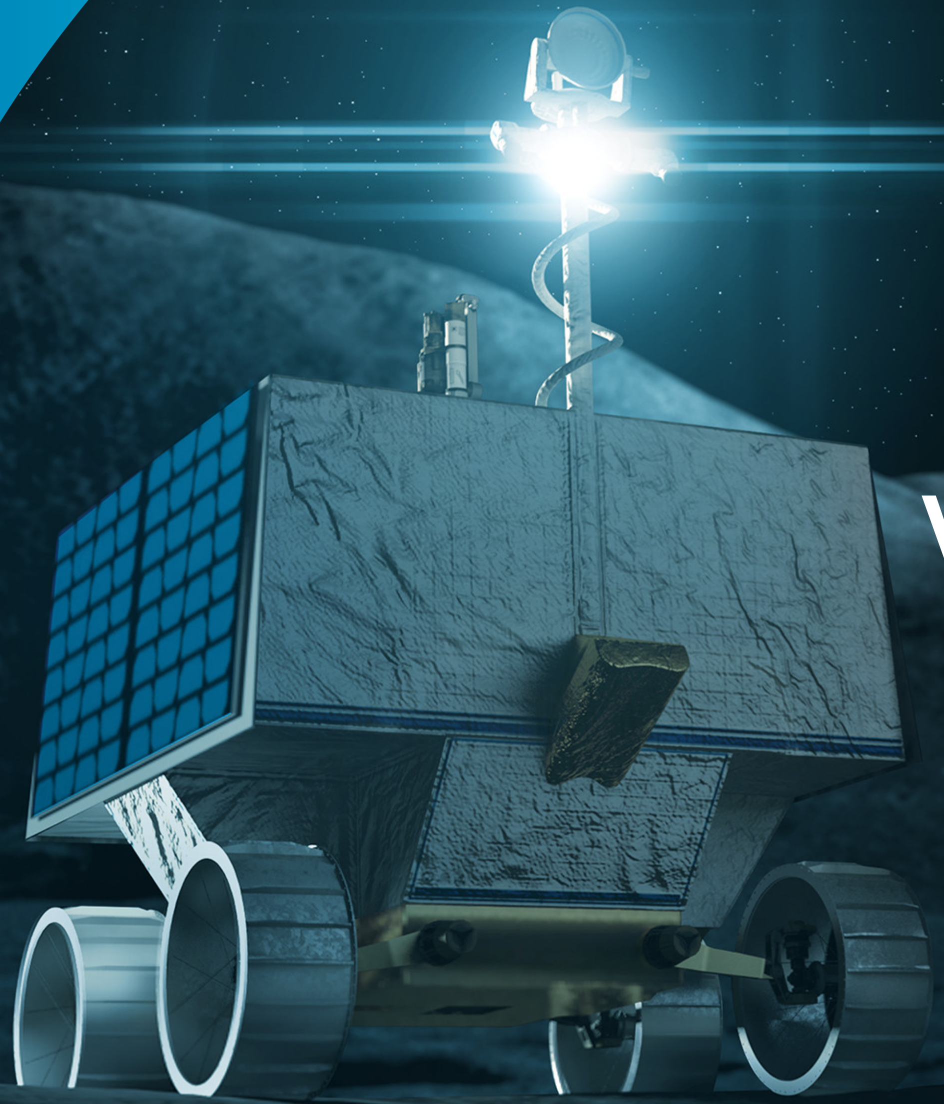
National Aeronautics and
Space Administration



VIPER

Volatiles Investigating Polar Exploration Rover

Terry Fong

Chief Roboticist

NASA Ames Research Center

29 March 2021

Just Two Decades Ago…

The Moon was a very different place from how we understand it today

Studied from the Earth, in-situ and with samples returned to Earth

The “general” thinking was:

- The surface was relatively constant
- A thin exosphere of Argon, Sodium, Potassium
- ***Bone* dry (~100 ppm of water in soils)**

Toward Understanding Lunar Water

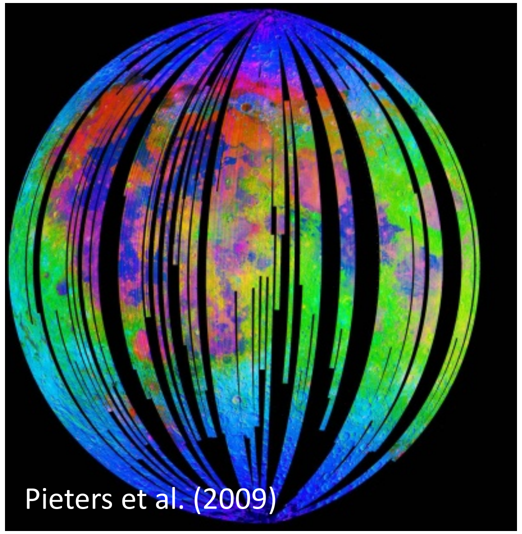
Moon now known to host all three forms of Solar System water: endogenic, sequestered external and in-situ*

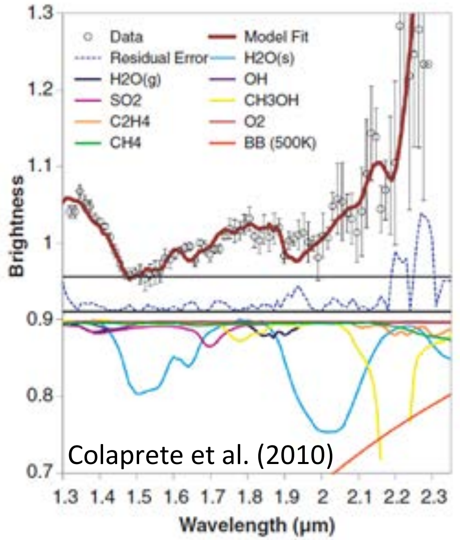
- Do not yet understand the concentration, evolution and interrelated dynamics of these varied sources of water

Understanding the distribution, both laterally and with depth, addresses key exploration and science questions

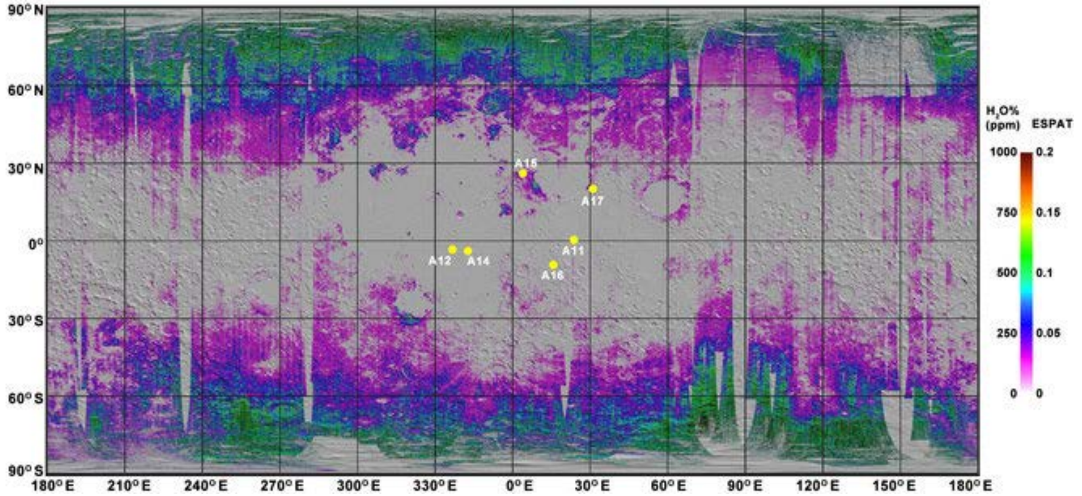
- Surface measurements across critical scales are necessary to characterize the spatial distribution and state of the water

"Prospecting" for lunar water at poles is the next step in understanding the resource potential and addressing key theories about water emplacement and retention


Pieters et al. (2009)



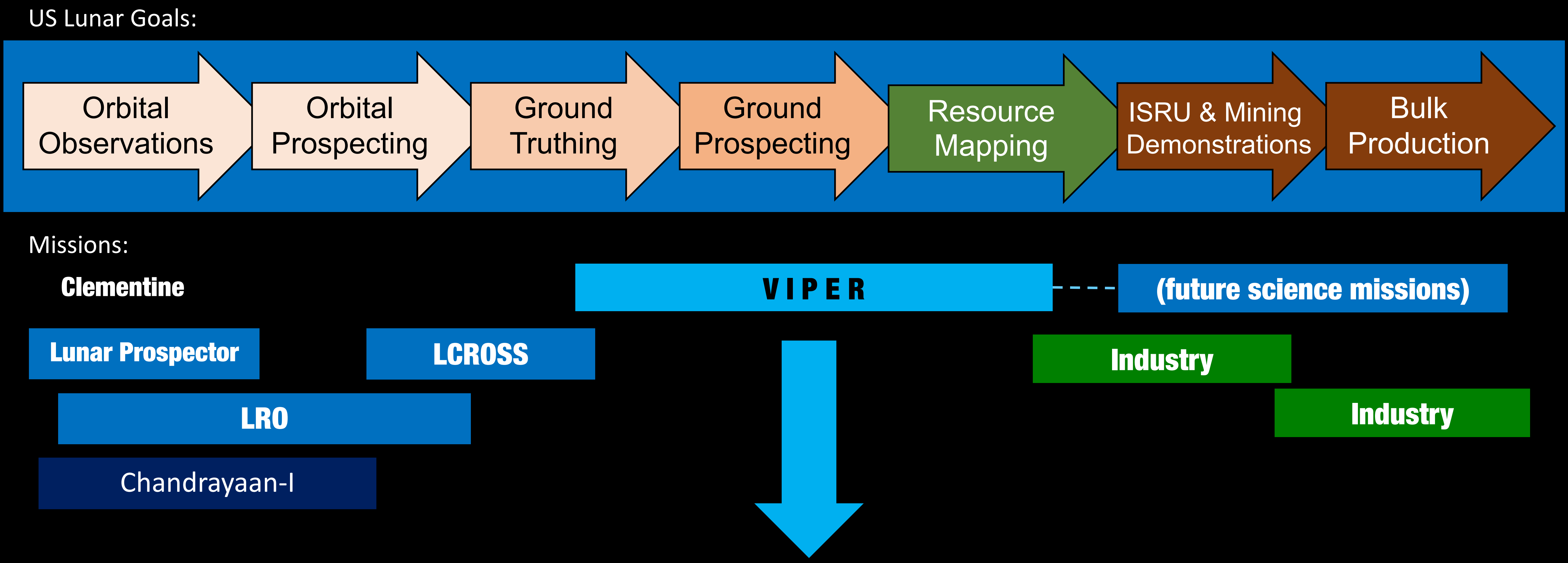
Colaprete et al. (2010)



Li and Milliken (2017)

*From Peters et al. Transformative Lunar Science (2018)

The Big Picture of Lunar Resources



VIPER bridges Government and Industry missions, addressing volatiles mapping, in support of the Economic opportunity of the Moon

Narrator: We know from decades of study

VIPER Mission

Lunar south pole

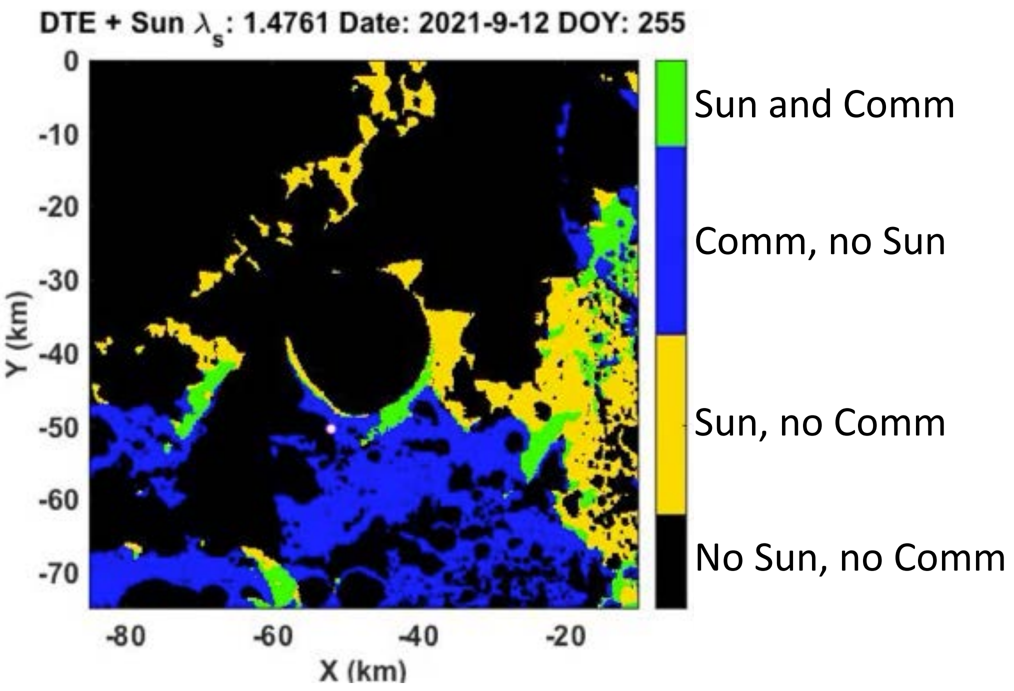
- 11/2023 launch
- ~100 day mission (including extended survival periods)

