LunaH-Map

Lunar Polar Hydrogen Mapper

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Interplanetary Small Satellite Conference 2022

LunaH-Map

Lunar Polar Hydrogen Mapper

- 1st NASA Science Mission Directorate SIMPLEx mission selection in 2015. Solicitation via NASA ROSES 2014.
- Developed from 2015 - 2020. Spacecraft delivered to NASA KSC in July 2021.
- Launching on SLS Artemis-1 no-earlier-than August 2022.
- Life cycle costs <$18M

LunaH-Map

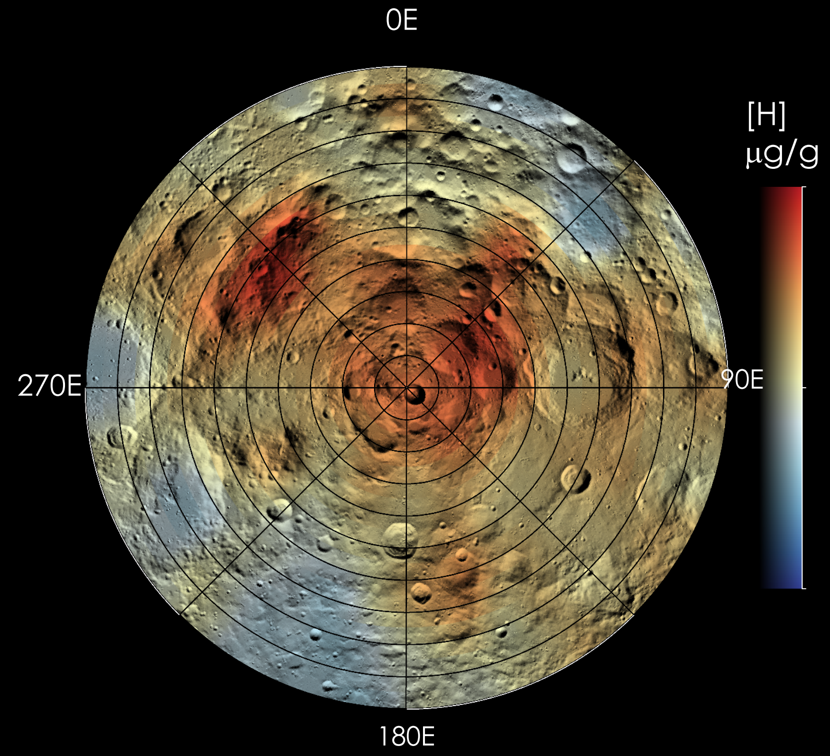
Lunar Polar Hydrogen Mapper

Outline

- LunaH-Map Science and Mission Overview
- Development and Delivery Accomplishments
- Low Cost Interplanetary Mission Thoughts

Lunar Polar Water Abundance and Distribution

Lunar Prospector (2001) → Diviner (2015) → Lunar Reconnaisance Orbiter (2017)



Feldman, W. C. et al. (1998, 2000, 2001)

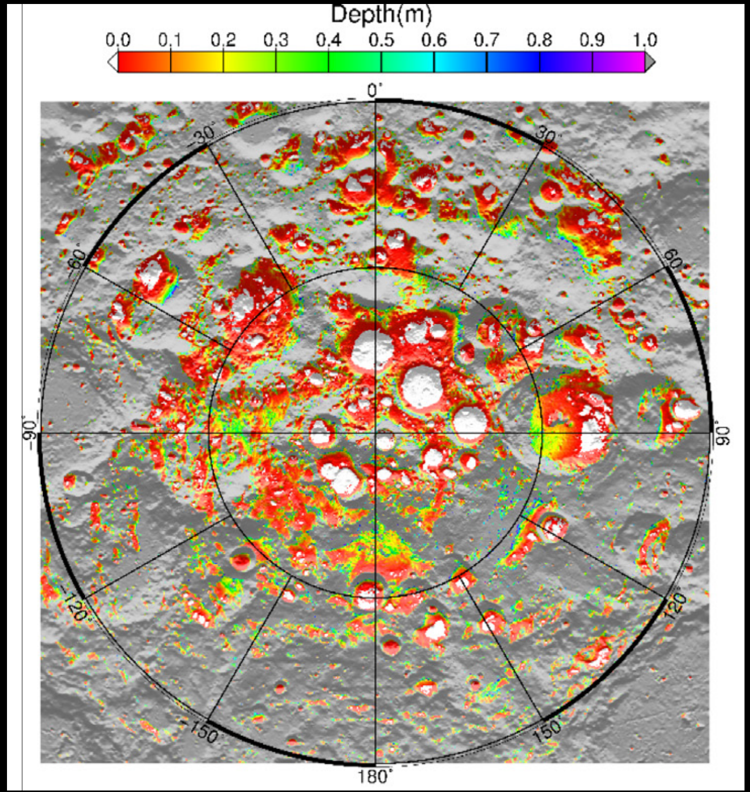
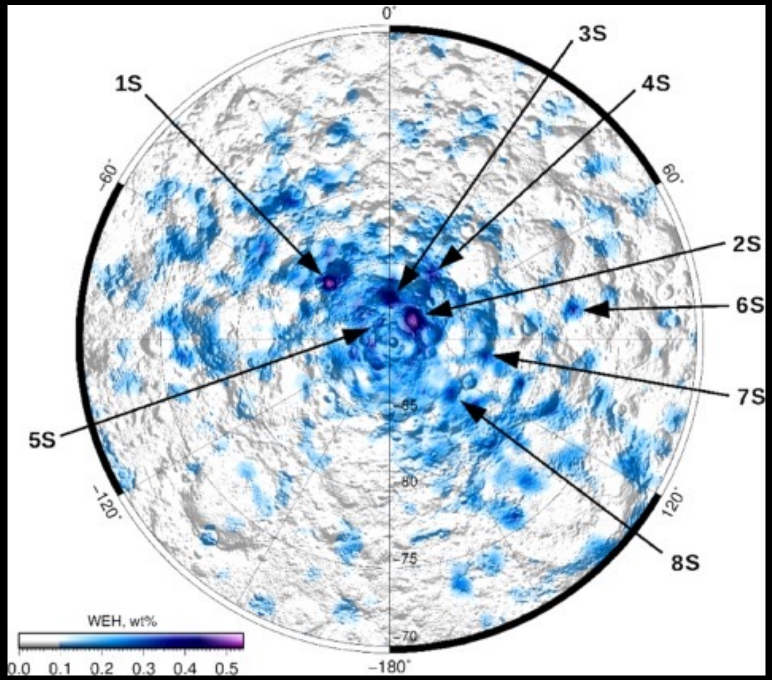


Figure 1 Map of current day ice stability depth from Siegler et al [2015] as used in constraint map development



Analysis of LEND data (Sanin et al 2017) reveals higher WEH abundances (~0.5 wt%) in south polar craters Shoemaker, Haworth, and Faustini

