

Development of the Lunar Polar Hydrogen Mapper Mission

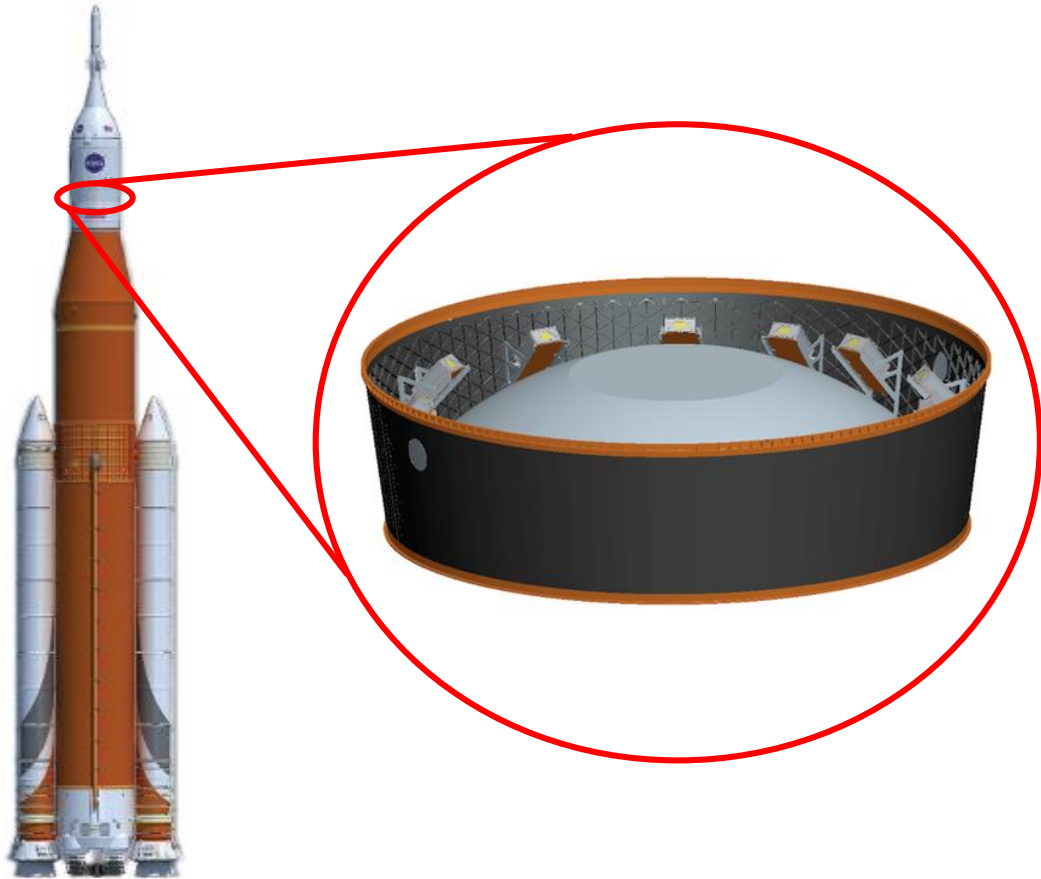
**Craig Hardgrove: Principal Investigator,
Assistant Professor, ASU**

ISSC 2018 – Caltech, Pasadena CA

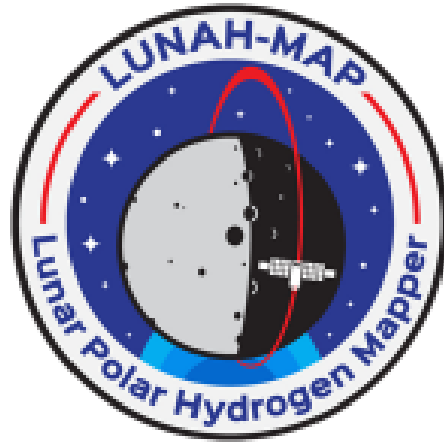
May 7, 2018



LunaH-Map Mission Overview



- NASA SMD SIMPLEx 2015 mission led by ASU
- 6U+ CubeSat form factor to launch on SLS EM-1
- **Science Objective:** Map hydrogen enrichments within PSRs at the lunar south pole
- **Tech Objectives:** Demonstrate neutron spectroscopy, deep space operations & propulsion from a small sat



Principal Investigator
Craig Hardgrove, ASU
Deputy Principal Investigator
Jim Bell, ASU

Project Management (ASU)
Teri Crain – *Project Coordinator*
Kevin Reinhart/Michael Fitzgerald - *Budget*
Stephanie Holaday - *Purchasing*

Science Team
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Anthony Colaprete, *NASA/Ames*
Mark Robinson, *ASU*

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Chief Engineer
Igor Lazbin, *AZ Space Tech*
Student Project Systems Engineer
Stephen West, *ASU PhD Student*

SLS Safety/Requirements
Dawn Gregory, *AZ Space Tech*

Navigation / Mission Design
Navigation
Derek Nelson, *KinetX*
Mission Design
David Dunham, *KinetX*
Anthony Genova, *NASA/Ames*

Spacecraft Bus
EPS, ACS, C&DH
Steve Stem
Blue Canyon Technologies
Propulsion
Mike Tsay
Busek
Radio/Ground Comm (DSN)
Alessandra Babuscia
Jet Propulsion Laboratory
Solar Arrays
Sean Parlapiano
MMA Designs

Flight Software
Steve Stem
Blue Canyon Technologies
Hannah Kerner, *ASU PhD Student*

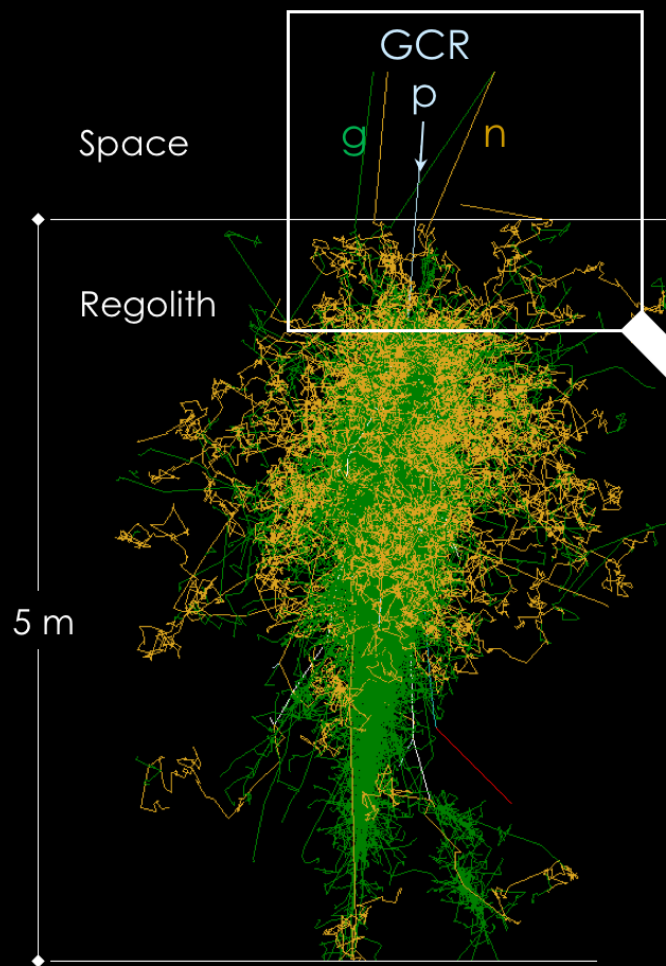
Assembly, Integration and Test
Electrical Integration and Test
Bob Roebuck, *AZ Space Tech*
Instrument Integration
Paul Scowen, *ASU*

Payload
Mini-Neutron Spectrometer
Erik Johnson
Radiation Monitoring Devices

Mission Operations
Patrick Hailey, *Qwaltec*
Ernest Cisneros, *ASU*
Logan Vlieger, *ASU Student*
Max Flanagan, *ASU Student*
Teagan Gilbert, *ASU Student*

Thermal/Structure
Joe DuBois, *ASU*
Valentin Ivaniski, *AZ Space Tech*
Nathaniel Struebel, *AZ Space Tech*
Robert Amzler, *ASU Student*

Neutron Detection Physics

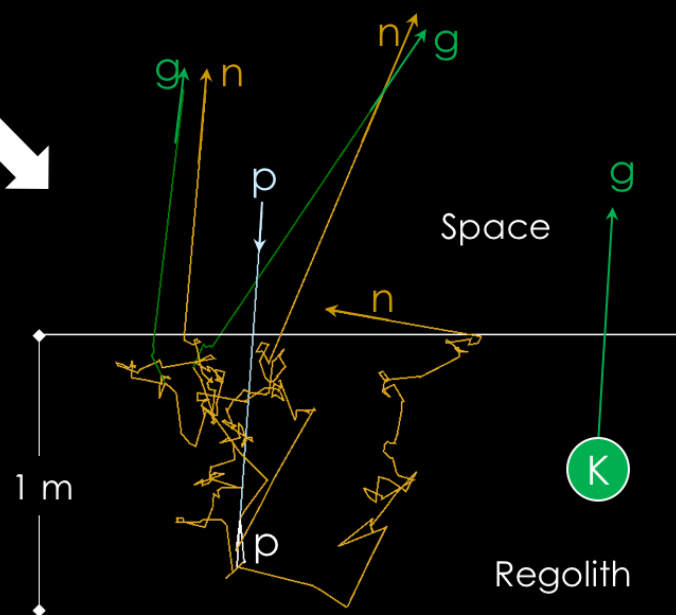


Gamma rays (g)

Major elements (O, Mg, Al, Si, Ca, Fe), alteration products (Na, S, Cl, K)

