Blue Ghost Mission 1 Science Highlights

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[13]Agenzia Spaziale Italiana,
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European Lunar Symposium: June, 2025

NASA CLPS Task Order – 19D

Manifest

- Next Generation Lunar Retroreflector (NGLR) - PMPO
- Radiation Tolerant Computer System (RadPC) - PMPO
- Regolith Adherence Characterization (RAC) - PMPO
- Lunar Magnetotelluric Sounder (LMS) - PMPO
- Lunar Environment heliospheric X-ray Imager (LEXI) - PMPO
- Lunar PlanetVac (LPV) - PMPO
- Lunar Instrumentation for Subsurface Thermal Exploration with Rapidity (LISTER) - PMPO
- Stereo Cameras for Lunar Plume Surface Studies (SCALPSS) – STMD
- Electrodynamic Dust Shield (EDS) - STMD
- Lunar GNSS Receiver Experiment (LuGRE) - SOMD

Mission Details

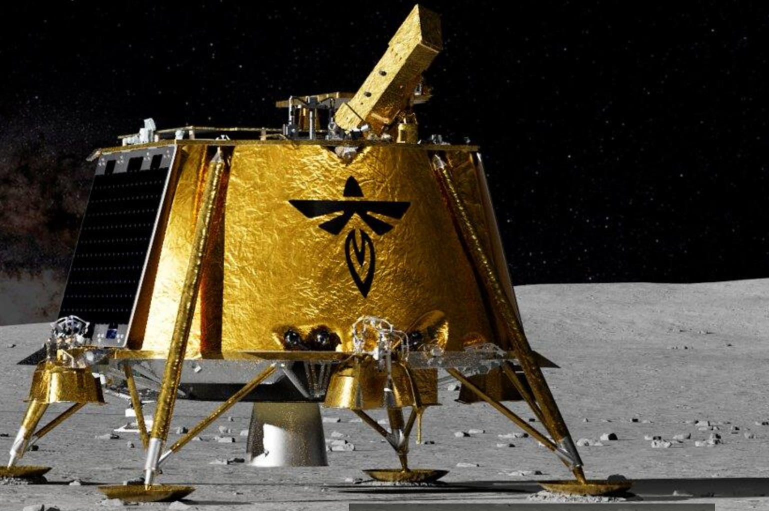
- *Lander/Mission Provider*: Firefly Aerospace
- *Vehicle:* Blue Ghost Lunar Lander
- *Launch Date:* **January 15, 2025**
- *Landing Date:* **March 2, 2025**
- *Landing Site:* Mare Crisium

Science Goals

- **Lunar fiducial marker -** NGLR
- **Test dust adherence on different materials -** RAC
- **Dust mitigation using electrodynamic fields -** EDS
- **Investigate the heat flow of the lunar interior -** LISTER
- **Study plume-surface interactions -** SCALPSS
- **Acquire X-ray images of Earth's magnetosphere -** LEXI
- **Constrain mantle temperature structure and evolution from electric and magnetic fields-** LMS

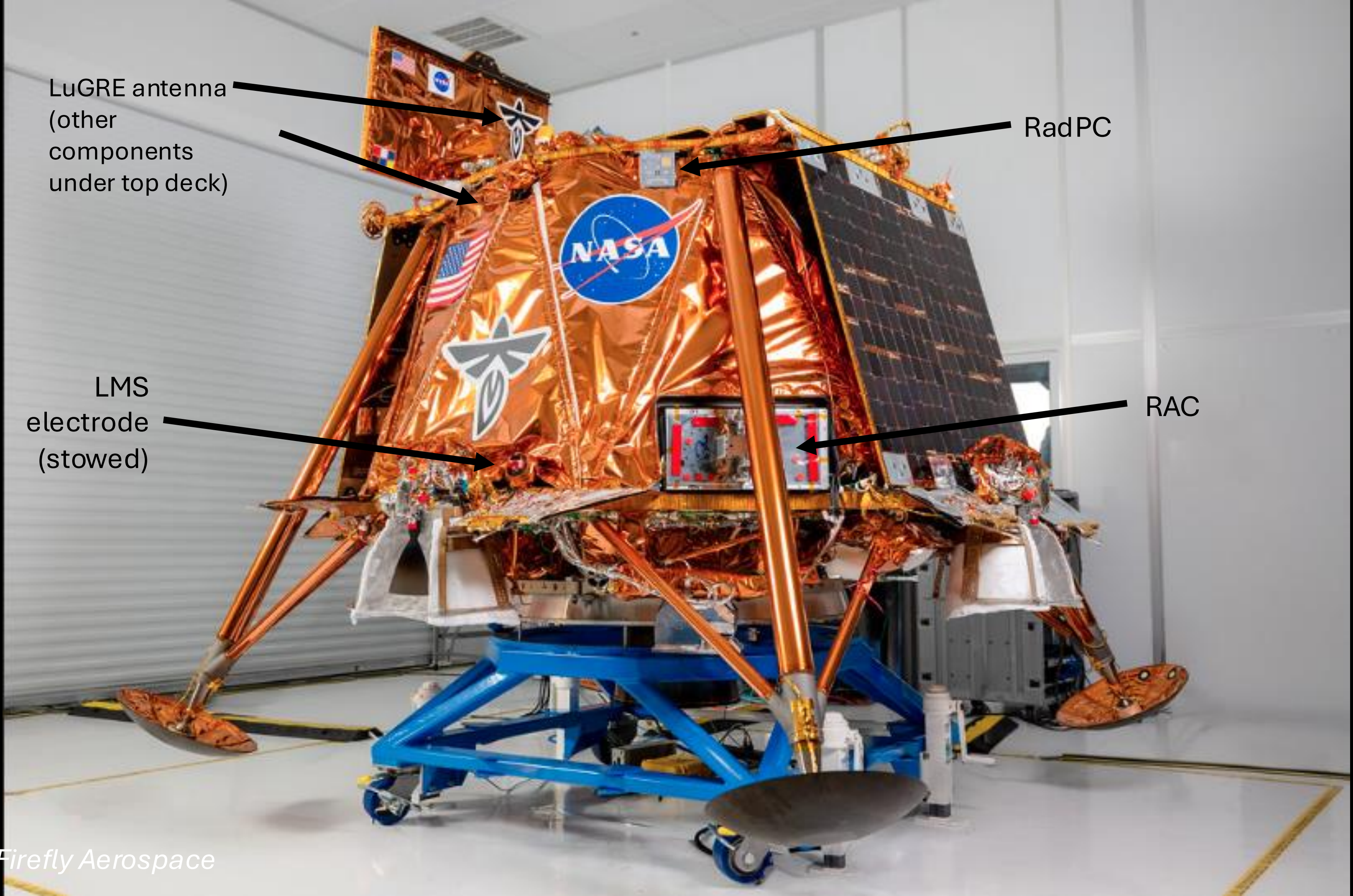
Technology goals

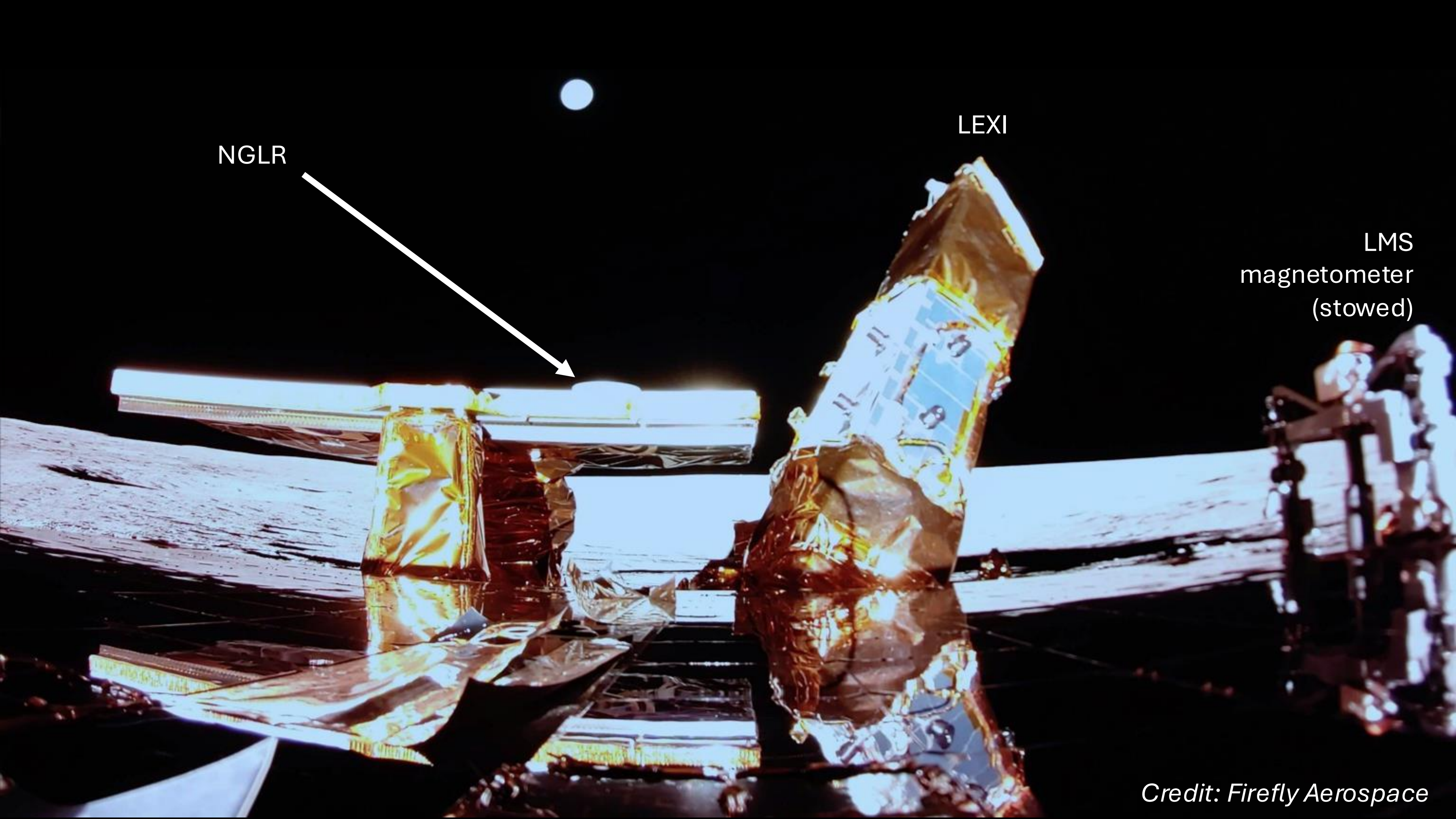
- **Test a radiation tolerant computer system -** RadPC
- **Investigate the first use of GNSS (Global Navigation Satellite System) in transit to and on the lunar surface -** LuGRE
- **Test regolith sampling technologies -** LPV

