Resource Prospector (RP)

A lunar volatiles prospecting and In-Situ Resource Utilization (ISRU) demonstration mission

Briefing to IEEE Robotics and Automation Society

Daniel Andrews, RP PM

2016-07-20

http://www.nasa.gov/resource-prospector @NASAexplores

No Export Controlled materials (ITAR/EAR)

The Hunt for 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/LRO (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 (2020): "Land and prospect for the water-ice. Experiment with ISRU to extract water from the soil…"

LCROSS not only confirmed presence of water-ice in a permanently-shadowed region, but showed there may be 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.

Evolvable Lunar Architecture Press Conference
2015-07-20

The Top Strategic Risk: we don't know exactly how much water is in the moon or how deep, or how plentiful it is. This is a key strategic issue we need to understand… and if there is one thing we should do soon, it is to send soon a resource prospector to the moon.

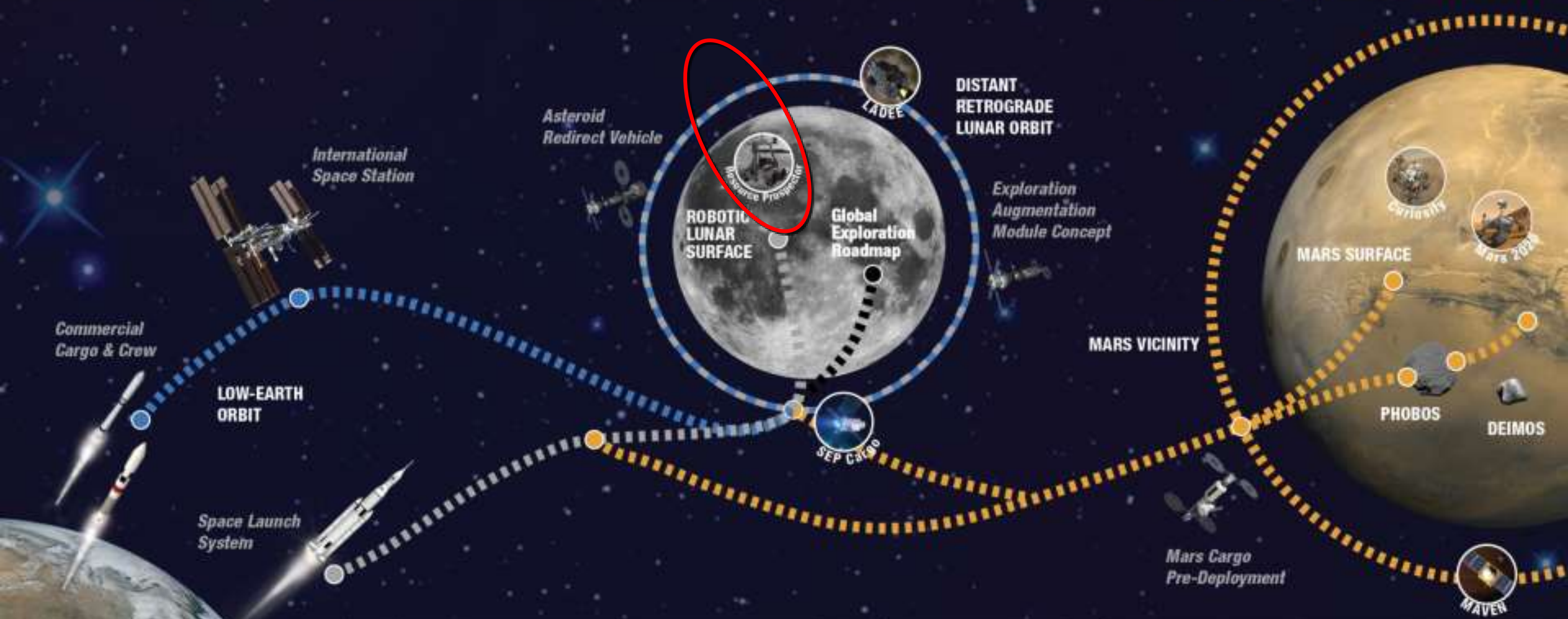
Charles Miller - Study PI & President of NexGen Space LLC

Press conference by National Space Society (NSS) and Space Frontier Foundation (SFF) announcing their support for NASA's funding of the newly released NexGen Space study. Study: "Economic Assessment and Systems Analysis of an Evolvable Lunar Architecture that Leverages Commercial Space Capabilities and Public - Private - Partnerships"; NASA funded the $100K study; Independent review of study occurred 2015-03

EVOLVABLE MARS CAMPAIGN

A Pioneering Approach to Exploration

EARTH RELIANT | **PROVING GROUND** | **EARTH INDEPENDENT**



THE TRADE SPACE

Across the Board | Solar Electric Propulsion • In-Situ Resource Utilization (ISRU) • Robotic Precursors • Human/Robotic Interactions • Partnership Coordination • Exploration and Science Activities

Cis-lunar Trades
- Deep-space testing and autonomous operations
- Extensibility to Mars
- Mars system staging/refurbishment point and trajectory analyses

Mars Vicinity Trades
- Split versus monolithic habitat
- Cargo pre-deployment
- Mars Phobos/Deimos activities
- Entry descent and landing concepts
- Transportation technologies/trajectory analyses

RP Mission Animation

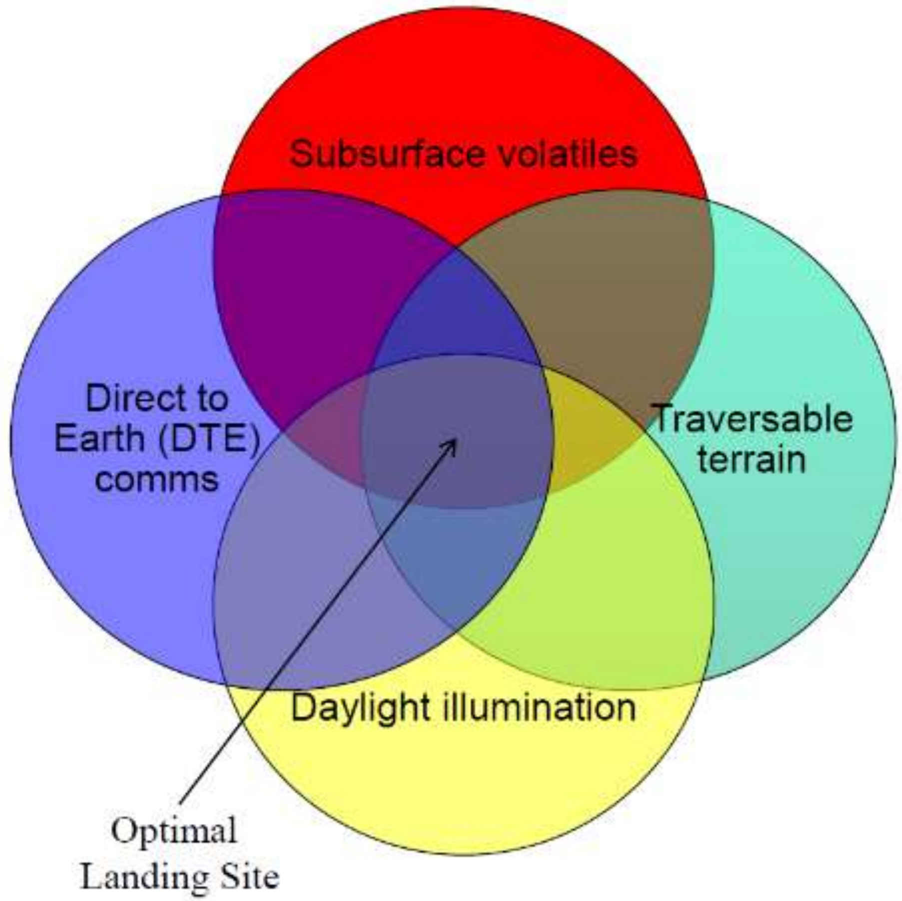
Site Selection Criteria

Likely subsurface volatiles
- Sustained low subsurface temperatures conducive to volatile retention
- Orbital neutron spectrometer hydrogen signature

