National Aeronautics and Space Administration

Resource Prospector:

Goals and Measurements

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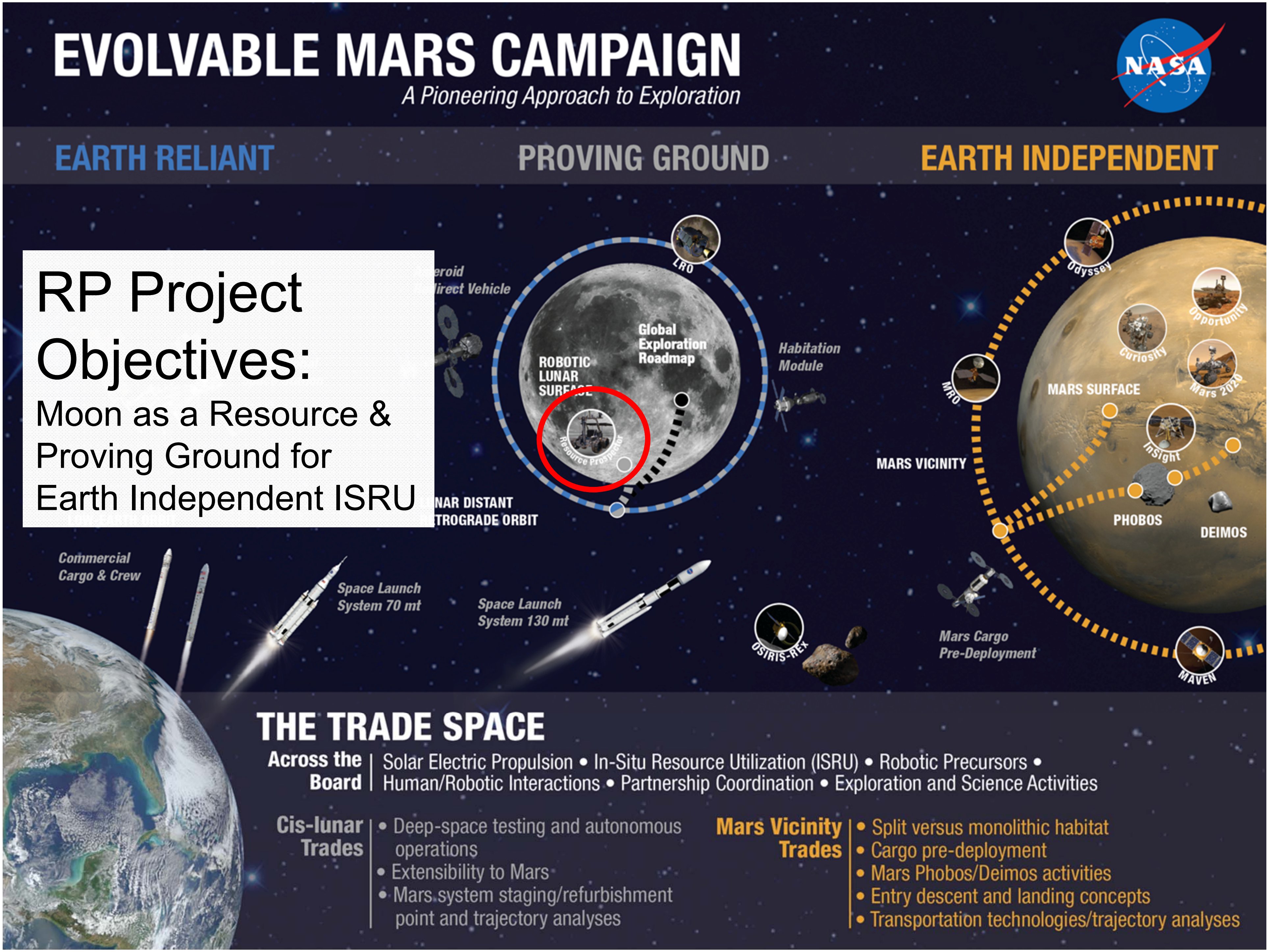
RP Project Objectives:

Moon as a Resource & Proving Ground for Earth Independent ISRU



RP Mission Goals and Relevance

From *LEAG Robotic Campaign Analysis (2011):*

Phase I: Lunar Resource Prospecting

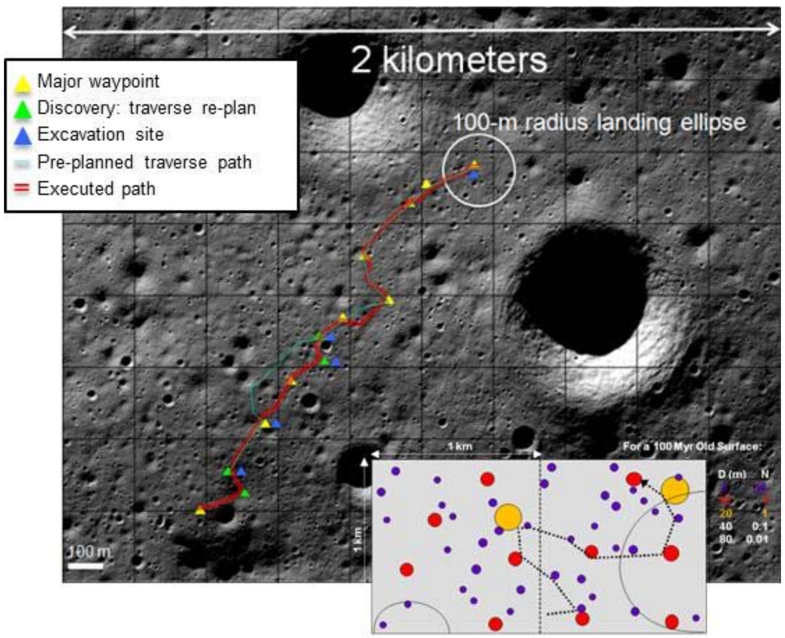
- Defining the composition, form, and extent of the resource;
- Characterizing the environment in which the resources are found;
- Defining the accessibility/extractability of the resources;
- Quantifying the geotechnical properties of the lunar regolith in the areas where resources are found;
- Being 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

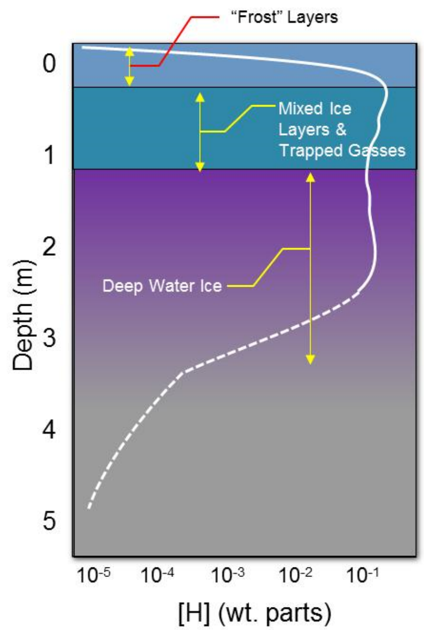
Determining 'Operationally Useful' Deposits

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

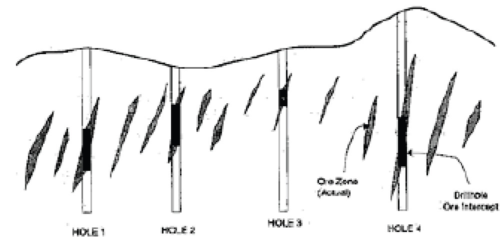
Need to Evaluate Local Region (1 to 3 km)



Need to Determine Vertical Profile



Need to Determine Distribution



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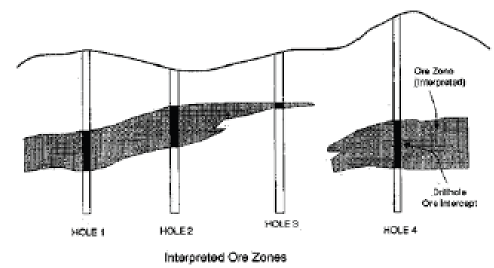


An 'Operationally Useful' Resource Depends on What is needed, How much is needed, and How often it is needed

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 Level 1 Requirements

1.1 RESOURCE PROSPECTOR 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 RESOURCE PROSPECTOR 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

