

Radio Astronomy from the Moon:

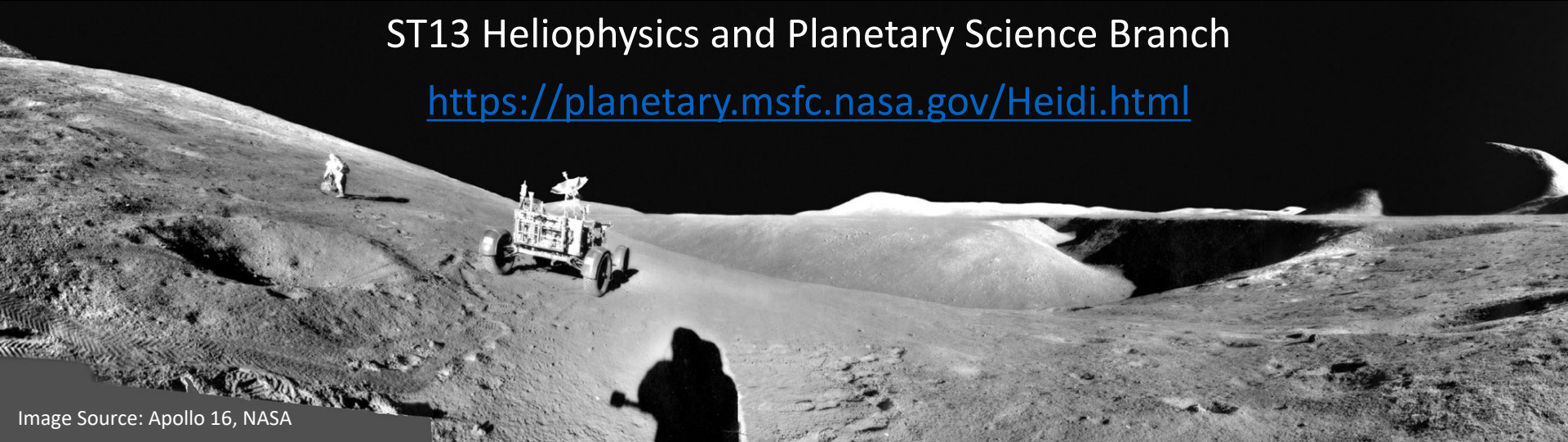
A discussion on the science from upcoming NASA Commercial Lunar Payload Services (CLPS) missions to the lunar surface with low frequency (<100 kHz) radio astronomy instruments and the need for radio quiet zone on the Moon

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ST13 Heliophysics and Planetary Science Branch

<https://planetary.msfc.nasa.gov/Heidi.html>



Outline

- Bio
- Planetary Science Research
- CLPS Program
- Intro to Radio Astronomy
- Radio Science Payloads: ROLSES, LuSEE
- My CLPS Deliveries: NMLS, CP11
- Future Lunar Missions: FARSIDE
- Q&A

Image Source:
Clementine, NASA

Education Path



- Bachelors of Science, Physical Science, Biola University , La Mirada, California
- Bachelors of Science, Aerospace (Astronautics) Engineering, Univ. Southern California (USC)
- Masters of Science, International Space University, Strasbourg, France
- PhD, Earth & Planetary Science, University of California, Berkeley
 - Geophysics
 - Dissertation: Identifying induced magnetic fields of the Moon

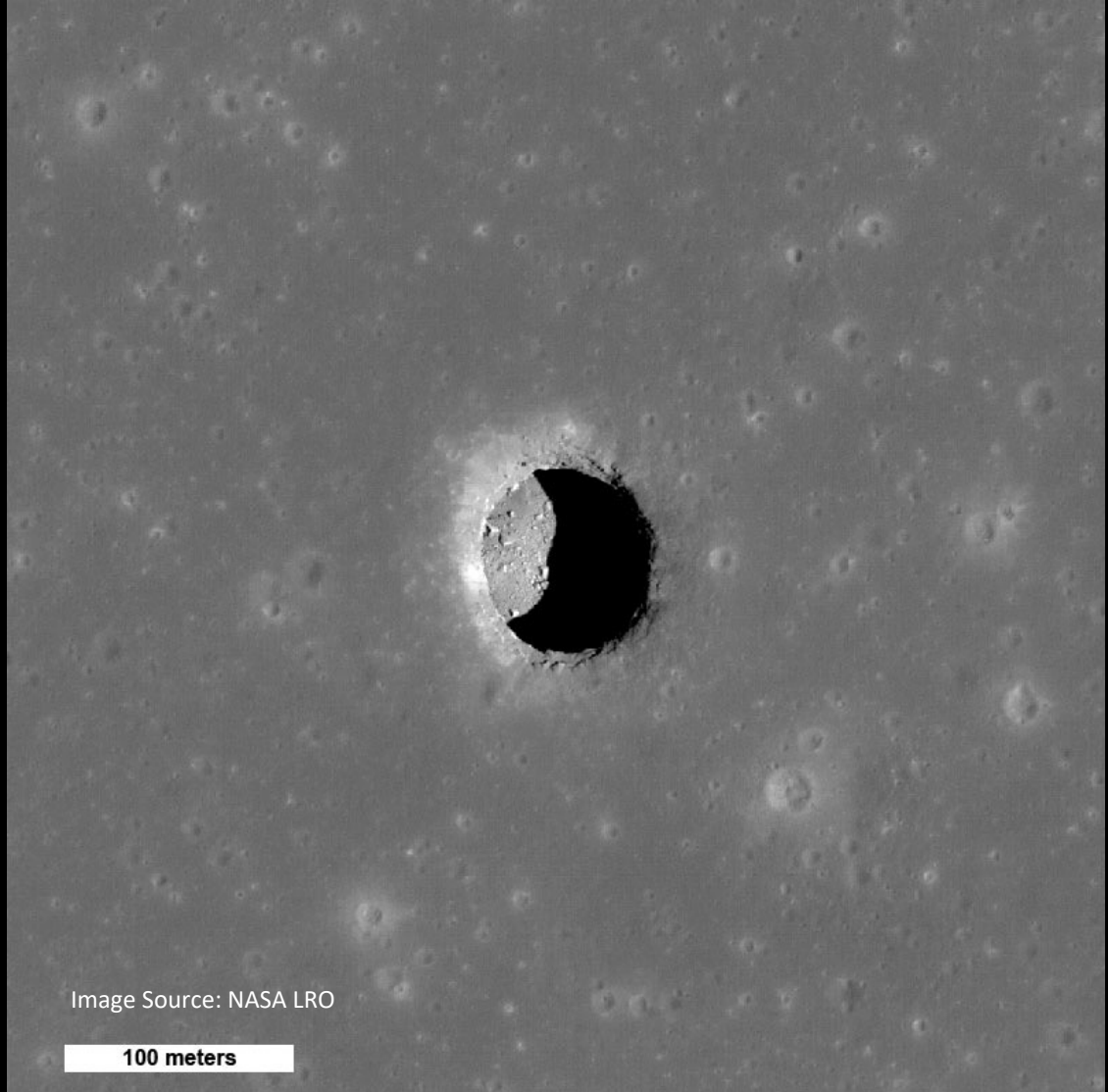


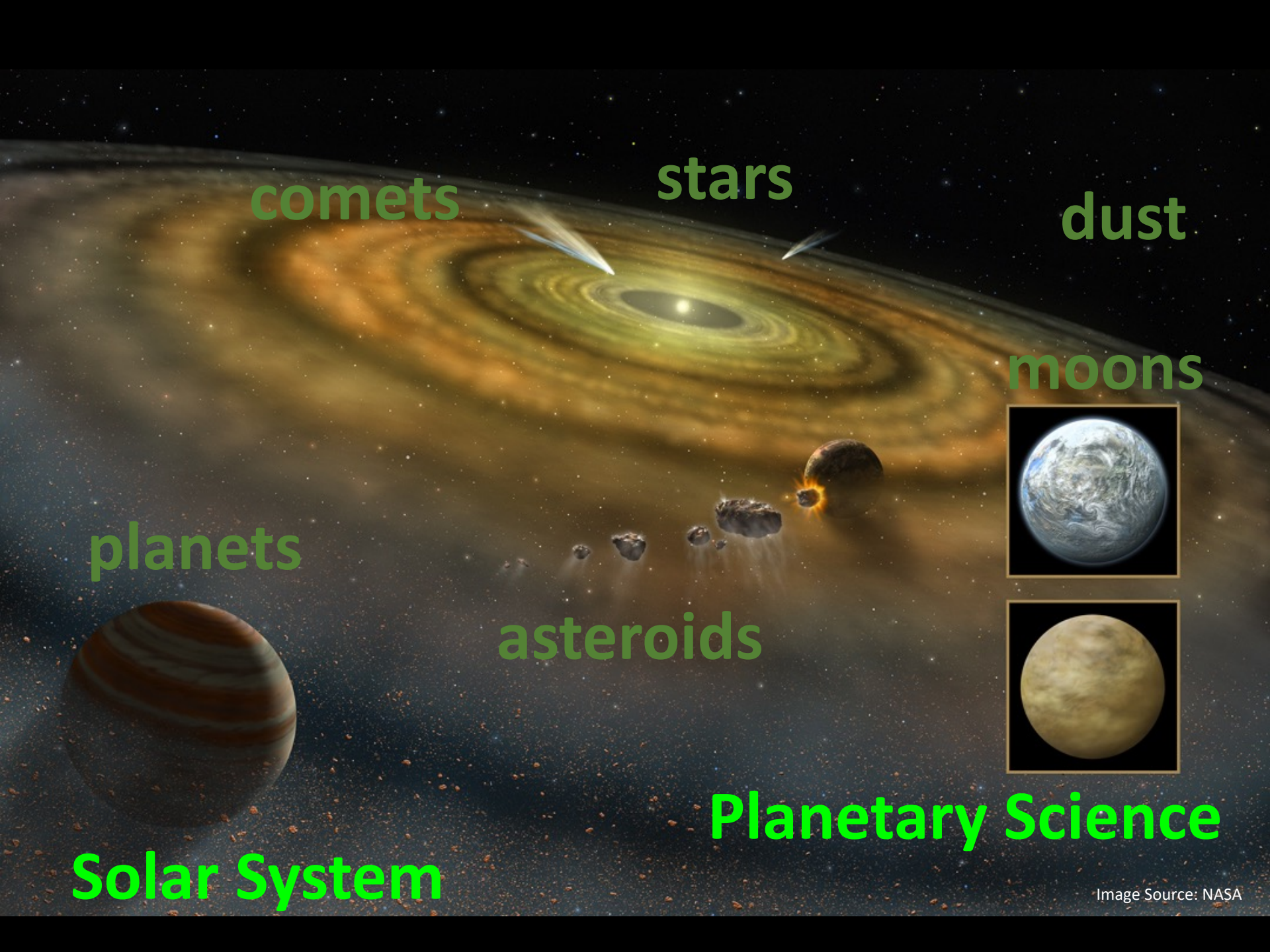
Career Path

- Engineering Internships, Boeing, Northrop Grumman & NASA Ames
- Mechanical Integration & Test Engineer, Northrop Grumman
- Mechanical Design Integration, Systems Engineering, Northrop Grumman
- Graduate Student Instructor & Researcher, UC Berkeley, Space Sciences Lab
- Invited Guest Researcher, Louisiana State University, Geology & Geophysics Department
- Research Scientist, NASA MSFC



What is a planet? How do we learn about planets?





