National Aeronautics and Space Administration

Overview of the Resource Prospector (RP) mission

Terry Fong

NASA Ames Research Center

Origins of Lunar Volatiles

Clementine (1994):
Bi-static radar tests with Arecibo could indicate water-ice in permanently shadowed craters

Lunar Prospector (1998):
Permanently-shadowed polar craters contain elevated Hydrogen levels

"Could that Hydrogen be trapped as water-ice?"

LCROSS (2009): *There is water-ice and other volatiles in the permanently-shadowed regions*

"How are the volatiles distributed and can we make use of them?"

RP (2019): *"Go down and prospect/ map the water-ice. Try an ISRU experiment to make water from the soil…".*

LCROSS not only confirmed presence of water-ice in a permanently-shadowed region, but showed there was enough to be economically viable.

RP will provide water-ice distribution on human-scales [m-km], and will explore if areas of *temporary sunlight* might also retain water ice, making water potentially much more accessible.

Mission Relevance


Chapter 3. A Long-Range Human Exploration Strategy

Use of Local Resources

Maintaining human presence beyond low-Earth orbit would

As much as 50 percent of near-Earth objects are thought to be potential resource targets, containing hydrated minerals and, in the case of dormant comets (e.g., P/Wilson-Harrington), subsurface reservoirs of water ice. Whether these volatiles can be used in a cost-effective manner is unclear. Because small bodies like asteroids and comets do not have significant gravity fields, the ISS may be a good location to demonstrate concepts for asteroid resource extraction and processing. A second step would be a small in-situ demonstration on a target remotely identified and characterized by ground-based and space-based telescope assets.

If these initial steps look promising, human missions to the Moon or an asteroid would provide valuable insight, assessment and troubleshooting for the robotic installation of a larger resource recovery and return facility.

While there are differences in the physical, mineral, and chemical forms of the soil on the Moon, asteroids, and on Mars, as well as different types and concentrations of ice and other volatiles, commonalities in technologies and processes can be found to reduce the cost and risk of using local resources. Planned robotic missions to the Moon and asteroids can provide information relevant to potential future Mars resource utilization by contributing information related to prospecting and processing techniques and equipment.

The RESOLVE payload concept shown prospecting for volatiles in a polar region of the Moon.

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*"To gain an understanding of whether lunar volatiles could be used in a cost effective manner, it is necessary to **understand more about the nature and distribution of the volatiles** and whether they could be processed cost effectively. **The first step is robotic prospecting to take measurements on the lunar surface"***

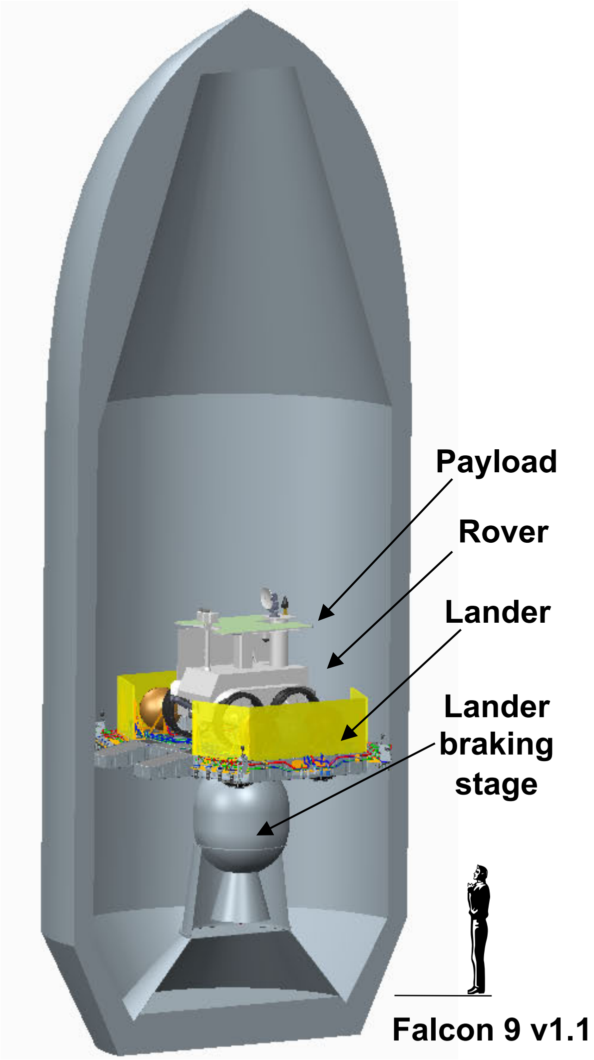
***"Additional information may be needed prior to committing to a processing demonstration mission**, such as a mission rover capable of entering permanently shadowed regions of the lunar poles"*

RP is attempting to accomplish both of these objectives in a single mission …

RP Top-level Objectives

The Resource Prospector (RP) mission is being developed to prospect for volatiles (water ice) in a polar region of the Moon, and demonstrate an In-Situ Resource Utilization (ISRU) capability.

Utilizing lunar resources to produce oxygen and propellants could enable new mission architectures for human exploration.

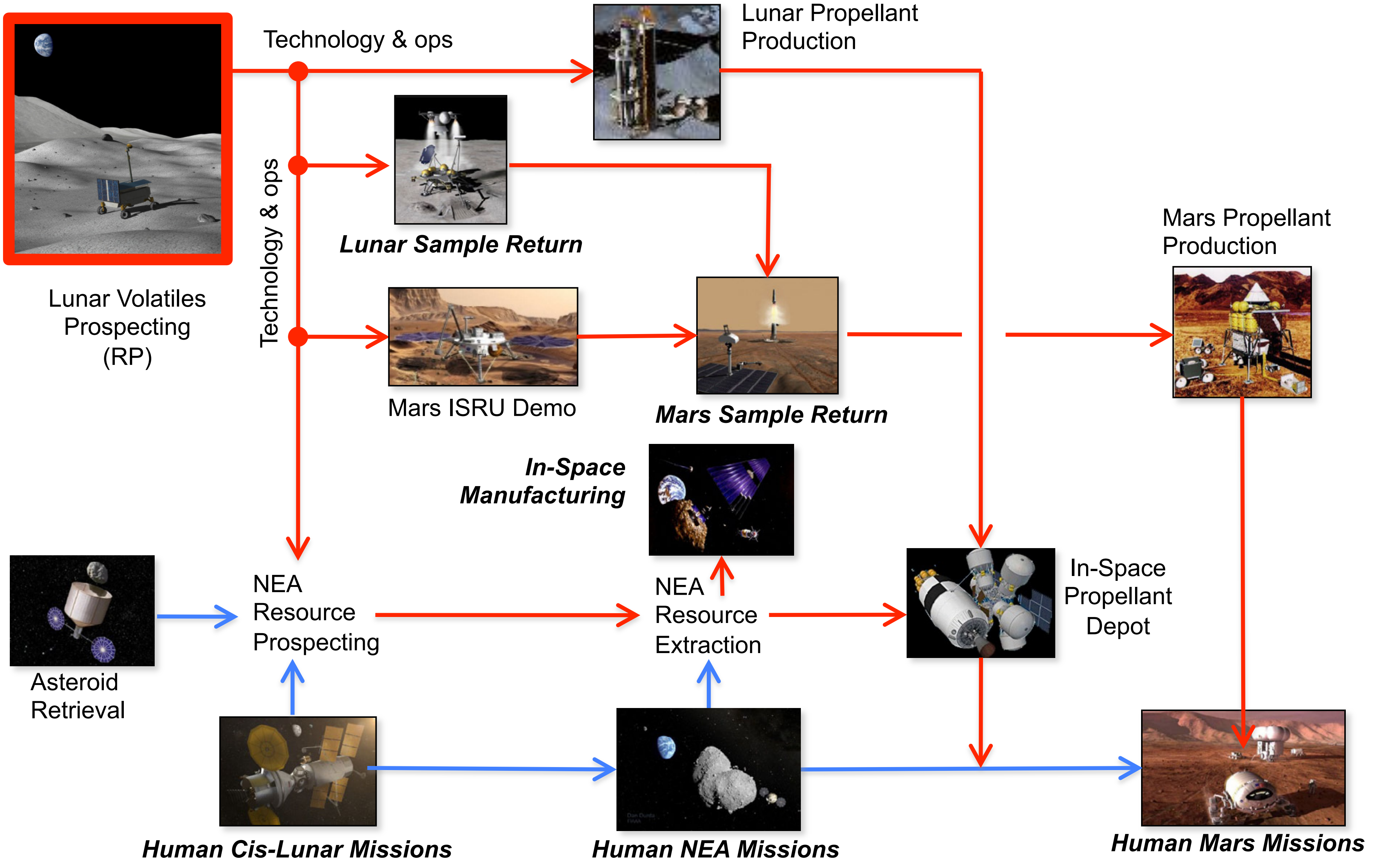


Mission elements include:

- **Lunar lander**
- **Lunar rover**
- **Prospecting, sampling & analysis payload**
- **Launch vehicle**
- **Mission operations**

NASA is working with international and commercial partners to expand the reach of the mission while sharing engineering and scientific results.

