

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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Outline

- Bio
- Planetary Science Research
- CLPS Program
- Intro to Radio Astronomy
- Radio Science Payloads: ROLSES, LuSEE
- 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

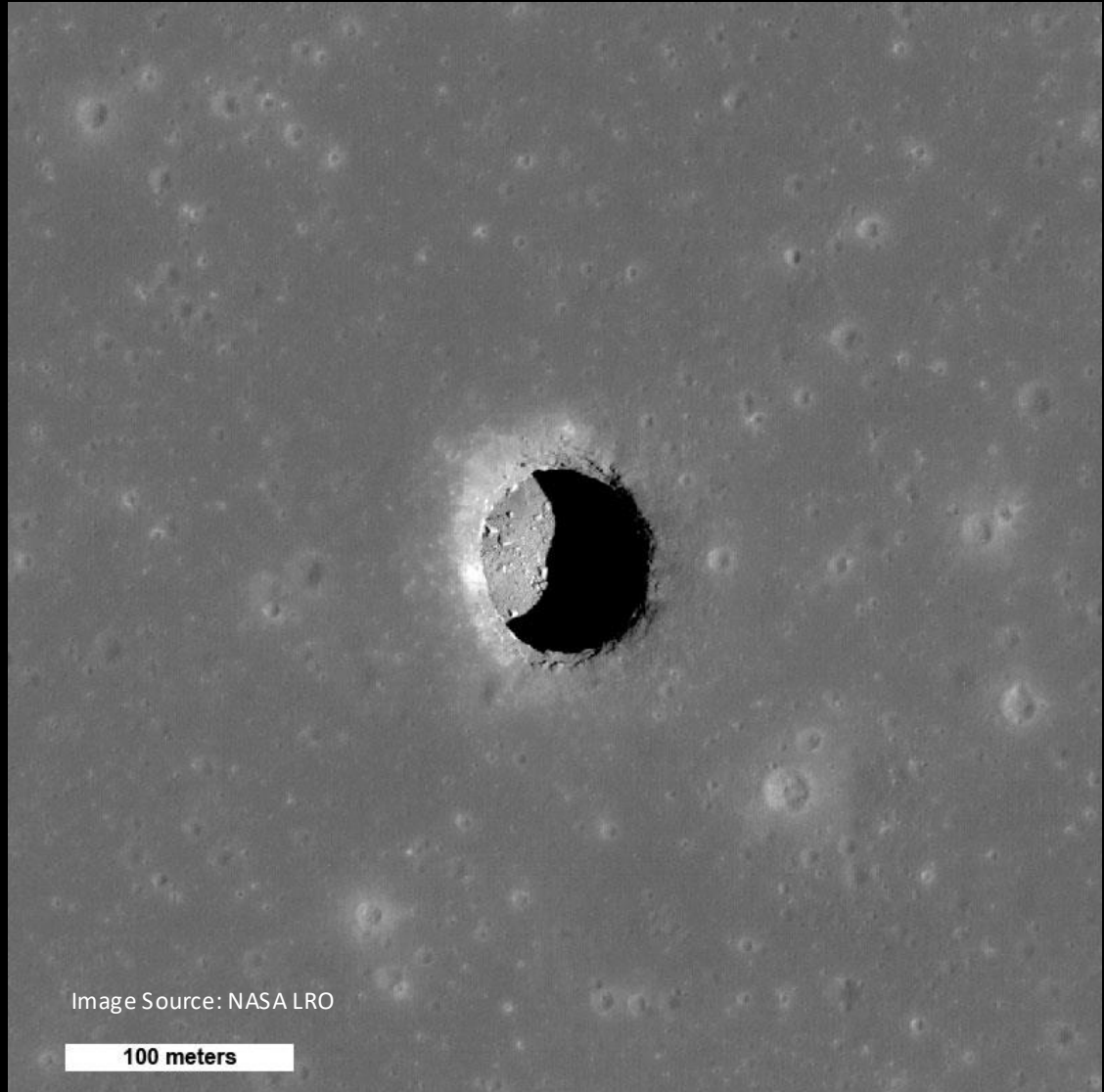


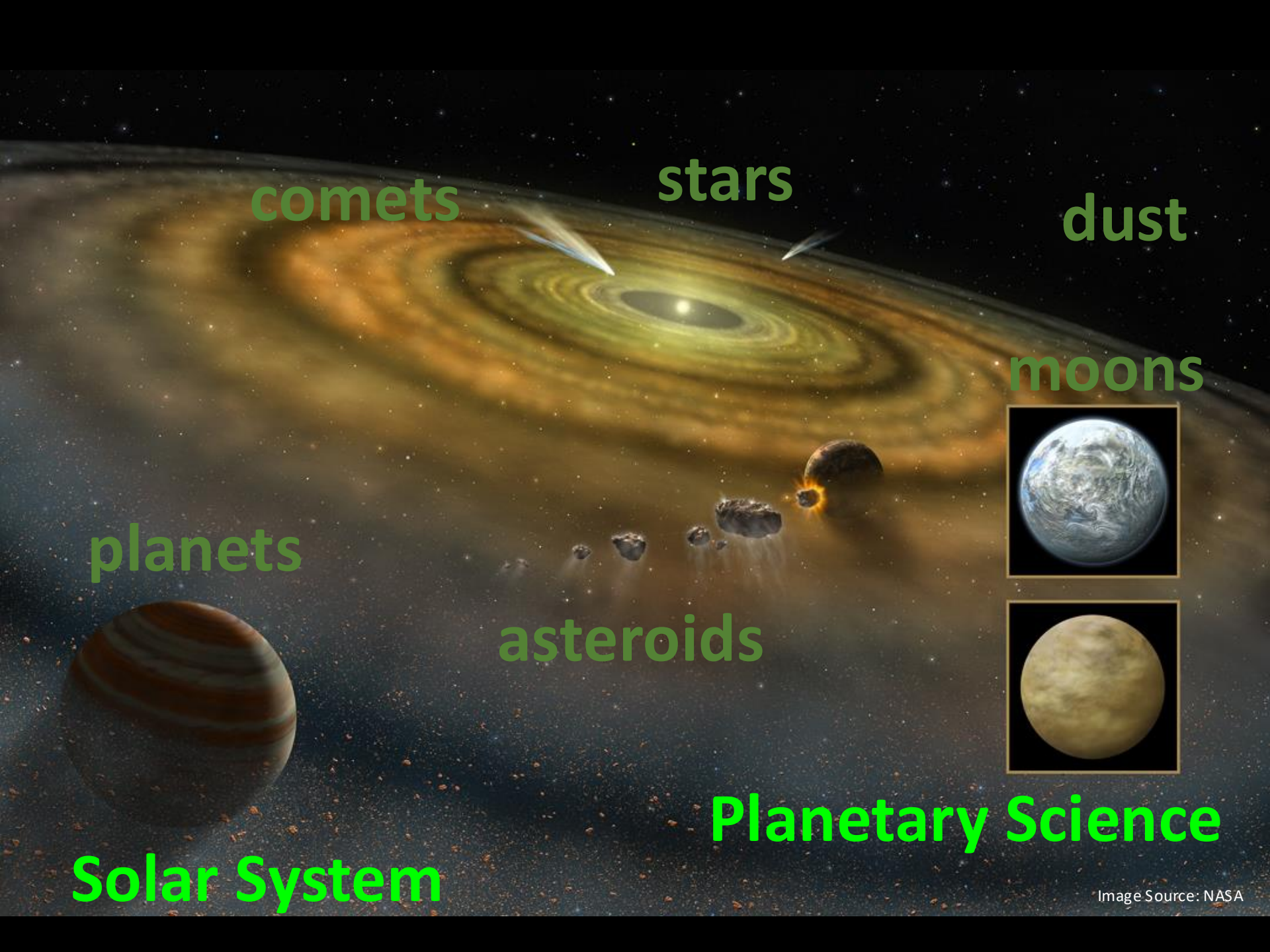
Career Path

- 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

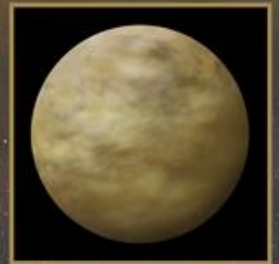
stars

dust

moons



planets



asteroids

Planetary Science

Solar System

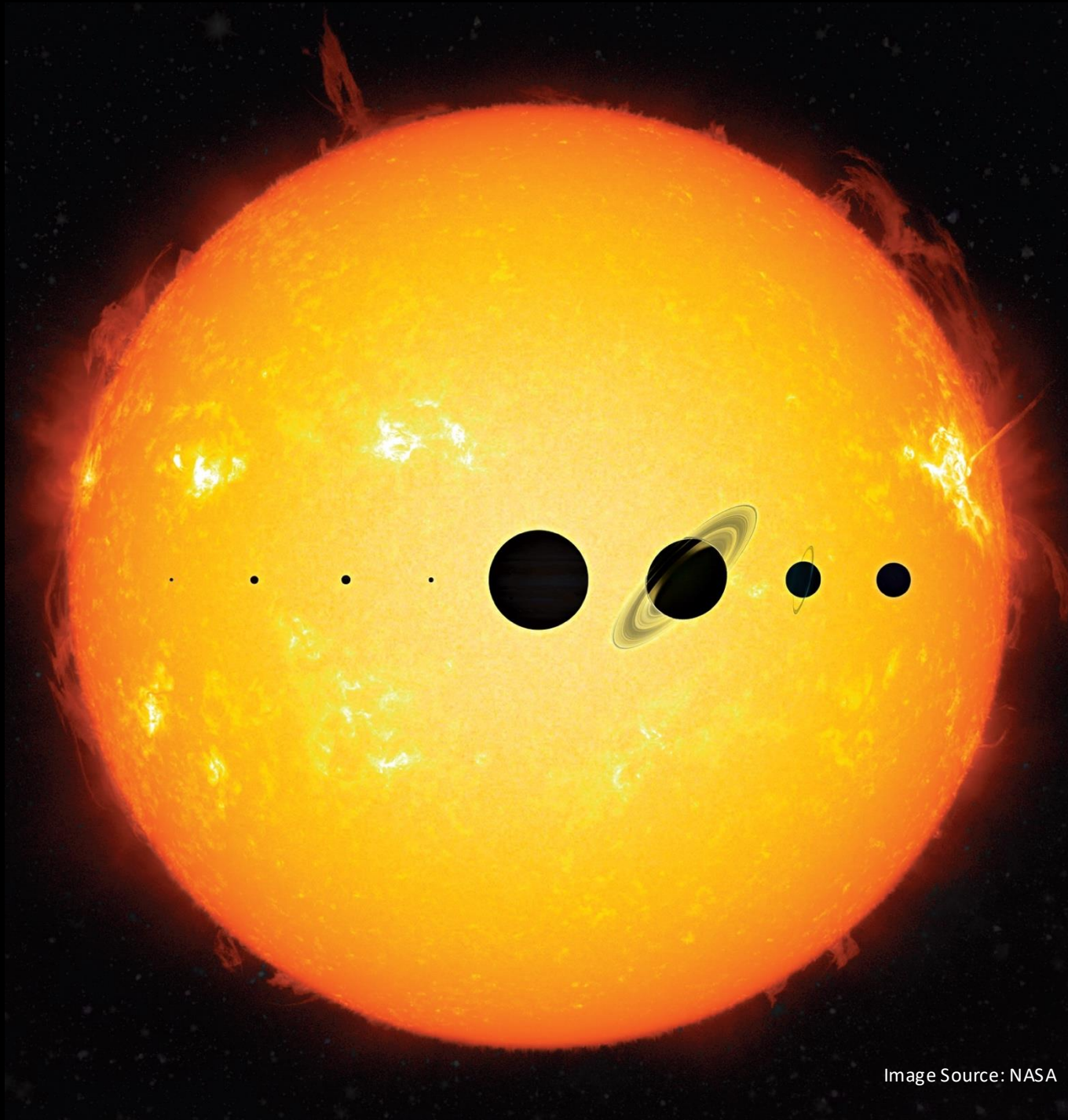


Image Source: NASA



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

2025

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

2026

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.

CLPS: Rapid Affordable Frequent Access to the Lunar Surface



★ Active Task Orders

CLPS Deliveries

2024-2028

Delivery Site:
Gruithuisen Domes
Provider TBD
PRISM 2a/CP-21 | 2027

Delivery Site:
Ina IMP
Provider TBD
CP-32 | 2027

Delivery Site:
Reiner Gamma
Provider Intuitive Machines (IM)
CP-11 | 2025

Delivery Site:
Sinus Viscositatis
Provider: Astrobotic
TO2-AB | Jan 2024

Delivery Site:
Mare Crisium
Provider: Firefly
TO 19D | Q4 2024

Delivery Site:
Farside
Provider: Firefly
TO CS3, CS4 | 2025

Delivery Site:
South Pole
Provider: IM
TO PRIME-1 | Q4 2024

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

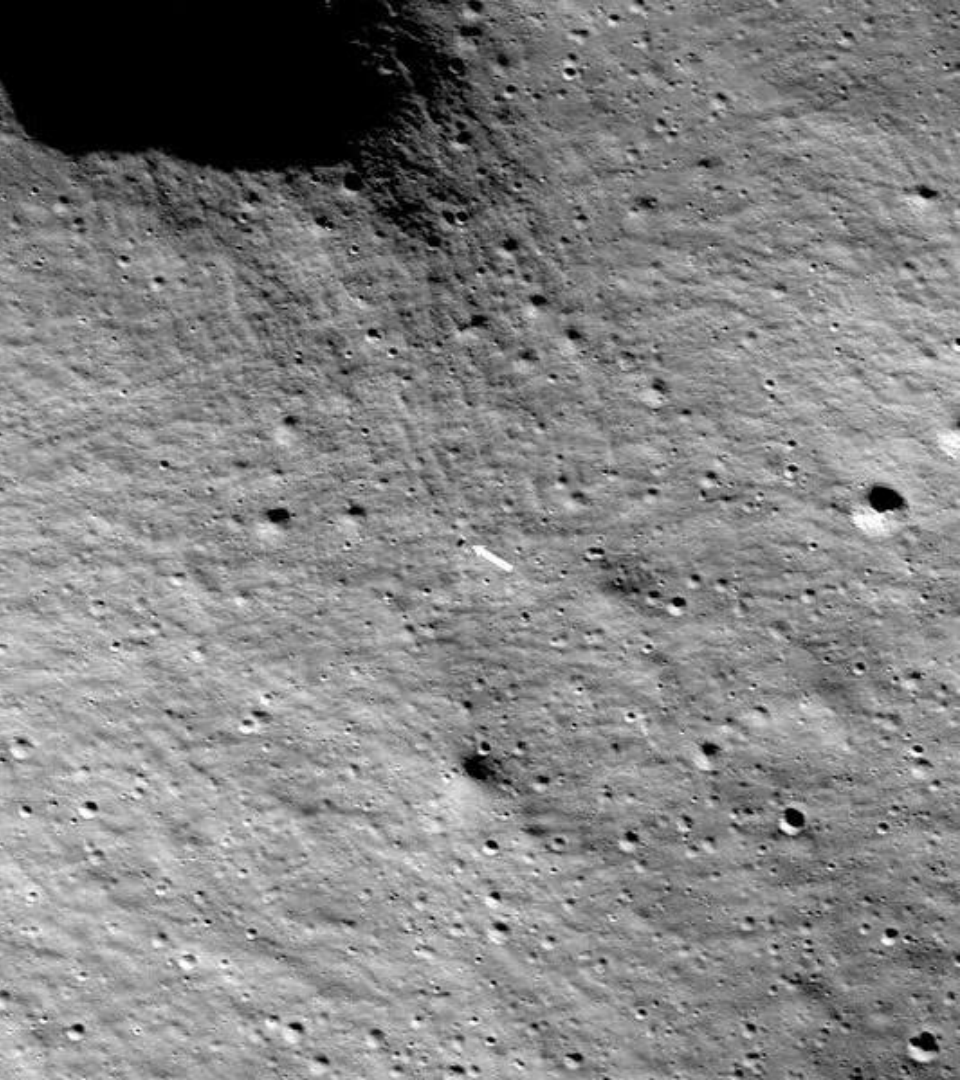
Delivery Site:
Malapert A
Provider: IM
TO2-IM | Feb 2024

Delivery Site:
Schrödinger Basin
Provider Draper
CP-12 | 2026

Delivery Site:
South Pole
Provider TBD
CP22 | 2027

Delivery Site:
South Pole
Provider TBD
CS6 | 2027

Updated 08/16/2024



TO2 IM, IM1, Landed Feb 2024

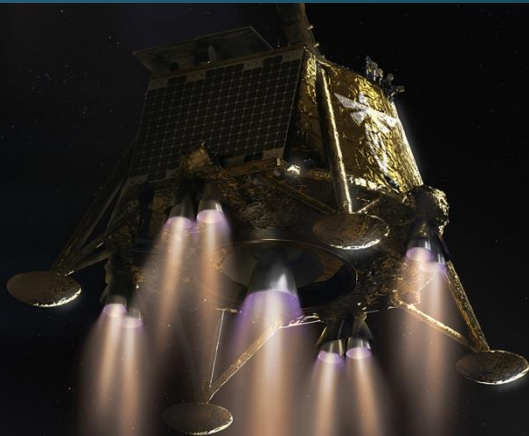


Next on the Pad

Lunar Surface Deliveries

TO-19D (*Firefly*)

1. Next Generation Retroreflector (NGLR)
2. Radiation Tolerant Computer System (RadPC)
3. Regolith Adherence Characterization (RAC)
4. Lunar Magnetotelluric Sounder (LMS)
5. Lunar Environment Heliospheric X-ray Imager (LEXI)
6. Lunar PlanetVac (LPV)
7. Lunar Instrumentation for Subsurface Thermal Exploration with Rapidity (LISTER)
8. Stereo Cameras for Lunar Plume-Surface Studies (SCALPSS) 1.1
9. Electrodynamic Dust Shield (EDS)
10. Lunar GNSS Receiver Experiment (LuGRE)



*Mare
Crisium*

*Firefly
Blue Ghost lander*

Image Source: NASA

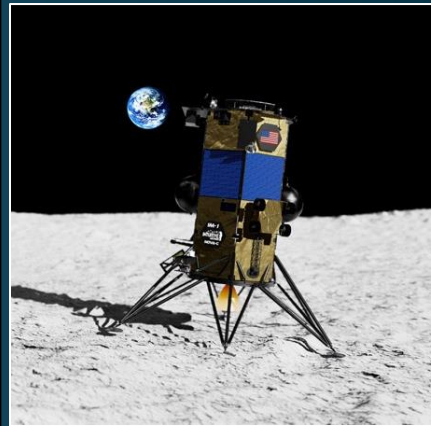
TO PRIME-1 (*Intuitive Machines*)

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 | 3RD NOVA-C
• Lunar Magnetic Anomalies |
| 1ST NOVA-C
• Plume/surface interactions, charged particles near surface
• Lander prop tank gauge test | GRIFFIN-1 & VIPER
• Search for volatiles, below surface & shadowed regions |
| 2ND NOVA-C
• Drilling for volatiles | SERIES-2
• Geophysics of the Schrödinger Basin |
| 1ST BLUE GHOST
• Characterize Earth's magnetosphere and Moon's interior | 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