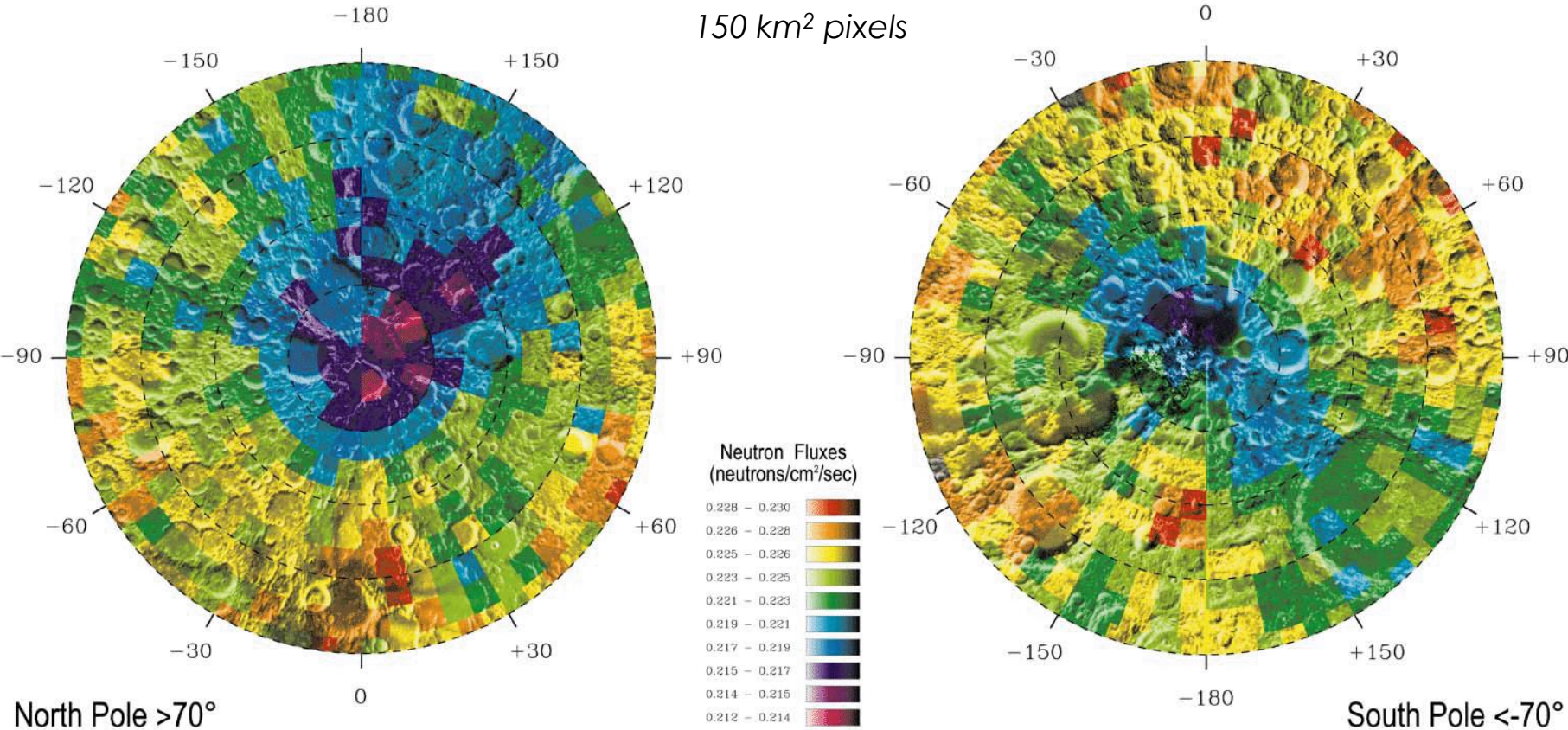
Neutrons (n)

H, C, absorption, atomic mass



T. H. Prettyman, 2016

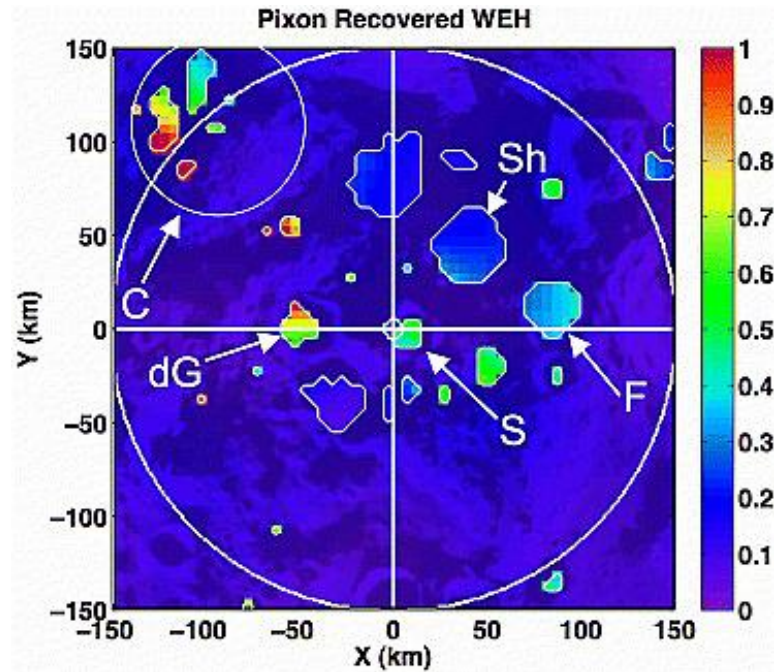
Polar Volatile Distributions from Neutron Spectroscopy



*Feldman et al., Science, 281, 1496, 1998

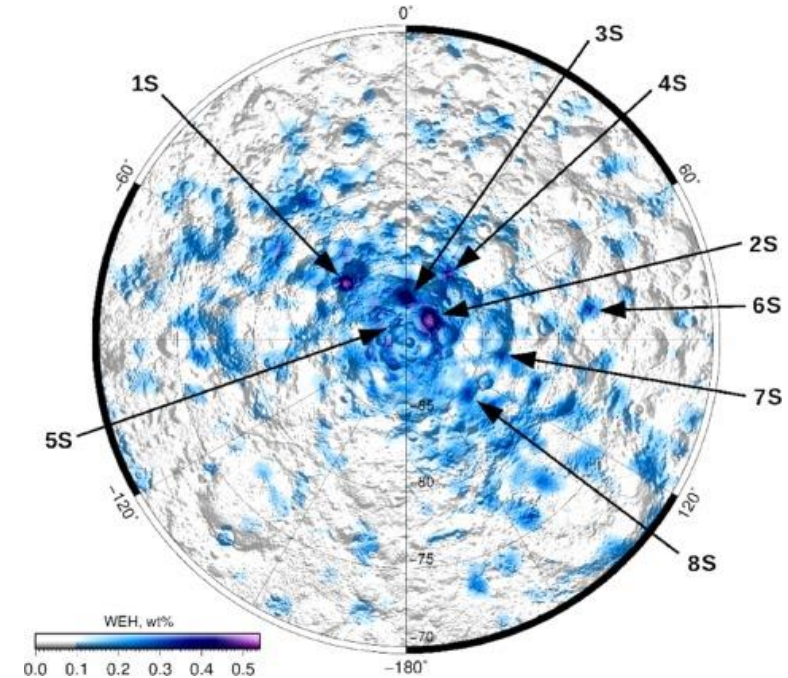
- Neutron measurements are sensitive to **bulk** hydrogen distributions at 1 meter depth
- Uncollimated neutron detector 'footprints' are approximately 1½ times orbital altitude
- Lunar hydrogen abundances within PSRs broadly ranging from 200 ppm up to almost 40 wt% could be consistent with LPNS data depending on spatial distribution, extent of coverage, and burial depth [Lawrence et al 2006].

Lunar Neutron Spectroscopy



35 km² pixels

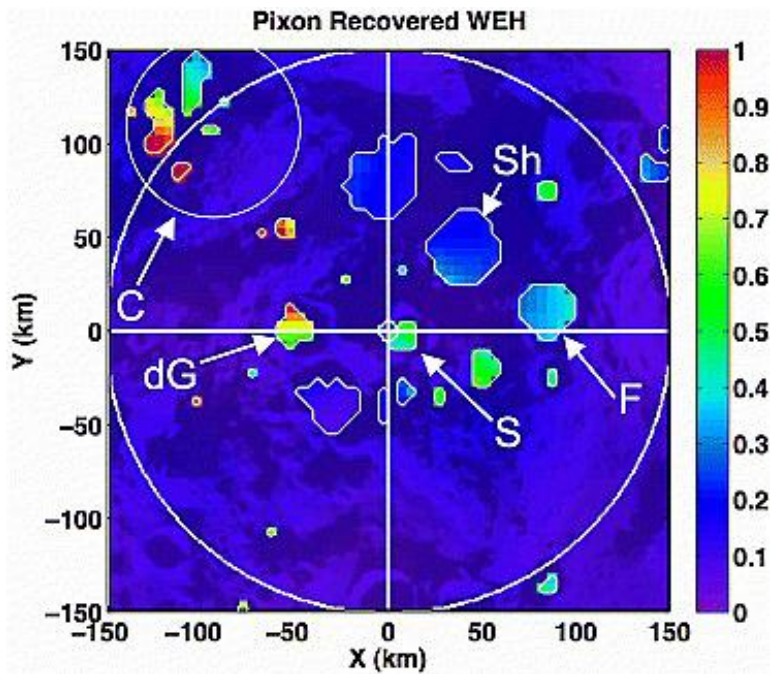
Pixon-based reconstruction of LPNS data (Elphic et al 2007) reveals high WEH abundances in Cabeus (near 1 wt%) and lower abundances in Shoemaker, Haworth, and Faustini (~0.3 wt%)



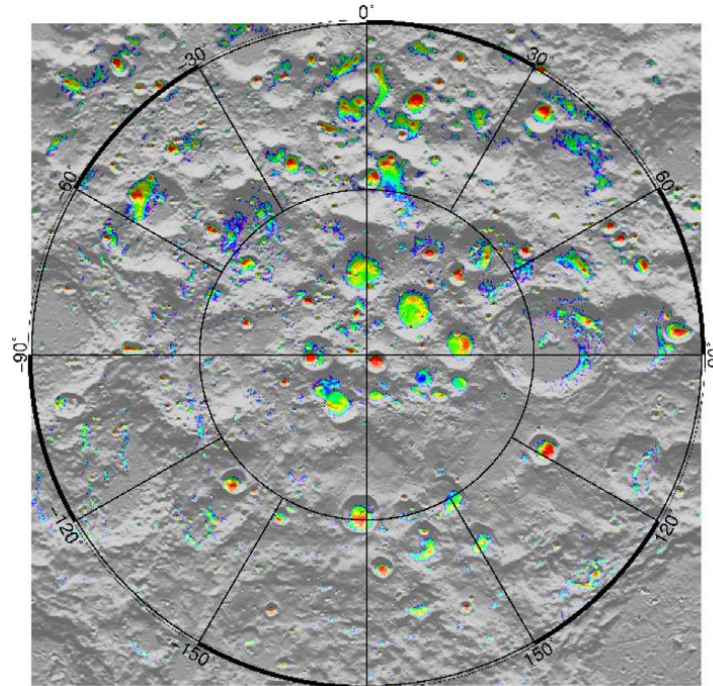
15 km² pixels

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

Lunar Neutron Spectroscopy

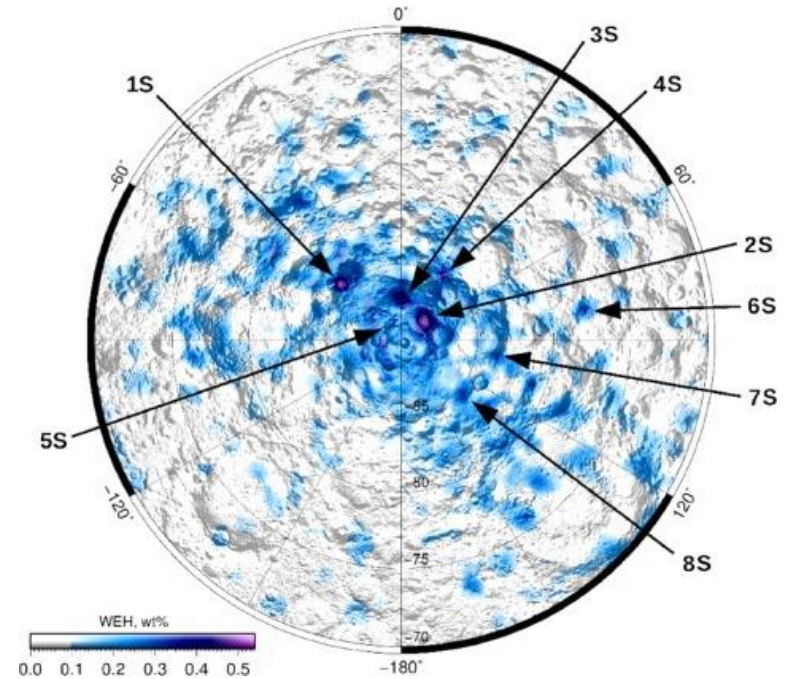


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(c)

