The Lunar polar Hydrogen Mapper (LunaH-Map) Mission

Revealing Hydrogen Distributions at the Moon’s South Pole with a 6U CubeSat

Pronunciation: /ˈluːnə/ /mæp/ ‘lOOna-map’

“The H is silent because the hydrogen is hiding in the permanently shadowed regions”

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The (LunaH-Map) Team

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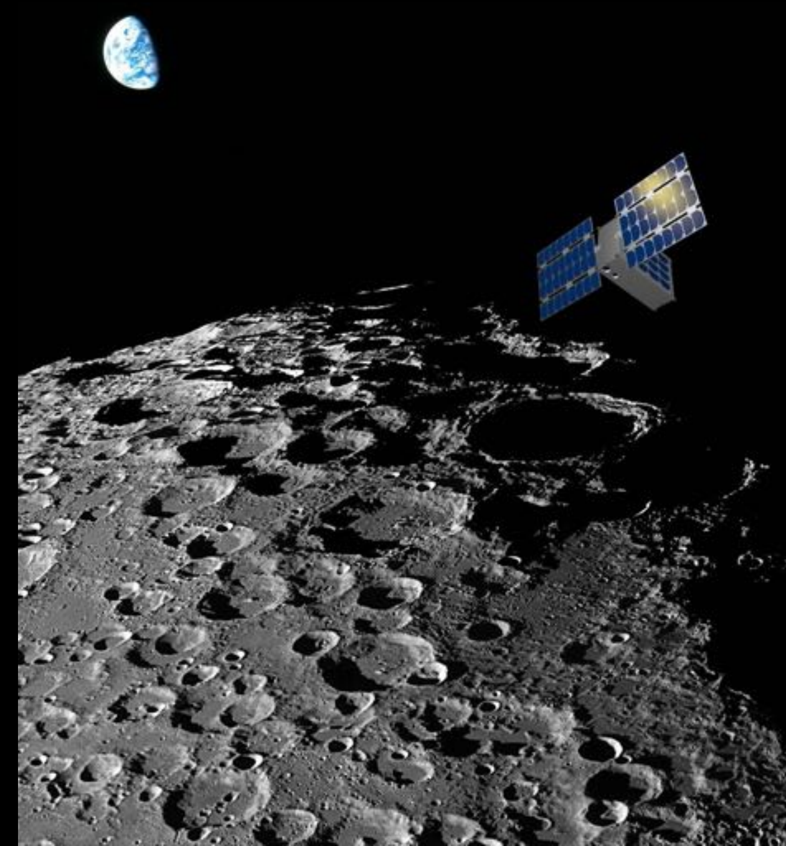
Outline

1. ROSES 2015: NASA SMD Mission - Small Innovative Missions for Planetary Exploration (SIMPLEx)

2. Science Goals

3. Mission

4. LunaH-Map Status

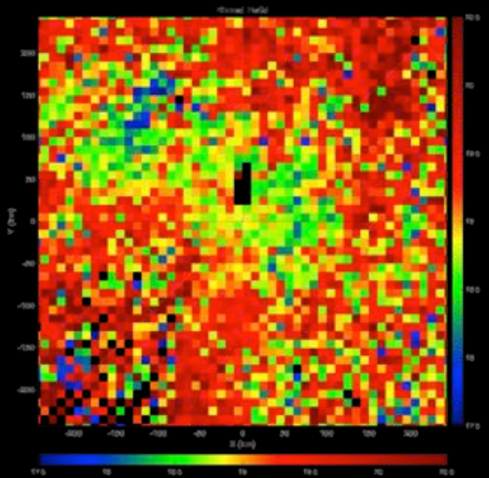


1. SIMPLEx

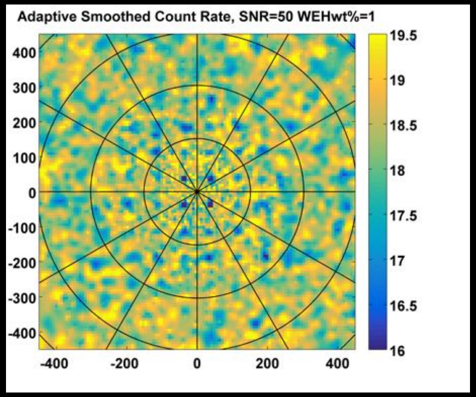
- Small, Innovative Missions for PLanetary Exploration Proposal Program from NASA Science Mission Directorate (SMD) ROSES 2015
- Science Goals: Must be responsive to *2014 NASA Science Plan*
  - *LunaH-Map is responsive to 2014 NASA Science Plan, LEAG Strategic Knowledge Gaps, and NASA Decadal Survey*
    - LEAG Strategic Knowledge Gap 1D, to "understand the quantity and distribution of H species in lunar cold traps," as well as to "determine lateral and vertical distribution of polar volatiles."
    - Planetary Decadal Survey goals to "determine the volatile budgets on surfaces of the inner planets and to determine the composition, distribution and sources of planetary polar volatiles."

2. Goals of the LunaH-Map Mission

- Constrain the quantity of H-bearing materials at the lunar South Pole at spatial scales <10km
    - Note: Sensitivities to H will vary based on orbital coverage



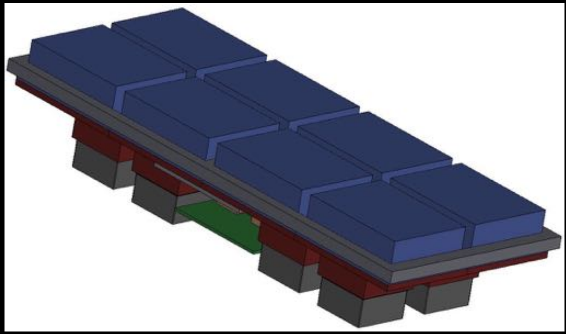
LPNS epithermal counts binned every 10km (derived from Elphic et al., 2007)



Preliminary independent analysis of LunaH-Map capabilities

2.1 How will we accomplish those goals?

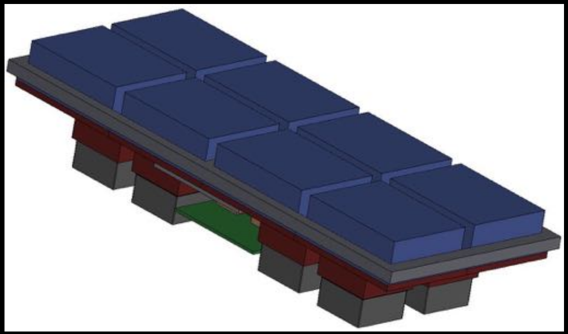
- LunaH-Map will use an uncollimated scintillator array ($200cm^2$) to acquire neutron counting rates for a minimum of 2 full lunar days (minimum of 140 orbits)



Preliminary Mini-NS design for LunaH-Map

2.2 Additional Goals of the LunaH-Map Mission

- Develop, build, fly and test in-flight a CubeSat-sized neutron detector (Mini-NS)
- Demonstrate the use of an ion propulsion system to maneuver, cruise, transition and achieve lunar orbit



Preliminary Mini-NS design for LunaH-Map

Busek BIT-3 solid I_2 ion propulsion

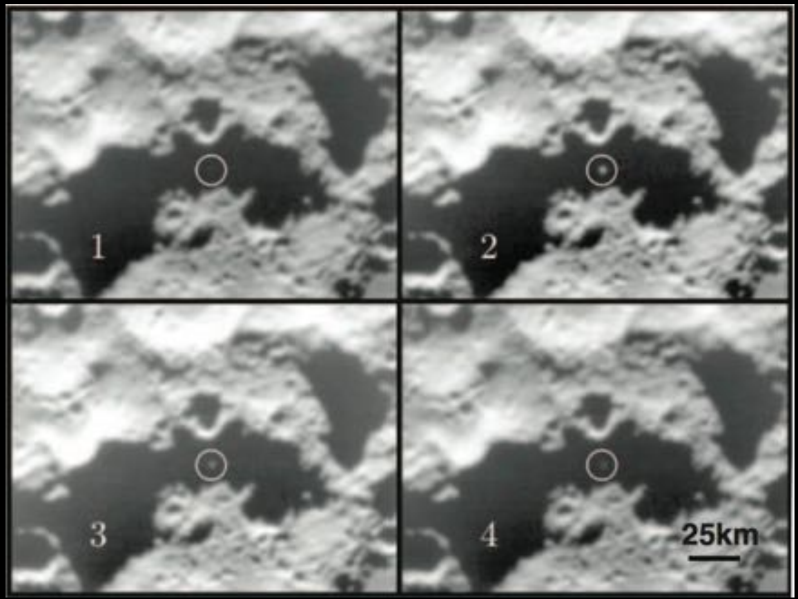
2.4 How will we accomplish those goals with LunaH-Map?

- Utilize a 6U CubeSat
- Enter an elliptical polar orbit with low altitude perilune centered ~89.9S
- Use two high-efficiency neutron detector arrays
- Orbit for two months

2.5 Observations of Lunar Hydrogen

Near-surface (top ~meter)

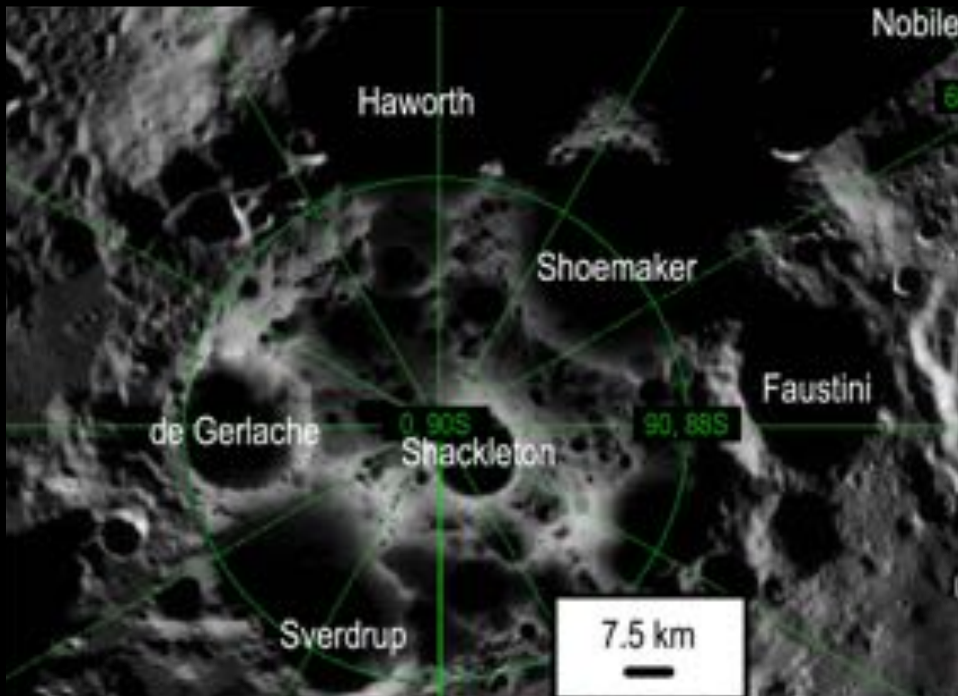
- LCROSS impactor
  - ~5 wt.% H_2O in plume (Colaprete et al., 2010)
- LRO – LEND
  - 10km/pixel; Suppressed epithermal counts in some PSRs (Mitrofanov et al., 2010)
- Lunar Prospector – Neutron Spectrometer (Lawrence et al., 2006)
  - 45km/pixel; Data consistent with 200ppm H to 40 wt.% H_2O in some regions
  - Average H abundances between 100-150pppm



