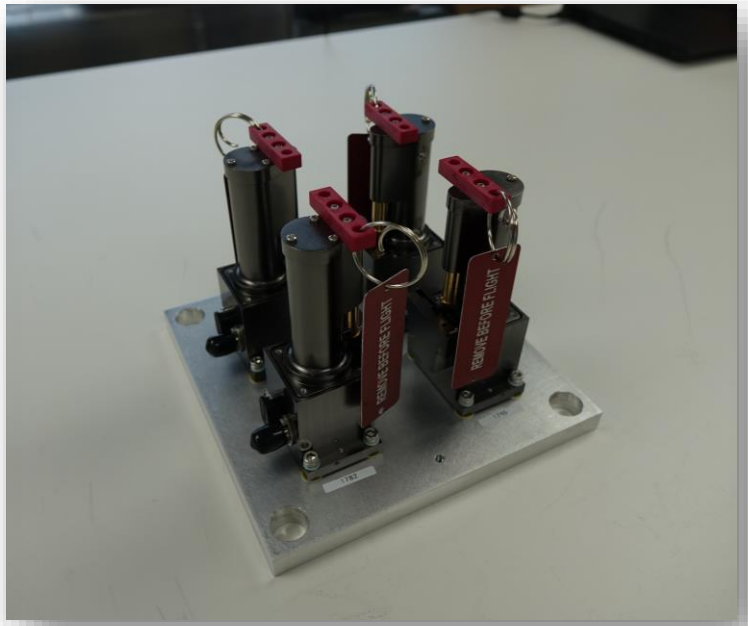
RADIO SCIENCE FROM THE MOON USING NASA's COMMERCIAL LUNAR LANDERS

Jack O. Burns for the ROLSES
& LuSEE Teams
University of Colorado Boulder

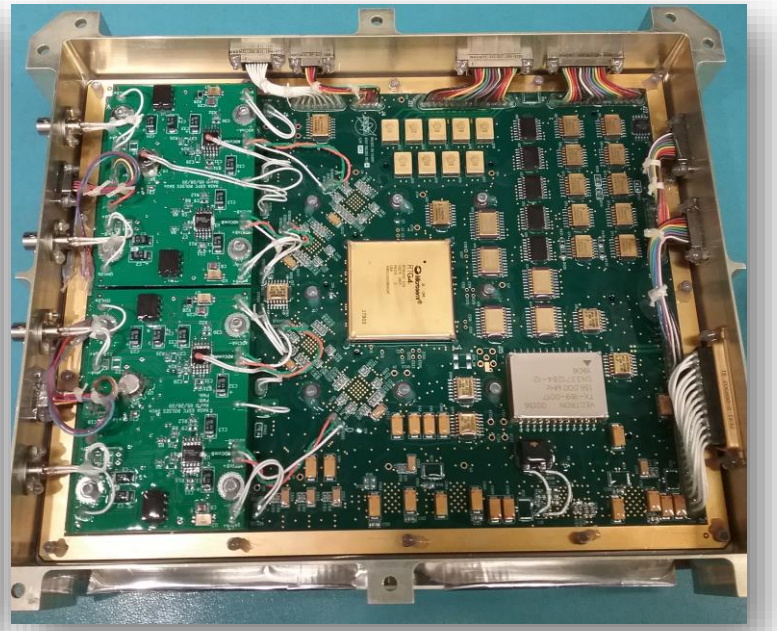
NAS Special Session on NASA's Artemis Program
Washington, DC
28 March 2023
see Burns+ 2021, *Planetary Science Journal*, 2, 44B