Figure 1 Map of current day ice stability depth from Sieglar 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

Dept

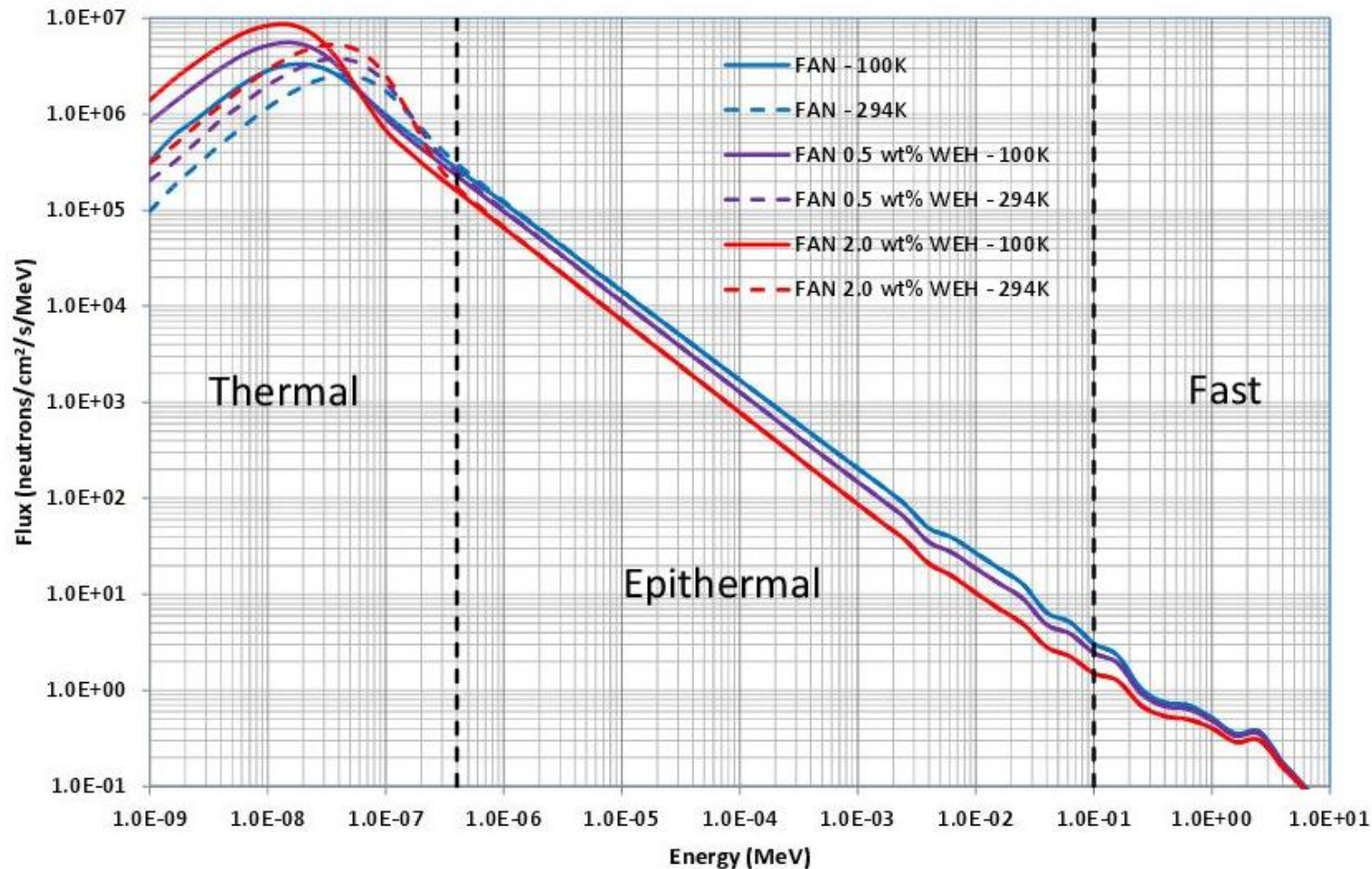


Neutron Measurements of the Moon

- Low-altitude (< 20 km) uncollimated measurements of lunar neutrons can be used to:
 - Determine the bulk hydrogen content and depth *within* PSRs (Diameter < ~35km)
- These data can be used to constrain:
 - Sources and sinks for polar volatiles
- LunaH-Map measures *only* epithermal neutrons:
 - Using a large (200 cm²) detector array
 - To constrain abundance of hydrogen within PSRs
 - To provide complementary data to LP-NS and LRO LEND



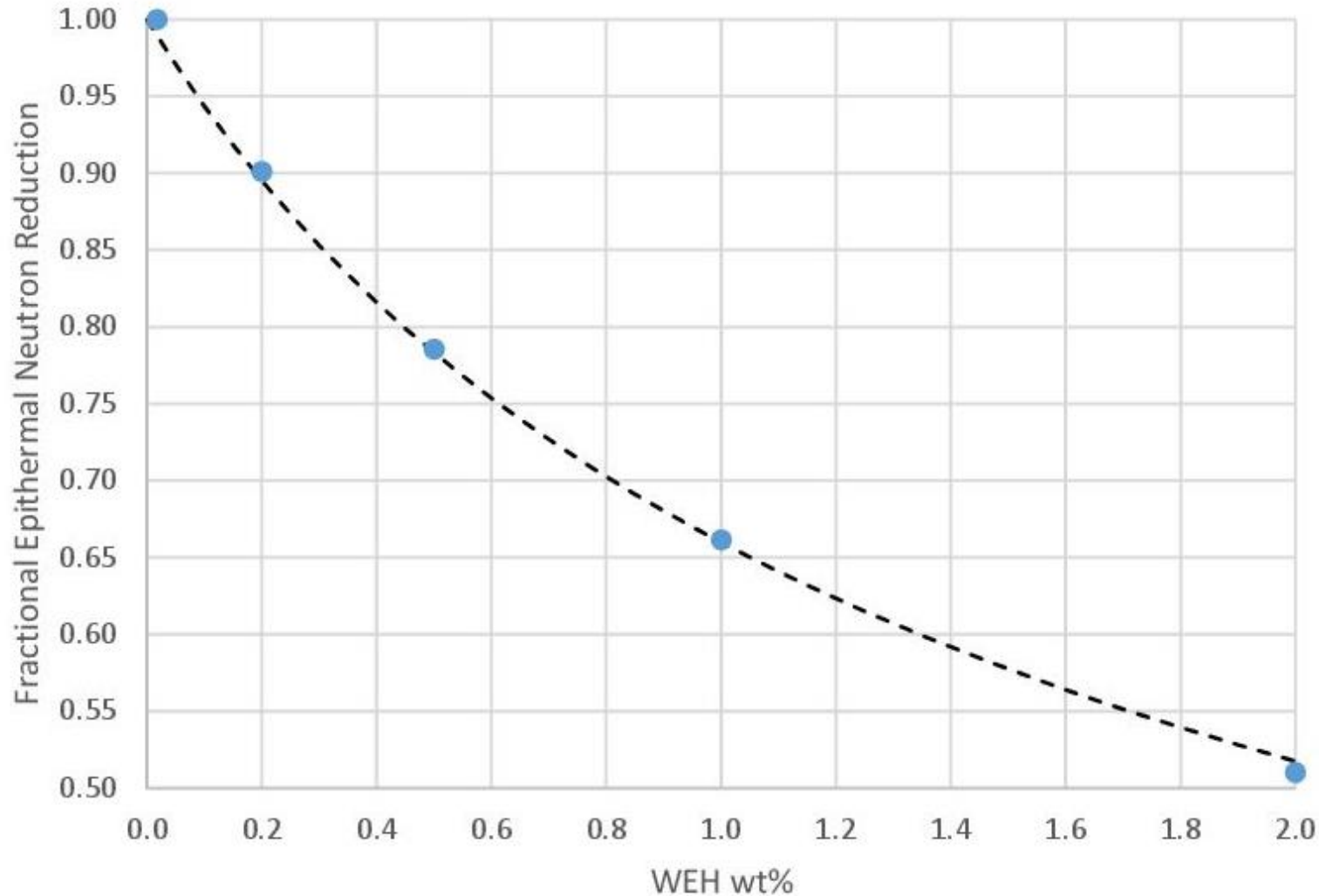
FAN Neutron Energy Spectrum



Increased hydrogen suppresses epithermal neutrons ($E > 0.4$ eV) and increases thermal neutrons ($E < 0.4$ eV)

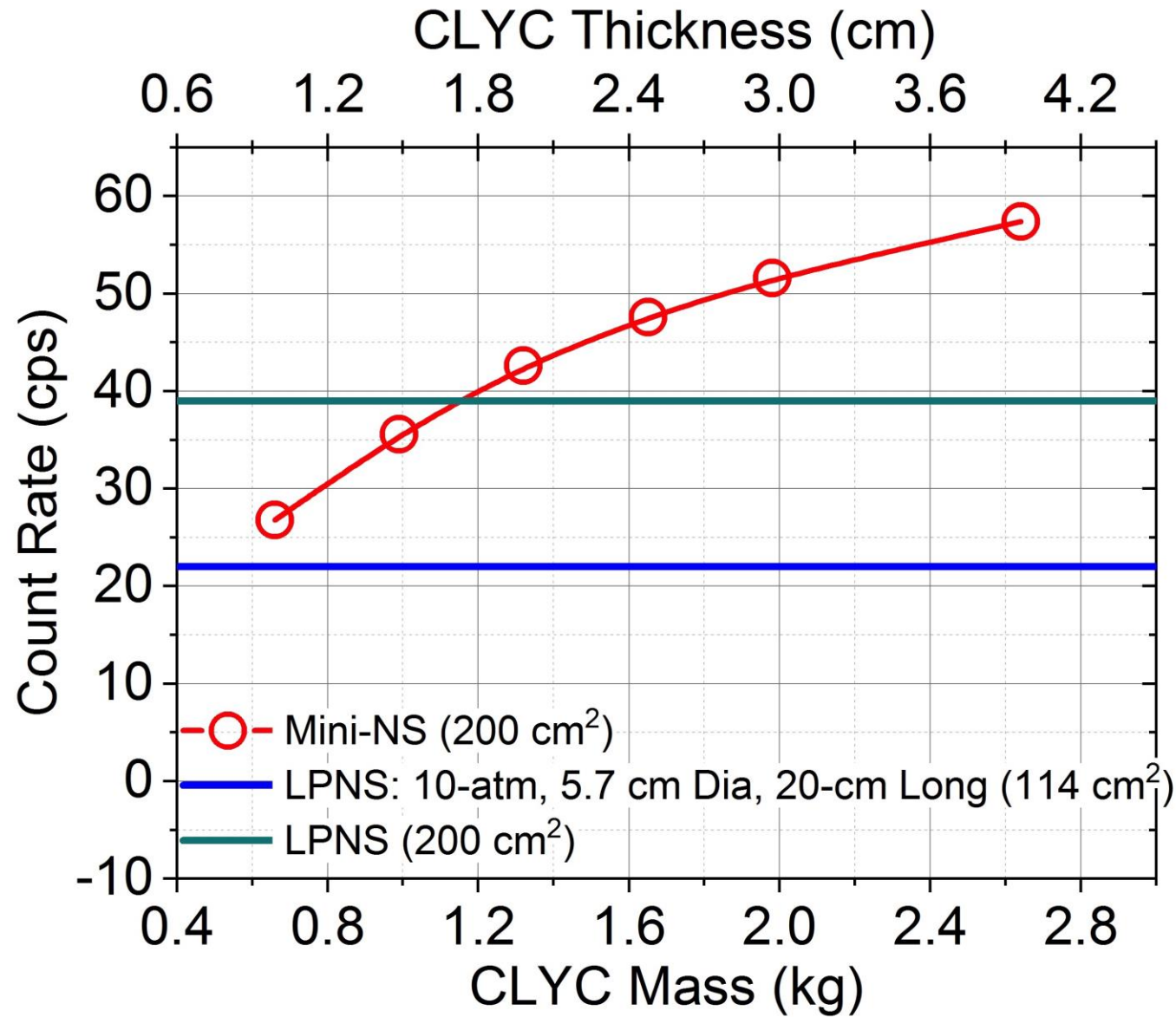
LunaH-Map's signal is the difference between **dry** epithermal count rate and **enriched** epithermal count rate