Strategic Value of RP



RP Simplified Overview

Get there…

- Launch
- Cruise
- Descent & Landing
- Quick Checkout
- Roll-off Lander
- Quick Checkout
- Begin Surface Ops

Find & Mine Volatiles…

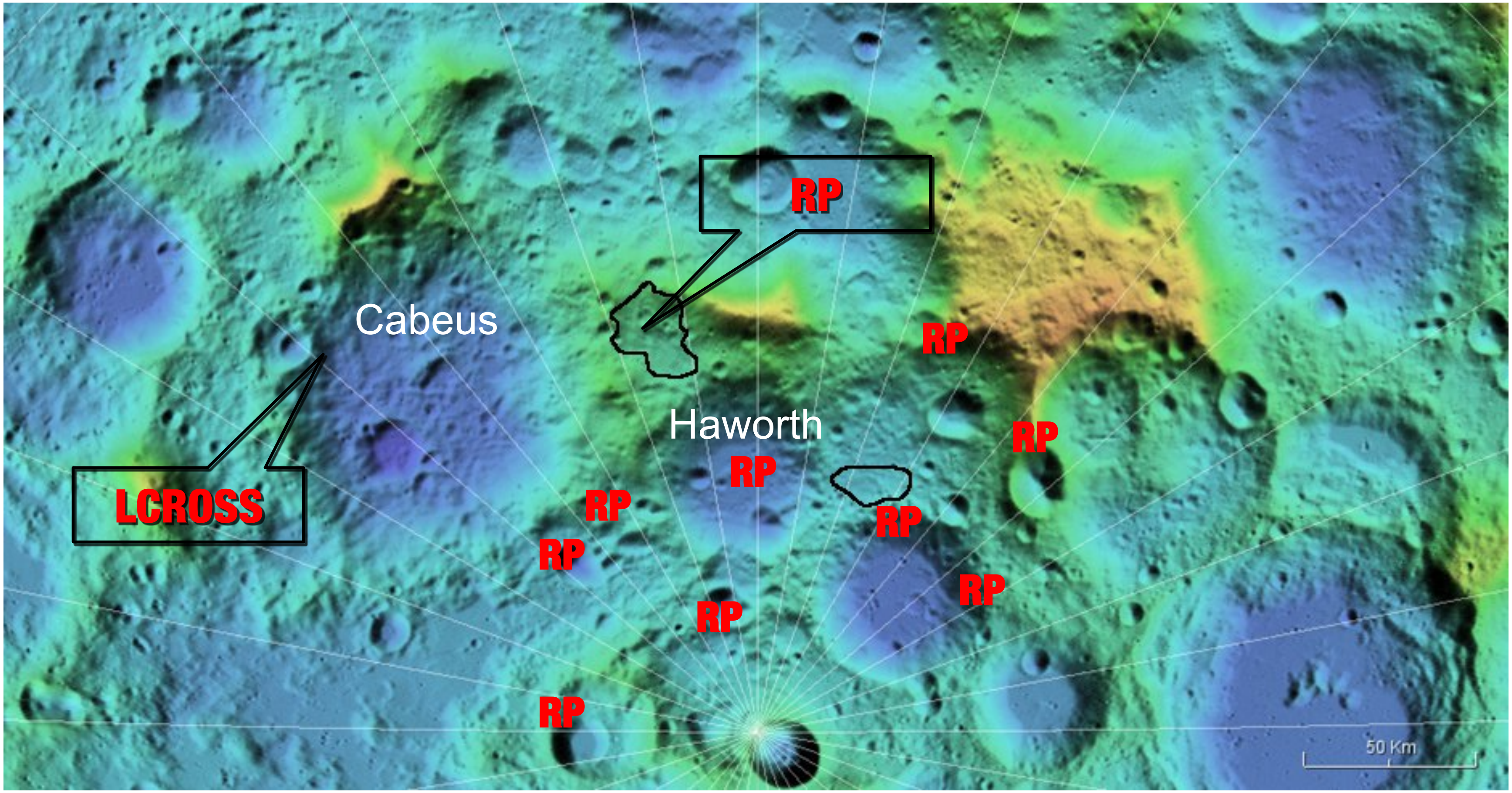
Map surface	Use the Neutron Spec & Near-IR Spec to look for Hydrogen-rich materials
Extract soil	Use the Drill Subsystem to auger down to 1[m]
Heat soil	Heat samples (150degC) in the OVEN Subsystem
Determine Volatiles	Determine type and quantity of volatiles in the LAVA Subsystem, (H_2, He, CO, CO_2, CH_4, H_2O, N_2, NH_3, H_2S, SO_2)

Utilize the volatiles…

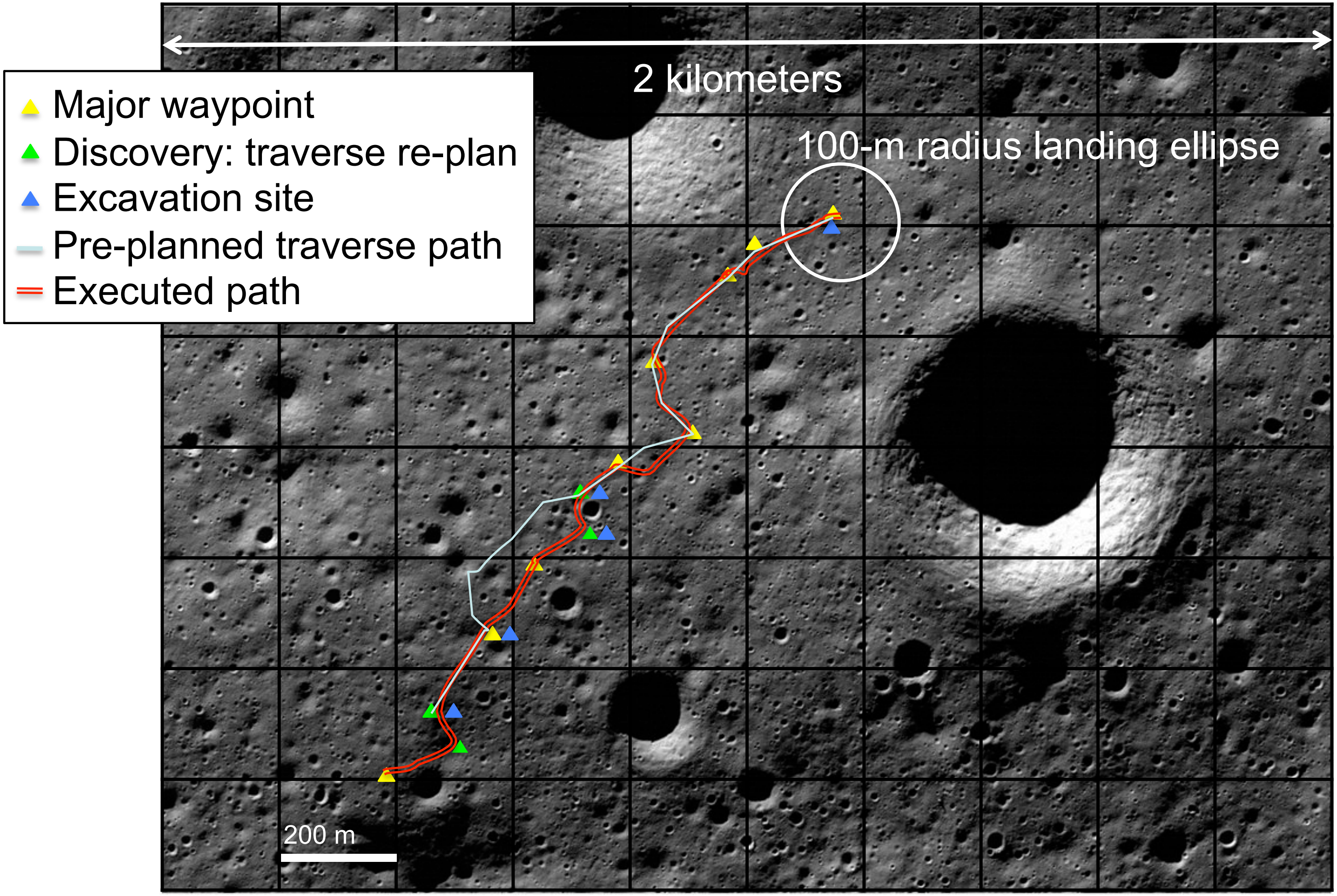
Super-heat soil	Heat sample to reaction temps (150-900degC) using the OVEN Subsystem
Make water	Flow H_2 through the heated soil to capture oxygen and make water using the OVEN Subsystem
Show me the water!	Image and quantify the water created using the LAVA Subsystem