Courtesy of Intuitive Machines

IM-1 with ROLSES antennas deployed



Stowed STACER antennas

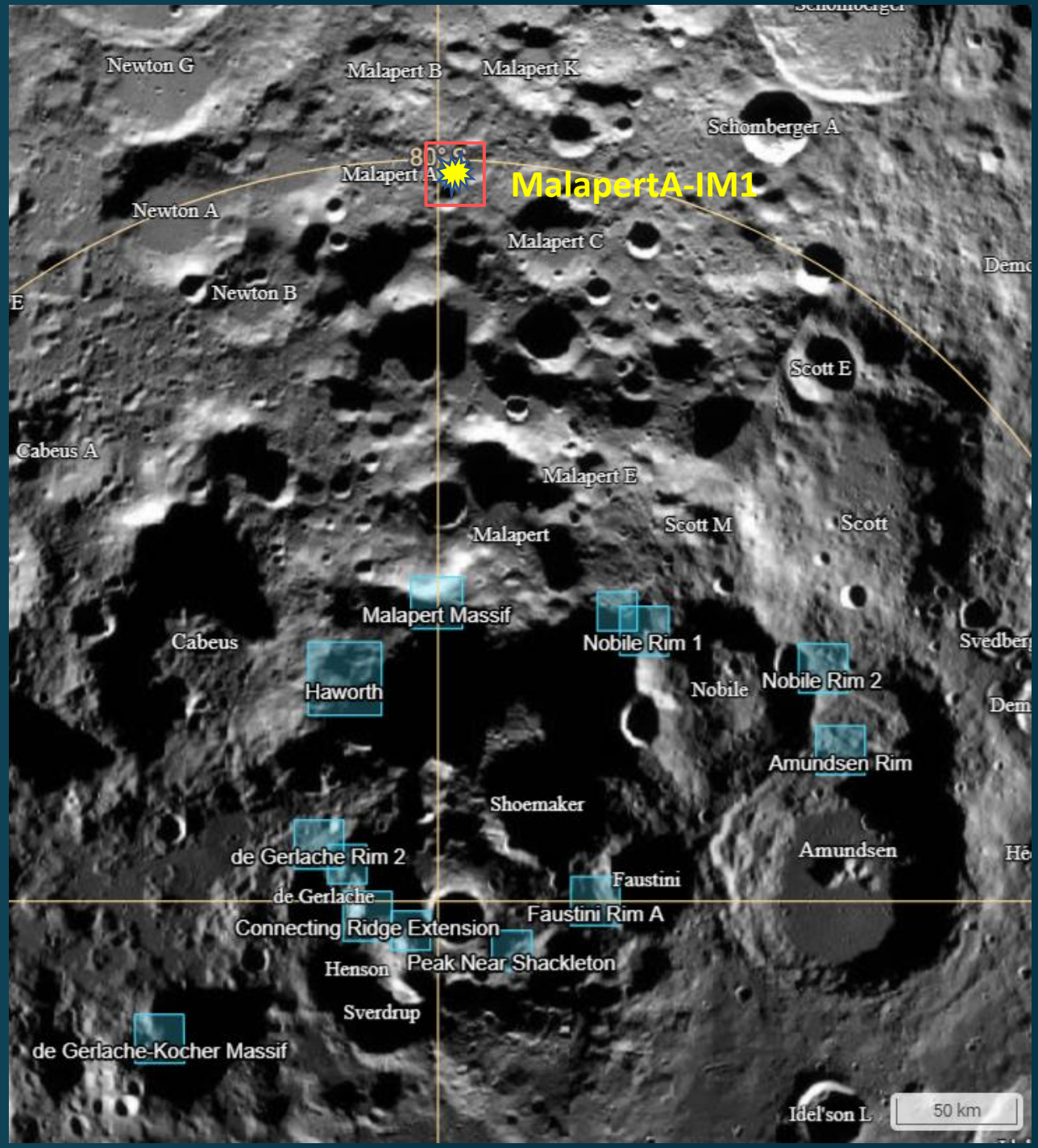


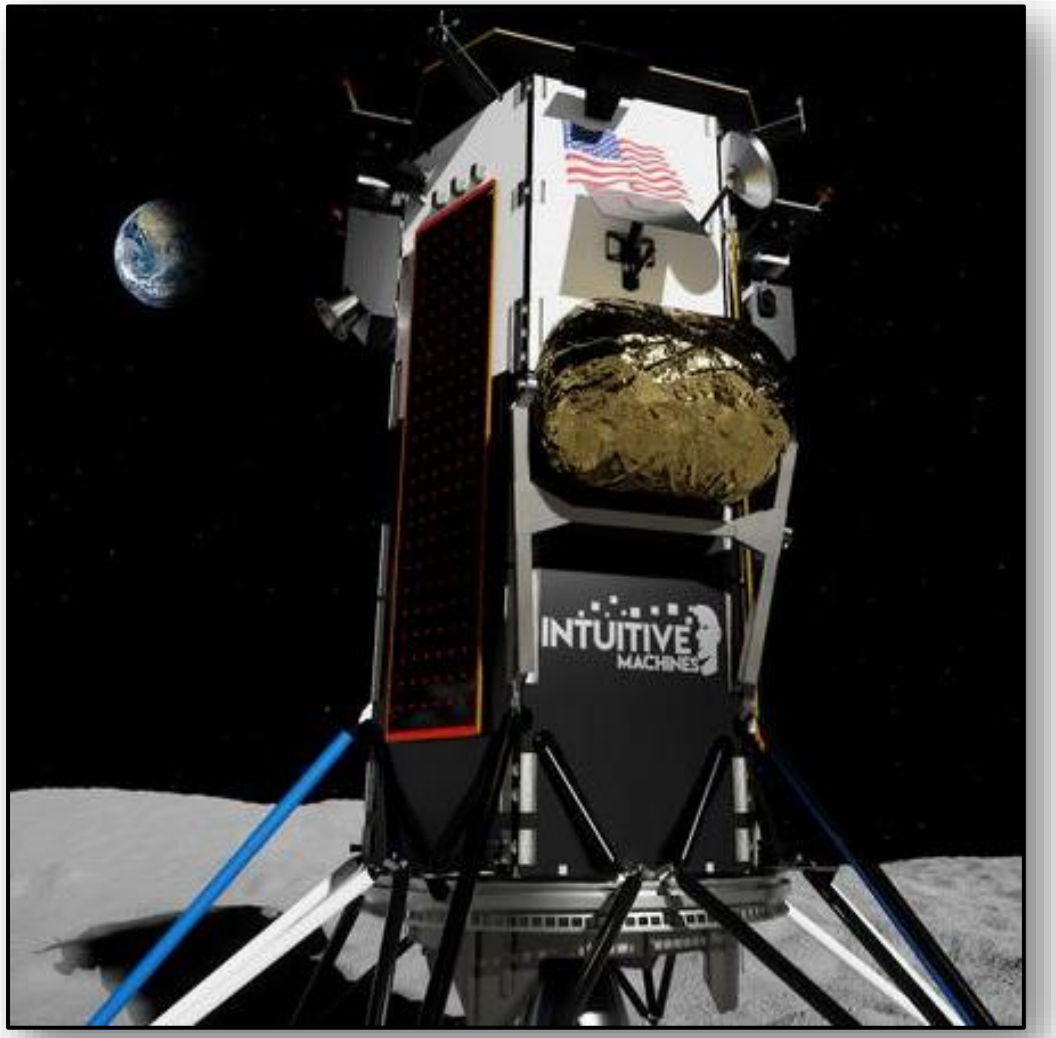
ROLSES spectrometer board

Radio wave Observations at the Lunar Surface of the Electron Sheath (ROLSES)

- ROLSES Instrument Team: Robert MacDowall (PI), William Farrell, Jack Burns, Damon Bradley, Nat Gopalswamy, Michael Reiner, Ed Wollack, David McGlone, Mike Choi, Scott Murphy, Rich Katz, Igor Kleyner.
- ROLSES instrument is a new build with heritage from NASA SMAP Earth Remote Sensing satellite:
  - Four 2.5-m monopoles forming cross-dipole antennas.
  - Radio spectrometer with 2 bands: 2 kHz – 1 MHz and 300 kHz – 30 MHz.
- Scheduled to land on lunar nearside using *Intuitive Machines (IM-1) Nova-C.*