Paraphrased Level 2 Measurement Requirements

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

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

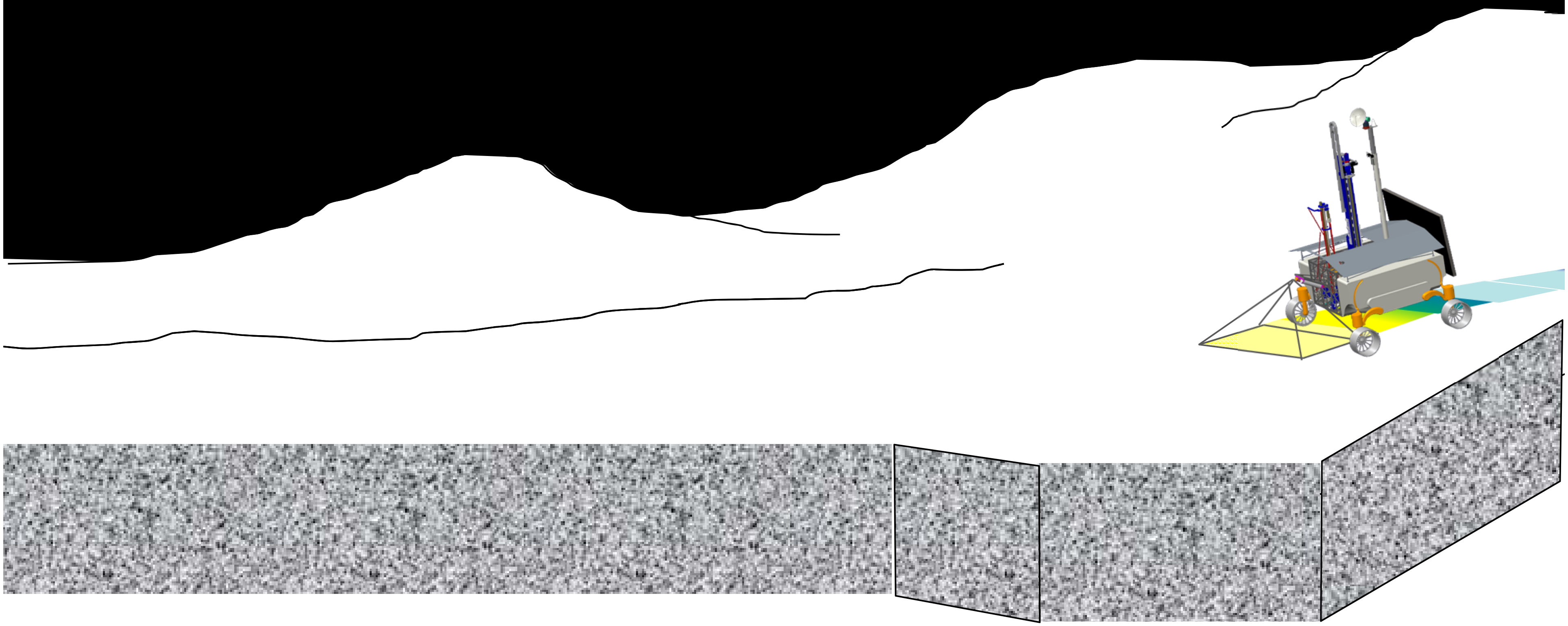
Stretch Goals (shoulds):
- Make subsurface measurements in at least eight (8) locations across 1000 m (point-to-point) distance
- Process and analyze subsurface material in at least four (4) locations across 1000 m (point-to-point) distance
- Provide geologic and thermal context

SKGs and RP – Address at Least 22 Lunar SKGs

Lunar Exploration Strategic Knowledge Gaps			Instrument or Activity	RP Relevance
I. Understand the Lunar Resource Potential				
	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 LM-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-LAVA, 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	
	F-4	Power Generation - Polar missions	Rover	M