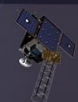
2023



2021

2022

2024



ORBITAL MISSIONS



2025

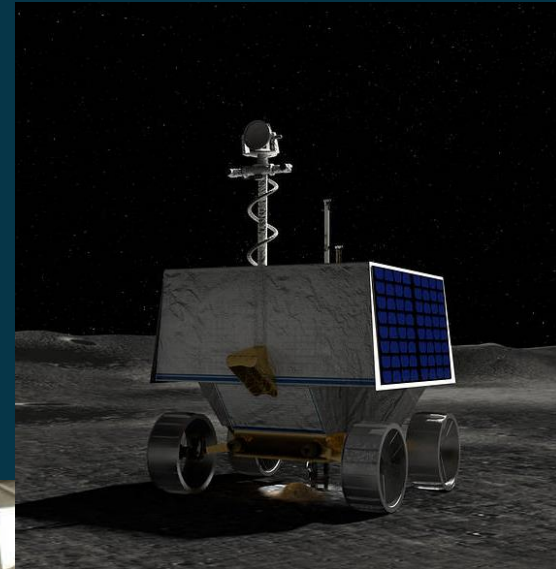


SURFACE MISSIONS

VIPER Rover

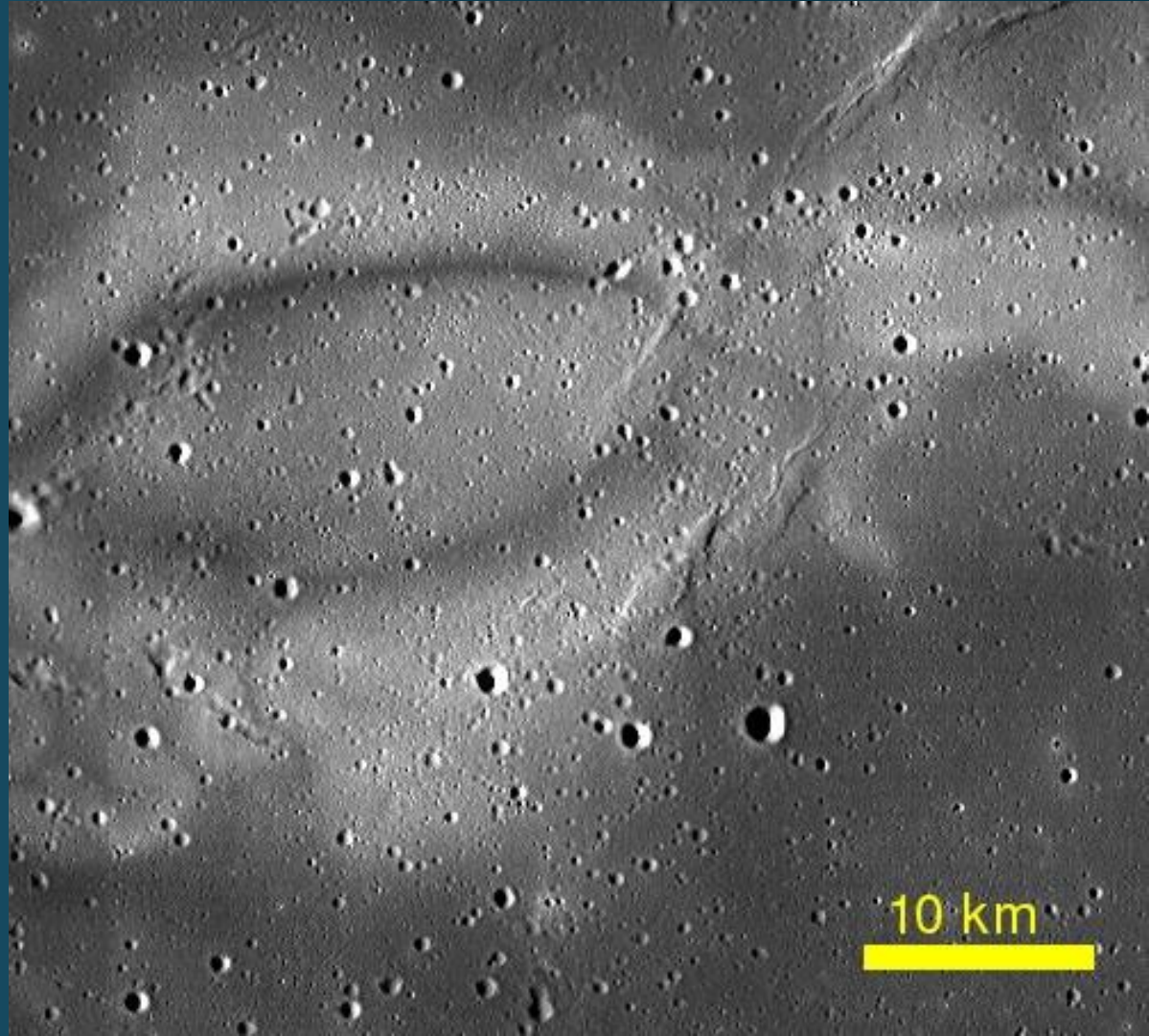
Canceled

- 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: **2025**

Landing Site: Reiner Gamma

Surface Ops Duration: 312 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



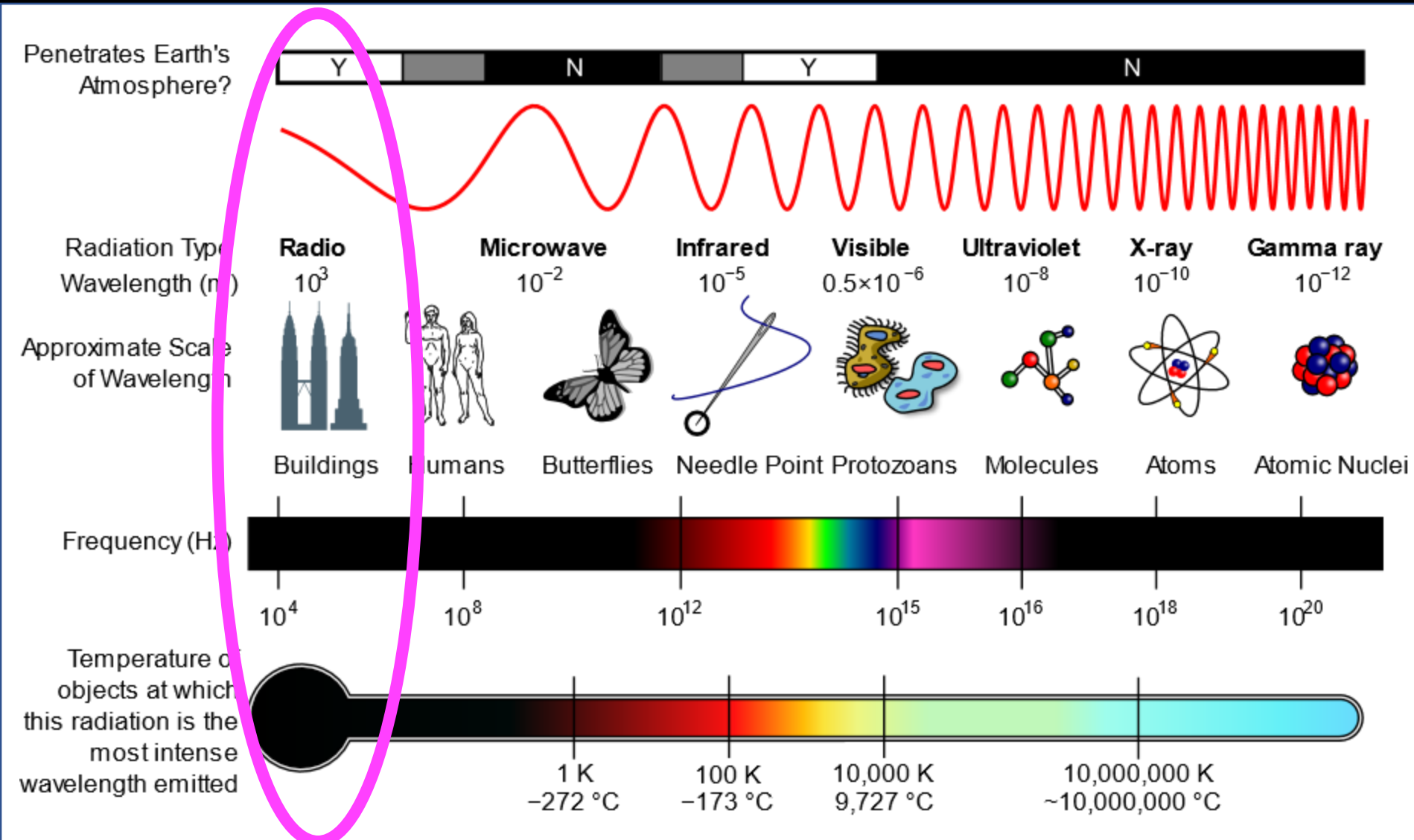
Credit: Intuitive Machines



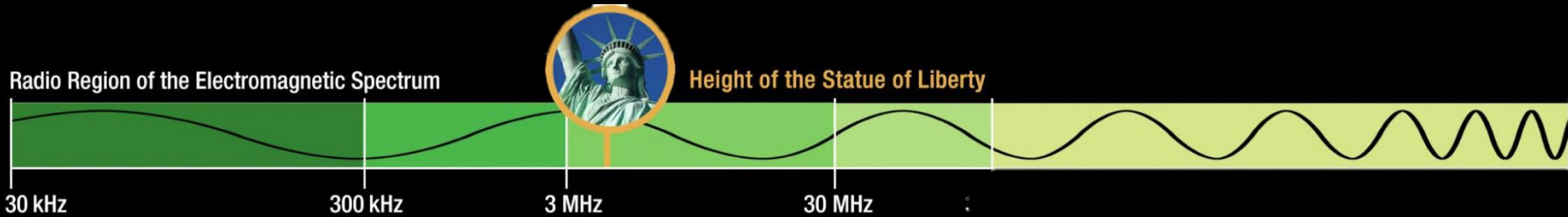
Radio Astronomy

The NSF Very Large Array: <https://public.nrao.edu/news/astronomers-satellite-internet-provider-develops-new-system-to-share-the-sky/>
Credit: Bettymaya Foott, NRAO/AUI/NSF