Fractional Epithermal Neutron Reduction with wt. % WEH



Increased hydrogen suppresses epithermal neutrons ($E > 0.4$ eV) and increases thermal neutrons ($E < 0.4$ eV)

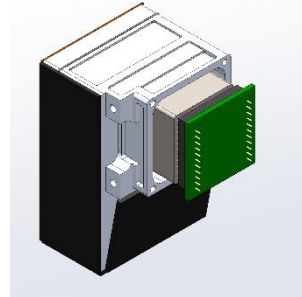
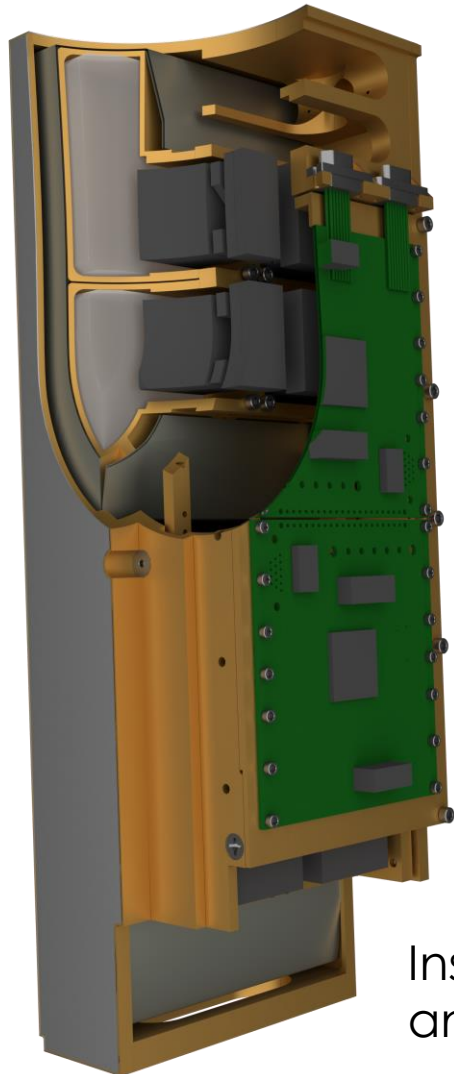
LunaH-Map's *signal* is the difference between **dry** epithermal count rate and **enriched** epithermal count rate



Increased hydrogen suppresses epithermal neutrons ($E > 0.4$ eV) and increases thermal neutrons ($E < 0.4$ eV)

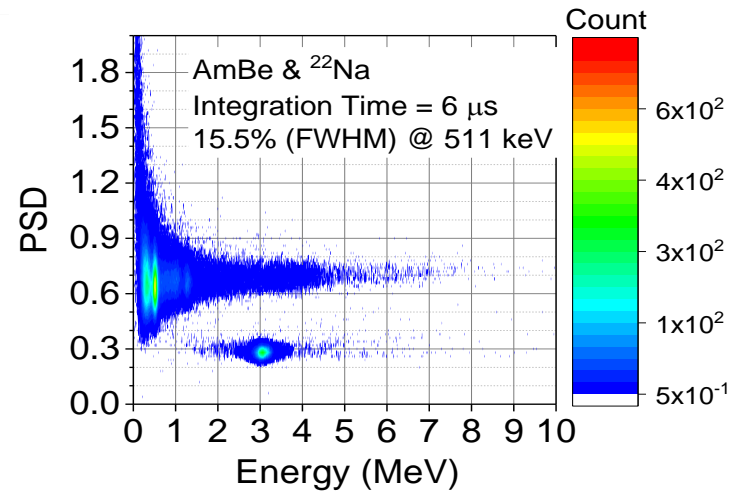
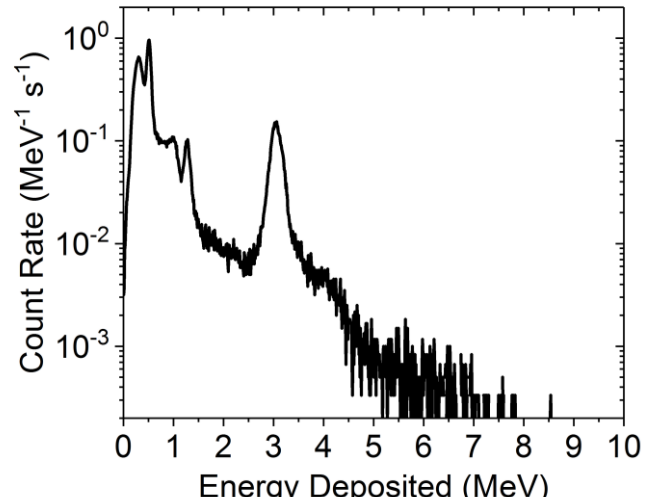
LunaH-Map's *signal* is the difference between **dry** epithermal count rate and **enriched** epithermal count rate

Miniature Neutron Spectrometer



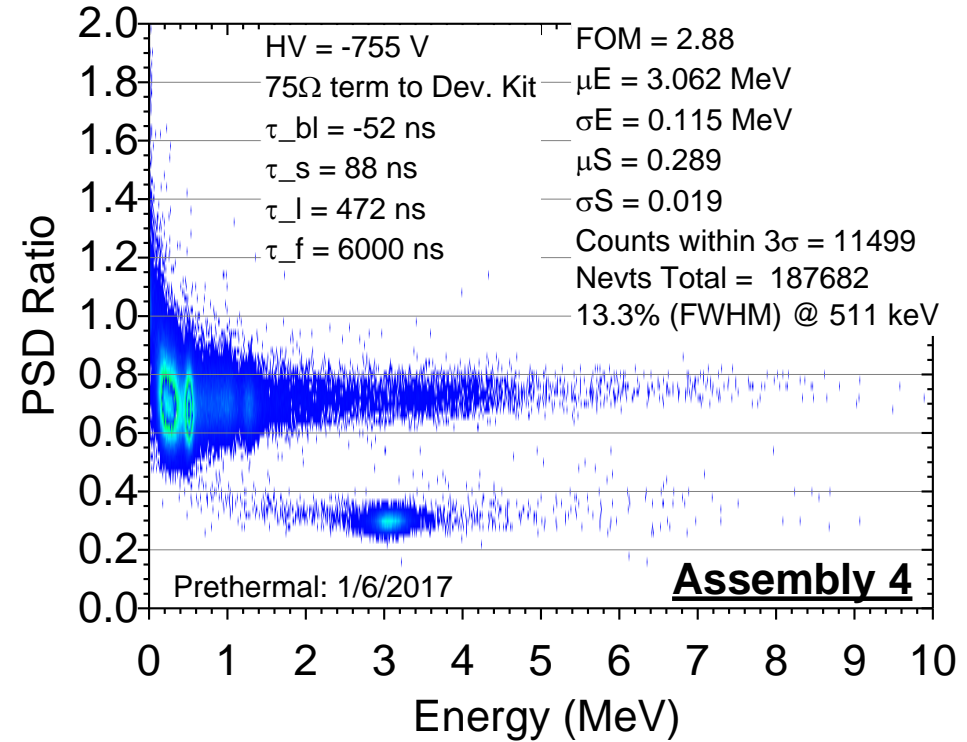
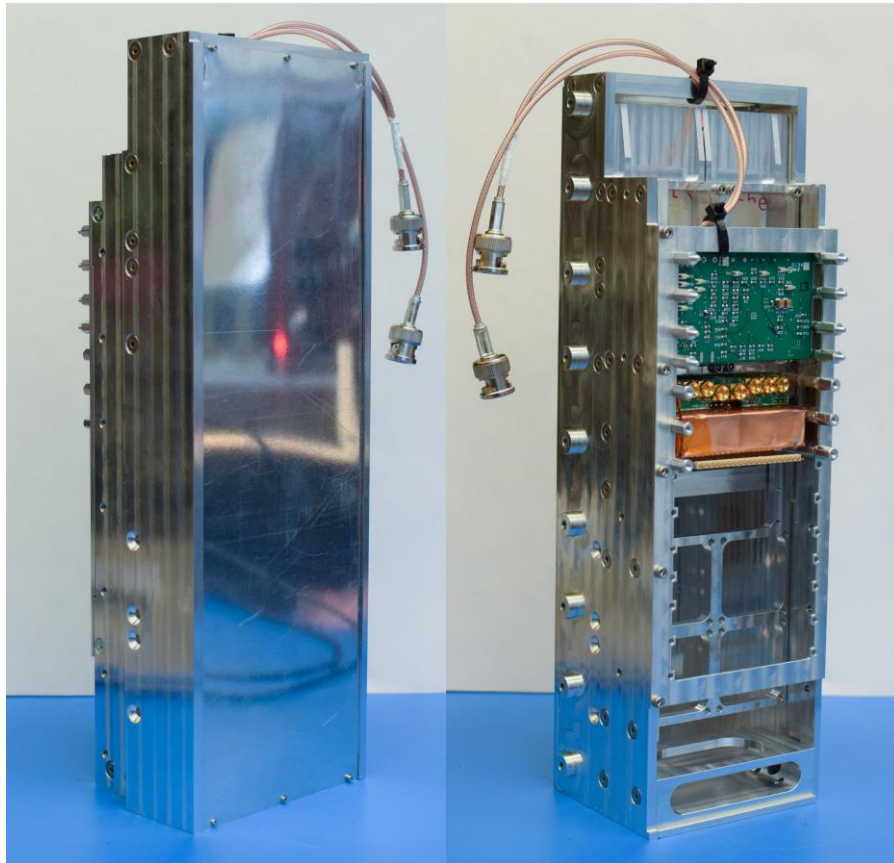
CLYC Module

Instrument Housing and Electronics



Detector	2x4 array of CLYC (elpasolite scintillator, Cs ₂ LiYCl 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 (min), 22W (max)
Data Acquisition	Counts binned every 1 sec