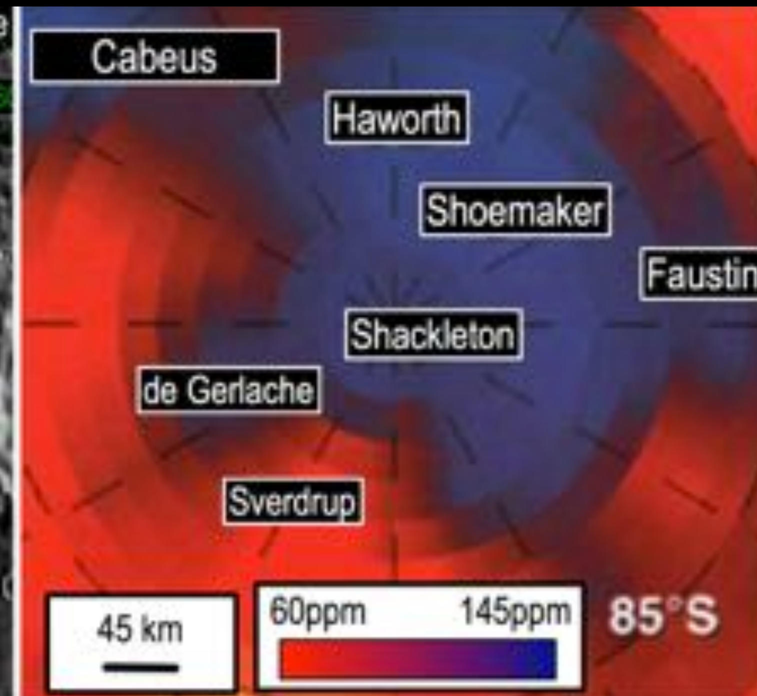
Schultz et al., 2010

If hydrogen is contained within PSRs the lunar South Pole has ~1 to 1.5 wt.% H_2O

2.6 Polar Hydrogen with Neutron Spectroscopy



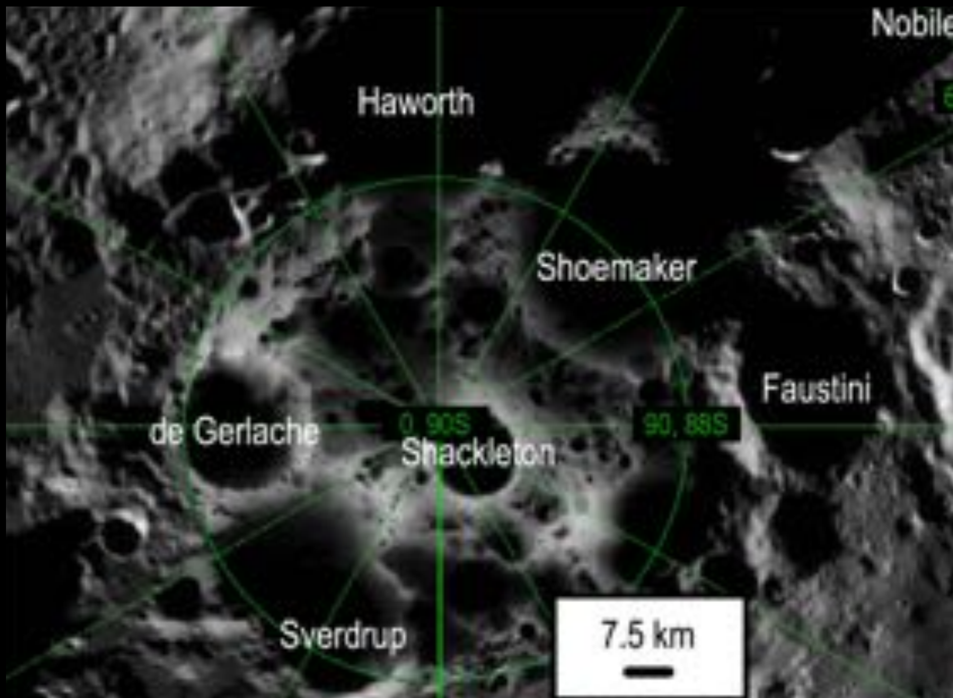
South Pole illumination map of craters observable by LunaH-Map at 7.5km resolution (Speyerer and Robinson, 2013).



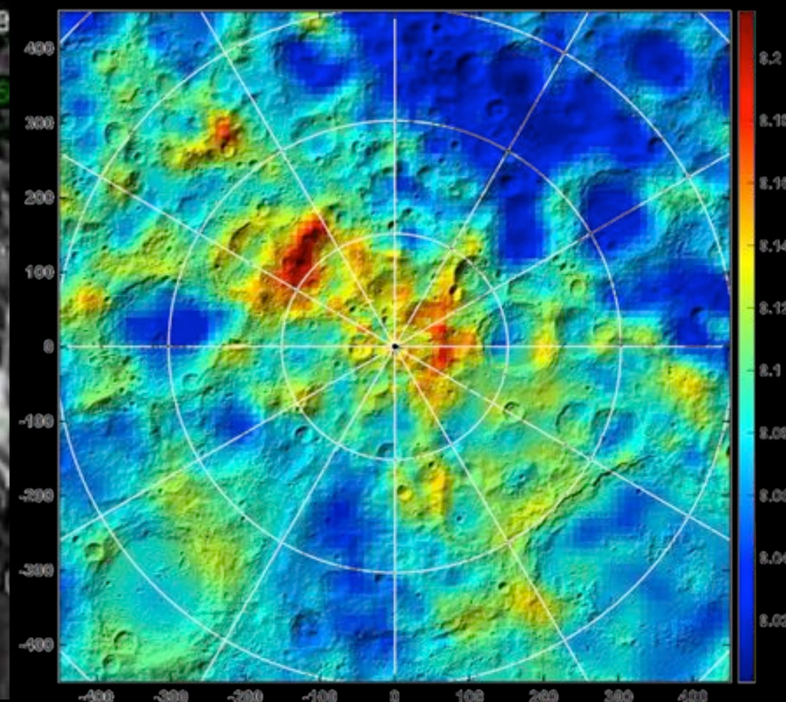
Lunar Prospector Neutron Spectrometer (LPNS) South Pole epithermal neutron counts at 45km/pixel resolution (Feldman et al., 1998)*. The approximate hydrogen abundances derived from LPNS data are shown in the color scale.

*Also see Lawrence et al., 2006; Elphic et al., 2007 and others

2.6 Polar Hydrogen with Neutron Spectroscopy



South Pole illumination map of craters observable by LunaH-Map at 7.5km resolution (Speyerer and Robinson, 2013).

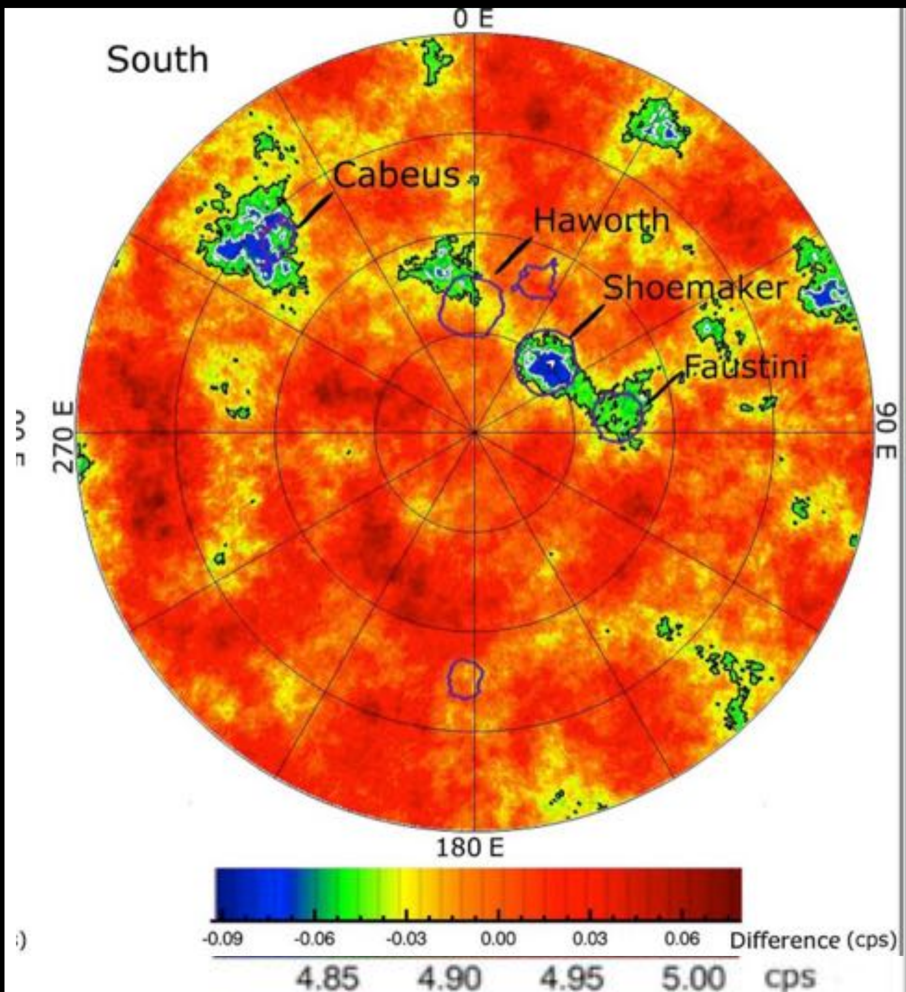


Lunar Prospector Neutron Spectrometer (LPNS) South Pole epithermal neutron counts binned at 10km resolution (Elphic et al., 2007)*. Epithermal count rates shown on the color scale.