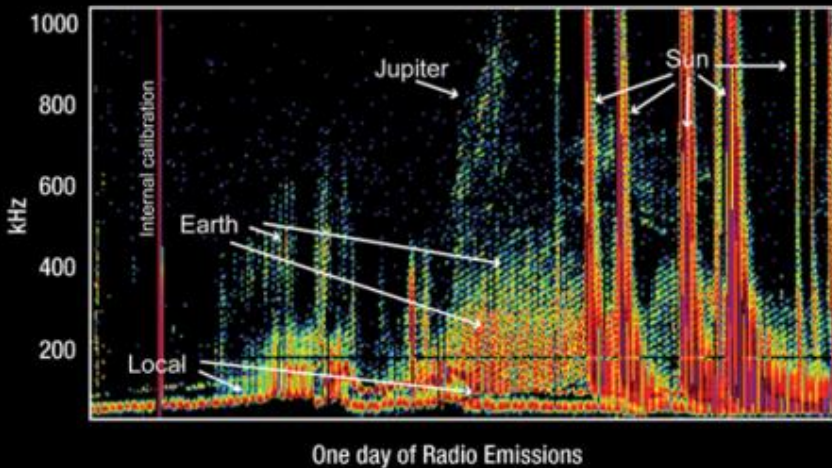
Electromagnetic Spectrum



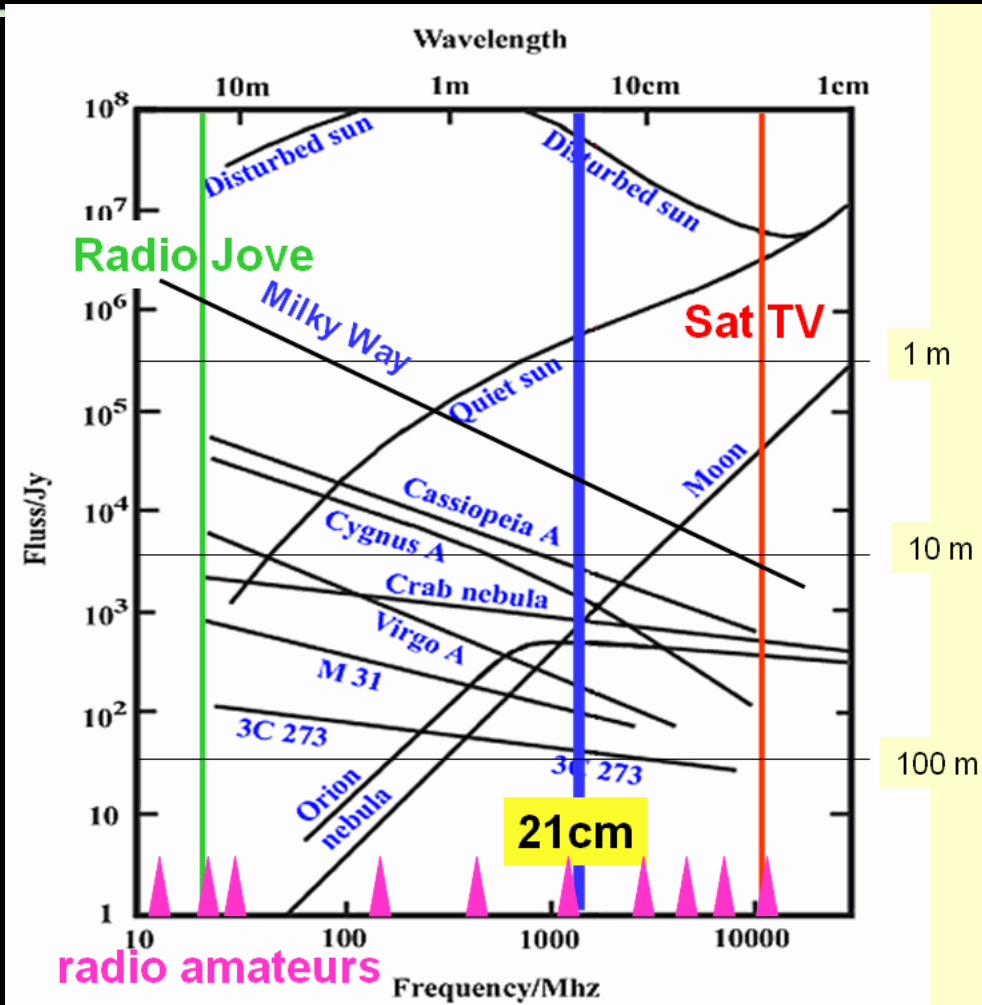
Radio Waves



RADIO EMISSIONS



(left) Image Source: NASA, Science Mission Directorate. "Radio Waves" NASA Science, 2010. National Aeronautics and Space Administration. [18 Aug. 2022] http://science.nasa.gov/ems/05_radiowaves



(right) Image Source: Fundamentals of Radio Science. Joachim Köppen Strasbourg 2010. [16 Aug. 2024] <https://portia.astrophysik.uni-kiel.de/~koeppen/Haystack/basics.html>