Science objectives

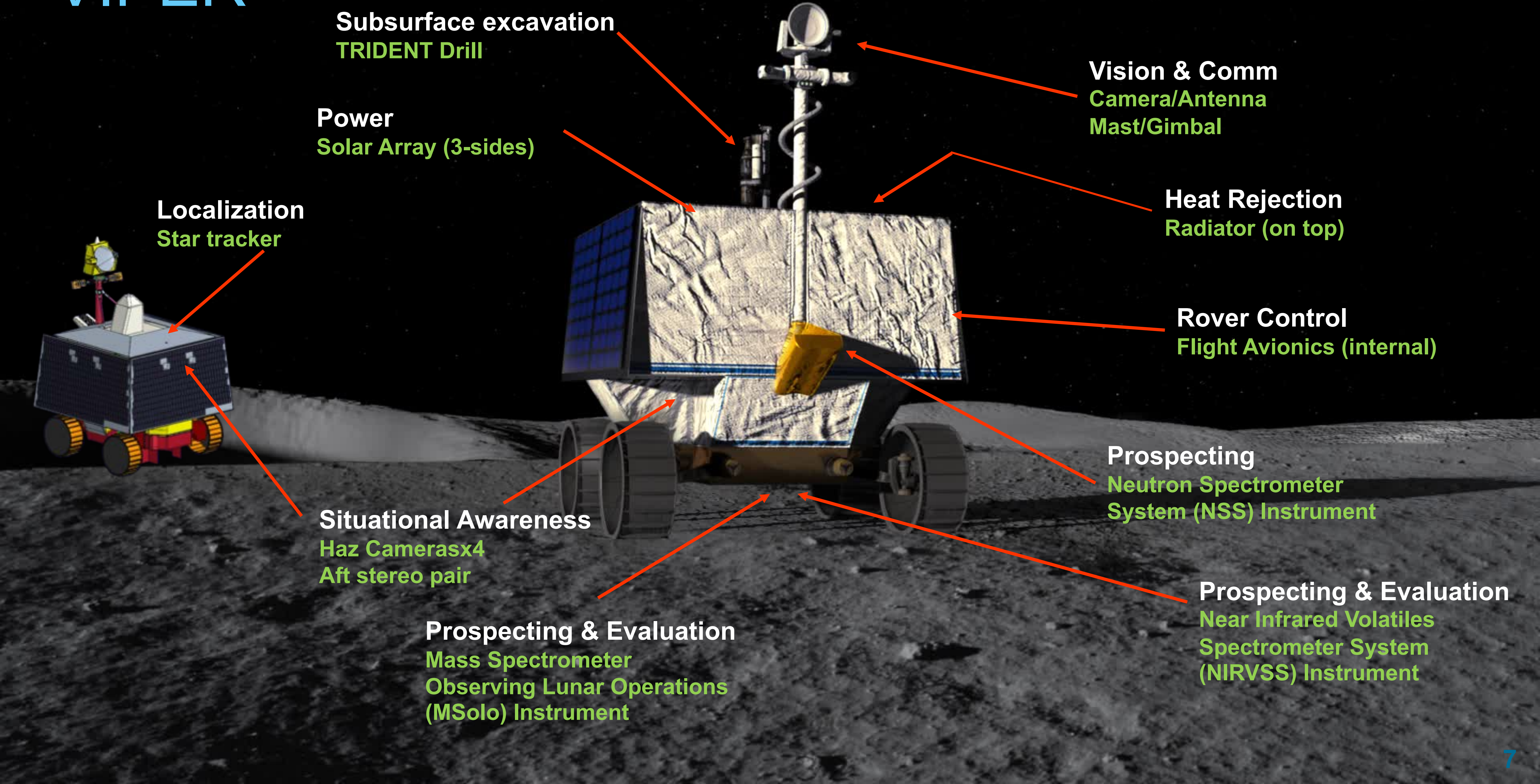
- Characterize distribution and physical state of volatiles (water ice, etc)
- Provide data to evaluate the potential for lunar in-situ resource utilization

A few unique challenges (among many…)

- Dynamic environment: light + shadows
- Real-time mission ops and science
- Prospecting & "speed made good"



VIPER



Subsurface excavation
TRIDENT Drill
Power
Solar Array (3-sides)
Localization
Star tracker
Vision & Comm
Camera/Antenna
Mast/Gimbal
Heat Rejection
Radiator (on top)
Rover Control
Flight Avionics (internal)
Prospecting
Neutron Spectrometer
System (NSS) Instrument
Situational Awareness
Haz Camerasx4
Aft stereo pair
Prospecting & Evaluation
Mass Spectrometer
Observing Lunar Operations
(MSolo) Instrument
Prospecting & Evaluation
Near Infrared Volatiles
Spectrometer System
(NIRVSS) Instrument

Neutron Spectrometer System (NSS)

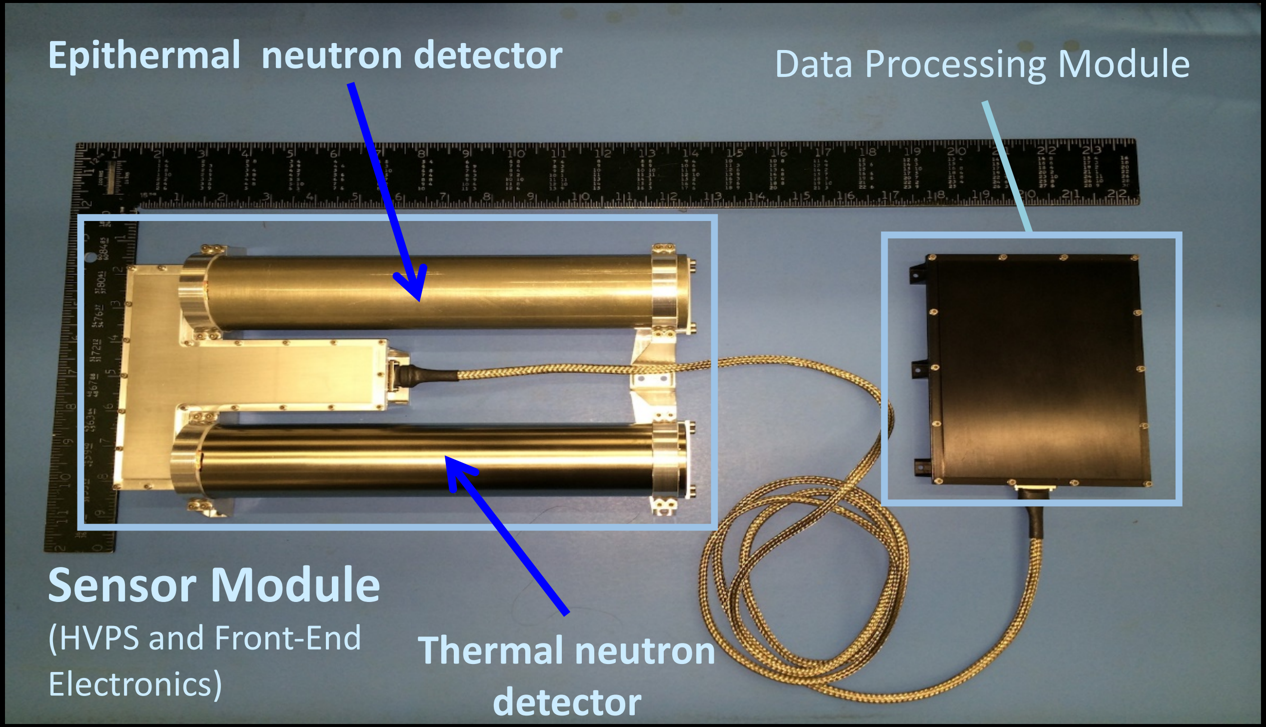
NSS (NASA-ARC, Lockheed Martin ATC)
PI: Rick Elphic (NASA ARC)

Instrument Type: Two channel neutron spectrometer

Key Measurements: NSS assesses hydrogen and bulk composition in the top meter of regolith, measuring down to 0.5% (wt) WEH to 3-sigma while roving

Operation: On continuously while roving

Instrument Name	NSS
Mass [kg], CBE	1.9kg (~4 lbs)
Dimensions [cm]	Sensor Module: 21.3 x 32.1 x 6.8 (9”x13”x3”) Data Processing Module: 13.9 x 18.0 x 3.0
Power [W]	1.6
Sensitivity	WEH to ≥0.5 wt% water-equivalent at 10 cm/s
Accuracy	5 – 10% absolute



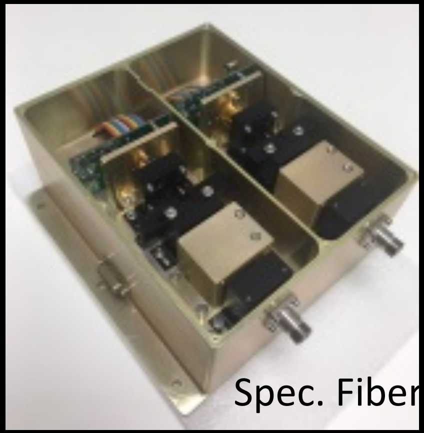
Near InfraRed Volatiles Spectrometer System (NIRVSS)

NIRVSS (NASA-ARC, Brimrose Corporation)
PI: Anthony Colaprete (NASA ARC)

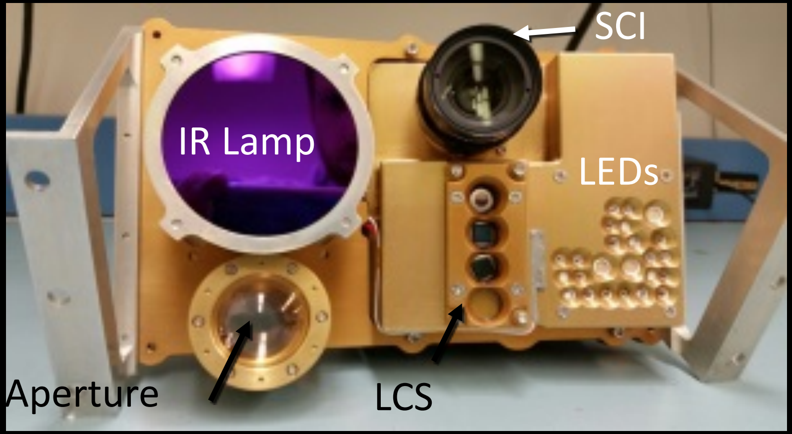
Instrument Type: NIR Point Spectrometer, 4Mpix Panchromatic Imager with 7 LEDs, four channel thermal radiometer
Key Measurements: Volatiles including H_2O, OH, and CO_2, minerology, surface morphology and temperatures
Operation: On while roving and during drill operations

Instrument Name	NIRVSS
Mass [kg]	3.57 kg (~9 lbs), not including fiber
Dimensions [cm]	Spectrometer: 18x18x8.5 (7"x7"x3") Bracket: 20.4x13x15.1 (8"x5"x6")
Power [W], Avg	Spectrometer = 12 Bracket Assembly = 5.26 Lamp = 12.3
Sensitivity	Range: 1.2 to 4.0 mm SNR>100 at 2 and 3 mm Water Ice to <0.25%
Accuracy	Radiance to <25%

Spectrometer



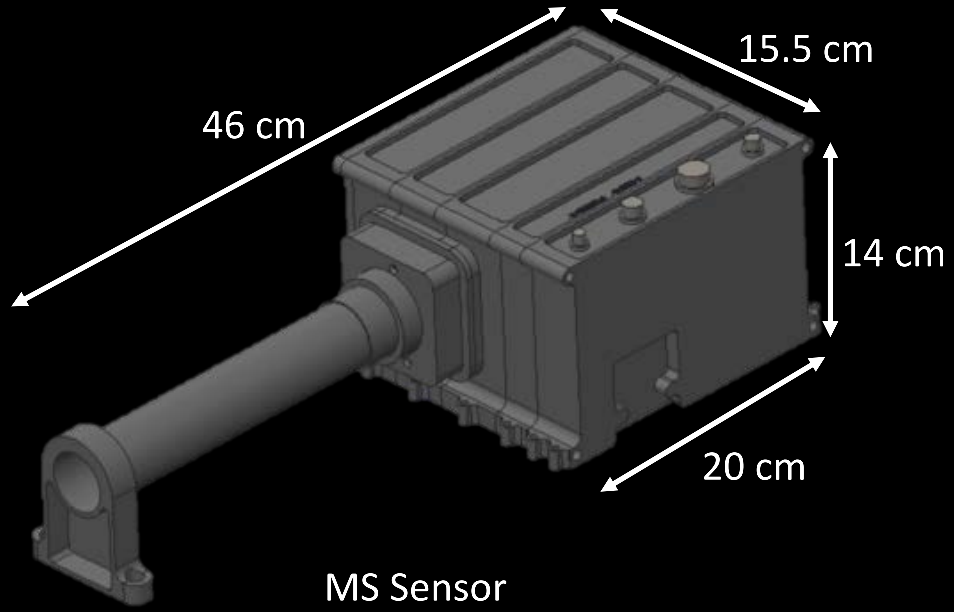
Bracket Assembly



Mass Spectrometer Observing Lunar Operations (MSolo)

MSolo (NASA-KSC, INFICON)
PI: Janine Captain (NASA KSC)

Instrument Type: Quadrupole mass spectrometer
Key Measurements: Identify low-molecular weight volatiles between 2-100 amu, unit mass resolution to measure isotopes including D/H and $0^{18}/0^{16}$
Operation: Views below rover and at drill cuttings, volatile analysis while roving and during drill activities



MS Sensor

Instrument Name	MSolo
Mass [kg], CBE	6 kg (~13 lbs)
Dimensions [cm]	15.5 x 20 x 46 cm (2”x8”x18”)
Power [W]	Average 35 W while scanning
Detectors	Faraday Cup (MDPP* 1.5e-12 Torr)
	Electron Multiplier (MDPP* 2e-15 Torr)

The Regolith and Ice Drill for Exploring New Terrain (TRIDENT)

TRIDENT (Honeybee Robotics)
PI: Kris Zacny (Honeybee)

Instrument Type: 1-meter hammer drill
Key Measurements: Excavation of subsurface material to 100 cm; Subsurface temperature vs depth; Strength of regolith vs depth (info on ice-cemented ground vs. ice-soil mixture).
Operation: Performs subsurface assays down to 100 cm in <1 hr, depositing cuttings at surface for inspection

Instrument Name	TRIDENT
Mass [kg], CBE	18 kg (~40 lbs) (includes launch locks)
Dimensions (stowed) [cm]	27 x 22 x 177 cm (11"x9"x70")
Power [W]	Idle: < 5 Augering: ~20 nominal, 175 max Percussion: 0 nominal, 150 max
Telemetry	~3.4 kbits/s

TRL6 Drill

Lunar cryo-chamber tests at GRC

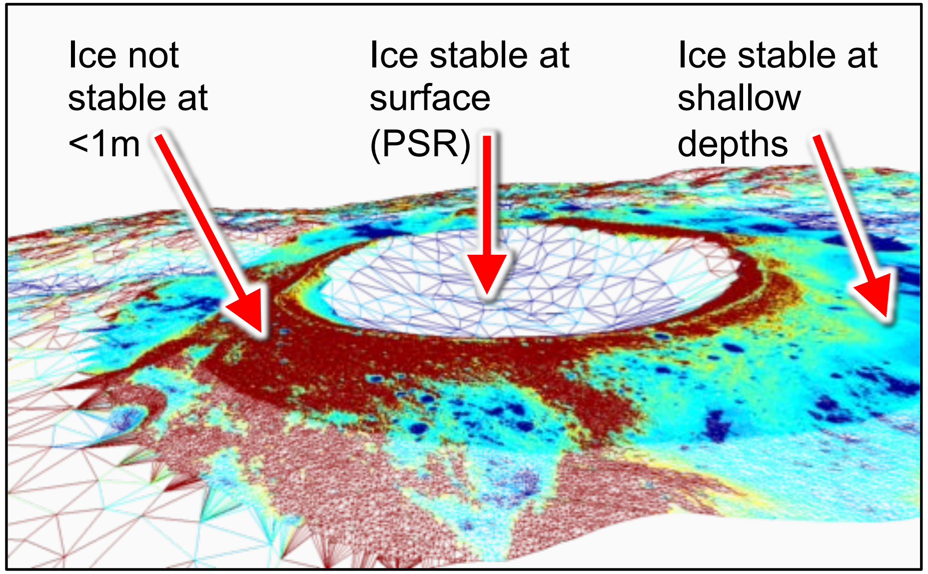
Where is water (ice) at the lunar poles?