Sufficient daylight illumination
- More than 4 Earth days of solar power for rover operations
- Clement surface temperature for rover survival

Suitable for Direct to Earth (DTE) communication
- DSN stations clear the horizon

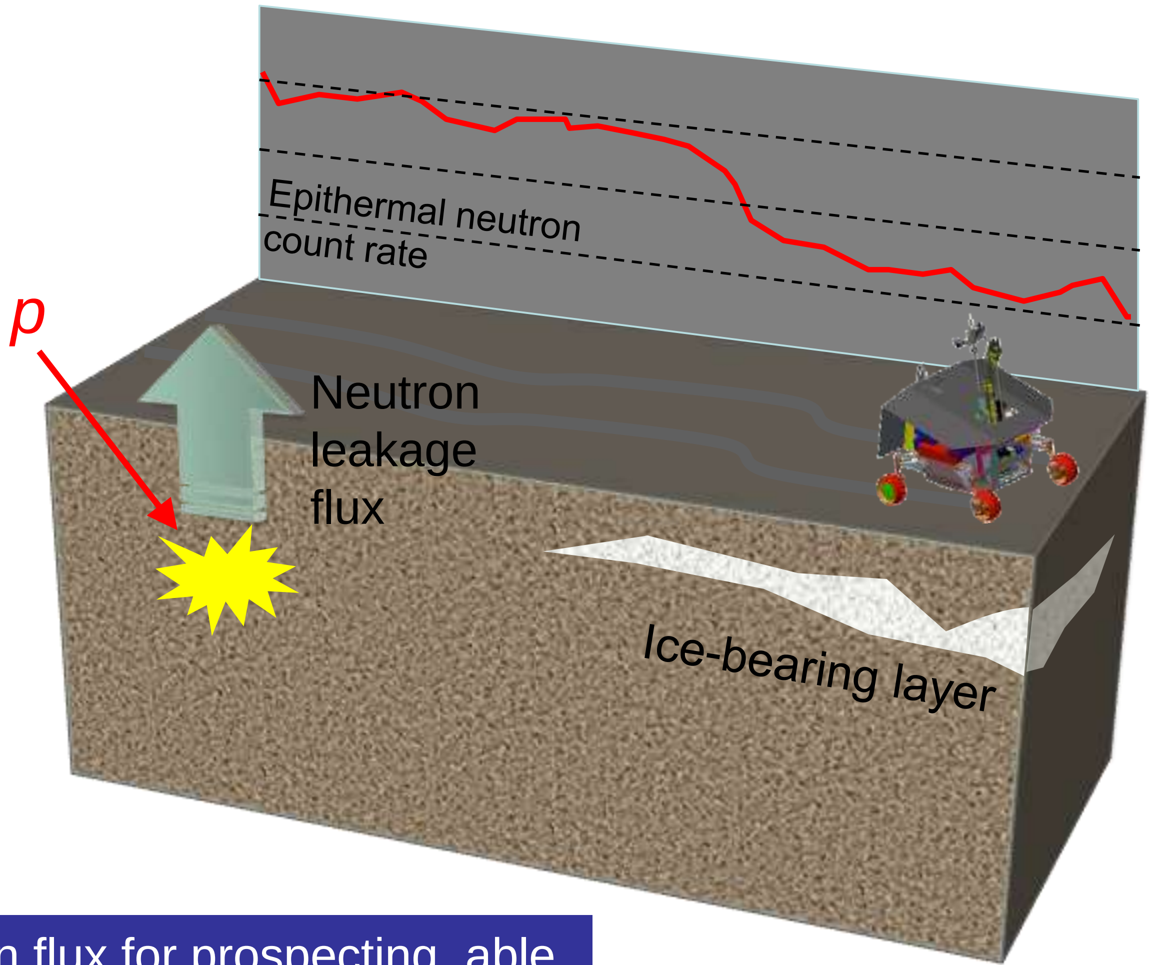
Traversable terrain
- Slopes < 10 deg
- Limited density of rocks



2011-10-18, “RESOLVE Sun & Shadow DRM 2.2”, RESOLVE Architecture Team

NSS Subsurface Hydrogen (Ice) Sensing

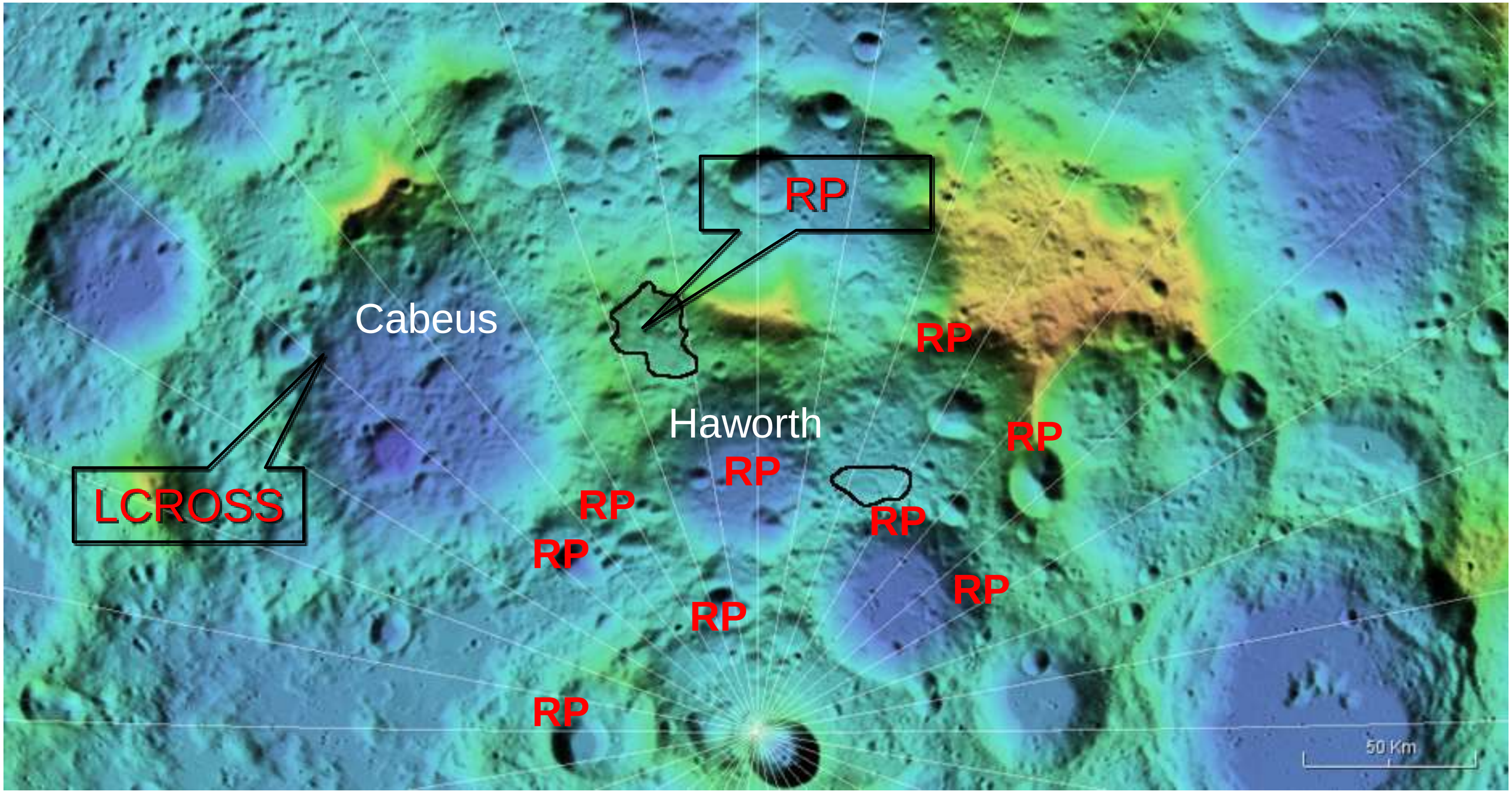
- Galactic cosmic rays shatter nuclei in the lunar soil
- The shattered nuclei release neutrons, creating a “flux” of neutrons leaking to space
- Those leaked neutrons tell us about near-subsurface composition
- Variations in that Neutron flux while roving, tell us about the abundance and burial depth of hydrogenous materials in subsurface