Lunar Polar Water Abundance and Distribution

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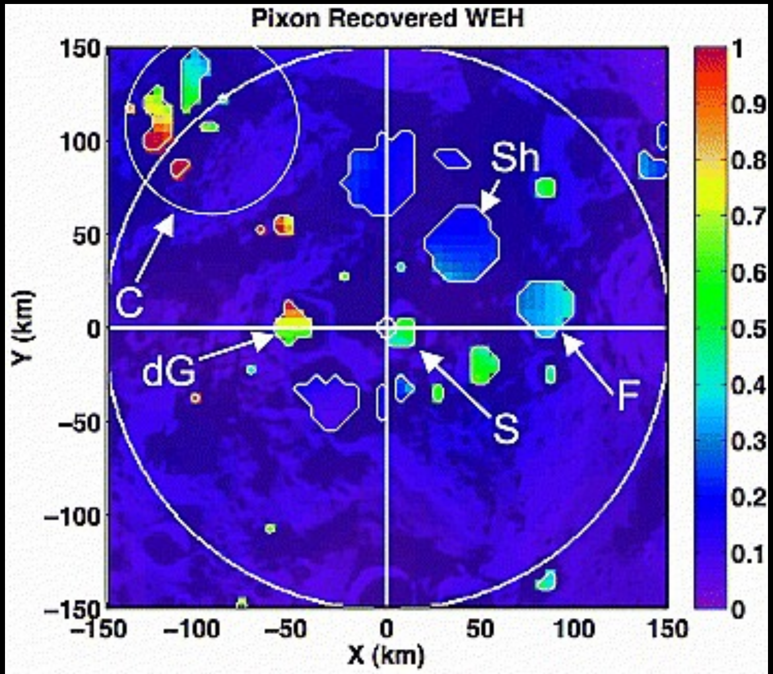
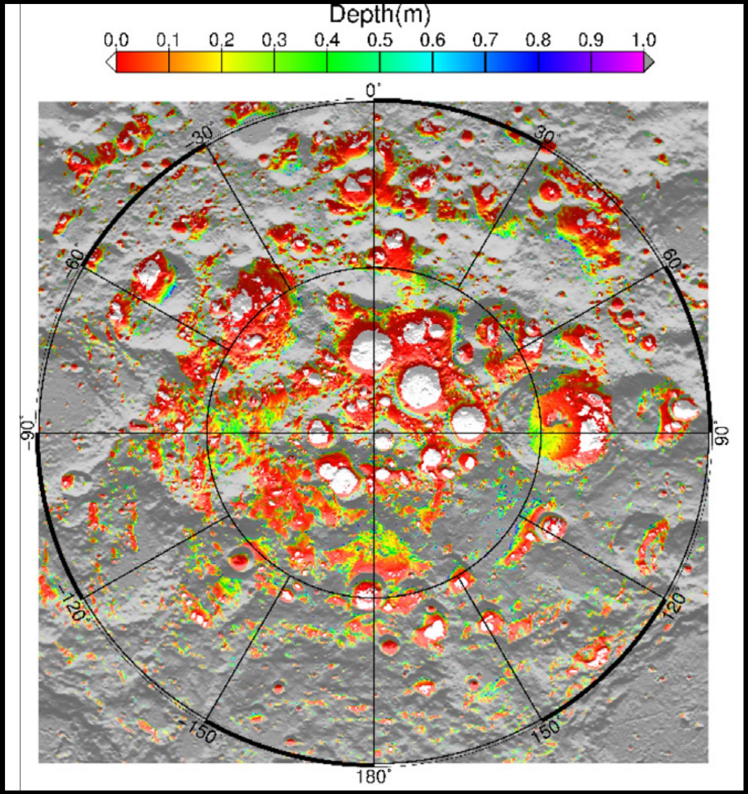


Pixon-based reconstruction of LPNS data (Elphic et al 2007) reveals high WEH abundances in Cabeus (near 1 wt%) and lower abundances in Shoemaker, Haworth, and Faustini (~0.3 wt%)



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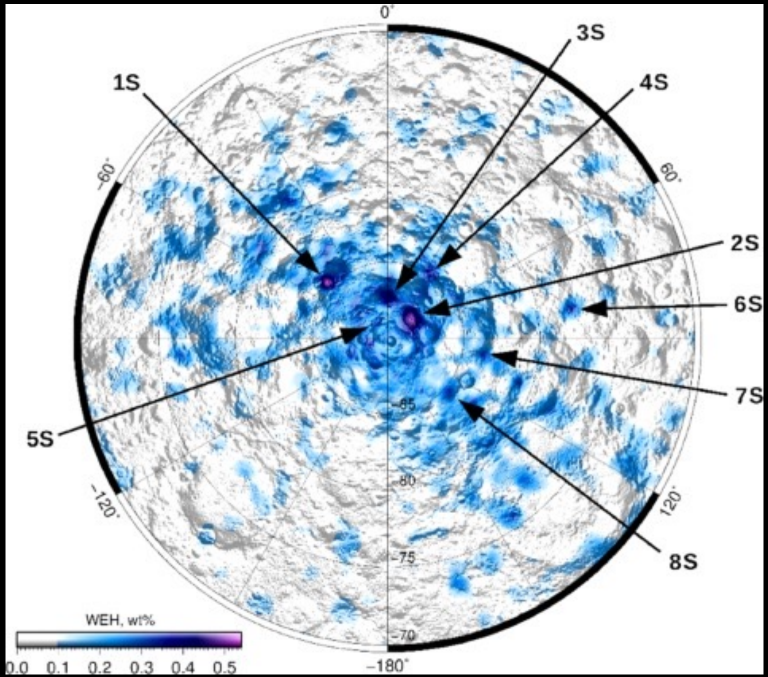
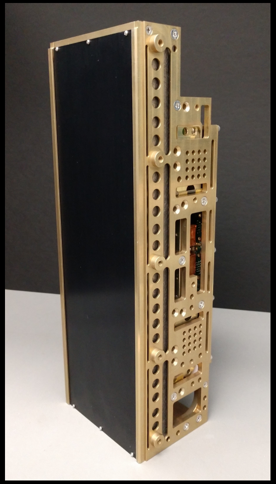
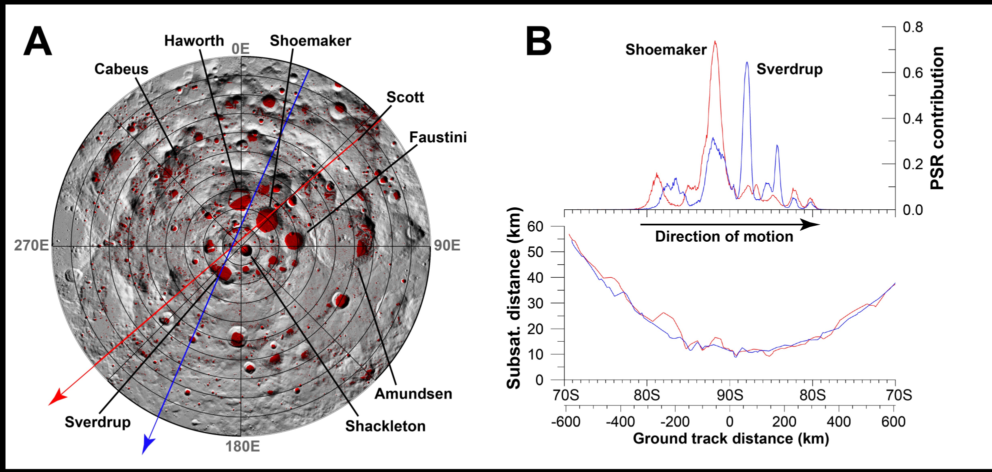


Analysis of LEND data (Sanin et al 2017) reveals higher WEH abundances (~0.5 wt%) in south polar craters Shoemaker, Haworth, and Faustini