Environmental factors

- Temperatures (surface or subsurface) must be low enough to retain water ice
- Geophysical properties (topography, materials, depth, etc.)

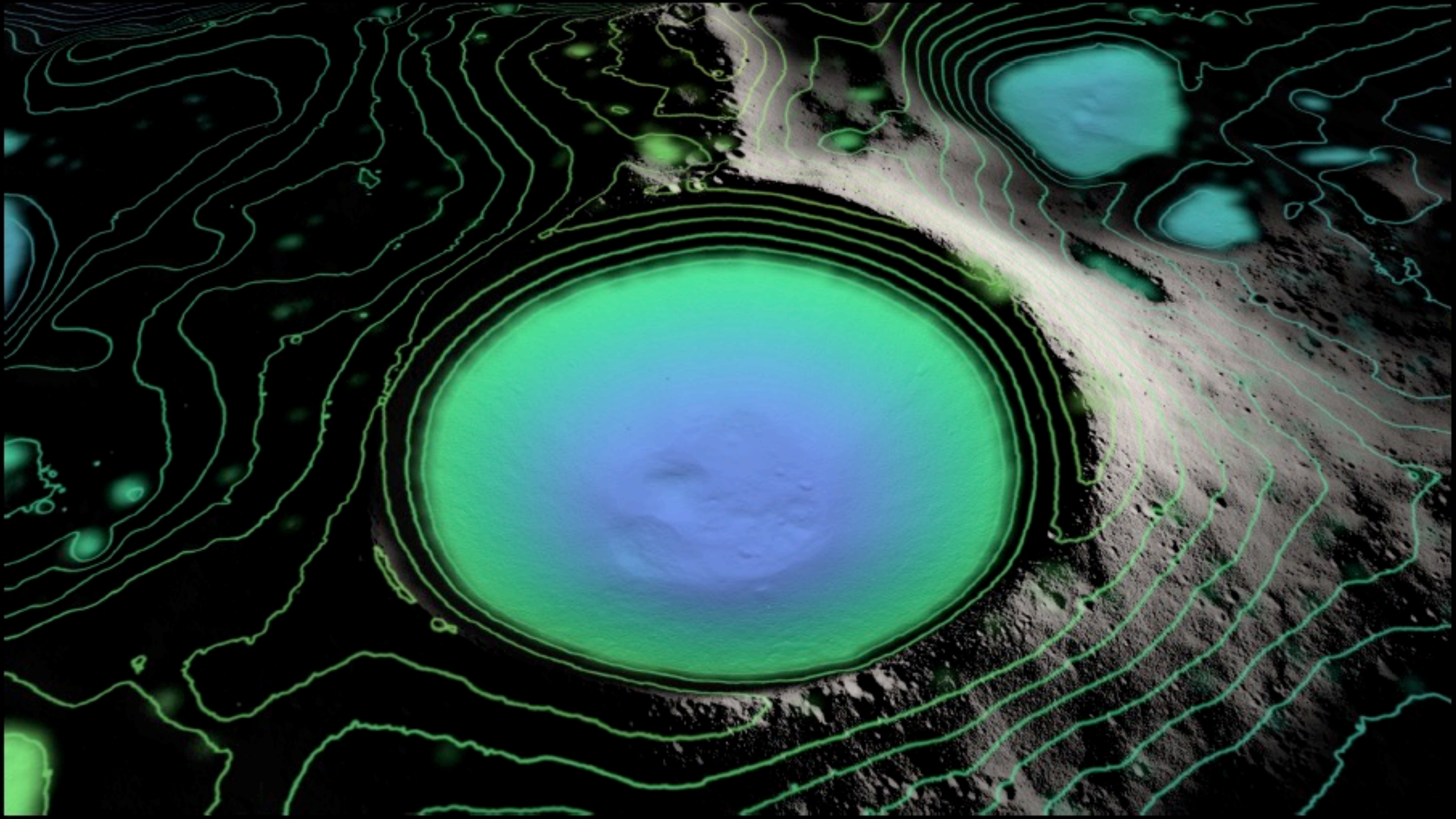
Ice Stability Regions

- **Dry**: Temperatures in the top meter expected to be too warm for ice stability
- **Deep**: Ice expected to be stable between 50-100 cm of the surface
- **Shallow**: Ice expected to be stable within 50cm of surface
- **Surface**: Ice expected to be stable at the surface (e.g., within a Permanently Shadowed Region or "PSR")



12

Permanently Shadowed Regions on the Moon

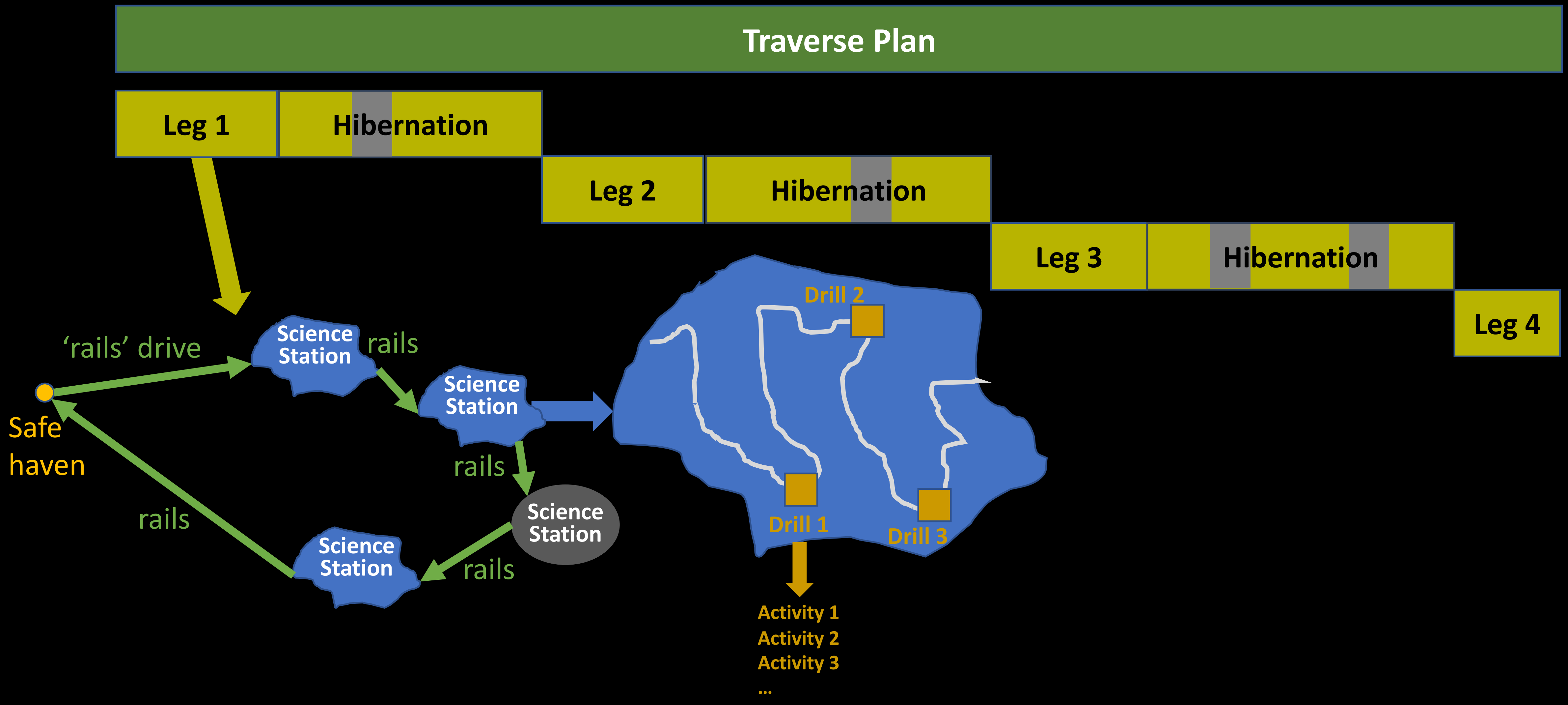


NASA SVS

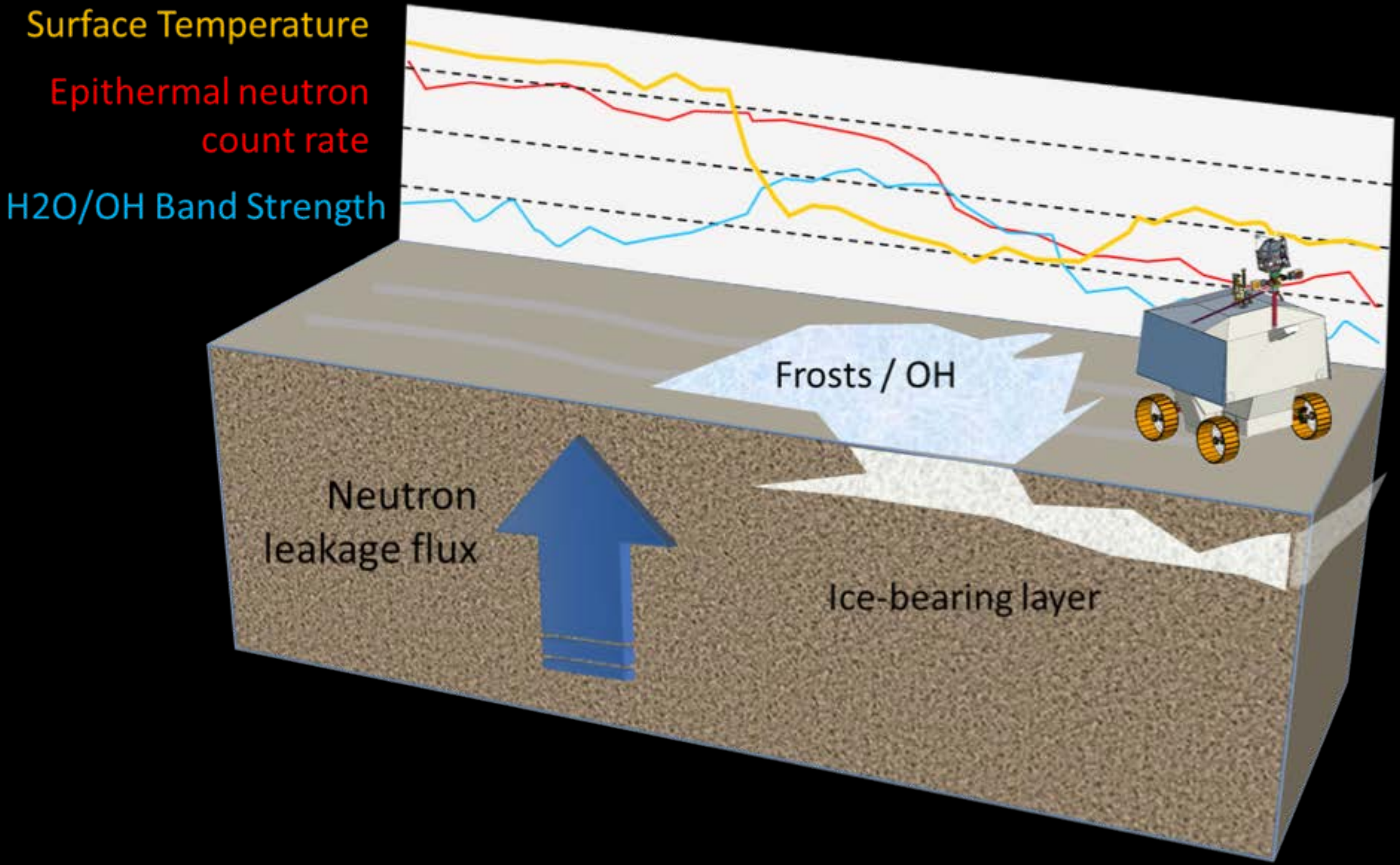
- Low obliquity.
- At high latitudes, topography creates permanently shadowed regions.
- $>10^4$ km^2 area of PSR.
- These exist on size scales ranging from sub-mm to 10 km.