The RP NSS measures neutron flux for prospecting, able to sense hydrogen-bearing materials (e.g. water-ice) up to 1 meter depth, enabling mapping while roving

Landing sites under discussion

- 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**



RP15 Field Testing

RP Neutron Spectrometer (NSS) & NIR Spectrometer (NIRVSS) field tests (2014-08)

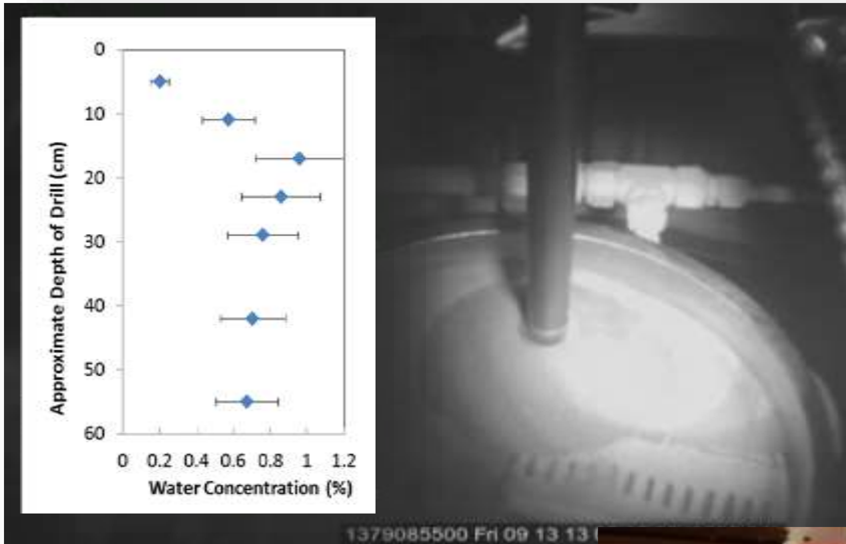
NSS in the NASA-ARC Roverscape

- The NSS is located on the rover and in front of that is a neutron source holder for Earth testing only (simulating lunar radiation activity)
- The team has driven across rock patches and an ice proxy for testing

NIRVSS in the NASA-ARC Roverscape

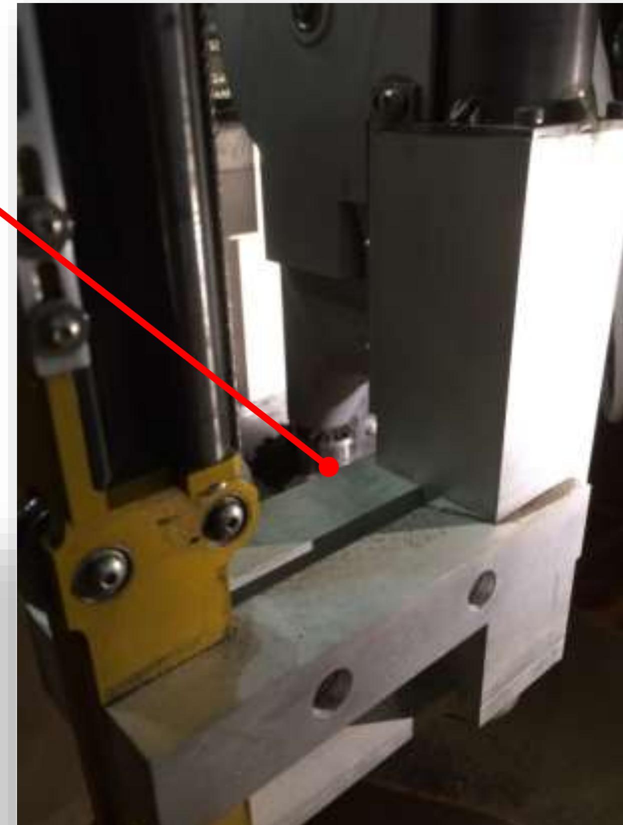
- The team drove across rock patches and an ice proxy for testing

RP Drill & NIRVSS testing
2013-09 & 2015-07



Drill & NIRVSS testing in TVAC chamber at NASA-GRC (-80^{o}C)