Notional Landing Sites

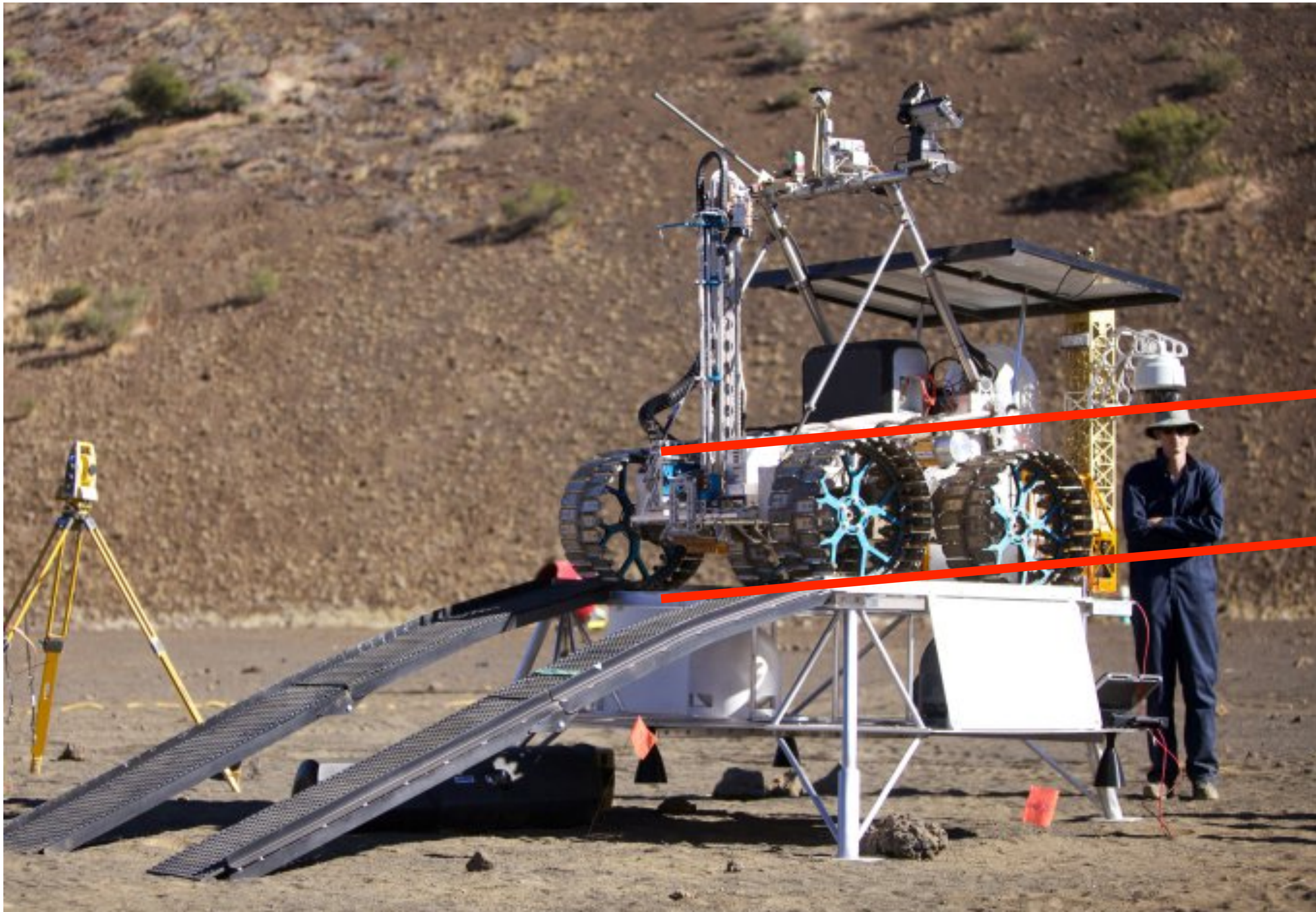
- RP Team is working with candidate partners to optimize landing site
  - Many possibilities exist trading **volatiles concentration**, **terrain**, **lighting, Direct-To-Earth Comm**, and **mission duration**



Notional Traverse Plan



2012 Field Test: Early Mission Simulation



NASA/CSA partnership doing initial prospecting demo at Mauna Kea, Hawaii

Payload

Rover

“Lander”

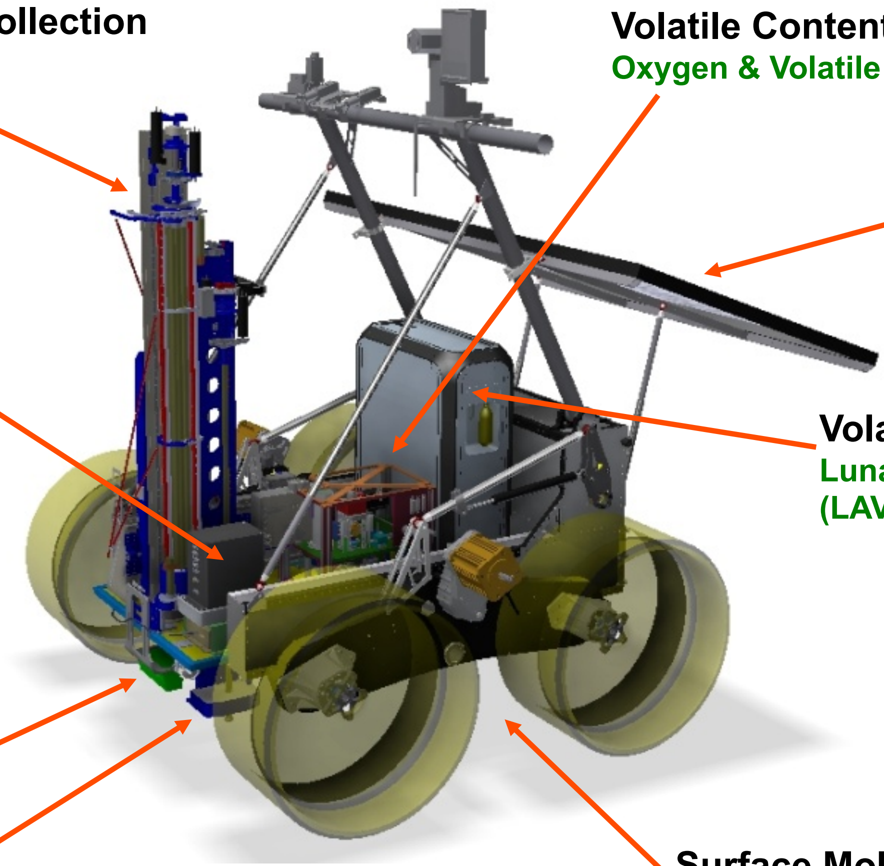
2012 Field Test: Prototype Rover & Payload

Subsurface Sample Collection
Drill/Auger

Volatile Content/Oxygen Extraction
Oxygen & Volatile Extraction Node (OVEN)