https://svs.gsfc.nasa.gov/4043

Surface Operations

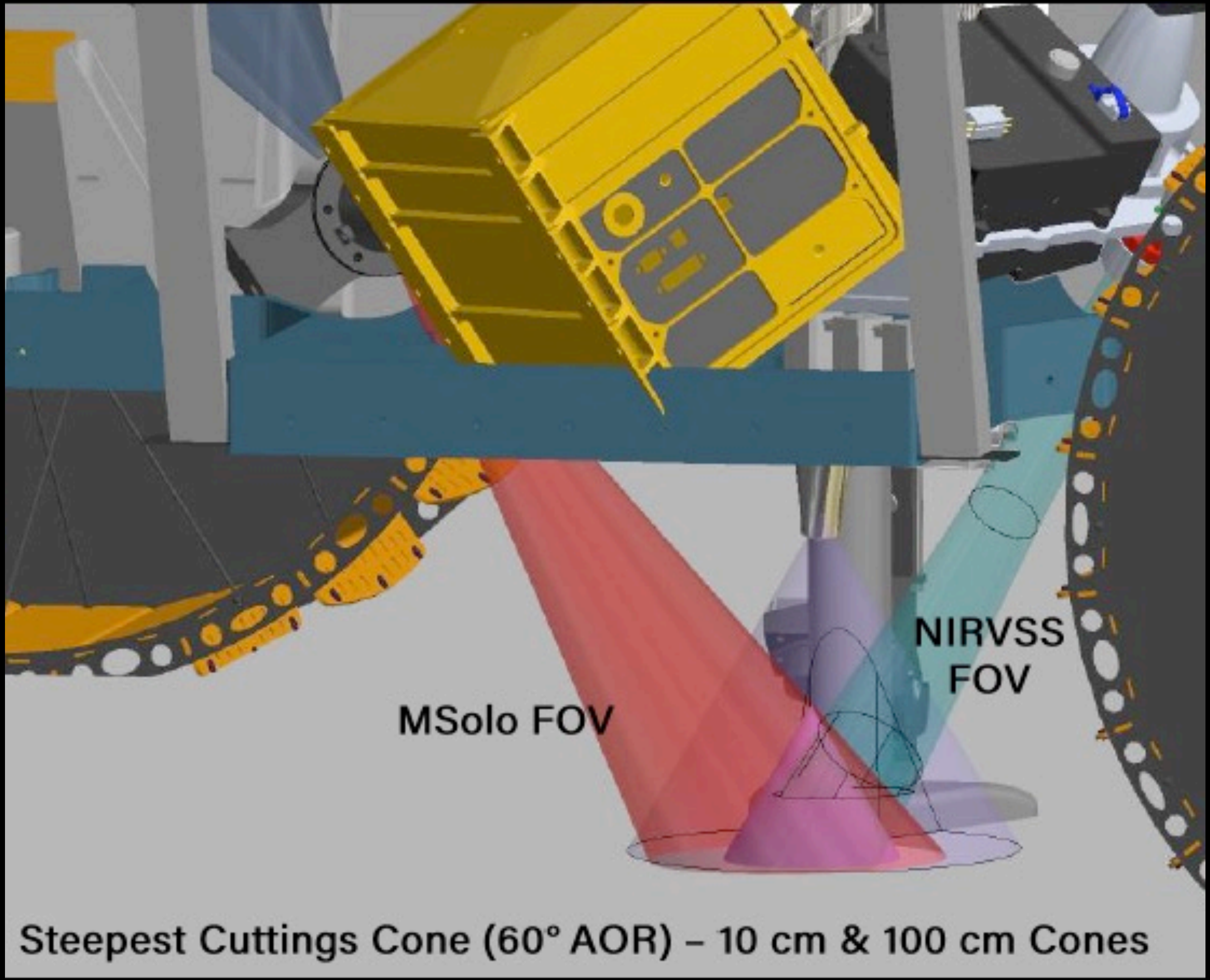


Prospecting



- NSS, NIRVSS & MSolo take data continuously while roving or parked
- NSS Neutron flux variations identify abundance and burial depth of hydrogenous materials
- NIRVSS NIR surface reflectance identifies surface and excavated hydration
- MSolo detects subliming gasses (H_2 or H_2O vapor) identify surface and excavated hydration

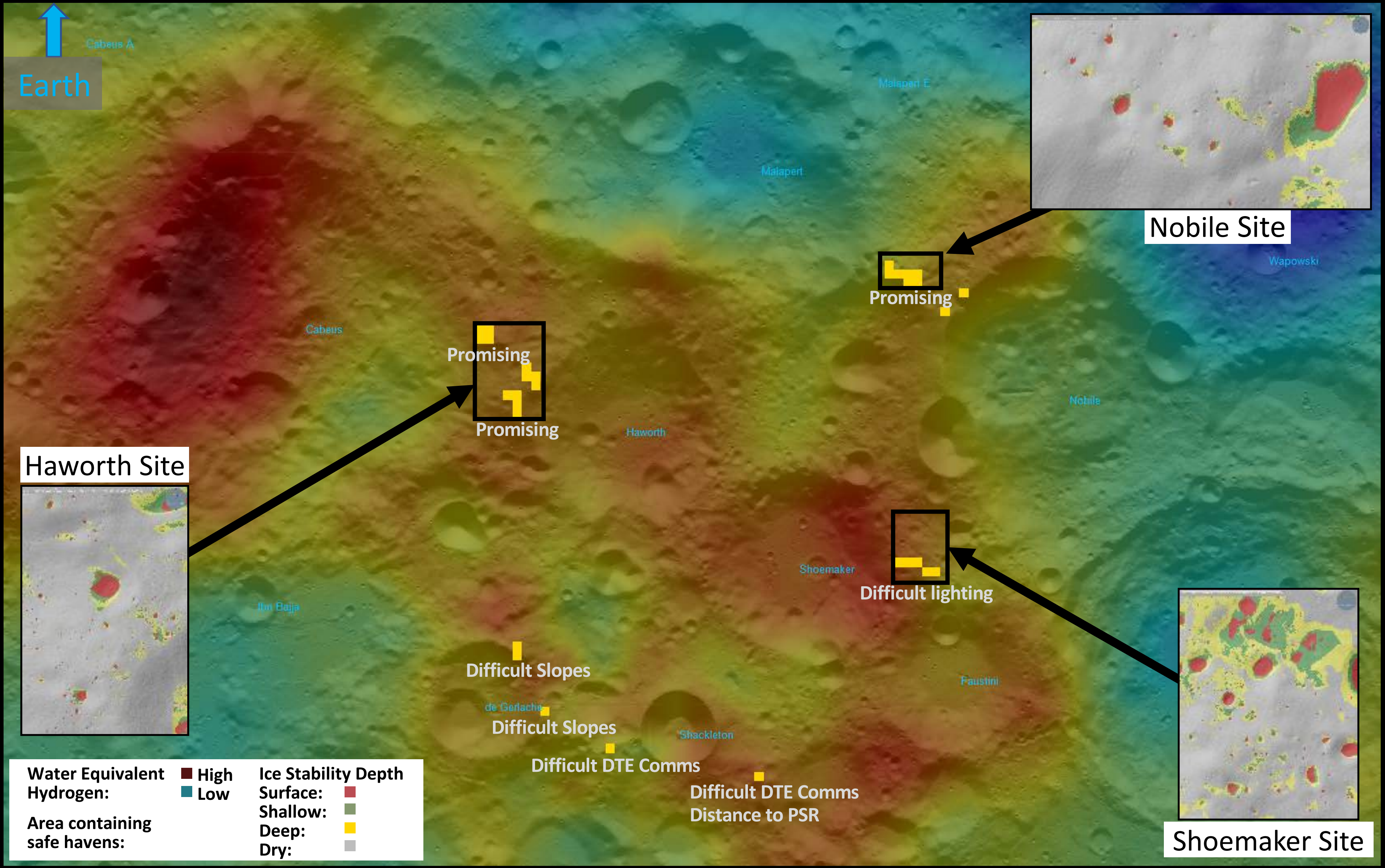
Sampling



- TRIDENT samples in 10 cm “bites” down to 1 meter, using a simple auger bit
- Each 10cm sample can be brushed to the surface for inspection by NIRVSS and MSolo
- NIRVSS images the cuttings at multiple wavelengths (providing context for NIRVSS and MSolo observations) and measures the scene temperature
- This process identifies the stratification of hydrogen bearing volatiles, “tying down” NSS measurements

Three locations for traverse studies

- High water-equivalent hydrogen
- A variety of thermal environments using ice stability depth as an indicator
- Periods of shadow short enough for the rover to survive
- Flat enough with Earth line-of-sight



Nobile Reference Traverse

Duration	91 days
Length	13.25 km
PSRs	2 (4 entries)
Shallow	6
Deep	3
Dry	2

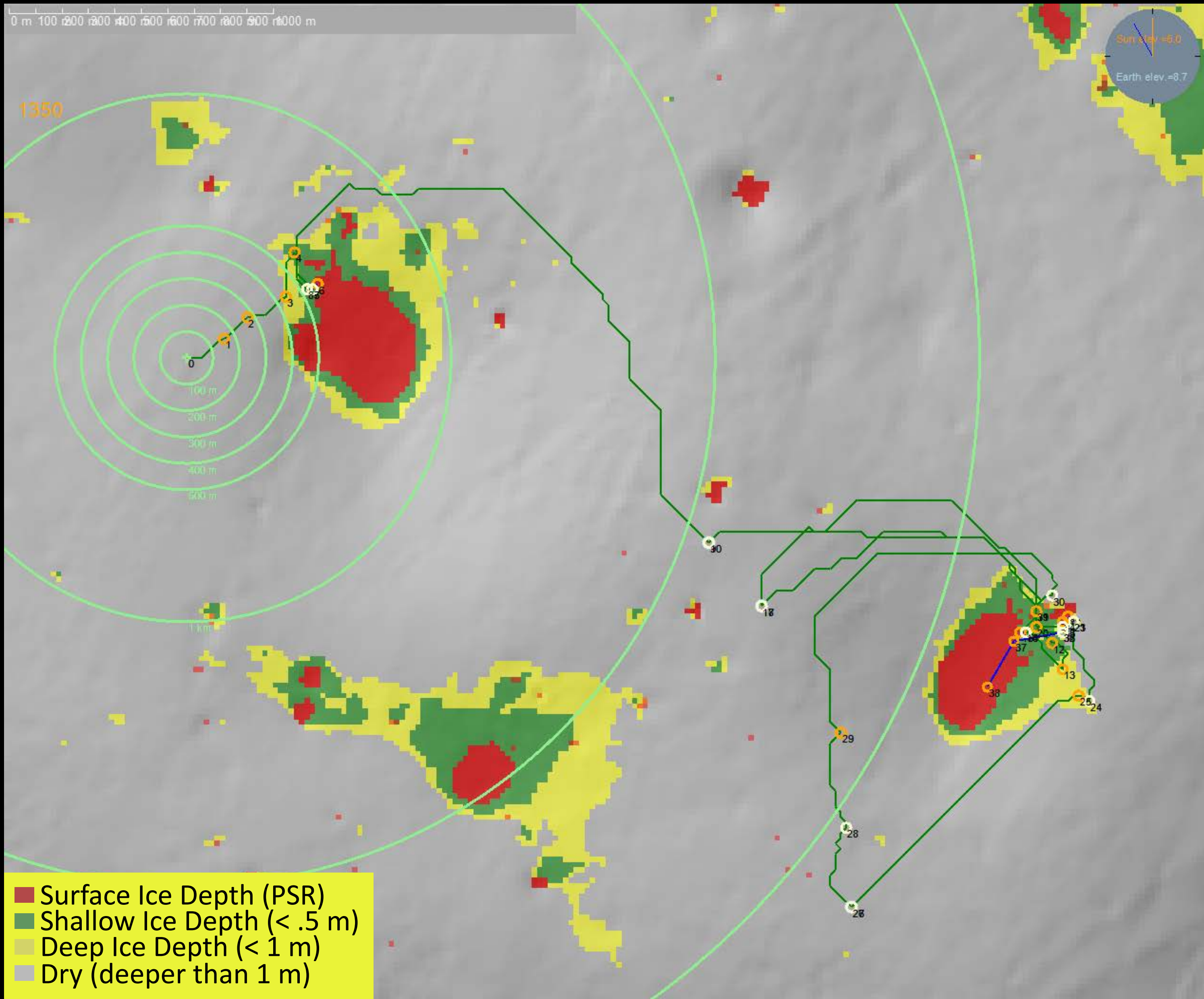
1st lunar day: 1 dry, 1 deep, 1 shallow, 1 PSR

Full mission success on mission day 36 (day 7 of second lunar day)

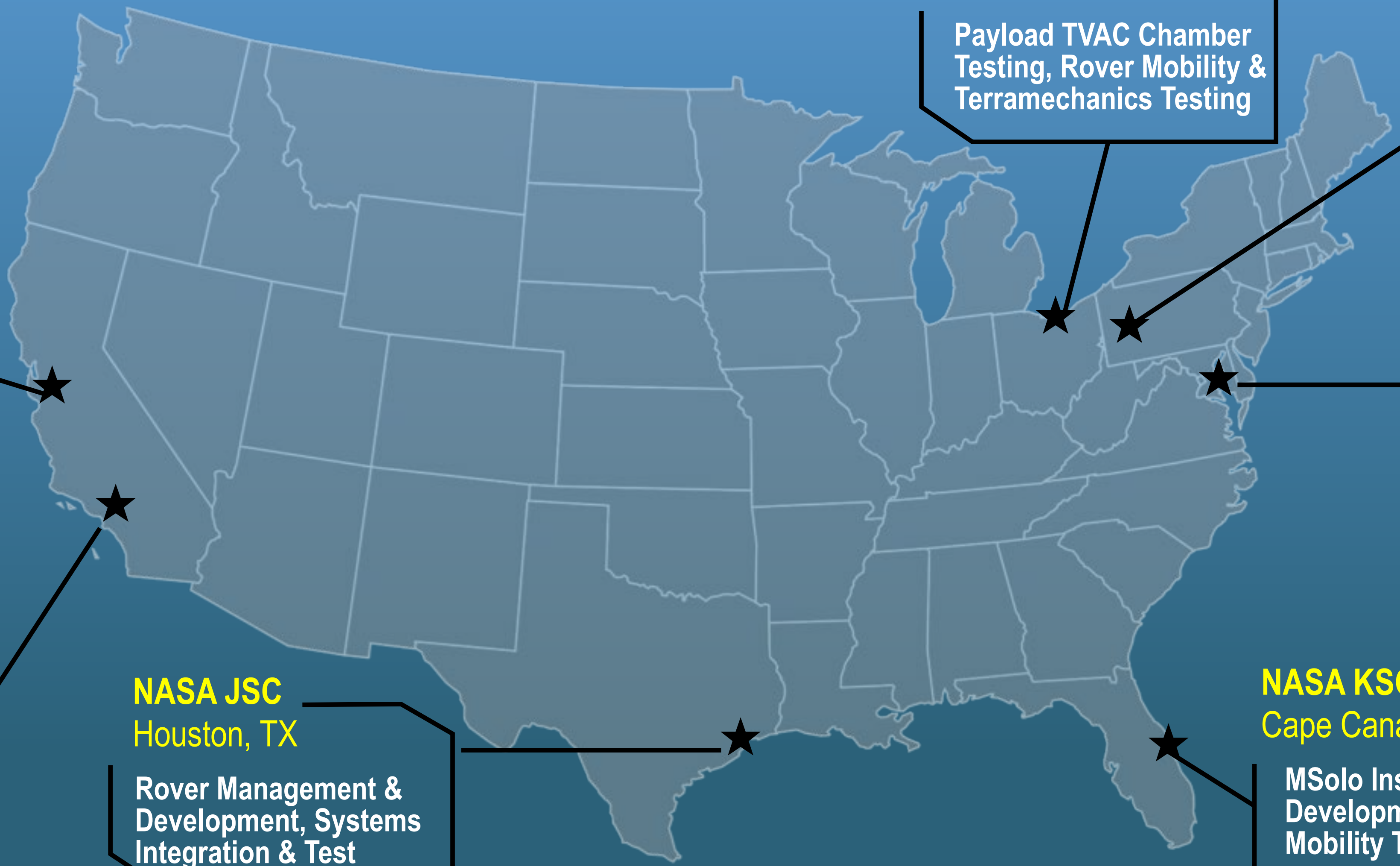
Total number of drill sites = 35

Total mapped ISR area (m^2):

- PSR = 765
- Shallow = 2295
- Deep = 1241
- Dry = 765



VIPER Development



NASA ARC
Moffett Field, CA
Mission Management, Science Management, NSS & NIRVSS Instruments, Rover Software & Mission Operations