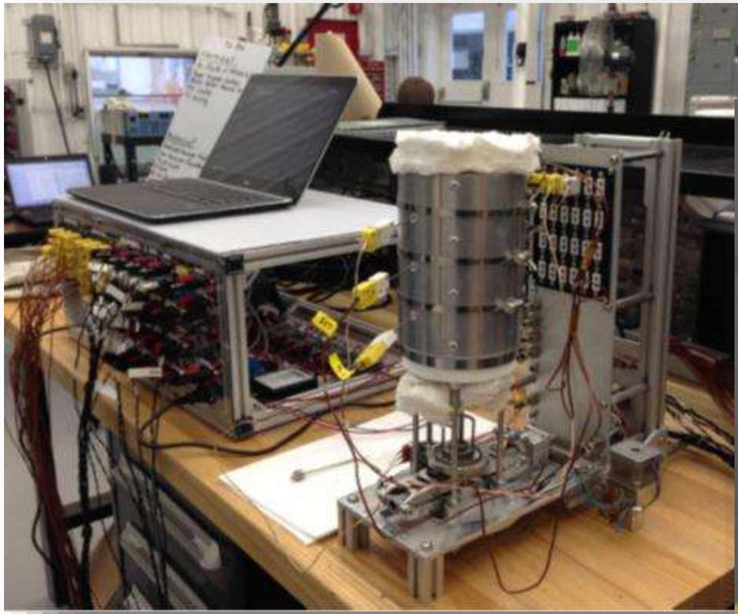
OVEN Crucible



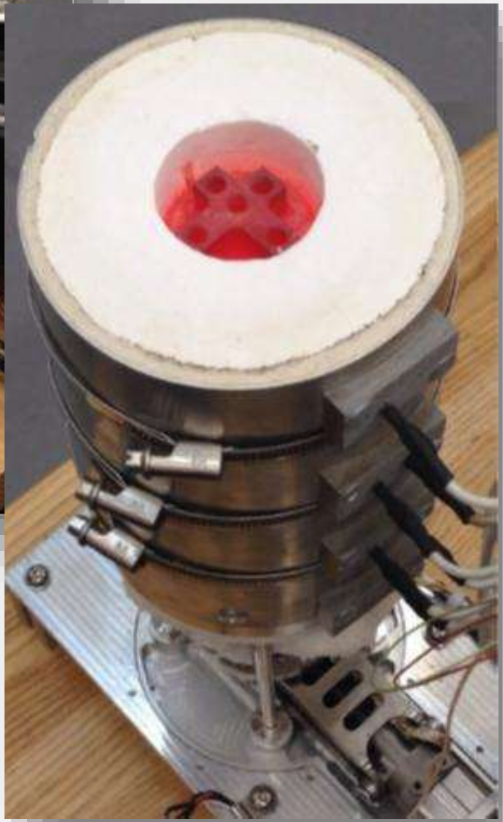
RP15 Rover-hosted Drill testing in doped simulant tube at NASA-JSC

RP OVEN ETU testing
2014-04

- RESOLVE ISRU payload systems undergoing engineering test
  - Subsystem TVAC and vibe testing, drilling in relevant environment, etc



OVEN Reactor Checkout Testing

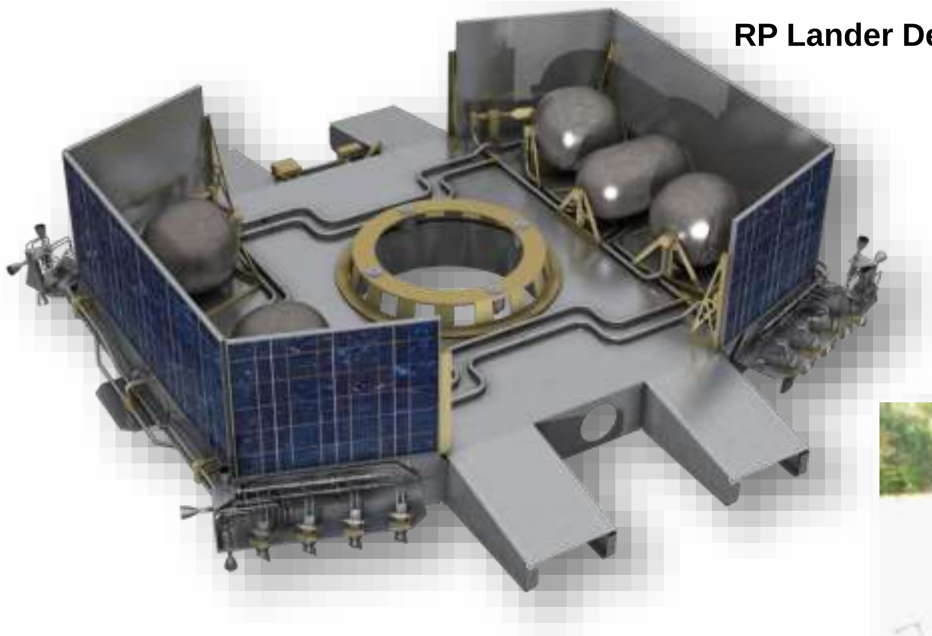


OVEN Reactor Heater at 700+ºC

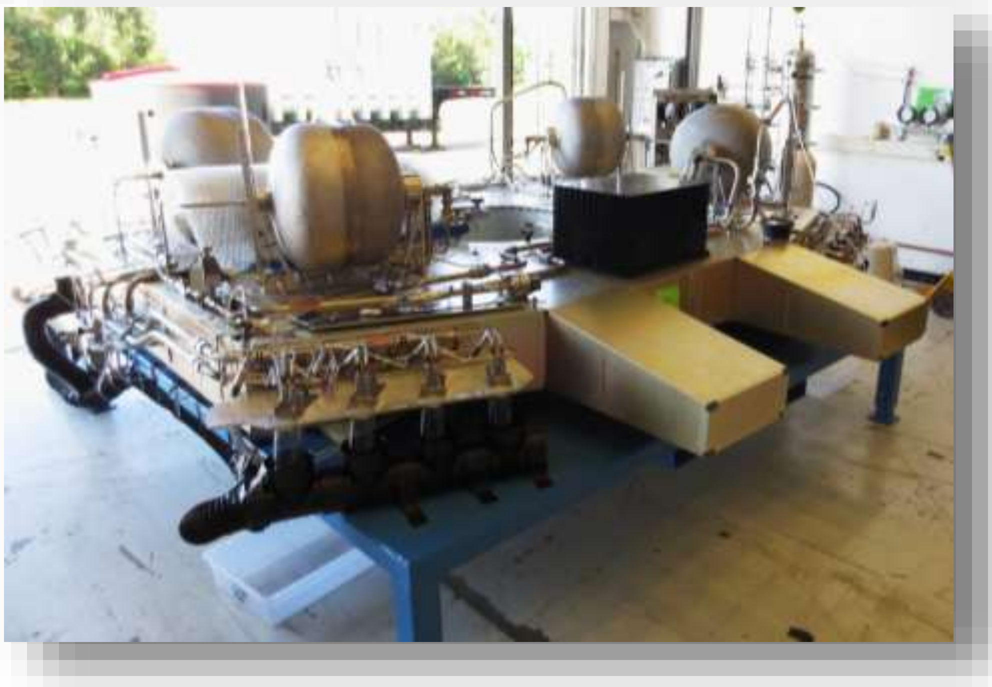
OVEN Reactor Mechanical Assembly

RP Partnering Lander Concept
2014-05

RP Lander Design



Lander Prototype & Propulsion testbed



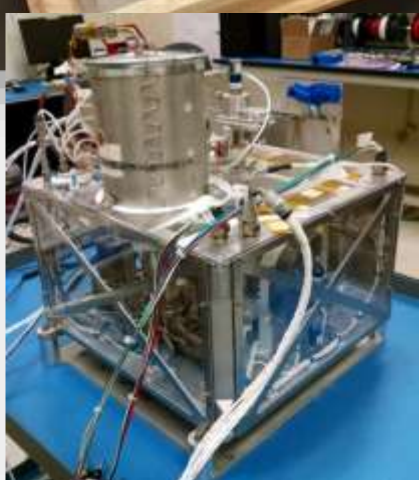
- Prototyped a cost-efficient lander
  - Novel aluminum riveted structure concept reduces complexity and cost
  - NASA looking for international partner to provide the lander