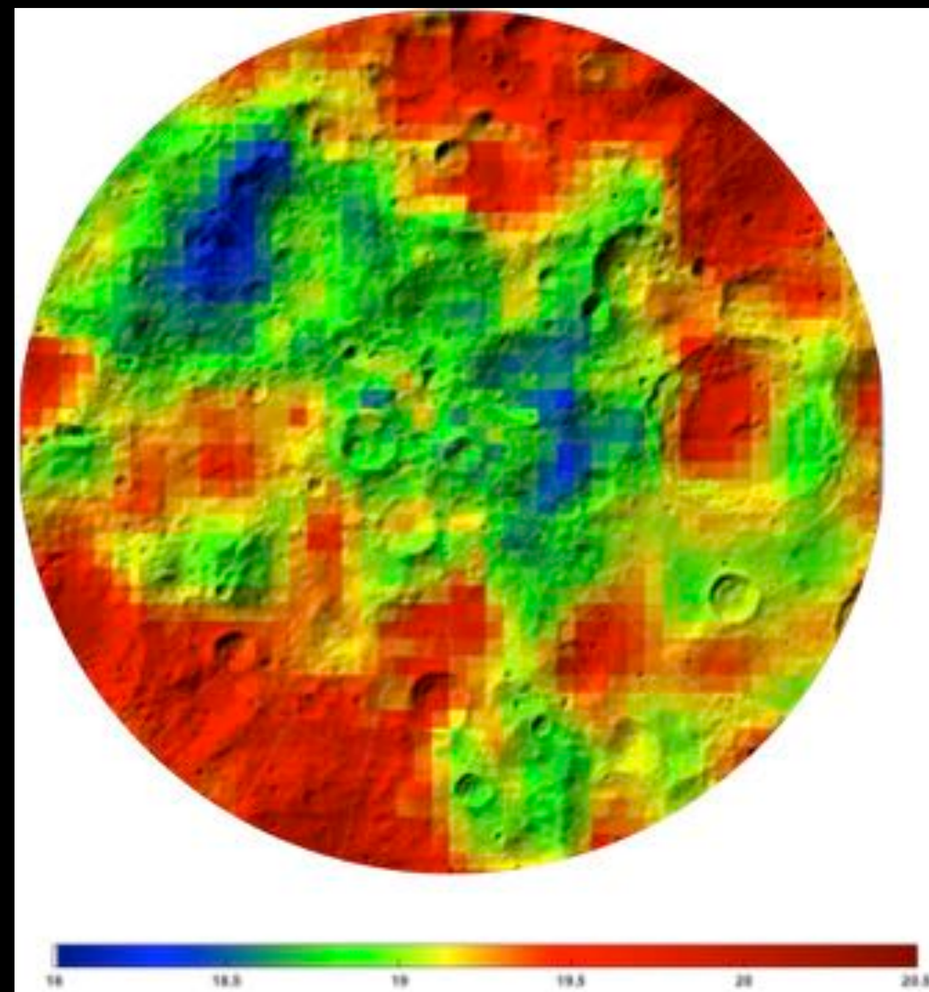
*Also see Lawrence et al., 2006; Elphic et al., 2007 and others

2.6 Polar Hydrogen with Neutron Spectroscopy

LEND CSETN ('collimated')
Total counts/sec



LPNS Adaptive Smooth
(SNR>100)



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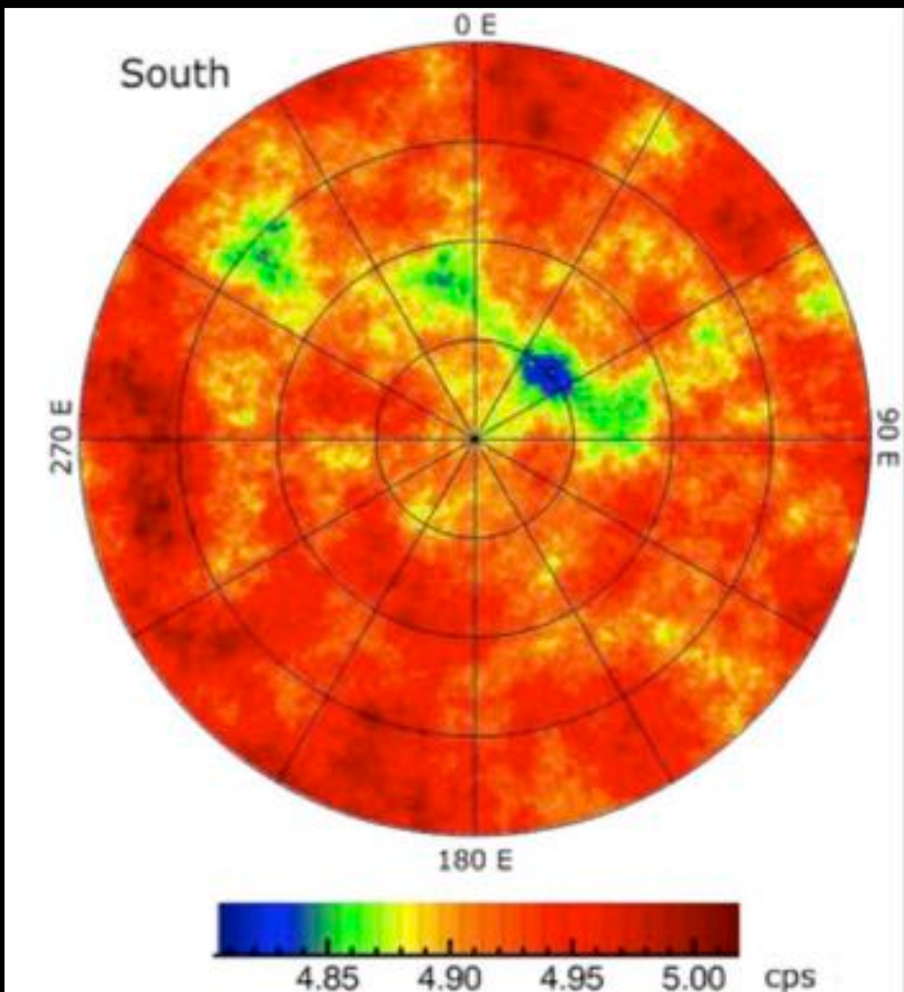
Total counts/sec