comets

stars

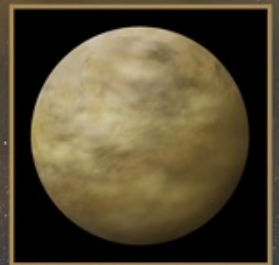
dust

moons



planets

asteroids



Planetary Science

Solar System

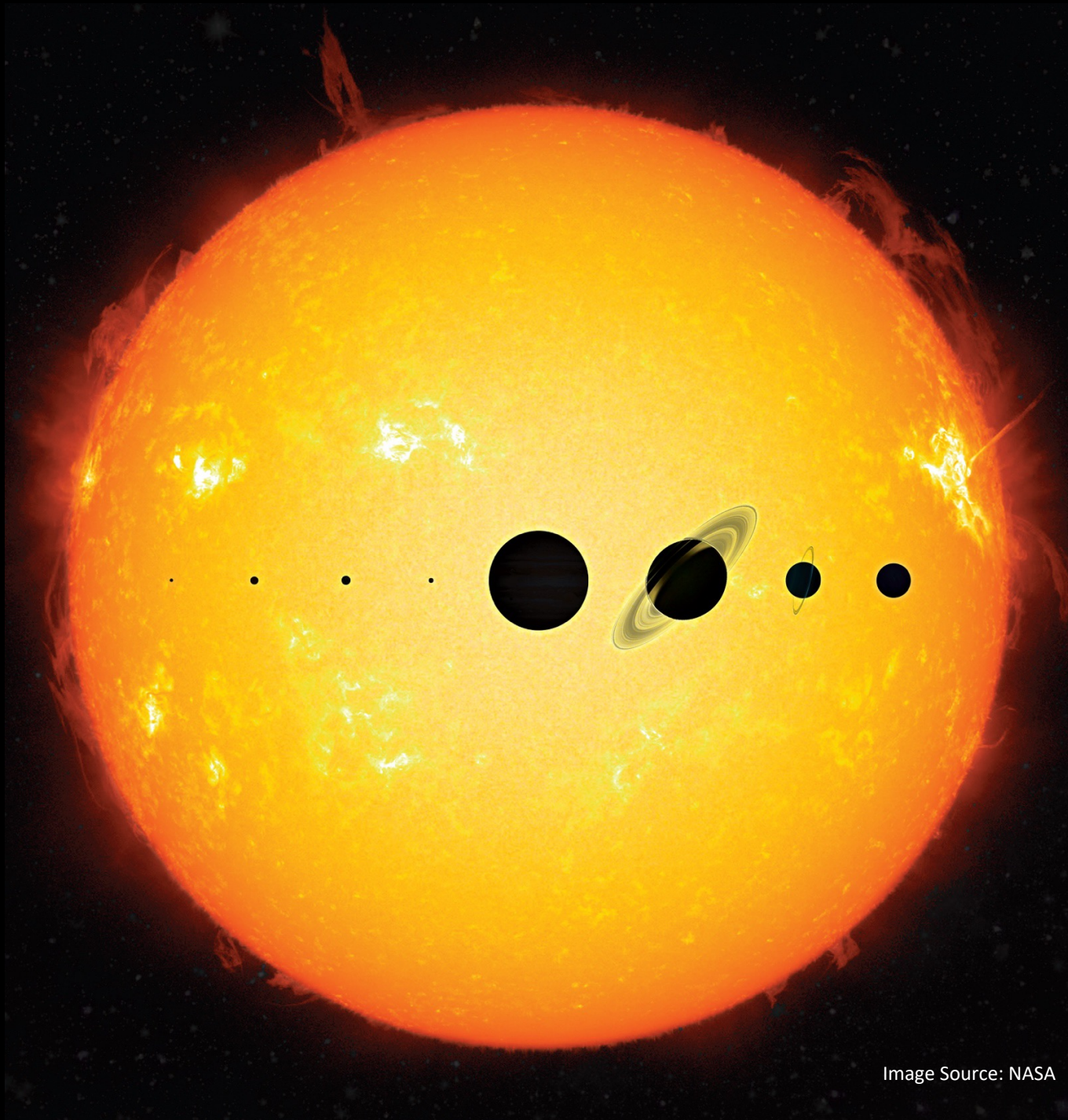


Image Source: NASA



Russia's Luna25

India's Chandrayaan 3



Artemis Phase 1: Path to The Lunar Surface

Artemis I: First human spacecraft to the Moon in the 21st century

Artemis II: First humans to orbit the Moon in the 21st century

Artemis Support Mission: First high-power Solar Electric Propulsion (SEP) system

Artemis Support Mission: First pressurized module delivered to Gateway

Artemis Support Mission: Human Landing System delivered to Gateway

Artemis III: Crewed mission to Gateway and lunar surface

Commercial Lunar Payload Services

- CLPS-delivered science and technology payloads

Early South Pole Mission(s)

- First robotic landing on eventual human lunar return and In-Situ Resource Utilization (ISRU) site
- First ground truth of polar crater volatiles

Large-Scale Cargo Lander

- Increased capabilities for science and technology payloads

Humans on the Moon - 21st Century

First crew leverages infrastructure left behind by previous missions

LUNAR SOUTH POLE TARGET SITE

2020

2025

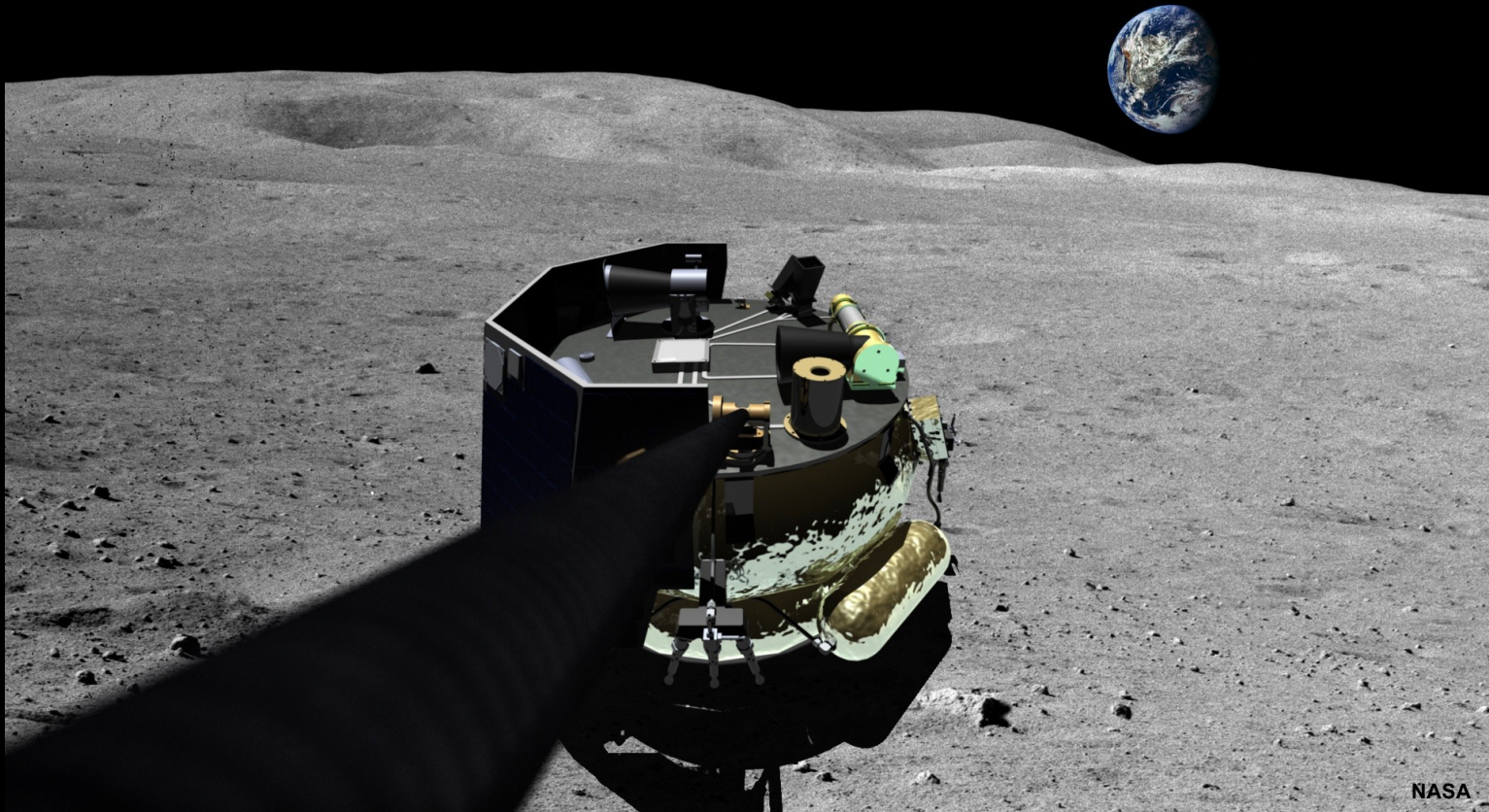
Upcoming Opportunities: Artemis & Commercial Lunar Payload System (CLPS)



NASA

- The Payloads and Research Investigations on the Surface of the Moon (PRISM) program solicits payloads annually to fly on upcoming CLPS deliveries.
- NASA's Science Mission Directorate has also solicited instruments to be deployed by Artemis crew on the surface of the Moon.

Commercial Lunar Payload Services (CLPS)



CLPS: Rapid Affordable Frequent Access to the Lunar Surface



★ Active Task Orders

CLPS Deliveries

2023-2026

Delivery Site:
Gruithuisen Domes
Provider TBD
PRISM 2a/CP-21 | 2026



Delivery Site:
Reiner Gamma
Provider Intuitive Machines
PRISM 1a/CP-11 | April 2024



Delivery Site:
South Pole
Provider: Intuitive Machines
TO PRIME-1 | NET June 2023

Delivery Site:
South Pole
Provider TBD
PRISM 2b/CP22 | 2025



Delivery Site:
South Pole
Provider:
Astrobotic
VIPER | Nov 2024



Delivery Site:
South Pole
Provider: Intuitive
Machines
TO2-IM | Mar 2023



Delivery Site:
Gruithuisen Domes
Provider: Astrobotic
TO2-AB | Q1 2023



Delivery Site:
Mare Crisium
Provider: Firefly
TO19D | May 2024



Delivery Site:
Farside
Provider: Firefly
TOCS3 | 2026



Delivery Site:
Schrödinger Basin
Provider Draper
PRISM 1b/CP-12 | 2025

Delivery Site:
Orbital
Provider: TBD
CS-4 | 2025-6

COMMERCIAL LUNAR PAYLOAD SERVICES **LANDING SITES**

National Aeronautics and
Space Administration



NEARSIDE

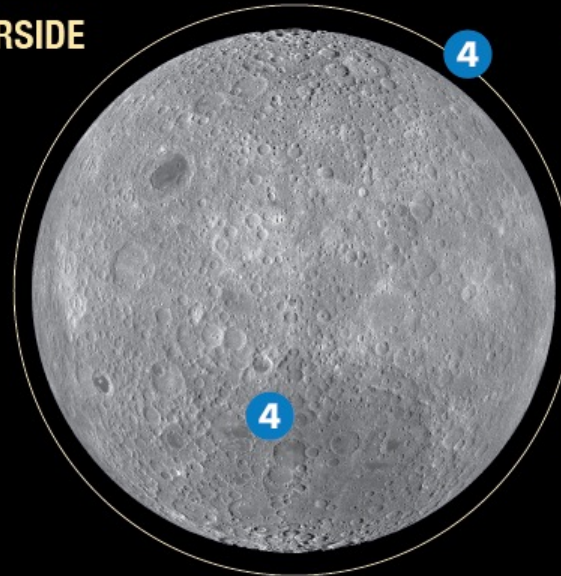


1 Astrobotic Peregrine Mission-1
EXPECTED LAUNCH DATE: 2023
LANDING SITE: Sinus Viscositatis
LANDER NAME: Peregrine
CLPS CONTRACT AWARD: T02-AB

2 Intuitive Machines IM-3
EXPECTED LAUNCH DATE: 2024
LANDING SITE: Reiner Gamma
LANDER NAME: Nova-C
CLPS CONTRACT AWARD: TO CP-11

3 Firefly Blue Ghost Mission 1
EXPECTED LAUNCH DATE: 2024
LANDING SITE: Mare Crisium
LANDER NAME: Blue Ghost
CLPS CONTRACT AWARD: TO 19D

