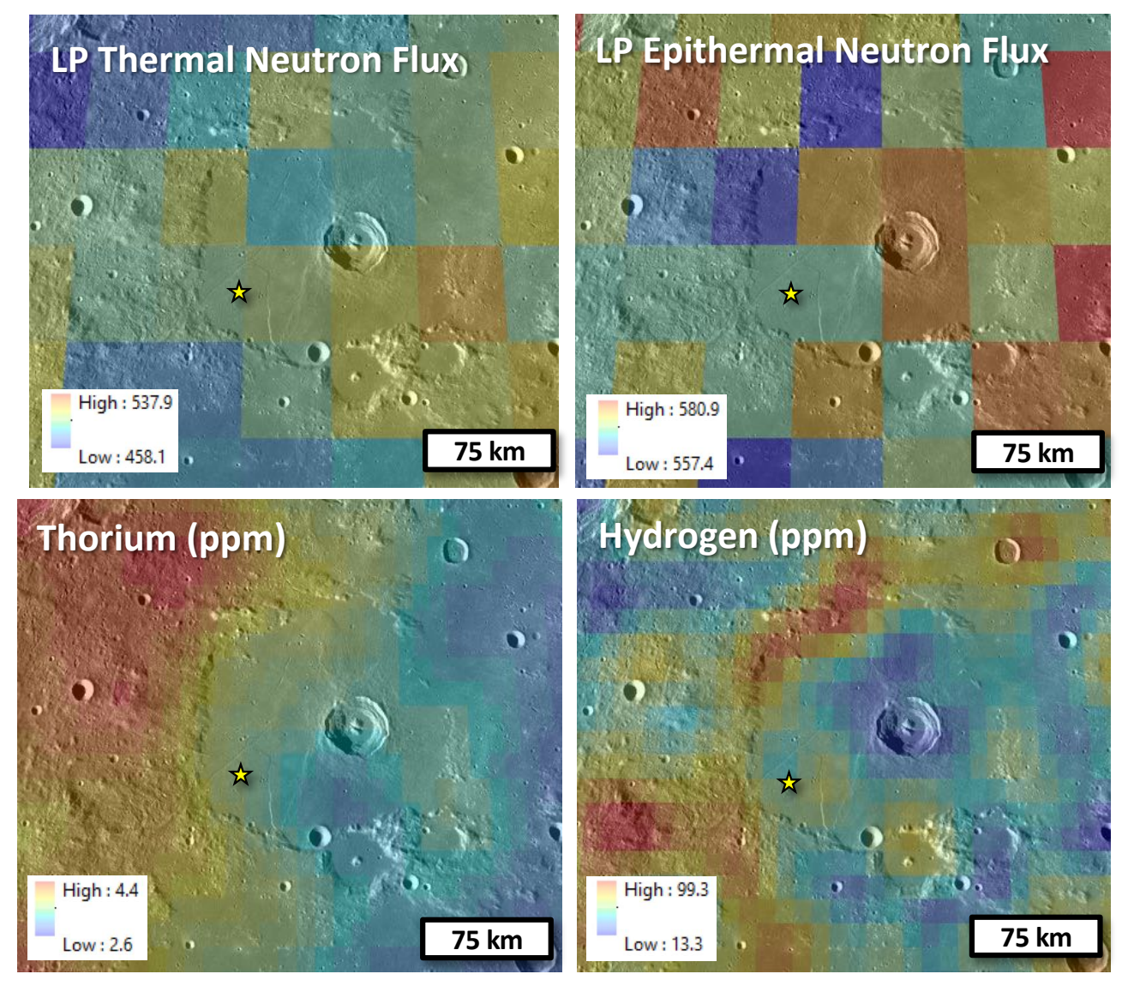

Figure 10. NMS will provide ground truth for calibrating orbital datasets. LP NS maps are ~50 km resolution for thermal and epithermal neutron flux. Star shows approximate ABM1 landing site [3].

Summary

- NMS will provide counts of the thermal and epithermal neutron rates at the lunar surface.
- NMS is on track to fly on Astrobotic's Mission One to Lacus Mortis.
- These observations will provide a ground truth for calibrating orbital datasets, constraints on composition, and will monitor the dynamic hydrogen cycle over the lunar day.

References and Acknowledgements

1. NASA HQ Artemis Phase 1 chart.
2. Astrobotic Lander, https://www.nasa.gov/press-release/nasa-selects-first-commercial-moon-landing-services-for-artemis-program
3. Michael Zanetti and Caleb Fasset, personal communications. Data is from the PDS. Inset: Quickmap. https://quickmap.lroc.asu.edu
4. Image credit: NASA. Schematic after Curran [2017].
5. Elphic et al. [2000]. JGR. “Lunar rare earth element distribution and ramifications for FeO and TiO2: LP observations.”

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