National Aeronautics and Space Administration

The Resource Prospector Expedition

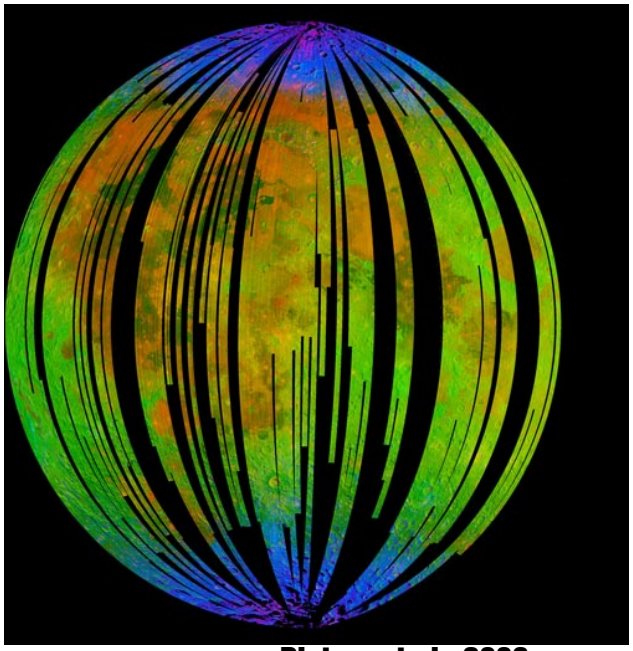
Anthony Colaprete

2014-07-23

Mission Goals & Relevance

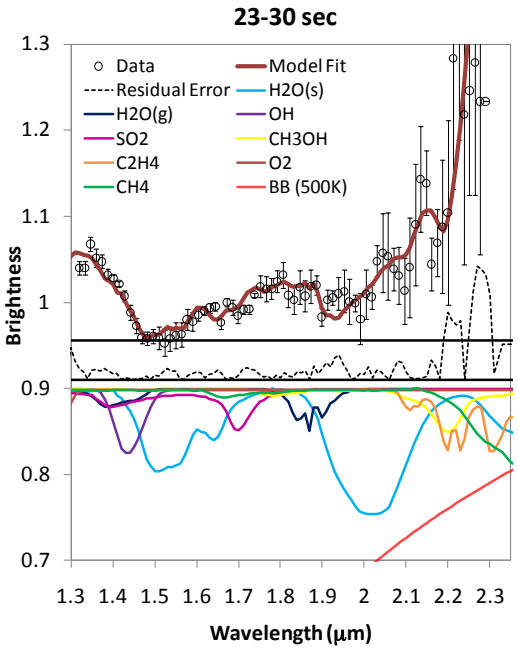
A range of forms, distributions and concentrations

~0.1-1%



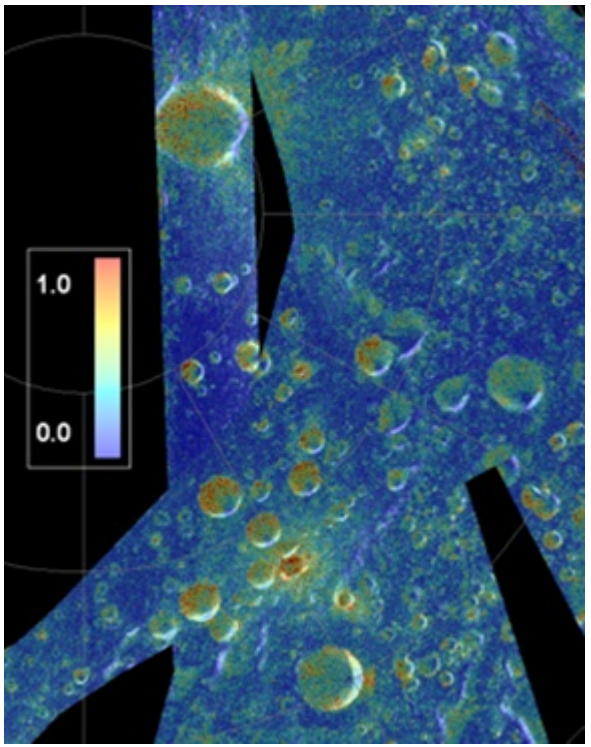
Pieters et al., 2003

~1-10%



Colaprete et al., 2010

~10-100%

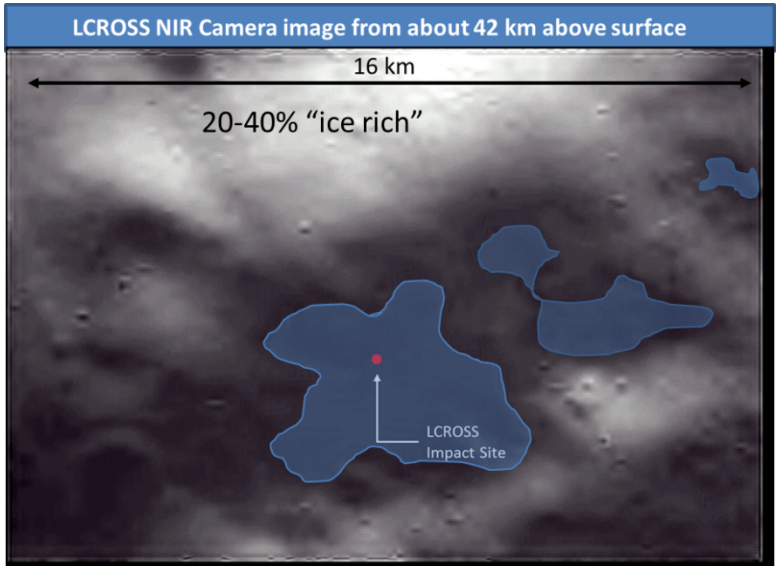


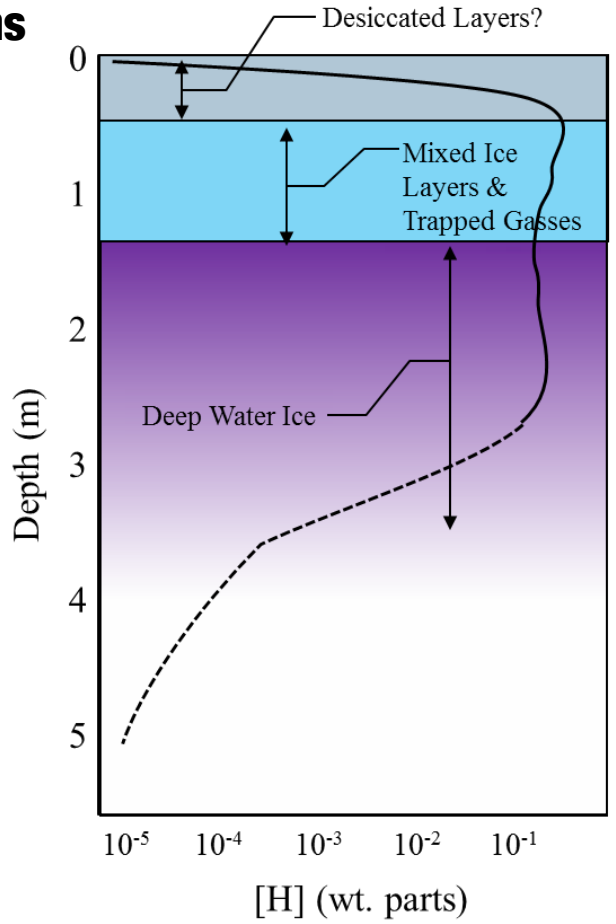
Spudis et al., 2010

We know that water (and other H-bearing compounds) are there…

Mission Goals & Relevance

- **LCROSS + Neutron analysis suggest patchy or buried (or both) distributions of hydrogen**
- **Impact gardening will create heterogeneity at lengths scale of ~10-100 m**
- **Several data sets suggest time-dependent surface component**
- **In areas of limited sun near sub-surface temperatures are cold enough to retain water**