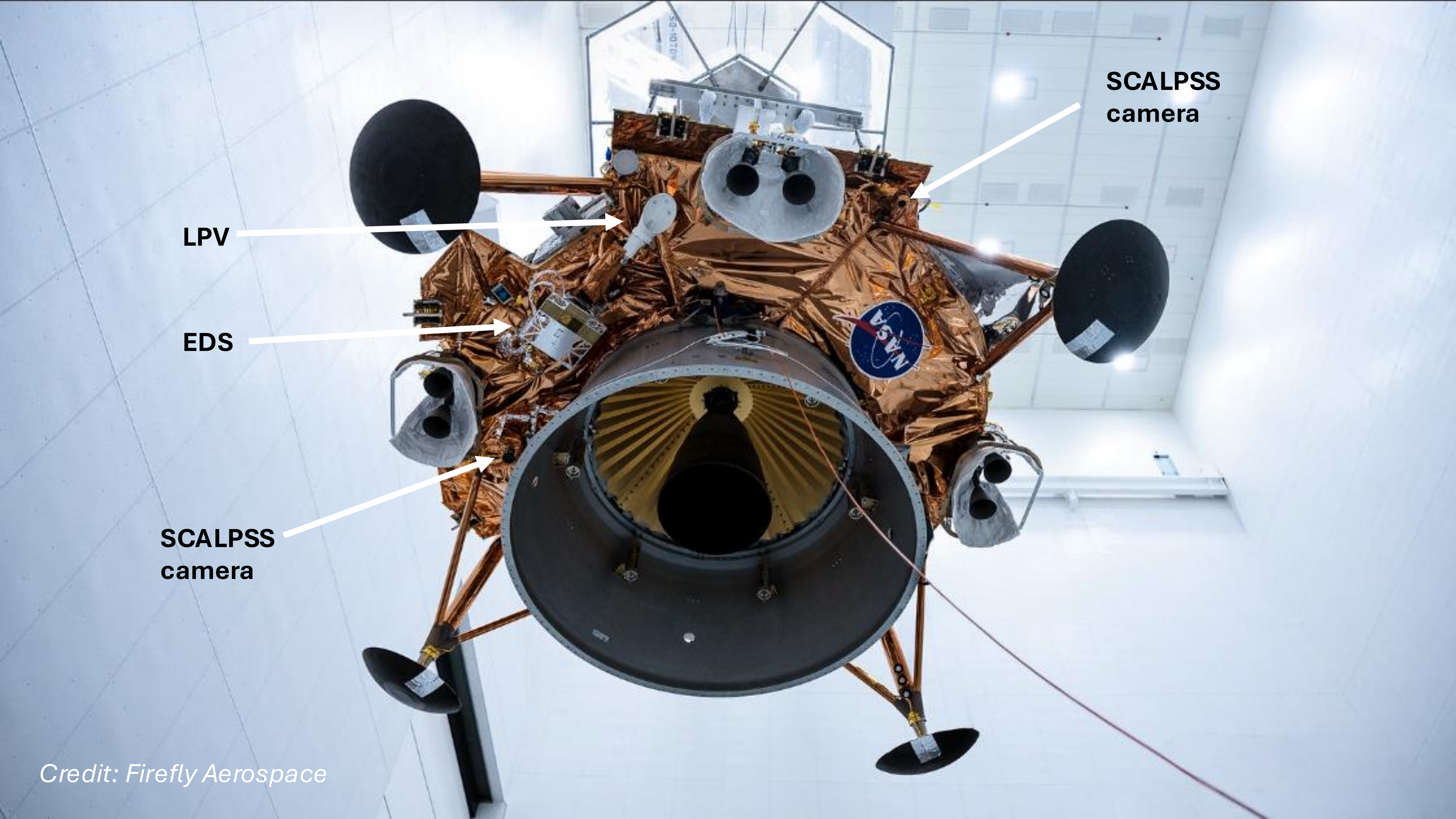


Mission: BGM-1

MARE CRISIUM


LuGRE antenna
(other
components
under top deck)
RadPC
LMS
electrode
(stowed)
RAC
Credit: Firefly Aerospace


NGLR
LEXI
LMS
magnetometer
(stowed)
Credit: Firefly Aerospace


SCALPSS
camera
LPV
EDS
SCALPSS
camera
Credit: Firefly Aerospace


LISTER
Credit: Firefly Aerospace

Firefly Aerospace's Blue Ghost lunar lander launched on January 15, 2025 carrying ten NASA science and technology instruments to Mare Crisium on the near side of the Moon.

Credit: Firefly Aerospace

LOI: Feb 13

Total transit time including Earth orbit and Lunar orbit:
45 days

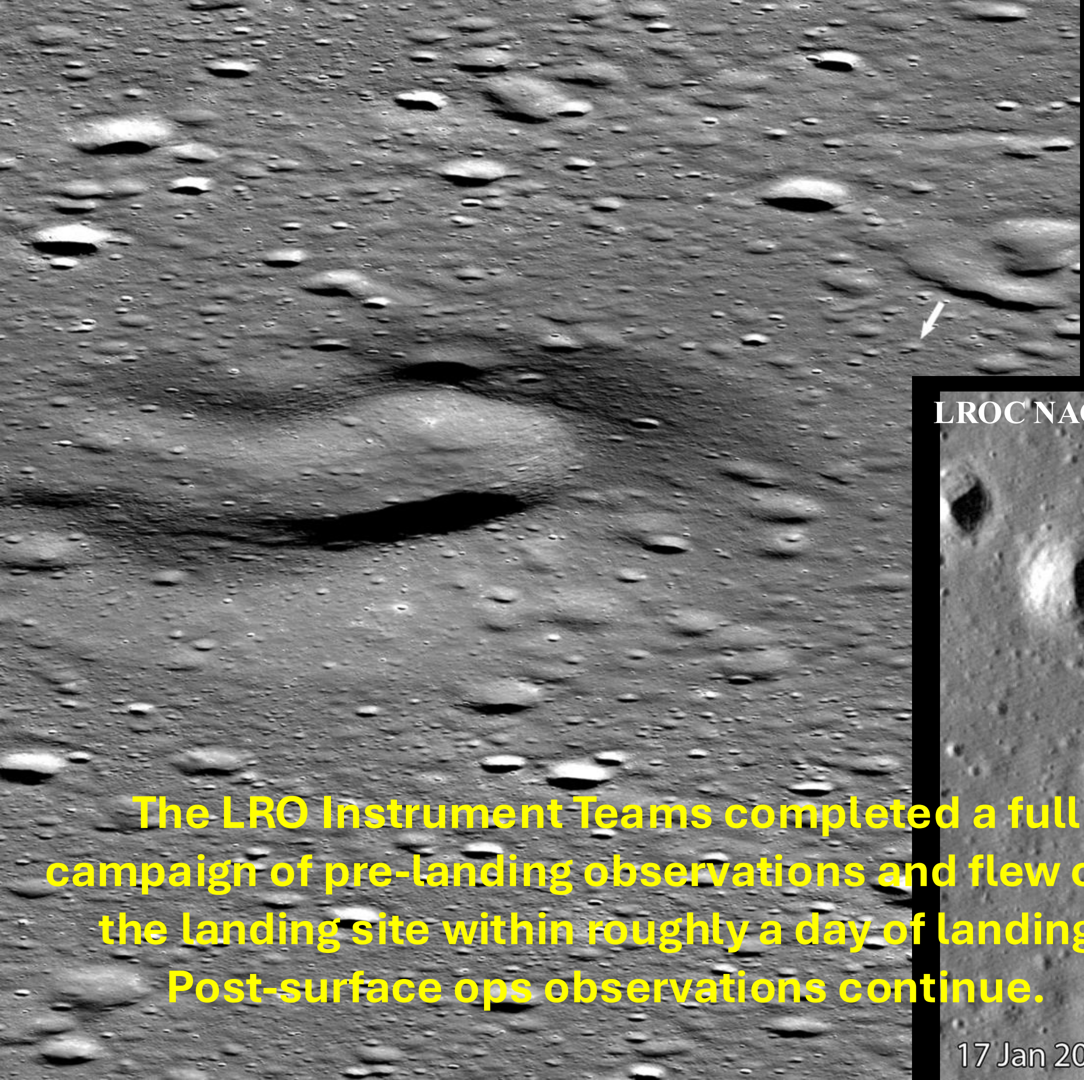
Credit: Firefly Aerospace


Landing: March 2, 2025
Mare Crisium: ~58 meters from the
edge of the original landing ellipse
Credit: Firefly Aerospace

New York Times, March 2, 2025
NASA/Firefly Aerospace, via Associated Press

Landing: March 2, 2025
Mare Crisium: ~58 meters from the edge of the original landing ellipse

Credit: Firefly Aerospace



Landing site: 18.5623°N, 61.8103°E

All ten NASA payloads successfully activated, collected data, and performed operations on the Moon; most performed first-of-their-kind science and technology demonstrations

LROC NAC: M1495619099LR [NASA/GSFC/Arizona State University].

The LRO Instrument Teams completed a full campaign of pre-landing observations and flew over the landing site within roughly a day of landing. Post-surface ops observations continue.

LPV: The Lunar PlanetVac

- LPV collected, transferred, and sorted lunar regolith particles using pressurized nitrogen gas

In first 5-sec test:

- successfully captured 13 g of regolith, including 5 grams of 2 mm scale rocklets in non-ideal conditions – sampling head was positioned above the ground!
- successfully cleaned the camera lens (from dust covering the lens during landing)
- put a spin on and lofted a 2.5 cm diameter rock (called Dwayne)!

LPV successfully demonstrated a low-cost, low-mass solution for future robotic sample collection.