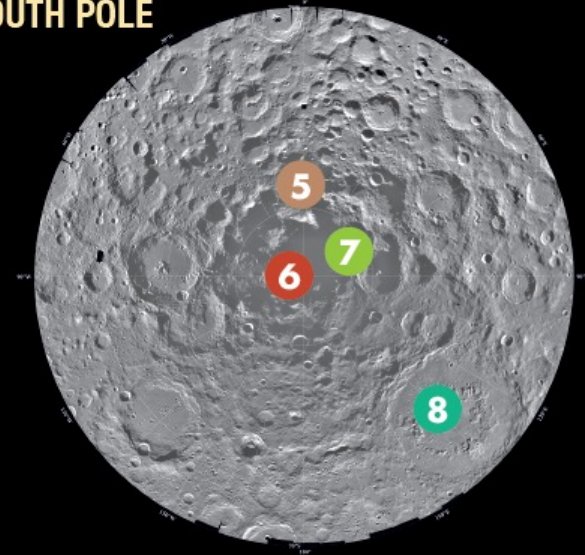
FAR SIDE



4 Firefly Blue Ghost Mission 2
EXPECTED LAUNCH DATE: 2026
LANDING SITE: Lunar farside
LANDER NAME: Blue Ghost
CLPS CONTRACT AWARD: TO CS-3

4 Firefly Blue Ghost Mission 2
EXPECTED LAUNCH DATE: 2026
DELIVERY SITE: Lunar orbit
ORBITER NAME: Lunar Pathfinder
CLPS CONTRACT AWARD: TO CS-3

SOUTH POLE



5 Intuitive Machines IM-1
EXPECTED LAUNCH DATE: 2023
LANDING SITE: Malapert A
LANDER NAME: Nova-C
CLPS CONTRACT AWARD: T02-IM

6 Intuitive Machines IM-2
EXPECTED LAUNCH DATE: 2023
LANDING SITE: Shackleton Connecting Ridge
LANDER NAME: Nova-C
CLPS CONTRACT AWARD: TO PRIME-1

7 Astrobotic Griffin Mission-1
EXPECTED LAUNCH DATE: 2024
LANDING SITE: Nobile Region
LANDER NAME: Griffin
CLPS CONTRACT AWARD: TO 20A (VIPER)

8 Team Draper
EXPECTED LAUNCH DATE: 2025
LANDING SITE: Schrödinger Basin
LANDER NAME: SERIES-2
CLPS CONTRACT AWARD: TO CP-12

Three Next on the Pad Deliveries

TO2-IM (*Intuitive Machines*)

- Lunar Node 1 Navigation Demonstrator (LN-1)
- Laser Retroreflector Array (LRA)
- Navigation Doppler Lidar for Precise Velocity and Range Sensing (NDL)
- Stereo Cameras for Lunar Plume-Surface Studies (SCALPSS)
- Radio-wave Observations at the Lunar Surface of the photoElectron Sheath (ROLSSES)
- Radio Frequency Mass Gauge (RFMG)

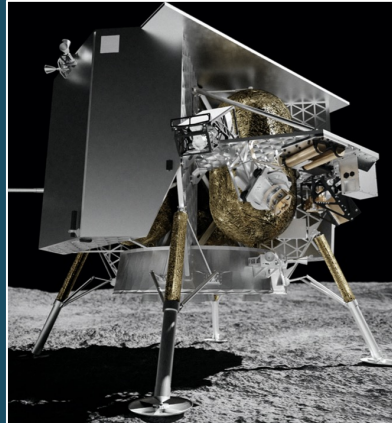


*Malapert
A*

IM-1
NOVA-C lander

TO2-AB (*Astrobotic*)

- Laser Retroreflector (LRA)
- Linear Energy Transfer Spectrometer (LETS)
- Near-Infrared Volatile Spectrometer System (NIRVSS)
- Neutron Spectrometer System (NSS)
- PROSPECT Ion-Trap Mass Spectrometer (PITMS)



*Sinus
Viscositatis*

Astrobotic
Peregrine lander

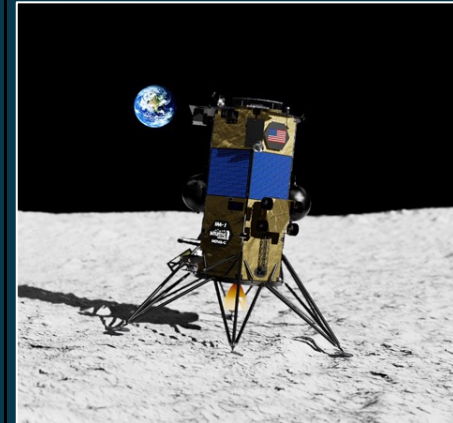
TO PRIME-1 (*Intuitive Machines*)

CLPS – PRIME-1

- *TRIDENT Drill* (Honeybee Robotics)
- *MSolo* (KSC)

STMD Tipping Point

- *Deployable μ -Nova Hopper* (IM & Arizona State)
- *LTE/4G Communication System & Rover* (Nokia)



*Connecting
Ridge*

IM-2
NOVA-C lander

National Aeronautics and
Space Administration



LUNAR MISSIONS

2021–2025

CLPS NASA PAYLOAD GOALS

- PEREGRINE-1**
 - Regolith volatiles composition
 - Local radiation environment
- 1ST NOVA-C**
 - Plume/surface interactions, charged particles near surface
 - Lander prop tank gauge test
- 2ND NOVA-C**
 - Drilling for volatiles
- 1ST BLUE GHOST**
 - Characterize Earth's magnetosphere and Moon's interior
- 3RD NOVA-C**
 - Lunar Magnetic Anomalies
- GRIFFIN-1 & VIPER**
 - Search for volatiles, below surface & shadowed regions
- SERIES-2**
 - Geophysics of the Schrödinger Basin
- 2ND BLUE GHOST**
 - Dark Ages observations from the lunar far side
 - ESA lunar comm relay satellite deployment

KEY

- ★ CLPS DELIVERY
- 🌐 INTERNATIONAL-LED
- 👤 HUMAN EXPLORATION
- 🔬 SCIENCE
- 🚀 SPACE TECHNOLOGY

5.04.2023

2023



PEREGRINE-1
ASTROBOTIC
★★★



1ST NOVA-C
INTUITIVE MACHINES
★★★



LRO



THEMIS-
ARTEMIS



LUNAR
TRAILBLAZER



2ND NOVA-C
INTUITIVE MACHINES
★★

2021

2022

2024



1ST BLUE GHOST
FIREFLY
★★★



3RD NOVA-C
INTUITIVE MACHINES
★★



ARTEMIS II
CREWED
FLIGHT TEST



GATEWAY
PPE & HALO
LAUNCH



LUNAR
PATHFINDER
★🌐



ARTEMIS III
CREWED SURFACE
MISSION

ORBITAL MISSIONS



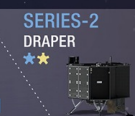
UNCREWED
LANDER
DEMO



GRIFFIN-1
ASTROBOTIC
★



VIPER
NASA
★



SERIES-2
DRAPER
★★



2ND BLUE GHOST
FIREFLY
★



CREWED
LANDER
DEMO

SURFACE MISSIONS

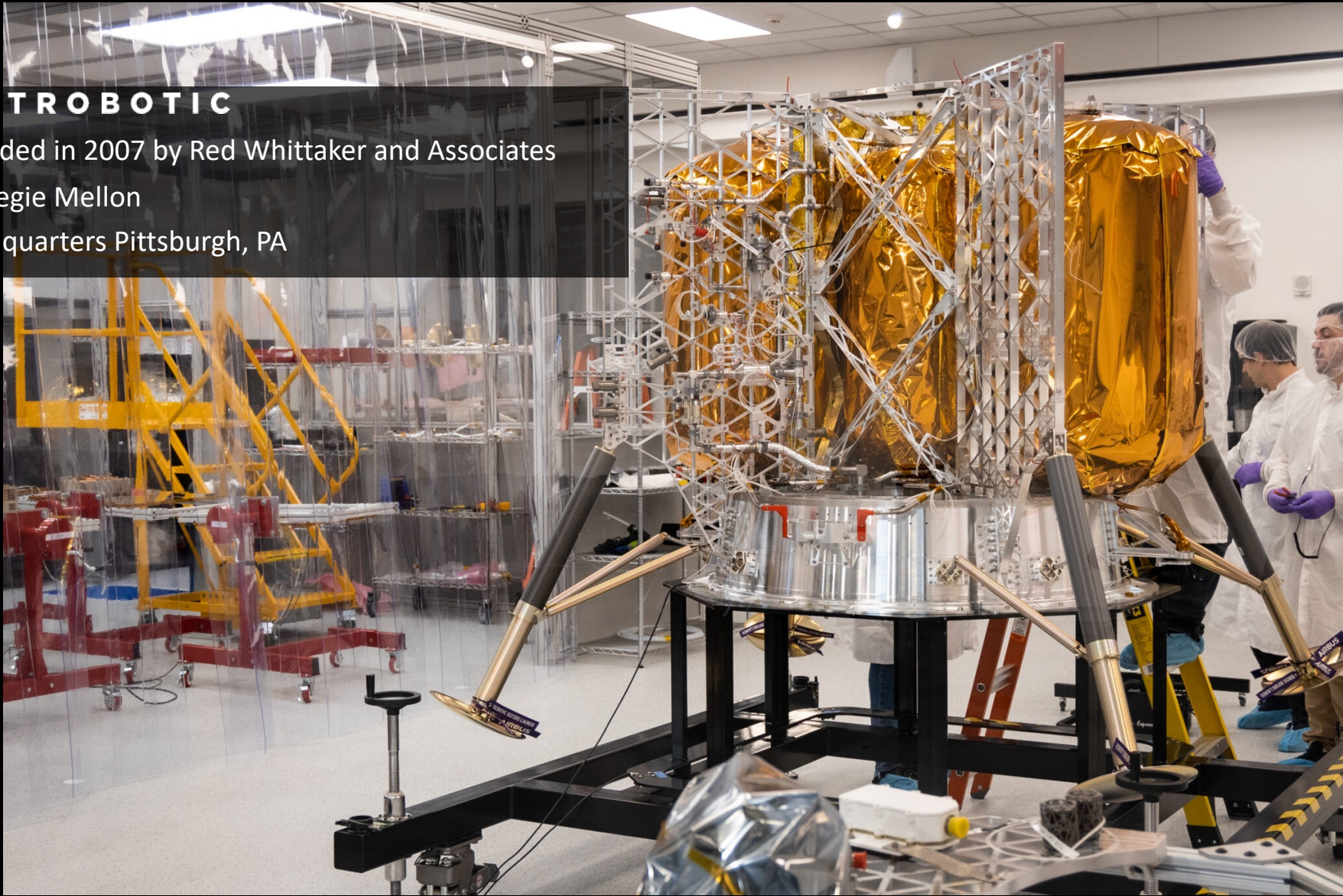
2025



- Founded in 2013 by Steve Altemus, Kam Ghaffarian, Tim Crain
- Headquarters Houston, TX

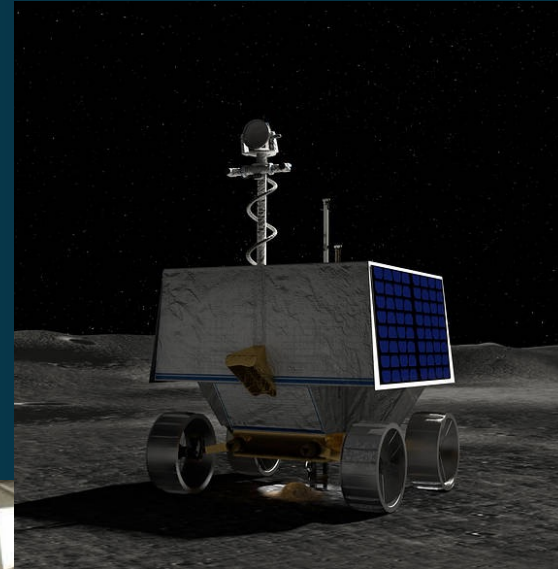
ASTROBOTIC

- Founded in 2007 by Red Whittaker and Associates
- Carnegie Mellon
- Headquarters Pittsburgh, PA