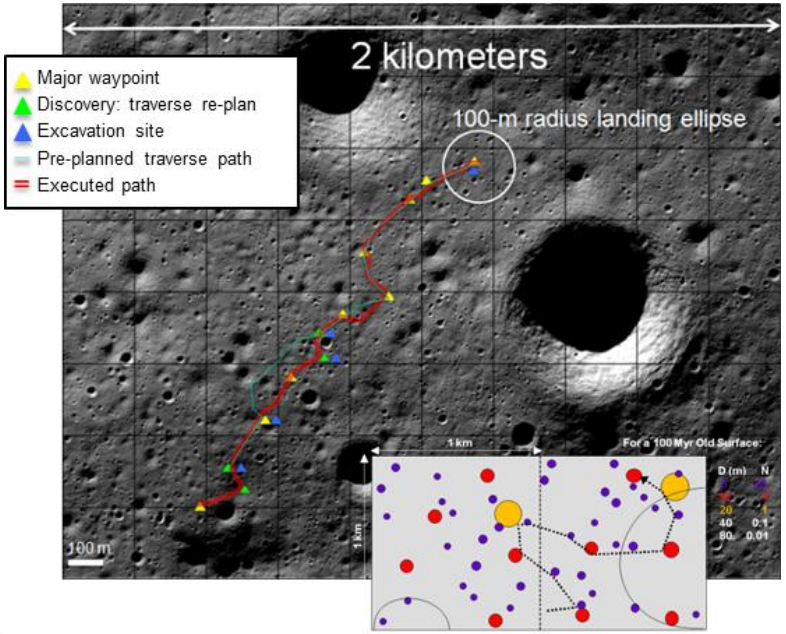




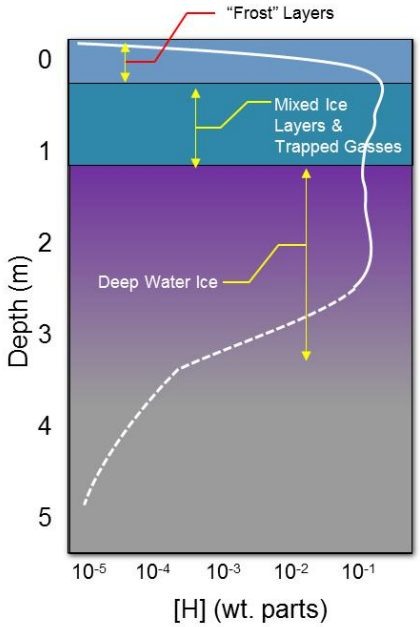
Determining 'Operationally Useful' Resource Deposits

Need to assess the extent of the resource 'ore body'

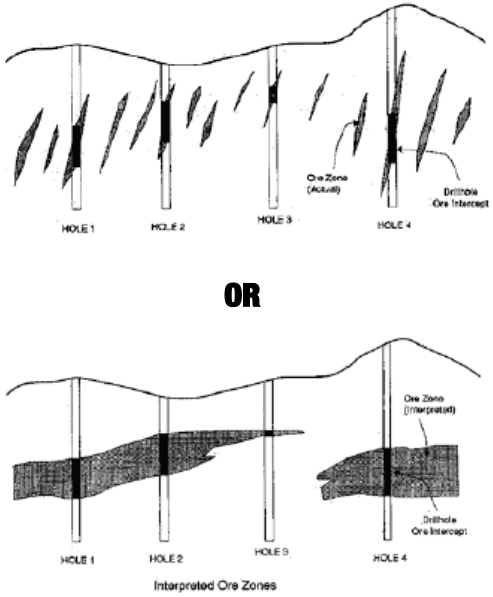
Need to Evaluate Local Region (1 to 3 km)



Need to Determine Vertical Profile



Need to Determine Distribution



An 'Operationally Useful' Resource Depends on What is needed, How much is needed, and How often it is needed

Potential Lunar Resource Needs*

- 1,000 kg oxygen (O_2) per year for life support backup (crew of 4)
- 3,000 kg of O_2 per lunar ascent module launch from surface to L_1/L_2
- 16,000 kg of O_2 per reusable lunar lander ascent/descent vehicle to L_1/L_2 (fuel from Earth)
- 30,000 kg of O_2/Hydrogen (H_2) per reusable lunar lander to L_1/L_2 (no Earth fuel needed)

*Note: ISRU production numbers are only 1st order estimates for 4000 kg payload to/from lunar surface

RP Mission Goals

From *LEAG Robotic Campaign Analysis (2011):*

Phase I: Lunar Resource Prospecting

- **Defining the composition, form, and extent of the resource;**
- **Characterizing the environment in which the resources are found;**
- **Defining the accessibility/extractability of the resources;**
- **Quantifying the geotechnical properties of the lunar regolith in the areas where resources are found;**
- **Being able to traverse several kilometers and sample and determine lateral and vertical distribution on meter scales;**
- **Identifying resource-rich sites for targeting future missions**

Resource Prospector is aligned with the community vision for the next lunar resource mission – Ro continues to work with LEAG

SKGs and RP – Address at Least 22 Lunar SKGs

Lunar Exploration Strategic Knowledge Gaps			Instrument or Activity	RPM Relevance
I. Understand the Lunar Resource Potential				
	B-1	Regollith 2: Quality/quanity/distribution/form of H species and other volatiles in mare and highlands	NSS, NIRVSS, OVEN-LAVA	VH
	D-3	Geotechnical characteristics of cold traps	NIRVSS, Drill, Rover	H
	D-4	Physiography and accessibility of cold traps	Rover-PSR traverses, Drill, Cameras	VH
	D-6	Earth visibility timing and extent	Mission Planning	VH
	D-7	Concentration of water and other volatiles species within depth of 1-2 m	NSS, NIRVSS, OVEN-LAVA	VH
	D-8	Variability of water concentration on scales of 10's of meters	NSS, NIRVSS, OVEN-LAVA	VH
	D-9	Mineralogical, elemental, molecular, isotopic, make up of volatiles	NIRVSS, OVEN-LAVA	VH- Volatiles L-M-Minerals
	D-10	Physical nature of volatile species (e.g. pure concentrations, intergranular, globular)	NIRVSS, OVEN-LAVA	H
	D-11	Spatial and temporal distribution of OH and H2O at high latitudes	NIRVSS, OVEN-LAVA	M-H
	D-13	Monitor and model movement towards and retenion in PSR	NIRVSS, OVEN-LAVA	M
	G	Lunar ISRU production efficiency 2	Drill, OVEN-ROE, LAVA-WDD	M
III. Understand how to work and live on the lunar surface				
	A-1	Technology for excavation of lunar resources	Drill, Rover	M
	B-2	Lunar Topography Data	Planning Products, Cameras	M
	B-3	Autonomous surface navigation	Traverse Planning, Rover	M-L
	C-1	Lunar surface trafficability: Modeling & Earth Tests	Planning, Earth Testing	M
	C-2	Lunar surface trafficability: In-situ measurements	Rover, Drill	H
	D-1	Lunar dust remediation	Rover, NIRVSS, OVEN	M
	D-2	Regolith adhesion to human systems and associated mechanical degradation	Rover, NIRVSS, OVEN, Cameras	M
	D-3	Descent/ascent engine blast ejecta velocity, departure angle, and entrainment mechanism: Modeling	Landing Site Planning, Testing	M
	D-4	Descent/ascent engine blast ejecta velocity, departure angle, and entrainment mechanism	Lander, Rover, NIRVSS	H
	F-2	Energy Storage - Polar missions	Stretch Goal: Lander, Rover	H
	F-4	Power Generation - Polar missions	Rover	M
VH = Very High, H = High, M = Medium, L = Low				

Resource Prospector:
A mission to explore lunar polar volatiles

Prospecting Mission:

- **Characterize the distribution of water and other volatiles at the lunar poles**
  - **Map the surface and subsurface distribution of hydrogen rich materials**
  - **Determine the constituents and quantities of the volatiles extracted**
    - **Quantify important volatiles: H_2, He, CO, CO_2, CH_4, H2O, N_2, NH_3, H_2S, SO_2**
  - **Measure or provide limits on key isotope ratios, including D/H, O18/O16, S36/S34, C13/C12**