Radio Telescopes



PARKES RADIO
TELESCOPE



RADIO EMISSIONS NEAR BLACK HOLE



QUASAR IN RADIO & INFRARED



Image Credit: NASA

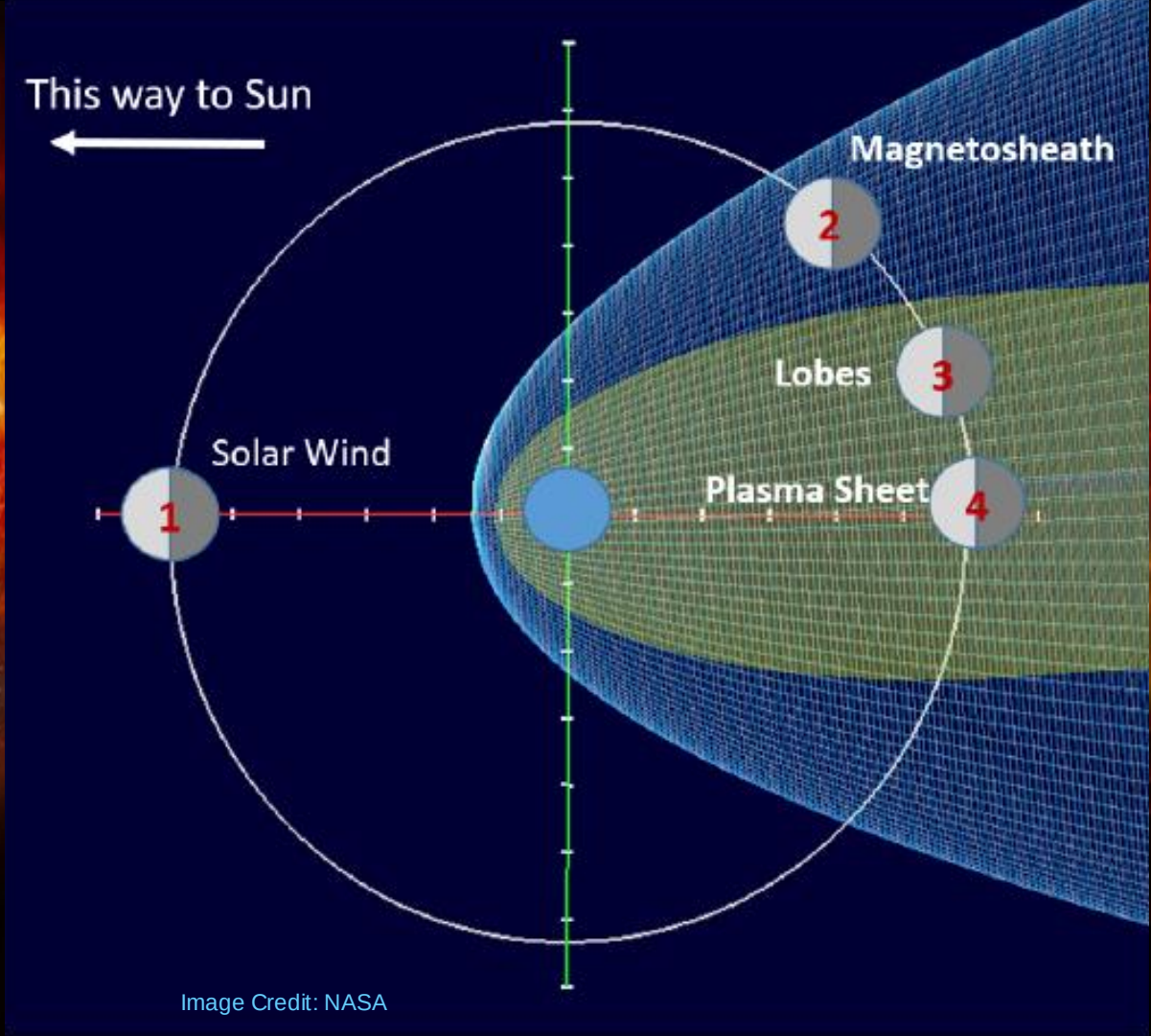


Image Credit: NASA

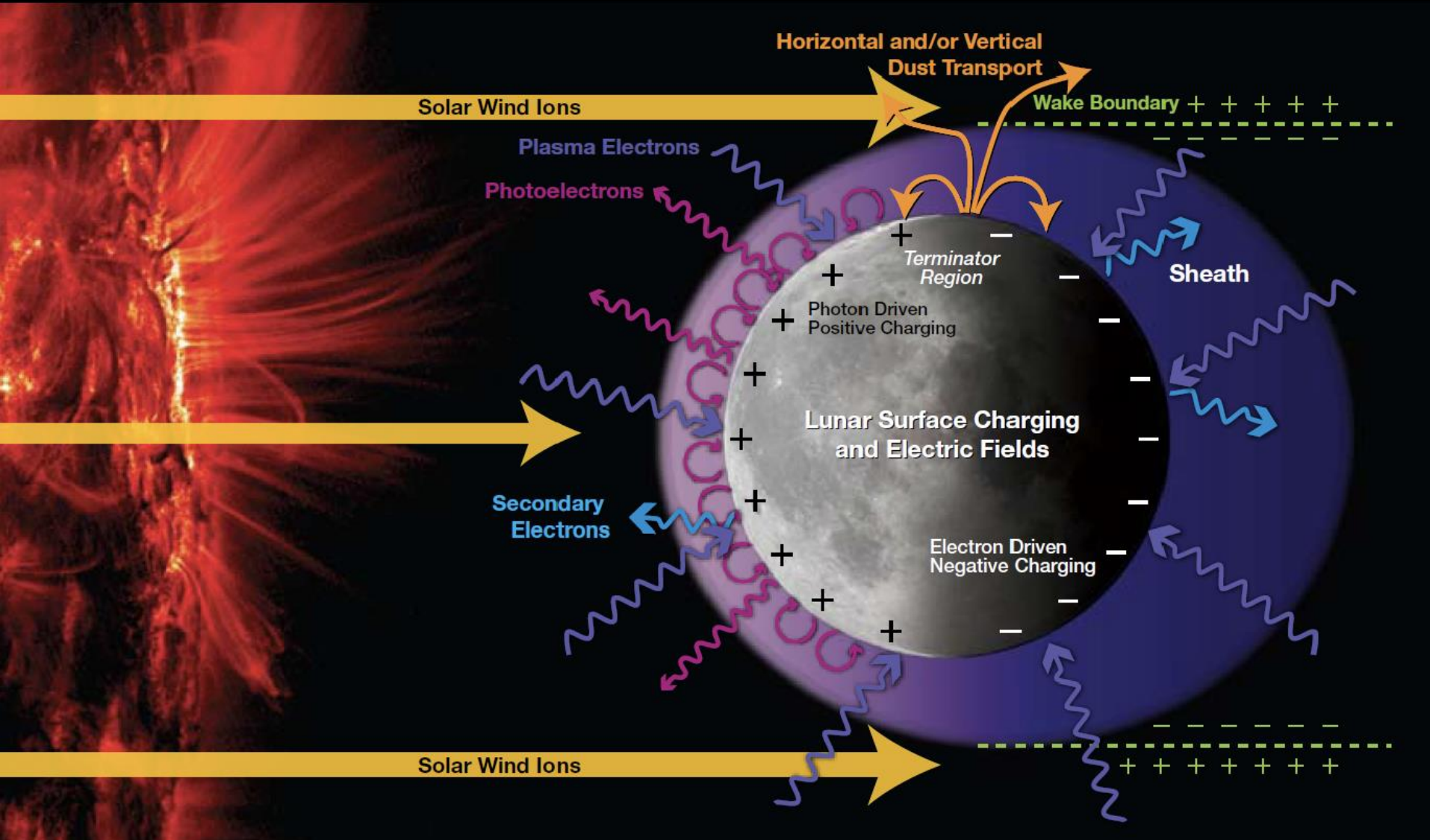


Image Credit: NASA

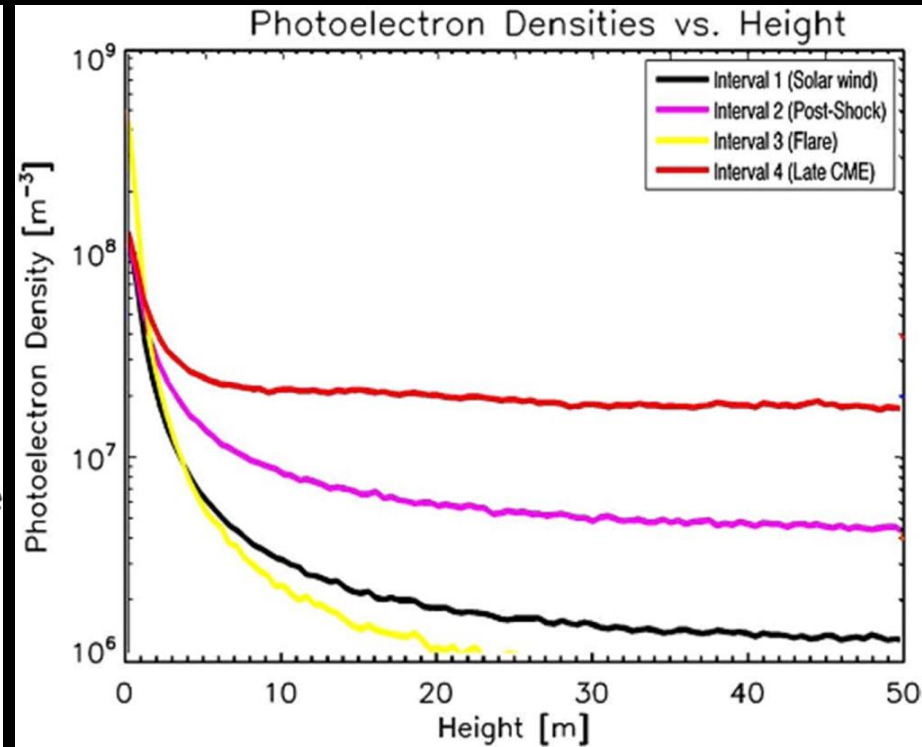
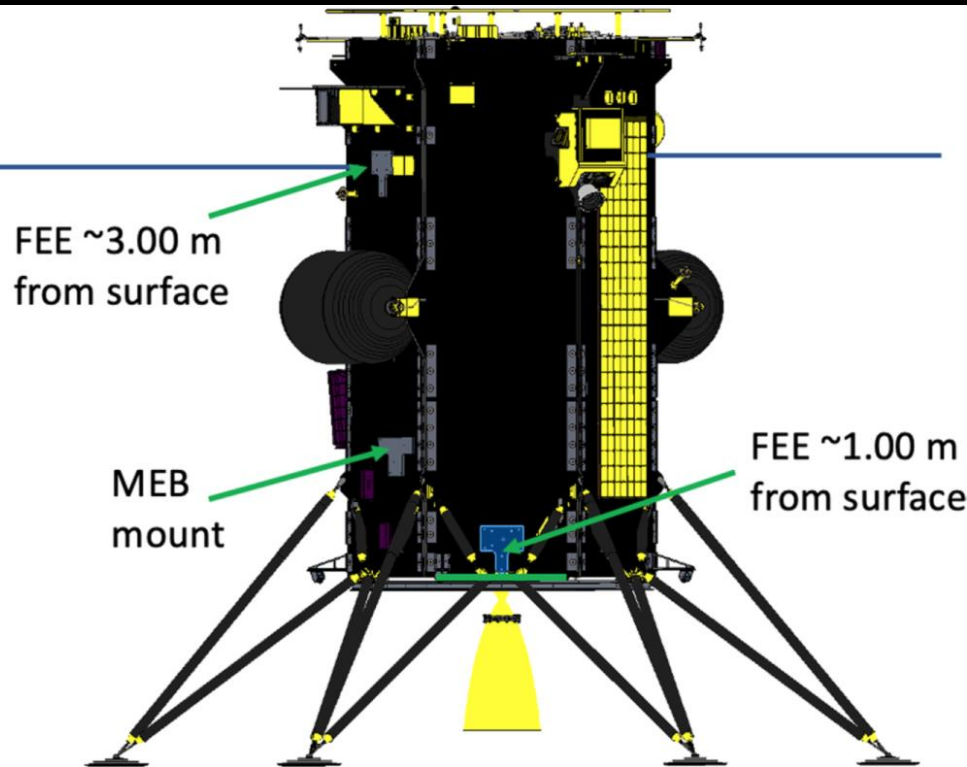
ROLSES

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.

ROLSES will fly again on CP21 in 2027.