LunaH-Map Mission Overview

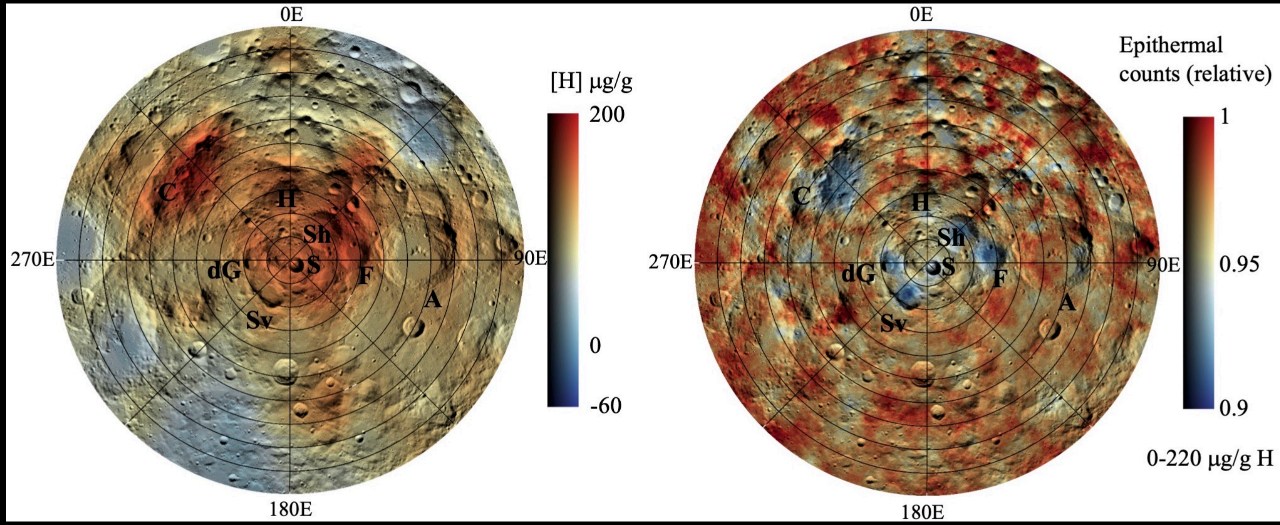
- 6U+ CubeSat form factor launching on SLS Artemis-1
  - 14 kg spacecraft
  - 1 science instrument.
  - Deploy SLS. Use ion propulsion to navigate to weak stability boundary and lunar capture. Transition from high altitude circular to elliptical science orbit
  - Science phase 2 months. Total mission duration 18 months.
- LunaH-Map will enter a low-altitude perilune orbit above the South Pole, enabling neutron measurements that can reveal hydrogen enrichments within and surrounding individual PSRs.
- **Science Objective**: Map hydrogen enrichments within PSRs at the lunar south pole at spatial scales <20 km^2
- **Tech Objectives**: Deep space navigation and operations using ion propulsion on a small sat





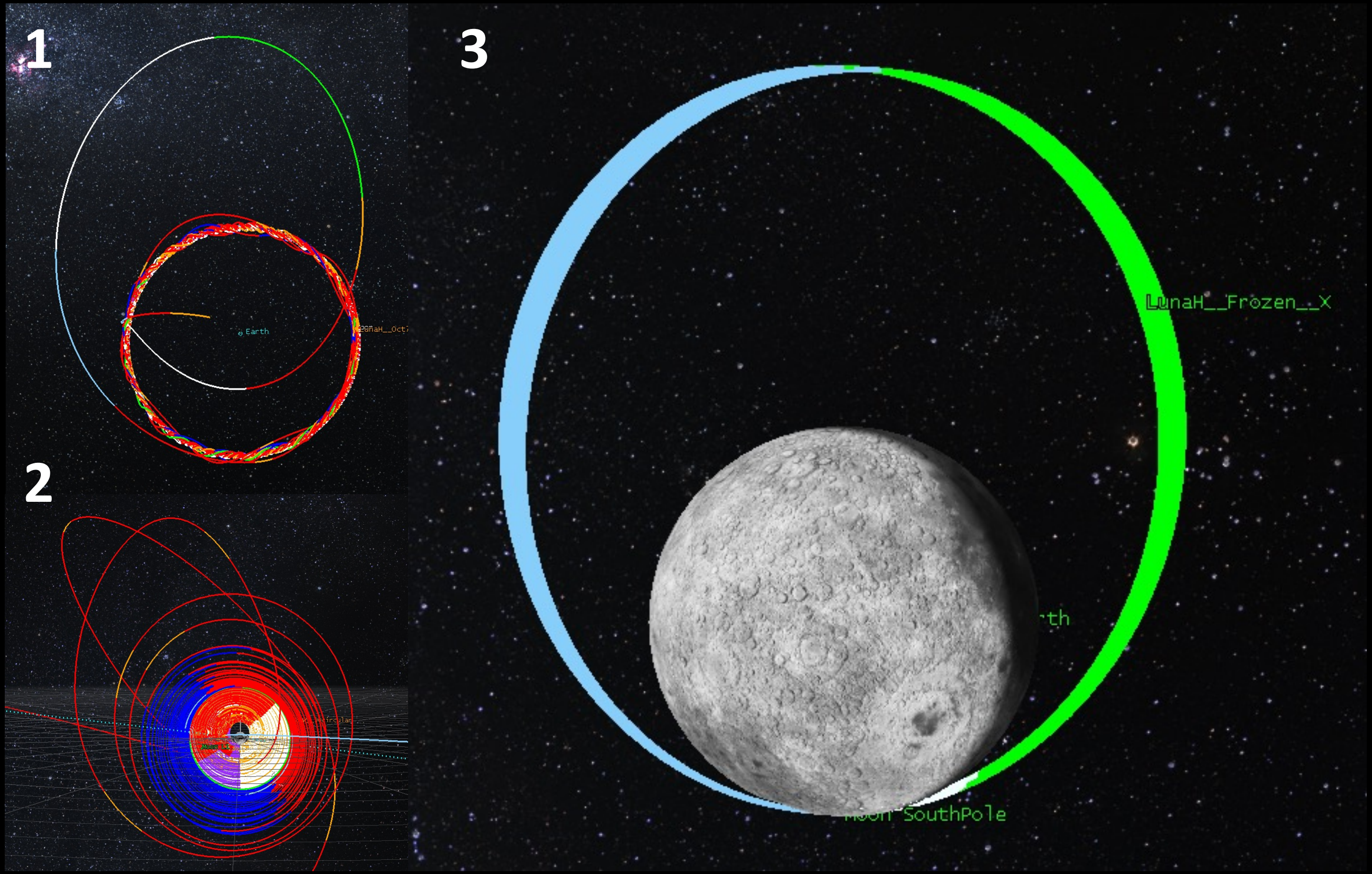
Ground tracks for select perilune passes during science orbit*

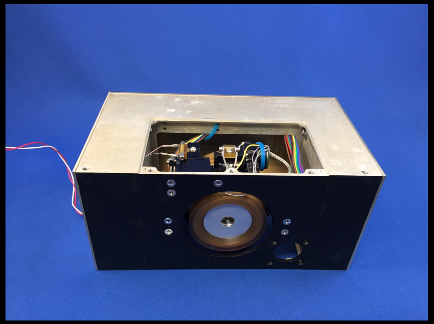
Mini-NS: Compact neutron and gamma-ray spectrometer for small spacecraft*



*Hardgrove et al., IEEE (2020); Heffern et al., NIM-A (2022)

LunaH-Map Navigation





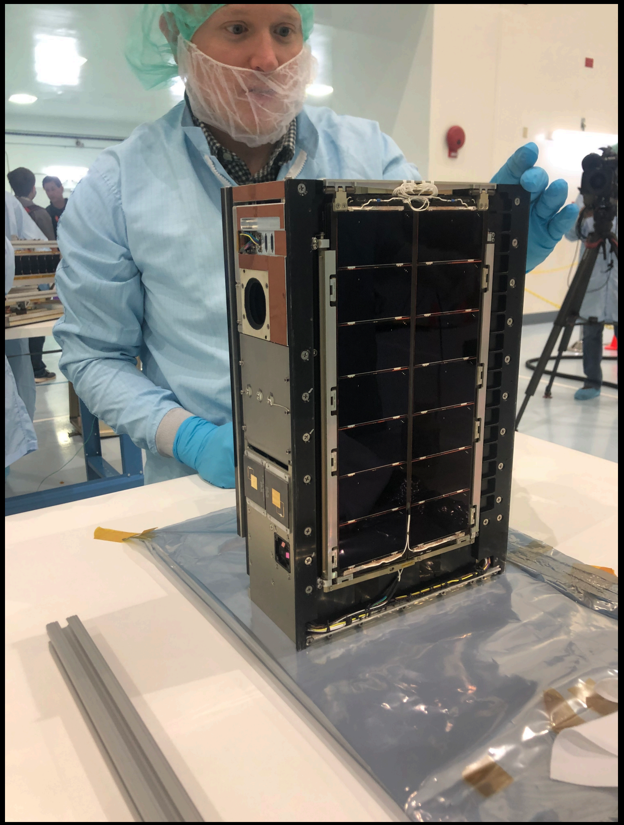
LunaH-Map Flight BIT-3 propulsion system – Delivered Decmber 2019