ISRU Processing Demonstration Mission:

- **Demonstrate the Hydrogen Reduction process to extract oxygen from lunar regolith**
  - **Demonstrate the hardware (e.g., oven, seals, valves) in lunar setting**
  - **Capture, quantify, and display the water generated**

Resource Prospector Level 1 Requirements

1.1 RESOLVE SHALL LAND AT A LUNAR POLAR REGION TO ENABLE PROSPECTING FOR VOLATILES

- Full Success Criteria: Land at a polar location that maximizes the combined potential for obtaining a high volatile (hydrogen) concentration signature and mission duration within traverse capabilities
- Minimum Success Criteria: Land at a polar location that maximizes the potential for obtaining a high volatile (hydrogen) concentration signature

1.2 RESOLVE SHALL BE CAPABLE OF OBTAINING KNOWLEDGE ABOUT THE LUNAR SURFACE AND SUBSURFACE VOLATILES AND MATERIALS

- Full Success Criteria: Take both *sub-surface measurements of volatile constituents via excavation and processing* and *surface measurements*, at multiple locations
- Minimum Success Criteria: Take either sub-surface measurements of volatile constituents via excavation and processing or surface measurements, at multiple locations

Measurement Requirement Summary

Paraphrased Requirements

Minimum Success:

- Make measurements from two places separated by at least 100 meters
- Surface or subsurface measurements

Full Success:

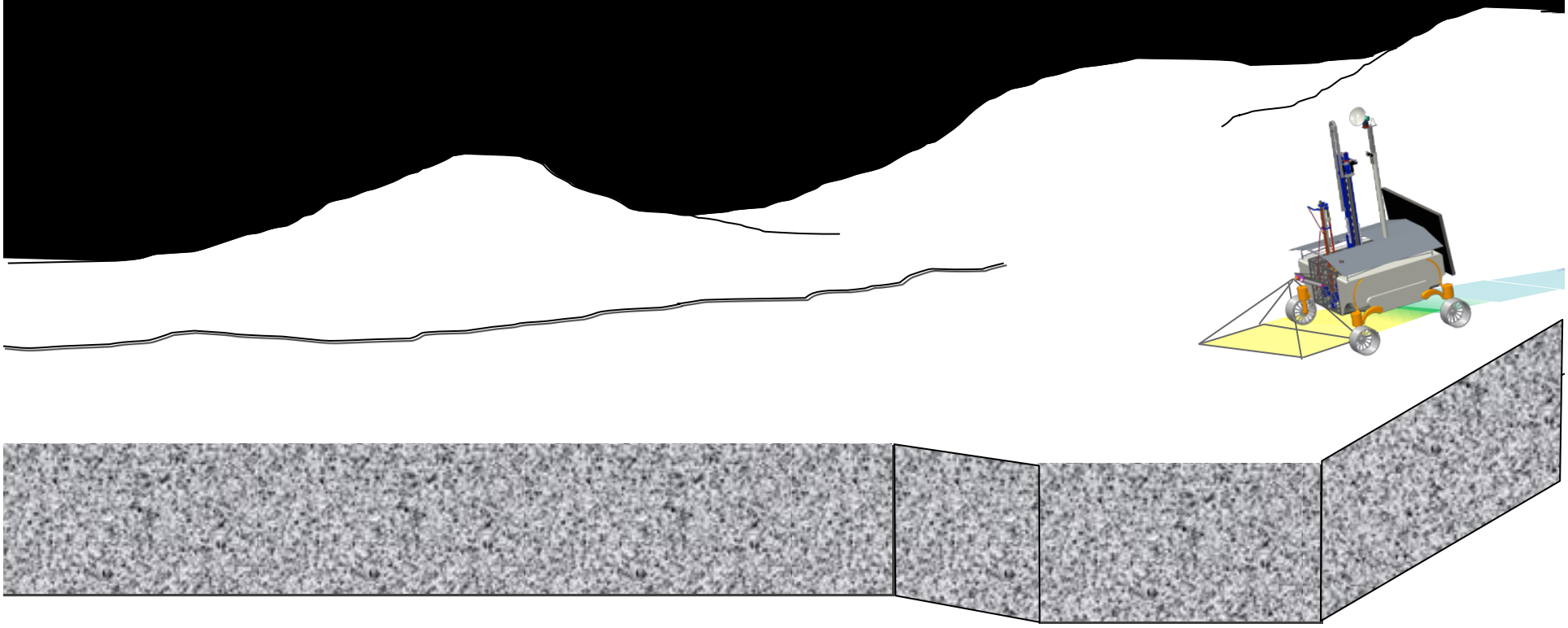
- Measurements from two places separated by at least 1000 meters
- Surface and subsurface measurements (drill)
- Measurements in and sample acquired from shadowed area
- Demonstrate ISRU

Stretch Goals:

- Make subsurface measurements (auger) at least eight (8) locations across 1000 m (point-to-point) distance
- Make subsurface measurements (core and process) at least four (4) locations across 1000 m (point-to-point) distance
- Provide geologic context

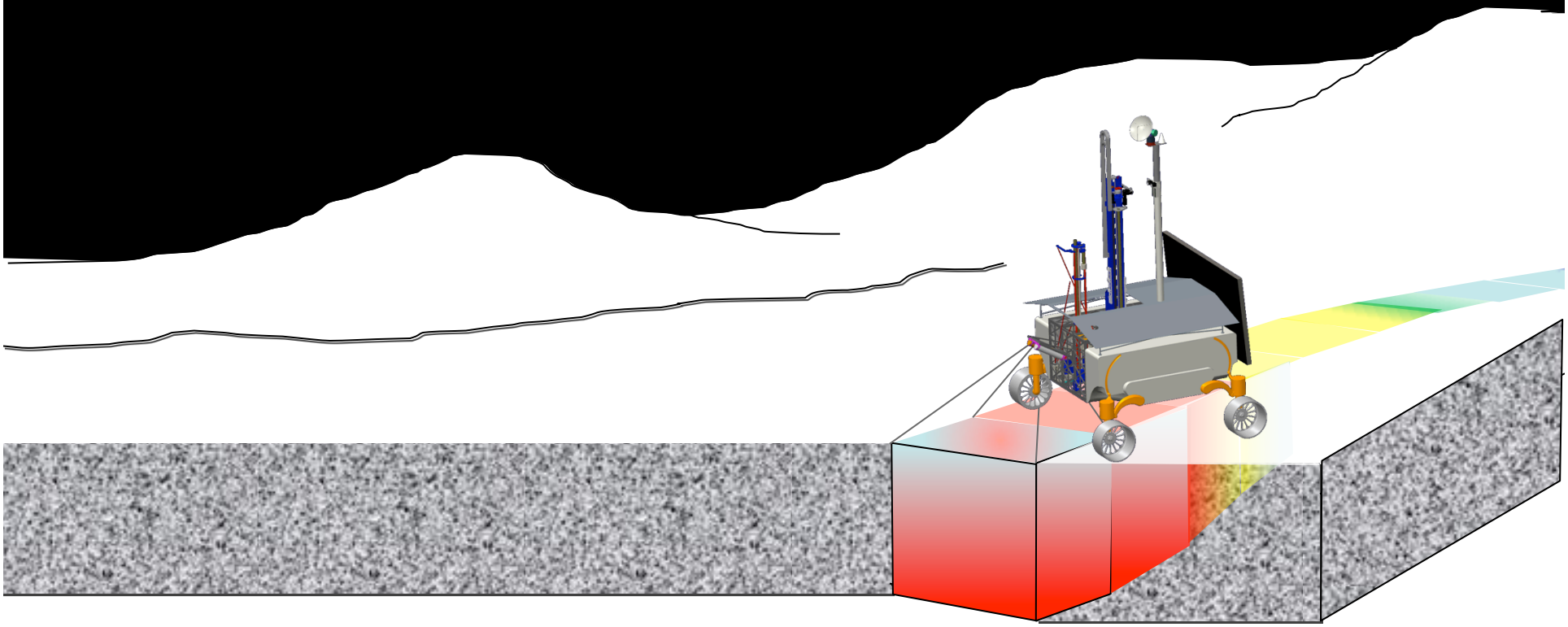
Prospecting…

1. **While roving, prospecting instruments search for enhanced surface H20/OH, other volatiles and volumetric hydrogen**