RP15 Payload Activities

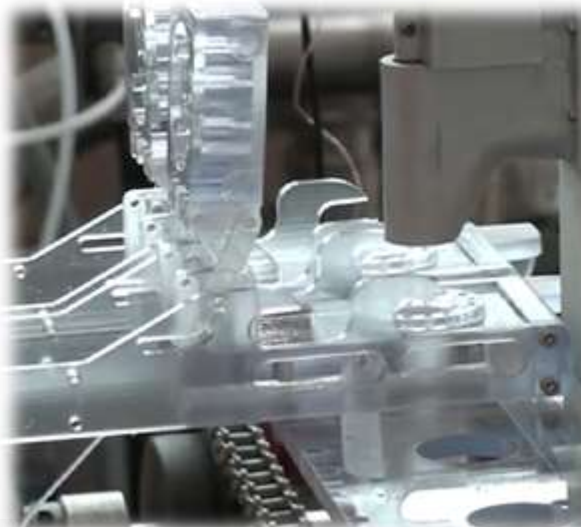
2015-05

Material capture

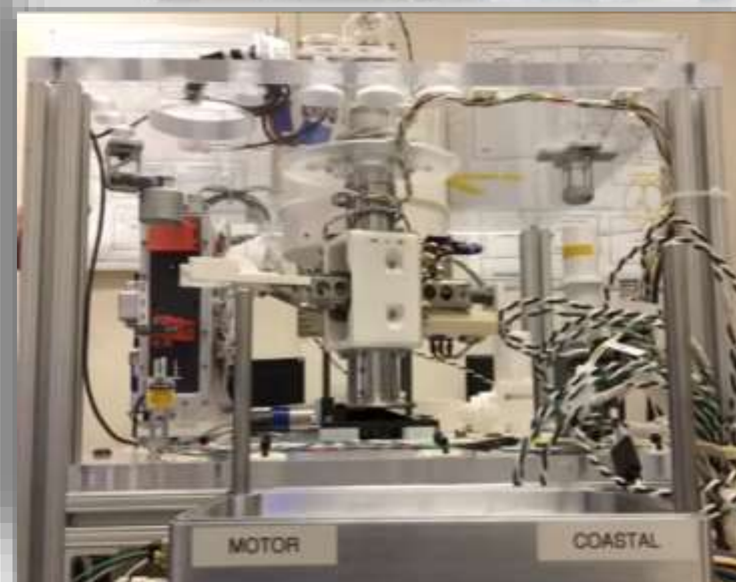
Payload & Drill subsystem



Material capture



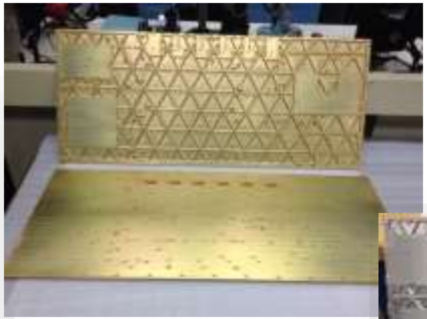
Regolith filling the crucible



Crucible processing

RP15 Rover Activities
2015-06

Rover Frame/Chassis



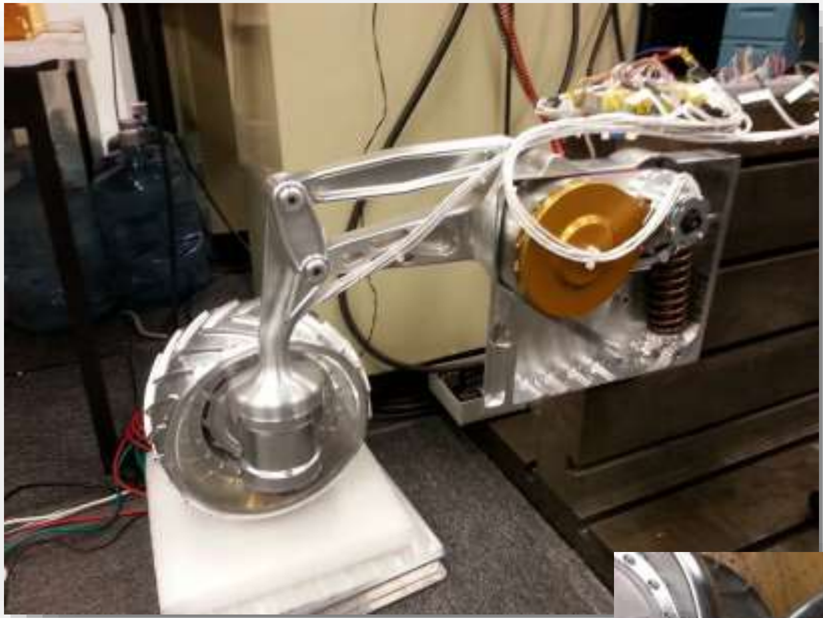
Heat spreaders

Batteries

RP15 Rover Activities

2015-06

Rover Suspension/Drive Subsystem



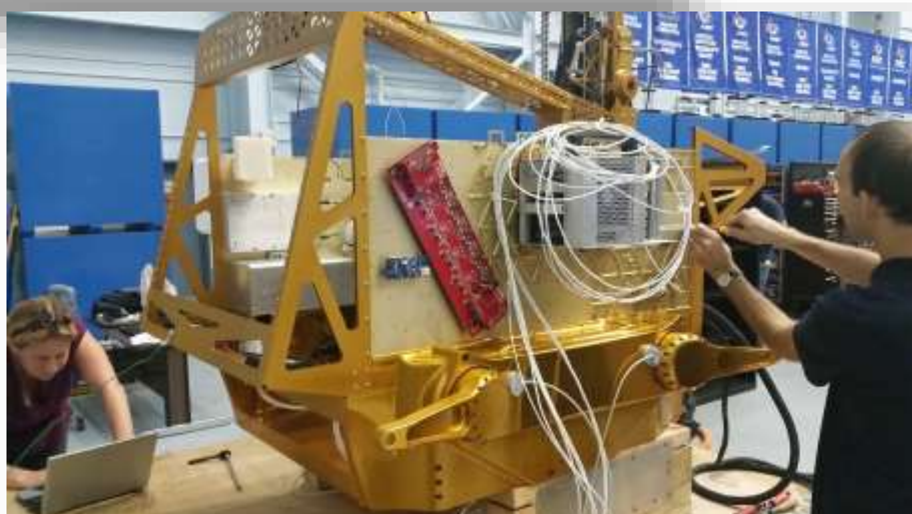
Suspension assembly

1g wheels

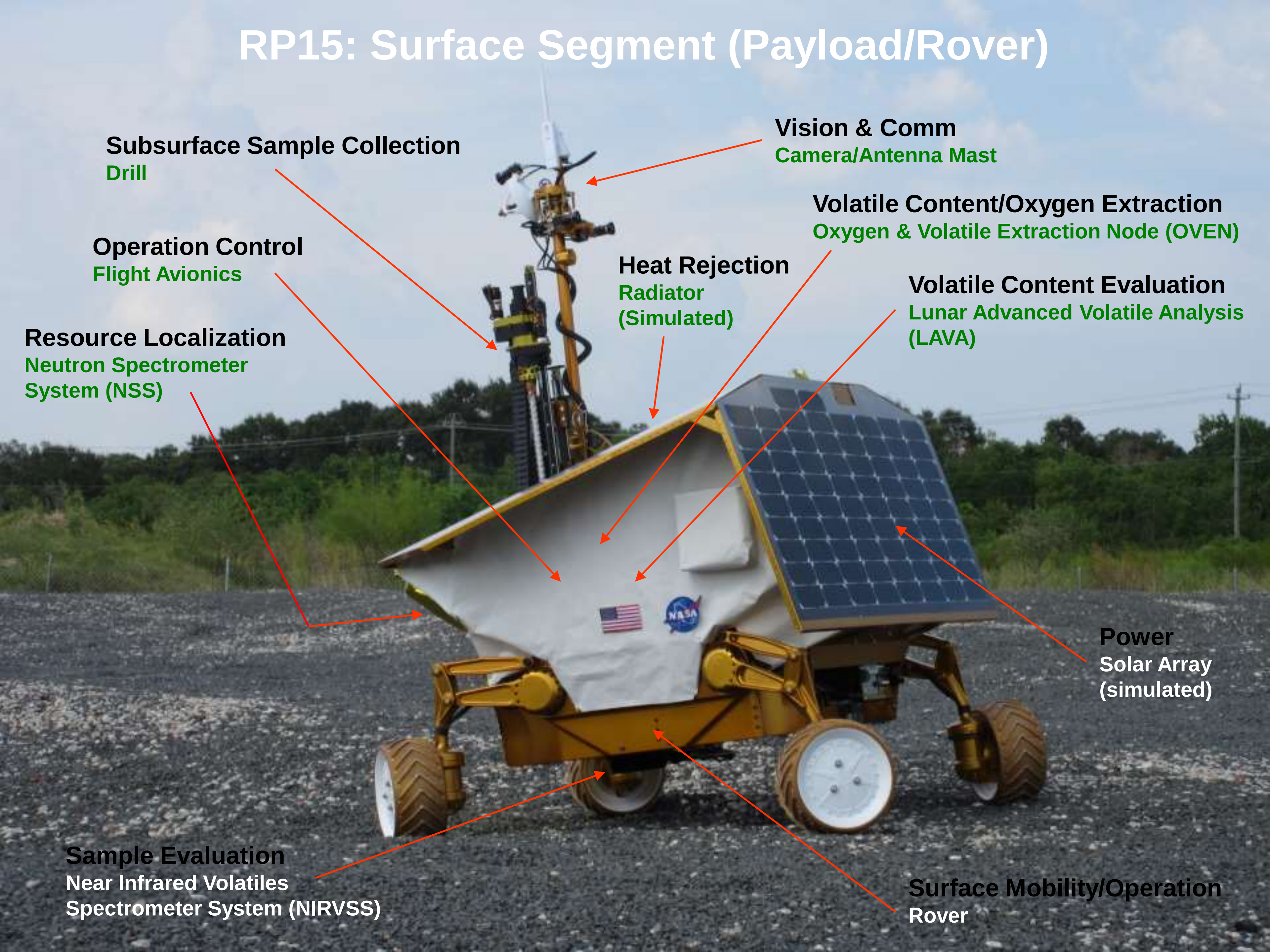
RP15 Rover/Payload integration

2015-07