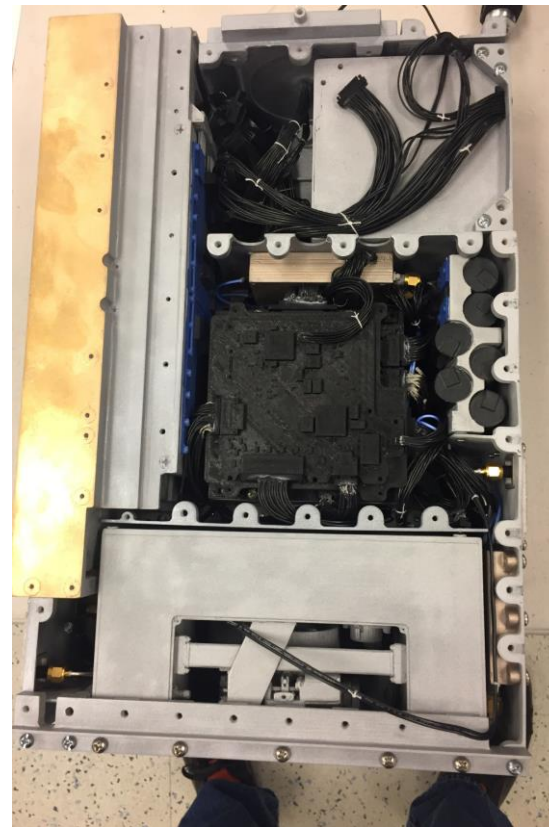
Mini-NS EDU



Test results from single EDU module exposed to Na-22 and AmBe



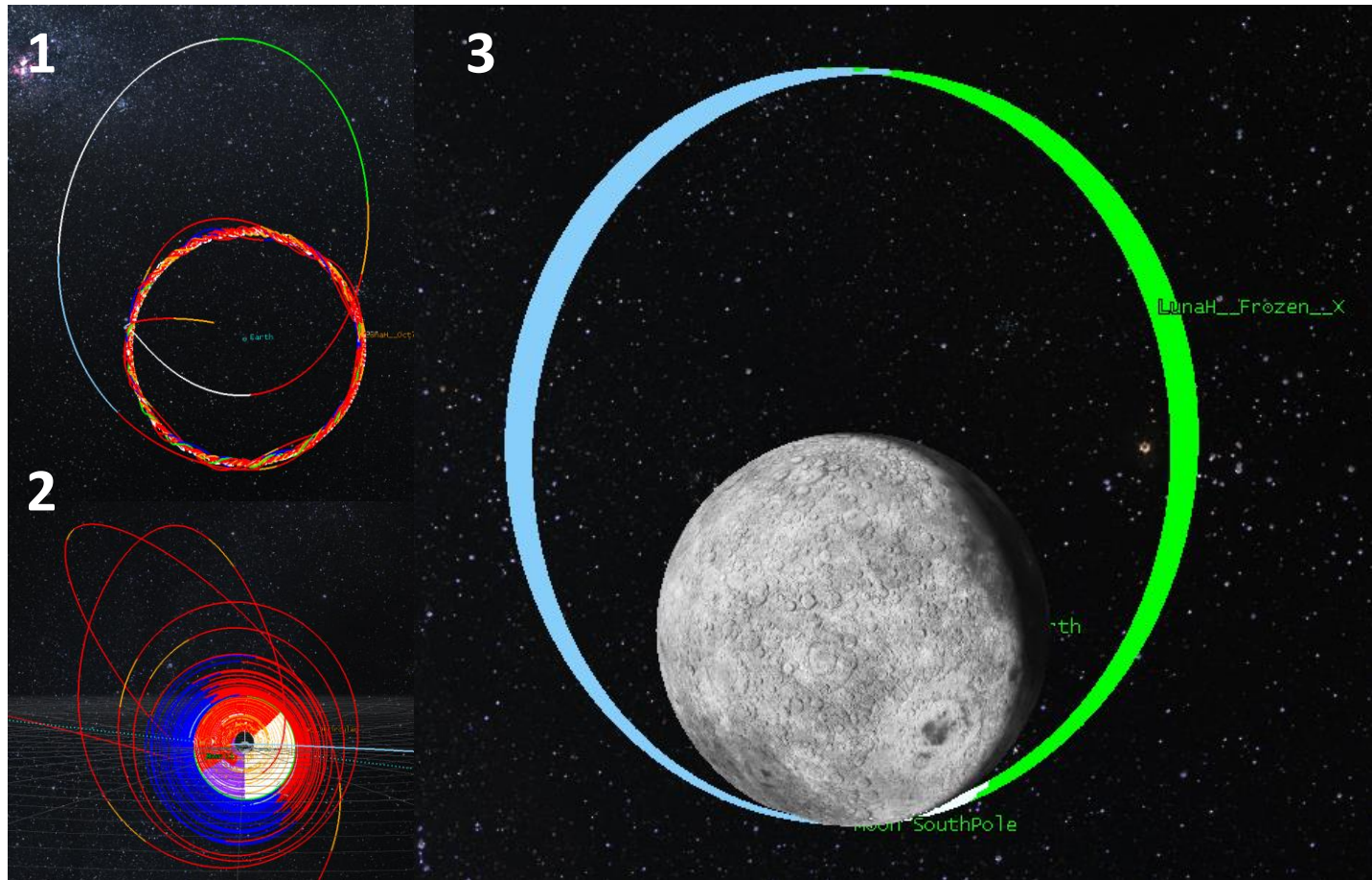
Mini-NS Flight Unit and Calibration



- Flight instrument chassis machined for fit checks in spacecraft EDU at ASU
- Mini-NS Flight Unit delivery in early summer 2017
- Mini-NS Flight Unit calibration at Los Alamos National Lab Neutron Free In-Air (NFIA) facility in late summer



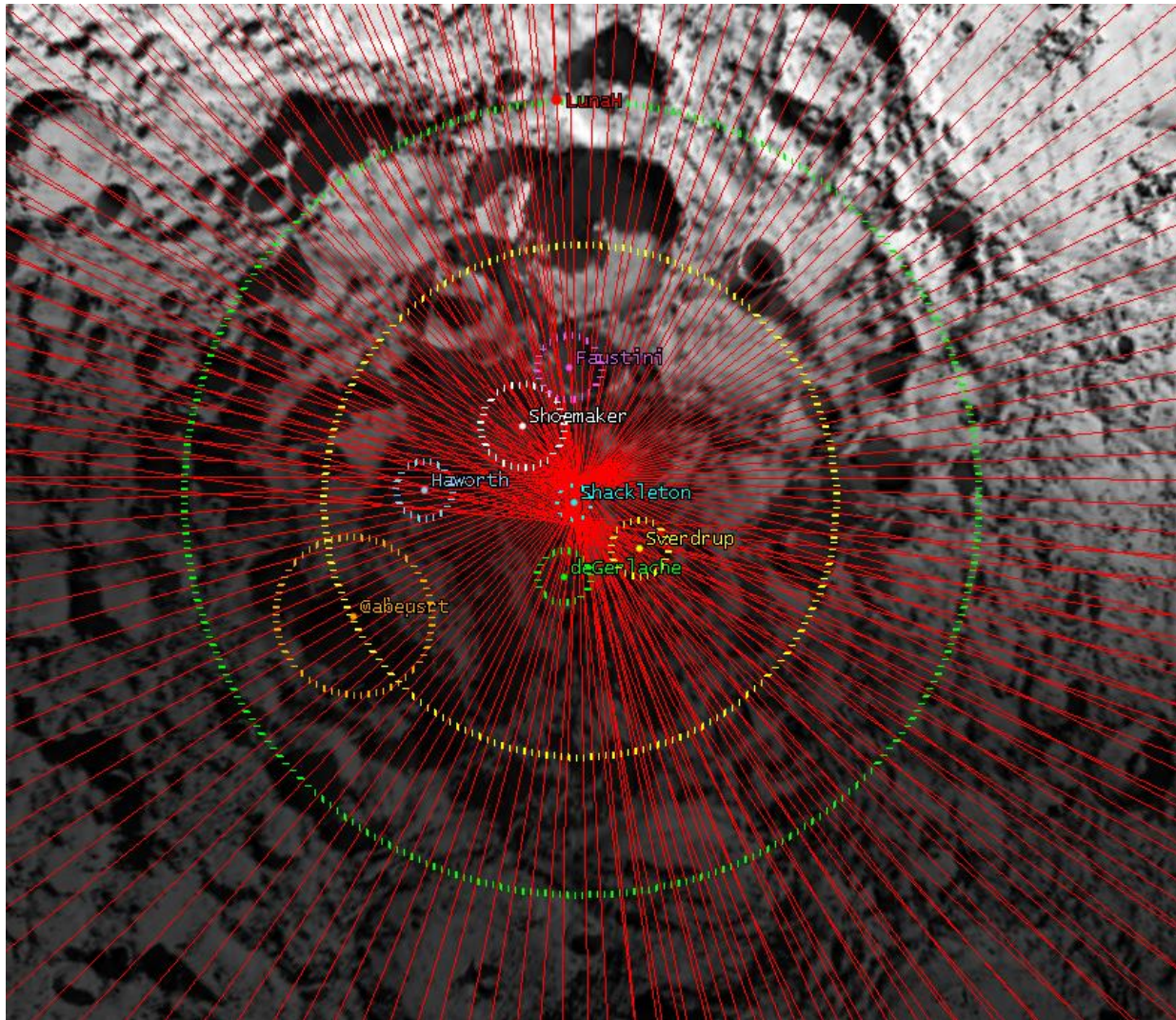
Trajectory Design



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.

Science Phase



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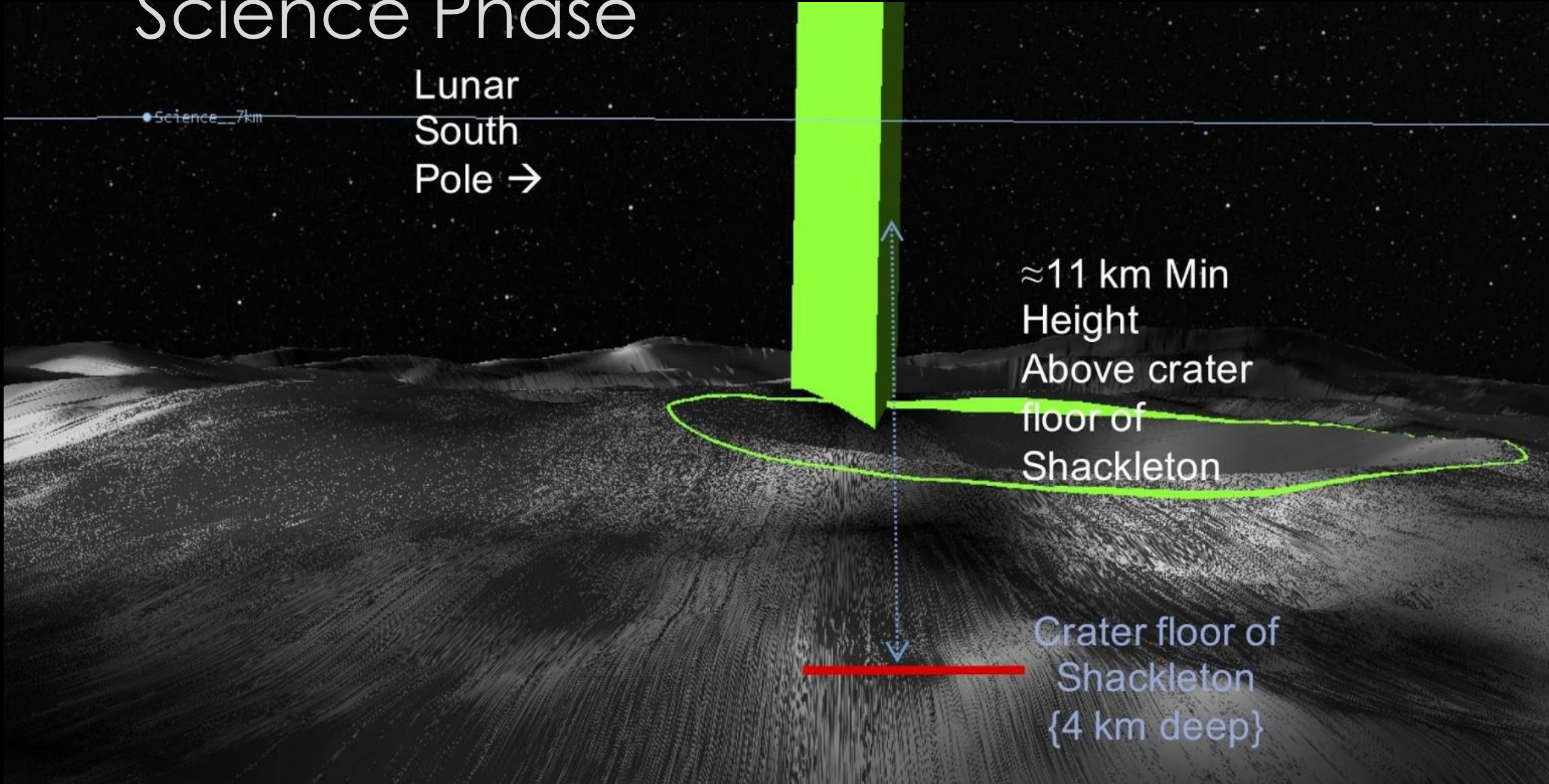
Science Phase