BIT-3 QM Hot Fire Iodine Testing

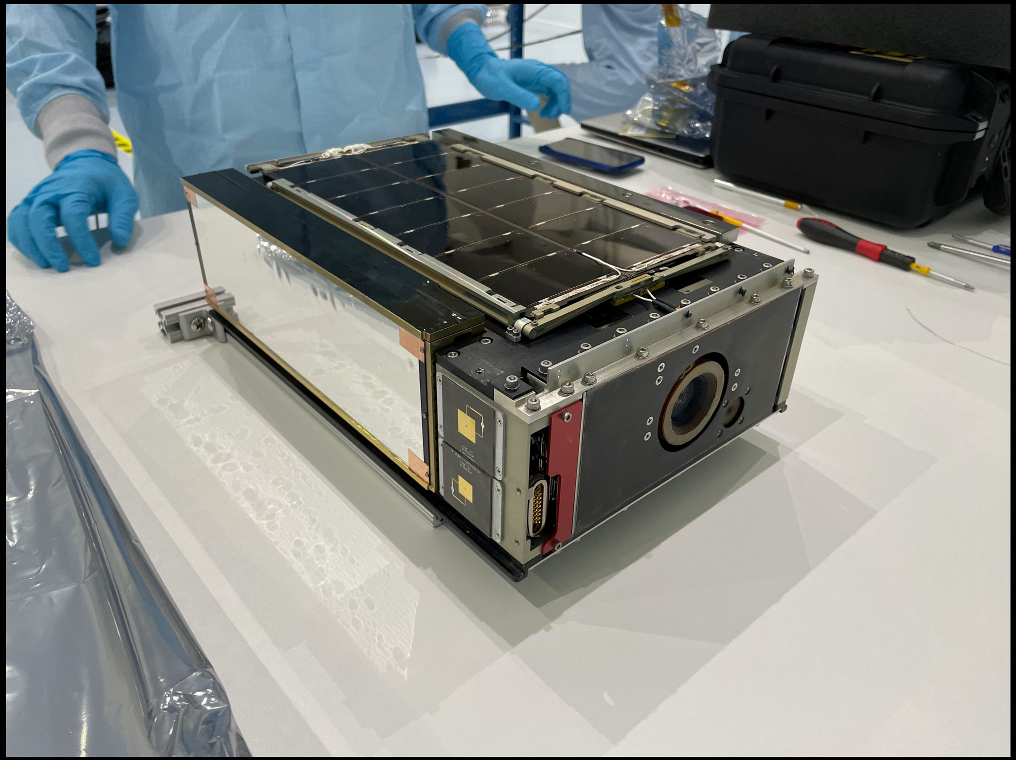
Orbit Period	4.76 hour
Aposelene Altitude	3150 km
Periselene Altitude	RAAN dependent 15-25 km
Inclination	90°
Argument of Periselene	273.5°

Genova, A. L. and Dunham, D. W. (2017) 27th AAS/AIAA Space Flight Mechanics Meeting 17-456.

LunaH-Map Delivery to SLS Artemis-1



Inspection: LunaH-Map delivery to NASA KSC July 2021



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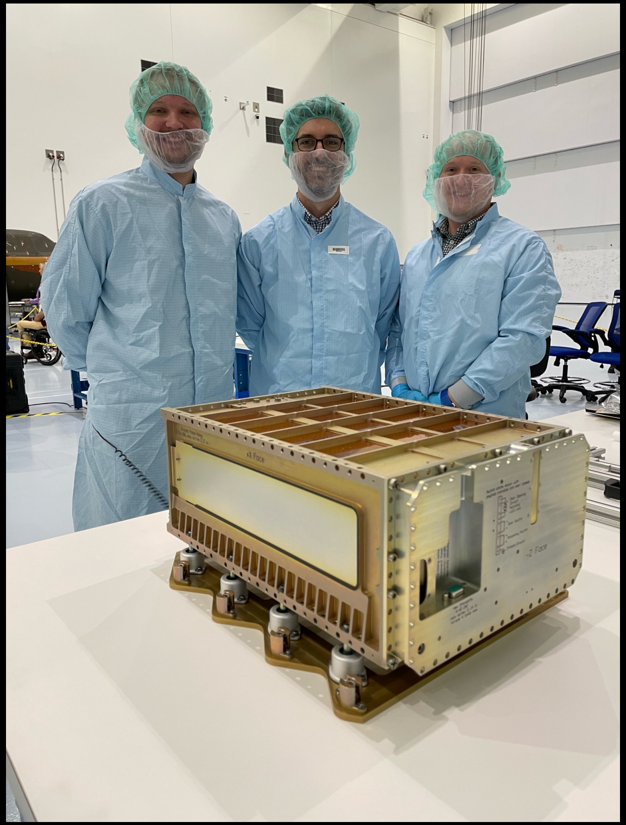
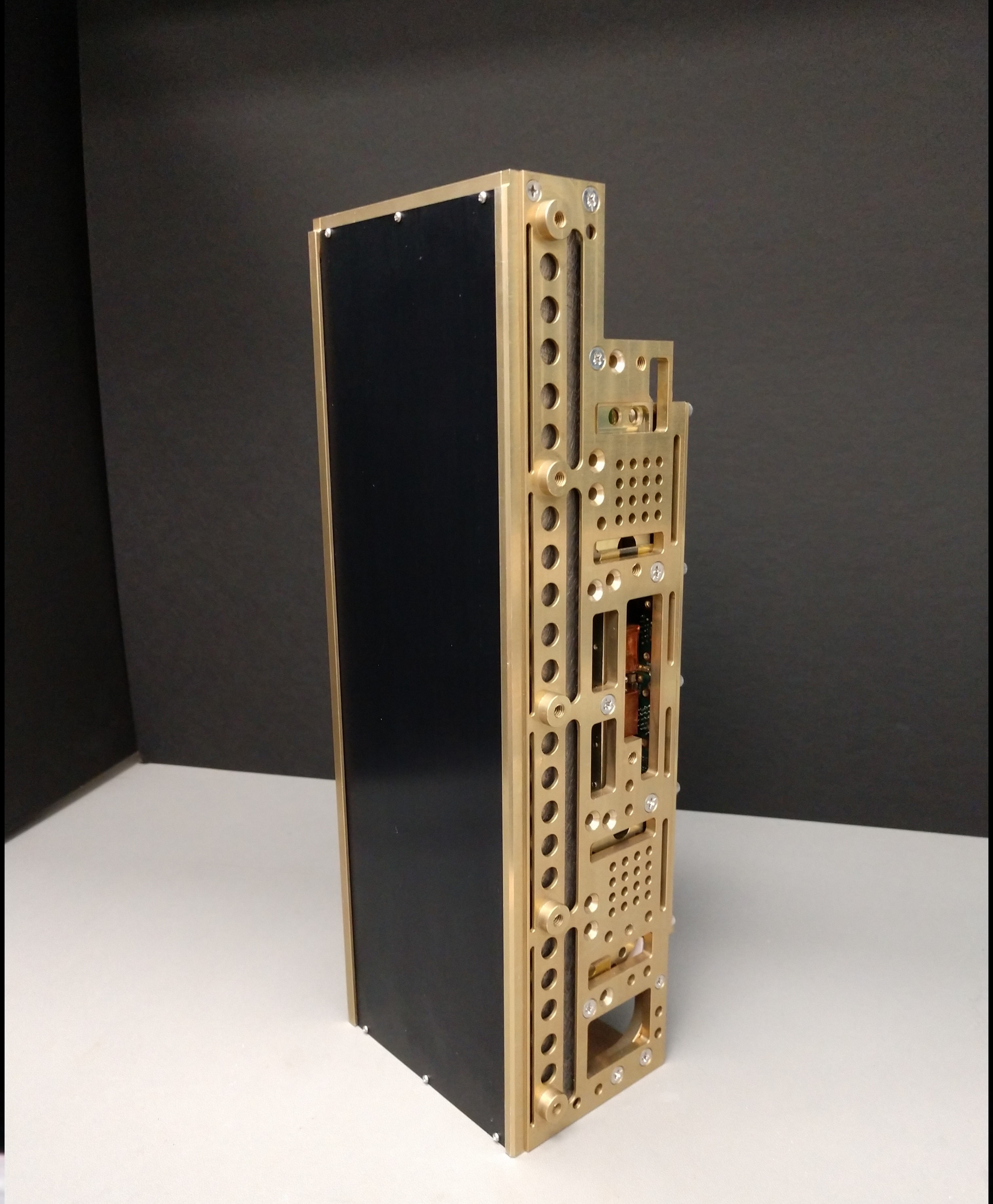
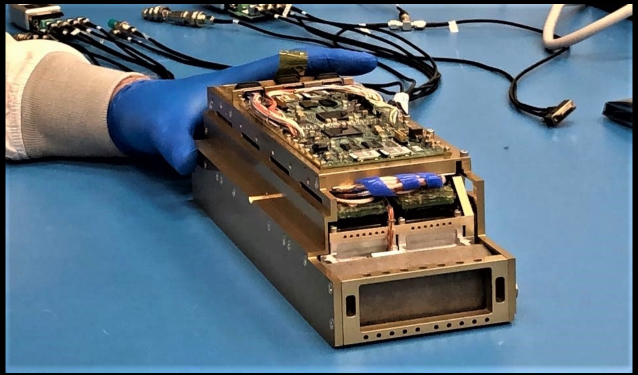