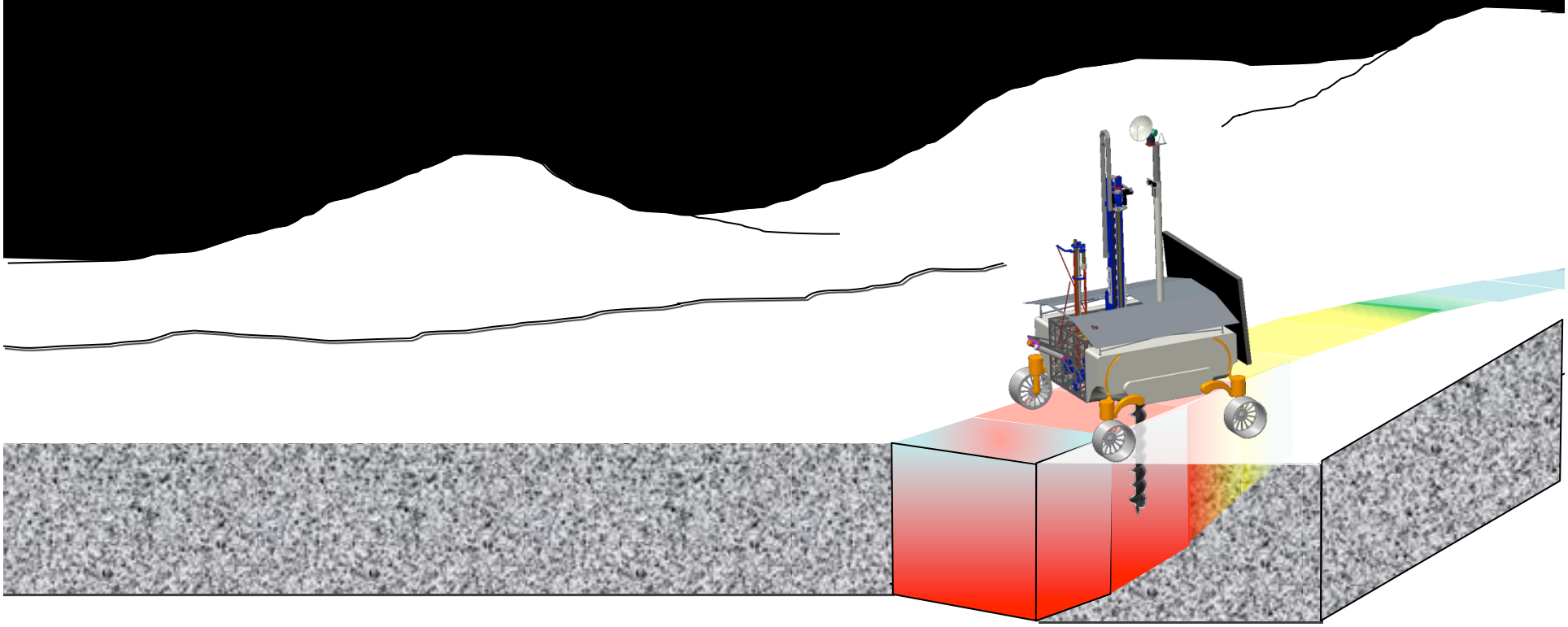
Prospecting…

1. While roving, prospecting instruments search for enhanced surface H20/OH and volumetric hydrogen
2. **When enhancements are found decision made to either auger or core (sample)**



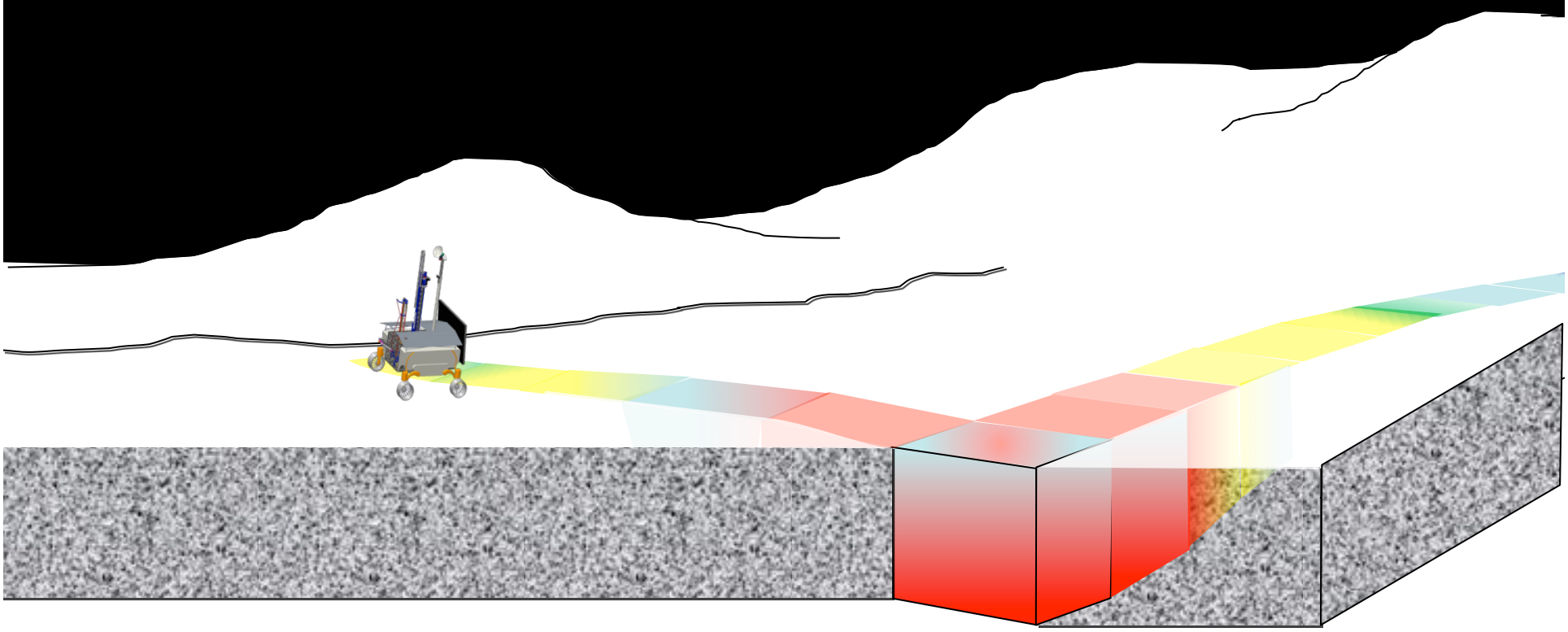
Excavating…

1. While roving, prospecting instruments search for enhanced surface H20/OH and volumetric hydrogen
2. When enhancements are found decision made to either auger or core (sample)
3. **Samples are processed and evolved volatiles measured**