● Science_7km

Lunar
South
Pole →

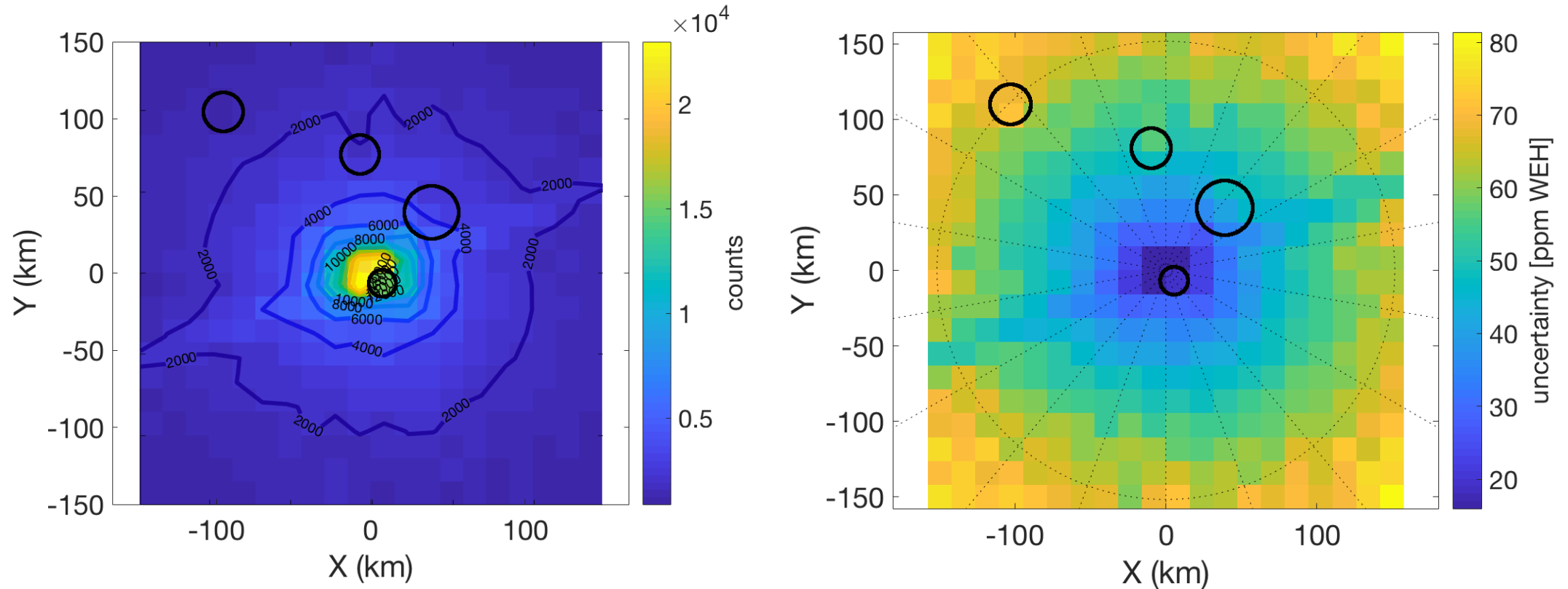
≈ 11 km Min
Height
Above crater
floor of
Shackleton

Crater floor of
Shackleton
{4 km deep}





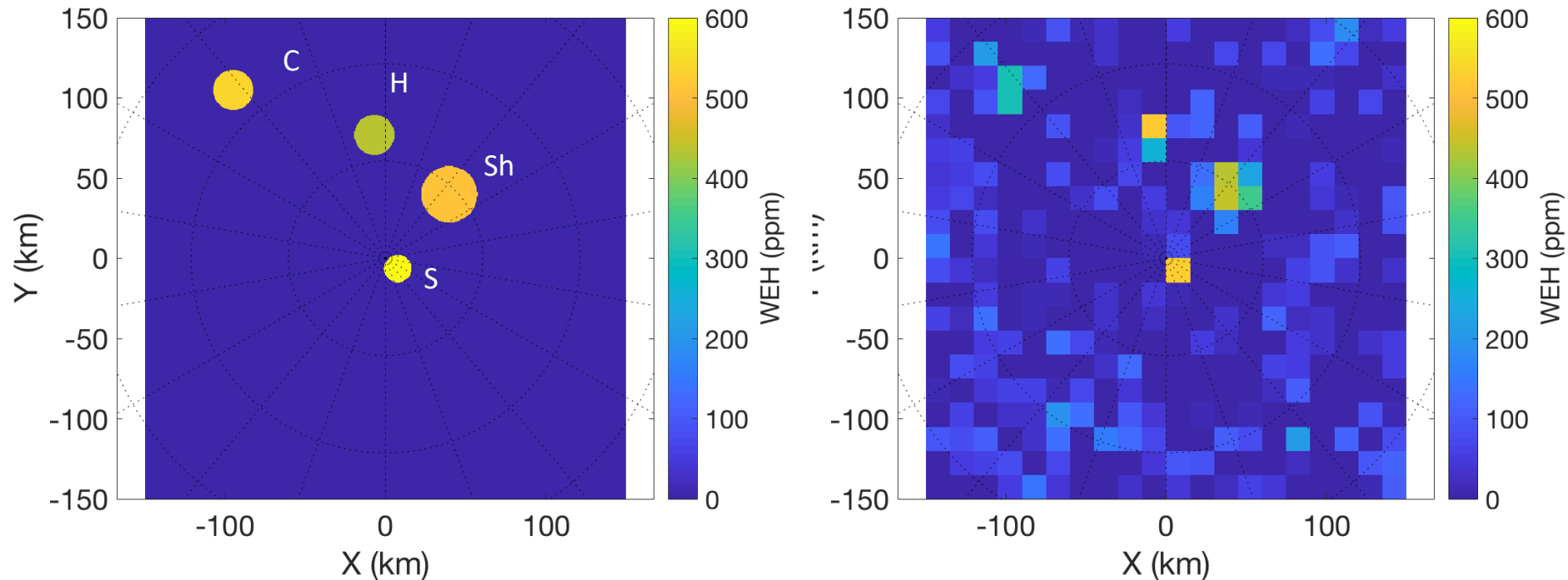
LunaH-Map Sensitivity



Enrichments of 600 ppm +/- 120 ppm WEH are detectable for ~94% of the surface poleward of 85°S in spatial bins of 15km x 15km.



South Polar Volatile Mapping



Simulations of maps made from 15x3150km science orbit. Basemap combines LEND high H regions (Sanin et al., 2017) and the Shackleton enrichment from pixon-reconstructed LPNS data (Elphic et al, 2007) to illustrate the type of map LunaH-Map will be able to create.



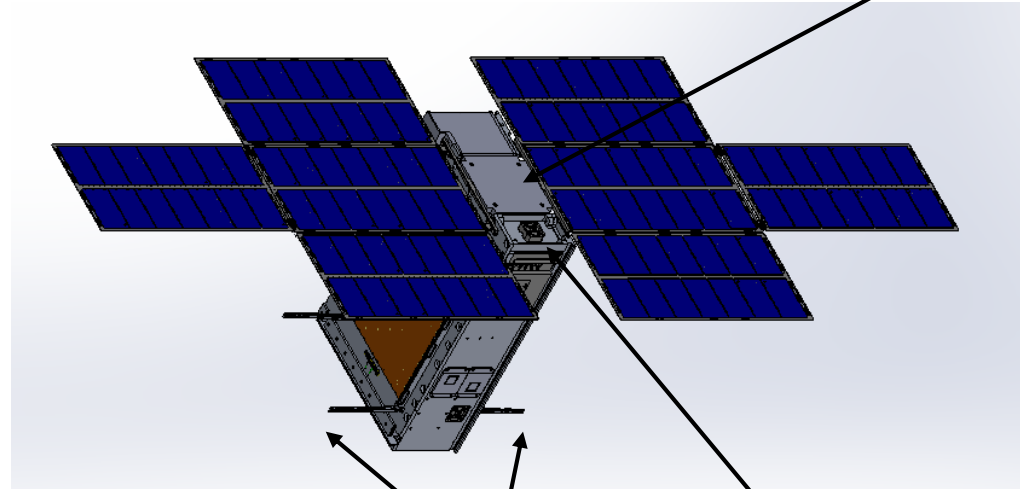
LunaH-Map Spacecraft

Single Axis
Solar Array Drive

Mini-NS
Instrument

LGA

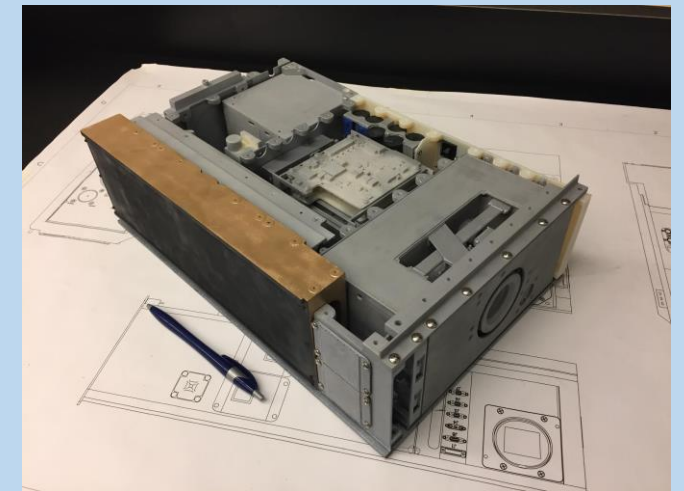
Separation BIT-3 Thruster
Connector



XB1-50 / Star Tracker
LGA
Coarse Sun Sensor

Solar Array Primary Coarse Sun Sensor
Hold Down Arms

1:1 3D Printed Model of
LunaH-Map Flight System



Spacecraft Specs

Dimensions:
(stowed)