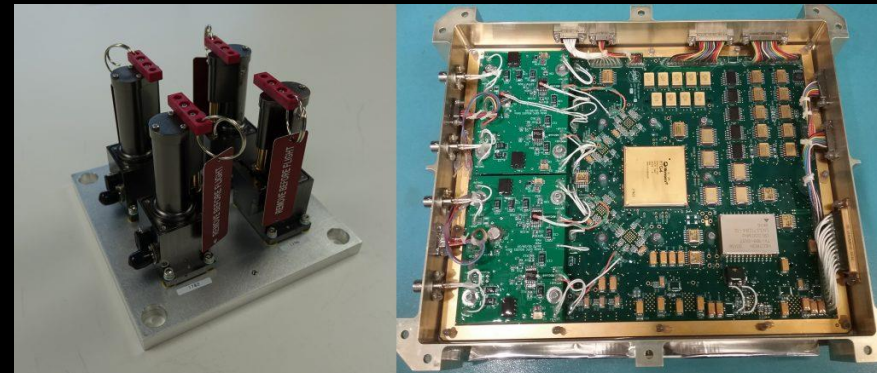


ROLSSES: Radio wave Observations at the Lunar Surface of the photoElectron Sheath (TO2 IM, Feb 2024 Landed)



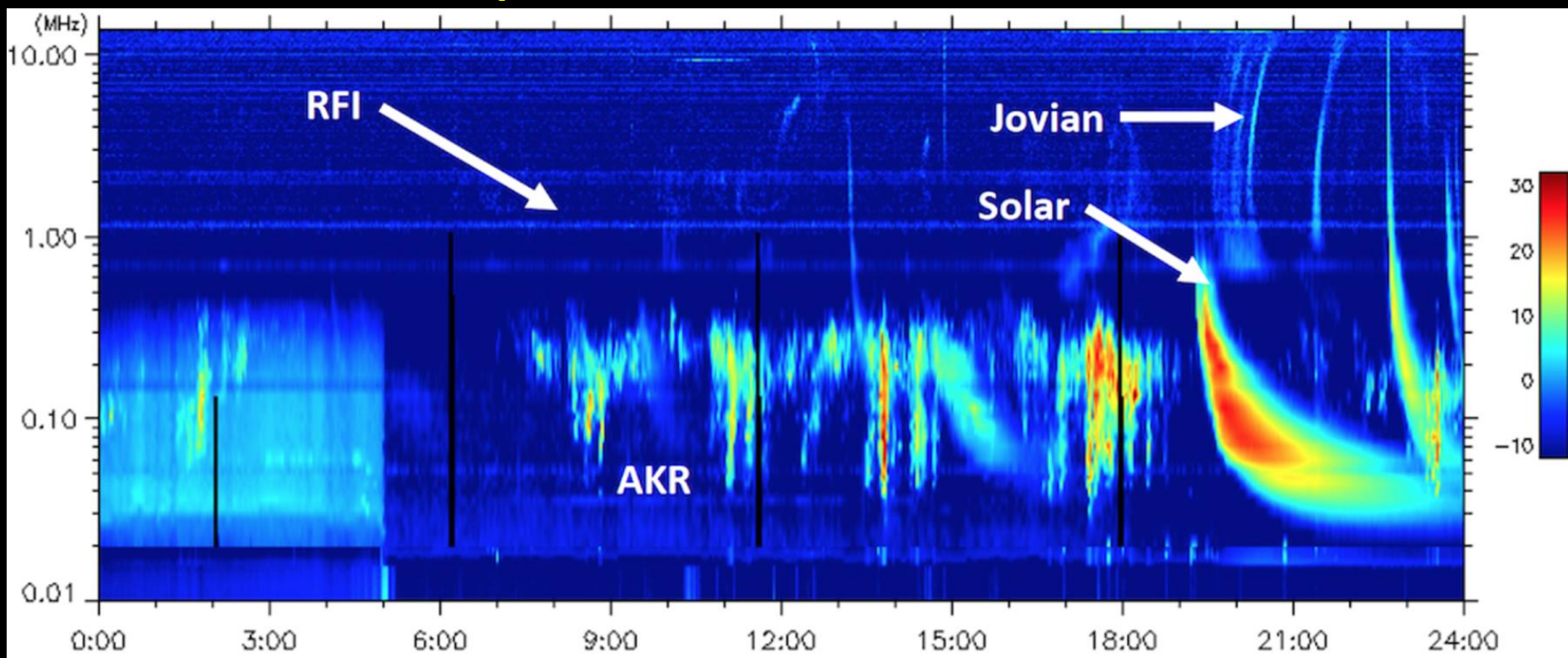
Radio spectra, 10 kHz–30 MHz, will investigate the plasma environment above the lunar surface and measure the fidelity of radio spectra on the surface. Locations of Electronics(FEE, MEB) are noted. Proof of concept that good, clean radio measurements can be made on the Moon.

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



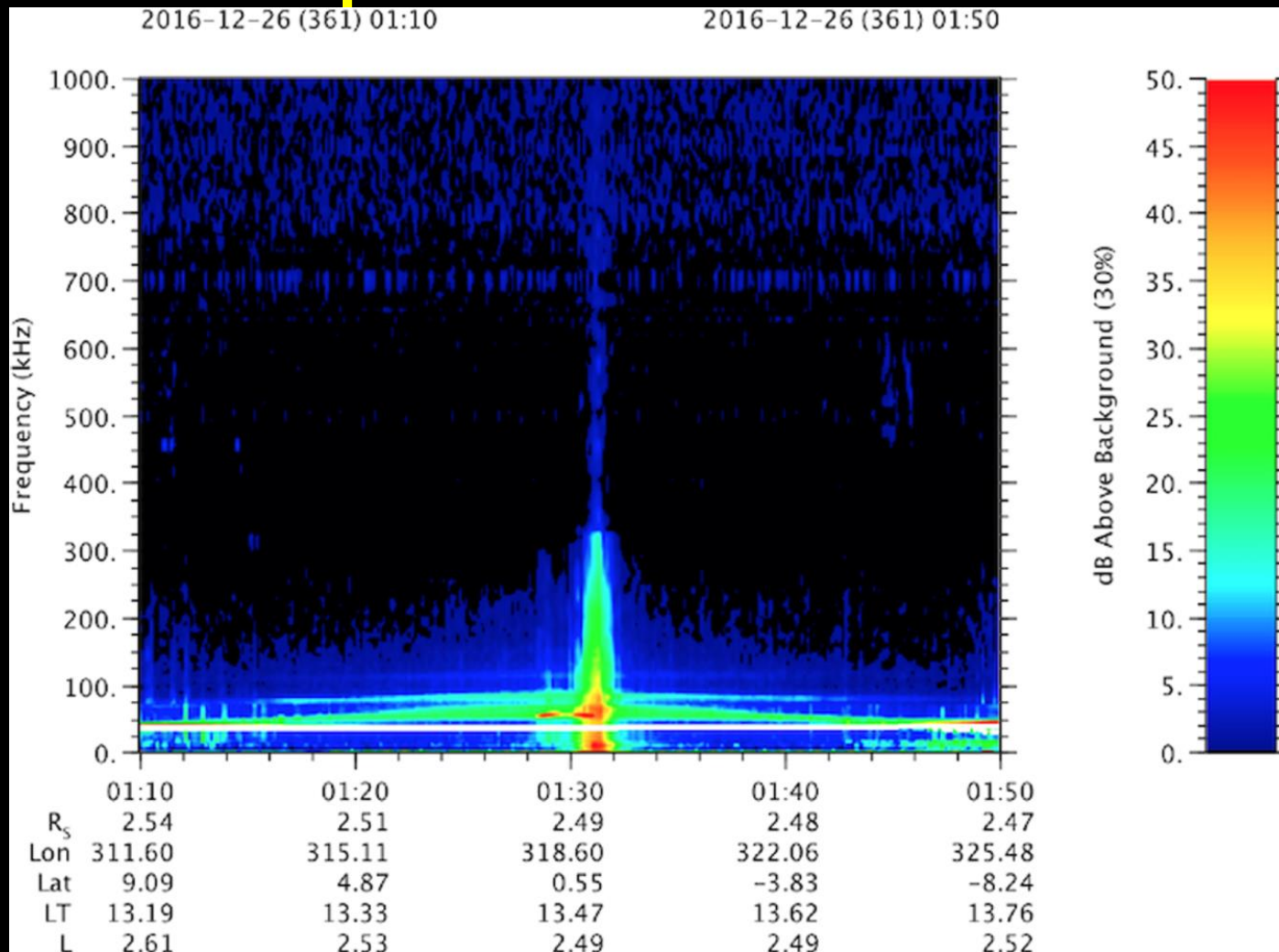
<https://etd.gsfc.nasa.gov/etd-featured-stories/rolses-are-red/>

ROLSES 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.