IM-1 Landing Site on the crater rim of Malapert A near the lunar South Pole



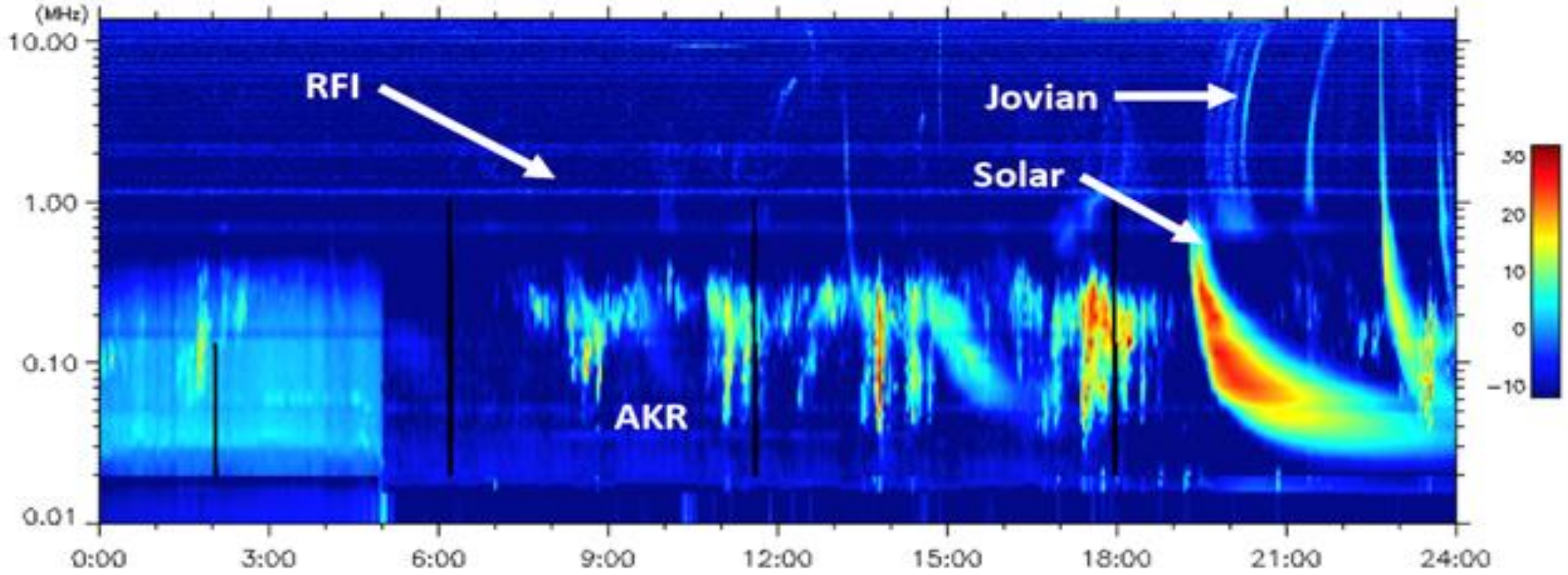


Courtesy of Intuitive Machines

ROLSES Science Goals

- Determine the electron sheath density from ~1 to ~3 m above the lunar surface by measuring electron plasma frequency.
- Demonstrate detection of solar, planetary, & other radio emission from lunar surface.
- Explore Galaxy radio spectrum at <30 MHz.
- Aid development of lunar radio arrays.
- Measure the local EM environment, including that from the lander.
- Measure reflection of incoming radio emission from lunar surface and below.

Demonstrate detection of solar, planetary, and other radio emission from lunar surface



The WAVES instrument on the Wind spacecraft at Solar-Earth L1 shows solar radio bursts, Earth's auroral radio bursts, terrestrial ground-based transmitters, and Jovian radio emissions, during the 24 hr interval of 2/20/2012. ROLSES could do the same.

ROLSES Instrument Parameters

- Frequency coverage: 2 kHz - 30 MHz
- Instrument Mass: 13.1 kg.
- Mechanical volumes: Total with radiators is 10^4 cm^3.
  - Electronic & thermal control box: : 20cm x 25cm x 8cm
  - Preamps (4) each 5 cm x 5 cm x 2 cm
  - Stacer antenna deployer base units 21 cm x 5 cm x 5 cm
- Power: average is 25 W.
  - Requires 1.25 A @ 7 Vdc for 35 sec to deploy each Stacer antenna
- Data rate: ~ 17 kbps

Images of integration of payload onto Lander panels
Courtesy of Intuitive Machines.

ROLSES delivery to the Moon on Intuitive Machines-1 lander in late June 2023

Courtesy of Firefly Aerospace

Lunar Surface Electromagnetics Experiment (LuSEE-Night)

The first 21-cm cosmology observations from the lunar far side at night

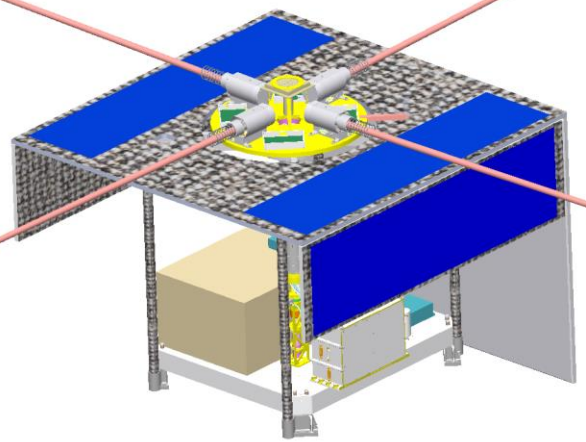
Stuart D. Bale (PI), Neil Bassett, Jack Burns, Johnny Dorigo Jones, Keith Goetz, Christian Hellum-Bye, Sven Herrmann, Joshua Hibbard, Milan Maksimovic, Ryan McLean, Raul Monsalve, Paul O'Connor, Aaron Parsons, Marc Pulupa, Rugved Pund, David Rapetti, Kaja Rotermund, Ben Saliwanchik, Anže Slosar, David Sundkvist, and Aritoki Suzuki

Bale+, 2023, https://arxiv.org/abs/2301.10345.