LPV has already been included in several additional CLPS proposals

LPV technology will be flying on MMX mission to Phobos in 2026

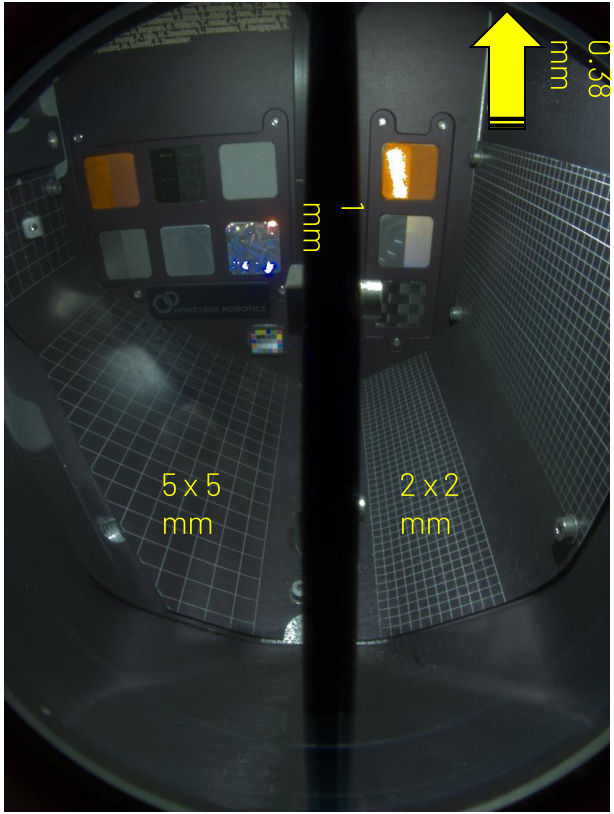
BLUE GHOST MISSION 1

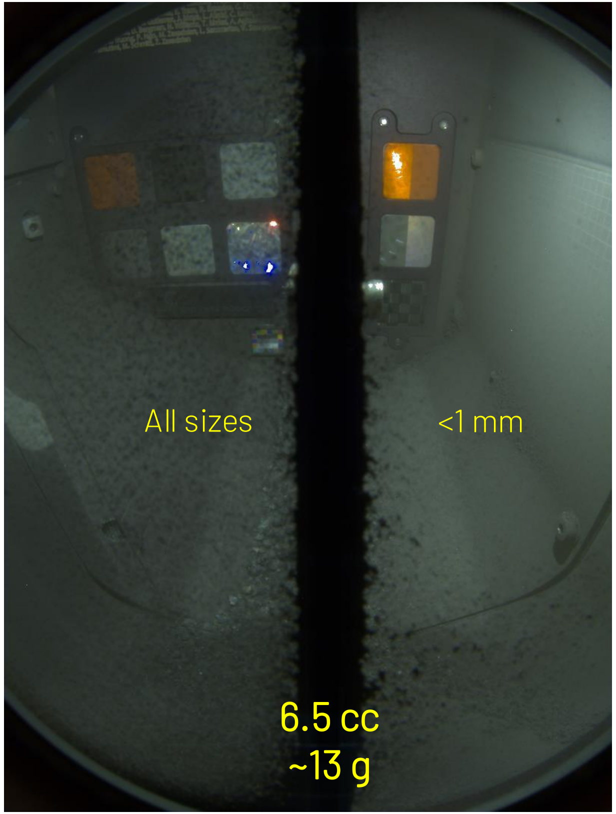
NASA's Lunar PlanetVac Surface Operations

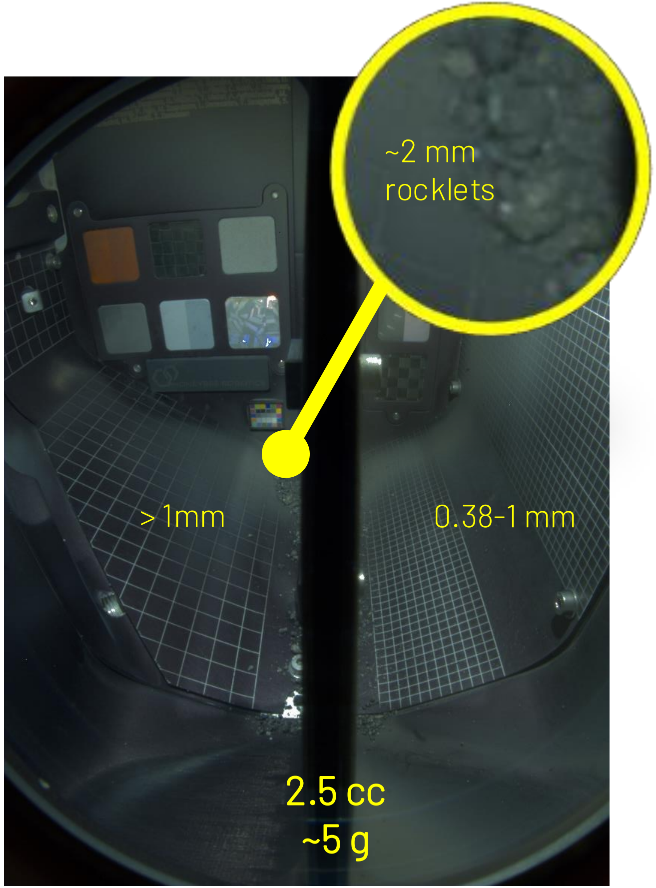
https://youtu.be/oLJu_XmteWI?si=v_veP46AX2bnyUBS

Credit: Firefly Aerospace

PlanetVac Sampling and Sieving







Blue Origin Proprietary Information /
Information Subject to Export Control

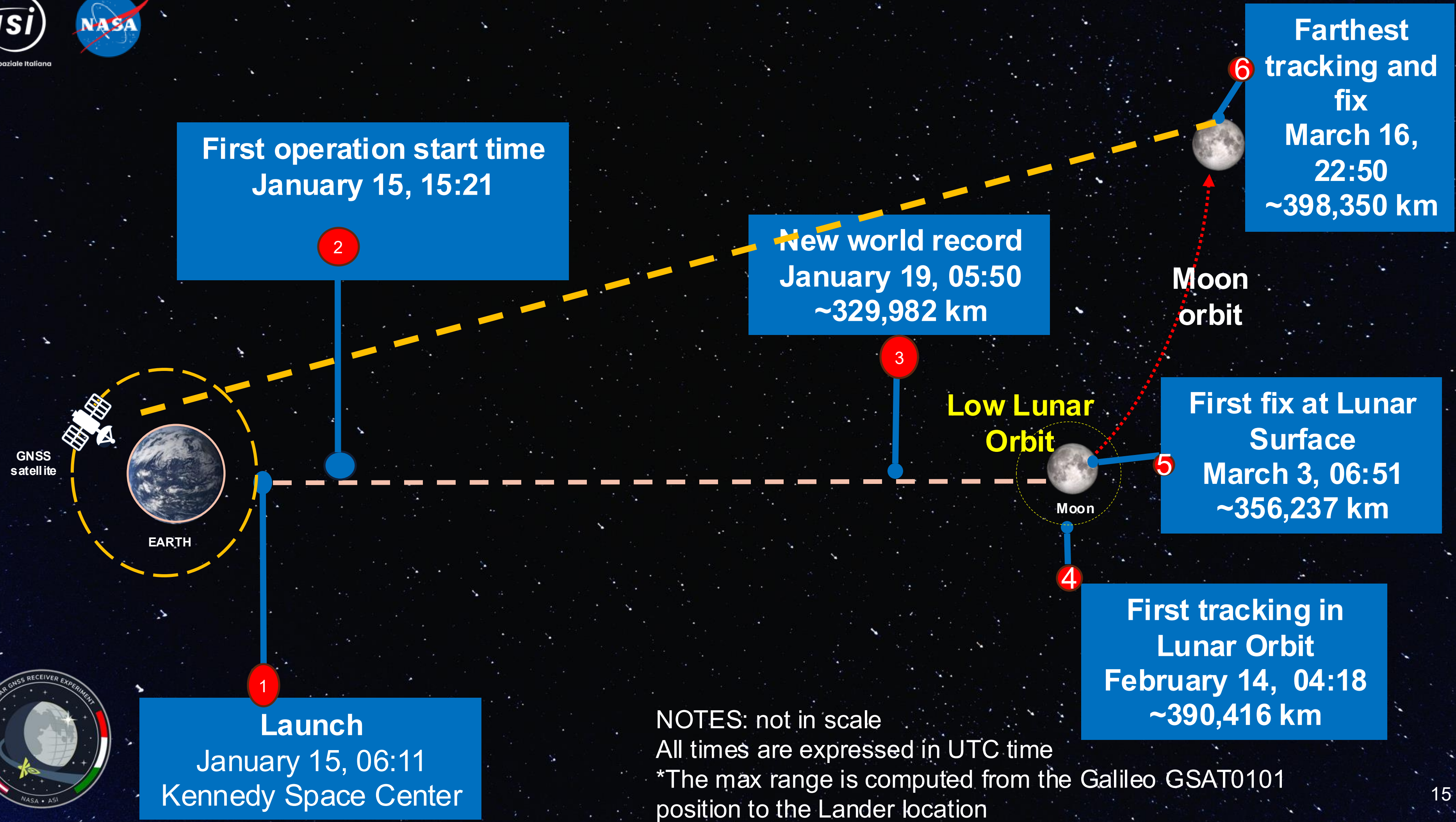
LuGRE: The Lunar GNSS Receiver Experiment

Acquired and tracked Global Navigation Satellite System (GNSS) signals from the GPS and Galileo constellations and calculated instantaneous navigation "fixes" enroute to and on the Moon's surface for the first time.

This achievement demonstrates that GNSS signals can be used to support navigation in cislunar space and at the Moon.