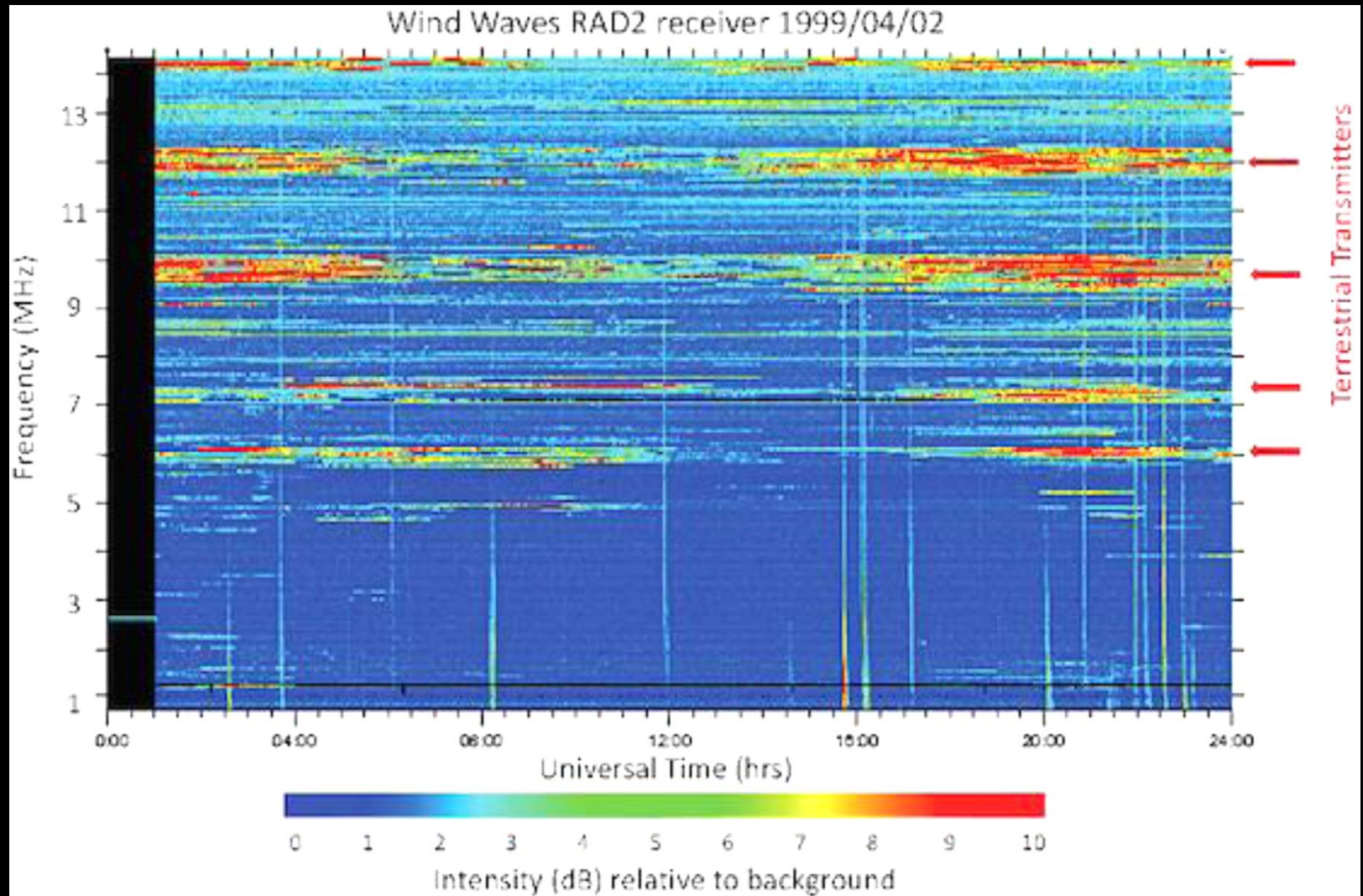
ROLSES Expected Observations



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>

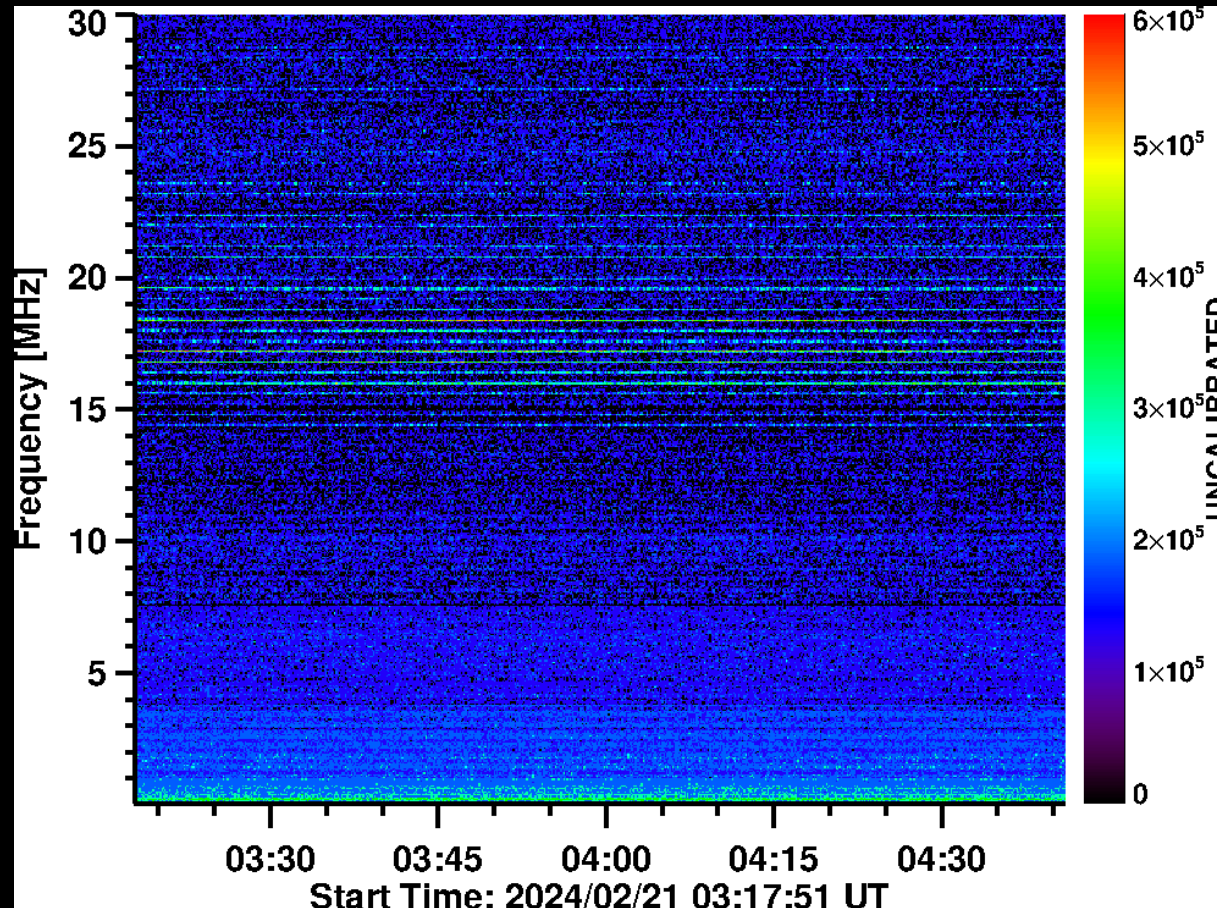
Earth Radio Frequency Interference (RFI)



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>

The first ROLSES Dynamic Spectrum!



ROLSSES observed radio emission from ~ 6000 miles from the moon for ~ 1 hr. Earth transmitters produced radio frequency Interference close to the Moon.

No interference at frequencies below 14 MHz. This is because the ionosphere blocks the lower Frequencies. This important for low frequency astronomy.

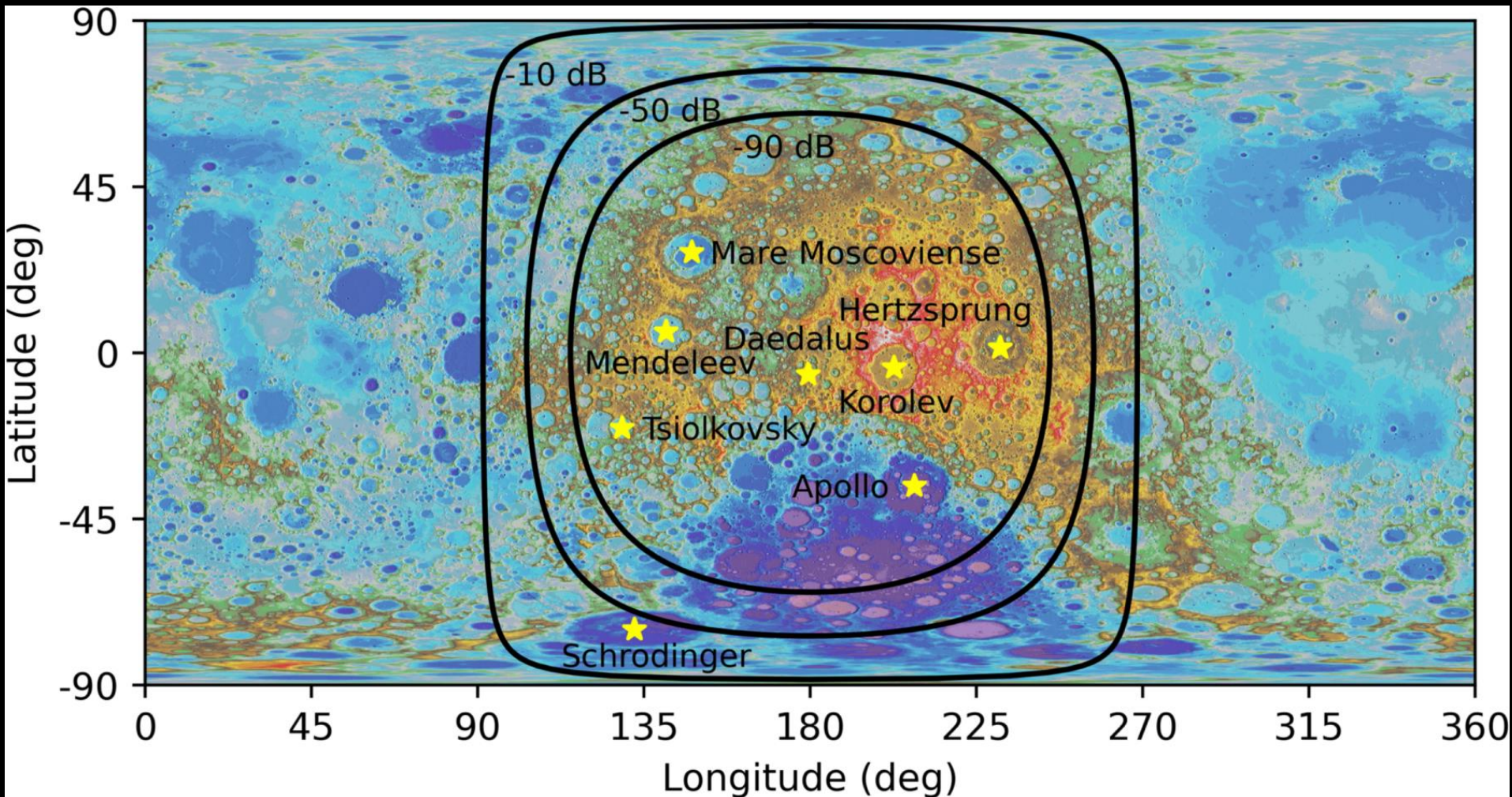
The horizontal lines between 15 and 25 MHz are from Earth's radio transmitters detected by ROLSES when it was ~ 6000 miles from the Moon

Ionospheric cutoff ~ 14 MHz

ROLSES, IM1 Results

- ROLSES instrument was commanded in transit and on the Moon.
- Antennas were successfully deployed on the Moon.
- ROLSES observed radio emission when the lander is ~6000 miles from the Moon (one occasion) and on the lunar surface (two occasions).
- Transit observations did not record human-made noise at frequencies below 15 MHz probably due to the ionosphere.
- High frequency radio noise (15-25 MHz) from Earth transmitters is observed close to the Moon.
- The spectra obtained using ROLSES are consistent with quiet solar conditions confirmed using STEREO data.