Loaded into PSC Deployer: Delivered!

LUNAH-MAP
Lunar Polar Hydrogen Mapper



Mini-NS Flight Unit

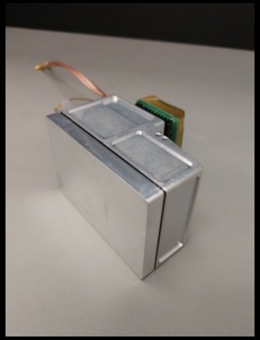


Mini-NS: Miniature Neutron Spectrometer

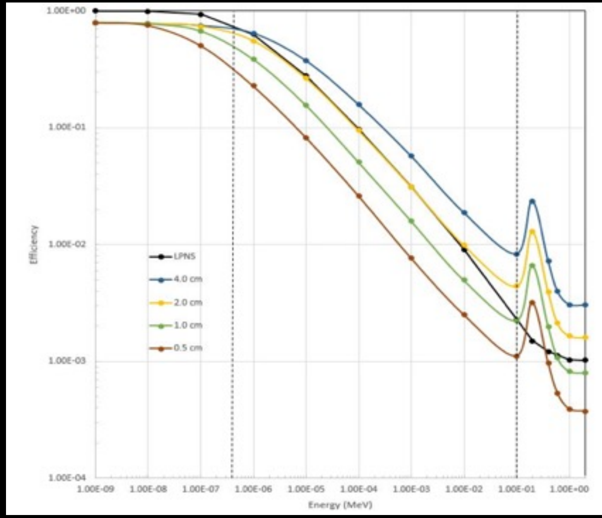
School of Earth & Space Exploration
Arizona State University

RMD
A Dynasil Company

Miniature Neutron Spectrometer for CubeSats and SmallSats – Flight Unit



Detector	2x4 array of CLYC (elpasolite scintillator, Cs_2LiYCl_6:Ce) crystals, each crystal 4 cm x 6.3 cm x 2 cm
Dimensions	25 cm x 10 cm x 8 cm
Mass	3.3 kg
Power	10W
Data Acquisition	Counts binned every 1 sec