Honeybee Robotics
Pasadena, CA
Payload Drill Development

NASA JSC
Houston, TX
Rover Management & Development, Systems Integration & Test

NASA GRC
Cleveland, OH
Payload TVAC Chamber Testing, Rover Mobility & Terramechanics Testing

Astrobotic Technology
Pittsburgh, PA
Commercial Lunar Payload Services (CLPS)

NASA HQ
Washington, DC
SMD Agency Management

NASA KSC
Cape Canaveral, FL
MSolo Instrument Development, Rover Mobility Testbeds

Commercial Lunar Payload Services (CLPS)

A new way to get the Moon

- Commercial “freight” delivery service (just like mailing a package)
- Started in 2018 with 9 vendors, now there are 14 able to provide service
- NASA is planning for at least two CLPS deliveries to the Moon each year beginning in fall 2021

Astrobotic Technology (CMU spin-off) will be delivering VIPER

- Astrobotic is responsible for launch and landing
- First flight of the Astrobotic “Griffin” lander (475 kg capacity, 100 m landing accuracy, 5 axial engines + 12 maneuvering thrusters)
- Griffin includes two sets of ramps (fore/aft) for VIPER egress

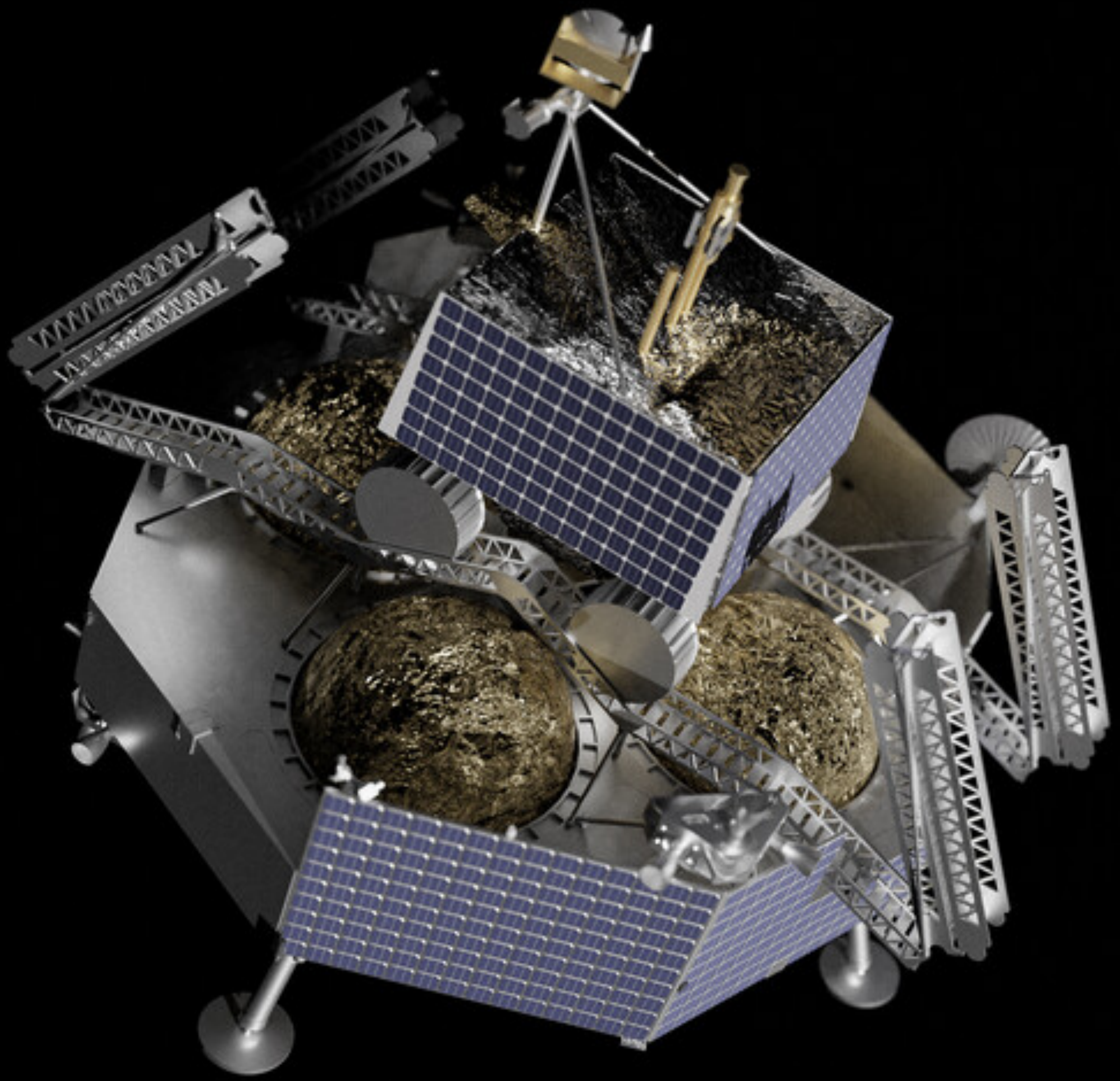


Image courtesy of Astrobotic

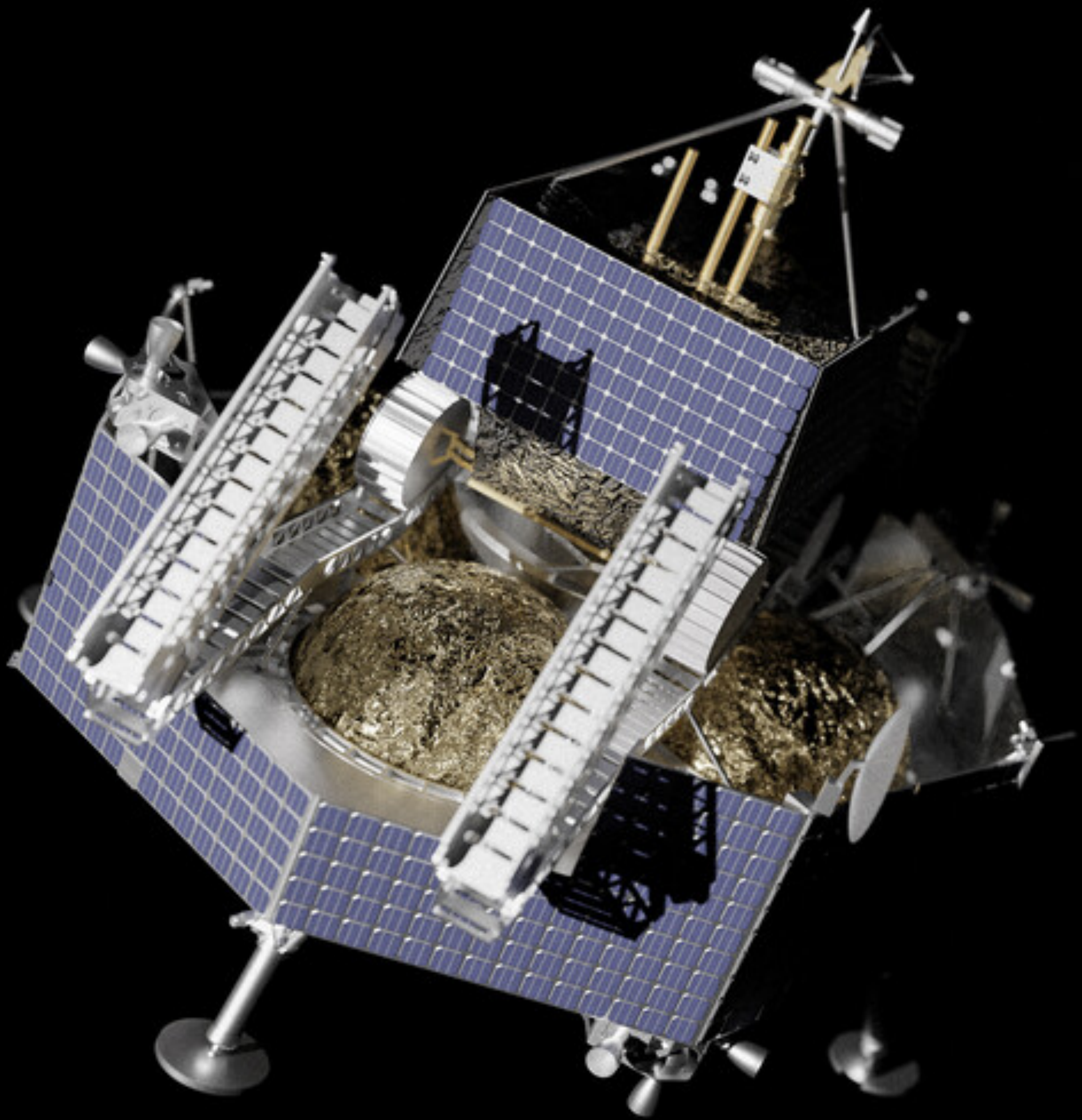


Image courtesy of Astrobotic

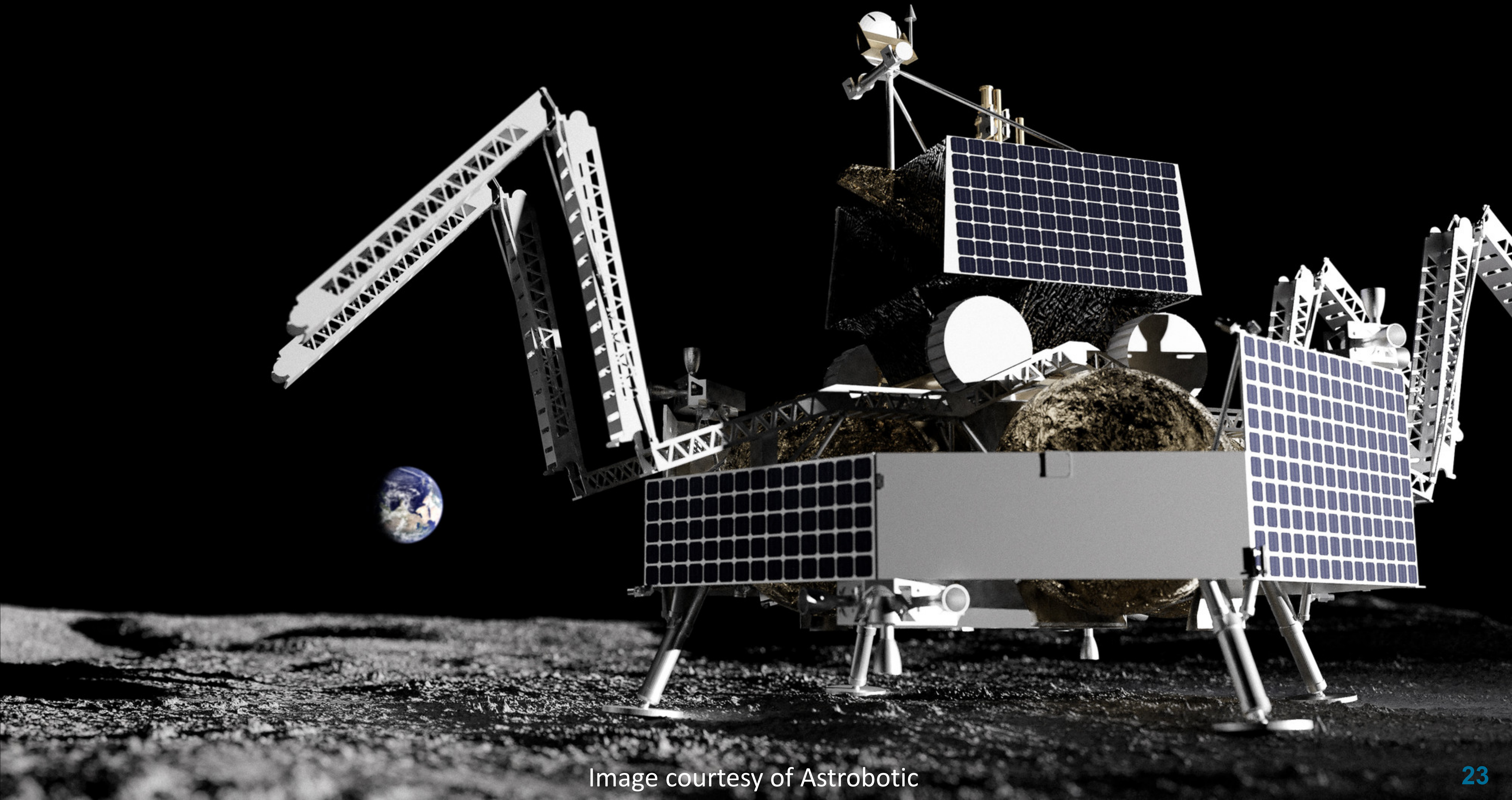


Image courtesy of Astrobotic

Image courtesy of Astrobotic

VIPER Rover

Mass: ~430 kg

- Rover, instruments, and lander release

Dimensions

- 1.8m x 1.8m x 2.6m (L x W x H)
- 0.5 m wheel diameter

Mobility: 4 wheels with adj. suspension

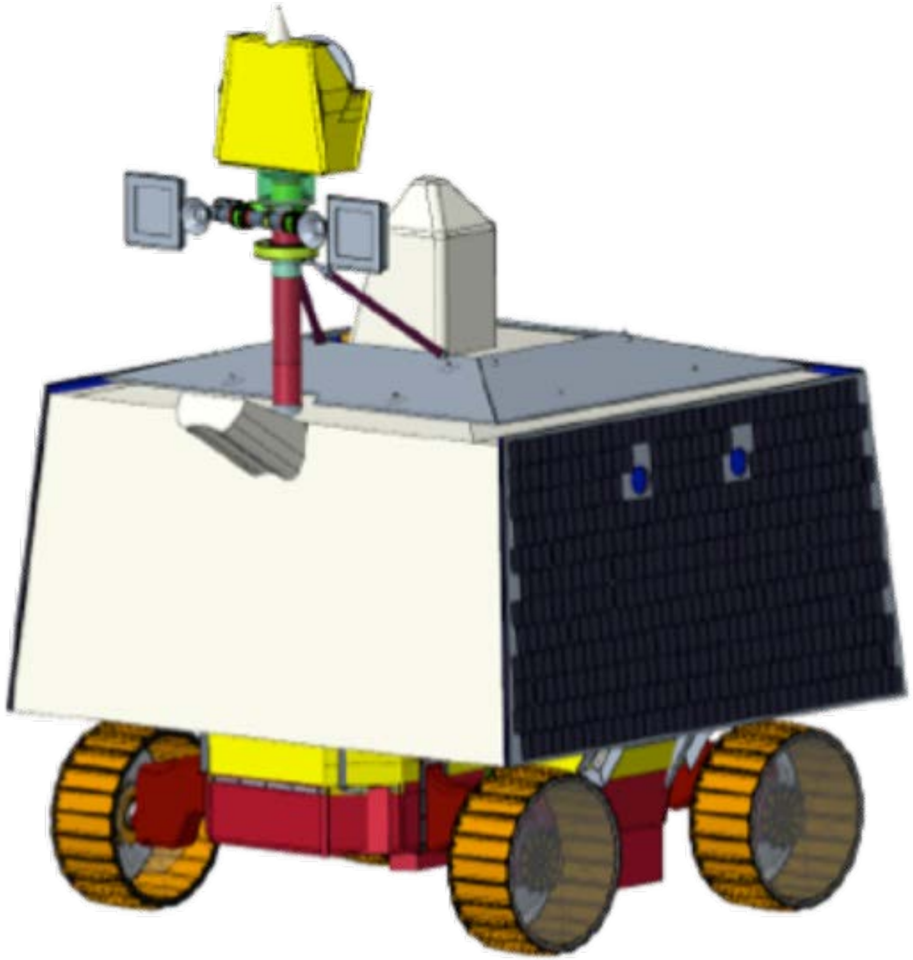
- 10-20 cm/s with 20 km range
- 20 cm obstacles, 15 deg slopes