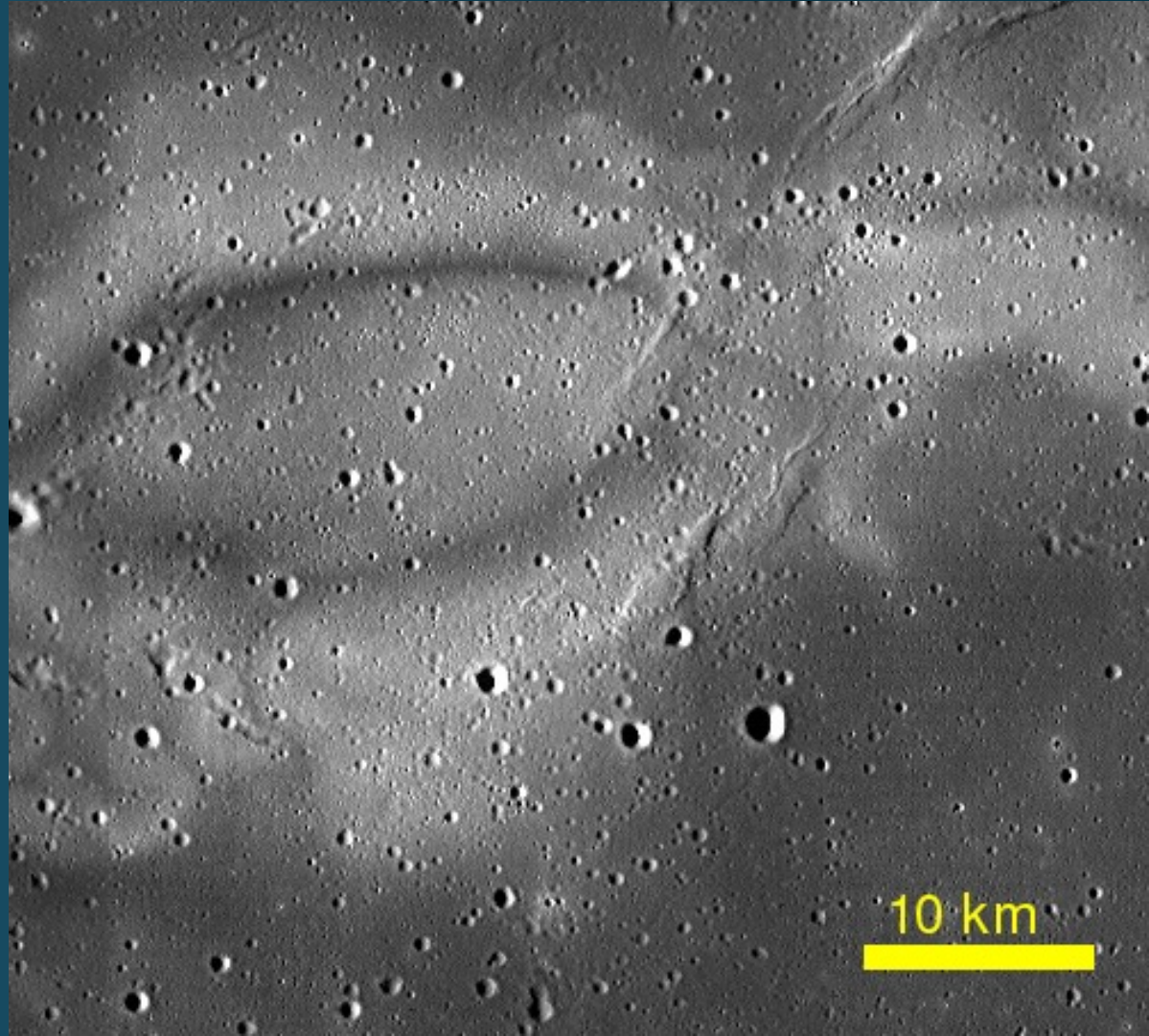
VIPER Rover

- Mission duration: 100 Earth days, covering 3 cycles of lunar day and night
- Distance goal: 12 miles (20 kilometers)
- Rover size: Similar to a golf cart: 5 feet by 5 feet by 8 feet (1.5 meters by 1.5 meters by 2.5 meters) and 992 pounds (450 kilograms)
- Power: Solar-charged battery, peak power of 450 watts
- Top speed: 0.45 mph (0.72 kph)
- Onboard instruments:
 - 3.28-foot (1-meter) drill
 - NIRVSS – Near Infrared Spectrometer
 - MSOLO – Mass Spectrometer
 - NSS – Neutron Spectrometer



Lunar Swirls – Reiner Gamma

- Reiner Gamma is one of several lunar “swirls”
- It is visible from Earth telescopes
- Origin is not well understood
 - Associated with crustal magnetic fields
 - Does not correspond to features on the surface
 - Could be impact related
- Lunar Vertex payload will explore this with a lander and rover scheduled for 2024



CLPS TASK ORDER CP-11 (PRISM 1A)

Mission Details

Lander/ Launch Provider: Intuitive Machines/SpaceX

Landing Date: **April 2024**

Landing Site: Reiner Gamma

Surface Ops Duration: 318 Hours

Manifest

- **Lunar Vertex Suite**
 - Magnetometer
 - Camera
 - Electron Spectrometer
 - Ion Spectrometer
 - Rover w/magnetometer + multispectral microscope
- **CADRE** (3 autonomous Swarm Rovers with Ground Penetrating Radar/JPL)
- **LUSEM** (Radiation detector) provided by the Korean Space Agency KASI
- **MPAc** (Actuated Retroreflector) provided by the European Space Agency

Science Goals

- To determine the origin of lunar swirls

Technology Goals

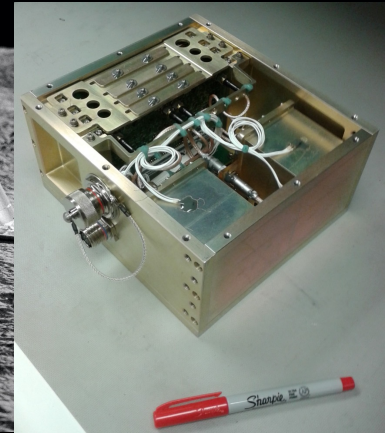
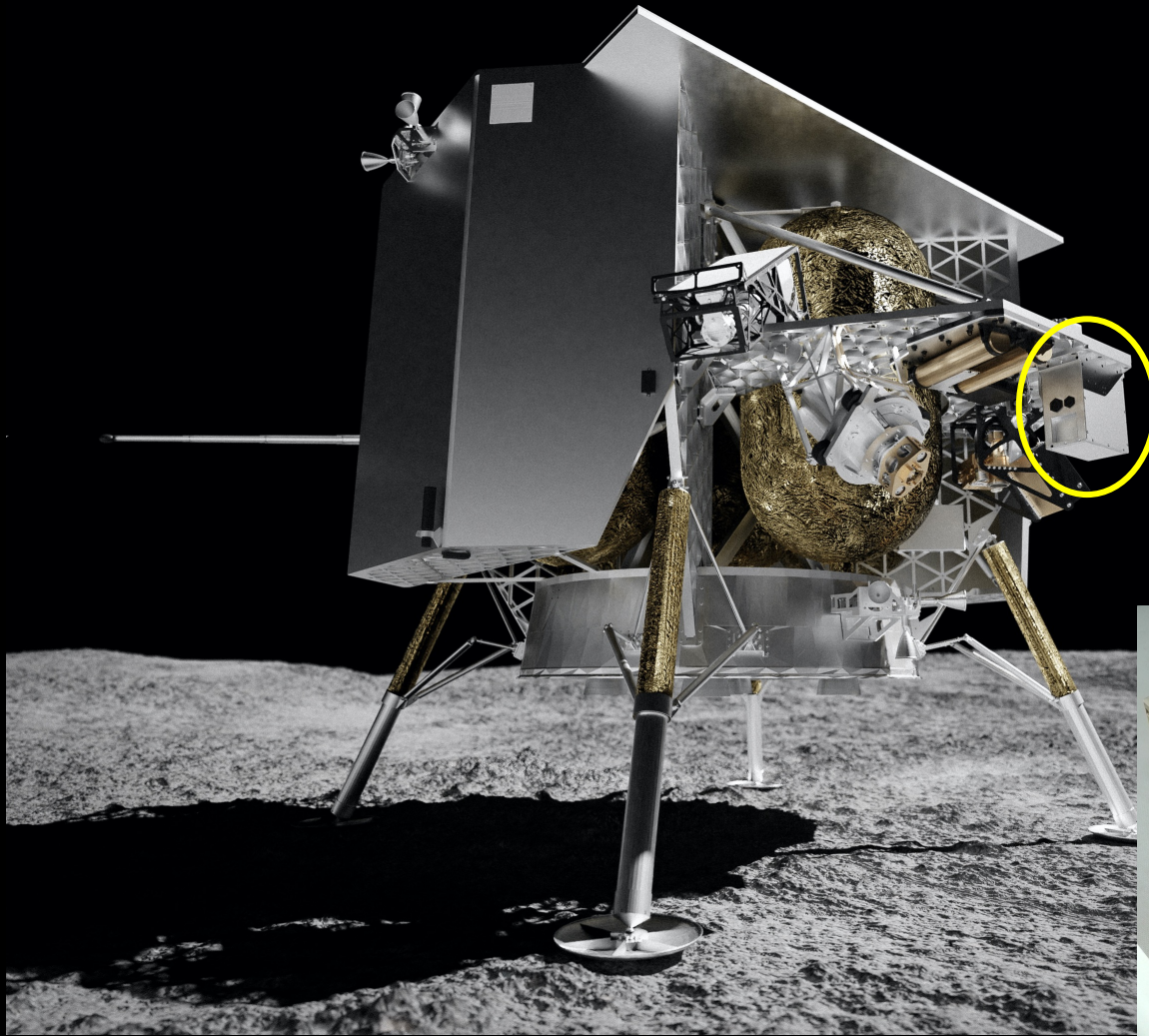
- To demonstrate autonomous roving and decision making

Nova-C Lander



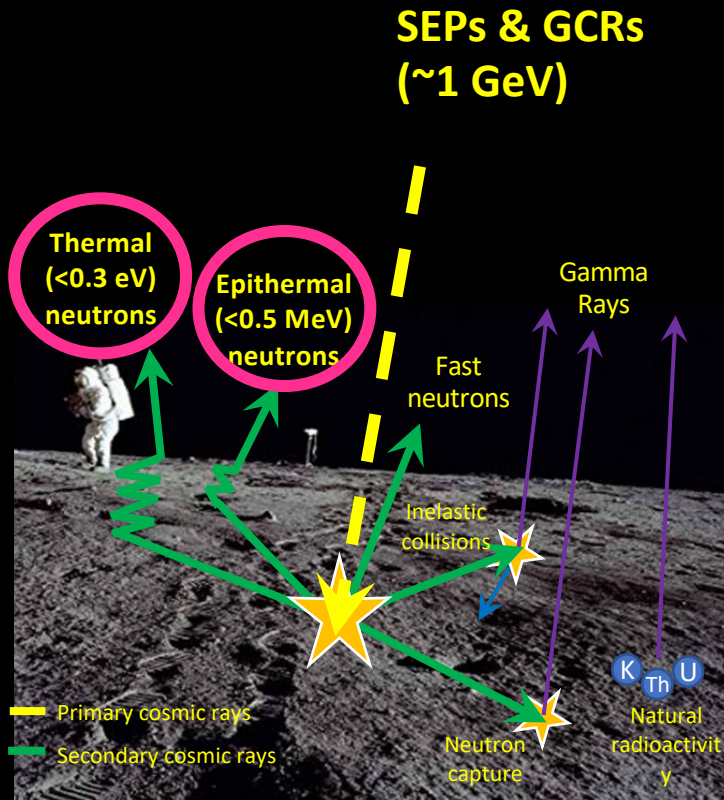
Credit: Intuitive Machines

Neutron Measurements at the Lunar Surface (NMLS)



Neutron Spectroscopy

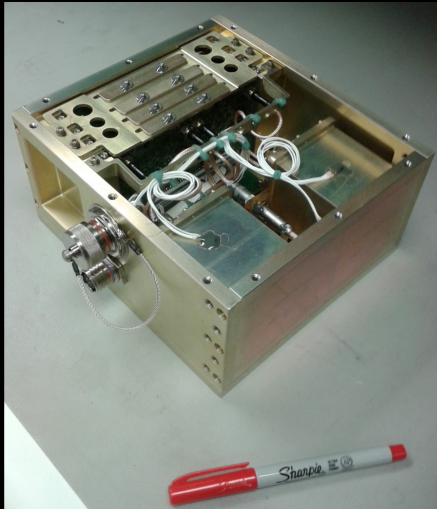
After Curran [2017]