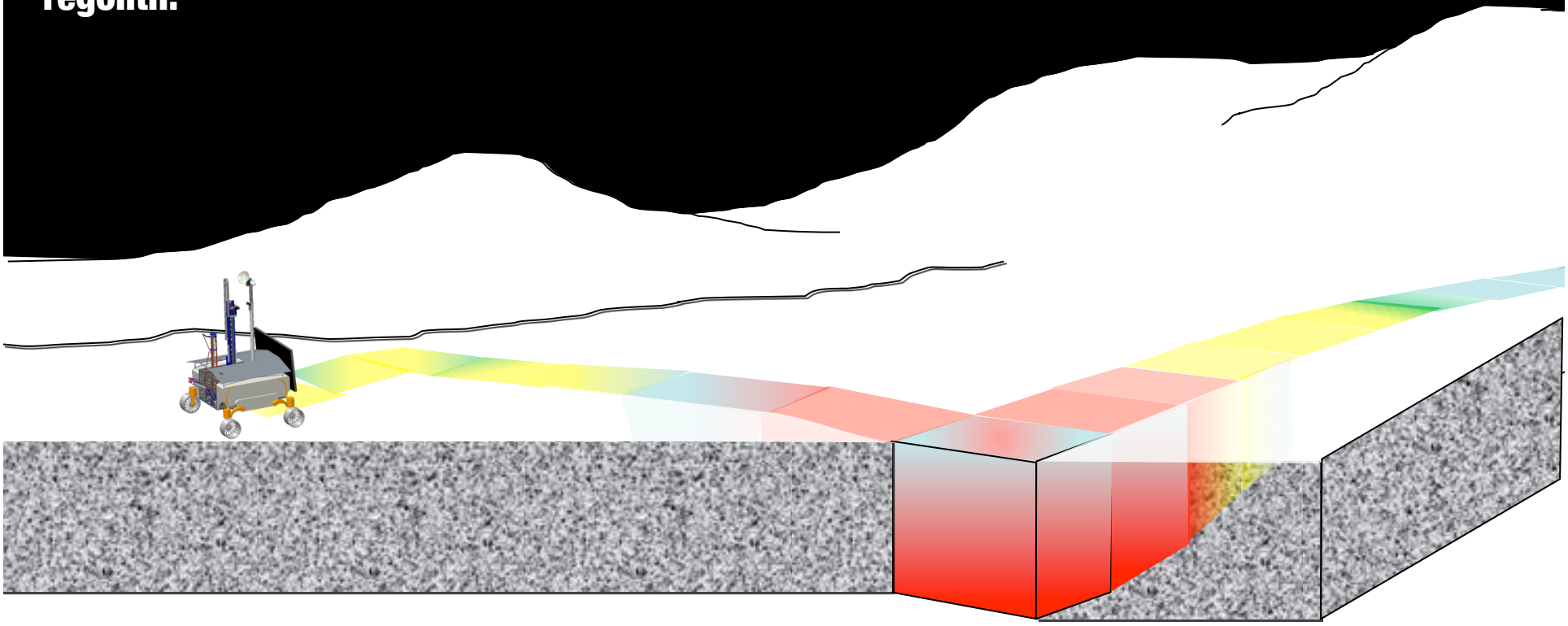
Mapping…

Mapping of volatiles and samples continue across a variety environments, testing theories of emplacement and retention, and constraining economics of extraction.



Demonstrating…

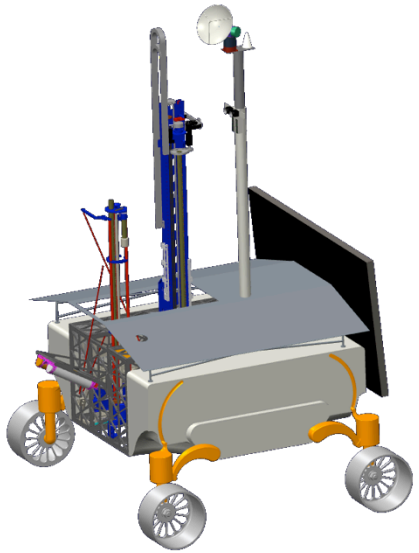
Concluding the primary mission, oxygen extraction from regolith with be demonstrated using hydrogen reduction, thus testing both possible ISRU pathways: local volatiles and water production from "dry" regolith.



Resource Prospector – The Tool Box

Mobility

Rover
- Mobility system
- Cameras
- Surface interaction



Prospecting

Neutron Spectrometer System (NSS)
- Water-equivalent hydrogen > 0.5 wt% down to 1 meter depth

NIR Volatiles Spectrometer System (NIRVSS)
- Surface H2O/OH identification
- Near-subsurface sample characterization
- Drill site imaging
- Drill site temperatures

Sampling

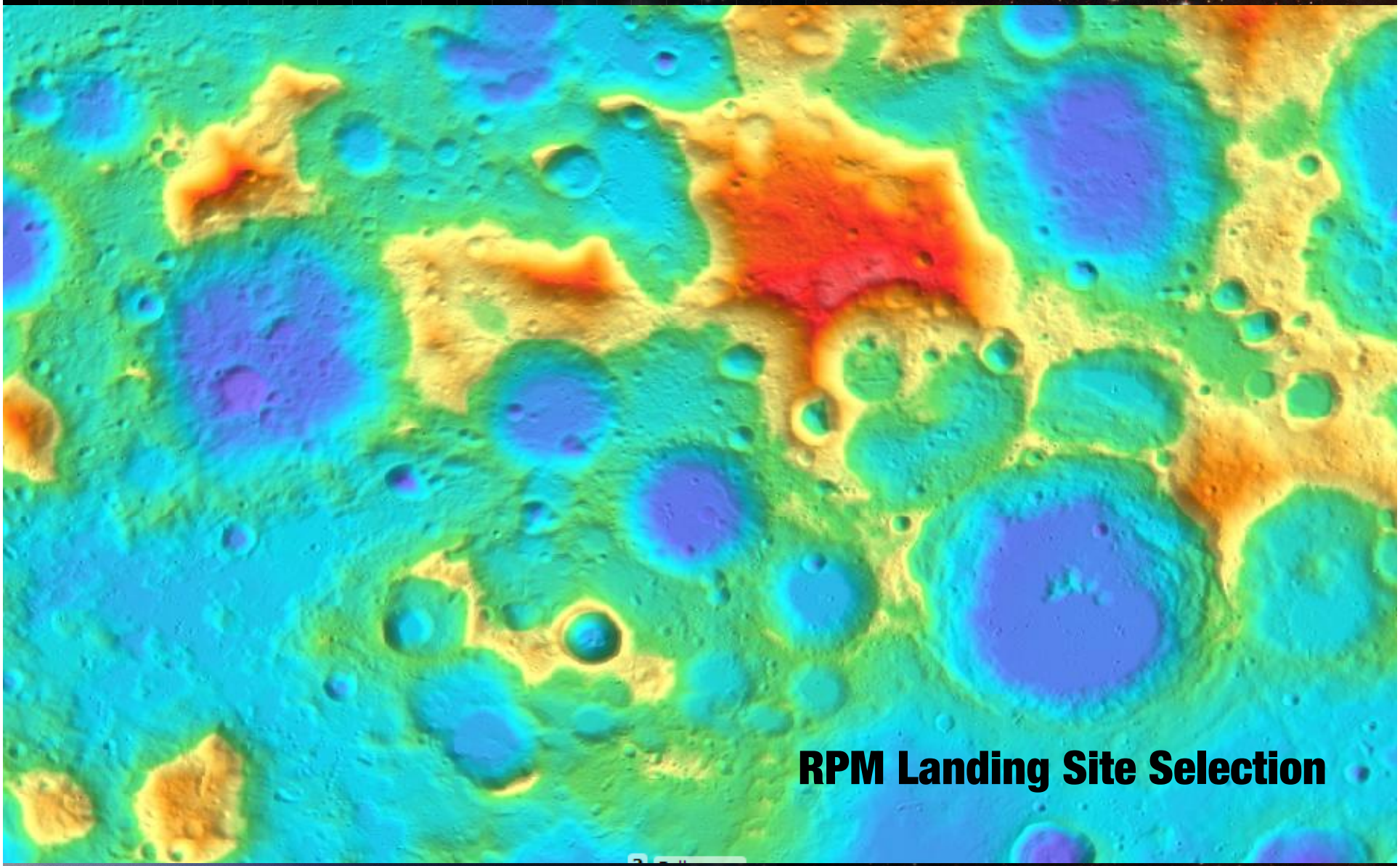
Drill
- Subsurface sample acquisition
- Auger for near-surface assay
- Core for detailed subsurface assay

Processing & Analysis

Oxygen & Volatile Extraction Node (OVEN)
- Volatile Content/Oxygen Extraction by warming
- Total sample mass