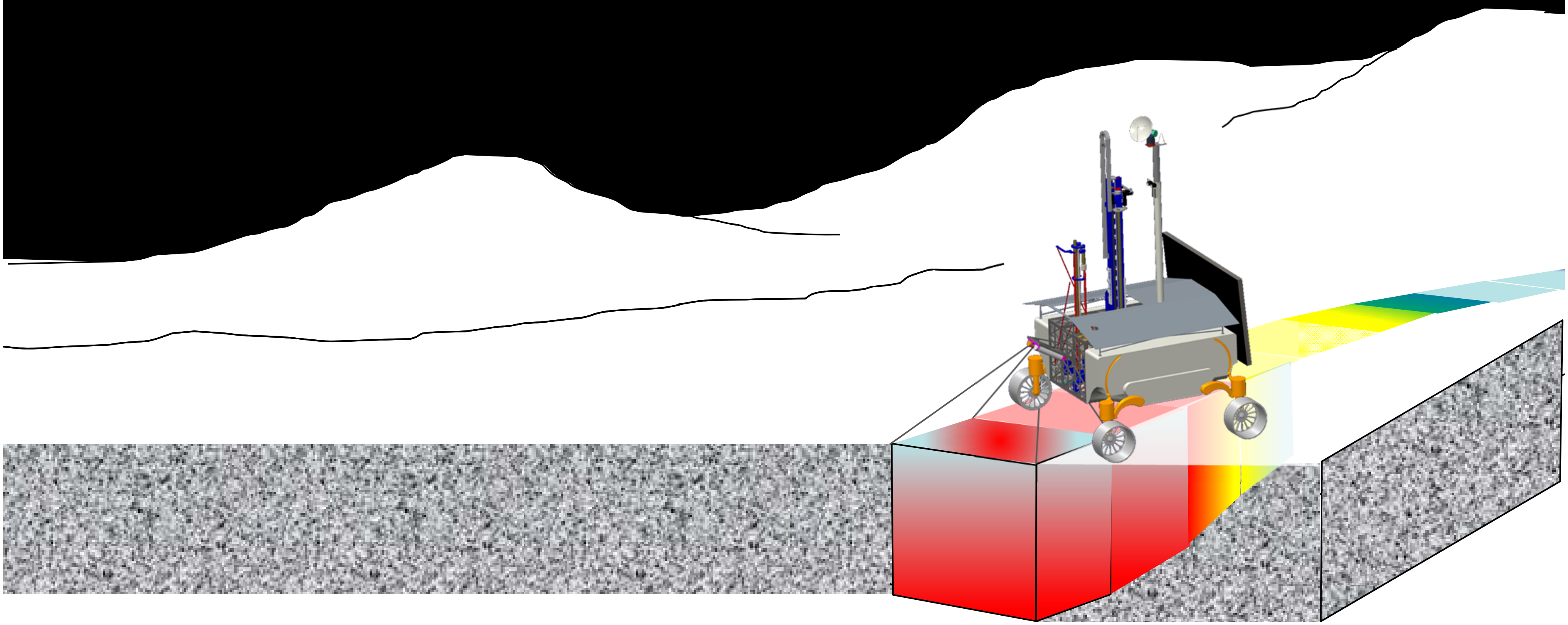
Prospecting…

1. While roving, prospecting instruments search for enhanced surface H2O/OH, other volatiles and volumetric hydrogen



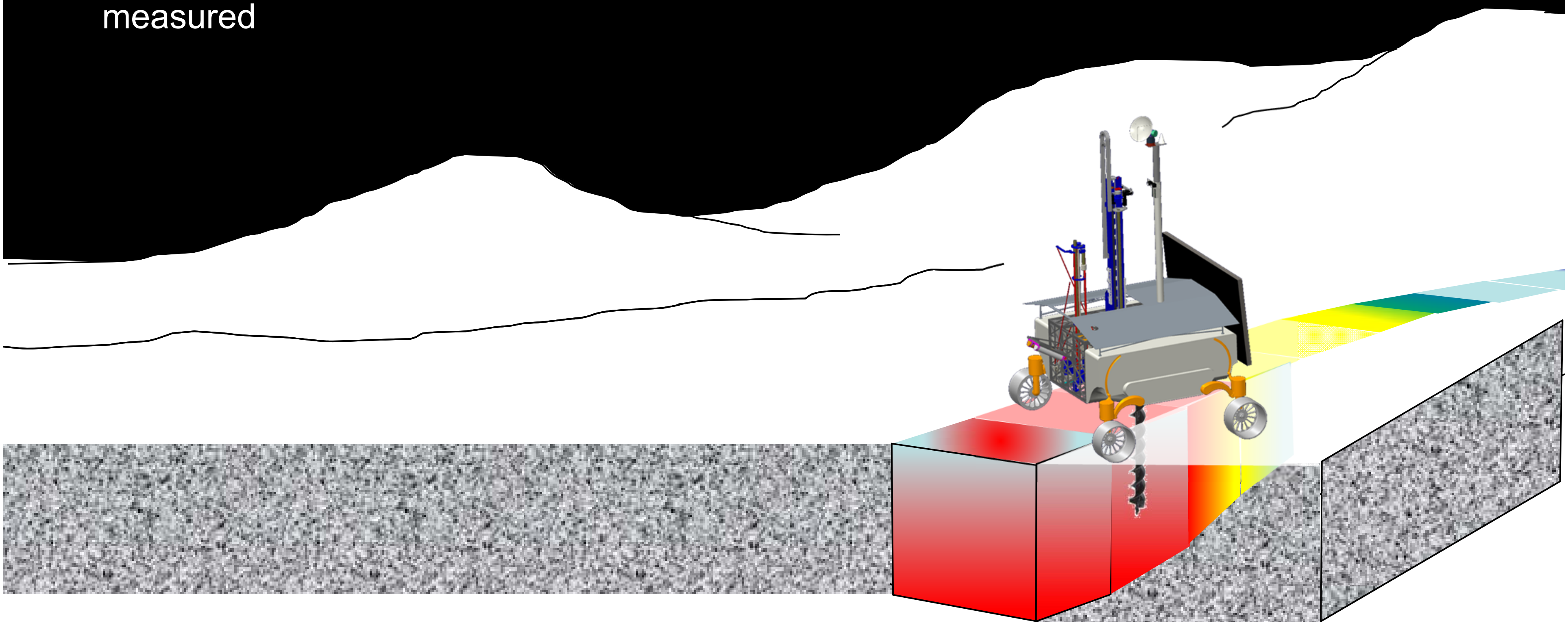
Prospecting…

1. While roving, prospecting instruments search for enhanced surface H2O/OH and volumetric hydrogen
2. When enhancements are found decision made to either auger or core (sample)