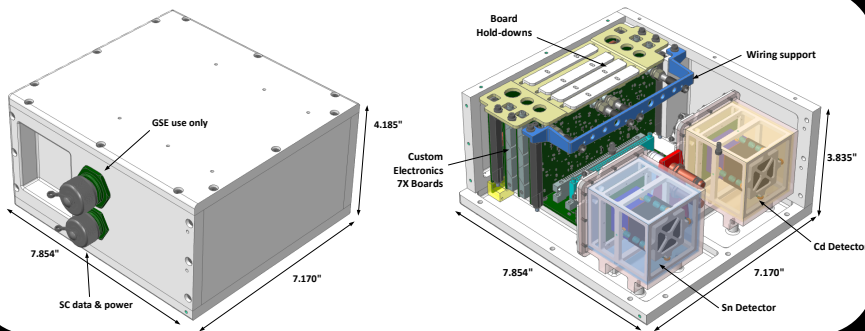
- “Epithermal neutrons”
 - Medium energy
 - ~constant for most lunar compositions (except H).
- “Thermal neutrons”
 - low energy
 - absorption cross section increases by nuclei
 - is highly composition dependent (flux is large for Fe, Ti)
 - Flux is greater in mafic materials (mare basalts, Mg or Fe-rich, of igneous/volcanic origin, dark in color, olivine, pyroxene)
 - Flux is smaller in the Fe-poor highlands (farside).
- MSFC scintillator technology effectively discriminates between pulse shapes and distinguishes between neutron and gamma ray (as well as other false) triggers.

Neutron Measurements at the Lunar Surface (NMLS)

PI Peter Bertone/ST12, Project Scientist Heidi Haviland/ST13,
Lead System Engineer Jeff Apple/ES11

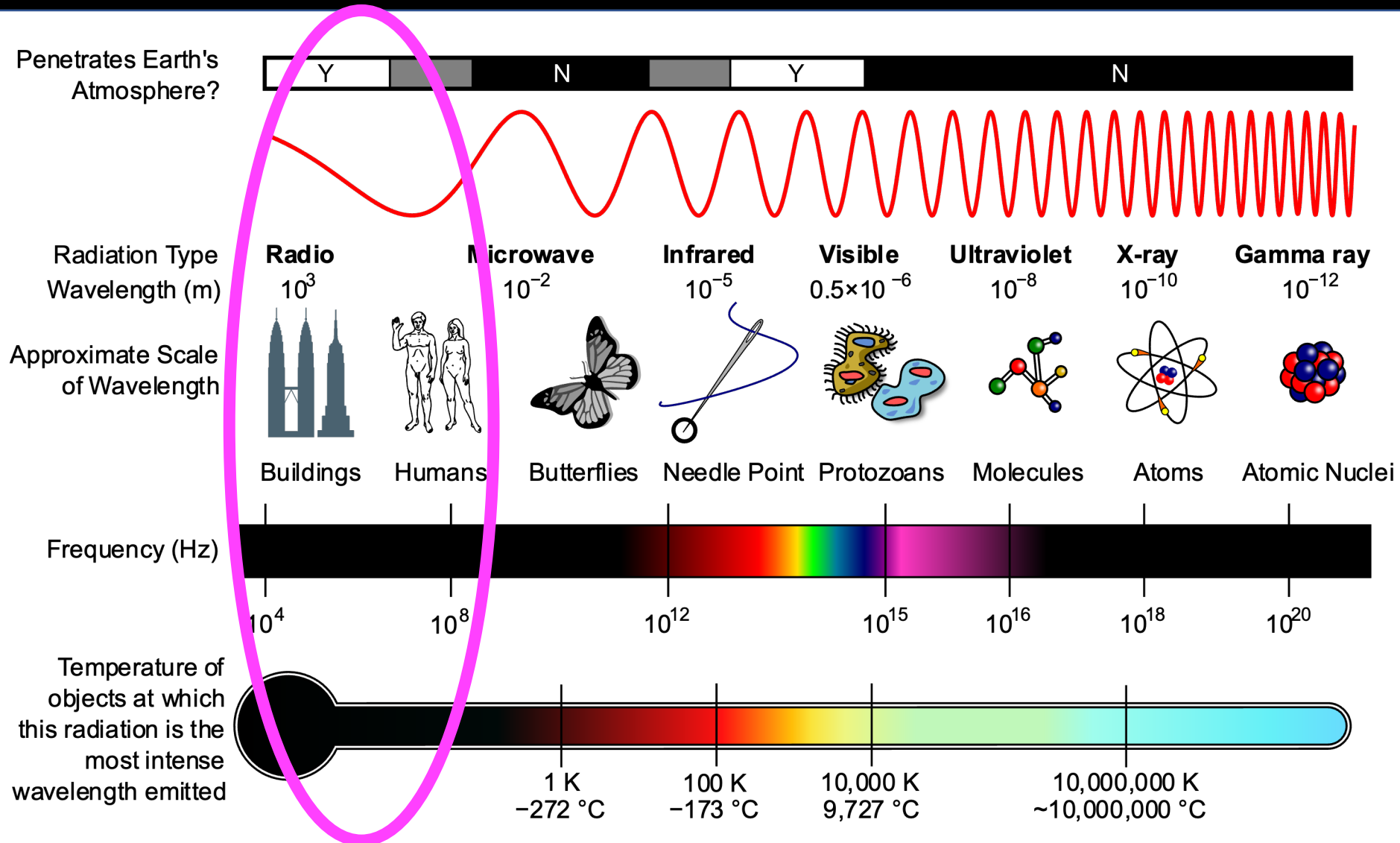


- Originally slated to fly on the Astrobotic Peregrine Mission 1 Lander in 2023. Due to Astrobotic's under performing engines, NMLS and other NASA payloads were removed.
- NMLS is currently awaiting a ride to the Moon.
- NMLS will measure thermal and epithermal neutron count rates using composite scintillator detectors.
- NMLS will infer surface composition from counting rates.
- Thermal neutron count rates are sensitive to minerals such as KREEP (Potassium K, Rare Earth Element, and Phosphorous).
- Epithermal neutron count rates are sensitive to hydrogen including water.