Power
Solar Array

Operation Control
Flight Avionics



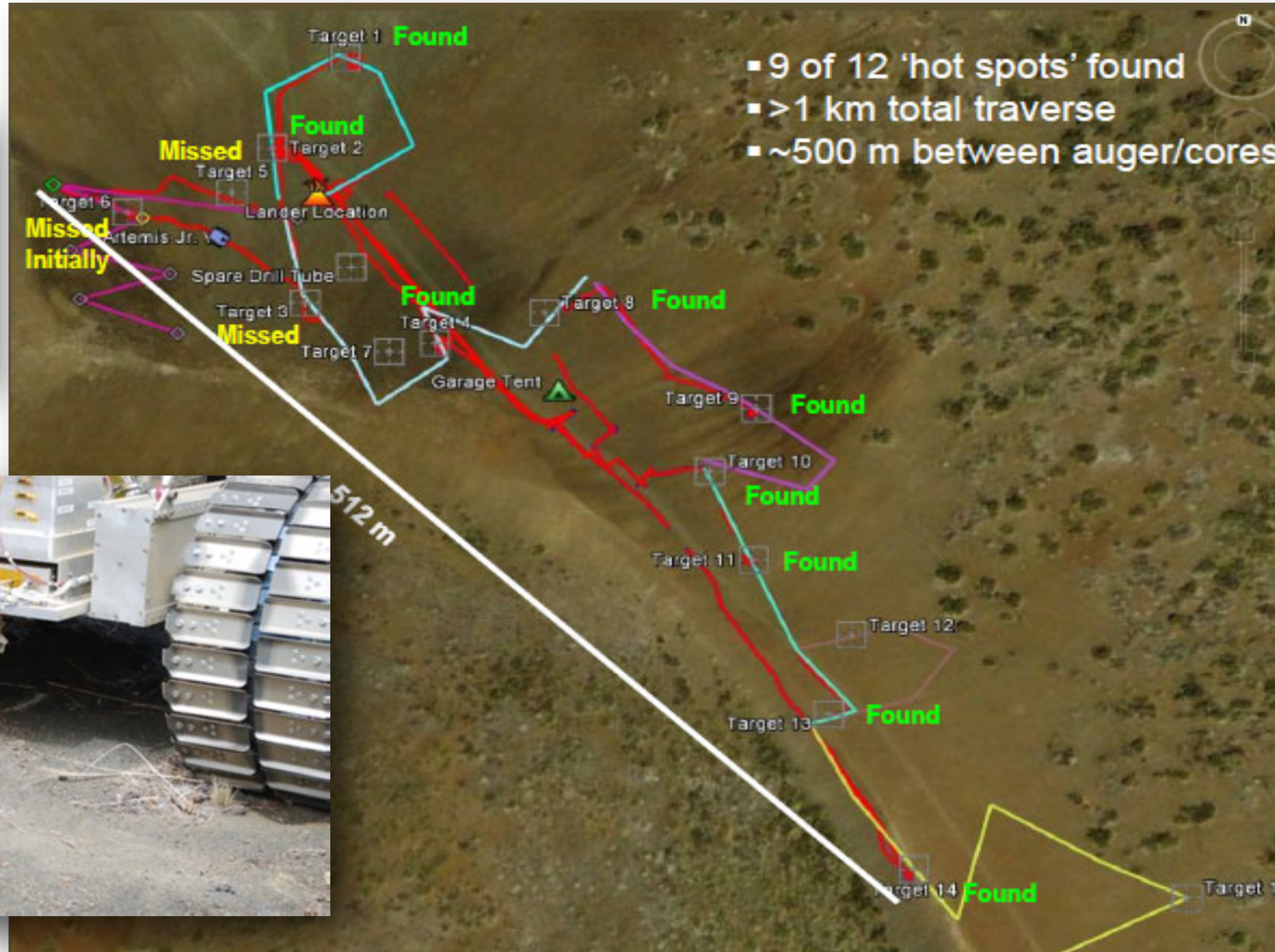
Volatile Content Evaluation
Lunar Advanced Volatile Analysis (LAVA)

Resource Localization
Neutron Spectrometer System (NSS)

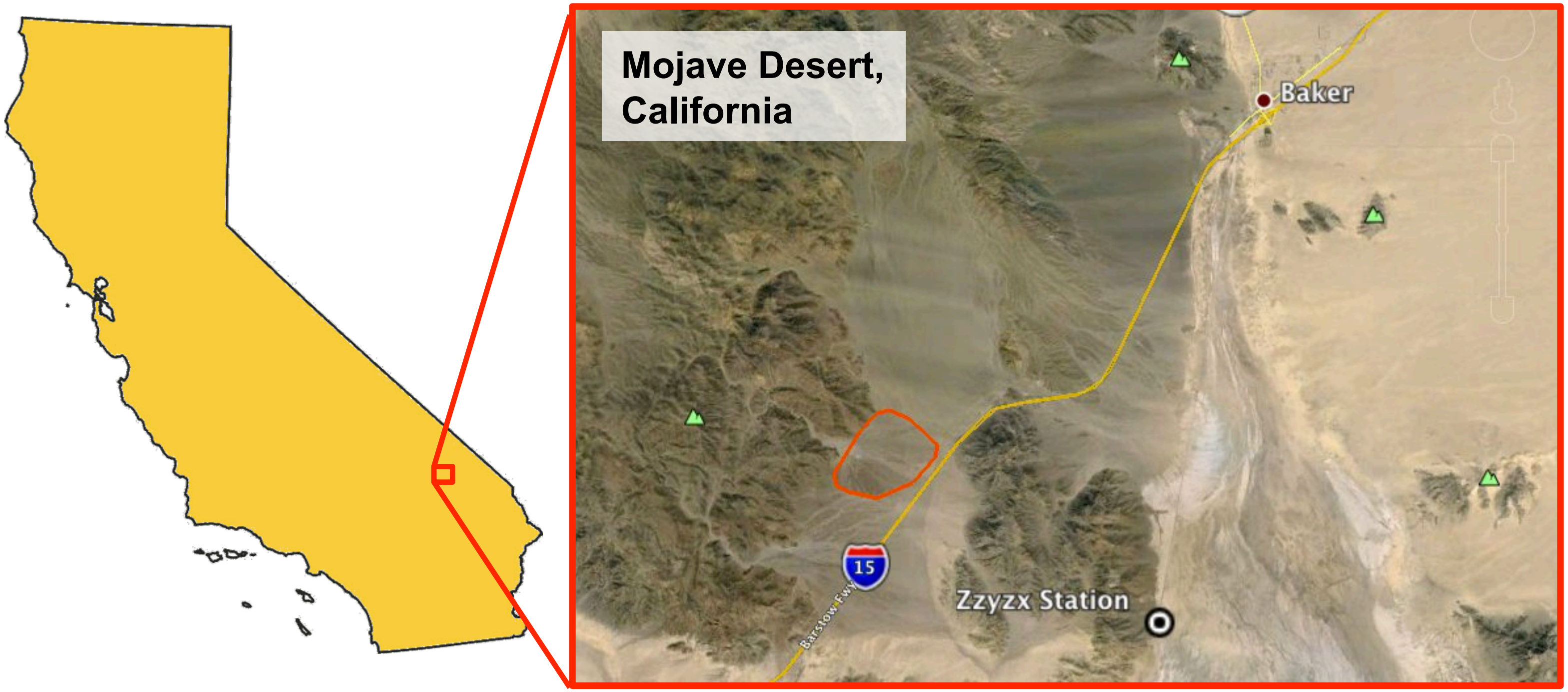
Sample Evaluation
Near Infrared Volatiles Spectrometer System (NIRVSS)

Surface Mobility/Operation
Rover

2012 Field Test: First Mission Simulation



2014 Field Test: High-Fidelity Analog Prospecting



Goal 1: Prospecting. Mature prospecting ops concept for NIRVSS and NSS instruments in a lunar analog field test

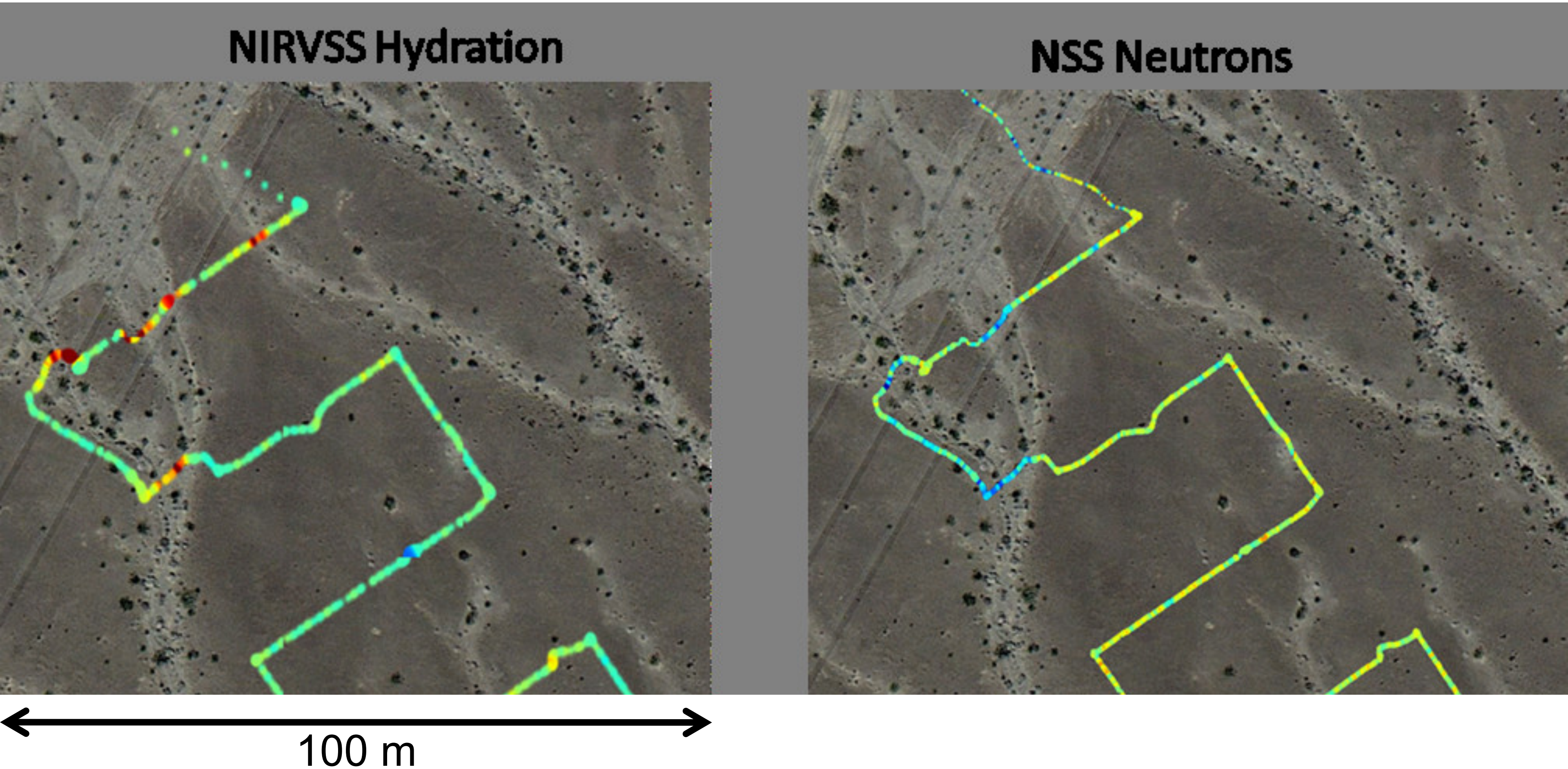
Goal 2: Real-Time Science Ops. Improve support software by testing in a setting where the abundance / distribution of water is <u>not</u> known *a priori*