10x20x30cm

Mass

14 kg

Power

90W BOL
56W-hr Battery

Propulsion

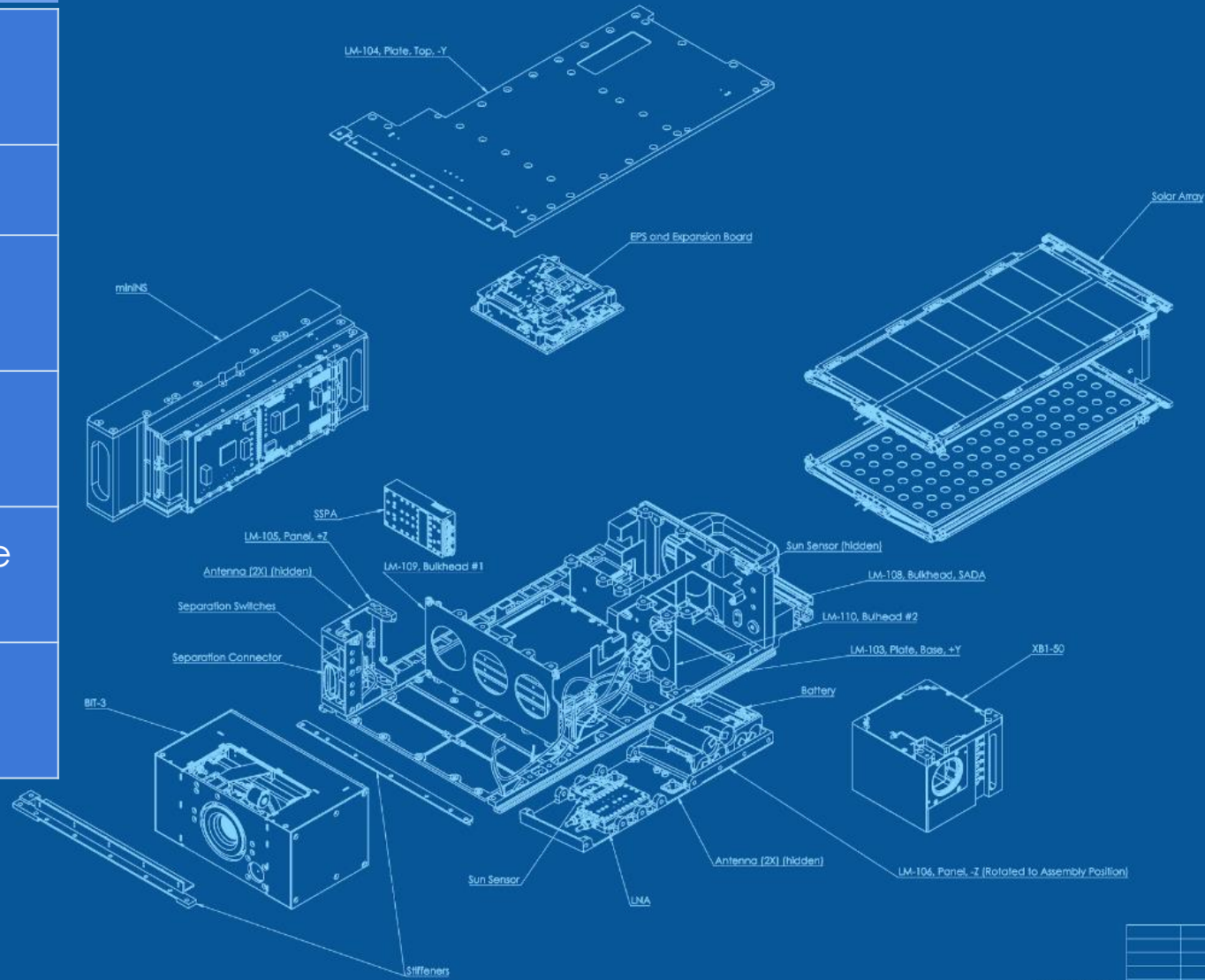
Busek BIT-3 Ion
Thruster

Comm.

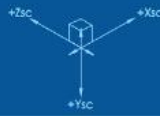
JPL Iris Deep Space
Transponder

C&DH /
GN&C

BCT XB1-50



A



8

7

6

5

4

3

2

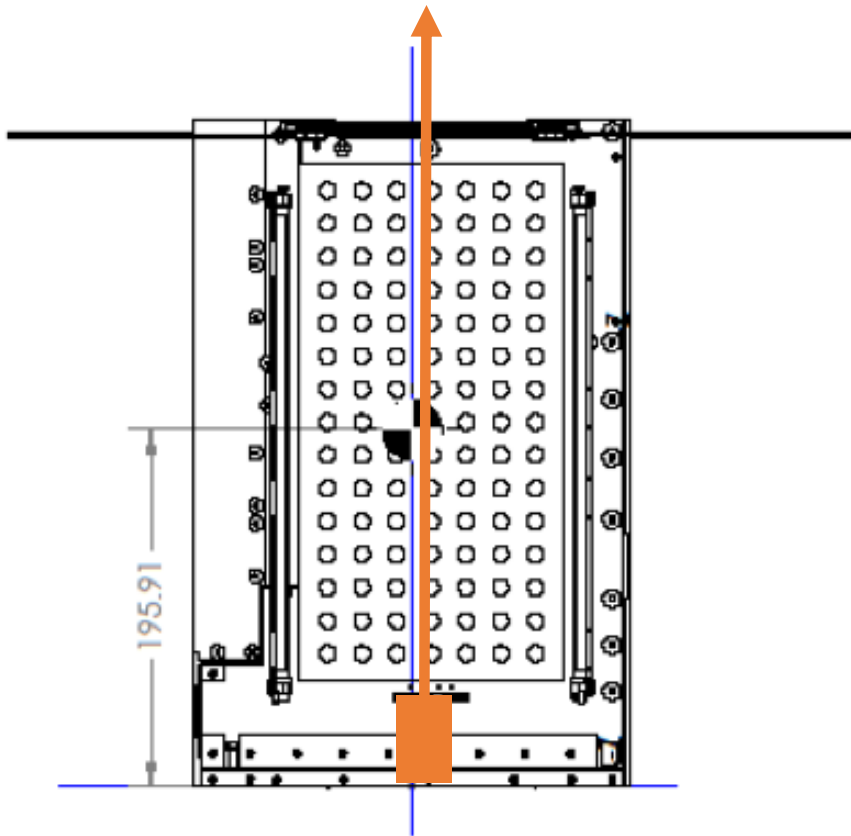
1

REVISIONS		DATE	BY	CHKD	APP'D
1	ISSUED FOR CONSTRUCTION				
2	DESIGN CHANGES INCORPORATED				
3	REVISIONS				
4	REVISIONS				
5	REVISIONS				
6	REVISIONS				
7	REVISIONS				
8	REVISIONS				

SCALE: 1:15	DATE: 10/10/2018	BY: [Signature]	CHKD: [Signature]	APP'D: [Signature]
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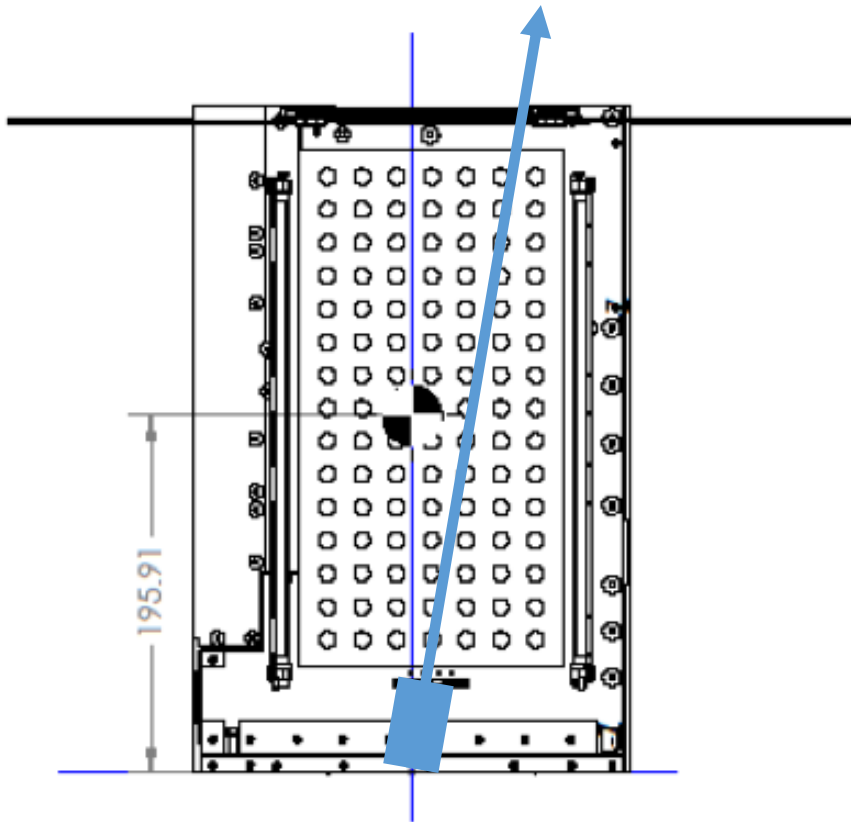
PROJECT: LunaH-Map	DATE: 10/10/2018	BY: [Signature]	CHKD: [Signature]	APP'D: [Signature]
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SIZE: D	DWG. NO.: LM-102	REV: pre	SHEET 1 OF 4	

Propulsion



- Busek BIT-3 ion thruster
- Iodine propellant
- 10° gimbal for momentum management

Propulsion



- Busek BIT-3 ion thruster
- Iodine propellant
- 10° gimbal for momentum management