LuGRE is an international partnership

Partner agencies: NASA, ASI



NOTES: not in scale
All times are expressed in UTC time
*The max range is computed from the Galileo GSAT0101 position to the Lander location

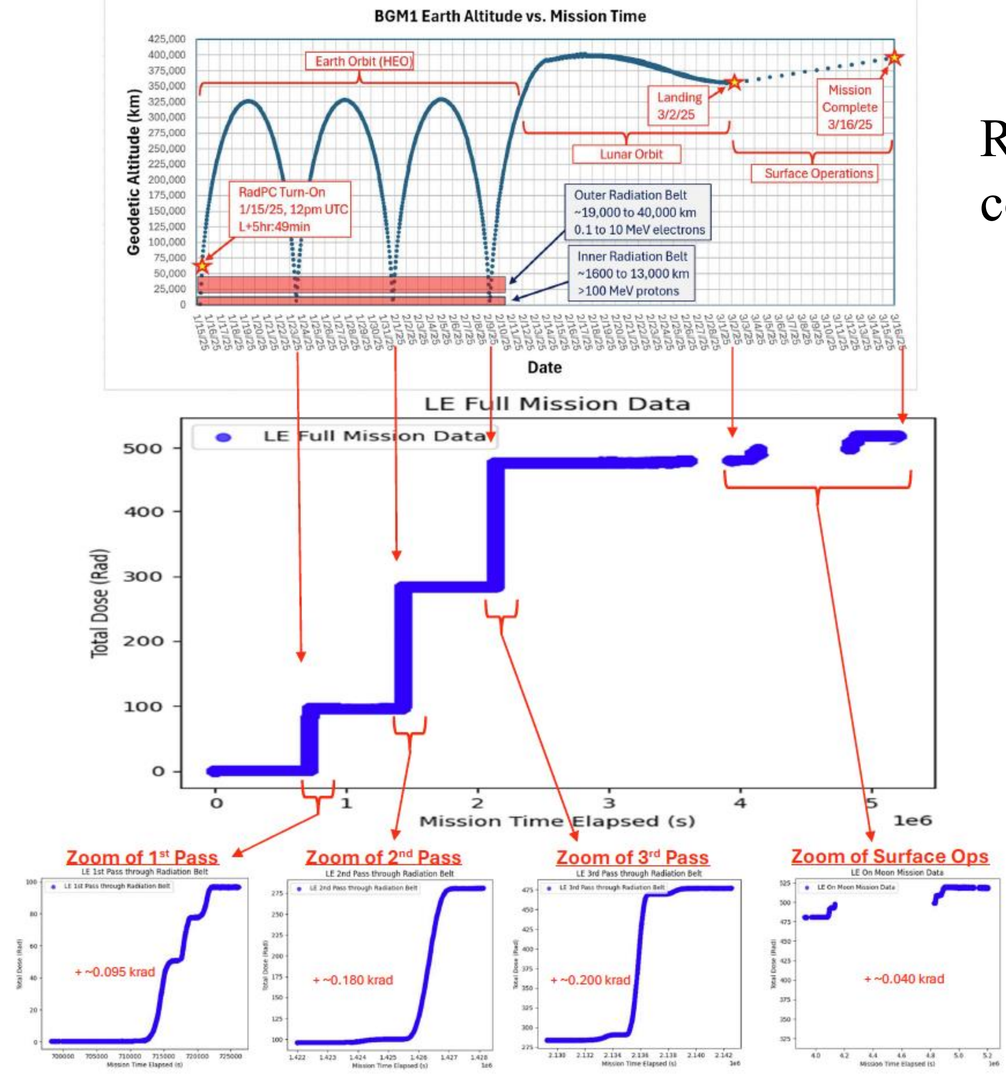
RadPC: The Radiation Tolerant Computer System

- RadPC is a space computing technology that mitigates the impact of single-event-effects (SEEs) through a series of novel fault recovery procedures.

Image provided by the RadPC Team

RadPC verified solutions to mitigate radiation effects on computers that could make future missions safer for equipment and more cost effective.

RadPC



RadPC successfully operated and collected radiation data through:

- Earth's Van Allen belts
- Transit to and in lunar orbit
- On the lunar surface: including during the solar eclipse, and into the lunar night.

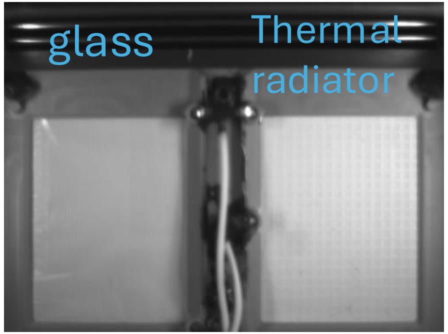
➢ The most severe radiation was experienced when passing through the Earth's Van Allen Belts.

➢ The RadPC radiation-tolerant computer successfully operated with 100% up-time the entire mission.

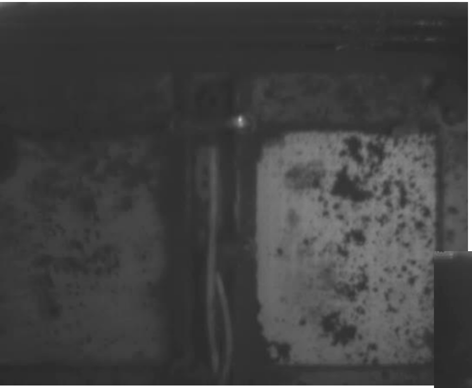
EDS: The Electrodynamic Dust Shield

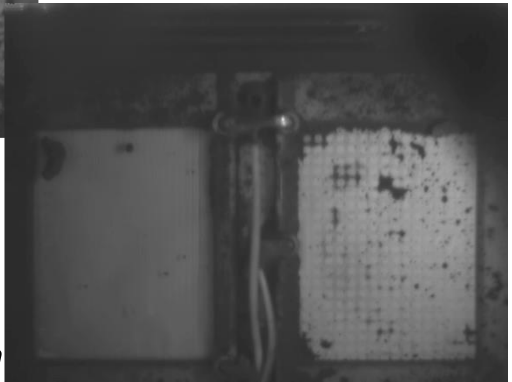
- Successfully lifted and removed lunar regolith from surfaces using electrodynamic forces.

This technology demonstrates a promising solution for dust mitigation on future lunar and interplanetary surface operations.



Before launch


At landing


After Cleaning


After LPV Operations


After extended Operations

Images provided by EDS team

Video provided by EDS team

LEXI: The Lunar Environment heliospheric X-ray Imager

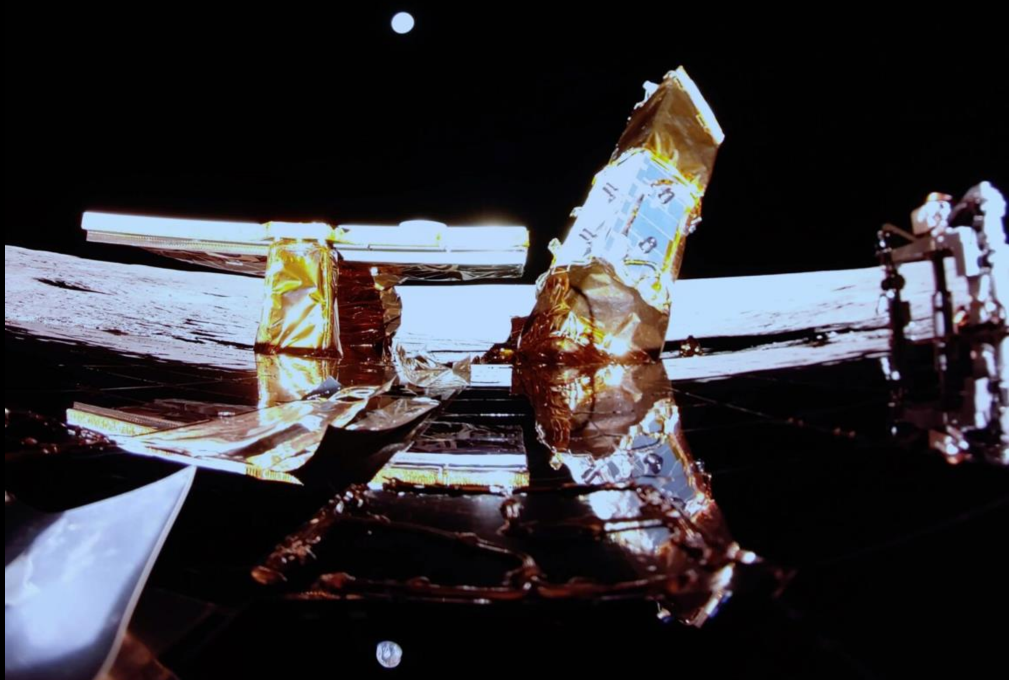
- Captured X-ray images to study the interaction of the solar wind and Earth's magnetic field.

Results are providing insights into how space weather and other cosmic forces surrounding Earth affect the planet.

Some of the cleanest data was collected after sunset!!

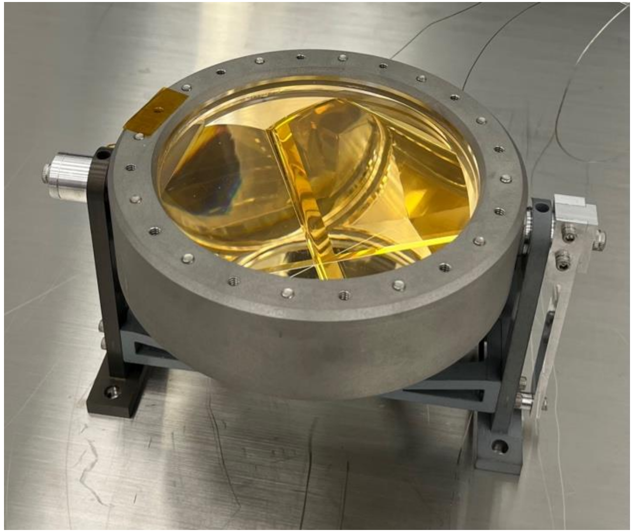
Several science papers are currently in preparation: some focused on emissions probing the moon's exosphere.

Credit: Firefly Aerospace



NGLR: The Next Generation Lunar Retroreflector

Image provided by NGLR Team



- Already successfully reflected and returned laser light from multiple Lunar Laser Ranging Observatories (LLROs) on Earth:
  - The LLRO in Grasse, France obtained three solid sequences of laser return measurements and returns with both the infrared (1064 nm) and Green lasers.
  - The LLROs in Wettzell, Germany and Apache Point, in New Mexico (USA) have also obtained returns to date.
- LOLA has now also successfully acquired a return from NGLR!