Goal 3: Science on Earth. Understand the emplacement and retention of water in the Mojave Desert by mapping water distribution / variability

2014 Field Test: Science Operations (NASA Ames)

2014 Field Test: Prototype Rover & Payload

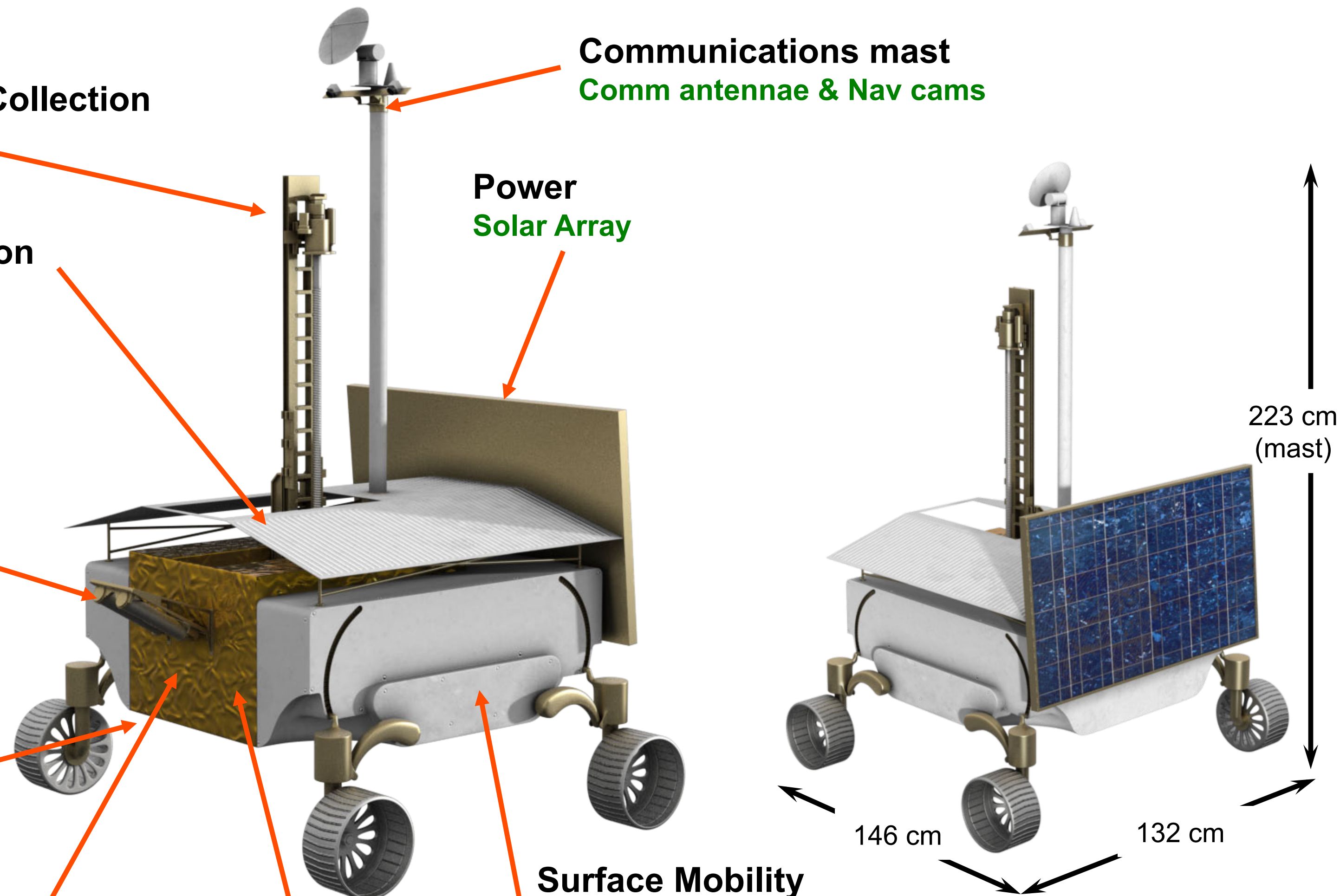
2014 Field Test: Prospecting Data



Yes, there is (subsurface) water in the Mojave !!!

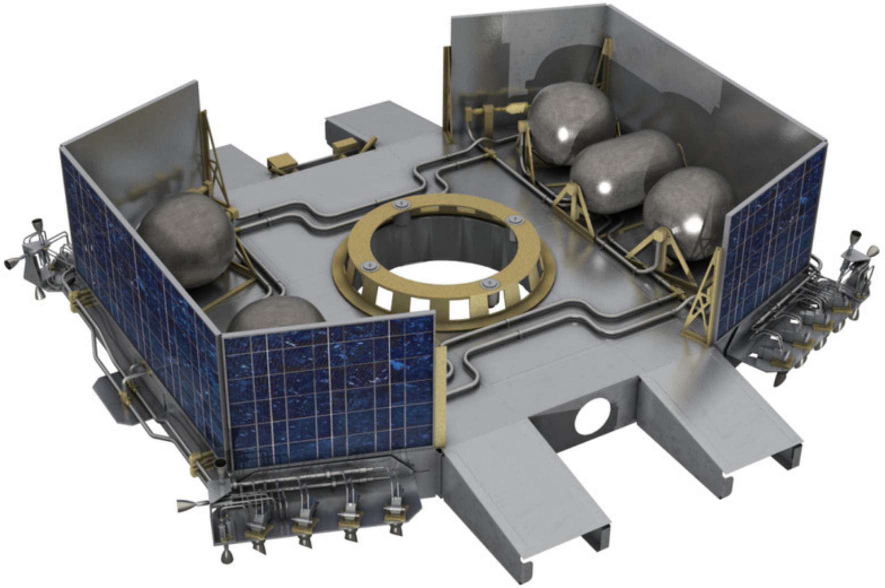
NIRVSS "hydration" (hot colors = more bound water)
and NSS neutrons (hot colors = more hydrogen)

Flight Concept Rover & Payload



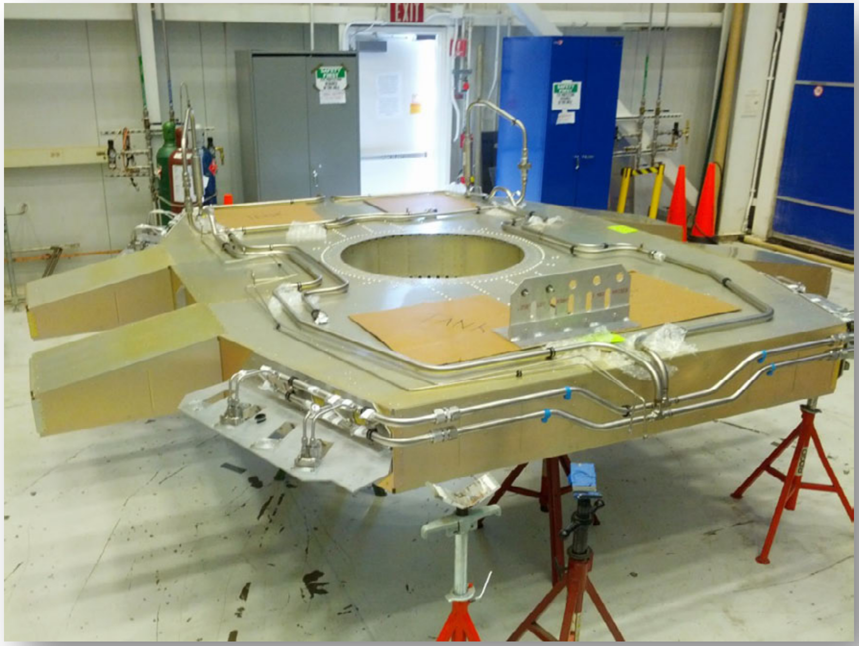
NASA Lander Concept

- Considerable effort put into prototyping a mass and cost-efficient lander
  - Novel aluminum riveted structure reduces complexity and cost
  - Partner will provide the lander, but prototyping helps define reference mission needs