Lunar Advanced Volatile Analysis (LAVA)
- Analytical volatile identification and quantification in delivered sample with GC/MS
- Measure water content of regolith at 0.5% (weight) or greater
- Characterize volatiles of interest below 70 AMU

RPM Landing Site Selection



RPM Landing Site Selection

A good bit of the landing site requirements are driven by L1.1:

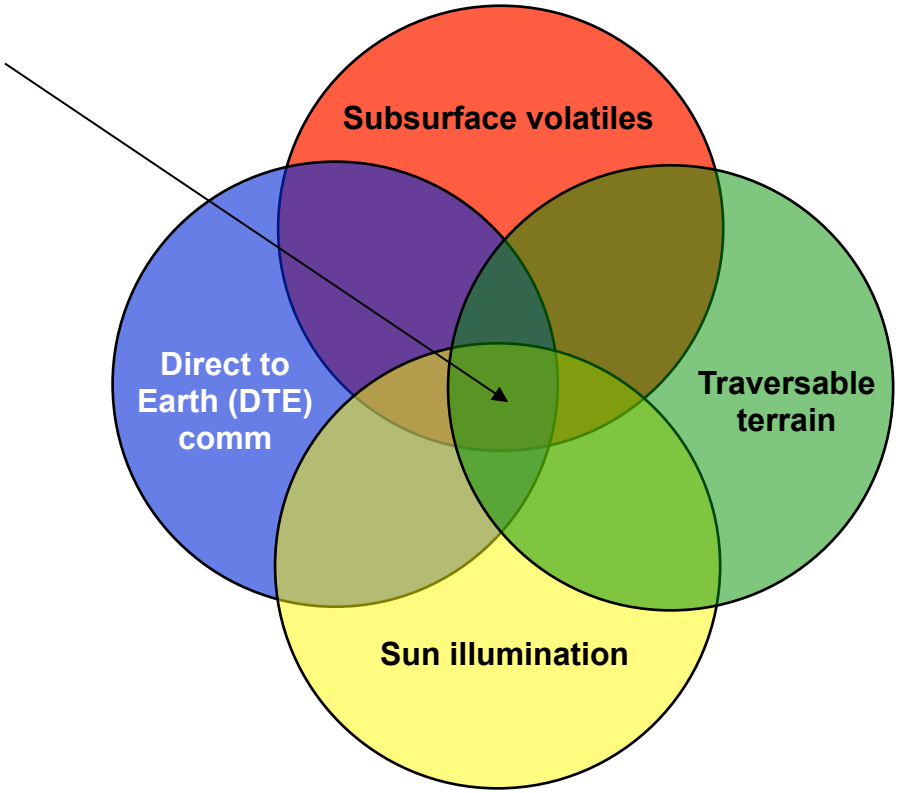
1.1 RESOLVE SHALL LAND AT A LUNAR POLAR REGION TO ENABLE PROSPECTING FOR VOLATILES

Full Success Criteria: Land at a polar location that maximizes the combined potential for obtaining a high volatile (hydrogen) concentration signature and mission duration within traverse capabilities

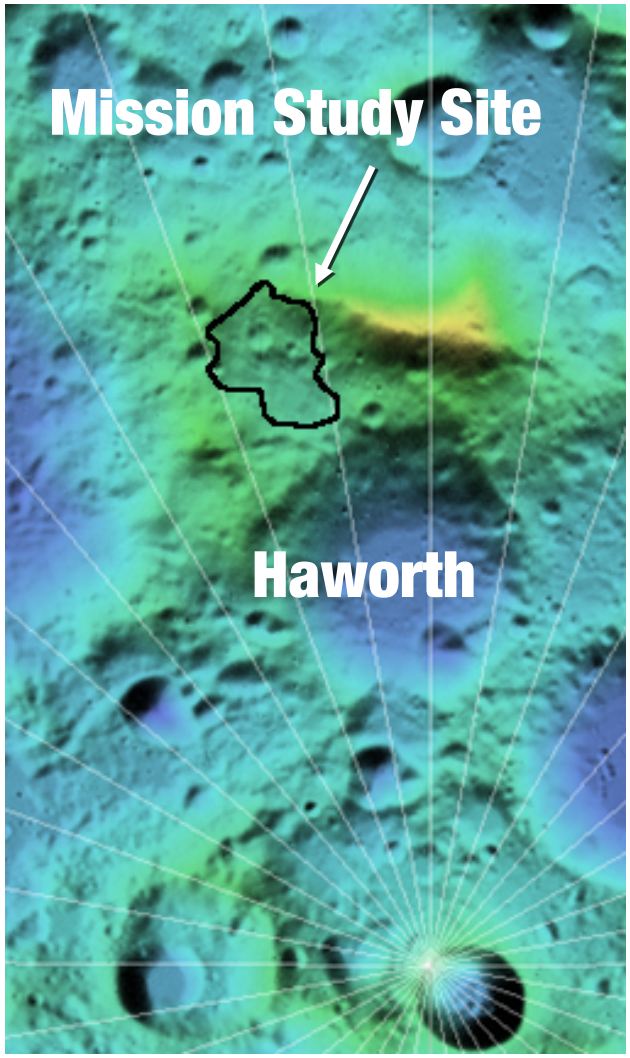
RPM Landing Site Selection

Polar landing site based on meeting the following four criteria

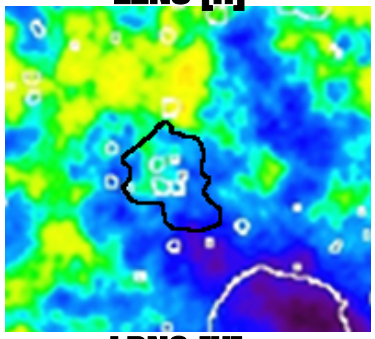
1. Surface/Subsurface Volatiles
   - High hydrogen content (LRO LEND instrument)
   - Constant <100 K temperatures 10 cm below surface (LRO Diviner instrument)
   - Surface OH/H_2O (M^3, LRO LAMP & Diviner)
2. Reasonable terrain for traverse
3. Direct view to Earth for communication
4. Sunlight for duration of mission for power



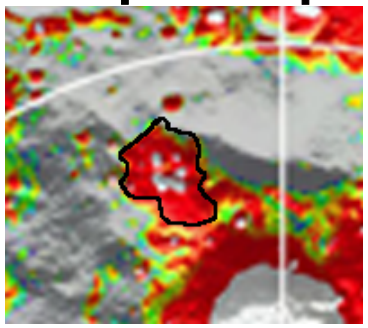
Site Selection – North Haworth Study Site



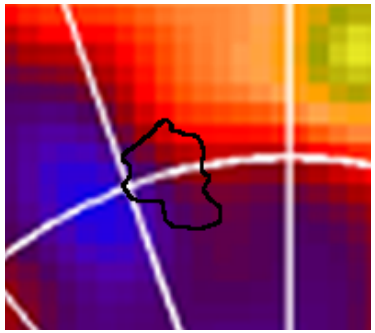
LENS [H]



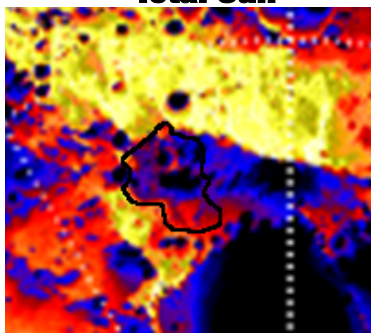
Frost Temperature Depth



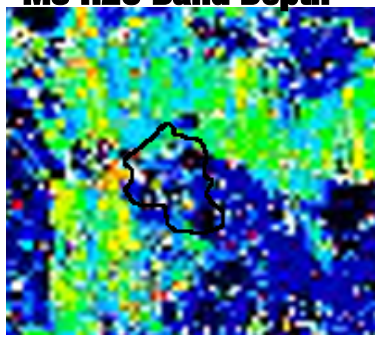
LPNS [H]