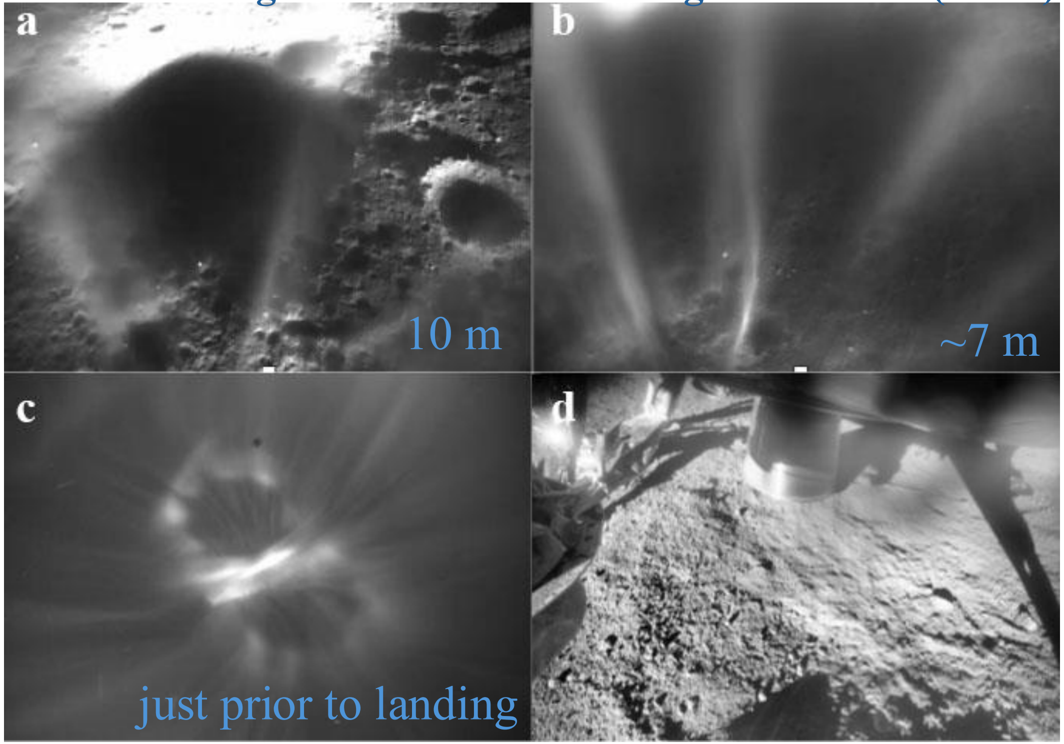
Measurements utilizing NGLR will enable precise measurements of the Moon's shape and distance from Earth, expanding our understanding of the Moon's inner structure.

Early observations show that the precision of the NGLR is better than results from returns from the Apollo 15 retroreflector by a factor as large as 17.

SCALPSS: The Stereo Cameras for Lunar Plume-Surface Studies instrument

- Captured more than 9,000 images including during the spacecraft's descent to the lunar surface, providing insights into the effects engine plumes have on the surface.
- The payload also operated on the surface during the lunar day, at the end of the solar eclipse, during the lunar sunset, and into the lunar night.

SCALPSS images from short focal length camera 2 (SFL2)

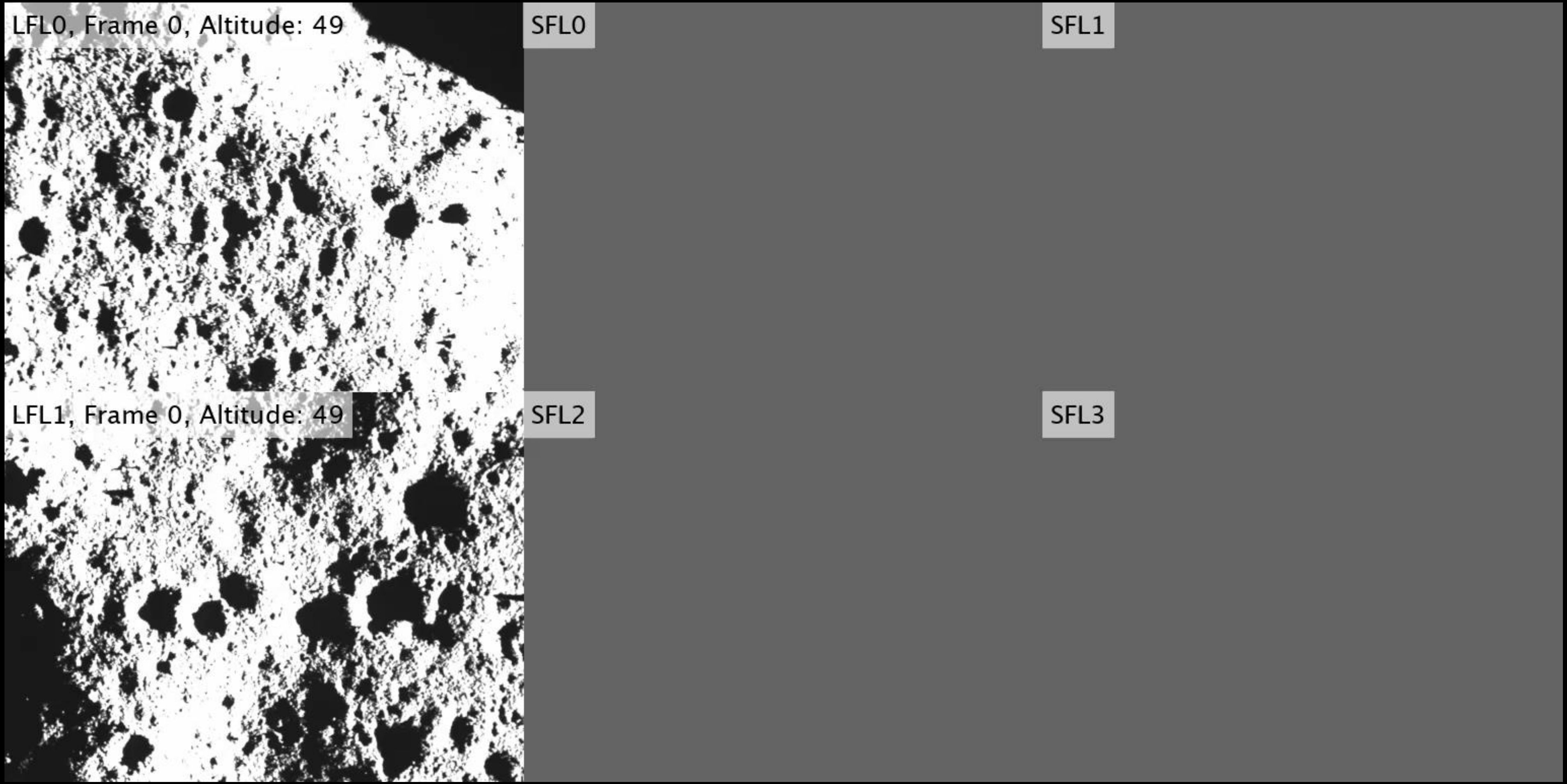


HDR composite from SFL camera 0 (SFL0) from the surface

images provided by O. Tyrrell and J. Weisberger/NASA LaRC

SCALPSS descent video

video provided by the SCALPSS Team/NASA LaRC



RAC: The Regolith Adherence Characterization instrument

RAC has 15 slots with 15 different materials:

- 10 samples from NASA Research/Space Centers
- 5 from commercial companies.

Examined how lunar regolith interacted with a range of materials exposed to the Moon’s environment.

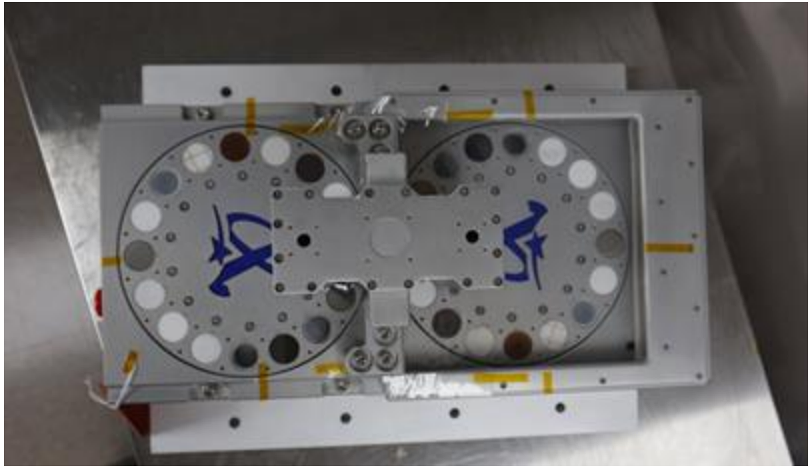
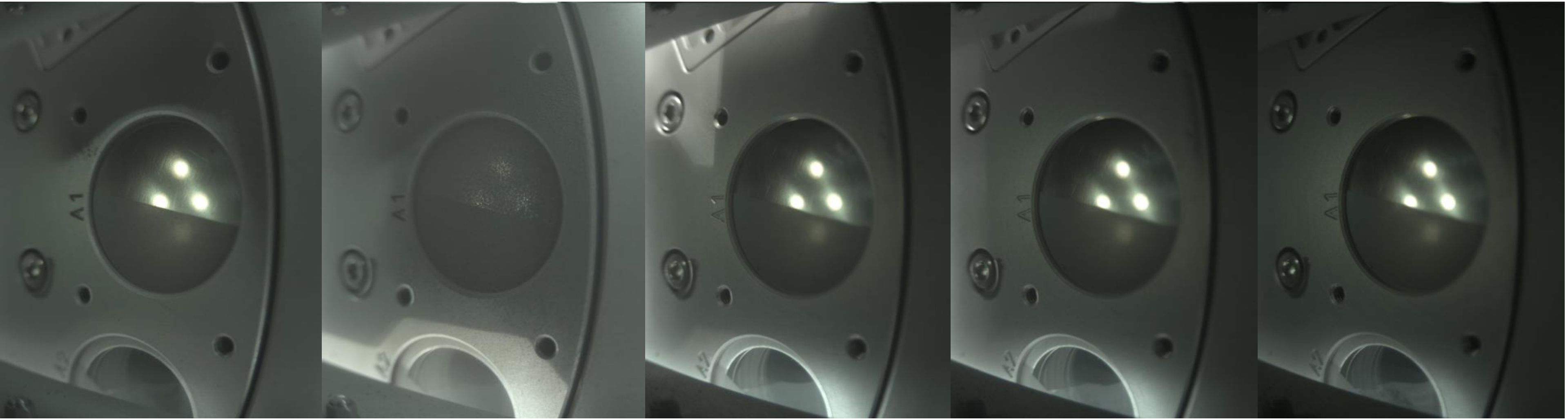


Image provided by the RAC Team

Results from RAC can help test, improve, and protect spacecraft, spacesuits, and habitats from abrasive lunar dust.