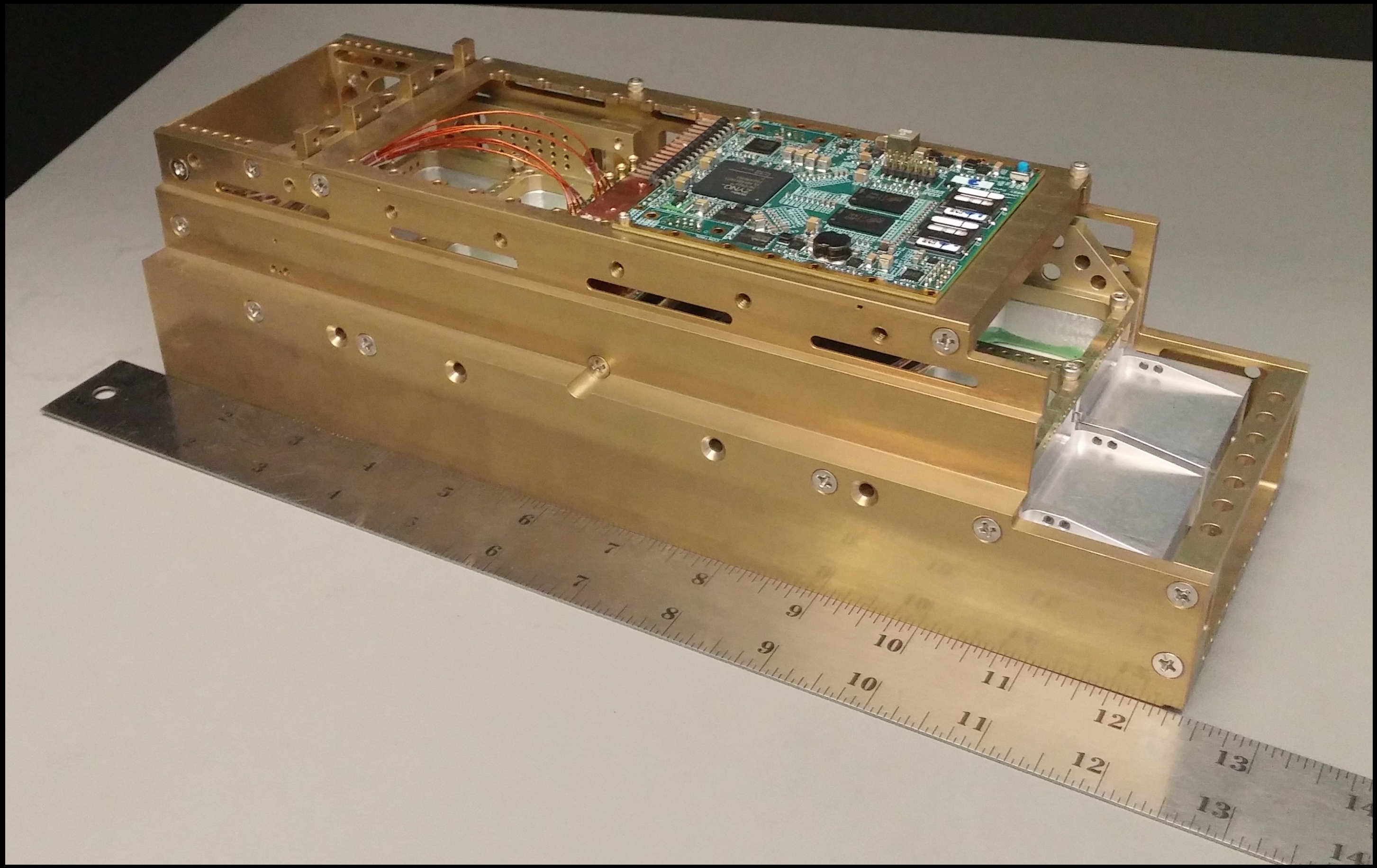


Mini-NS epithemal neutron intrinsic efficiency*

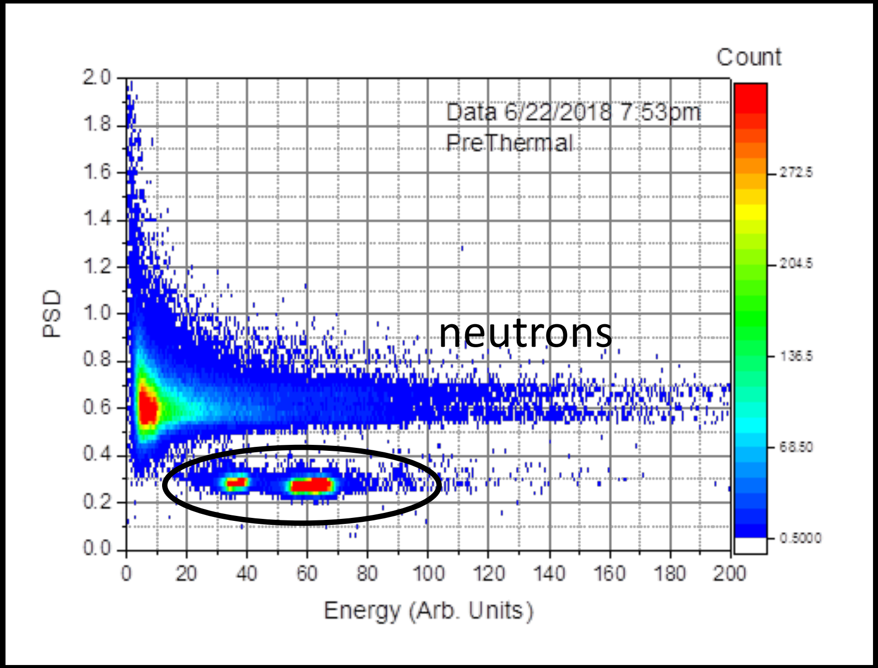
- Mini-NS achieves twice the epithermal neutron count rate of Lunar Prospector NS in a modular cubesat design.
- Mini-NS Flight Unit delivered and calibrated at Los Alamos National Lab Neutron Free In-Air (NFIA) facility in late Fall 2018

*Hardgrove et al., IEEE (2020)

Miniature Neutron Spectrometer for CubeSats and SmallSats – Dev Unit



LunaH-Map protoflight Miniature Neutron Spectrometer (Mini-NS) unit was developed with a subset of the 8 detector modules, analog and digital boards populated prior to final assembly and qualification.

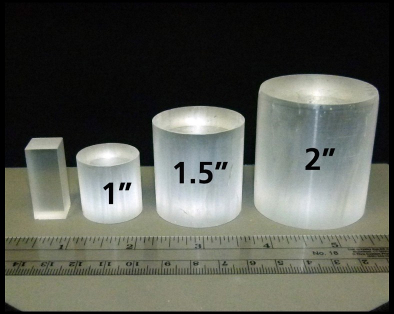


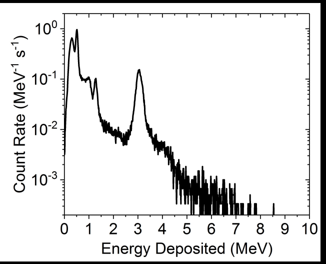
- Each Mini-NS detector module is sensitive to both neutrons (to detect hydrogen on planetary surfaces) and characteristic gamma-rays (to detect elements like Fe, K, Th, Si, Al, Mg) ← ready to be proposed with YOUR mission ☺

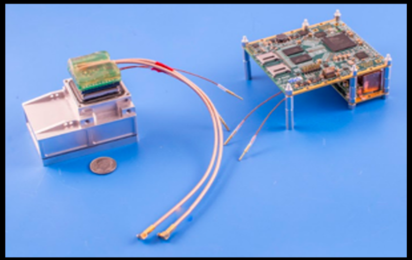
1. COMPACT, MODULAR NEUTRON AND GAMMA-RAY SPECTROMETER FOR SMALL SPACECRAFT

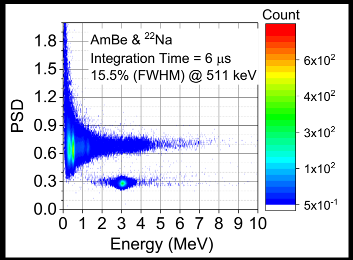
Sensitive to the top meter of Mars, can identify shallowly buried ice, salts, hydrated mineral enrichments

Used to identify enrichments or depletions in surface or buried hydrated materials (H2O, ice), Cl-rich salts, Fe-poor or high-Si materials.

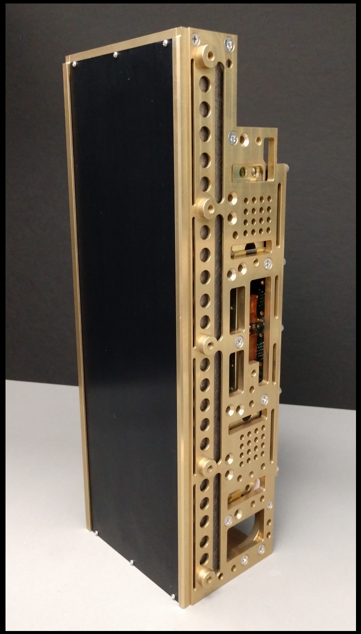




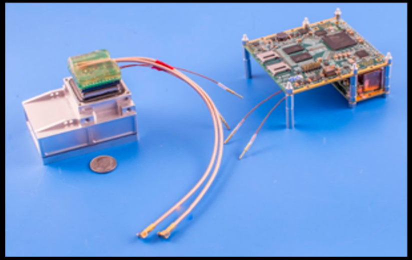




CLYC is a scintillator sensitive to both neutrons and gamma-rays. Pulse shape discrimination is used within the FPGA to record an energy spectrum per module

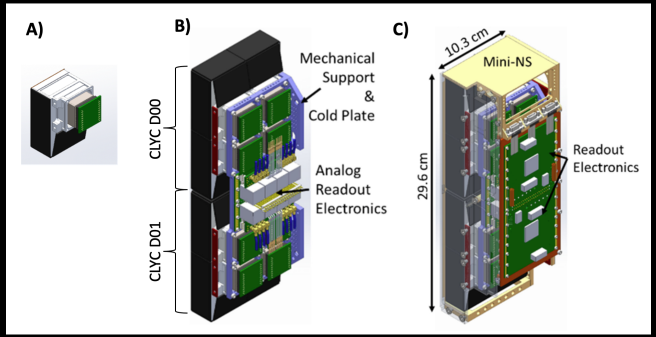


Flight Mini-NS for LunaH-Map (8 modules)



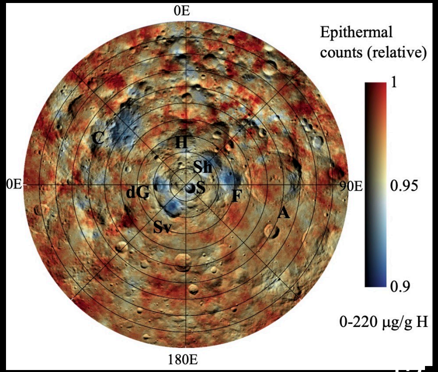
Mass = 400 grams per sensor head

Mini-NS Tech Specs	
Sensitivity	Thermal (<0.3 eV), epithermal (>0.3 eV - ~10 keV) and fast neutrons (>1 MeV and < 3 MeV); Gamma-rays (< 4 MeV) with energy resolution 4% FWHM at 662 keV
Sensor head	1 sensor head = 4cm x 6.3cm x 2cm rectangular CLYC crystal attached to ruggedized photomultiplier tube (Hamamatsu)
Mass	1.7 kg per 4 sensor head detector
Power	1.8 W (standby), 4.8 W (data acquisition) per 4 sensor head detector
Volume	12.5 cm x 5 cm x 4 cm per 4 sensor head detector
Data Rate	7 bytes/sec, 25 kB/sec stored locally per 4 sensor head detector
Data products	Counts per second, event-by-event
Internal Storage	16GB



At Mars, one or two sensor heads could be used on a surface or ariel vehicle to identify enrichments of 1-2 wt.% water

At the Moon, from orbit 8 sensor heads will be used to identify enrichments of 200 ppm H in tens of minutes.