LPNS Adaptive Smooth
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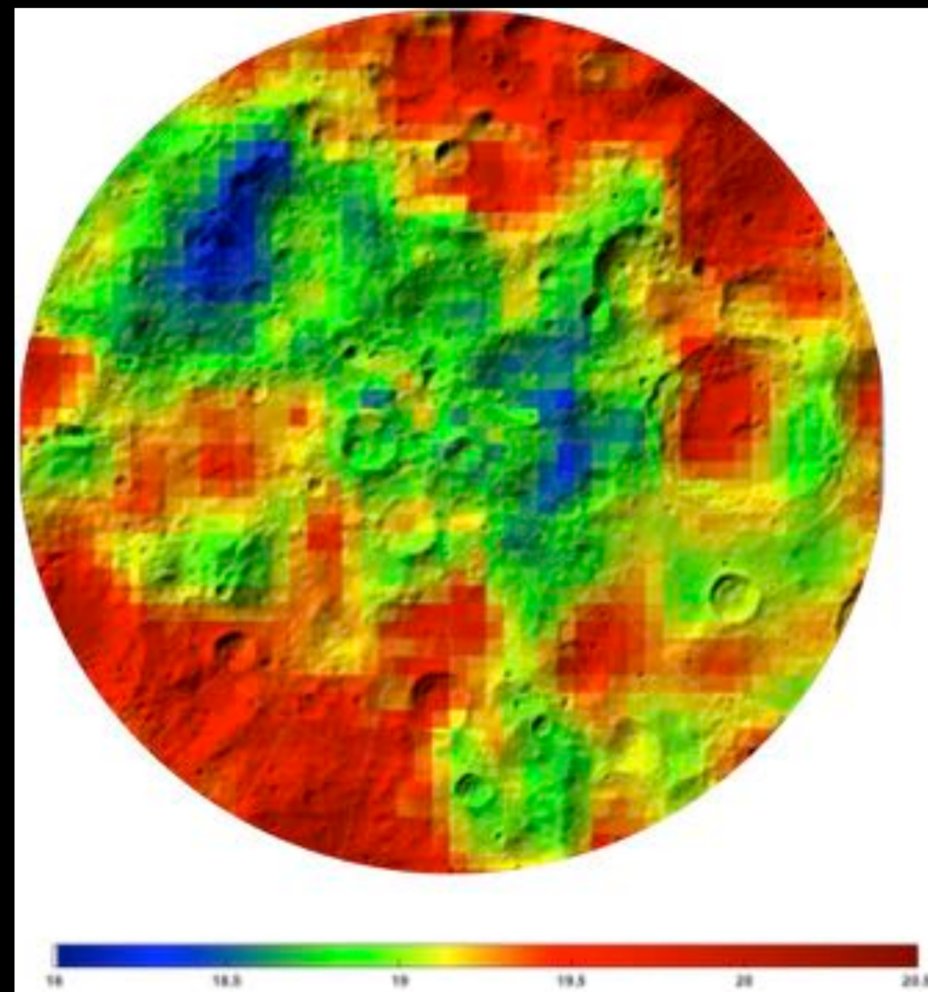
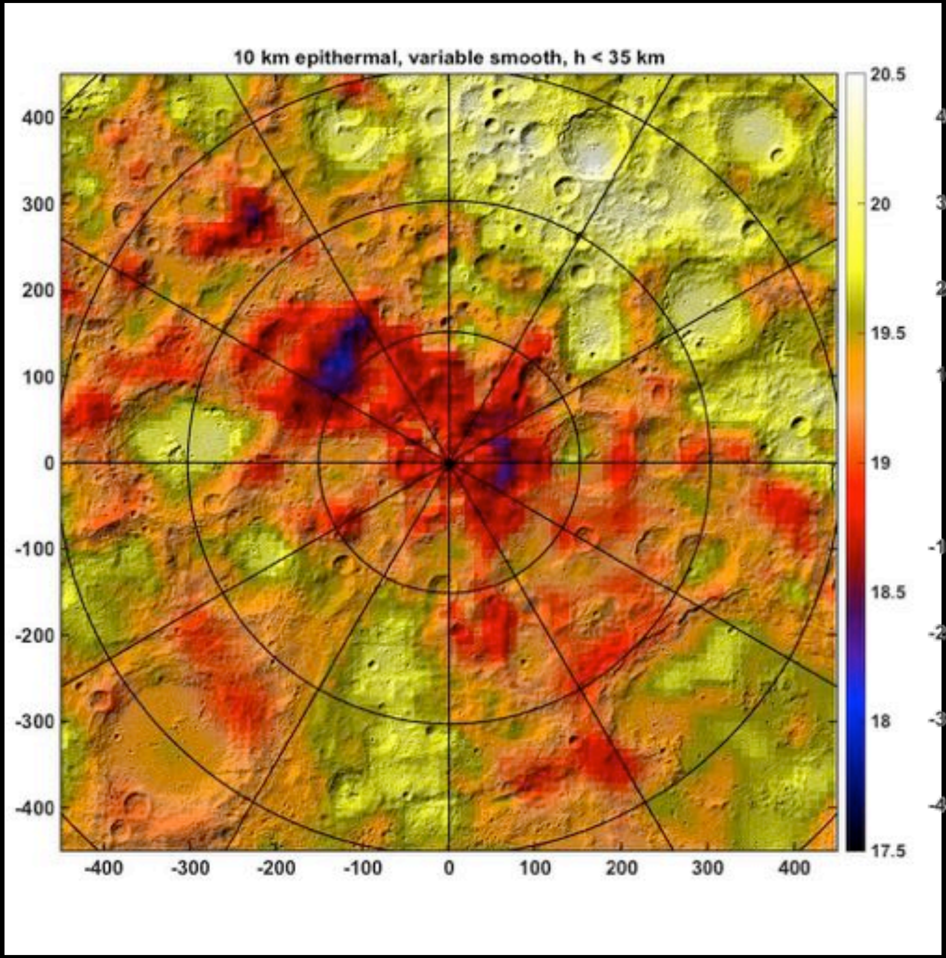
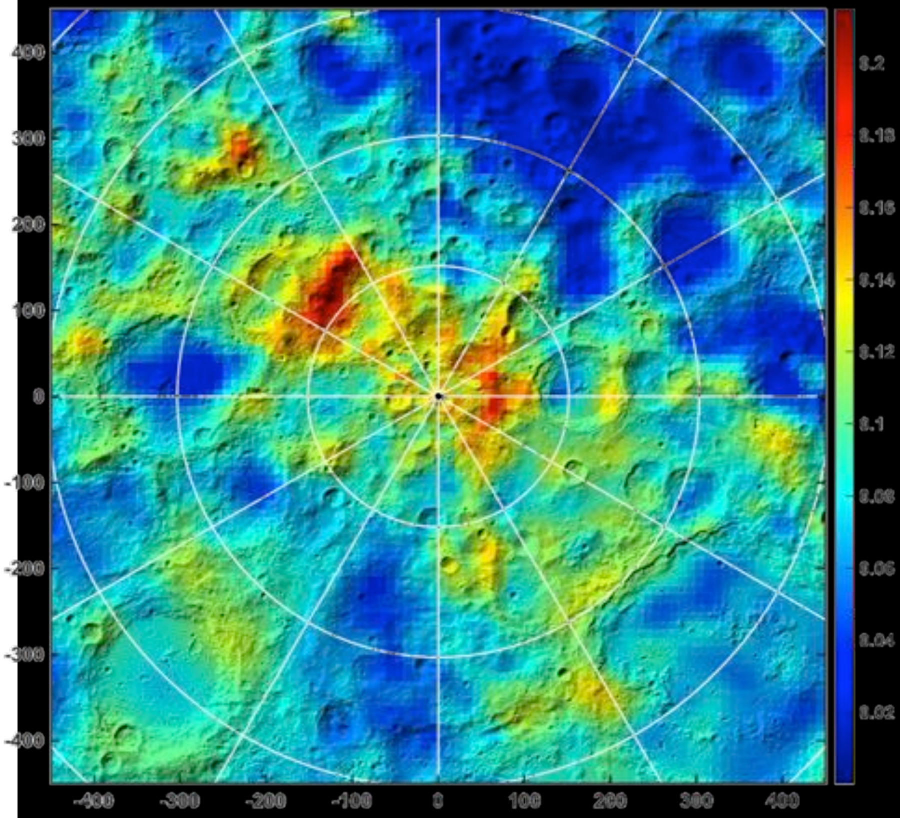


2.6 Polar Hydrogen with Neutron Spectroscopy

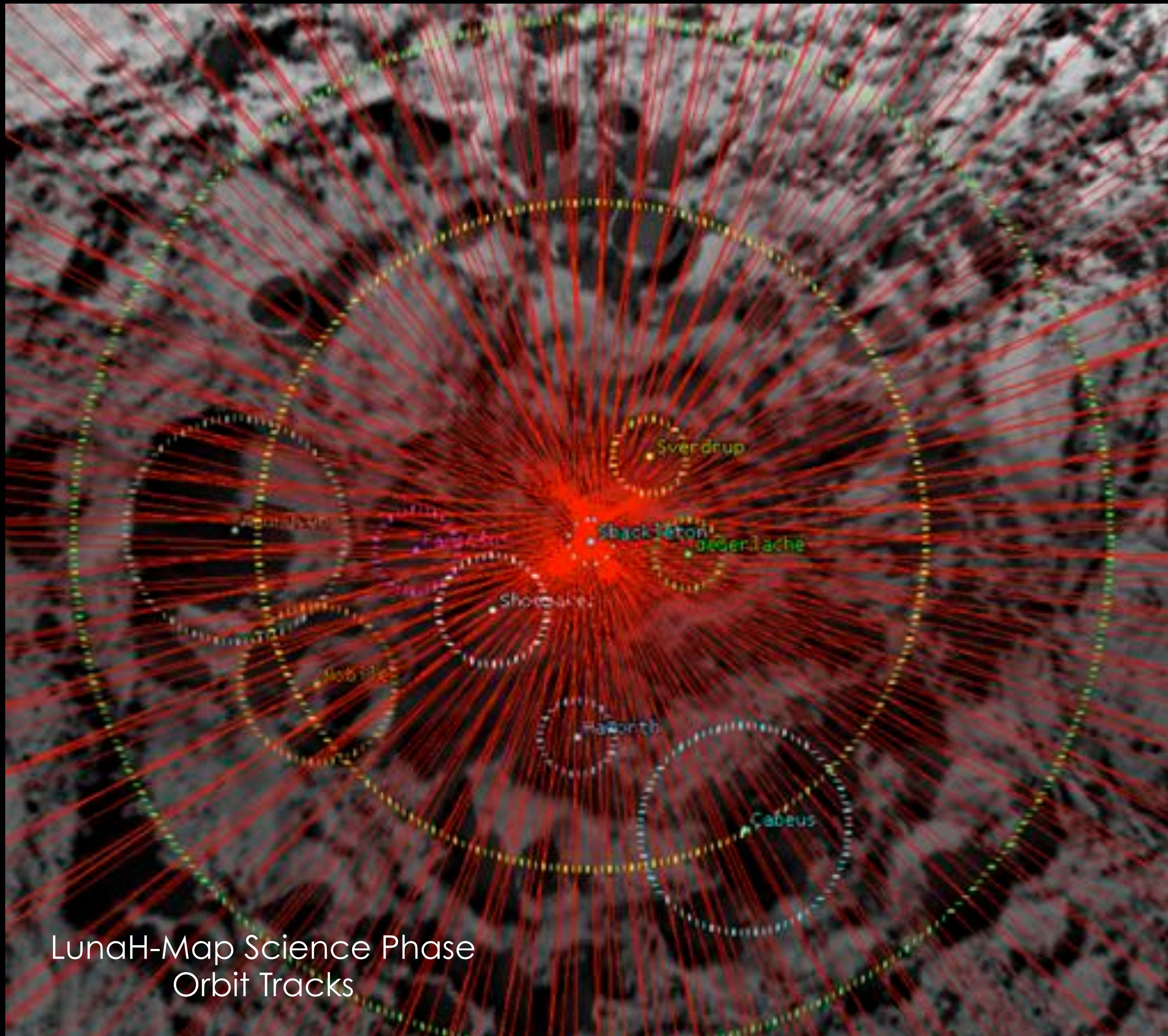
LPNS Adaptive Smooth
Alt<35 km, SNR>100



LPNS Adaptive Smooth
Water-equiv. Hydrogen
(wt%)



3. LunaH-Map Science Phase



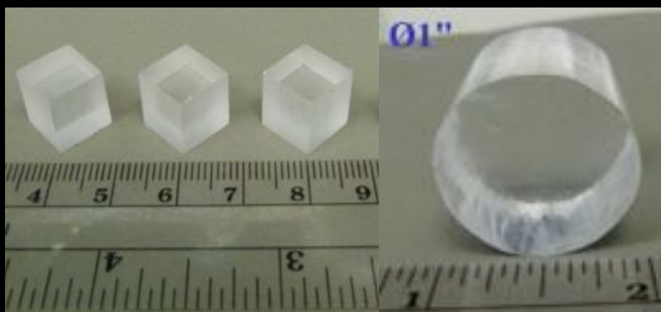
LunaH-Map Science Phase
Orbit Tracks

<u>Nominal Science Mission</u>

- 2 months = 141 Orbits
- 10 hour period
- Perilune <10km

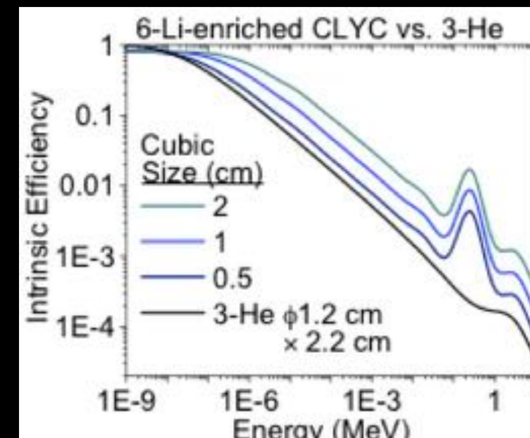
3. LunaH-Map Neutron Spectrometer

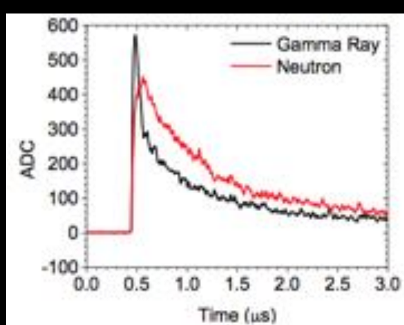
- Developed through NASA & DOD SBIR/STTR awards
- Similar efficiencies to thermal and epithermal neutrons as ^{3}He



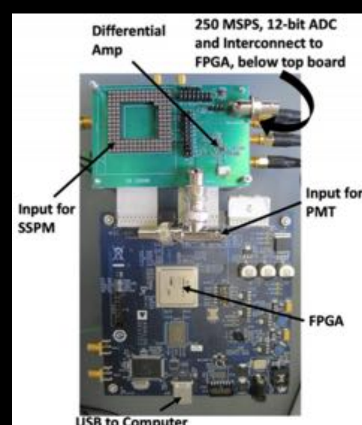
CLYC can be grown into a variety of shapes and sizes. Has been rad (~200 MeV and very high dose rates >50 rad/s), vacuum and pressure tested. Can operate at -40C.