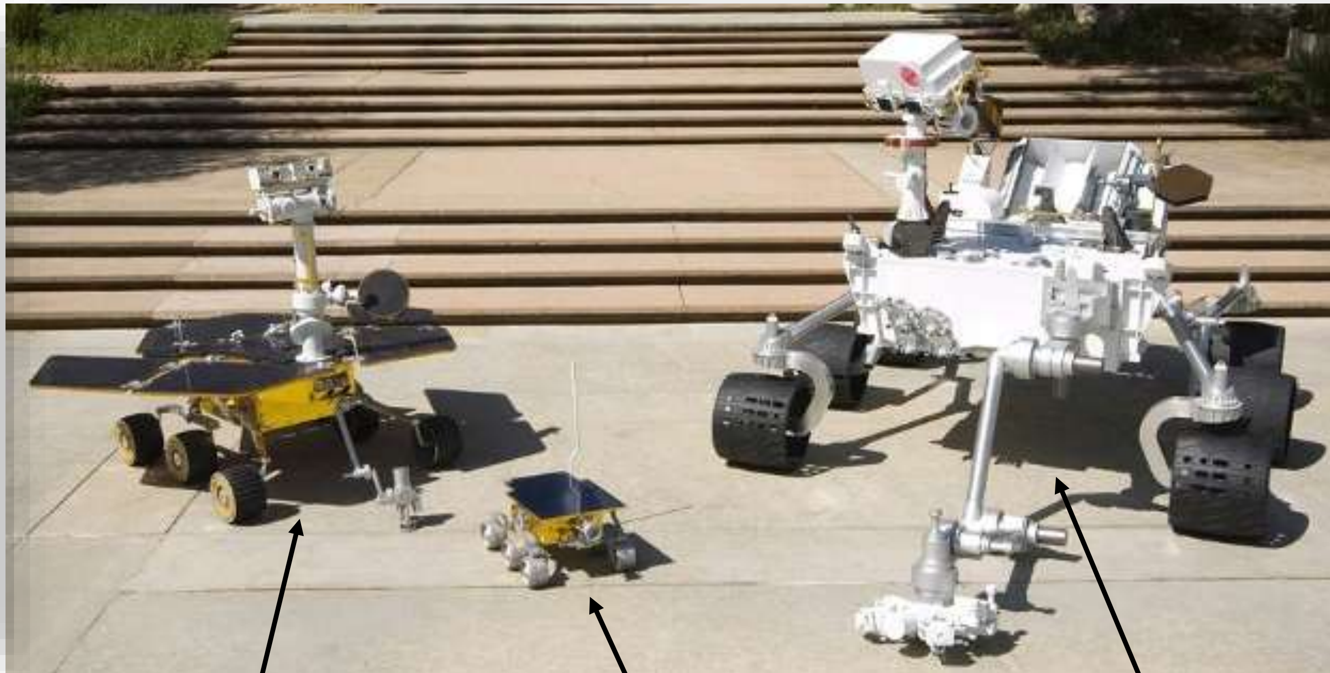
Rover Assembly



RP15 In the Dirt
2015-08-15


RP15: Surface Segment (Payload/Rover)
Subsurface Sample Collection
Drill
Vision & Comm
Camera/Antenna Mast
Volatile Content/Oxygen Extraction
Oxygen & Volatile Extraction Node (OVEN)
Operation Control
Flight Avionics
Heat Rejection
Radiator
(Simulated)
Volatile Content Evaluation
Lunar Advanced Volatile Analysis
(LAVA)
Resource Localization
Neutron Spectrometer
System (NSS)
Power
Solar Array
(simulated)
Sample Evaluation
Near Infrared Volatiles
Spectrometer System (NIRVSS)
Surface Mobility/Operation
Rover

Rover Dimensional Comparison (approx.)