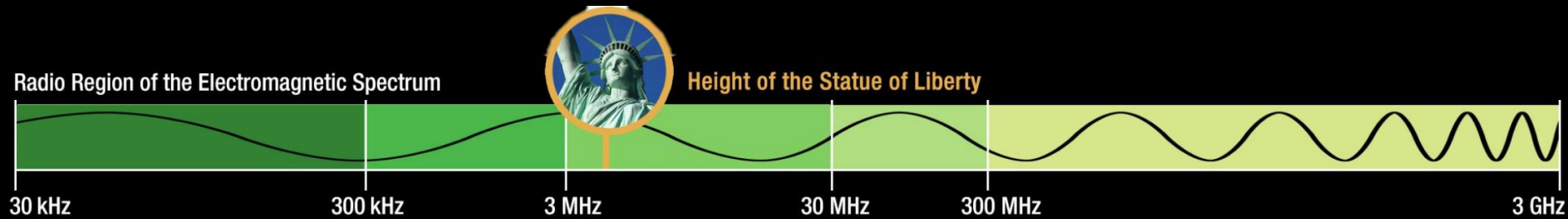


Radio Astronomy

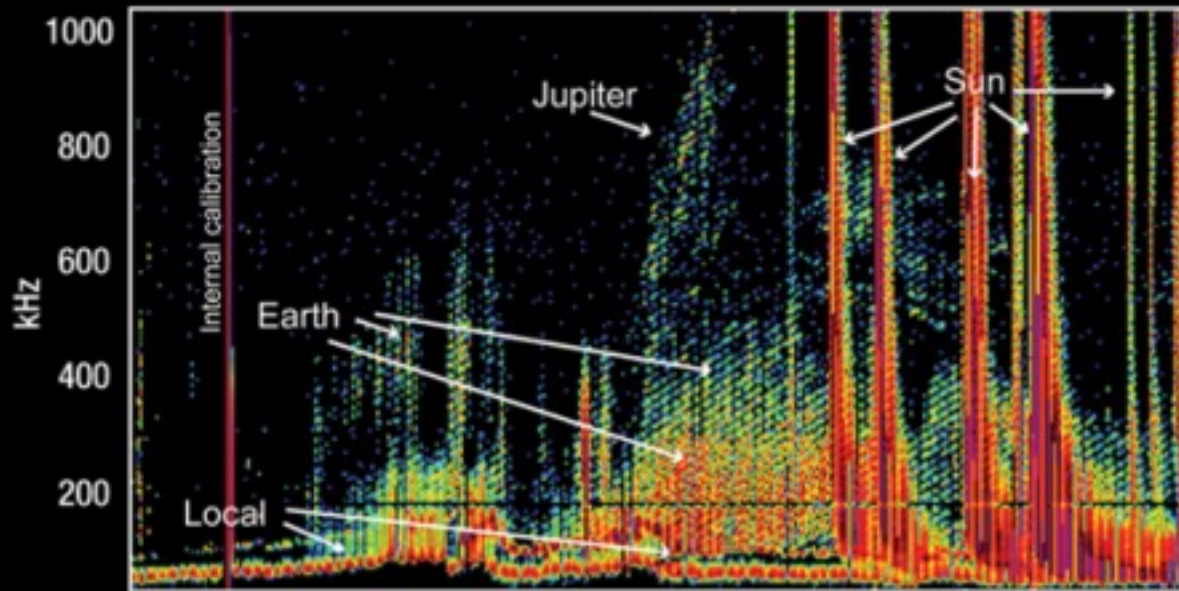
Electromagnetic Spectrum



Radio Waves



RADIO EMISSIONS

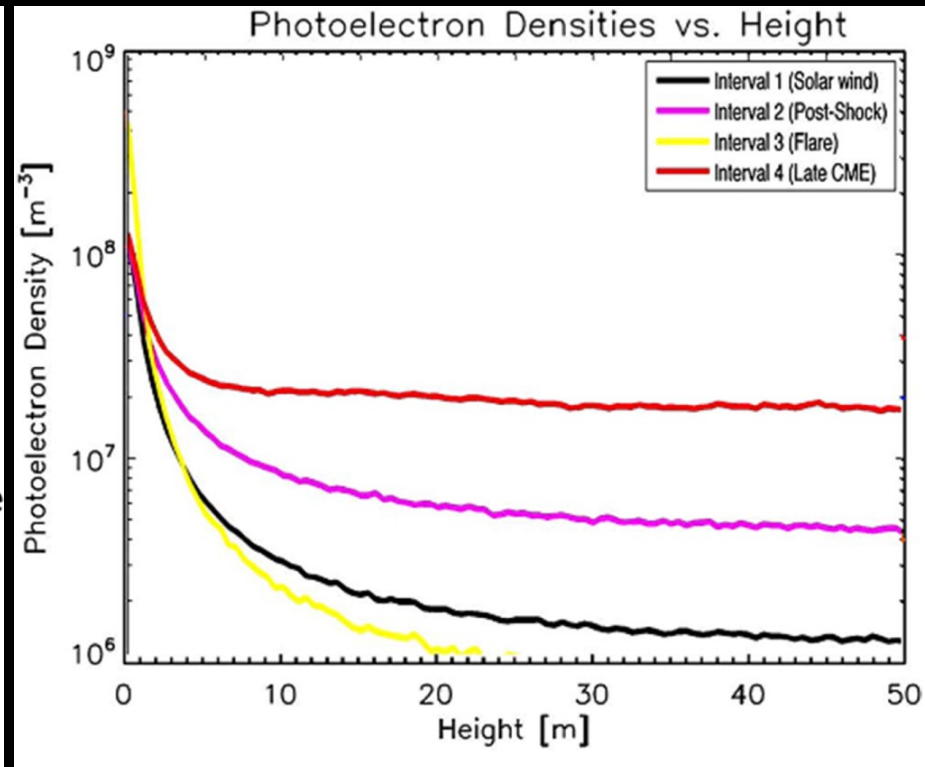
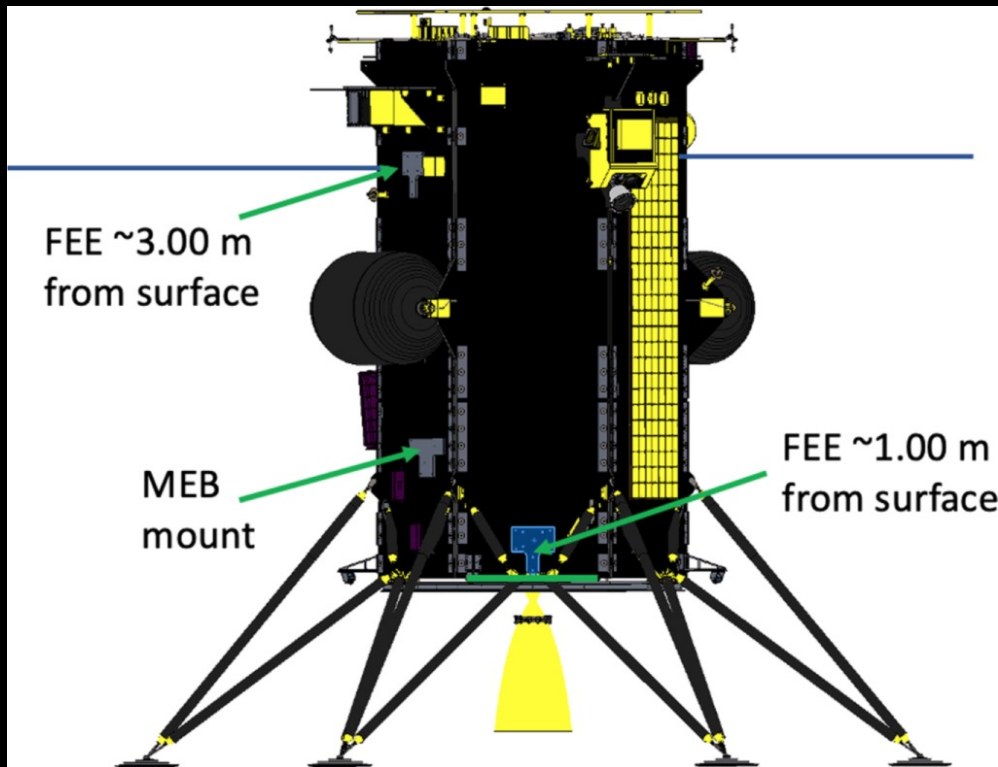


One day of Radio Emissions

Radio Telescopes



ROLSES: Radio wave Observations at the Lunar Surface of the photoElectron Sheath (TO2 IM, Q4 2023)



Radio spectra, 10 kHz–30 MHz, will investigate the plasma environment above the lunar surface and measure the fidelity of radio spectra on the surface. Locations of Electronics(FEE, MEB) are noted. Proof of concept that good, clean radio measurements can be made on the Moon.



Image Credit: NASA

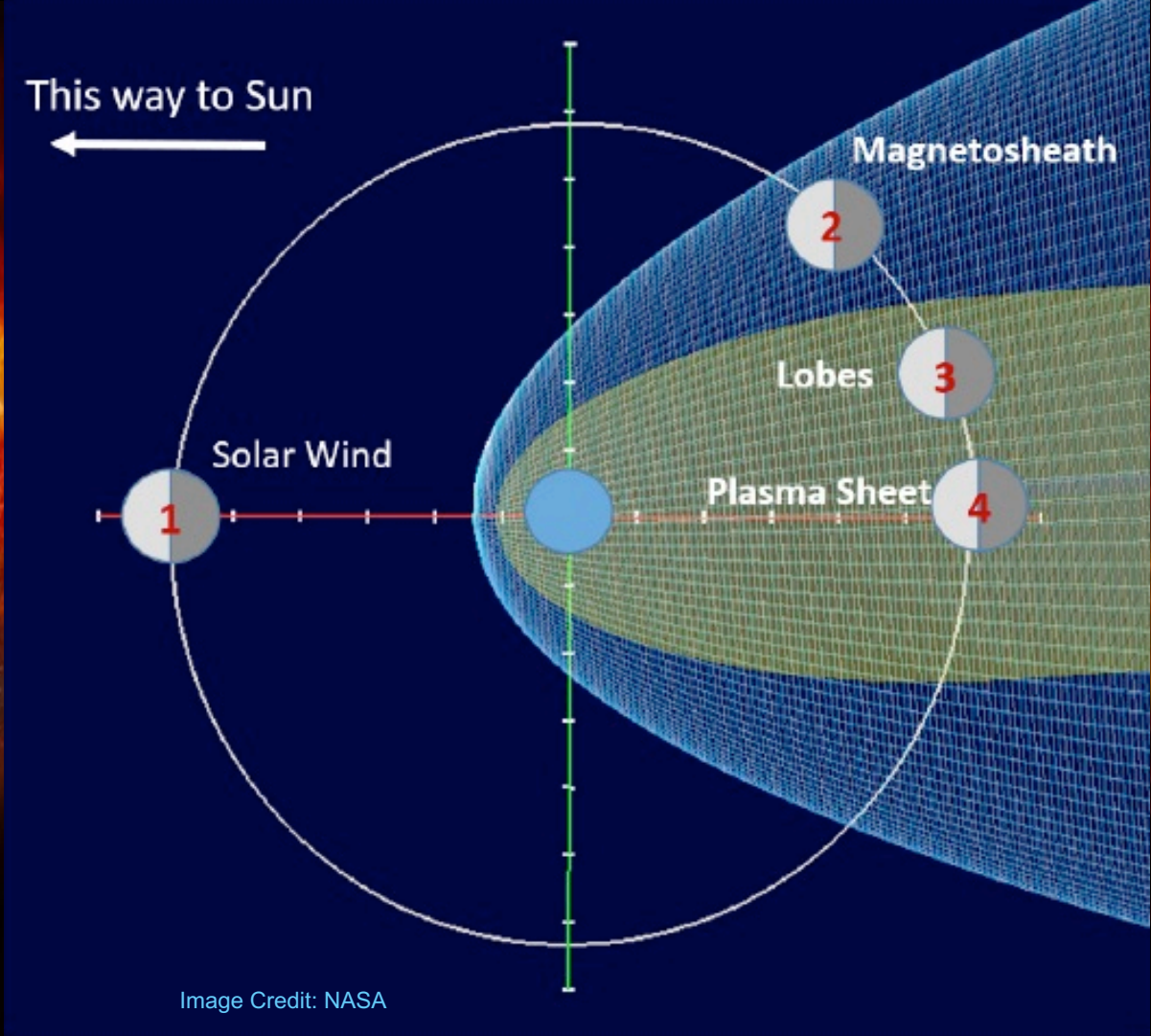


Image Credit: NASA

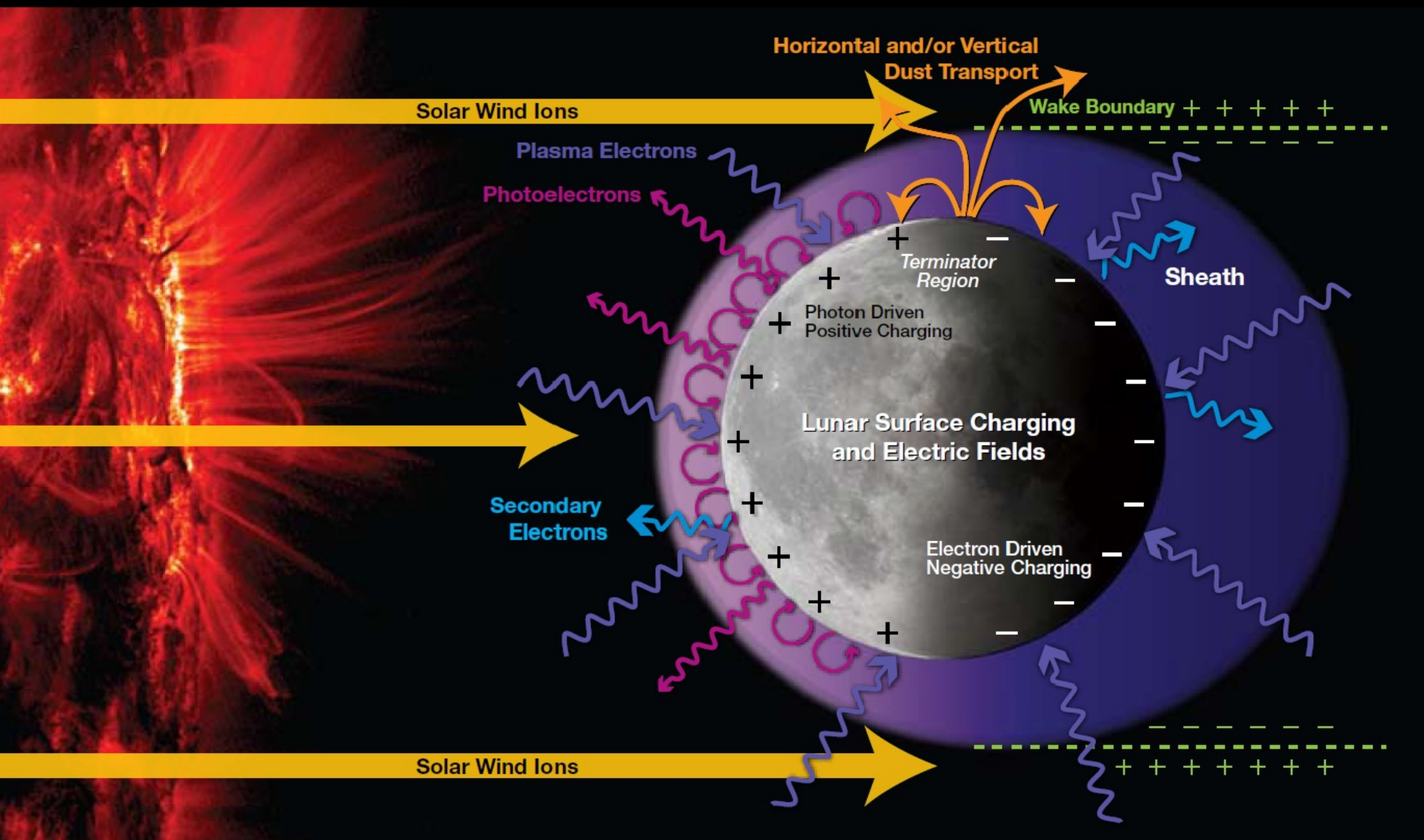
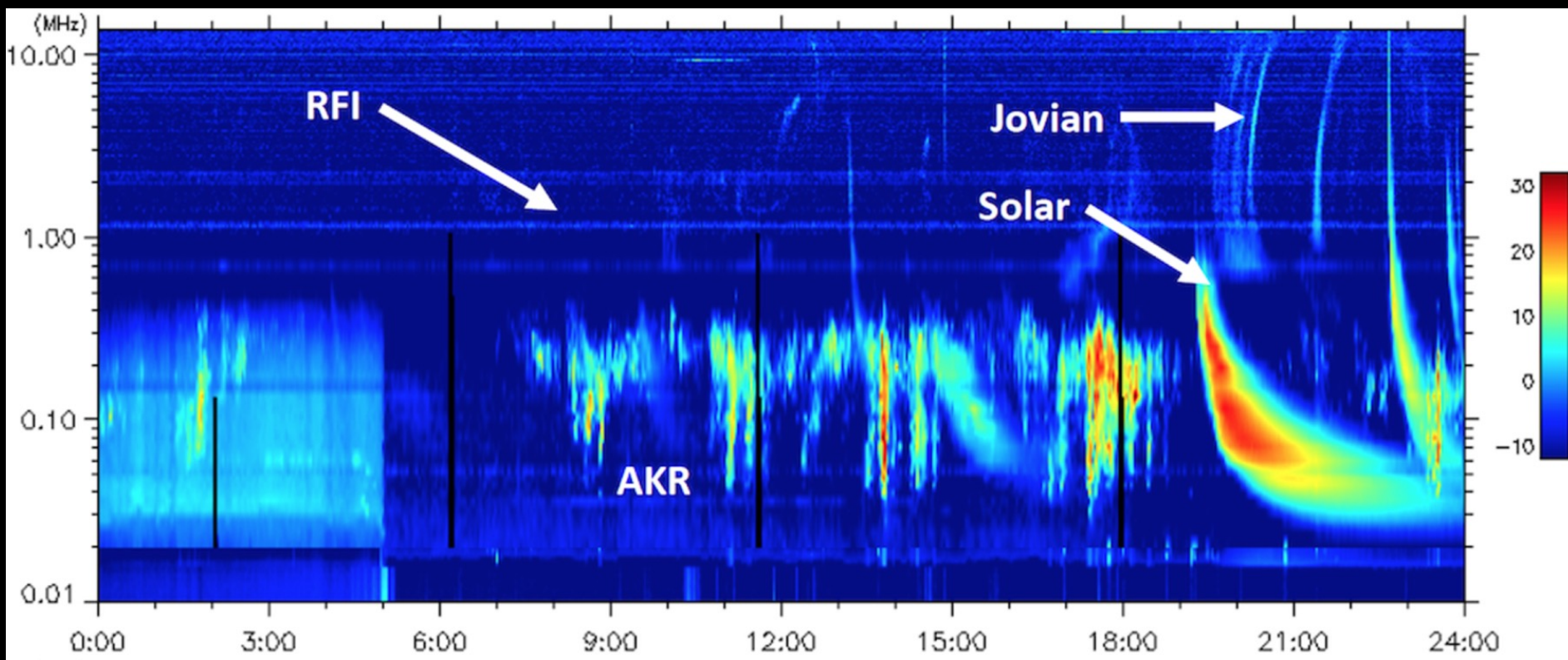