LUNAH-MAP
Lunar Polar Hydrogen Mapper

2. Mission Operations Center

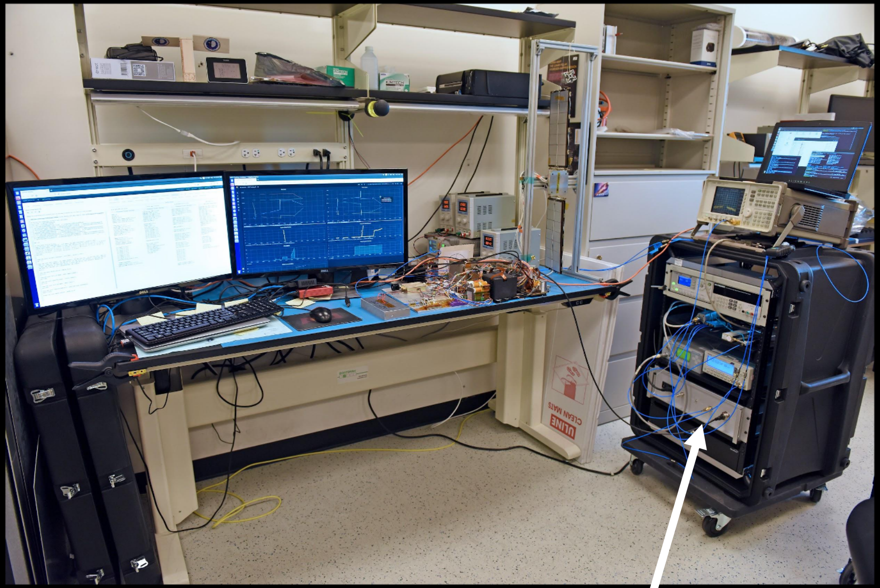
- MOC co-located in ASU's shared operations facility
- JPL AIT for spacecraft uplink and downlink
- KinetX provides mission navigation
- ASU science/instrument ops development coincident with Mars 2020 and Psyche missions

Qwaltec

KINETX AEROSPACE

Preparation for Launch

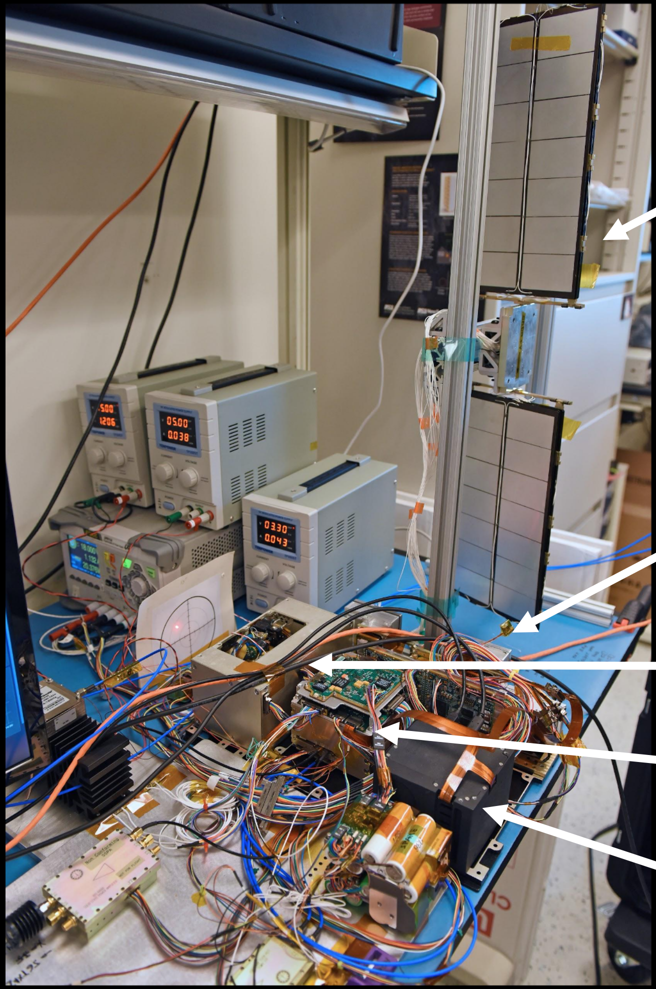
AIT and Grafana for commanding and telemetry visualization



CASSY to simulate DSN comms

Primary operations activities:

- Negotiating DSN schedule L+7 days
- Onboarding full time ops staff, training, rehearsals and ORTs
- Thread tests between MOC and NAV
- Preparing NASA PDS archiving agreement and draft archive plans



Solar array

Mini-NS (instrument)

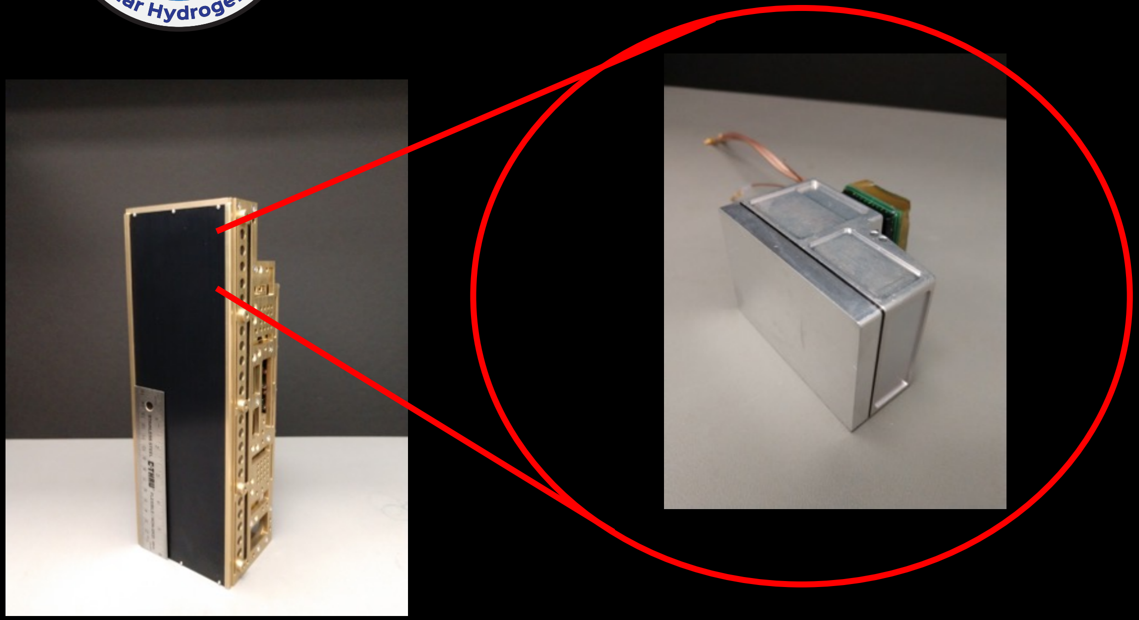
BIT-3

Iris

XB1-50 & XEPS

LunaH-Map flatsat and testbed at Arizona State University

Low-cost factors for LunaH-Map



Science

- 1 science instrument
- Small science team
- Few measurement observation requirements (i.e. pointing)
- Instrument technology developed via SBIR/STTR and NASA PICASSO programs. Partnerships with LANL enabled calibration.