Power: ~450W (peak)

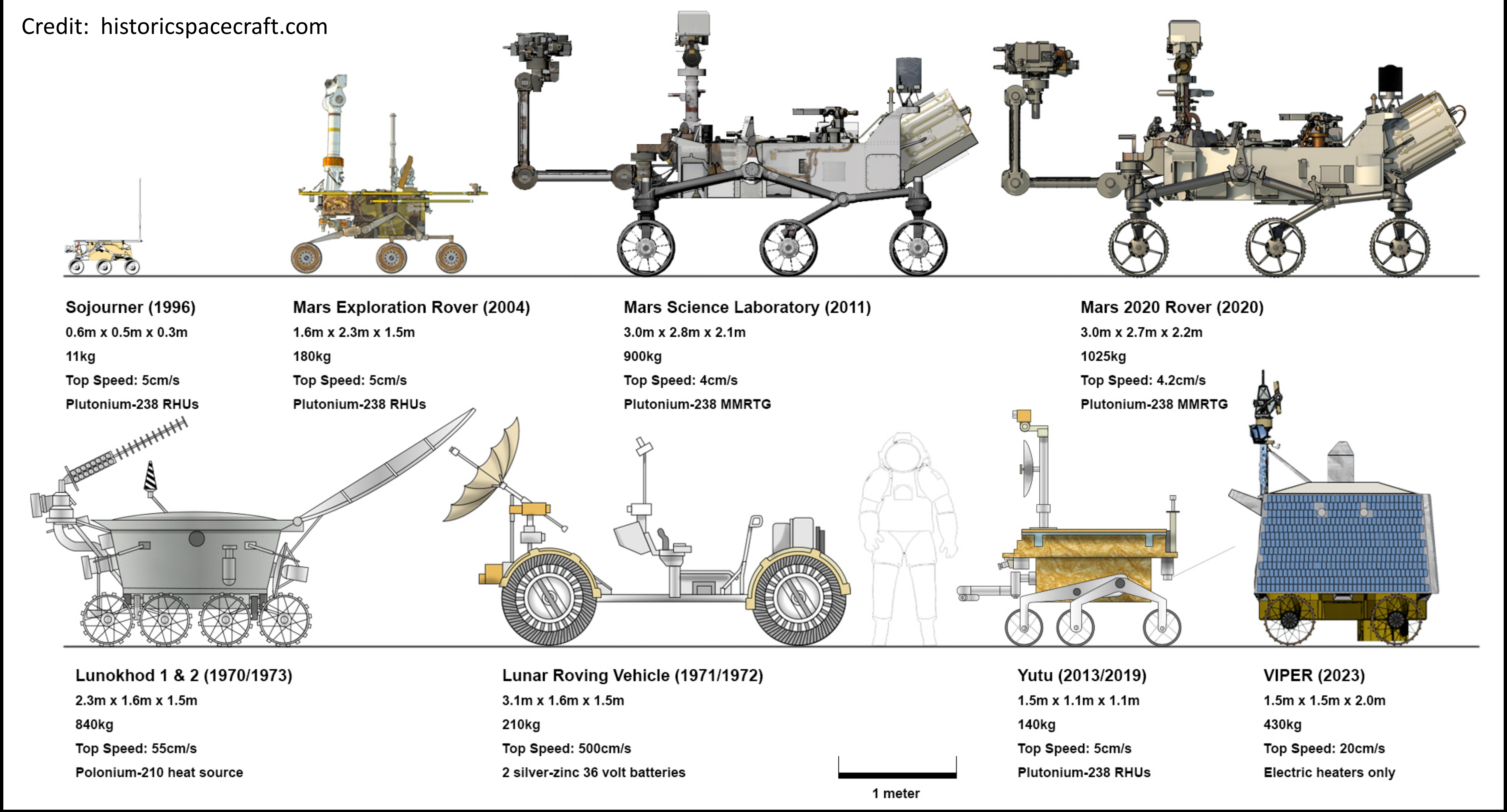
- Solar arrays (sides + aft) & batteries

Comm: X-band "Direct to Earth" (DTE)

- 256 kbps downlink, 2 kbps uplink
- 6-10 sec round-trip delay



Rover Comparison



A new type of planetary rover

First NASA lunar rover

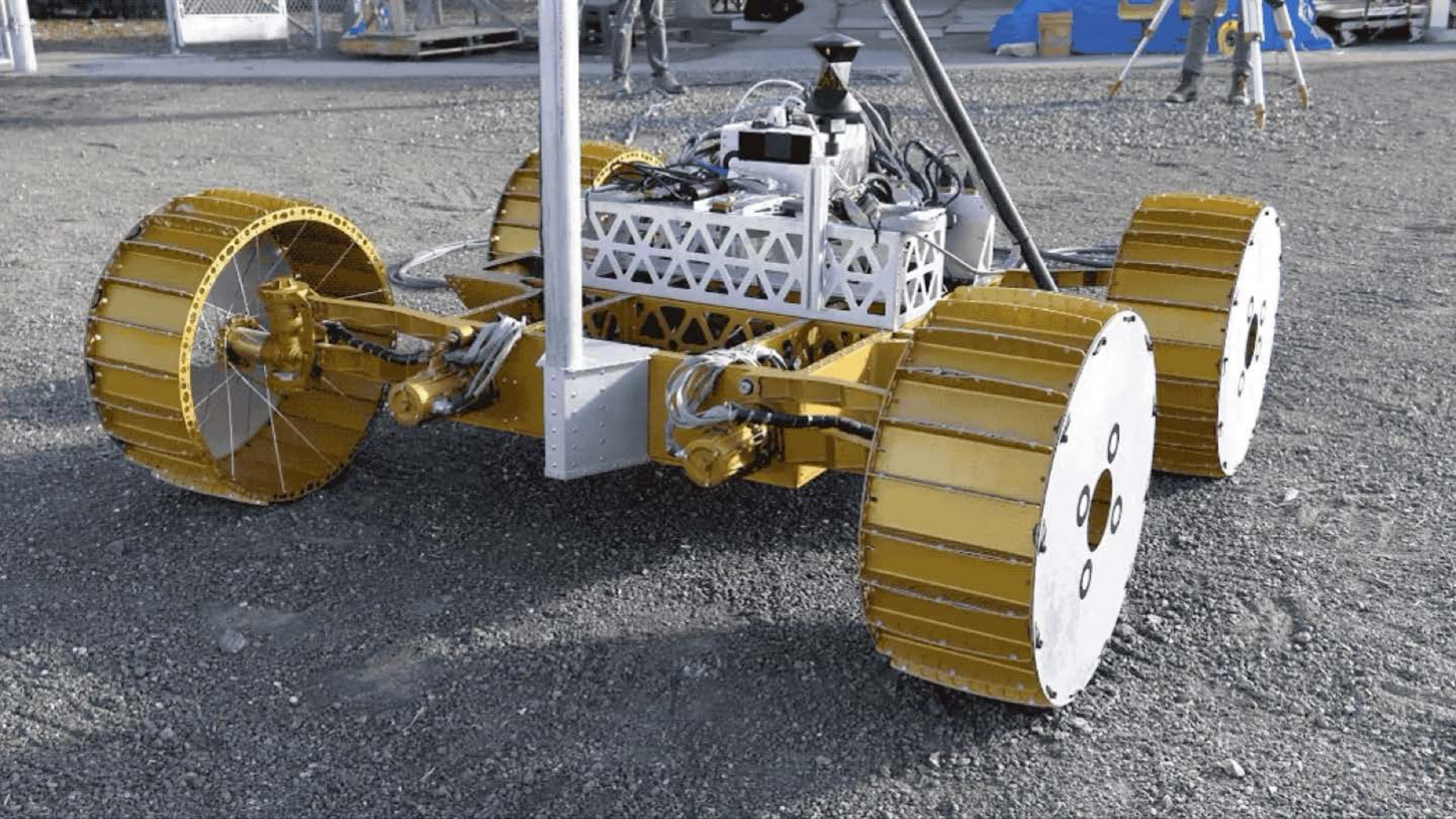
- Designed for the “dynamic” lunar environment
- Emphasis on high operational cadence and traverse speed
- Significantly lower cost than Mars rovers (but higher risk)

Interactive operations

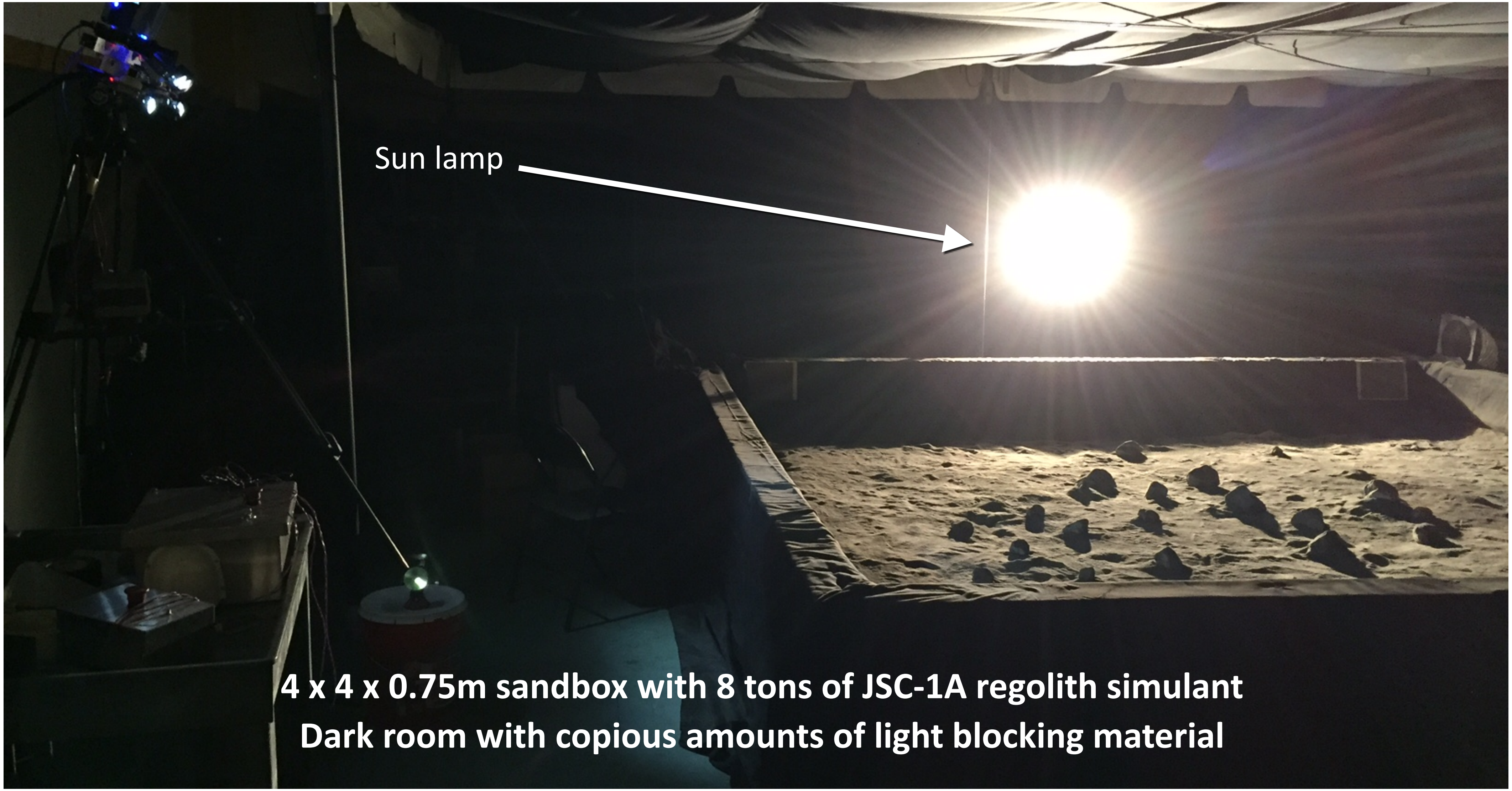
- “Real-time” mission control: rover operations + science team
- Single waypoint driving (approx. 4 m / command cycle)
- Hybrid of human exploration (Shuttle, Space Station) and Mars rover concept of operations

Hybrid avionics and software

- RAD 750 (rad-hard) + SP0 (rad-tolerant) computing
- Flight software is split between on-board and ground
- Ground software uses Robot Operating System 2 (ROS2)



Simulating Lunar Surface Conditions



Test Cases

Negative Obstacle

Defined Rim → **Eroded**

Positive Obstacle

Smooth → **Rough/Rocky**

Synthetic Lunar Terrain Modeling

Need

- High-resolution DEMs (10 cm/post) are needed for conops studies, development of rover navigation systems, mission simulations, etc.
- Best-available lunar DEMs are 1-10 m/post and typically noisy