LuSEE-Night Mission to the Lunar Far Side

- 3m BeCU stacer antennas (6-m tip-to-tip) with turntable to change orientation
- ~50 MHz bandwidth, 4-channel baseband receiver, 1-50 MHz.
- Far-field calibration source (CLPS CS-4 mission)
- ESA *Lunar Pathfinder* (LPF) comms – ~2GB/night
- Daytime comms, charging, turntable ops

Major involvement from US **DOE**
DOE MIE contract
NASA MSFC/PMPO contract



(no lander shown)

Standalone system

- Instrument electronics
- Solar arrays
- ~40+kg battery - ~15W operational power = heat
- S-band Comms (JPL/Vulcan User Terminal)
- PRISM FSS-like (JPL PALETTE) thermal design

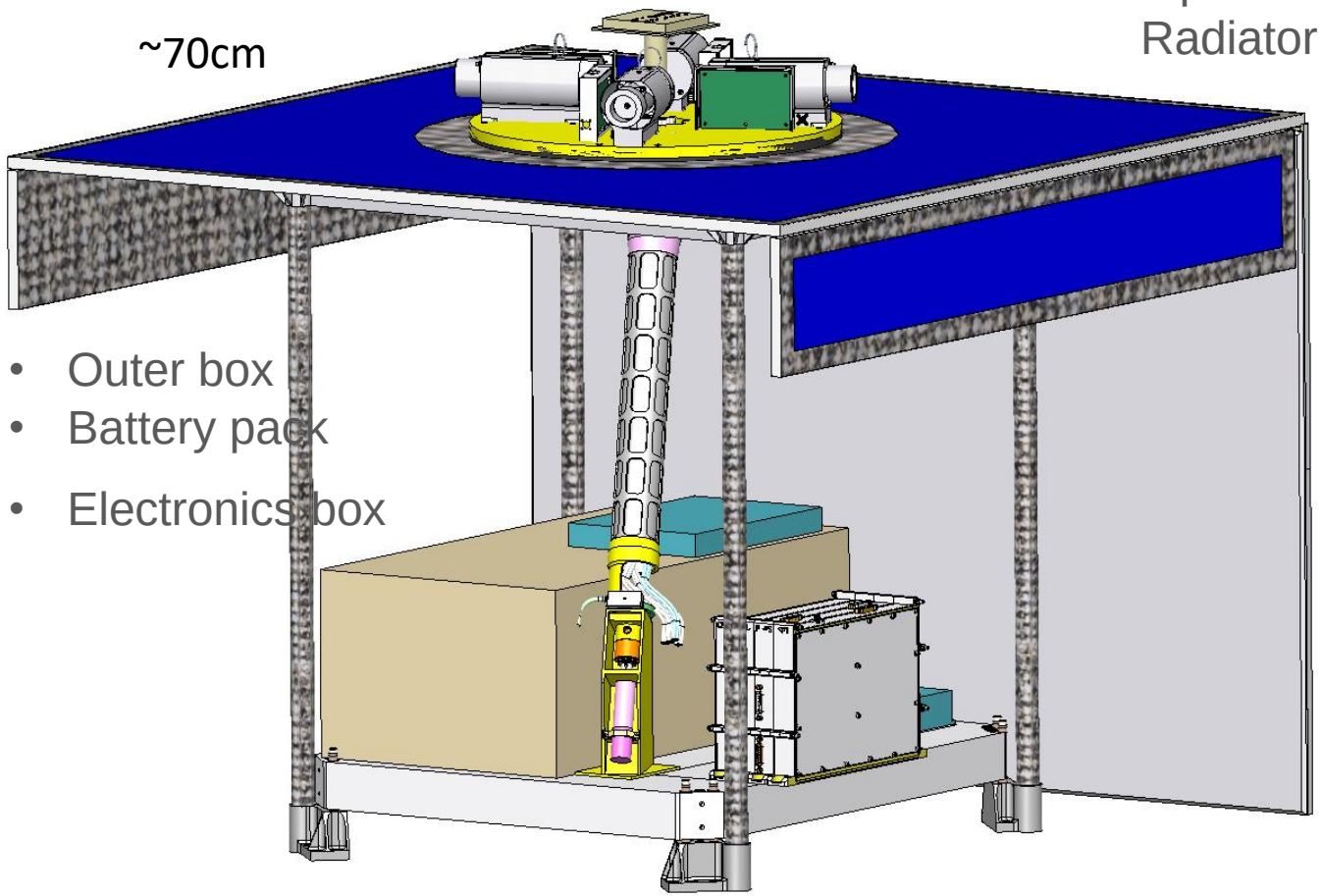
On CS-3 CLPS mission with ESA Lunar Pathfinder Relay