RP/RP15 (2015):
- 1.5m x 1.5m x 2.0m (LxWxH)
- Weighs about 300kg

Spirit/Opportunity (2004):
- 1.6m x 2.3m x 1.5m (LxWxH)
- Weighs about 180kg

Sojourner (1996):
- 0.6m x 0.5m x 0.3m (LxWxH)
- Weighs about 11kg

Curiosity (1996):
- 3.0m x 2.8m x 2.1m (LxWxH)
- Weighs about 900kg

RP15 First Prospecting/Processing in the Field

2015-08-18

RP15 drilling
in the JSC
Rock Yard

Crucible
awaiting sample
inside the rover

RP15 Drilling on a slope in the Field

2015-08-24

Sloped Drilling at JSC

Sand Captured in Drill
Brush Housing & Flutes

RP15 Rocky Weather in Houston

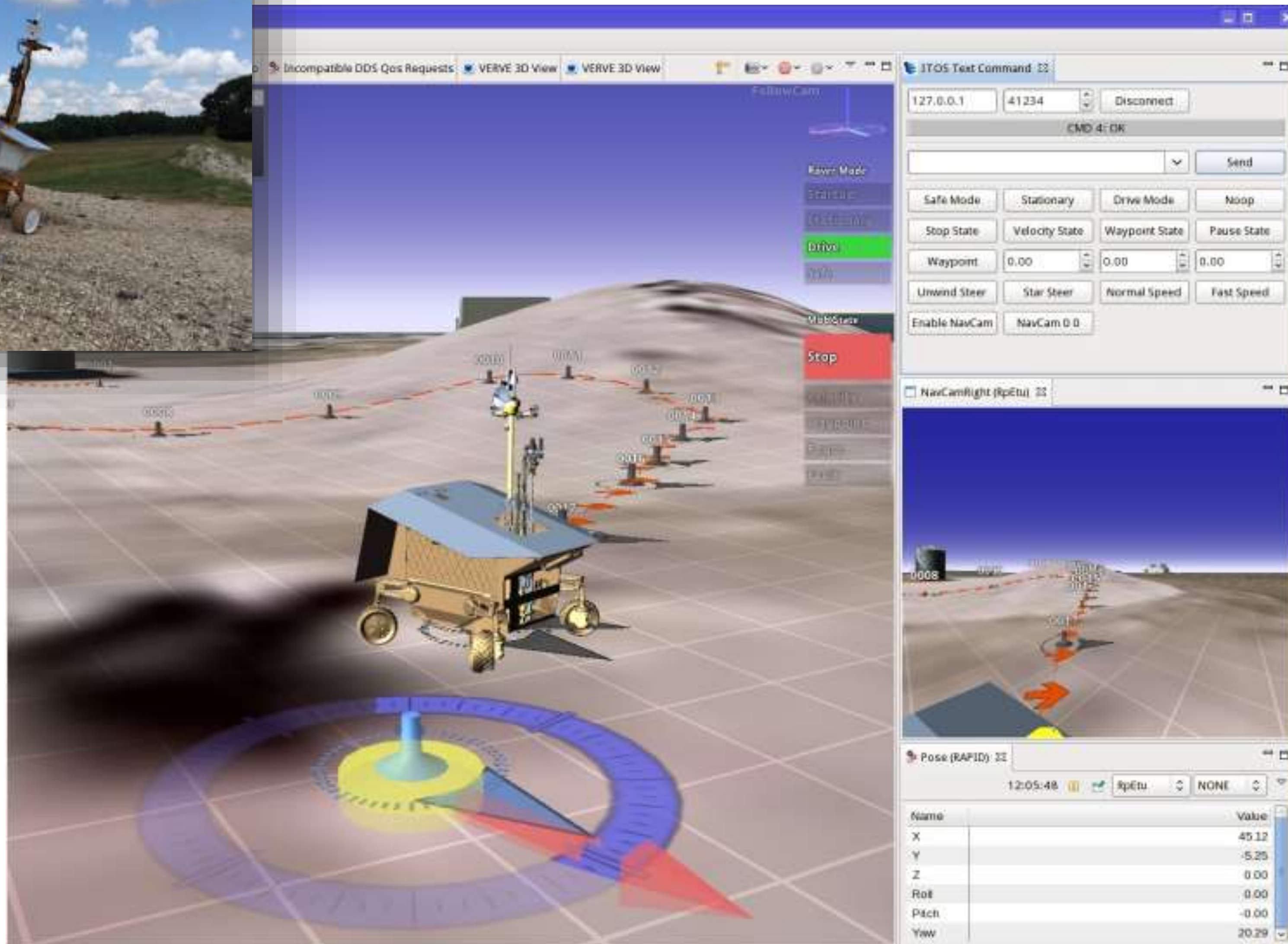
2015-08-18

Mother Nature rebelling. Building sand barriers to flowing water

Heading back to the highbay to do a systems check

RP15 First Prospecting/Processing in the Field

2015-08-21



"VERVE" driving tool funded by STMD…

…. how we drove RP15 at JSC from ARC

Distributed Operations Test testing

2015-08-21

NASA-ARC Mission Control room driving RP15 rover @ NASA-JSC

NASA-JSC Rock Yard from the rover (left) stereo camera

3-D Image Viewing of NIRVSS Camera Images During DOT

NASA-KSC Payload Control room

RP15 Environmental Testing

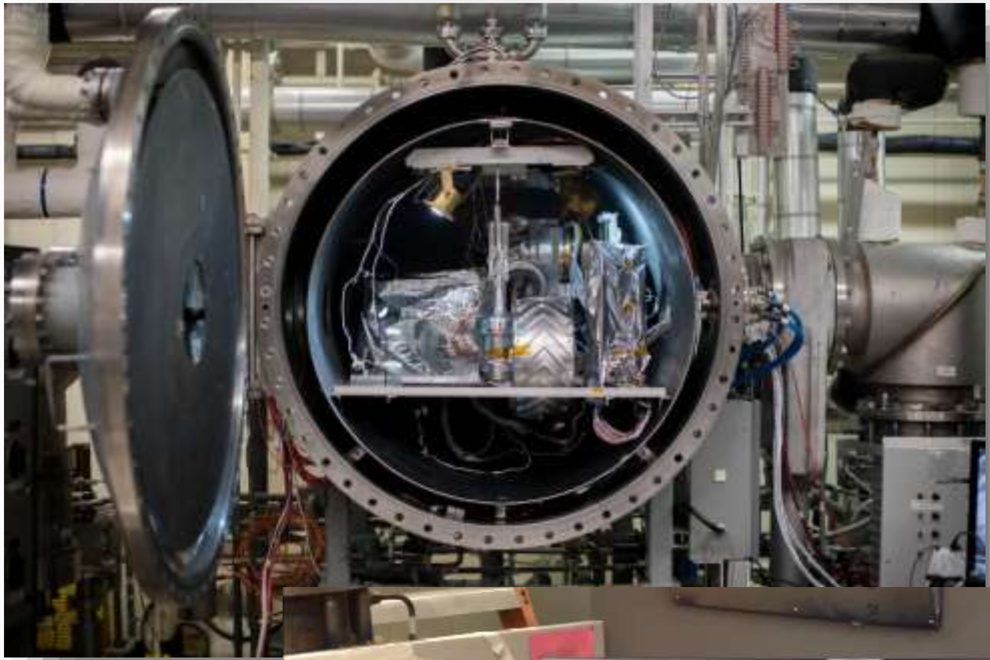
RP15 in ARGOS gravity offload facility (1/6g) (VIDEO)