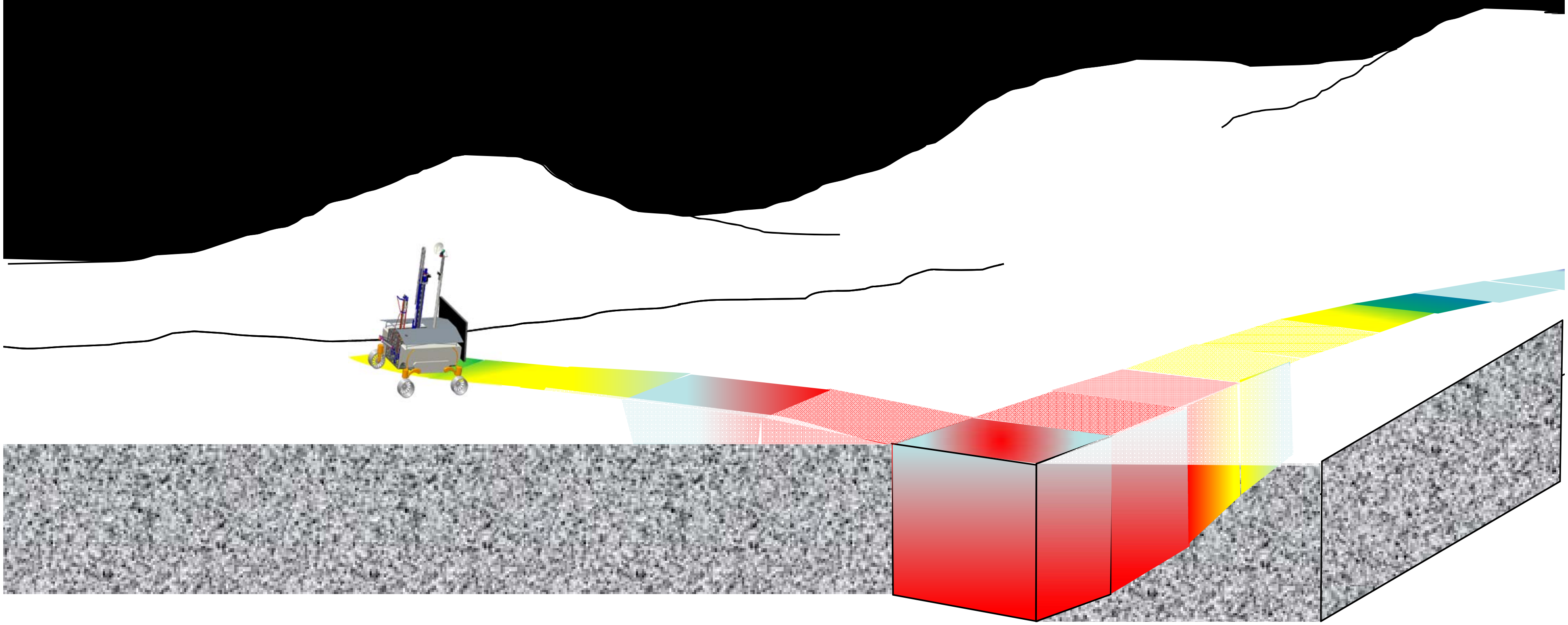
Excavating…

1. While roving, prospecting instruments search for enhanced surface H2O/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.



Resource Prospector – The Tool Box

The Rover

- **300 kg class rover**
  - **Solar powered, DTE comm**
  - **Mobility system**
- **Active suspension**
- **All-Wheel Steering & All-Wheel Drive**
- **Cameras**
  - **Navigation & Hazard**
  - **Hazard Detection / "Virtual Bumper"**
- **Nominal speed is 10 cm/s (Prospecting) with sprint speeds of 50 cm/s**

RP15 Rover – NASA Edge

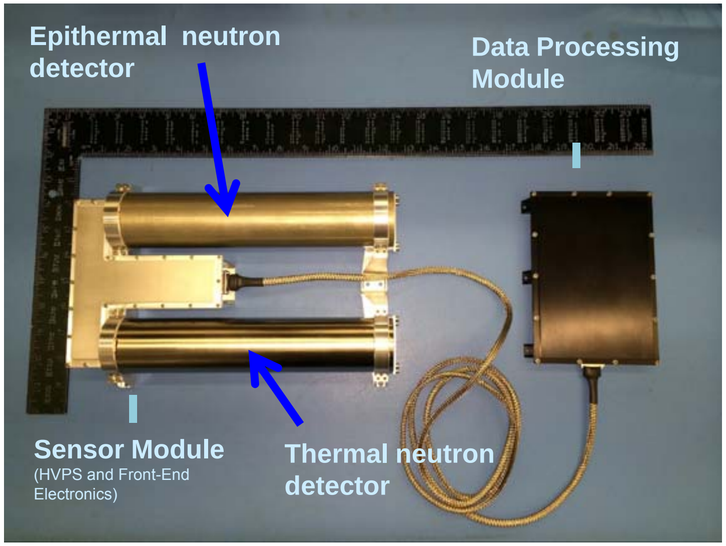
Resource Prospector – The Tool Box

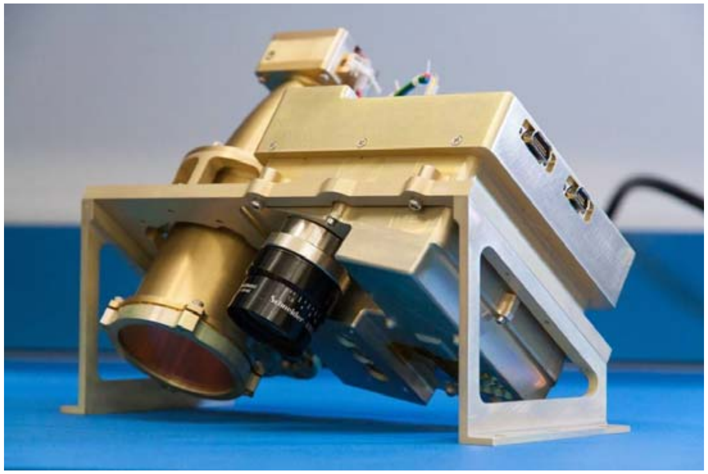
Neutron Spectrometer System (NSS)