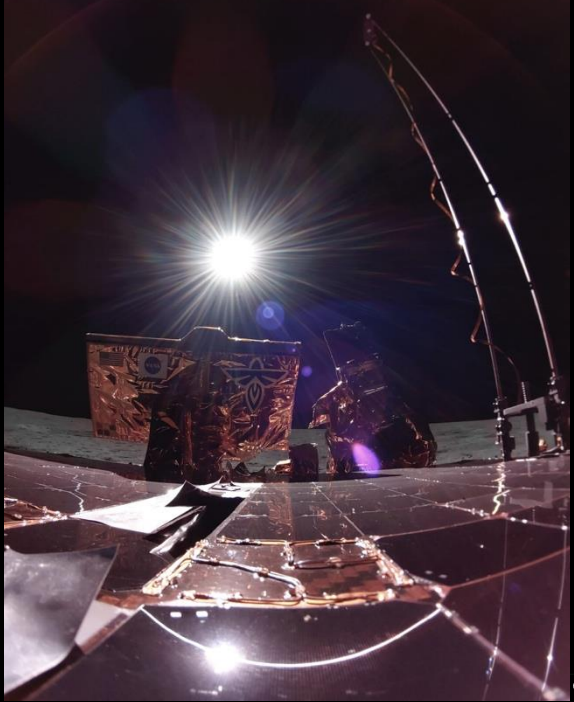
RAC: Slot 1 (Ti-6Al-4V) (NASA LaRC)

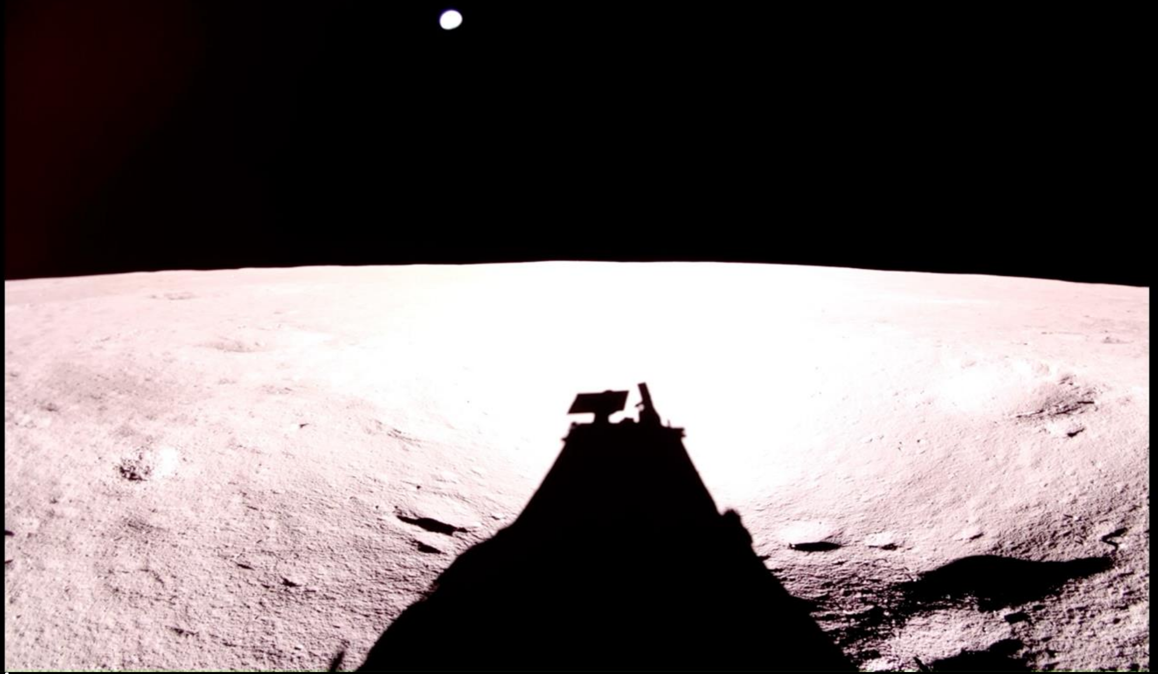


02 March | 03 March | 13 March | 14 March | 15 March

Photos of Slot 1 material (Ti-6AL-AV) during the lunar surface ops.

LMS: The Lunar Magnetotelluric Sounder





Credit: Firefly Aerospace

- Successfully deployed sensors to study the Moon's interior by measuring electric and magnetic fields.

LMS enables characterization of the interior of the Moon to depths over 1000 km, or more than half the distance to the Moon's center.

LISTER: The Lunar Instrumentation for Subsurface Thermal Exploration with Rapidity

- Is now the deepest robotic planetary subsurface thermal probe
- Drilled and acquired thermal measurements at eight depths down to ~1-m depth

LISTER provides a first-time demonstration of robotic thermal measurements at varying depths.

SCALPSS short focal length camera number 3 (SFL3)

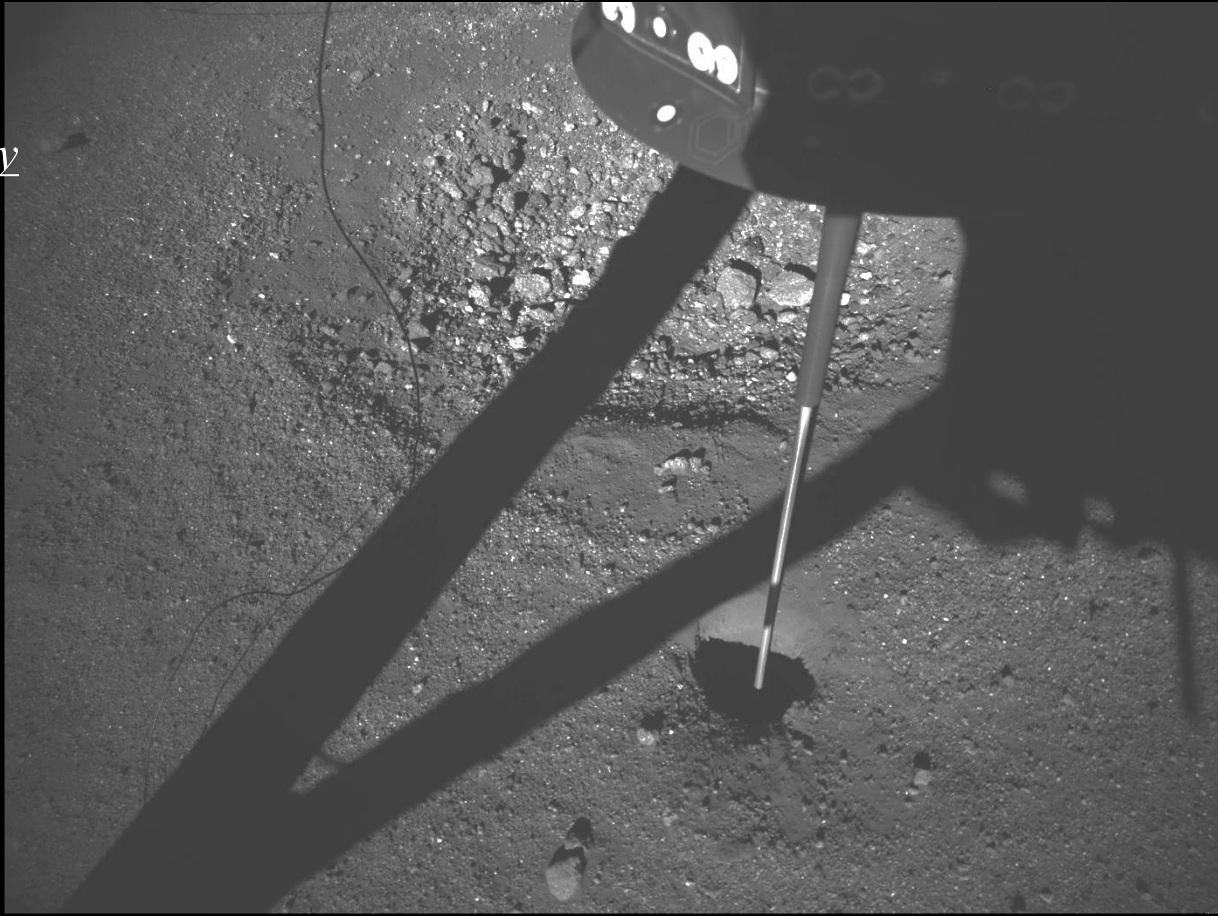
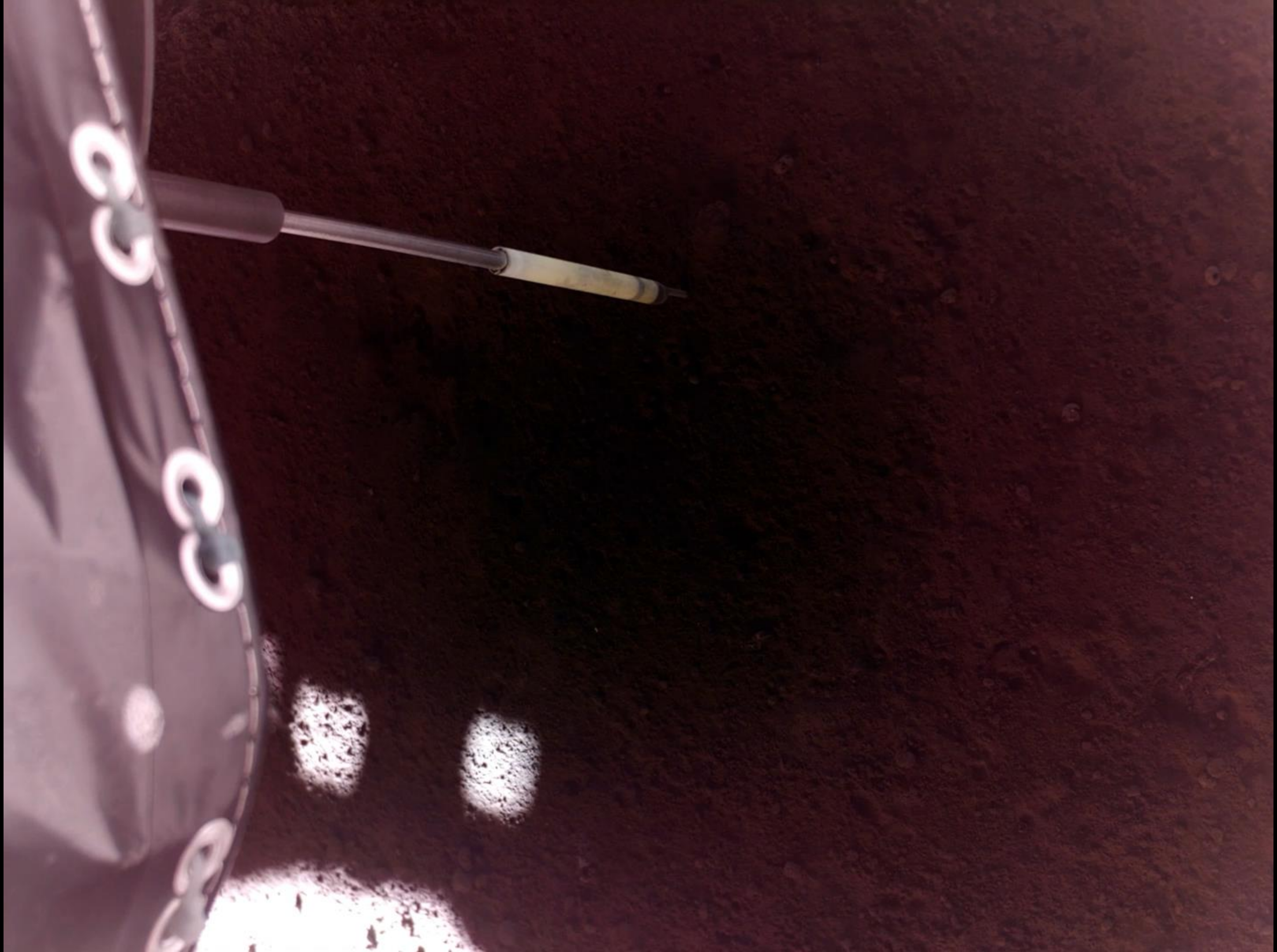
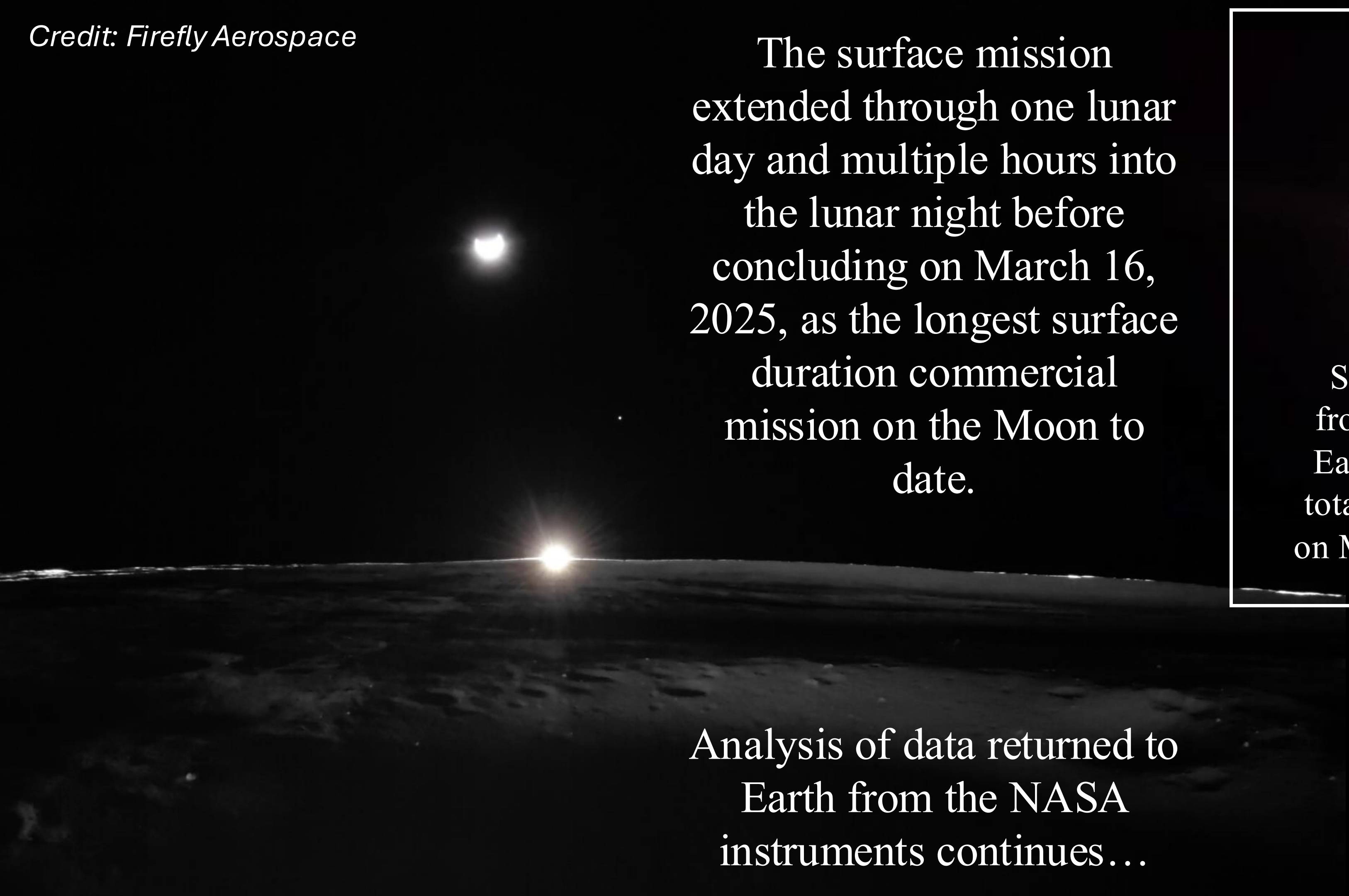