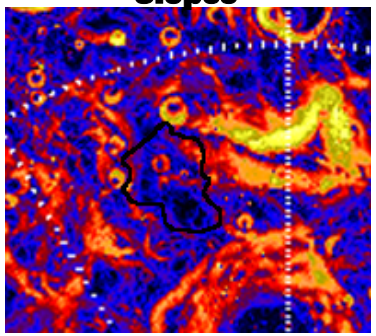
Total Sun



M3 H20 Band Depth

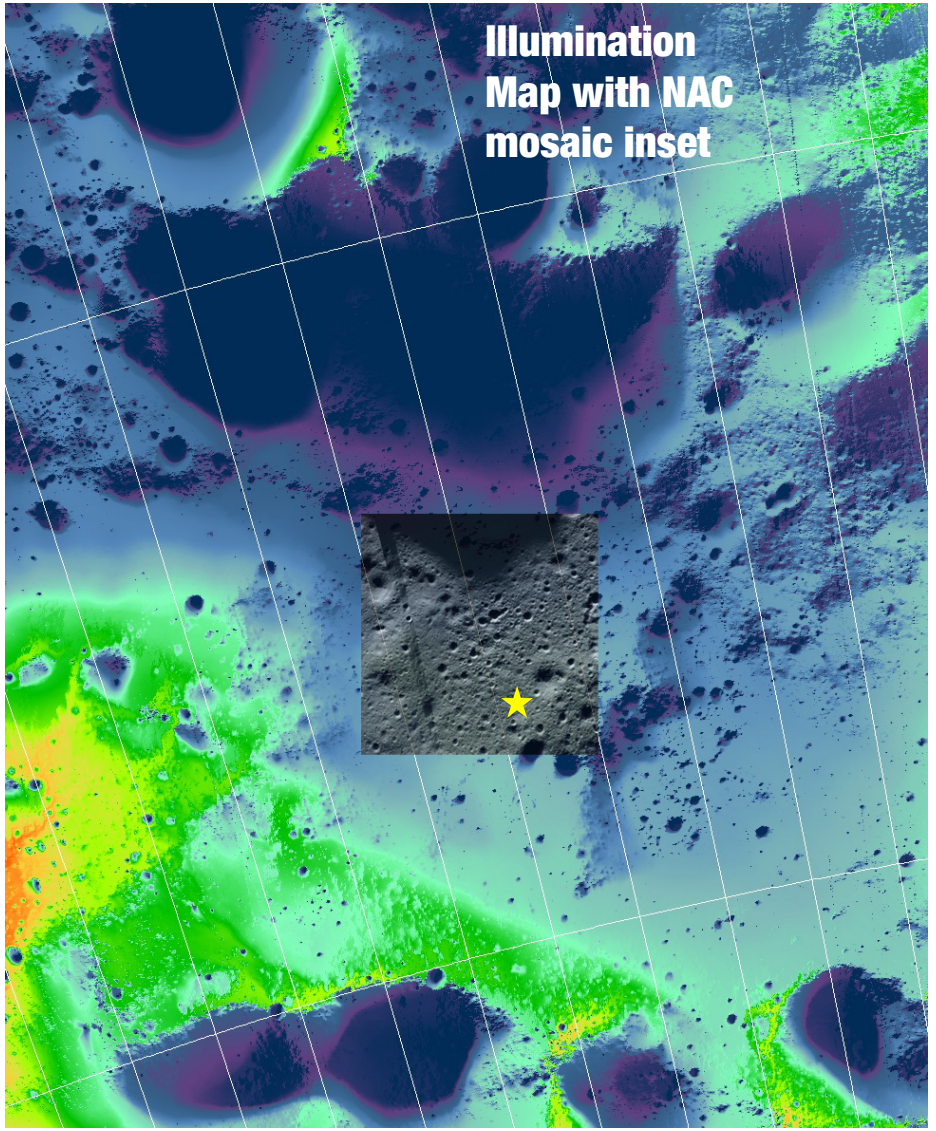


Slopes

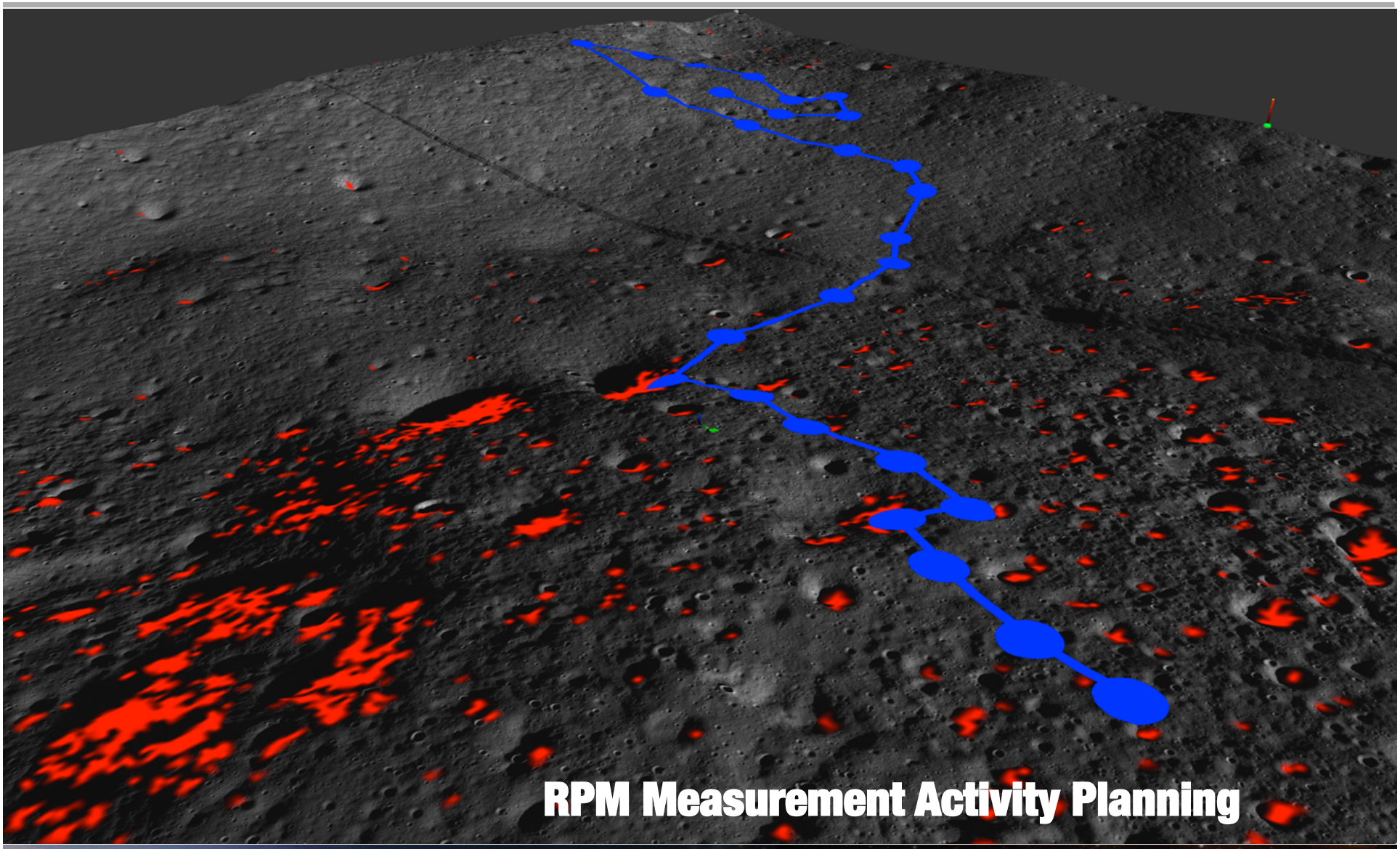


Site Analysis Summary

- **Have considered several sites in detail**
  - **SP and NP**
- **Considered all criteria to the limits of existing data and data products**
  - **All meet RPM requirements**
  - **Preliminary hazard analysis for landing completed**
- **Have provided coordinates to LRO LROC Team to capture additional stereo image pairs**
  - **NAC stereo DEMs resolution down to ~5 meters**
  - **Additional site identification continues**
- **Will conduct site selection workshop to engage community**