Comparison of CLYC to ^{3}He efficiency. CLYC shows a greater efficiency above 0.01 eV, saturating at 80%.

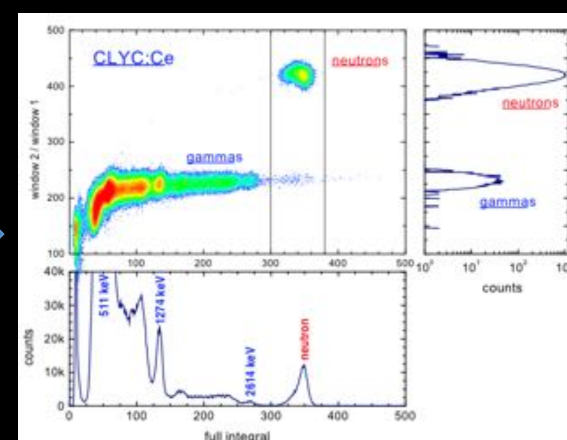




CLYC light pulses are different for gamma rays and neutrons



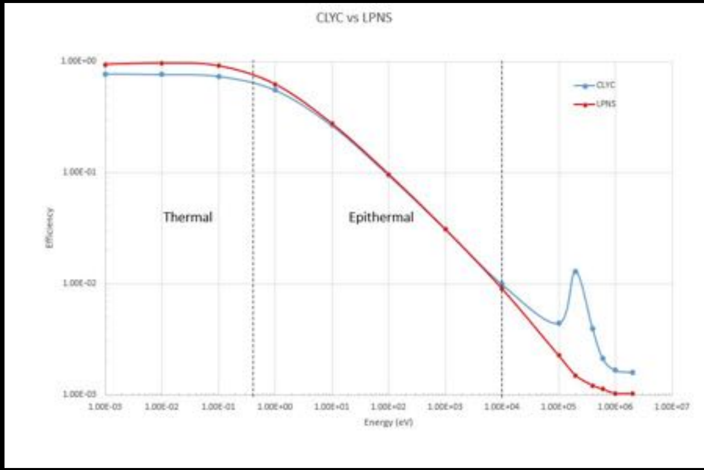
DAQ System developed for NASA SBIR/STTR



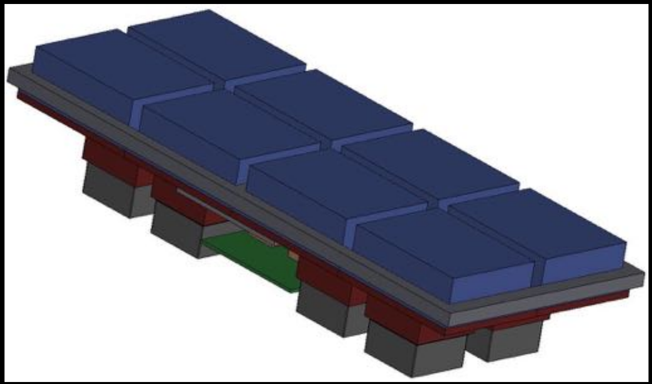
Gamma-rays and neutrons are discriminated by energy and light pulse shape

3. LunaH-Map Neutron Spectrometer

Mini-NS will have two 100-cm^2 CLYC arrays ($200 cm^2$ total). A thin Cd foil will be used for epithermal neutron detection



LunaH-Map Mini-NS (2cm) compared to 5.7-cm diameter LPNS ^3He counter



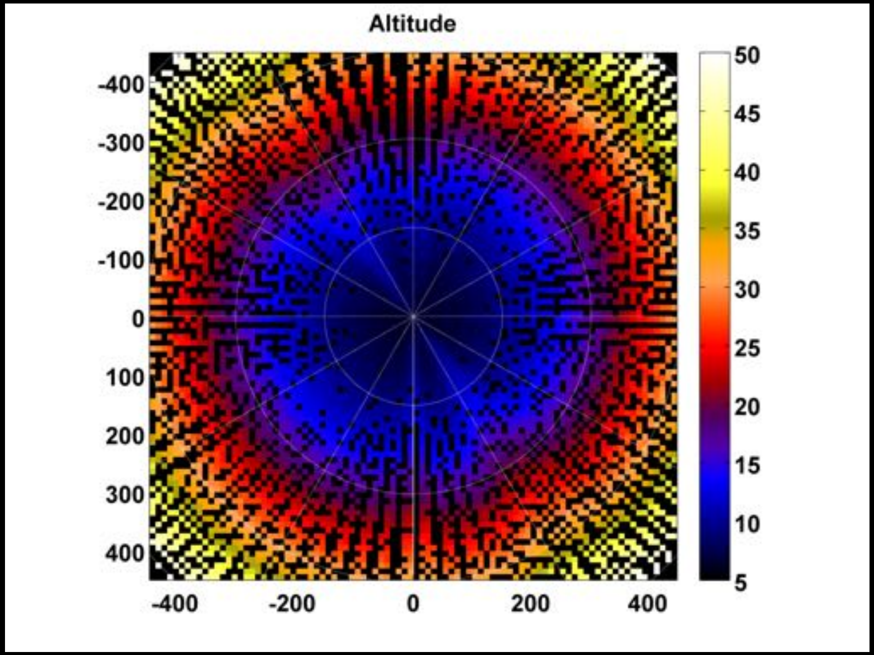
Preliminary design of Mini-NS for LunaH-Map

Specifications	
Detector	2, 4x4 Detector Arrays of CLYC (each 2.5cm x 2.5cm x 2cm)
Sensitivities	Thermal (<0.3 eV) and epithermal (with Cd shield) neutrons and 3.9% FWHM at 662 keV
Dimensions	27.94 cm x 11.43cm x 6cm
Mass	2.6 kg
Power	2 Watts (during data acquisition); 0.35 Watts (idle)
Data Acquisition Times	Counts binned every 3 seconds
Data Volume	<1 Mbit for mission duration

3. Preliminary Independent Science Phase Comparison of Lunar Prospector Neutron Spectrometer (LPNS) with LunaH-Map* (assumes 100cm^2 detector array)

Important Notes:

- Independent analysis
- Models need to verified and correlated with LunaH-Map team models and designs
- Models do not include energy-angle dependence of the detector
- Assumes 100cm^2 for epithermal neutrons (200cm^2 available)
- Assumes 2 month science phase