image provided by SCALPSS Team: C. Nguyen/NASA LaRC



Credit: Firefly Aerospace



The surface mission extended through one lunar day and multiple hours into the lunar night before concluding on March 16, 2025, as the longest surface duration commercial mission on the Moon to date.

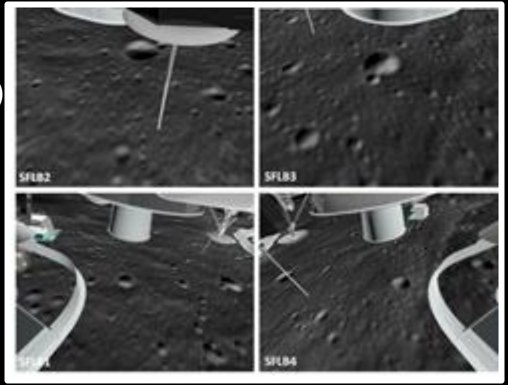
Sun emerging from behind the Earth during the total solar eclipse on March 14, 2025

Analysis of data returned to Earth from the NASA instruments continues…

Back up slides

SCALPSS 1.1 *Stereo Cameras for Lunar Plume-Surface Studies*

- Flight Hardware Heritage: Mars 2020 EDLCam, SCALPSS 1.0
  - 4 Cameras Assemblies
    - 2 combo mounts
    - 2 single mounts
  - 1 Data Storage Unit (DSU)
  - 1 USB Hub



Goals/Objectives

- Return video and still images of the lunar surface as the lander descends and its engine plume interacts with the surface.
- (G) Assess the effect of engine plume interactions with the lunar surface on the landing vehicle, the landing site, and nearby assets and region, resulting in better predictive capabilities to lower risk and ensure landing success.
- (O) Collect plume-surface interaction data that can be used for computational model validation:
  - Primary: Capture 3D post-landing site alteration morphology
  - Primary: Capture pre-PSI 3D landing site morphology
  - Primary: Measure crater depth/size and erosion volume
  - Primary: Detect PSI onset
  - Primary: Record transient site alteration morphology
  - *Secondary: Measure ground obscuration (onset and extent)*
  - *Secondary: Measure dust settling density as a function of time*

Payload Team

- PI: Michelle Munk (LaRC)
- PM: Robert Maddock (LaRC)
- Science Team:
  - Wesley Chambers (MSFC
  - Paul Danehy (LaRC)
  - Olivia Tyrrell (LaRC)
  - Mike Manginelli (MSFC)

Technical Lead	Chi Nguyen (LaRC)
Electronics	Ray Lueg (LaRC)
Thermal	Amanda Stark (LaRC)
Structures	Kevin Roscoe (LaRC)
Mechanical	Nick Vitullo (LaRC)
Camera/Lens	Bill Witherow (MSFC)
AI&T	Joshua Beverly (LaRC)
SMA/QA	K C Johnson (LaRC)
CCE	Sarah Foyer (LaRC)
Flight Software	Cory Wilson (LaRC)
Ground Software	Matt Rogers (LaRC)

Performance Metrics

- (Metrics) Image sets (1 frame each/4 cameras) + timestamp
- (Min) 1 full resolution (HDR) SFL image set taken after the lander is at rest on the surface and all dust has settled (@ TD+10s) plus 1 full resolution LFL image set taken from altitude (~8m).
- (Full) Descent LFL image sets @ 10 fps from 50 m to 5 m altitude plus descent SFL image sets @ 8 fps from 30 m altitude to TD+10s, plus surface full resolution (HDR) image sets every 10 sec from TD+10s for 1 min, them every 1 min for 10 min, then every 10 min for 1h and then every hour to TD+4h.
- (Augmented): 1 full resolution (HDR) image set each hour during day ops beginning at TD+5h; 1 HDR image set each minute beginning around sunset - 10m.