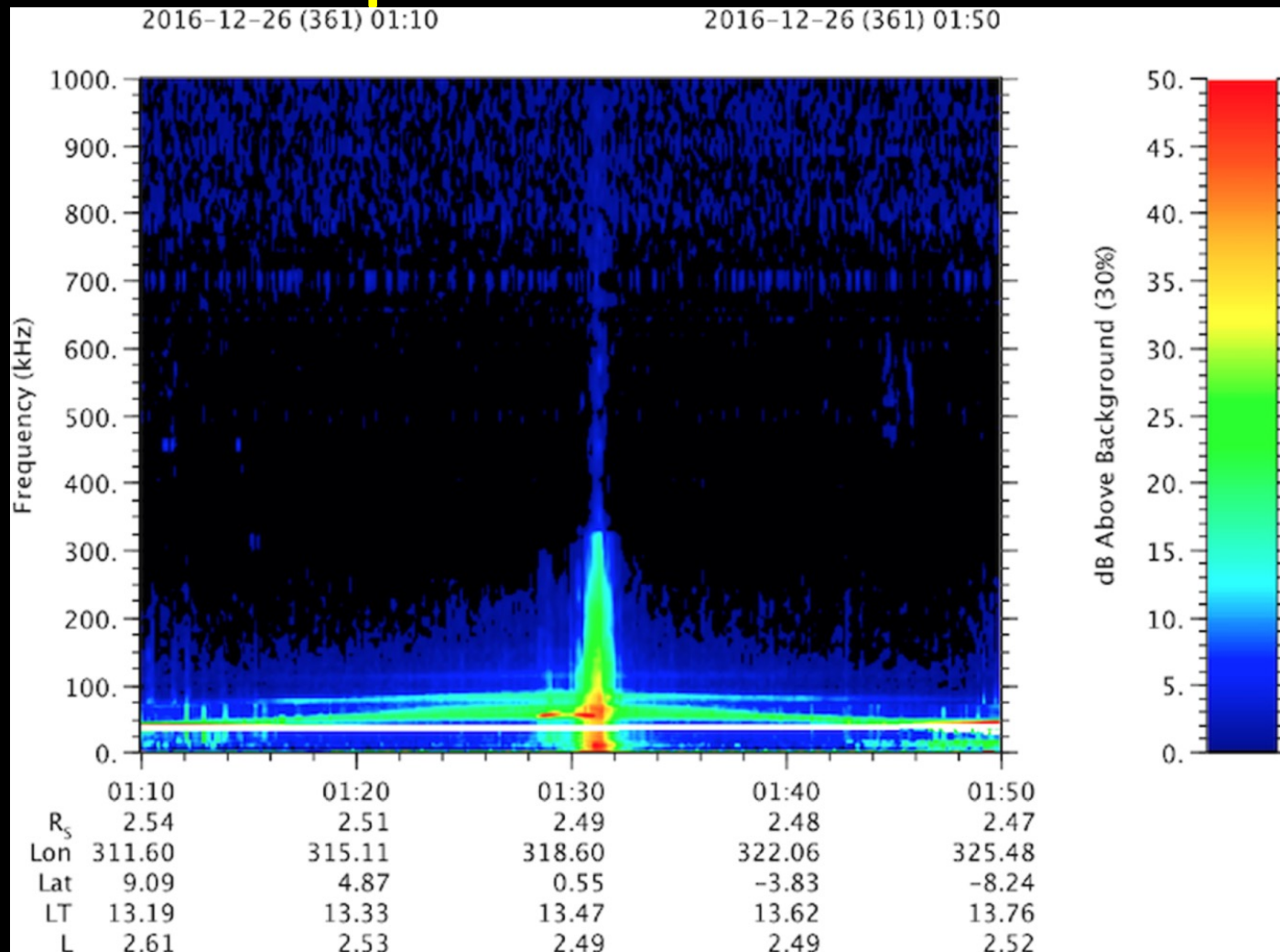
Image Credit: NASA

ROLSSES Expected Observations



The WAVES instrument on the Wind spacecraft (Bougeret et al. [1995](#)) at Sun–Earth L1 shows solar radio bursts, Earth's auroral kilometric-wavelength radio bursts (AKR), terrestrial ground-based transmitters (RFI), and Jovian radio emissions, during a 24 hr interval on 2012 February 20. ROLSES will be capable of making similar observations, which would demonstrate some of the science data provided by the lunar radio array, FARSIDE.

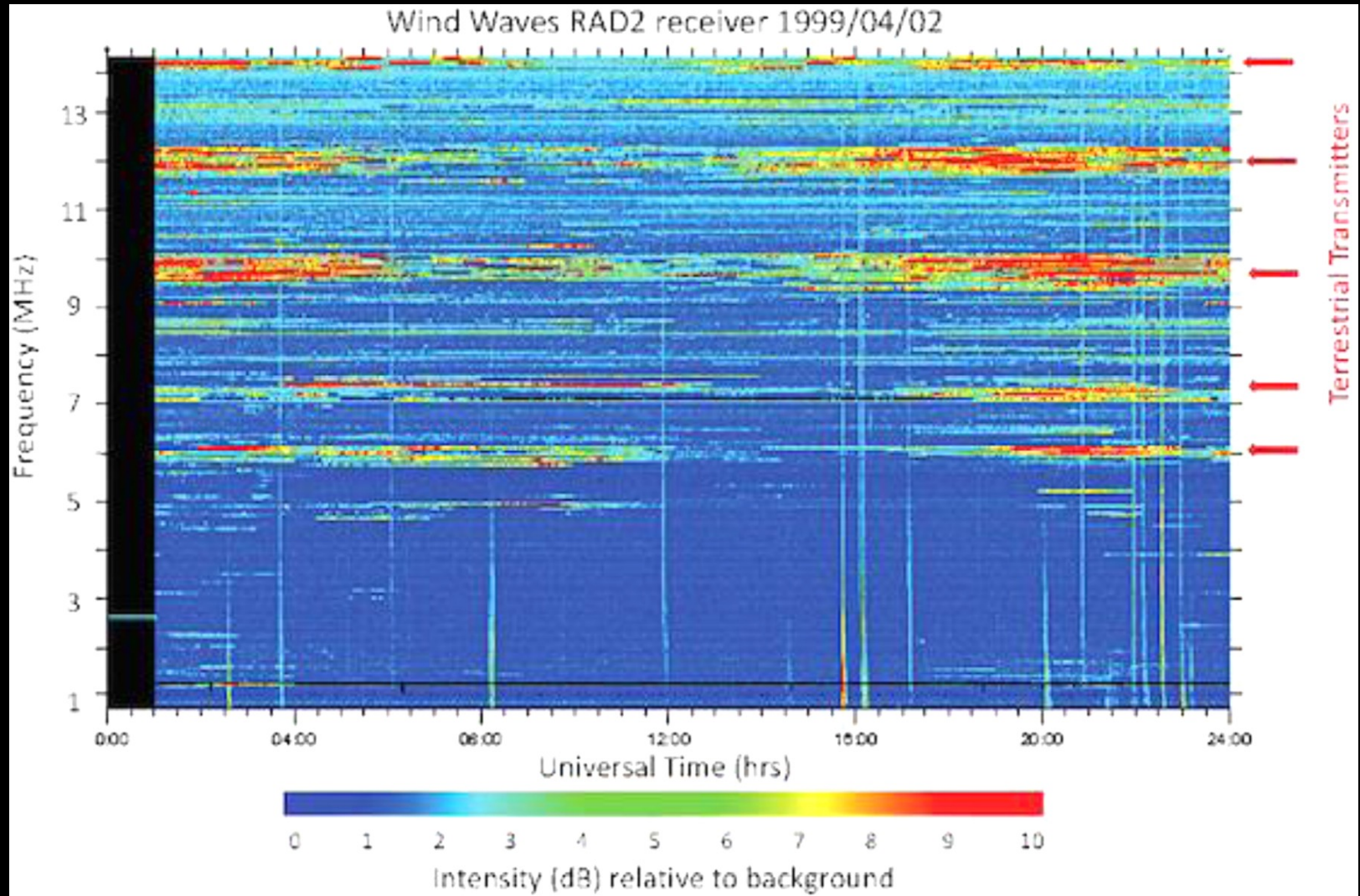
ROLSES Expected Observations



Plot showing the dust signal detected by the Cassini spacecraft when crossing the Saturn F-ring.

Burns *et al* 2021 *Planet. Sci. J.* **2** 44, <https://doi.org/10.3847/PSJ/abdfc3>

Earth Radio Frequency Interference (RFI)