Mobility, Lander Egress, Drilling

RP15 in ARGOS gravity offload facility (1/6g) (VIDEO)

Wheel grouser studies: Obstacle climbing @ 1/6g

RP15 Undergoing TVAC testing
2016-03



TVAC chamber testing of
RP15 rover subsystems

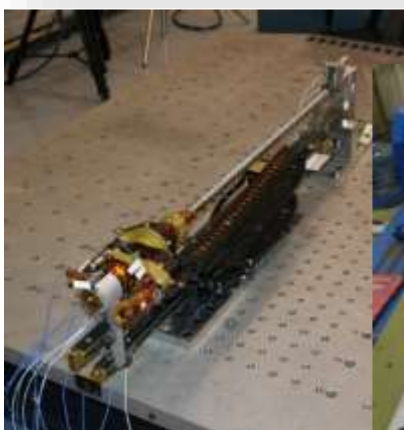
RP15 wheels & steering
assemblies undergoing
TVAC test

RP15 Undergoing Vibe testing

2016-03

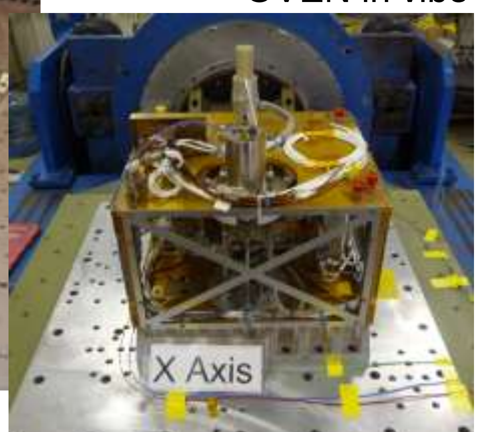
TVAC chamber X/Y-axes testing of RP15 rover

TVAC chamber Z-axis testing of RP15 rover



Drill in vibe

OVEN in vibe



RP15 Drill testing

2016-06

Drill and sample-handling system readied for sample collection

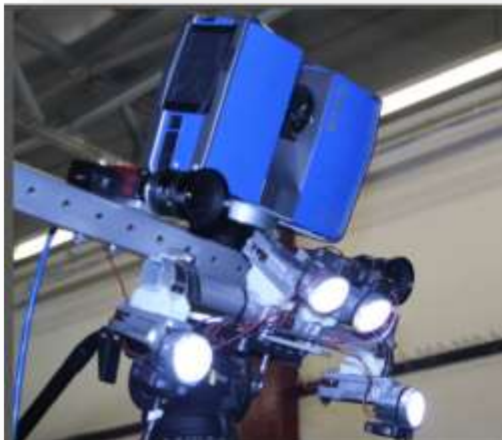
Drill testing at NASA-GRC's VF-13 TVAC chamber measuring lunar volatiles loss when drilling a meter deep into lunar soil and transferring materials into the RP rover

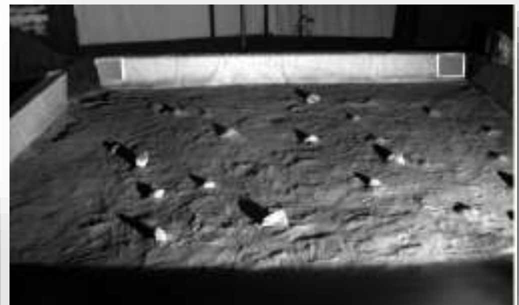
Testing the flight-like RP system, including spectrometers, a drill, and sample-handling system at lunar conditions, with engineered lunar-like soil conditions, doped with 5% water and chilled to -100C

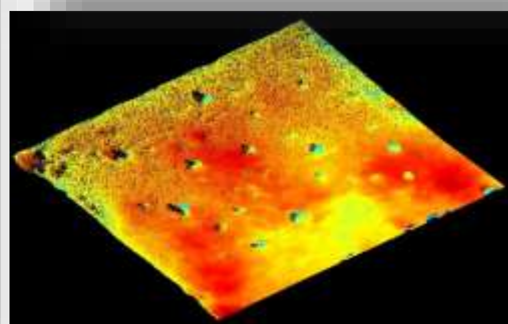
Stereo Vision testing in lunar polar contexts

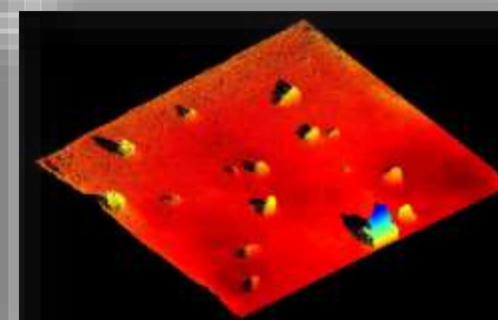
2016-06

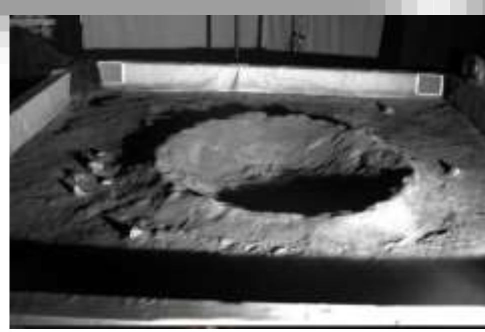
Studying stereo camera effectiveness with different rocks sizes/distributions and low-angle sunlight (long shadows)

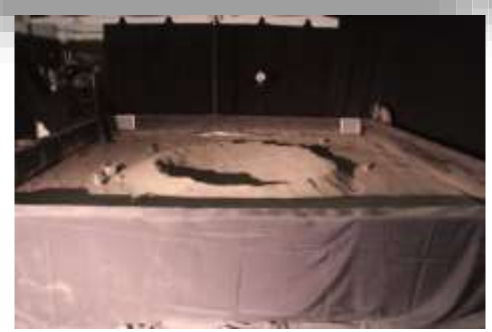












RP Education and Public Outreach Activities

- Full assault on Social Media!
  - Actively putting RP's message our there
  - Ranking member Rep Mike Honda's Chief staffer requested an RP briefing @ NASA-ARC because of what he "and other techie staffers" read on Twitter

Resource Prospector (RP) Overview

Mission:

- Characterize the nature and distribution of water/volatiles in lunar polar sub-surface materials
- Demonstrate ISRU processing of lunar regolith

RP Specs:

- Mission Life: 6-14 earth days
  (extended missions being studied)
- Rover + Payload Mass: 300 kg
- Rover Comm: X-band 600kbps directional / 4kbps omni downlink
- Rover Dimensions: 1.4m x 1.4m x 2m
- Rover Power (nom): 300W
- Max speed: 25cm/s. Prospecting: 10cm/s
- Cost: <$350M (excl LV)
- Mission Class: D-Cat III
- Launch Vehicle: Falcon 9 v1.1

Project Timeline:

✓ FY14: Phase A (Formulation)
✓ FY15: Phase A (Demonstration: RP15)
- FY16: Phase A (Environmental testing: RP15)
- FY17: Phase B SRR/MDR
- FY18: PDR (Implementation)
- FY19: CDR (Critical design)
- FY20: SIR/I&T
- FY21/22: RP launch


Let’s go.