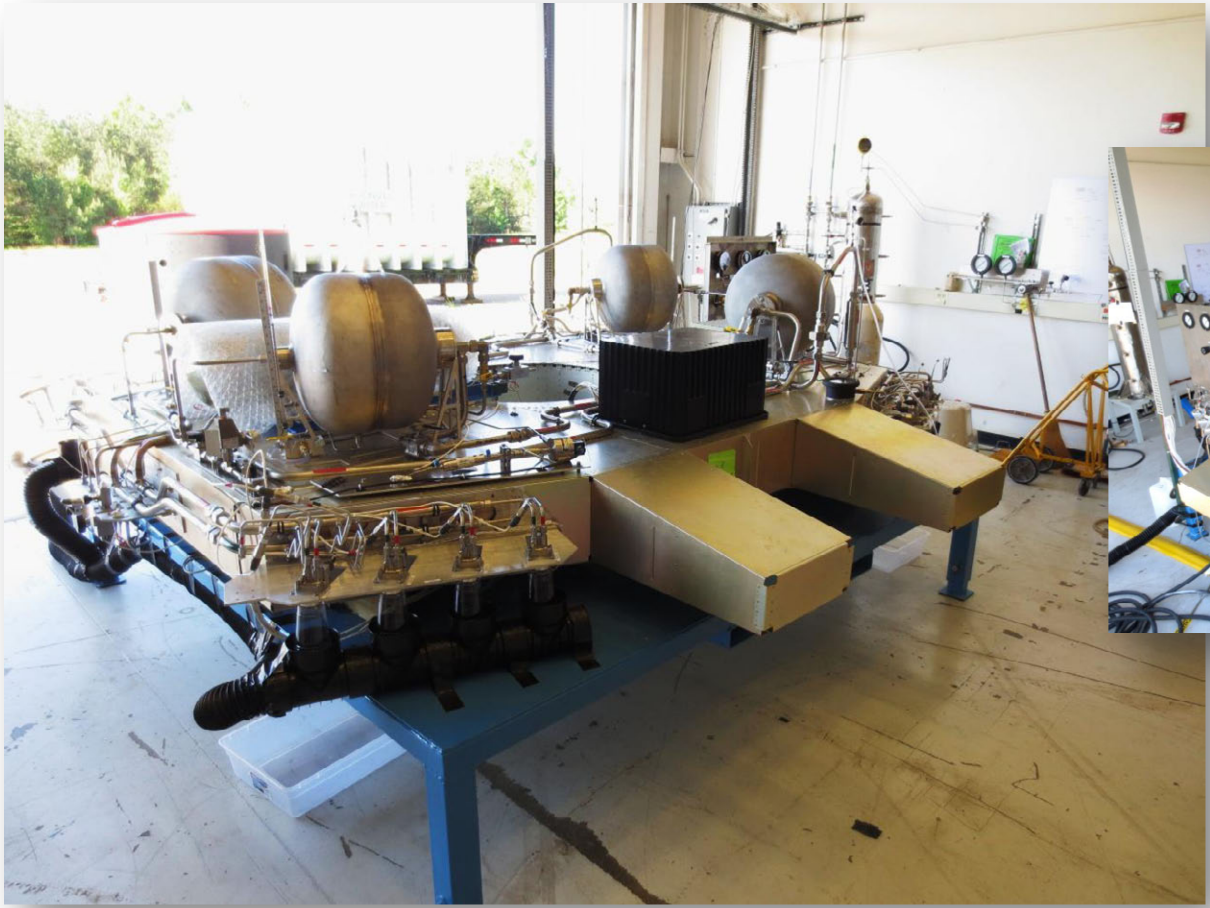
NASA-MSFC / NASA-JSC Lander Model

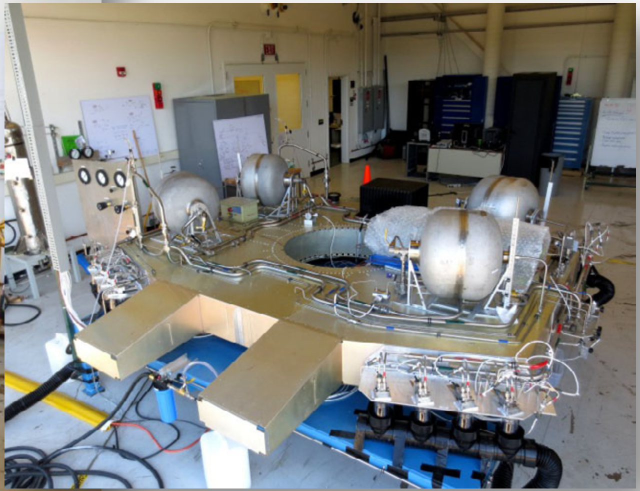
NASA-MSFC / NASA-JSC Lander structural prototype



NASA Lander Concept Development (2014-15)

- Lander prototype - Cold flow propulsion testing

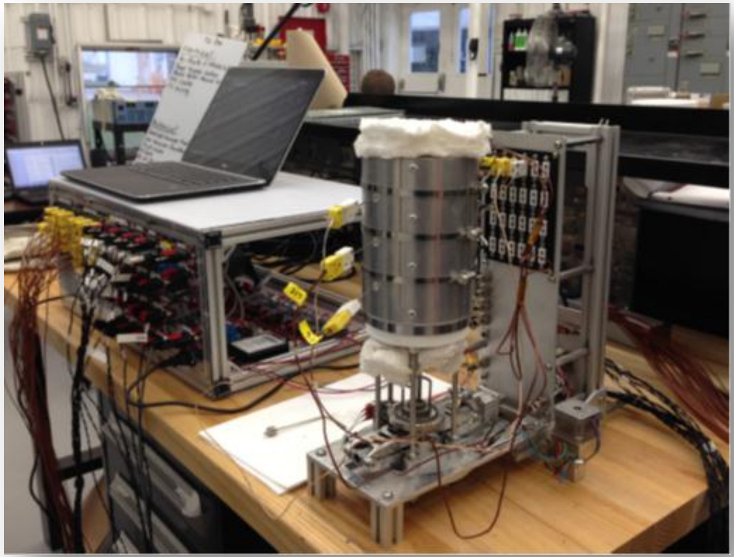




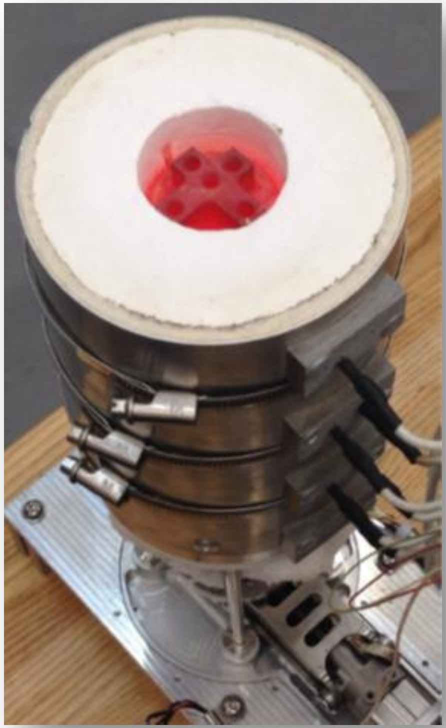
NASA-MSFC / NASA-JSC
Lander propulsion testbed

Payload Engineering Testing

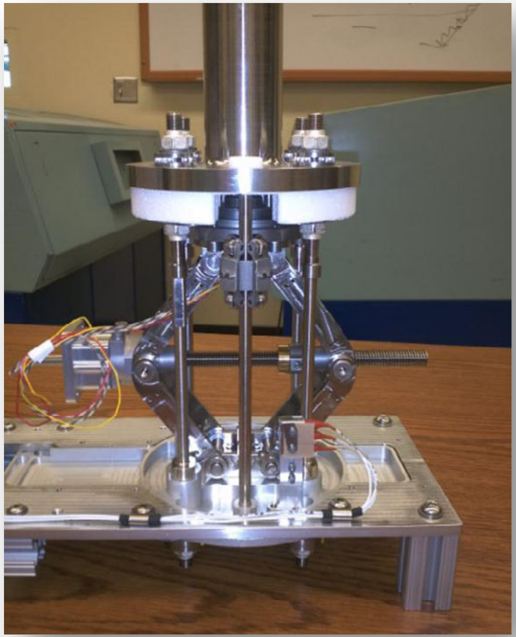
- In-Situ Resource Utilization (ISRU) systems undergoing engineering test
  - Subsystem TVAC and vibe testing, drilling in relevant environment, etc
  - Some instruments are near protoflight-ready
  - Held independent Payload review held @ KSC w/ 9 independent reviewers