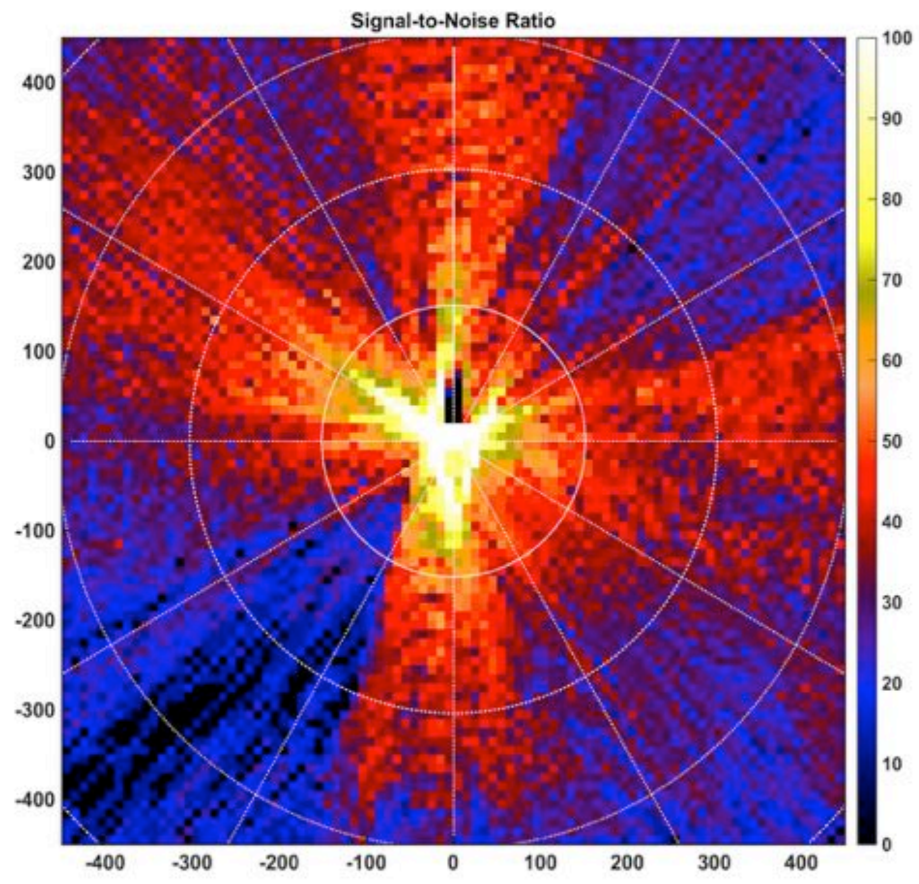


LunaH-Map Altitude Map over South Pole

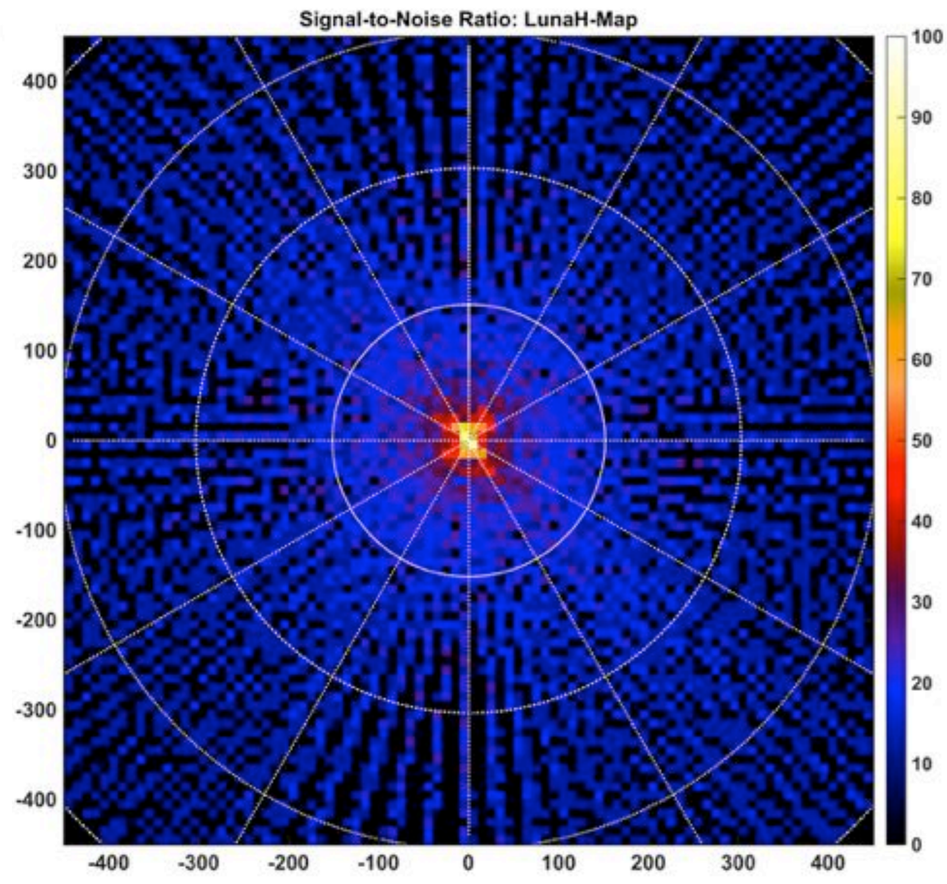
***Independent Analysis of LunaH-Map Detection Capabilities by Rick Elphic**

3. Preliminary Independent Science Phase Comparison of Lunar Prospector Neutron Spectrometer (LPNS) with LunaH-Map* (assumes 100cm^2 detector array)

LPNS Raw Binned SNR in 10 km Bin
Altitude < 35 km

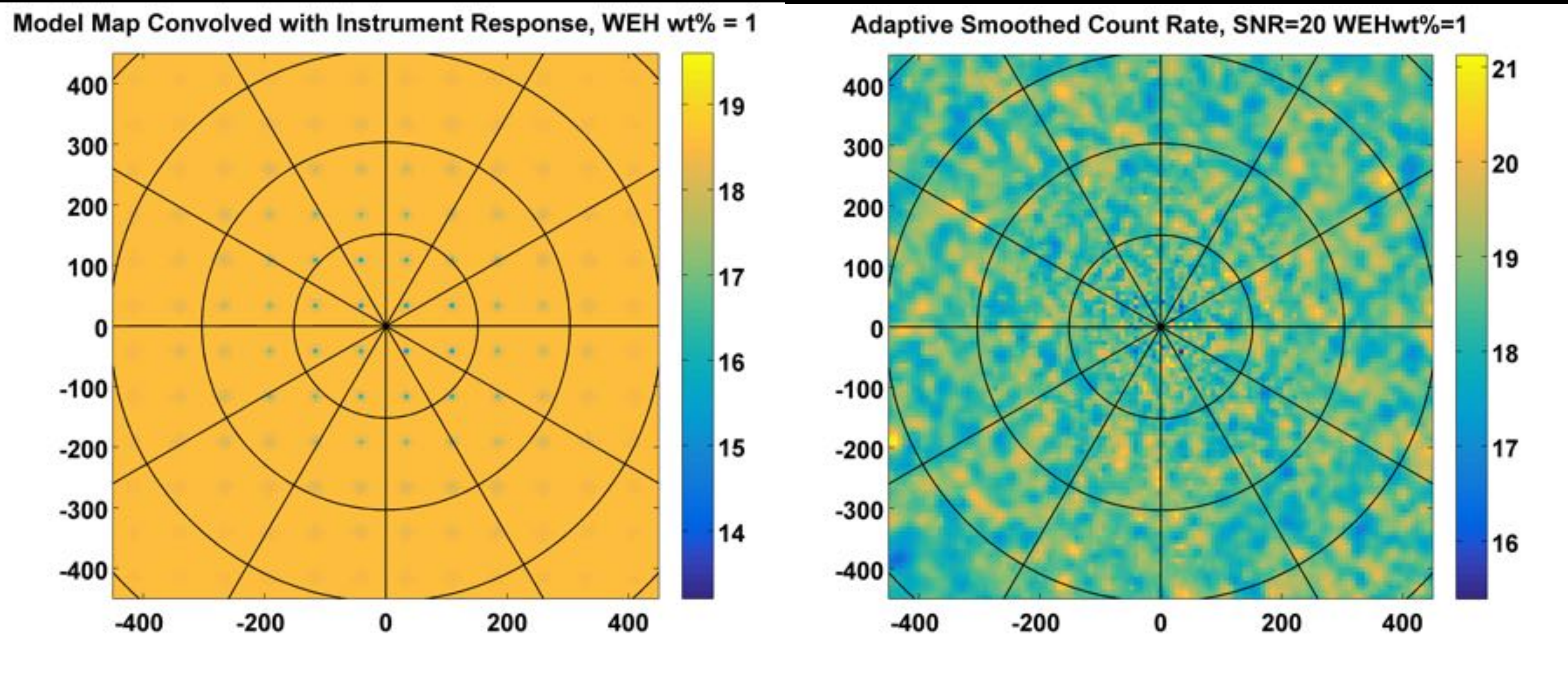


LunaH-Map Binned SNR in 10 km Bin



***Independent Analysis of LunaH-Map Detection Capabilities**

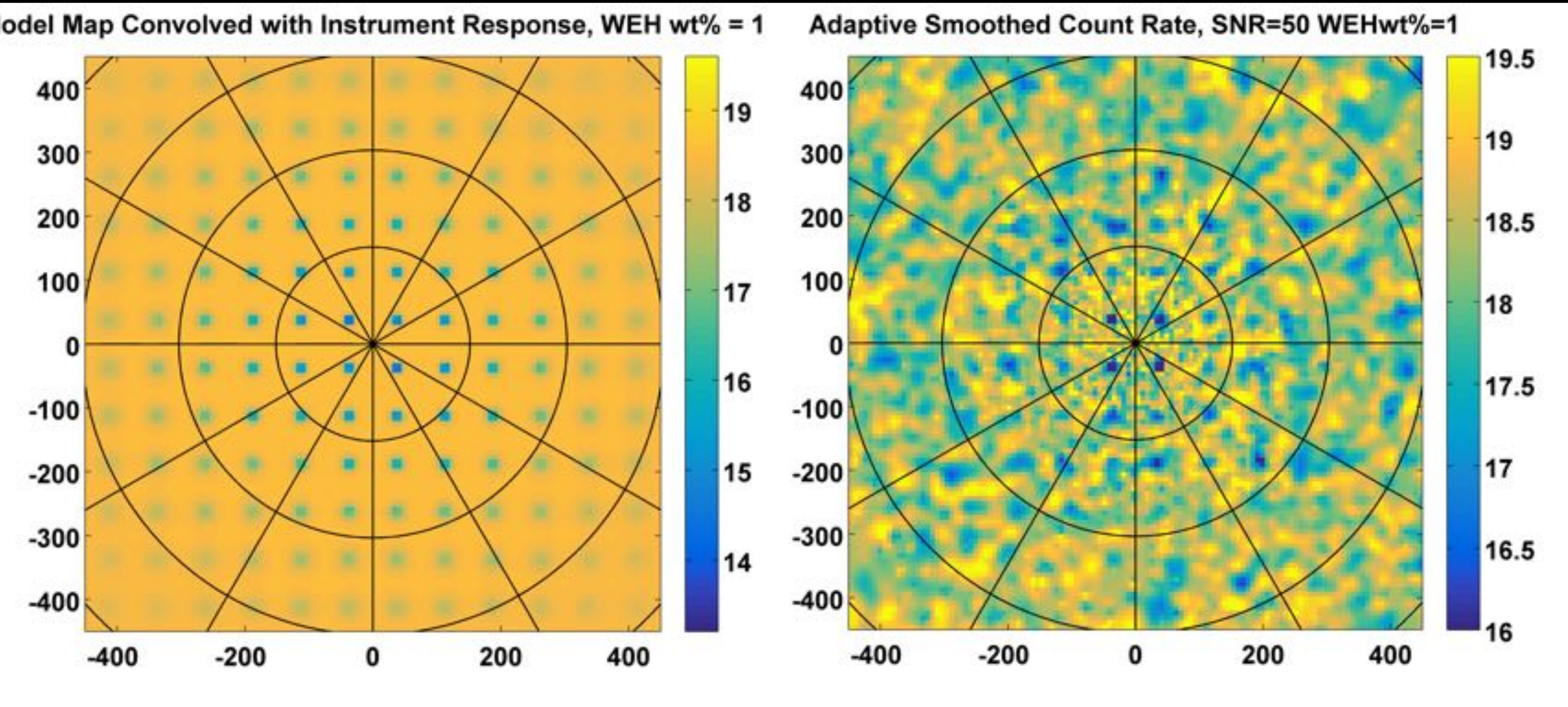
3. Preliminary Independent Science Phase Comparison of Lunar Prospector Neutron Spectrometer (LPNS) with LunaH-Map* (assumes $100cm^2$ detector array)



7.5km², 1 wt.% WEH "spots"

*Independent Analysis of LunaH-Map Detection Capabilities

3. Preliminary Independent Science Phase Comparison of Lunar Prospector Neutron Spectrometer (LPNS) with LunaH-Map* (assumes 100cm^2 detector array)



15km^2, 1 wt.% WEH "spots"

***Independent Analysis of LunaH-Map Detection Capabilities**

4. LunaH-Map Mission Design - Trajectory: Transfer to Lunar Capture

TRAJECTORY SEQUENCE

A) Launch → Dec 15, 2017

B) Separation → within 1 hr of drop-off
32,000 km from Earth's surface

C) 1st thrust segment begins 24 hrs after separation

D) 1st Lunar Flyby → L+ 4 days

E) Post flyby thrust segment (42 hrs)