- Early 2026 landing
- Lander will **die** after commissioning
  - No spacecraft EMI!
- Landing site selected
  - Mid-latitudes
  - Farside
  - Slightly south

LuSEE-Night System Design

Medium gain comm antenna
Stacer antenna housing
Turntable
Solar panels
Radiator

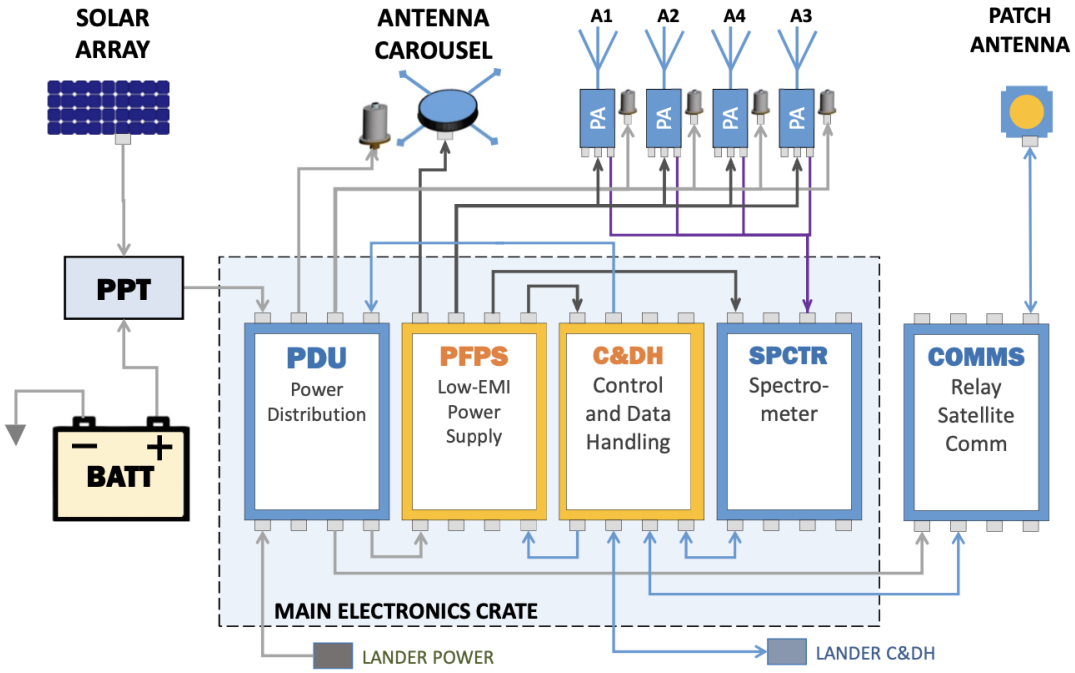
~70cm



- Outer box
- Battery pack
- Electronics box

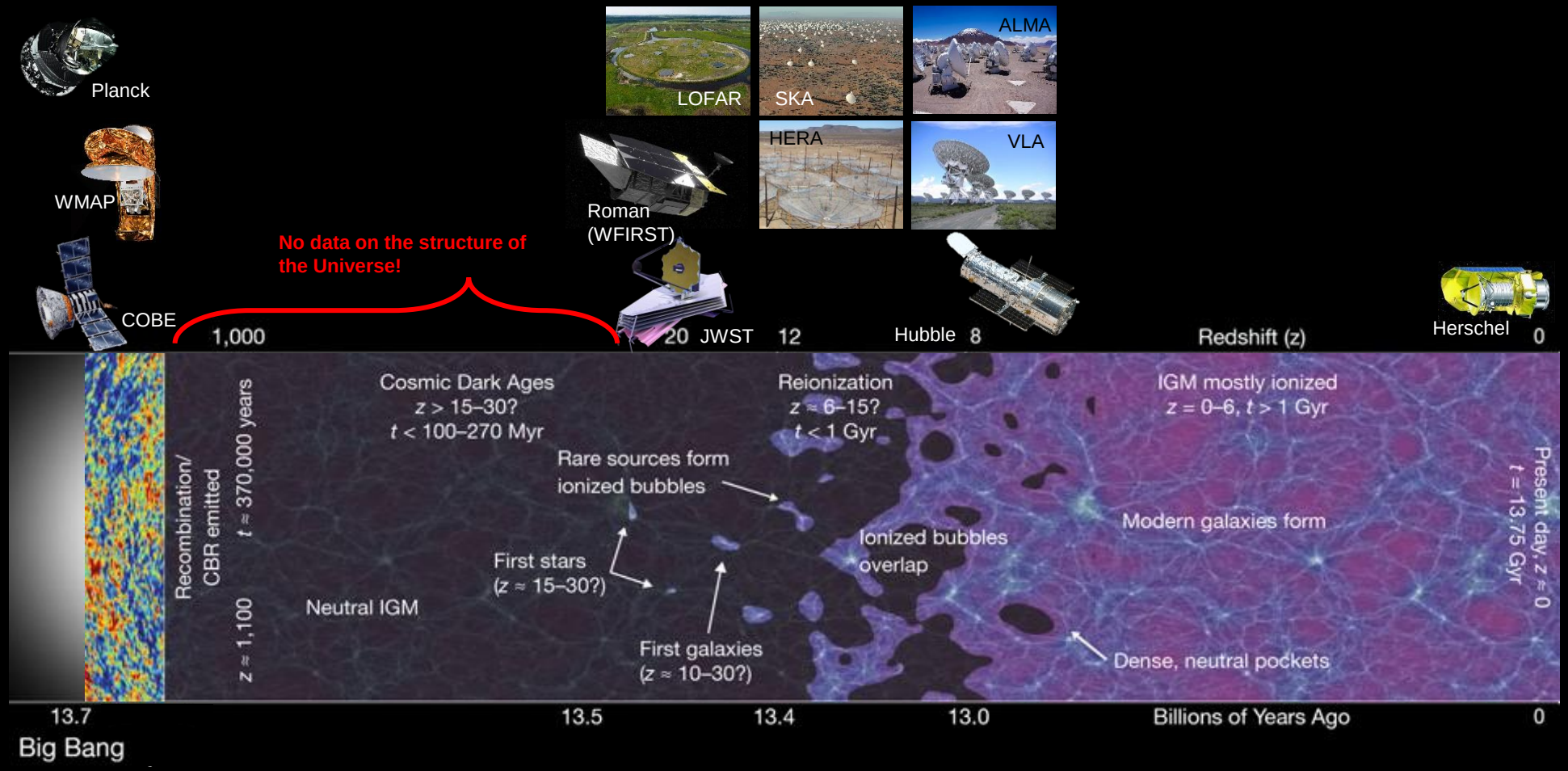