OVEN Reactor Checkout Testing



OVEN Reactor Heater at 700+ºC



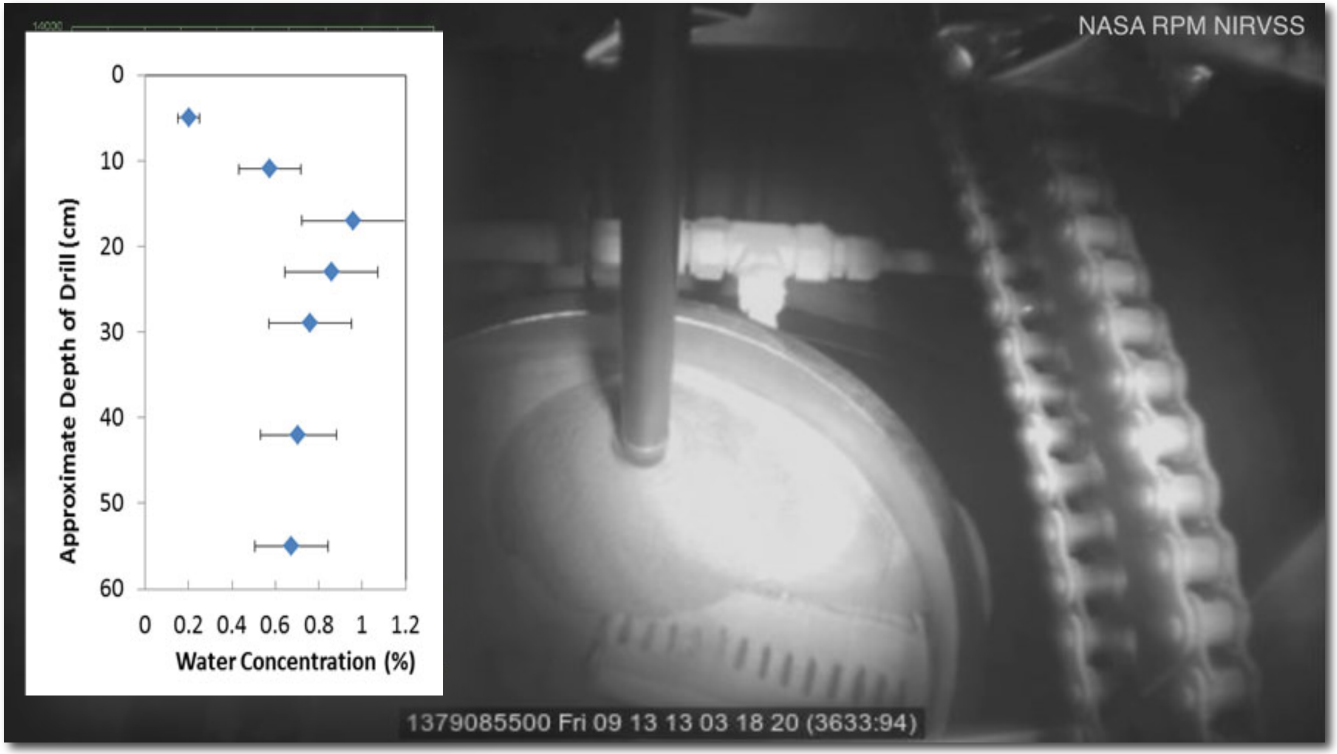
OVEN Reactor Mechanical Assembly

TVAC Volatiles testing at NASA-GRC (2013)

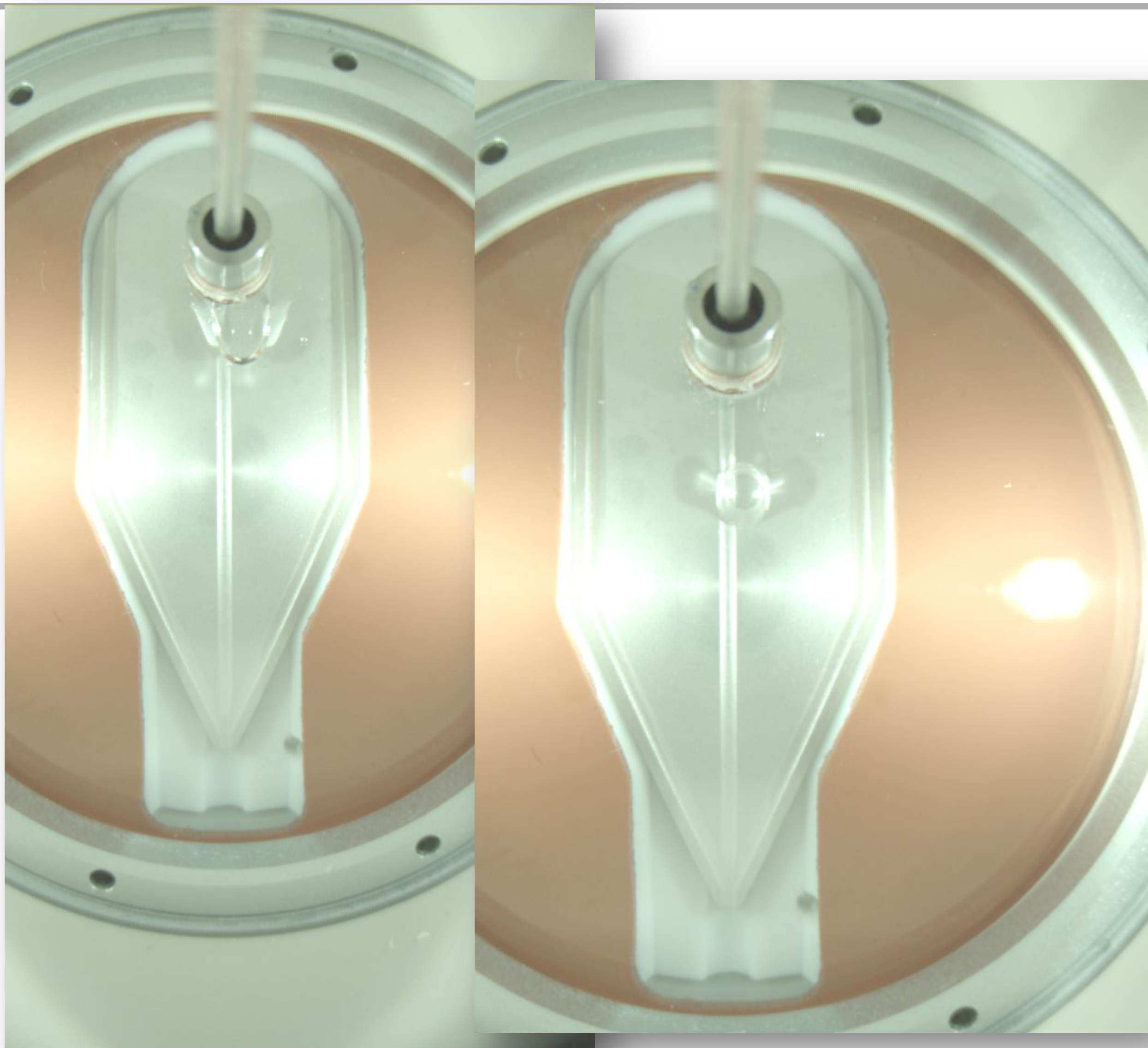
- NIRVSS was full tested at NASA-ARC, including TVAC testing
- NIRVSS was then installed in a TVAC chamber at NASA-GRC to be operated while a CSA auger drill was tested
  - Lunar simulant mixed/packed with 1% water, cooled to -80C and in vacuum
  - NIRVSS took images, spectra and radiometric data (screen shot below)

Image from NIRVSS Drill Operations Camera (DOC)

Data inset (on left) shows drill depth vs. water concentration *(derived from NIRVSS spectrum)*