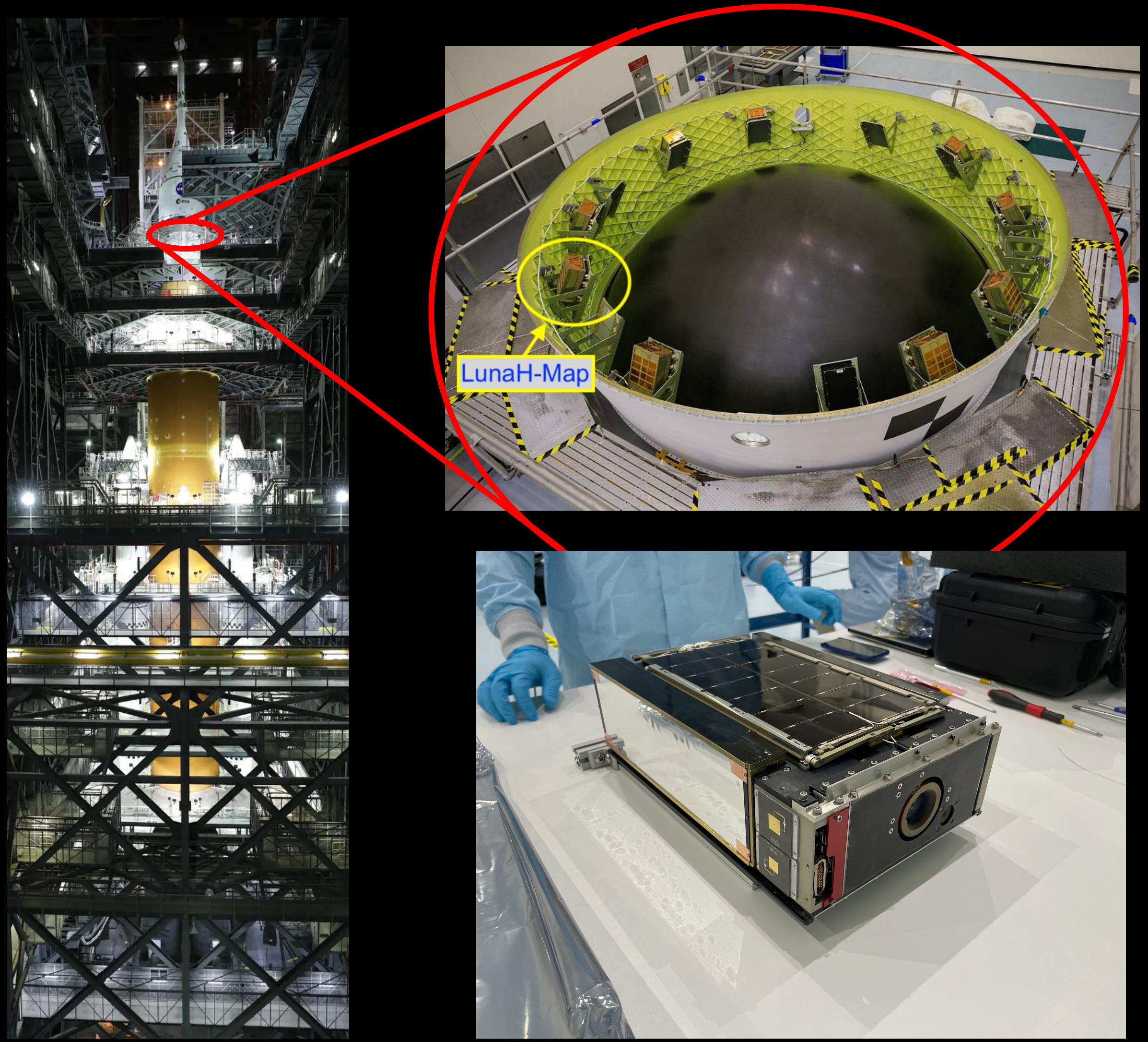
Technical

- Few redundant systems
- Fault protection prioritizes spacecraft health and safety over science
- Acceptance and testing of COTS parts
- I&T and environmental testing at ASU
- I&T team became operations team, with mission ops at ASU
- Testing of critical mission scenarios
- Propulsion technology developed via SBIR/STTR and NextSTEP programs. Also flying on Lunar IceCube.

Management

- Minimal project personnel. Each person in multiple roles.
- Tailored 7120.8 (NASA Research and Technology Program and Project Management Requirements) for management and reviews
- Table-top reviews with SMEs at milestones
- Reviews and outcomes convened by the project

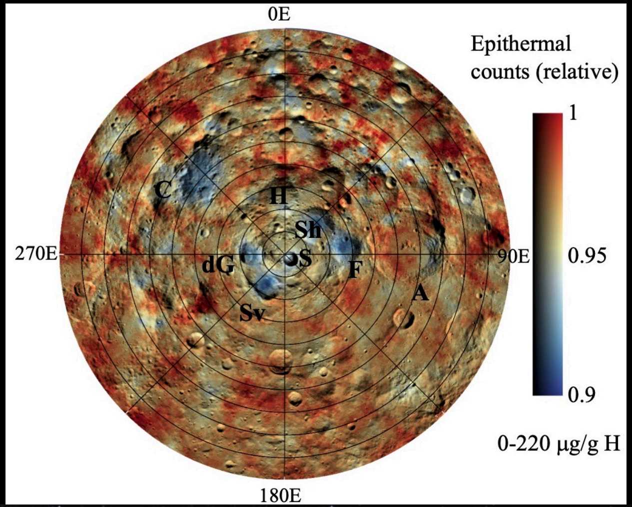
Low-cost factors for LunaH-Map



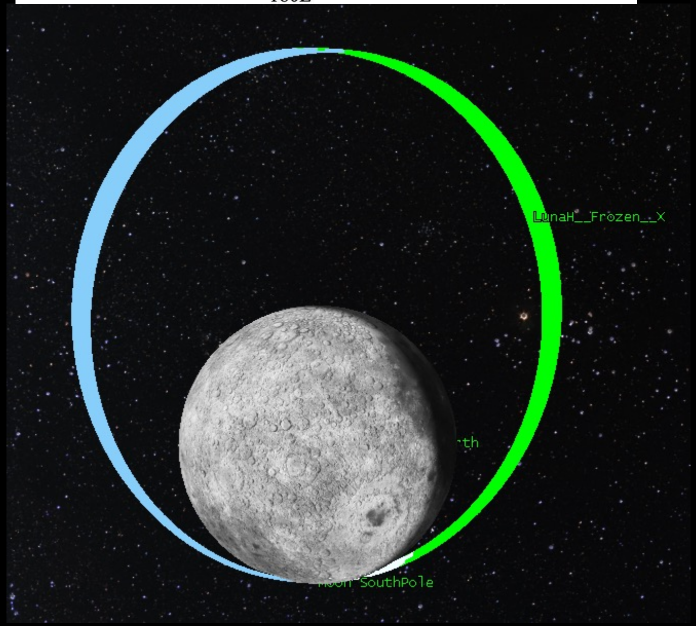
Some lessons so far….

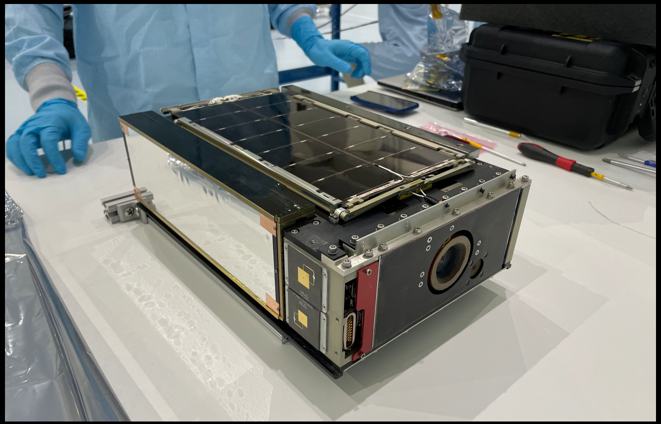
- Most/all of your team will be part-time, however, flexibility in accommodating full-time periods was critical.
- You may not be able to afford EMs. Prototypes, EDUs, development units, etc are all useful. A flatsat is <u>essential</u>.
- Your vendors are your partners.
  - You need "buy in" from everyone on your team.
- Test as much as you can
  - Set clear mission expectations with your team and with NASA
- Launch vehicle challenges. New requirements and documentation for SLS. Now at 11 months advance delivery. Safety engineers are critical. Plan for delays if you can.

Low-cost factors for LunaH-Map



It's the team that makes it possible





Don't let anyone tell you you can't build this

Some lessons so far….

- Executing a mission at this end of the cost spectrum is challenging… but you **CAN** build a spacecraft (and a science instrument) capable of achieving a science mission at this price point (<$18M TLC). The LunaH-Map flight unit went through environmental and qualification testing at both the system and subsystem level. So….**The rest is all about risk.**

- At this size, the mission should fill a niche. *High-risk, high-reward* is a good mantra. I.E. LunaH-Map science measurements require a low-altitude perilune (~10-12 km altitude) orbit over the lunar South Pole. This sets the risk posture and associated mission risks can flow from there. **IMO: THESE TINY BUT MIGHTY MISSIONS SHOULD BE DARING AND EXCITING!** ☺ **now that we know they are possible**