- Water-equivalent hydrogen > 0.5 wt% down to 1 meter depth with 2 m spatial sampling

NIR Volatiles Spectrometer System (NIRVSS)

- Surface H2O/OH identification (1.6-3.4 μm)
- Subsurface sample characterization (with drill)
- Multi-color imaging of drill cuttings/surface (eight colors between 0.4-1.1 μm)
- Scene thermal radiometry (8, 10, 12 & 25 μm)

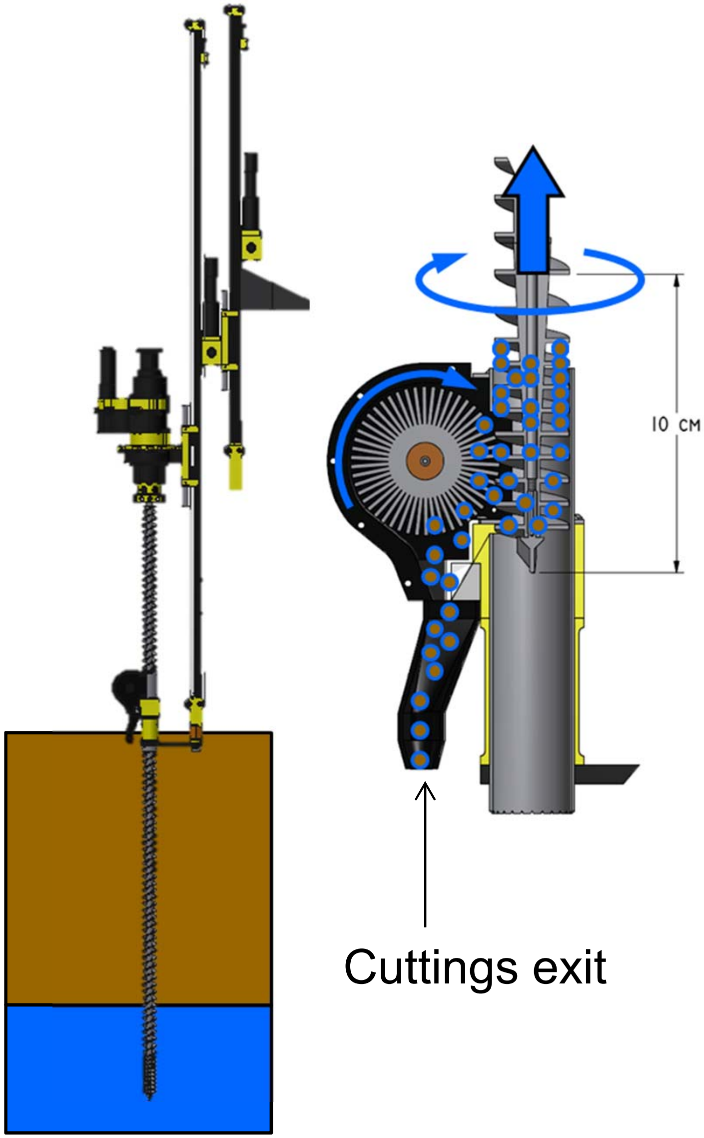




Resource Prospector – The Tool Box

Drill

- Subsurface sample acquisition down to 1 meter in 0.1 m "bites"
- Auger for fast subsurface assay with NIRVSS
- Sample transfer to OVEN for detailed subsurface assay