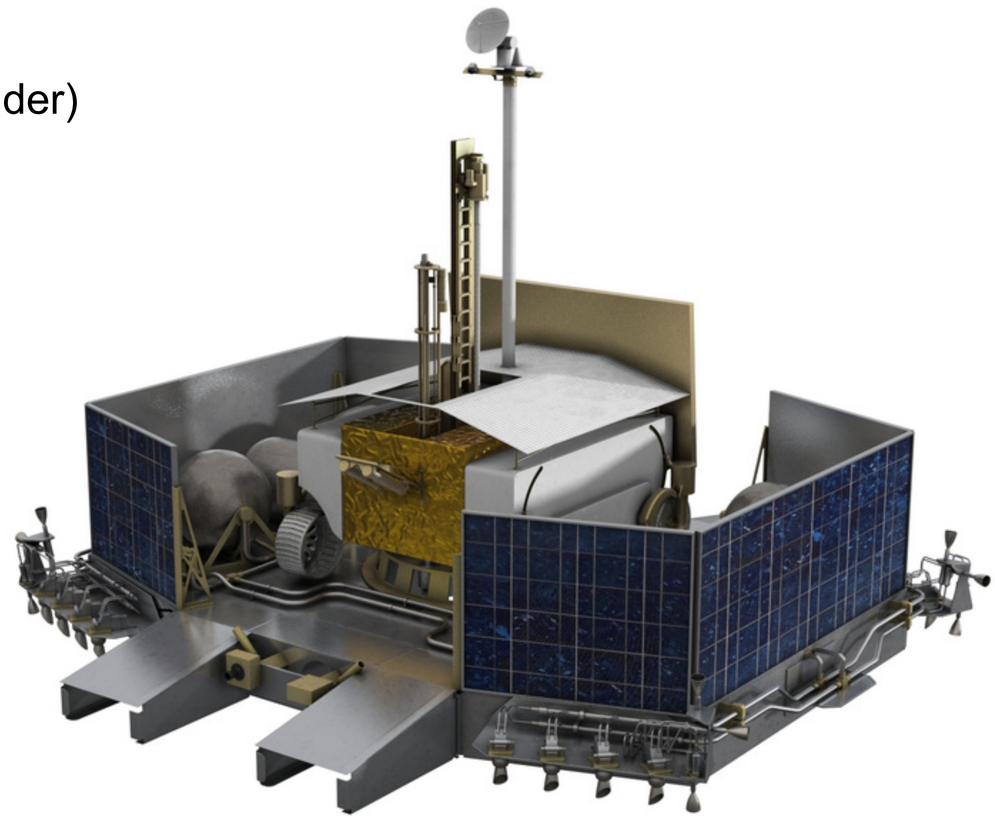
Water Droplet Demo (WDD)



- Water from Regolith!
- Demonstrating Regolith Oxygen Extraction from doped simulant to test H_2O creation

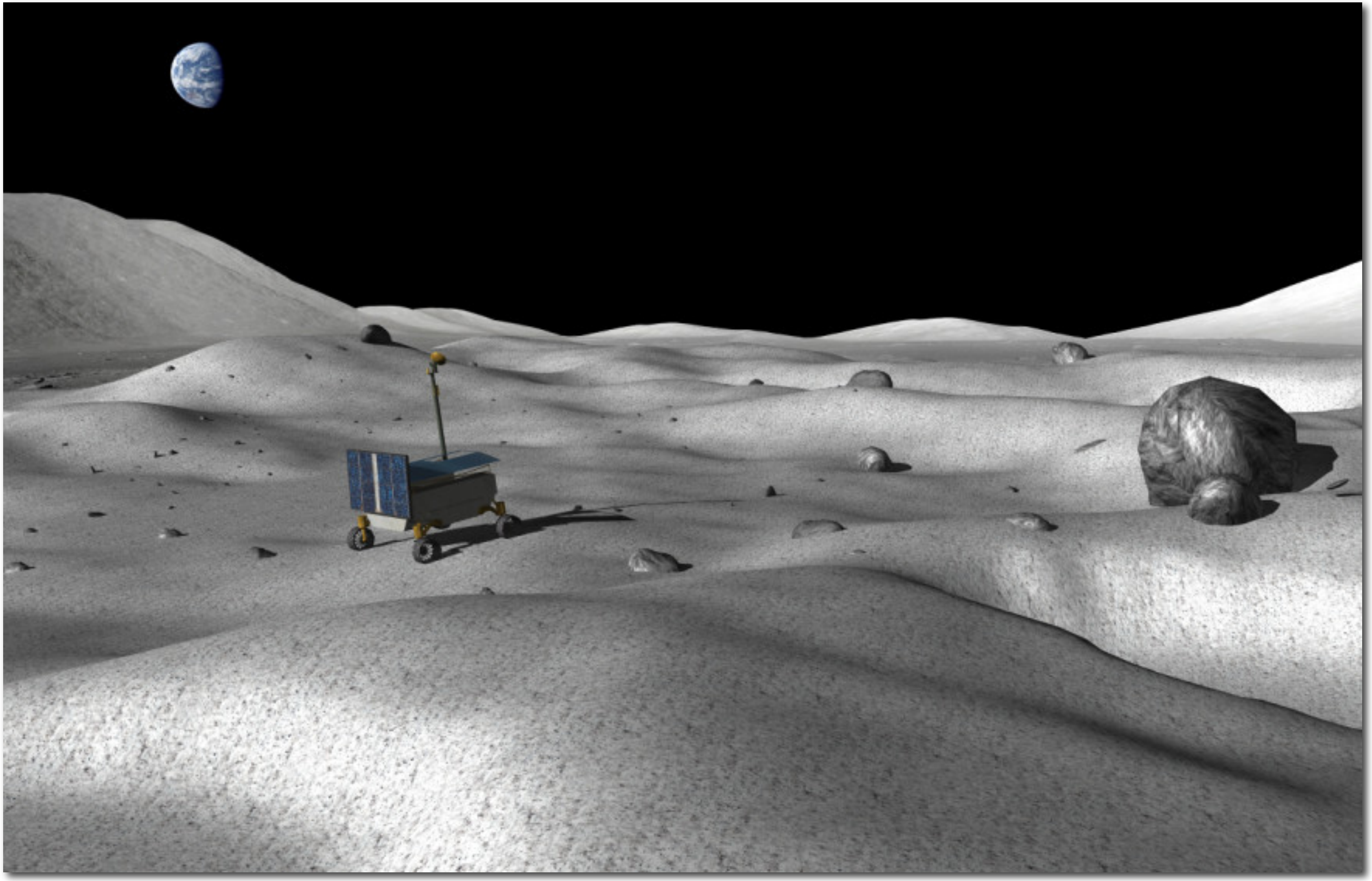
Programmatic Status

- NASA led mission
  - Budget: $200M (without launch & lander)
  - NASA Class D / Category III project
  - Risk-tolerant, streamlined approach (LCROSS mission model)
- Partnerships
  - NASA to provide rover and payload
  - TBD partner to provide drill system
  - Detailed discussions and study with JAXA for Lander
- Status
  - Completed Mission Concept Review (MCR) in 2013-09
  - Rover Engineering Test Unit (ETU) currently under development
  - Payload Engineering Units in test
  - Early 2020 launch date



NASA team lander concept with rover and ISRU demonstration

Questions ?



Backup

RP Payload Instruments

- The Neutron Spectrometer (NS) Subsystem will be used to verify the presence of hydrogen rich materials and then map the distribution of these materials to assist in sample site selection and better understand the morphology of the resource. The Near Infrared (NIR) Spectrometer instrument will be used to scan the immediate vicinity of the drill site before and during drill/auger operations to look for near real-time changes in the properties of the materials exposed during the drilling process
- The Near Infrared (NIR) Spectrometer will be used to provide an additional means of surveying the surface and immediate excavation site for water and other volatiles. Provides surface and regolith mineral context. The Near Infrared (NIR) Spectrometer instrument will be used to scan the immediate vicinity of the drill site before and during drill/auger operations to look for near real-time changes in the properties of the materials exposed during the drilling process
- The Drill Subsystem includes the hardware to physically excavate/extract regolith from the lunar surface to a depth of 1 m and perform any type of preparation necessary (grinding, crushing, sieving, etc.) before delivering the sample to one or more reactor chambers for further processing by the Reactor Subsystem. This subsystem will be provided by the Canadian Space Agency (CSA) through a partnering agreement and integrated into the RESOLVE. The excavation device will be instrumented to measure forces/displacements etc. to determine critical bulk properties of the regolith
- The NIR Volatiles Spectrometer System (NIRVSS) is the system including the NIR spectrometer, the Drill Operations Camera (looks at what the spectrometer is looking at), and the Longwave Calibration Sensor (which helps correct for thermal contamination at the longwave water bands).
- The Oxygen and Volatile Extraction Node (OVEN) Subsystem will accept samples from the Drill Subsystem and will evolve the volatiles contained in the sample by heating the regolith in a sealed chamber and will also extract oxygen from the remaining regolith sample. Each sample will be sealed in the OVEN chamber and heated up to 150 C to evolve volatiles (H_2O, CO, etc.). At most one sample from each core will continue to be heated up to ~900 C and be subjected to hydrogen reduction processing
- The Lunar Advanced Volatile Analysis (LAVA) Subsystem will accept the effluent gas/vapor from the OVEN Subsystem and analyze that effluent gas using gas chromatograph and/or mass spectrometer sensor technologies. LAVA Subsystem will design, develop, test, and provide all of the fluid system hardware necessary to support OVEN Subsystem and LAVA Subsystem instrumentation operations. The subsystem will measure constituents below atomic number 70 (including H_2, He, CO, CO_2, CH_4, H_2O, N_2, NH_3, H_2S, SO_2, etc.).