Spectrometer – BNL from UCB/PSP design
Antennas – LBNL w/ UCB design
DCB-CSAC/Power – UCB and UMN from PSP design
Comms – JPL/Vulcan

System Block Diagram



Voltage measurement!

LuSEE-Night is a Radio Cosmology Pathfinder Experiment

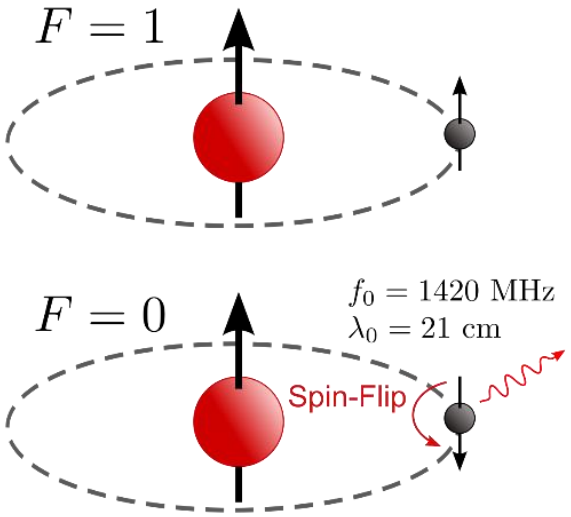


Astrophysics Decadal Survey identified the Dark Ages as “The Discovery Area for Cosmology”