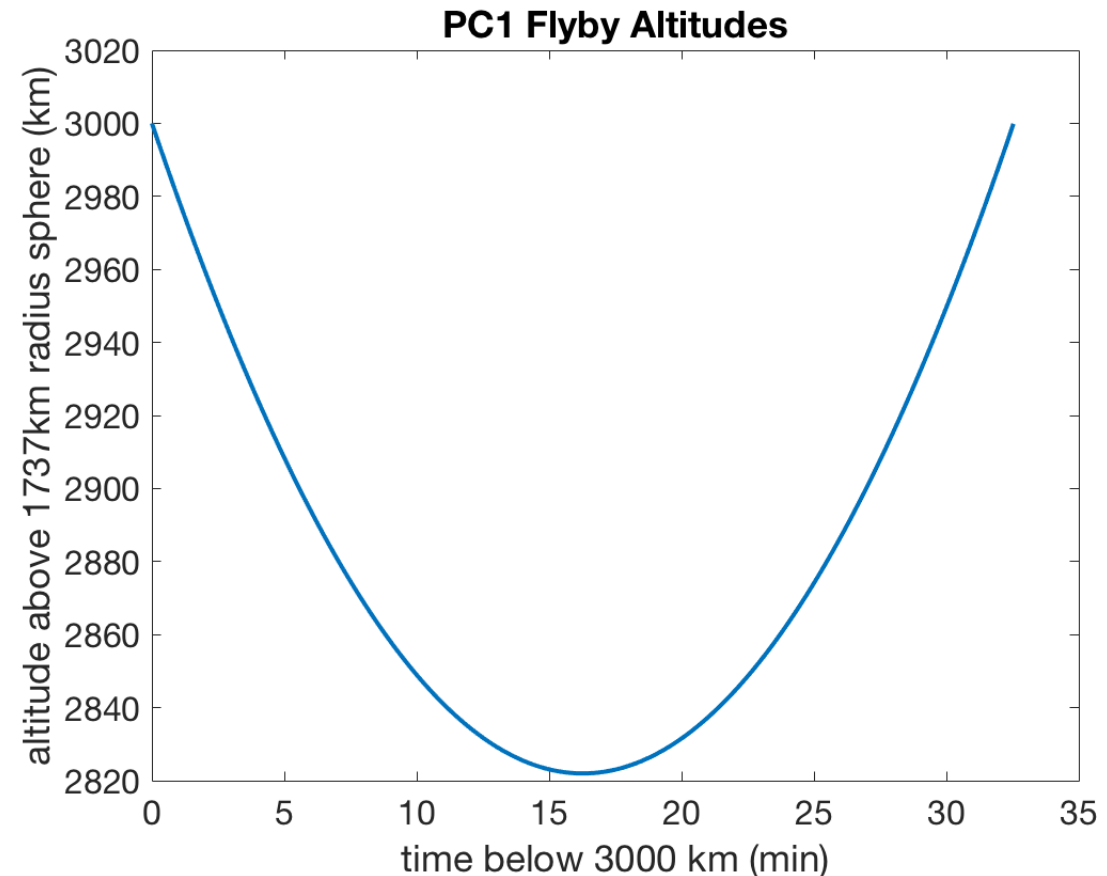


PC1 – Instrument Qualification

During first lunar flyby, LunaH-Map will observe the lunar neutron count rate of ~ 3.15 cps at the PC-1 flyby altitude of ~ 2800 km.

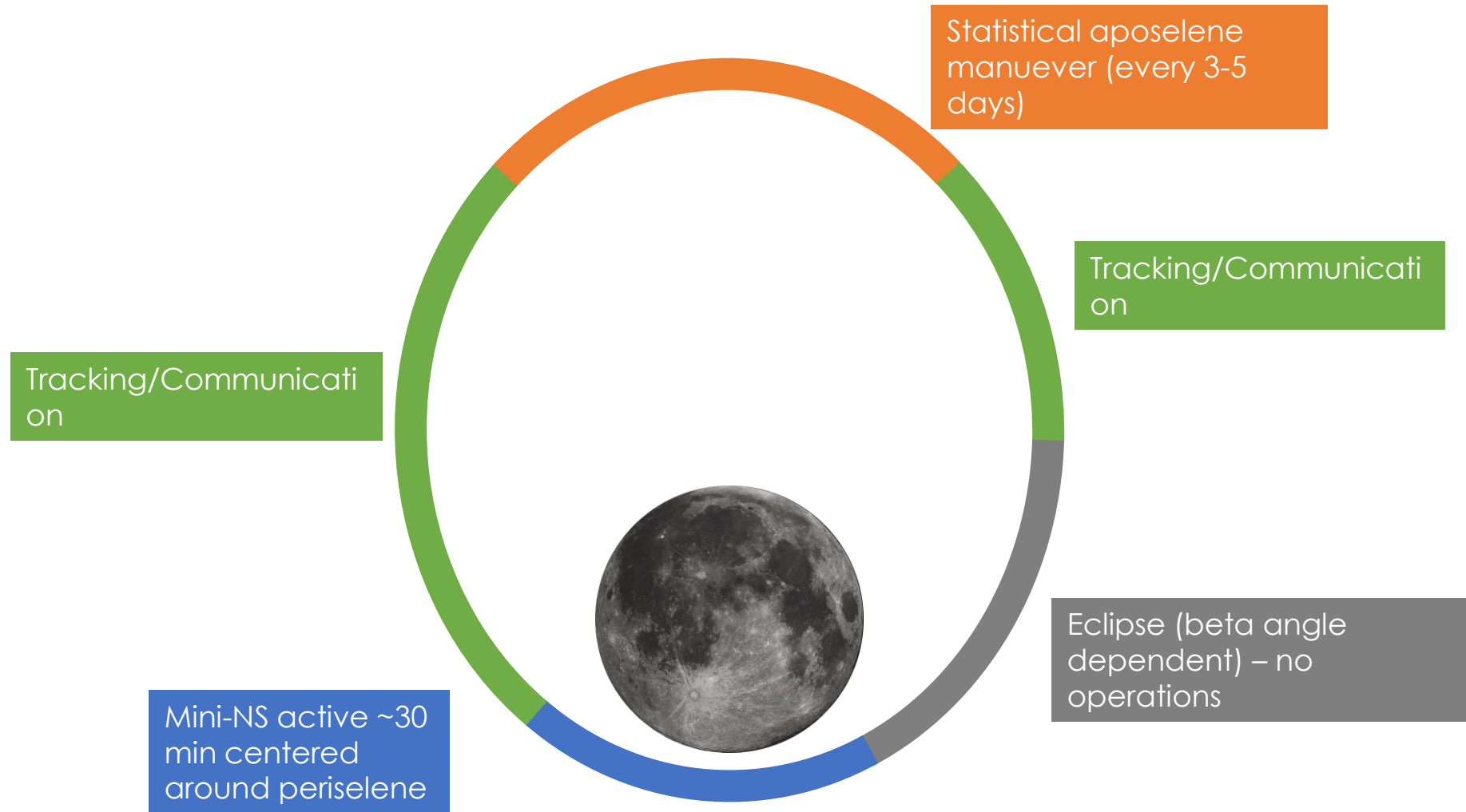
LunaH-Map is below 3000 km altitude for >30 minutes. The predicted epithermal neutron count rate of 3.15 cps can be measured to ± 0.04 cps.

Demonstrate Mini-NS operation in the lunar environment





Day in the Life - Science





Mission/Science Operations



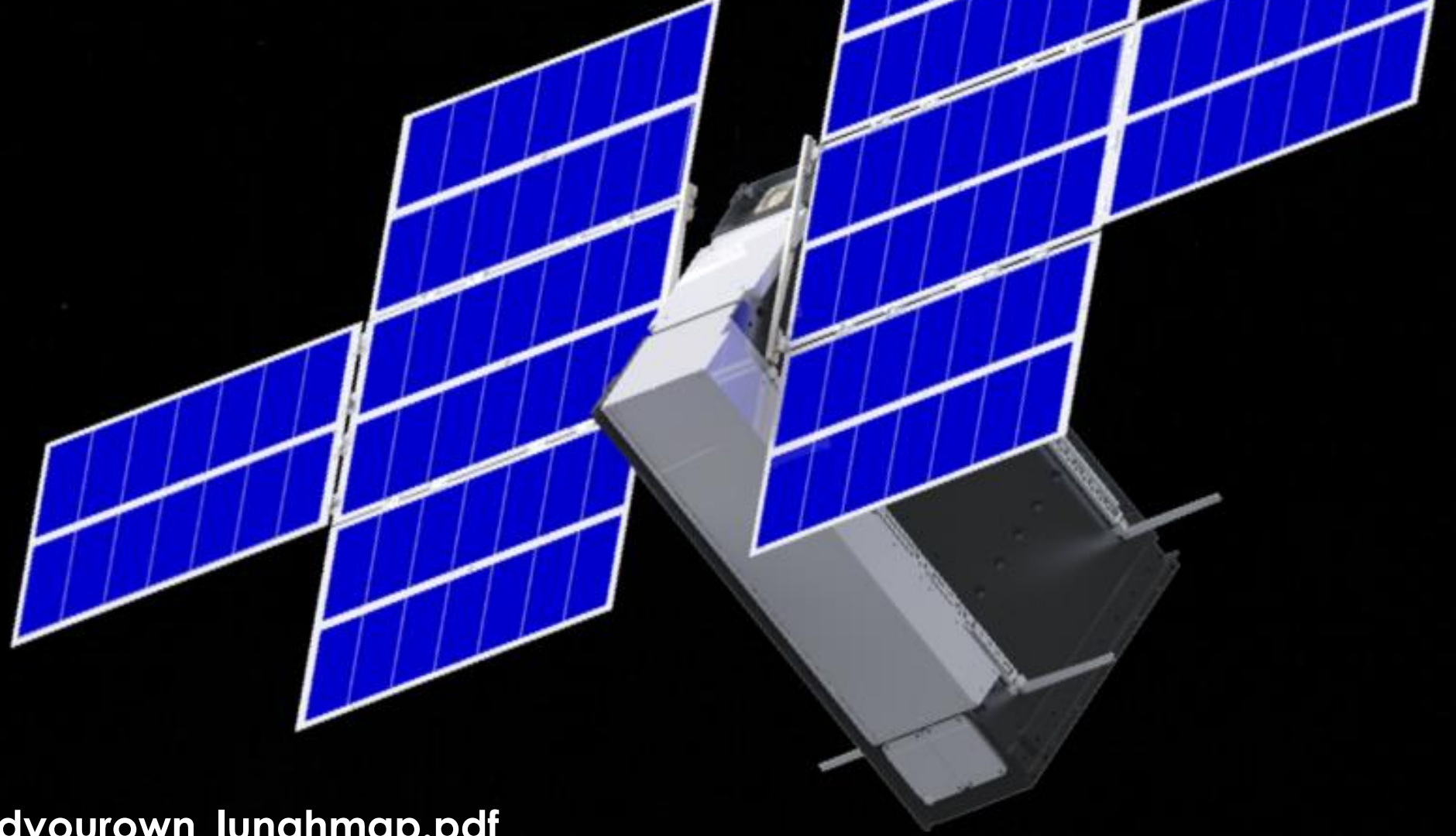
- Co-located in ASU's shared operations facility
- JPL AMMOS/AMPCS for uplink and downlink
- Science/instrument ops heritage from MER, LROC, and MSL
- Science/instrument ops development coincident with Mars 2020 and Psyche missions

Road to Launch

- Critical Design Review – Completed June 29, 2017
- Phase 2 Safety Review – August 8, 2017
- Enter Assembly, Integration, and Test – Q4 2017
 - AI&T Review/Workshop with review board
- Launch – SLS EM-1, December 2019

LunaH-Map Program Milestones to Date		
IAA	11 December 2015	Δ-IAA REQUIRED
Δ-IAA	24 February 2016	PASSED with RFAs
SRR	8 April 2016	PASSED with RFAs
I-PDR	9 June 2016	PASSED with RFAs
Phase 1 SR	21 June 2016	PASSED
M-PDR	25 July 2016	PASSED with RFAs
CDR	29 June 2017	COMPLETED
Phase 2 SR	11 Nov 2017	COMPLETED
Integration Workshop	8 Dec 2017	COMPLETED

Review Board Members: Dr. Andrew Klesh, Jet Propulsion Laboratory (Review Board Chair), Dr. Thomas Werne, JPL, Dr. Travis Imken, JPL, Dr. Juergen Mueller, JPL, Dr. Eric Gustafson, JPL, Dr. Thomas Prettyman, Planetary Sciences Institute, Dr. James Bell, Arizona State University, Dr. Jordi Puig-Suari, California Polytechnic State University, Richard Elphic, NASA Ames.



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lunahmap.asu.edu/foldyourown_lunahmap.pdf