Typical model

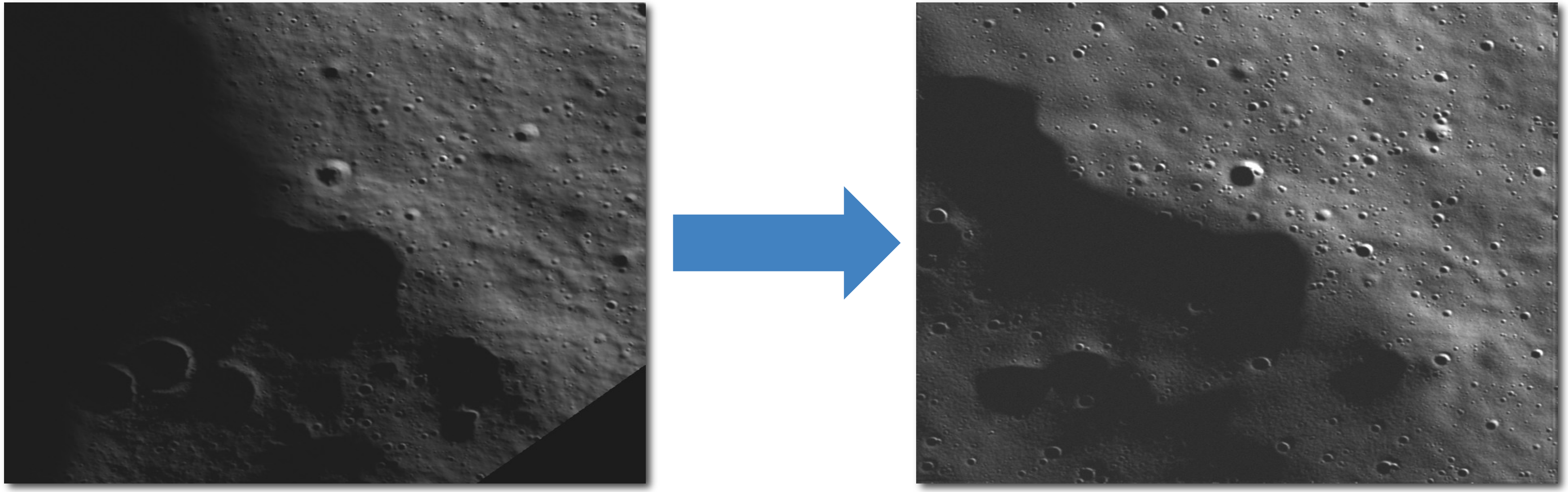
- 1 km x 1 km area, high-latitude site (e.g., Hermite A)
- 4 cm / post

Disclaimer

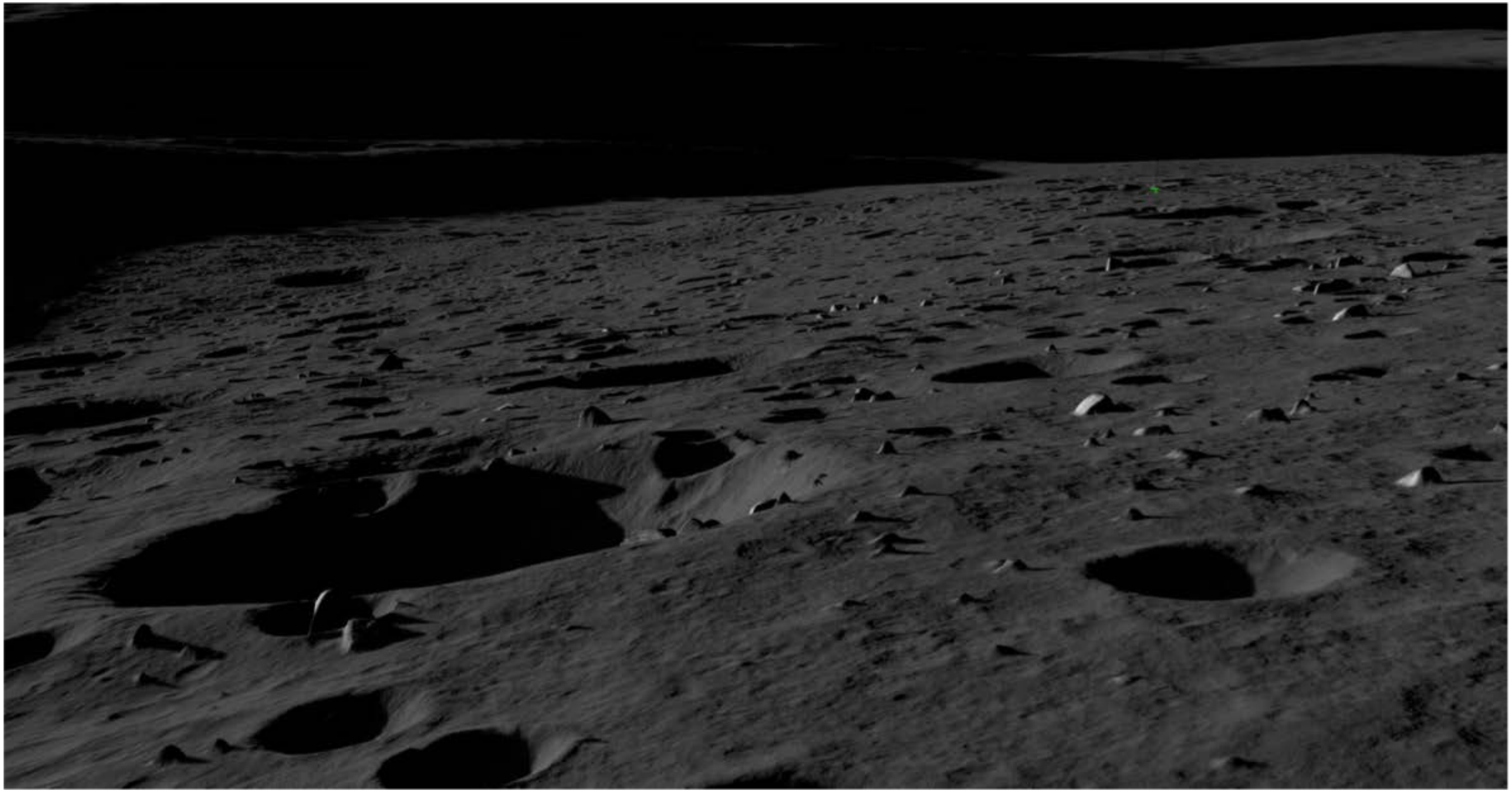
- NOT an accurate measurement of the actual lunar terrain
- NOT appropriate for lunar mission planning or operations
- Suitable for education use, outreach activities, research, or simulation

Synthetic DEM Generation Process

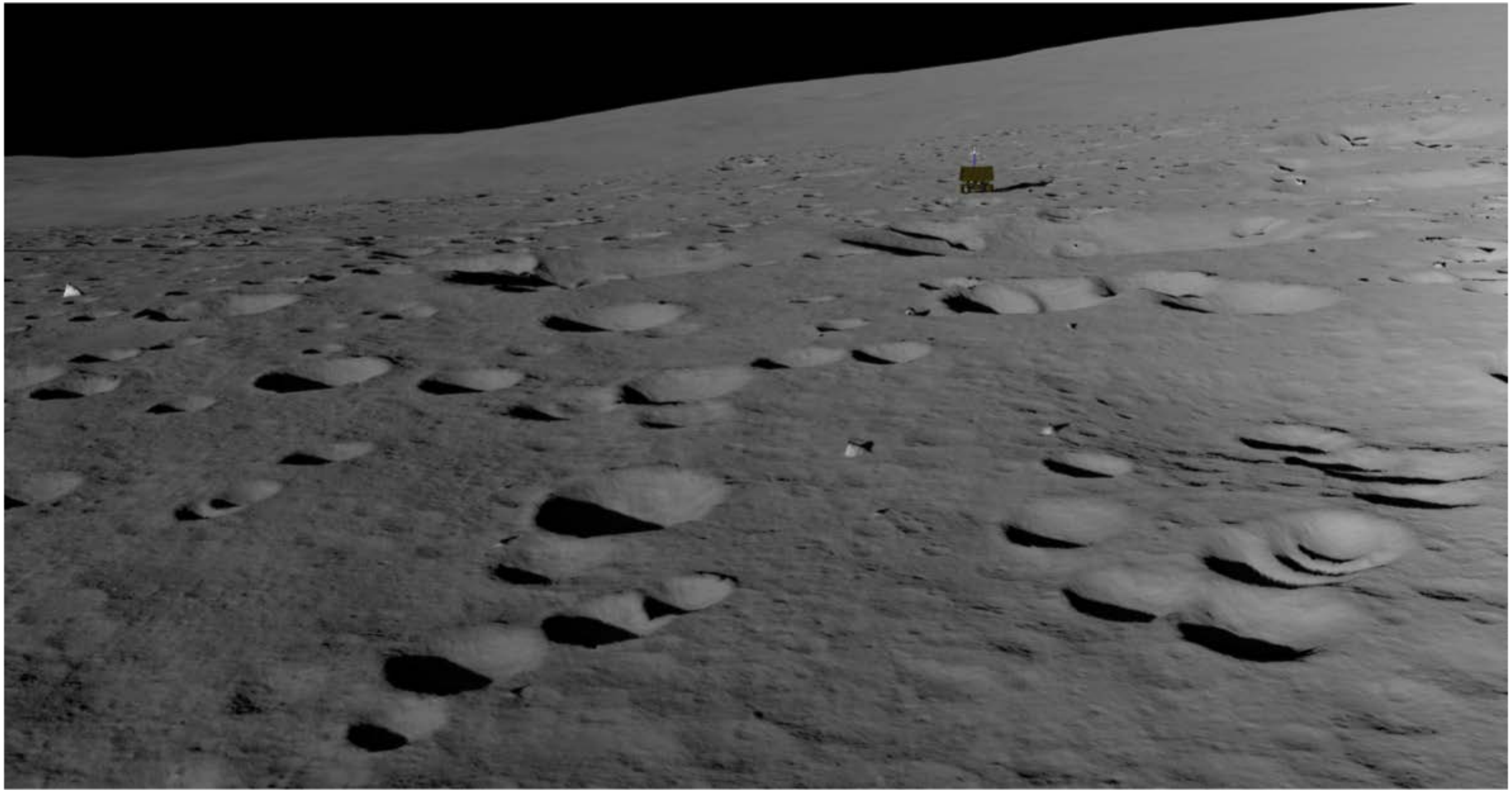
- LROC-NA Images and LOLA laser altimetry of the Hermite A region
- Create initial DEM with 1 m/post using photoclinometry
- Synthetically enhance DEM via fractal synthesis to create high-resolution surface detail that is consistent with lunar morphology
- Add synthetic craters and rocks using a parametric shape model with size-frequency distributions to control density