LuGRE - Lunar GNSS Receiver Experiment

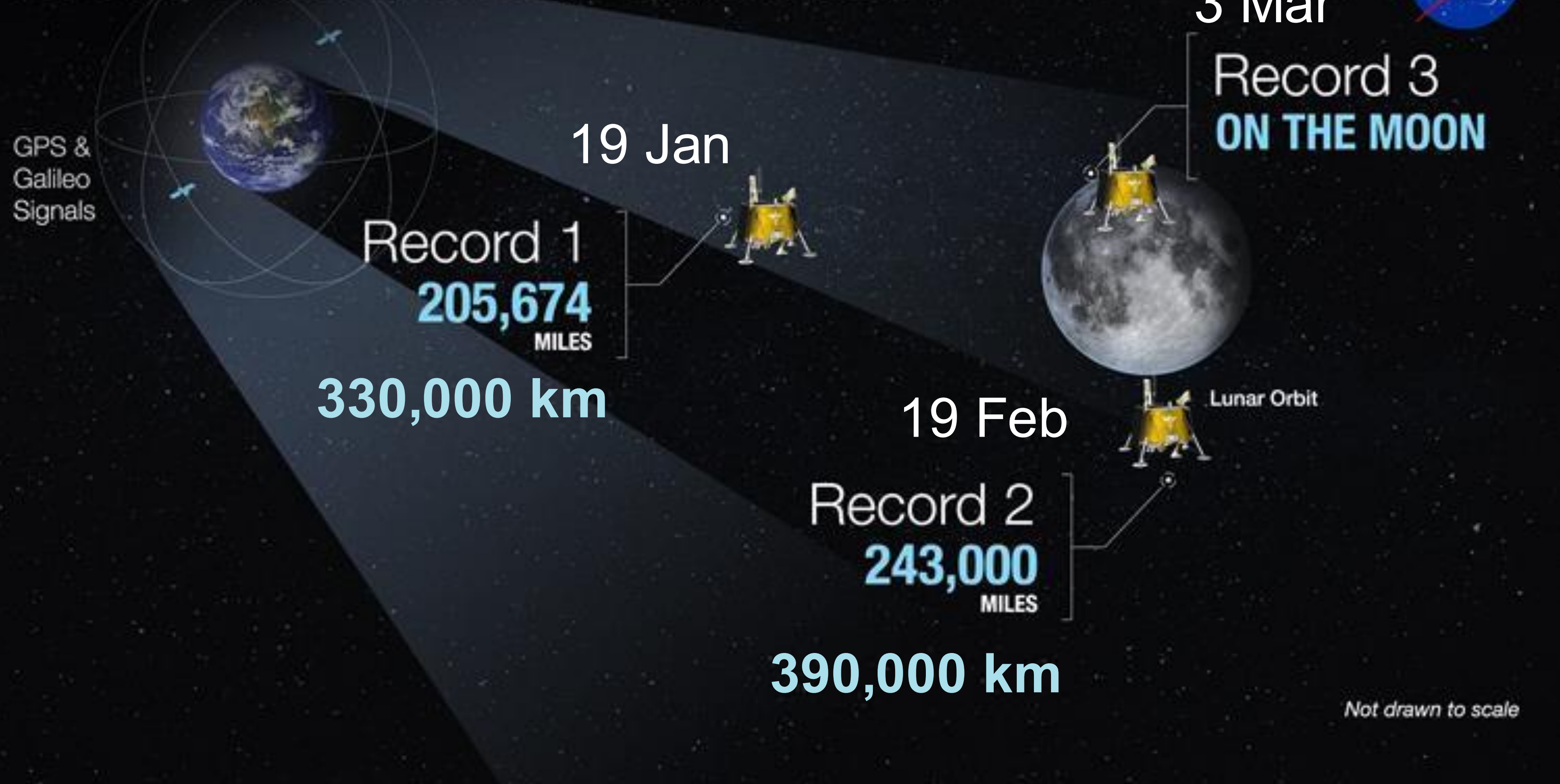
LuGRE is an international partnership that will, for the first time, demonstrate global navigation satellite system (GNSS)-based navigation at the Moon.

Partner agencies: NASA, ASI
PI: Joel J. K. Parker, NASA GSFC

Goals/Objectives

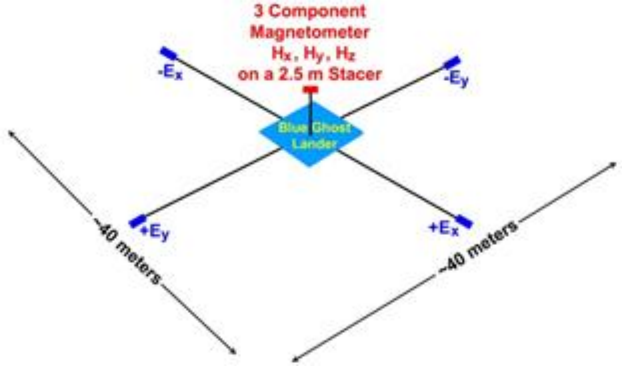
- (G) Extend GNSS-based navigation and timing to the Moon.
- (O1) Receive GNSS signals at the Moon. Return data and characterize the lunar GNSS signal environment.
- (O2) Demonstrate navigation and time estimation using GNSS data collected at the Moon.
- (O3) Utilize collected data to support development of GNSS receivers specific to lunar use.

LuGRE Records on Blue Ghost



LMS - Lunar Magnetotelluric Sounder

- LMS will determine the electrical conductivity of the lunar interior over depths ~100-1000 km by measuring ambient electric and magnetic fields over six decades in frequency.



PI: Robert Grimm, SwRI

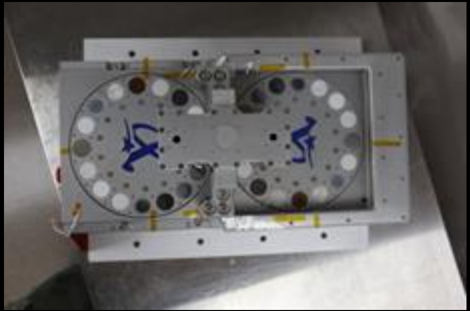
Goals/Objectives

- (G) Assess interior temperature and composition (Fe, H_2O) from electrical conductivity.
- (O) Primary - Characterize vertical structure due to magma-ocean differentiation.
- (O) Primary - Determine the nature of lunar global asymmetry in the mantle.
- (O) Secondary - Assess local static electric and magnetic fields.

RAC - Regolith Adherence Characterization

- Characterization of 30 material samples of their interaction with lunar regolith.

PI: Matt Carter,
Aegis Aerospace
PM: Jeff Buell



Goals/Objectives

- (G) RAC's data will help inform materials selection for lunar landers, space suits, rovers, and other lunar surface systems by demonstrating relative affinity to lunar regolith among the RAC materials samples. The data may also affect operational requirements if it is discovered that operations can cause regolith adhesion. This data can also provide baselines for testing active methods of regolith repellent in the future.

LISTER - Lunar Instrumentation for Subsurface Thermal Exploration with Rapidity

- LISTER will determine the Moon's endogenic heat flow at the landing site as a product of two separate measurements of the thermal gradient and the thermal conductivity.

  - PI: Seiichi Nagihara, Texas Tech University
  - D-PI: Kris Zacny, Honeybee Robotics

Goals/Objectives

- (G) Determine the Moon's endogenic heat flow at the landing site.
- (O) Primary - Determine the thermal properties of the lunar regolith for the subsurface depth interval penetrated by LISTER
- (O) Primary - Demonstrate pneumatic drilling
- (O) Primary - Measure subsurface temperature
- (O) Primary - Measure regolith thermal conductivity
- (O) Secondary - Capture images of cuttings pile and determine subsurface stratigraphy/layering

LPV - Lunar PlanetVac

Lunar PlanetVac (LPV) is a pneumatic regolith delivery system. It transfers regolith from the lunar surface to a sample collection chamber via a tube between the surface and lander deck.

PI: Kris Zacny, Honeybee Robotics
PM: Vince Vendiola, Honeybee Robotics

Goals/Objectives

- (G) Demonstrate autonomous regolith acquisition and delivery
- (O) Primary - Deliver regolith from lunar surface into Sample Sorting System and demonstrate this technology for future sampling missions on the Moon, Mars, and other planetary bodies
- (O) Secondary - Image delivered sample
- (O) Secondary - Image dust adhesion coupons before and after regolith delivery
- (O) Secondary - Perform pneumatic sieving
- (O) Secondary - Demonstrate beam-breaker functionality

LEXI - Lunar Environment heliospheric X-ray Imager

- LEXI will take wide field-of-view soft X-ray images of Earth's magnetosphere and magnetosheath to study large-scale solar wind-magnetosphere coupling

Goals/Objectives

- (O) Under what conditions is solar wind-magnetosphere coupling temporally steady versus impulsive?

- PI: Brian Walsh, Boston University
- Co-I: K.D. Kuntz, Johns Hopkins, F.S. Porter NASA GSFC, D.G. Sibeck NASA GSFC, Hyunju Connor NASA GSFC

NGLR - Next Generation Lunar Retroreflector

- Lunar Laser Ranging to NGLR-1 target on the Moon
- NGLR-1 Reflects laser pulses from Lunar Laser
- Ranging Observatories (LLROs). Located on Earth.
- The return is timed and entered into the analysis program at JPL.

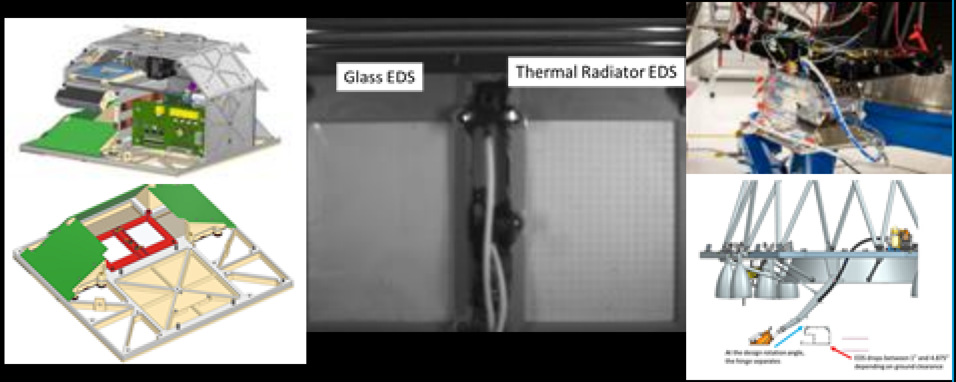
When all three NGLRs are deployed, and the analysis programs developed the LLR program will address Lunar Physics, Astrophysics, tests of General Relativity.

Goals/Objectives

- Obtain a Measurement by the APOLLO LLRO
- Prepare for future program of evaluation of NGLR-1 performance.

- PI: Professor Douglas G. Currie, University of Maryland
- Co-PI: Professor Drew Baden, University of Maryland

EDS - Electrodynamic Dust Shield



Goals/Objectives

- (G) Demonstrate effective lunar dust removal from a thermal radiator and glass EDS (Footpad EDS) on the surface of the moon

- (O) Collect images:
  - *With dust on the Footpad EDSs*
  - *During dust removal from the Footpad EDSs*
  - *After dust removal from the Footpad EDSs*

- PI: Dr. Charles Buhler, NASA-KSC
- CO-PI: Dr. Joseph Toth, NASA-KSC

RadPC - Radiation Tolerant Computing System

- RadPC is a space computing technology that mitigates the impact of single-event-effects (SEEs) through a series of novel fault recovery procedures.

- PI: Dr. Brock LaMeres, Montana State University

Goals/Objectives

- (G) Test the reliability of RadPC in the harsh radiation environment of lunar transit and lunar surface.
- (O) Record RadPC's reliability performance as it passes through Earth's radiation belts during transit to the moon.
- (O) Log Radiation data using on-board dosimeters as the payload passes through Earth's radiation belts during transit to the moon.
- (O) Record RadPC's reliability performance on the surface of the the moon.
- (O) Log Radiation data using on-board dosimeters on the surface of the the moon.