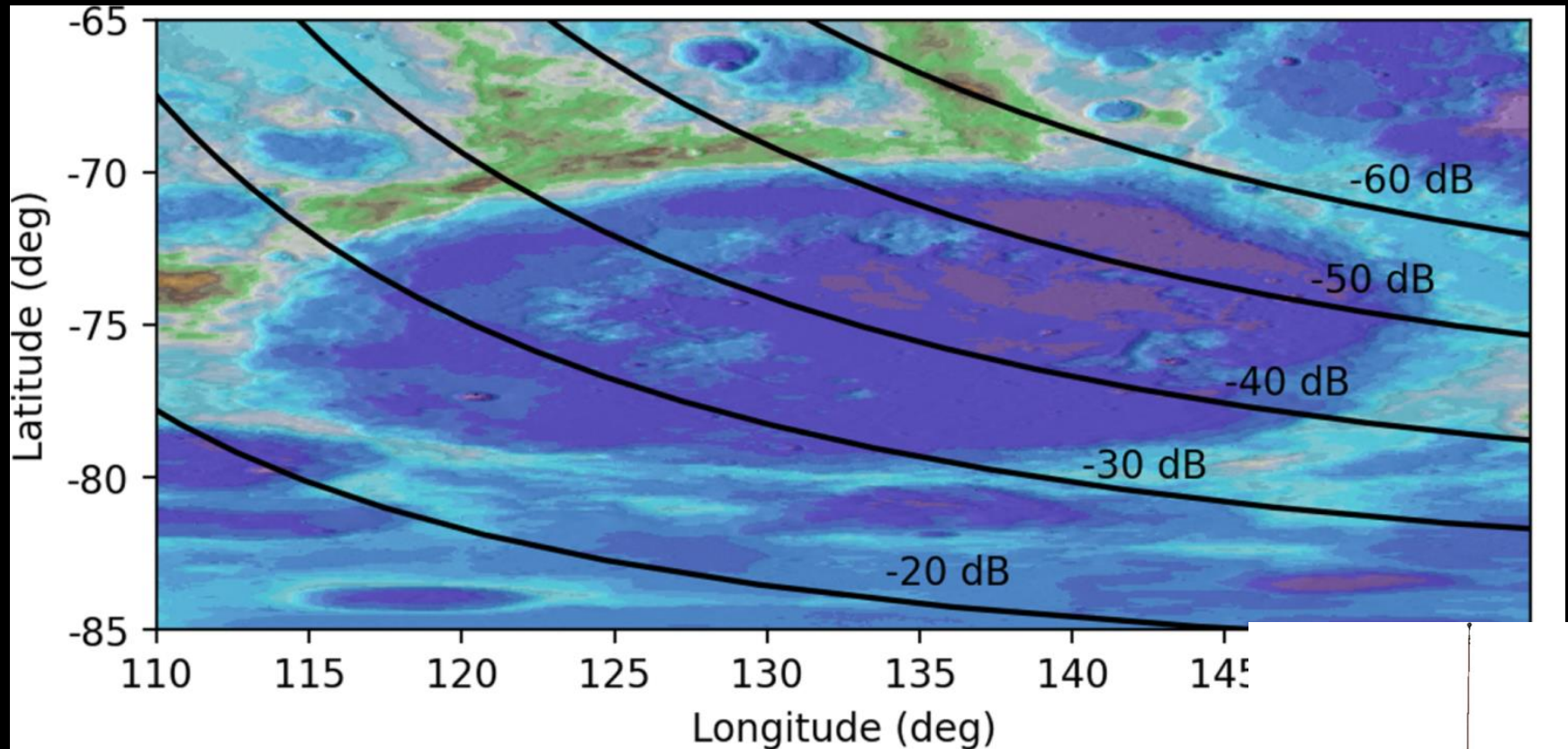
Radio Frequency Suppression



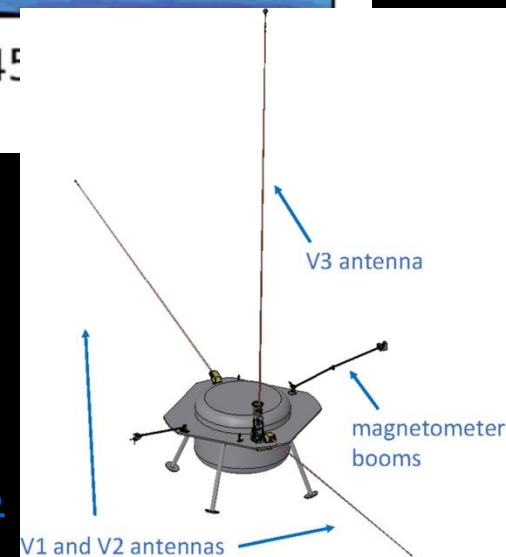
Map of RFI suppression at 100 kHz based upon numerical simulations from Bassett et al. (2020). Contours indicate suppression of -10, -50, and -90 dB relative to the incident intensity. Map colors indicate elevation. Potential landing sites are indicated by the yellow stars.

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

LuSEE: Lunar Surface Electromagnetics Experiment (CS3, FireFly)



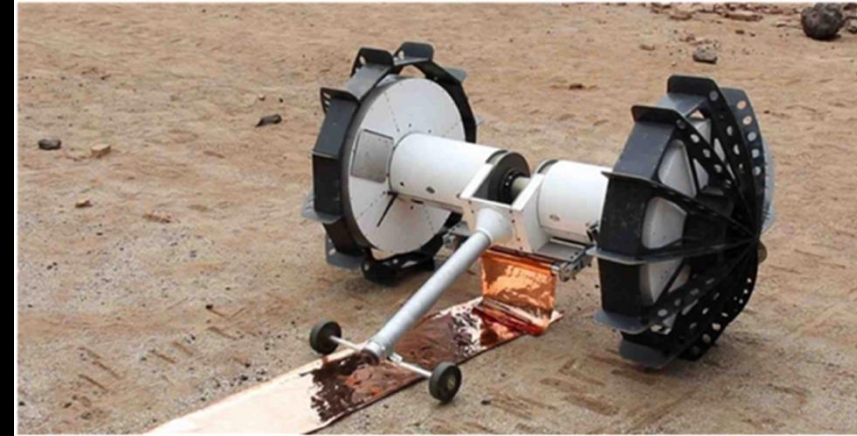
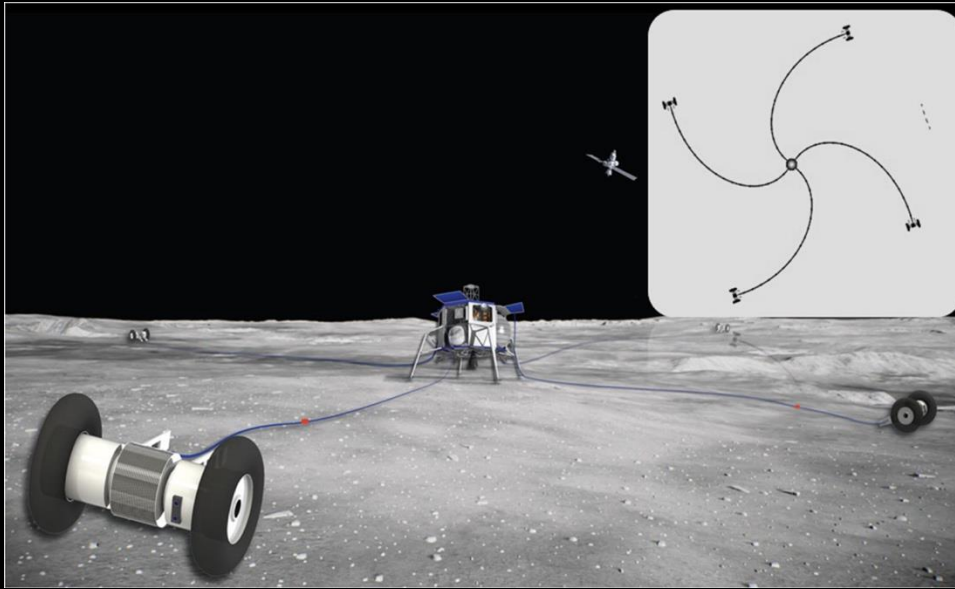
At 100 kHz, the level of suppression of radio interference will vary significantly across the basin. As shown in Figure above, the level of attenuation varies from a factor of approximately 25 dB at the southwest corner of the basin to near 55 dB at the northeast corner



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 exo-ionospheric 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>