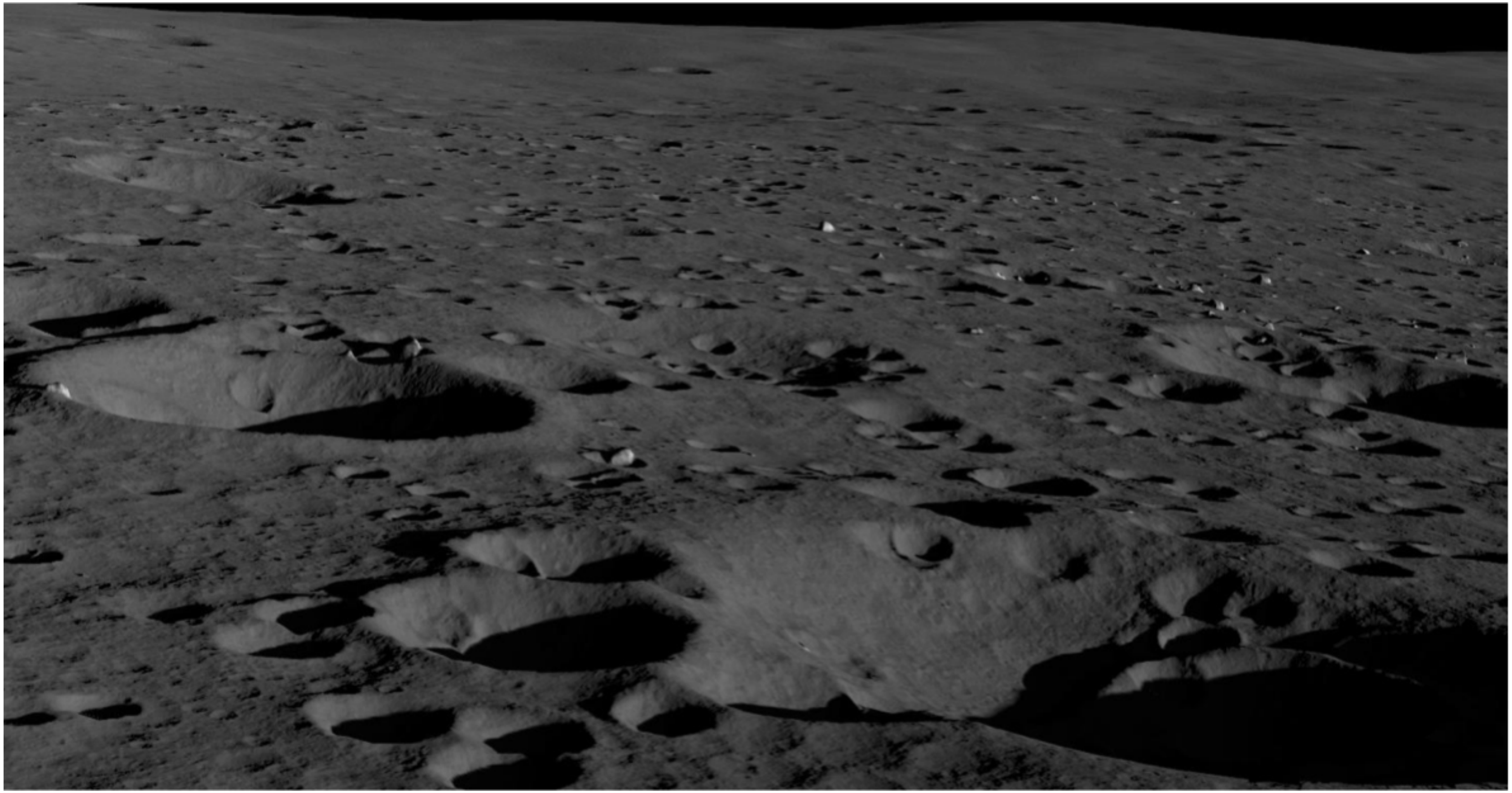
Synthetic Terrain Results



Synthetic Terrain Results



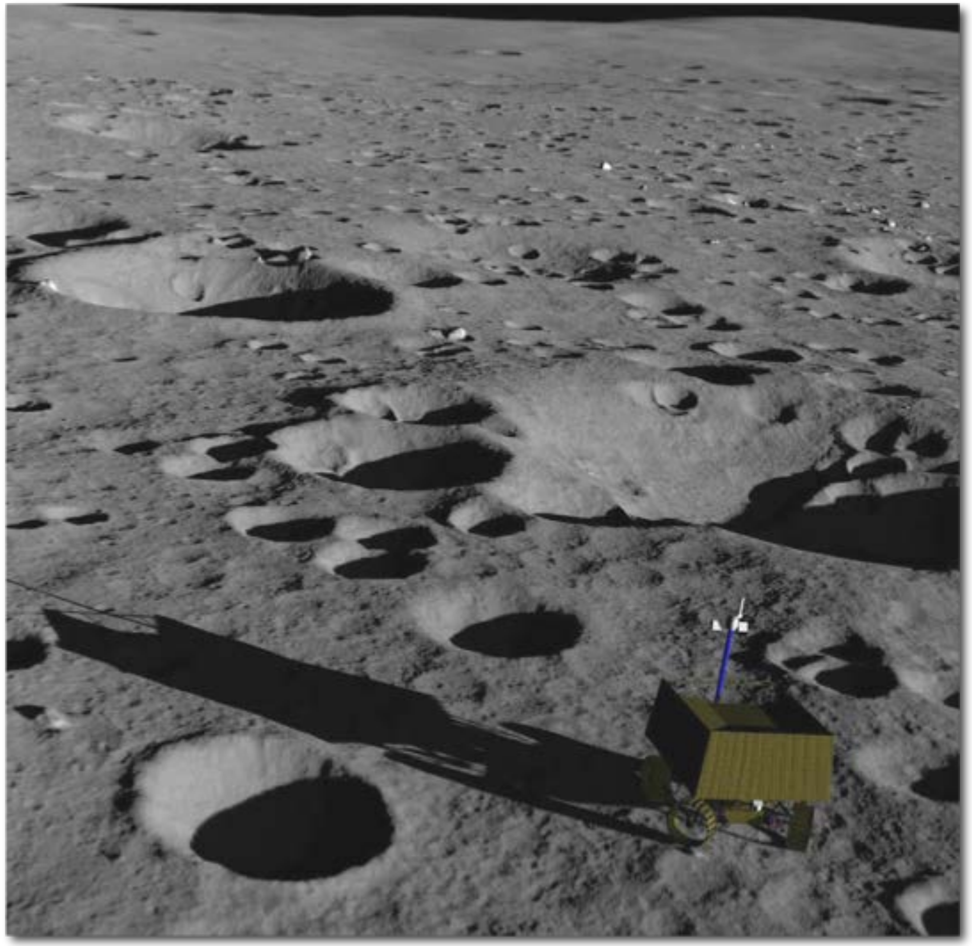
Synthetic Terrain Results



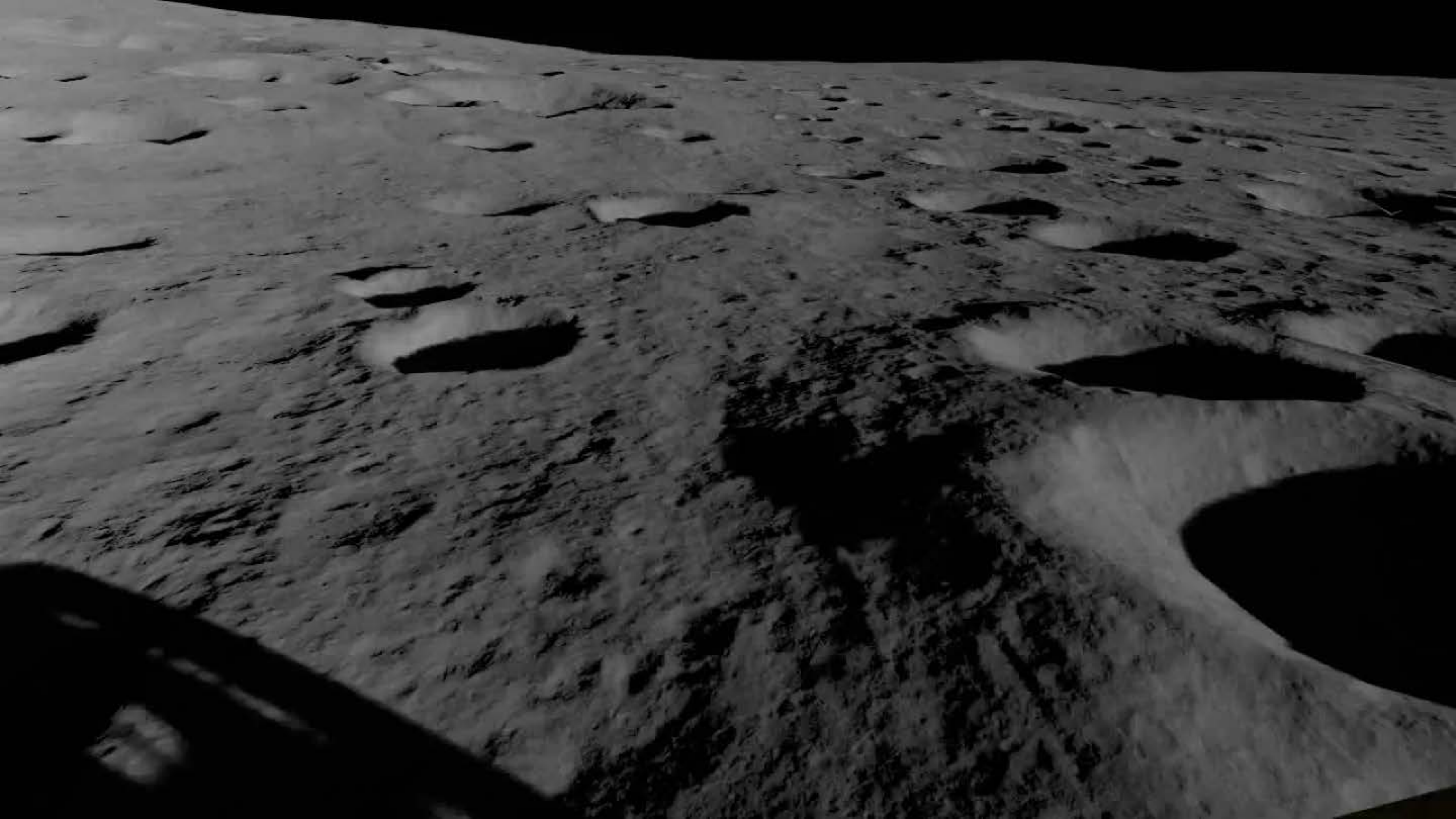
Lunar Surface Simulator

Features

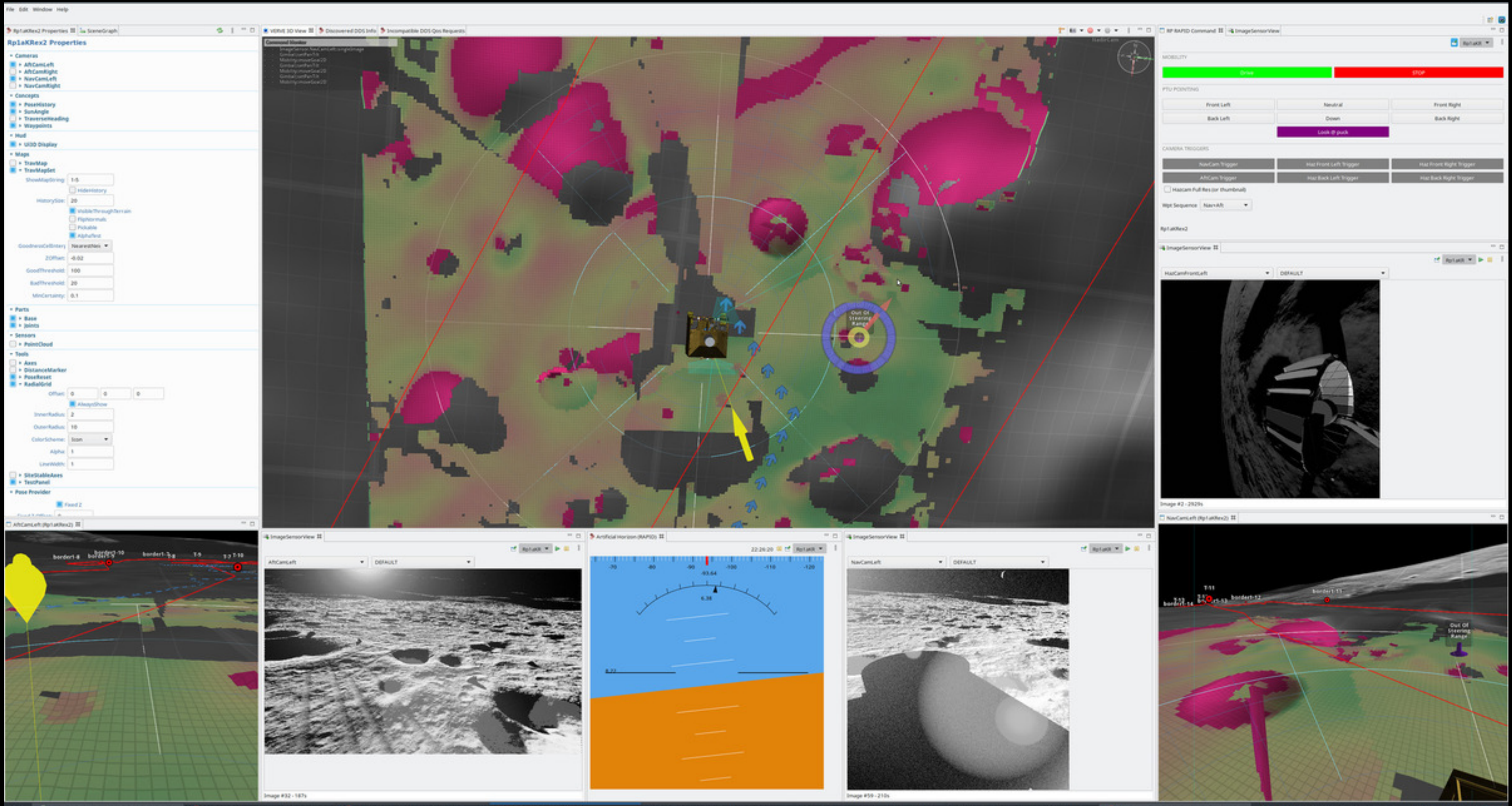
- High dynamic range rendering
- Real-time shadows
- Support for high resolution terrains
- Support for custom terrain appearance
- Rover wheel tracks and slip modeling
- Rover lights with custom pattern
- Simulated lens flare and noise
- Lunar regolith reflectance model
- Accurate Sun & Earth emphemeris

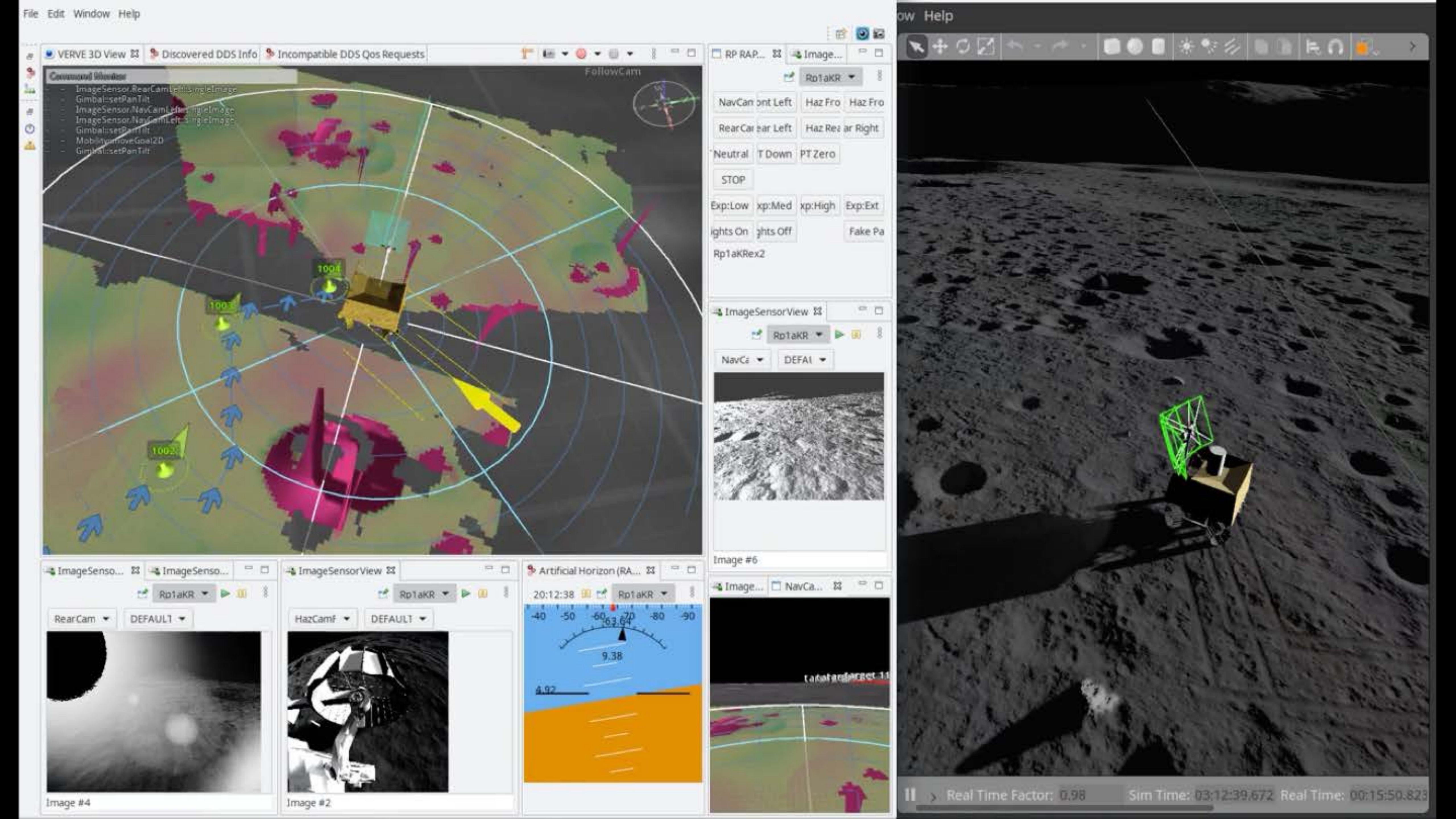


Lunar surface simulator based on Gazebo



VERVE: Rover Driving Interface




File Edit Window Help
VERVE 3D View
Discovered DDS Info
Incompatible DDS Qos Requests
FollowCam
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1003
1002
RP RAP...
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Rp1aKRex2
ImageSensorView
Image #6
Image #4
Image #2
Artificial Horizon (RA...
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RearCam
HazCamf
DEFAULT
Real Time Factor:
Sim Time:
Real Time:

Questions ?