Resource Prospector – The Tool Box

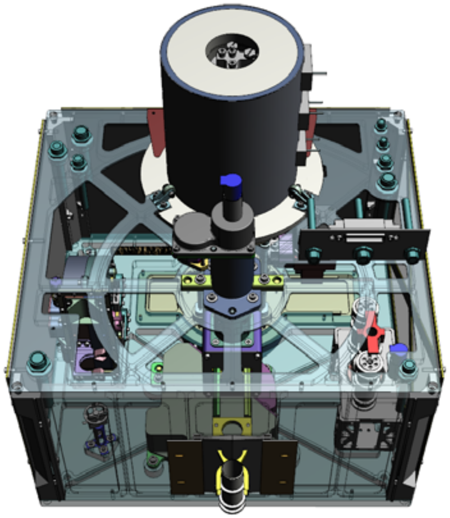
Processing & Analysis

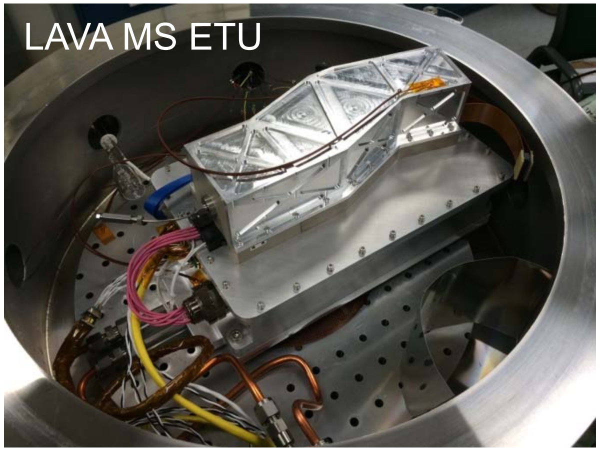
Oxygen & Volatile Extraction Node (OVEN)

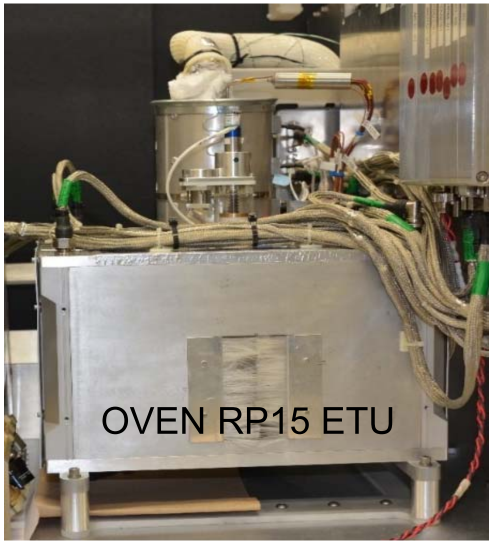
- Volatile Content/Oxygen Extraction by step-wise sample heating (150 to 450C)
- Total sample volume & mass

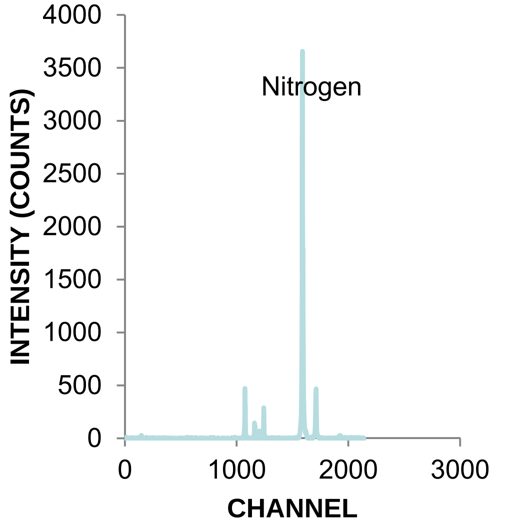
Lunar Advanced Volatile Analysis (LAVA)

- 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









Mass spectrum of air *measured using TRL5 mass spectrometer system.*

RP Landing Site Selection

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

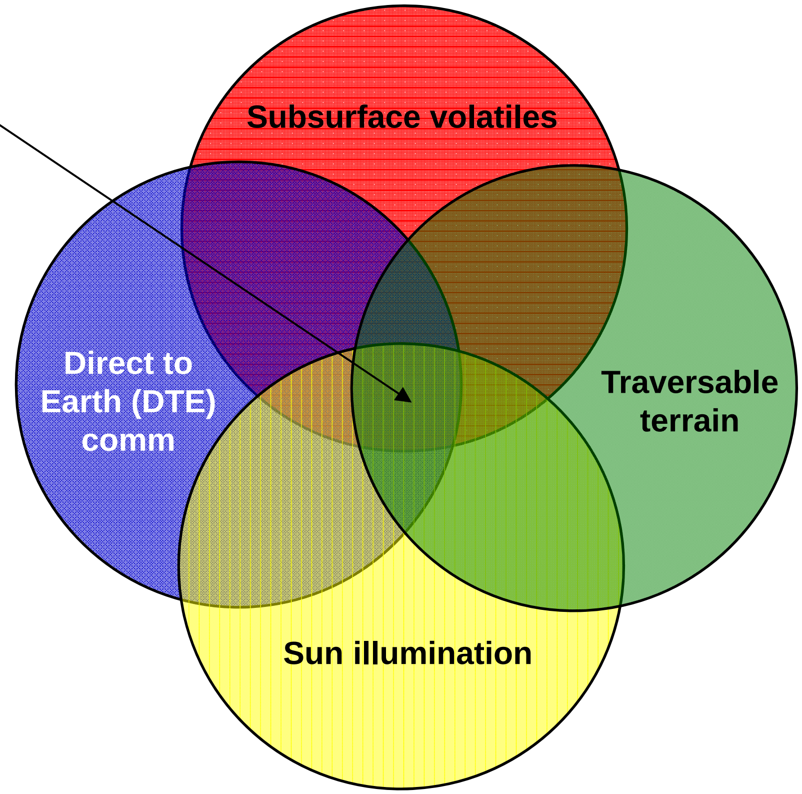
1.1 RESOURCE PROSPECTOR SHALL LAND AT A LUNAR POLAR REGION TO ENABLE PROSPECTING FOR VOLATILES