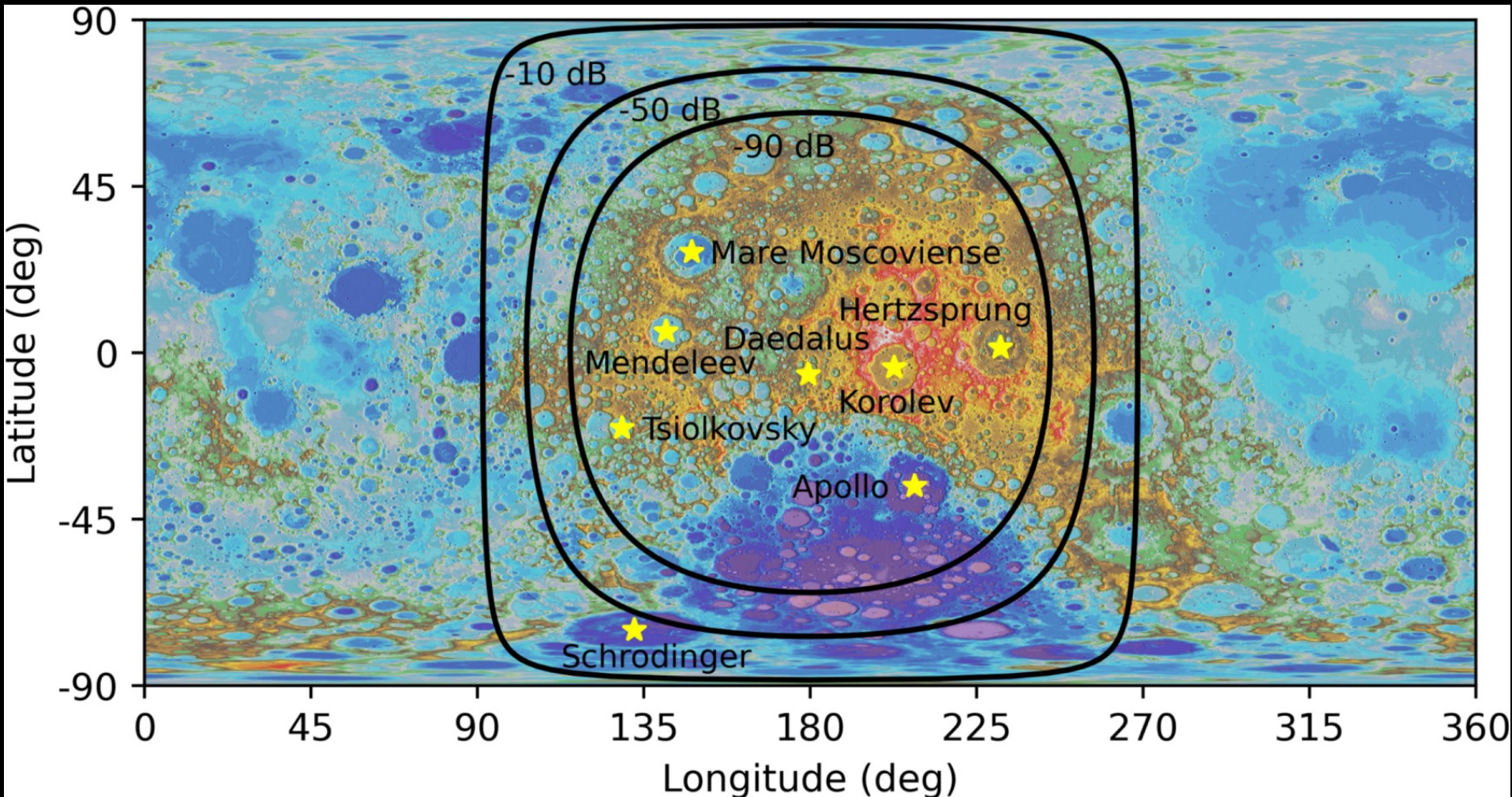
Dynamic spectrum shows terrestrial RFI observed by Wind/WAVES on 1999 April 2 when it passed the Moon.

Burns *et al* 2021 *Planet. Sci. J.* **2** 44, <https://doi.org/10.3847/PSJ/abdfc3>

ROLSES

ROLSES will measure the photoelectron sheath density to better understand the charging of the lunar surface via photoionization and impacts from the solar wind, charged dust, and current anthropogenic radio frequency interference.

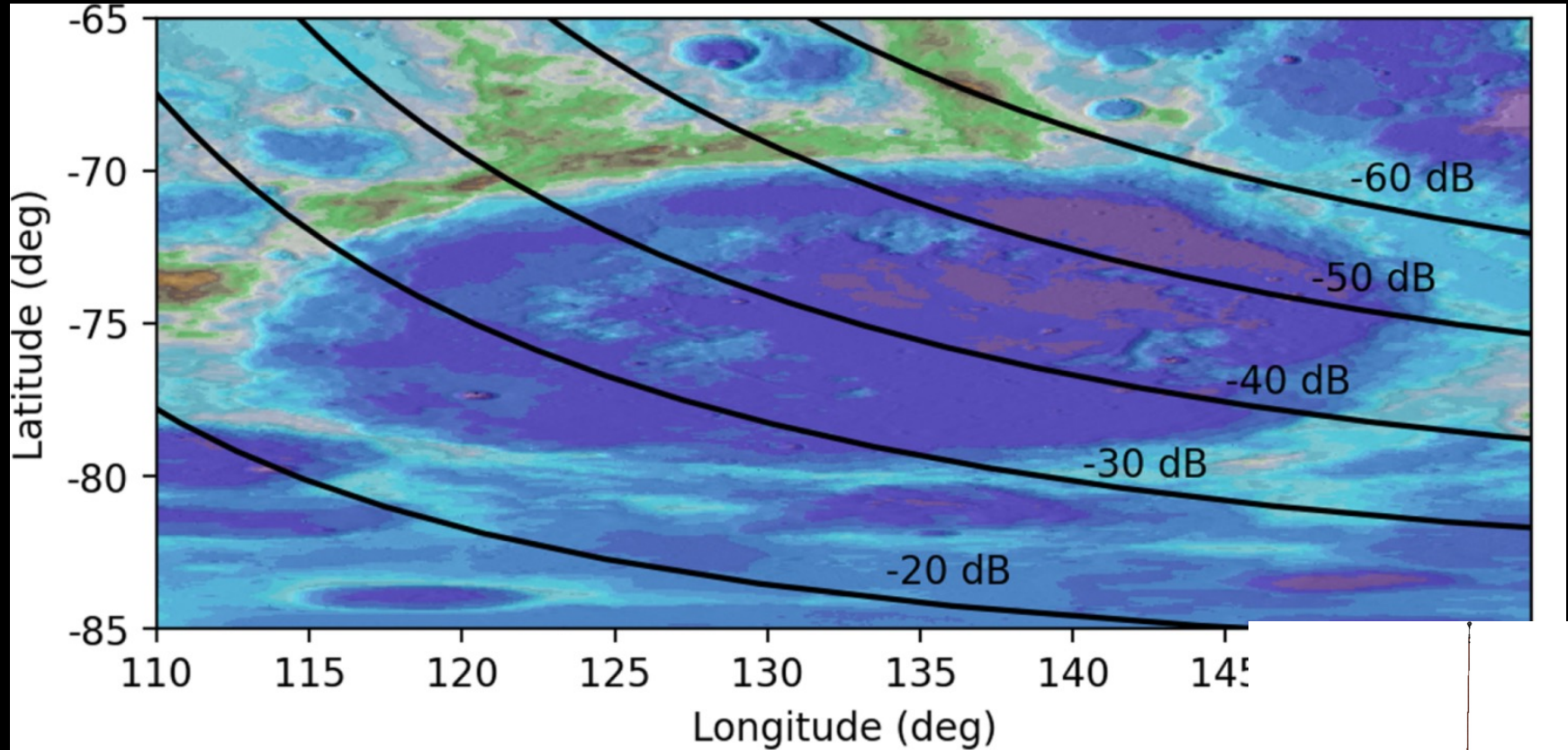
Radio Frequency Suppression



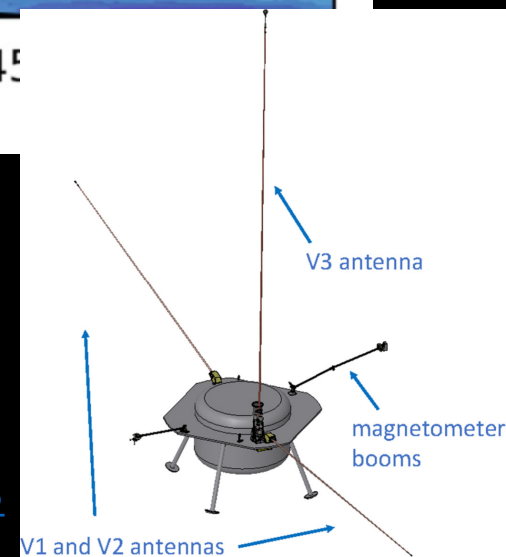
Map of RFI suppression at 100 kHz based upon numerical simulations from Bassett et al. (2020). Contours indicate suppression of -10, -50, and -90 dB relative to the incident intensity. Map colors indicate elevation. Potential landing sites are indicated by the yellow stars.

Burns et al 2021 *Planet. Sci. J.* 2 44, <https://doi.org/10.3847/PSJ/abdfc3>

LuSEE: Lunar Surface Electromagnetics Experiment (CS3, FireFly)



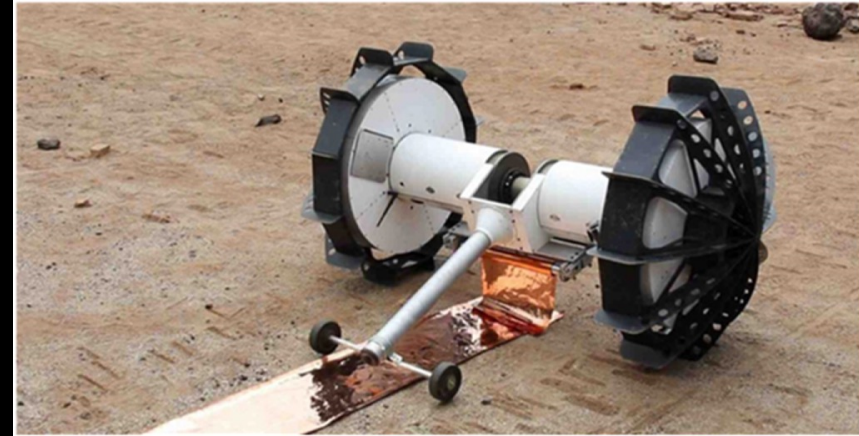
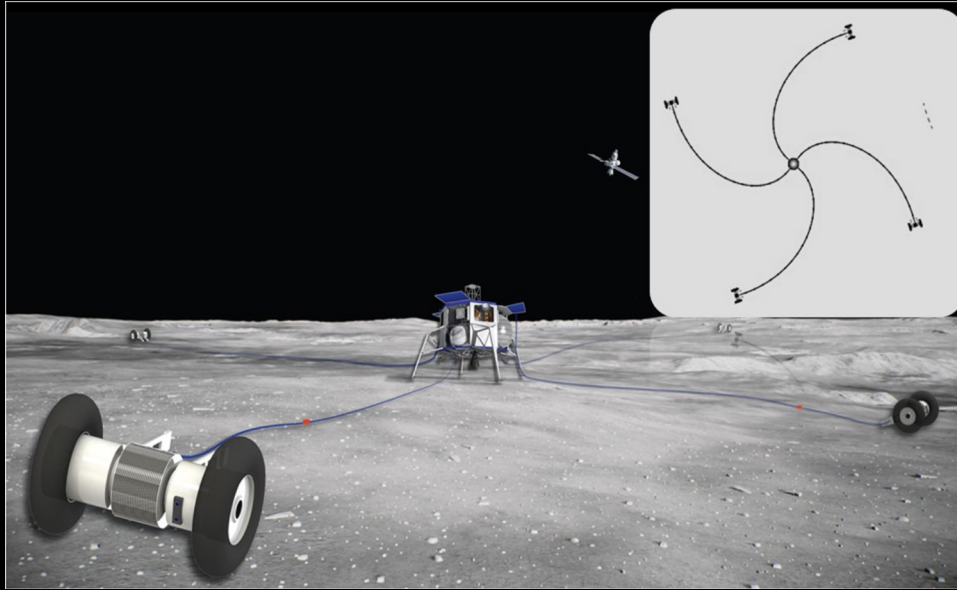
At 100 kHz, the level of suppression of radio interference will vary significantly across the basin. As shown in Figure above, the level of attenuation varies from a factor of approximately 25 dB at the southwest corner of the basin to near 55 dB at the northeast corner



LuSEE

- LuSEE (LuSee Lite, LuSEE Night) is a suite of sensors and electronics designed to make comprehensive measurements of the electromagnetic environment of the lunar surface from DC to radio frequencies (~ 20 MHz).
- LuSEE will measure the local magnetic field and exoionospheric density, interplanetary radio bursts, Jovian and terrestrial natural radio emission, and the galactic synchrotron spectrum.

Farside Array for Radio Science Investigations of the Dark ages and Exoplanets (FARSIDE) Future Mission Concept



- 10 km diameter interferometric array
- 128 pairs of dipole antennas
- The first radio interferometers on the Moon

FARSIDE would break new ground by:

- imaging radio emission from coronal mass ejections (CME) beyond 2Re.
- monitor auroral radiation from the B-fields of Uranus and Neptune (not observed since Voyager).
- detect radio emission from stellar CMEs and the magnetic fields of nearby potentially habitable exoplanets.



EXPLORE MOON_{to}MARS

MOON LIGHTS THE WAY

<https://www.nasa.gov/clps>

<https://science.nasa.gov/lunar-discovery/elements/clps>