RPM Measurement Activity Planning



Measurement Activity Planning

Current travers plans are meant to:

- **Validate the mission concept**
- **Identify areas in which additional stereo NAC imaging would be helpful**
- **Provide input to Mission systems for planning and design**

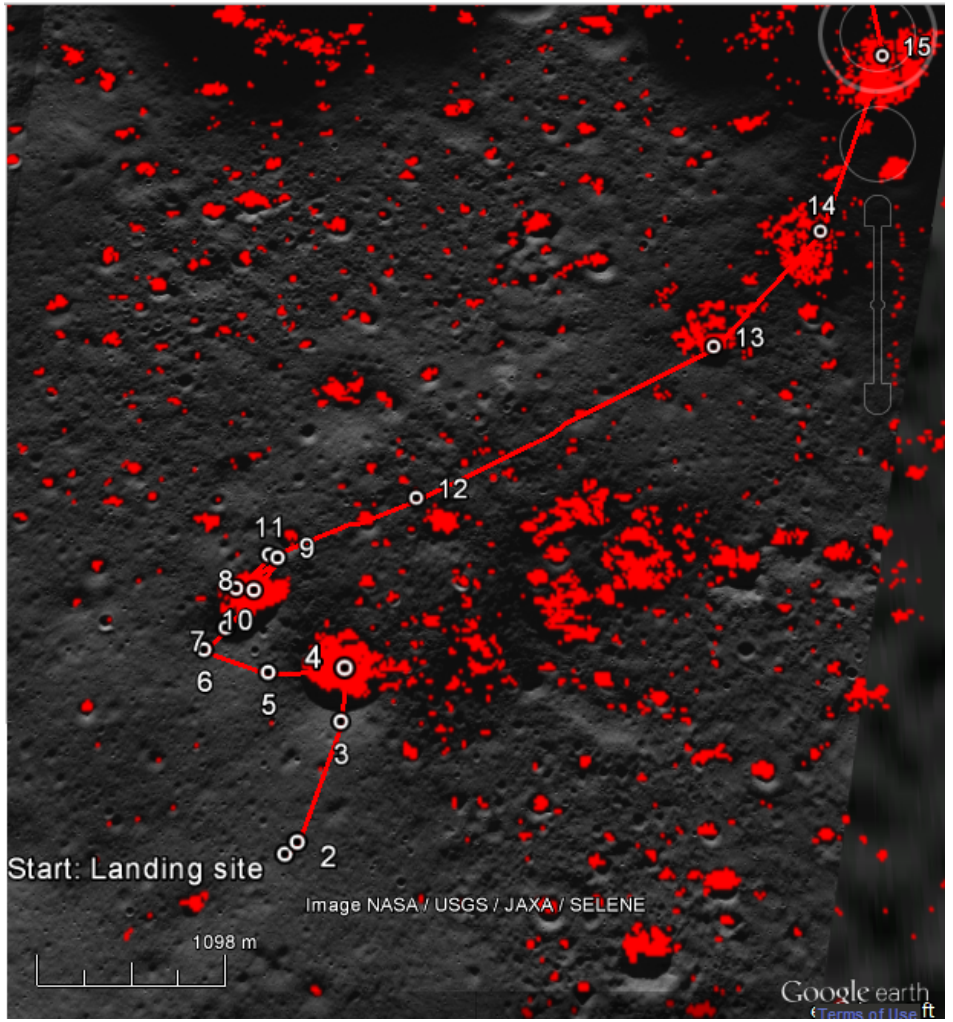
Measurement Team planning study traverse against requirements
Meet mission measurement goals

Activities fed to CONOPS team for mission profiling

- **Time, data, power, communication**

Red areas PSRs (McGovern & Bussey)
Overlaid on LRO LROC NAC

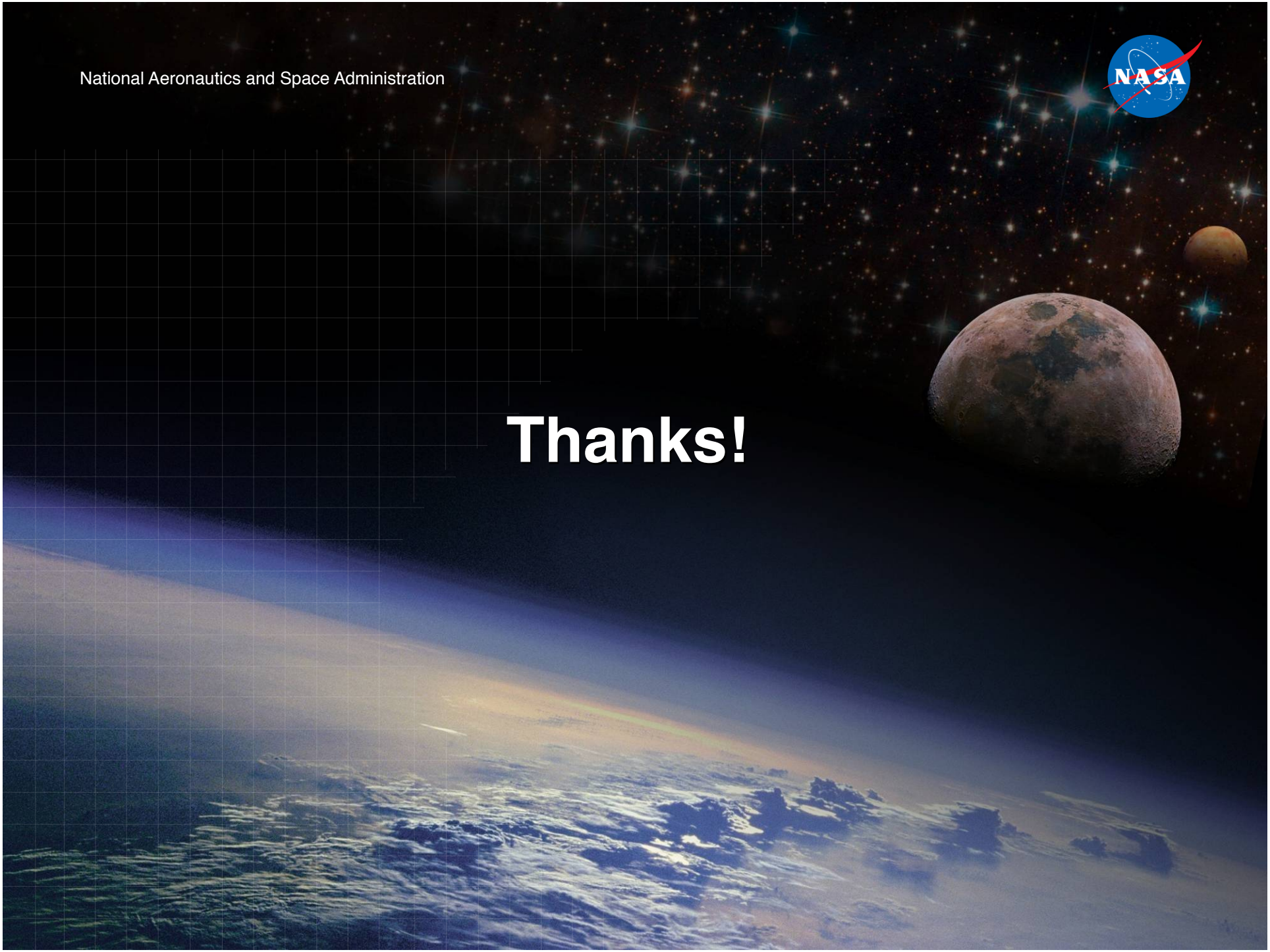
Traverse at Landing Study Site in NW of Haworth (using xGDS)



Summary

- RP will address a multitude of HEOMD SKGs
- Has a robust payload
- A landing site selection process has been developed and a number of sites shown to meet mission requirements
- Mission traverse planning, tools and process, have been developed and show mission goals can be met
- Will build on current community interactions to maximize value

National Aeronautics and Space Administration



Thanks!