F) Thrust near apogee

G) 2nd Lunar Flyby → L+ 159 days

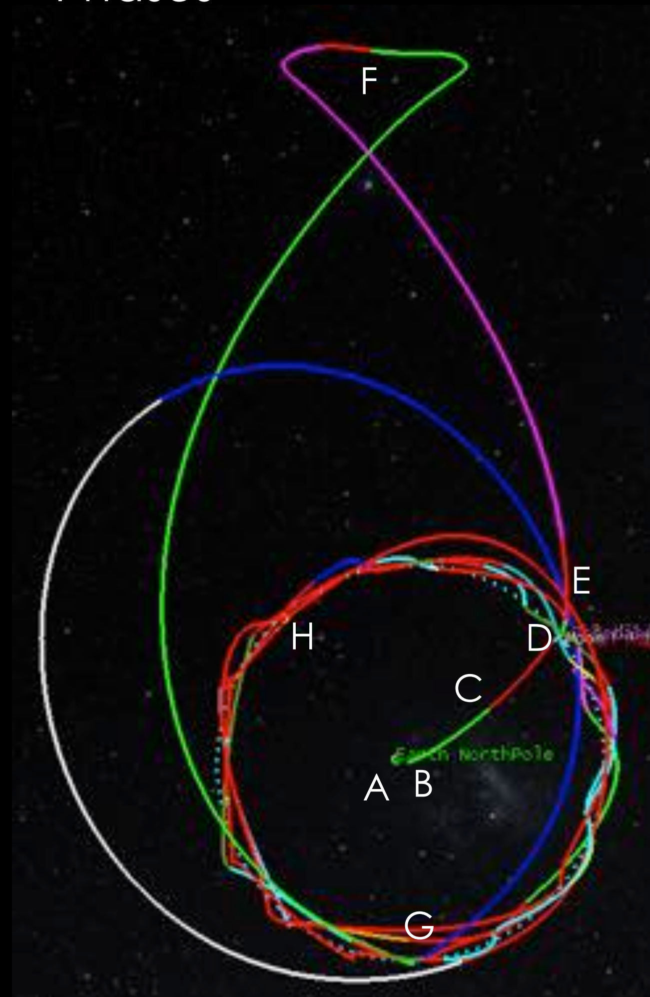
H) Lunar Capture → L+ 229 days
** ballistic capture required*

I) Transition Phase
** 90 deg orbit axis (apses) rotation*
** 90 deg plane change*
** Apolune altitude drop to 7500 km*

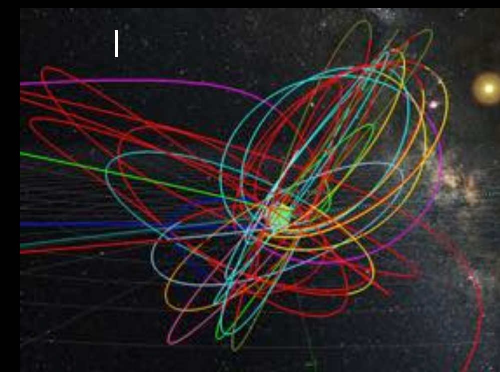
J) Science Phase
* 141 total science measurements
* shown on next slide

Spacecraft: 12 kg initial SC wet mass
Thruster: 0.7 mN thrust & 1900 s Isp @65W

Deployment & Cruise Phases



Transition Phase



Transition Phase
(strong)

4. LunaH-Map Mission Design – Trajectory: Science Orbit

Science Orbit Maintenance Sequence

A) Science Pass at Perilune {TA = 0°}

B) Begin Maneuver #1 {TA = 123°}
→ 1 hr after "A"

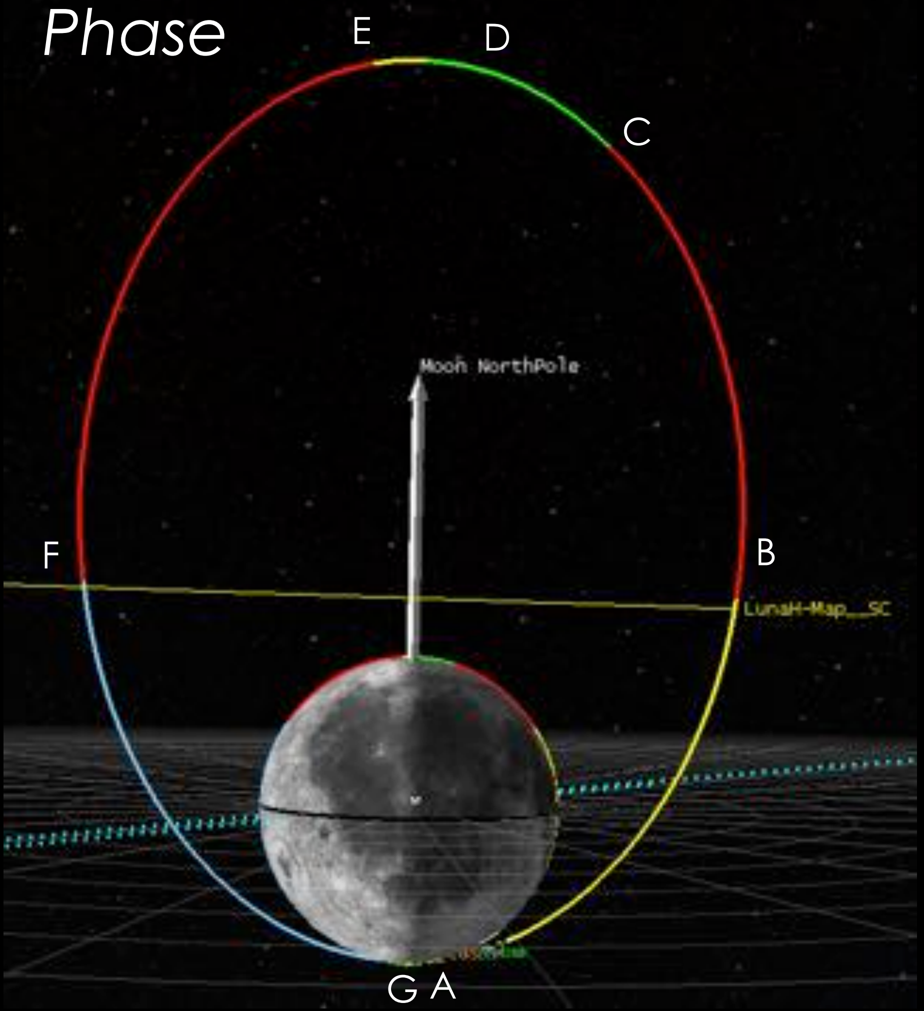
C) End Maneuver #1
→ TA varied, near 172°

E) Begin Maneuver #2

F) End Maneuver #2 {TA = 237°}

G) Perform Science Measurement
{1 hr after "F"→ TA = 0°}

Science Phase



Moon Inertial View YZ

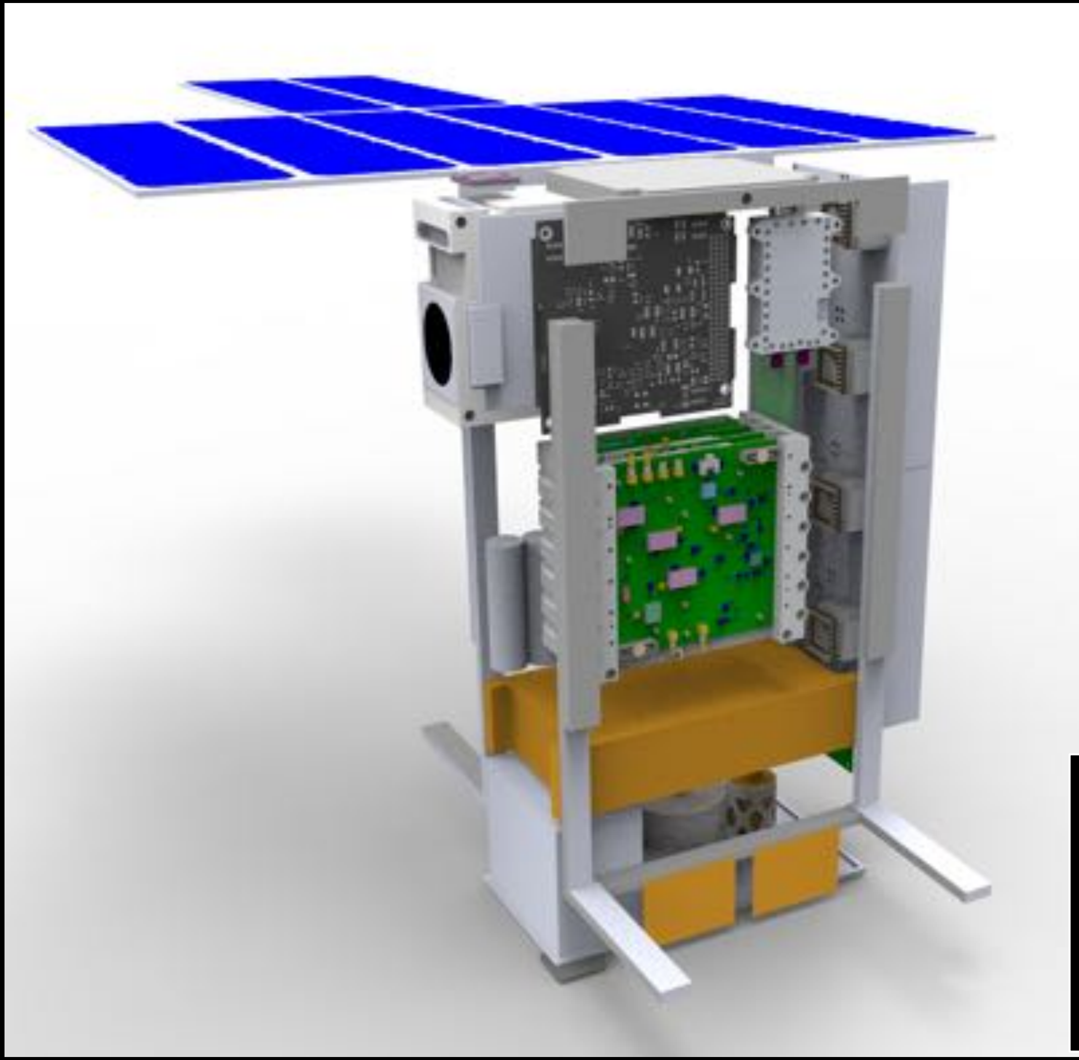
4. LunaH-Map Propellant & Mission Duration Requirements

	RF Ion Prop Option (Iodine)	
Mission Event/Sequence	**Prop Required**	**Duration Required**
To Weak Lunar Capture	0.15 kg	192 days
Apolune Drop, Δi, Δω	0.8 kg	158 days
Nav. TCMs & Attitude	0.1 kg	n/a
Science Orbit Maintenance	0.2 kg	110 days
Total (excluding margin)	**1.25 kg**	**460 days**
Prop Margin Available	**+0.25 kg**	n/a