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**

RP Landing Site Selection

Polar landing site based on meeting the following four criteria

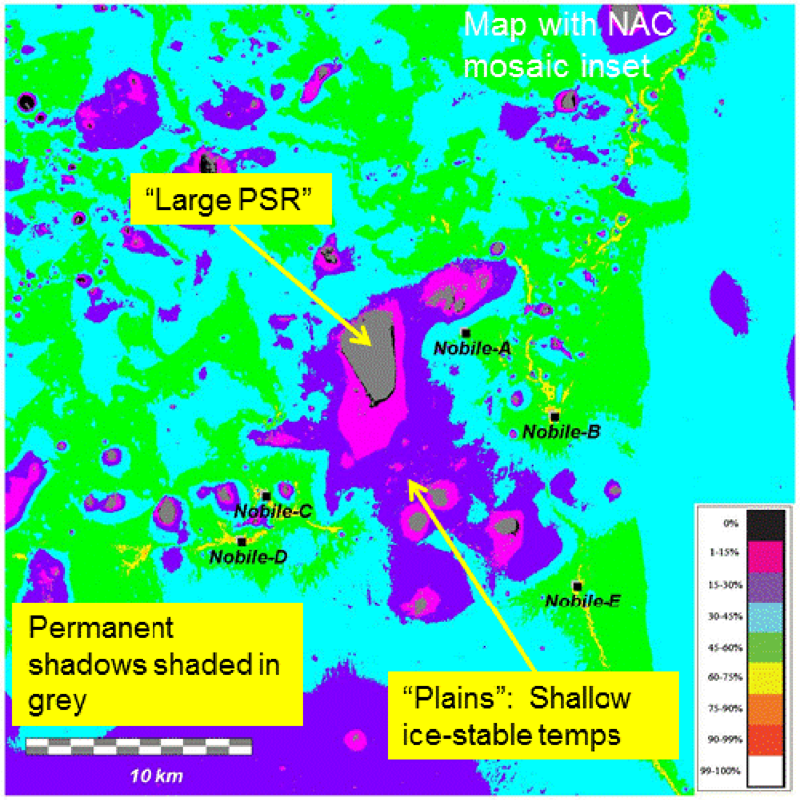
1. Surface/Subsurface Volatiles
   - High hydrogen content (LRO LEND instrument)
   - Constant <100 K temperatures 10 cm below surface (LRO Diviner instrument)
   - Surface OH/H_2O (M^3, LRO LAMP & Diviner)
2. Reasonable terrain for traverse
3. Direct view to Earth for communication
4. Sunlight for duration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



Site Analysis

- 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
- Working with UCM and APL on long-duration traverse planning
  - Utilizes corridors of connected sun and DET comm
  - From persistently-lit region traverses of 10s of kilometers, over several weeks may be possible

North Nobile Study Site



Summary

- RP will address a multitude of HEOMD SKGs with a robust payload
- A landing site selection process has been developed and a number of sites shown to meet mission requirements (looking toward a site analysis workshop next summer)
- Mission operations and traverse planning and process, have been developed and show mission goals can be met within power, time, etc.
- In FY15, RP is developing (building) a rover prototype with Payload to demonstrate the fundamental aspects of the mission

National Aeronautics and Space Administration

Extensibility to Mars and Small Bodies

SKG		Gap-Filling Activity	RP* Relevance / Feed-forward
Mars			
B4	Dust Effects on Surface Systems	B4-2. Dust physical, chemical and electrical properties	
		B4-3. Regolith physical properties and structure	
D1	Water Resources	D1-2. Water ISRU demo	
		D1-3. Hydrated mineral compositions	
		D1-4. Hydrated mineral occurrences	
		D1-5. Shallow water ice composition and properties	
		D1-6. Shallow water ice occurrences	
Small Bodies (NEAs, Phobos & Deimos)			
II. Understand how to work on or interact with the SB surface.	B. Hazards to equipment and mitigation	II-B-1. Mechanical/electrical effects of SB surface particles.	
	C. SB surface mechanical properties	II-C-2. Geotechnical properties of SB surface materials.	
IV. Understand the SB resource potential.	A. NEO resources	IV-A-4. Prepositioning and caching extracted resources.	
		IV-A-2. Knowledge of how to excavate/collect NEO material to be processed.	
	B. Phobos/Deimos resources	IV-B-1. Phobos/Deimos subsurface resource potential.	
		IV-B-2. Knowledge of how to access resource material at depth	

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