Spacecraft: 12 kg initial SC wet mass
Thruster: 0.7 mN thrust & 1900 s Isp @65W

Preliminary propellant margins support a potential science phase extension beyond 2 months which would increase sensitivity to H and Mini-NS ability to discern small (<10 square-km) enhancements in lunar PSRs

3. LunaH-Map Spacecraft



Dimensions

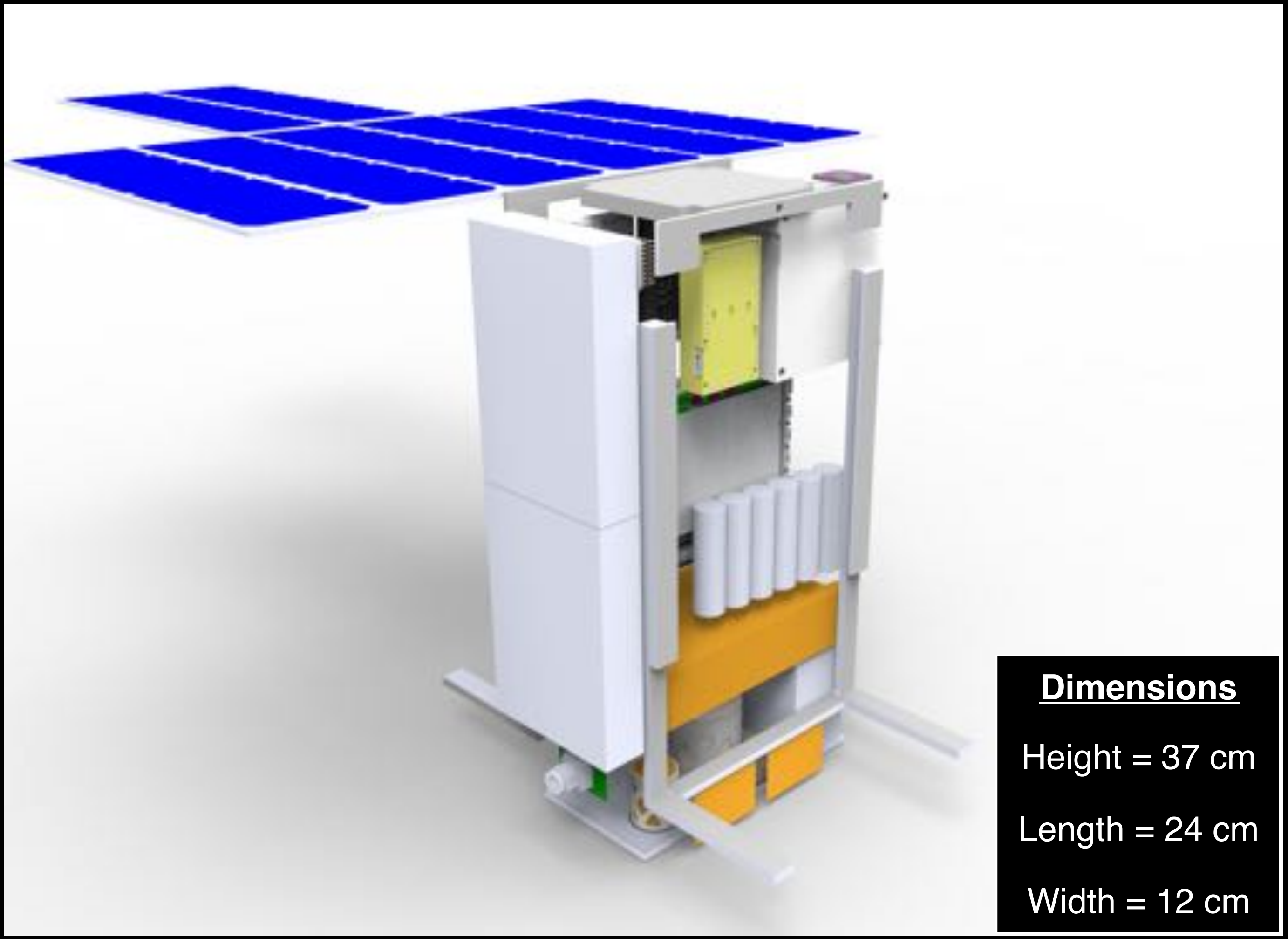
Height = 37 cm

Length = 24 cm

Width = 12 cm

Preliminary spacecraft design

3. LunaH-Map Spacecraft



Preliminary spacecraft design

Dimensions

Height = 37 cm

Length = 24 cm

Width = 12 cm

3. LunaH-Map Spacecraft

Preliminary spacecraft design

Dimensions

Solar Array Wingspan (Deployed) = 126 cm

3. The LunaH-Map Spacecraft

Preliminary spacecraft design

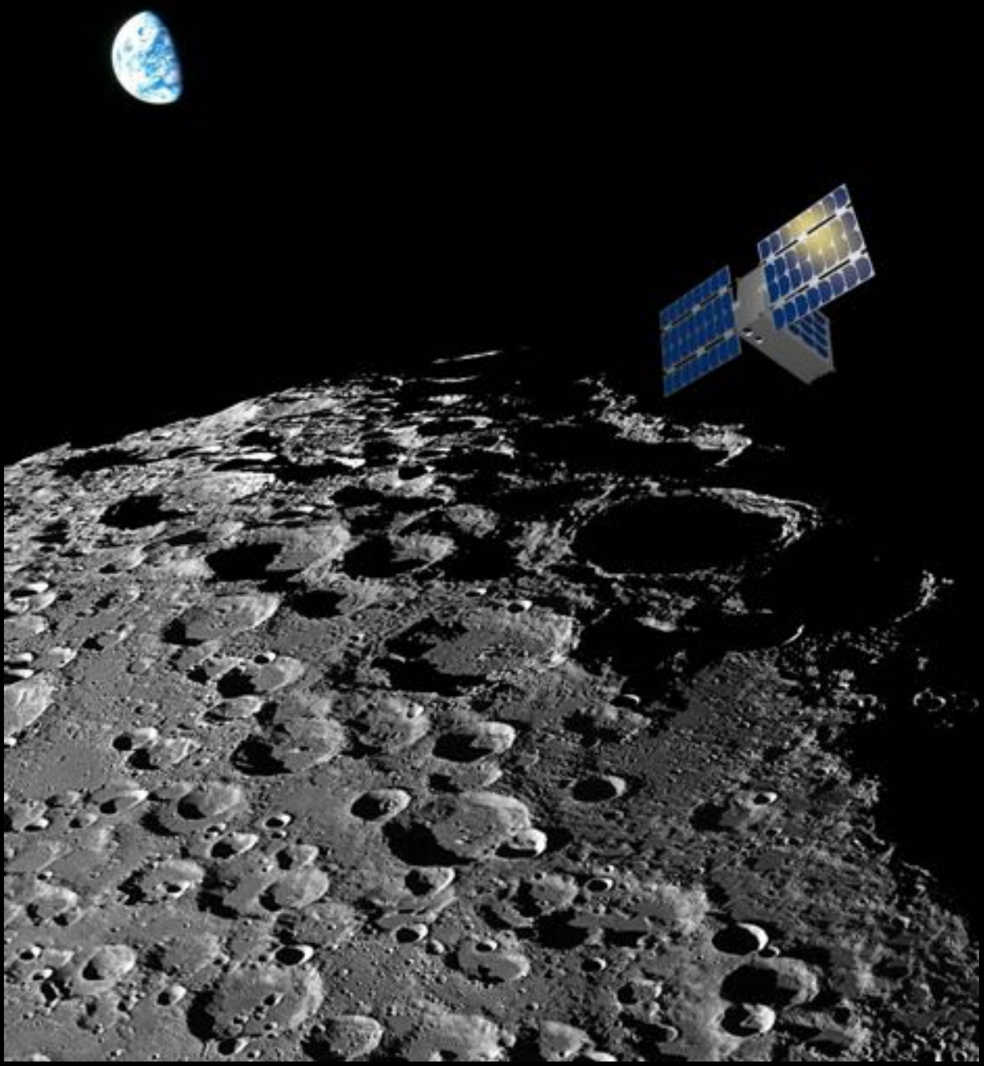
4. LunaH-Map Status

- Selected in late August, 2015
- Recently passed Accommodation Audit with external review board
- Systems Requirements Review held April 8th
- Instrument and Spacecraft PDR (by end of 2016)
- CDR early 2017

5. Impact of Small Satellites on Planetary Science

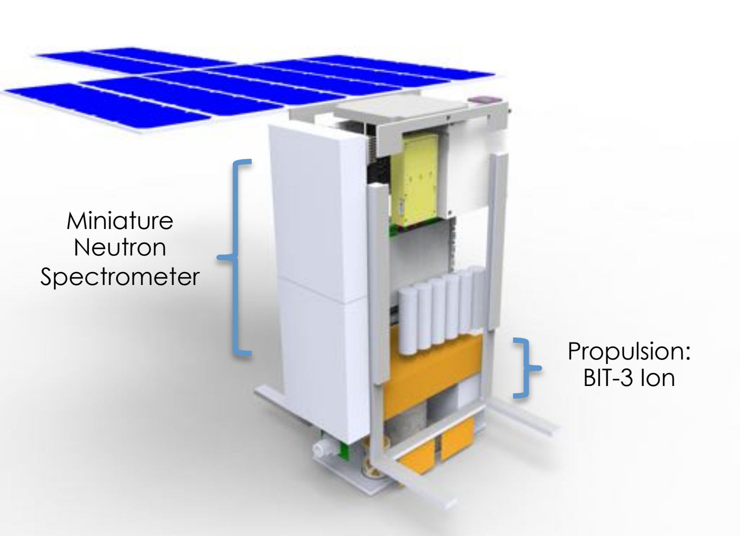
- SIMPLEx requires new solutions to address questions in planetary science
  - Targeted science mission, shorter schedules, smaller teams, more iteration, collaboration
  - LunaH-Map combines a high-heritage technique in planetary science with new detector materials (developed through NASA SBIR/STTR)
  - Many small business partnerships
  - LunaH-Map is University-led with many small businesses partners serving key roles.
  - Multiple missions on the same launch is critical! Collaboration on development is important for every mission’s success.

To the Moon!



The Lunar polar Hydrogen Mapper (LunaH-Map) Mission

Revealing Hydrogen Distributions at the Moon's South Pole with a 6U CubeSat



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