The 21-cm Global signal

$$\delta T_b \propto \bar{x}_{HI}\left(1 - \frac{T_R}{T_S}\right)$$

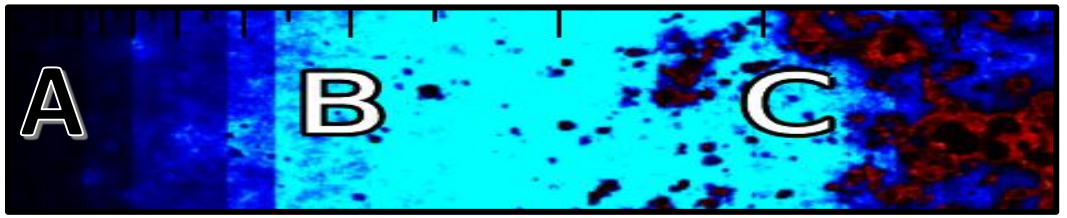
Spectral Features:

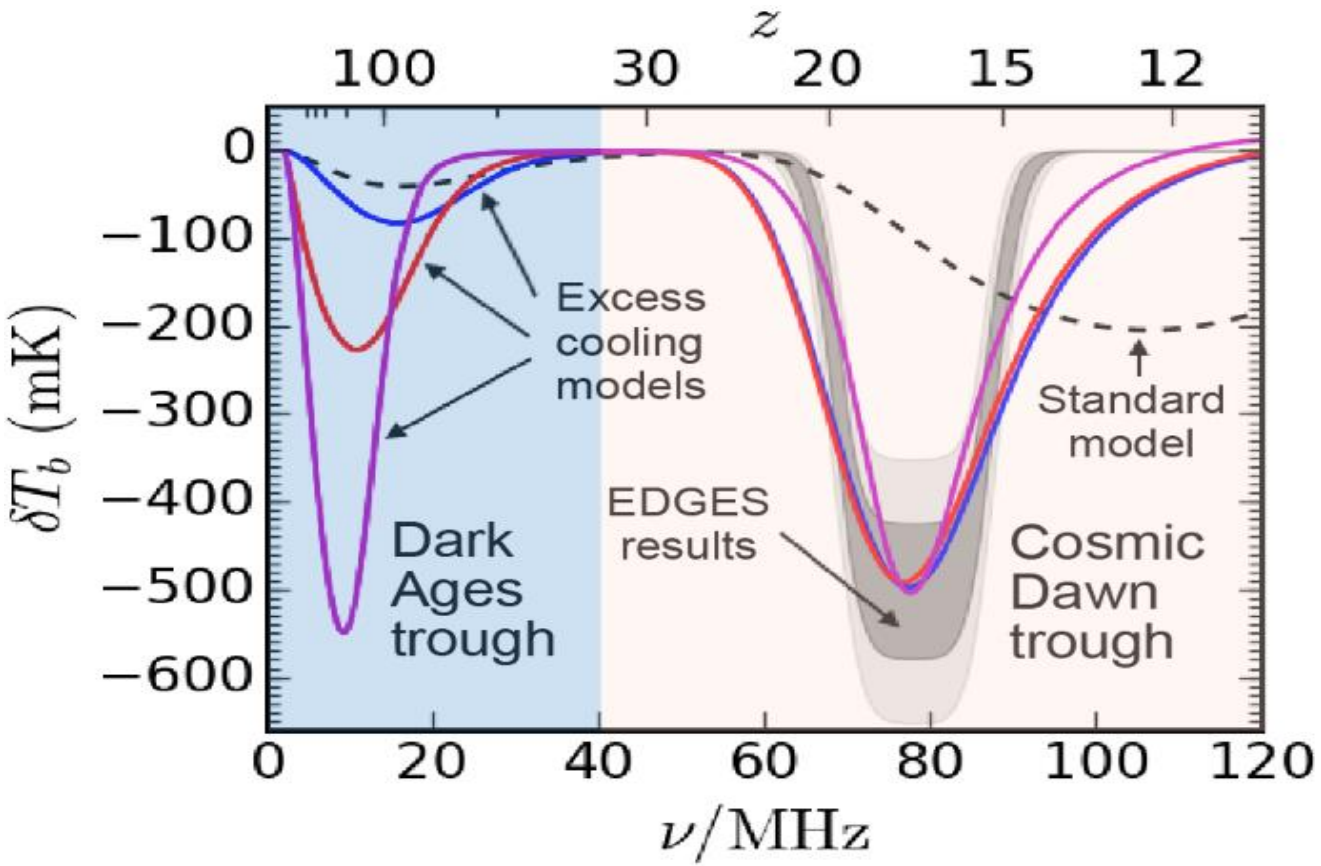


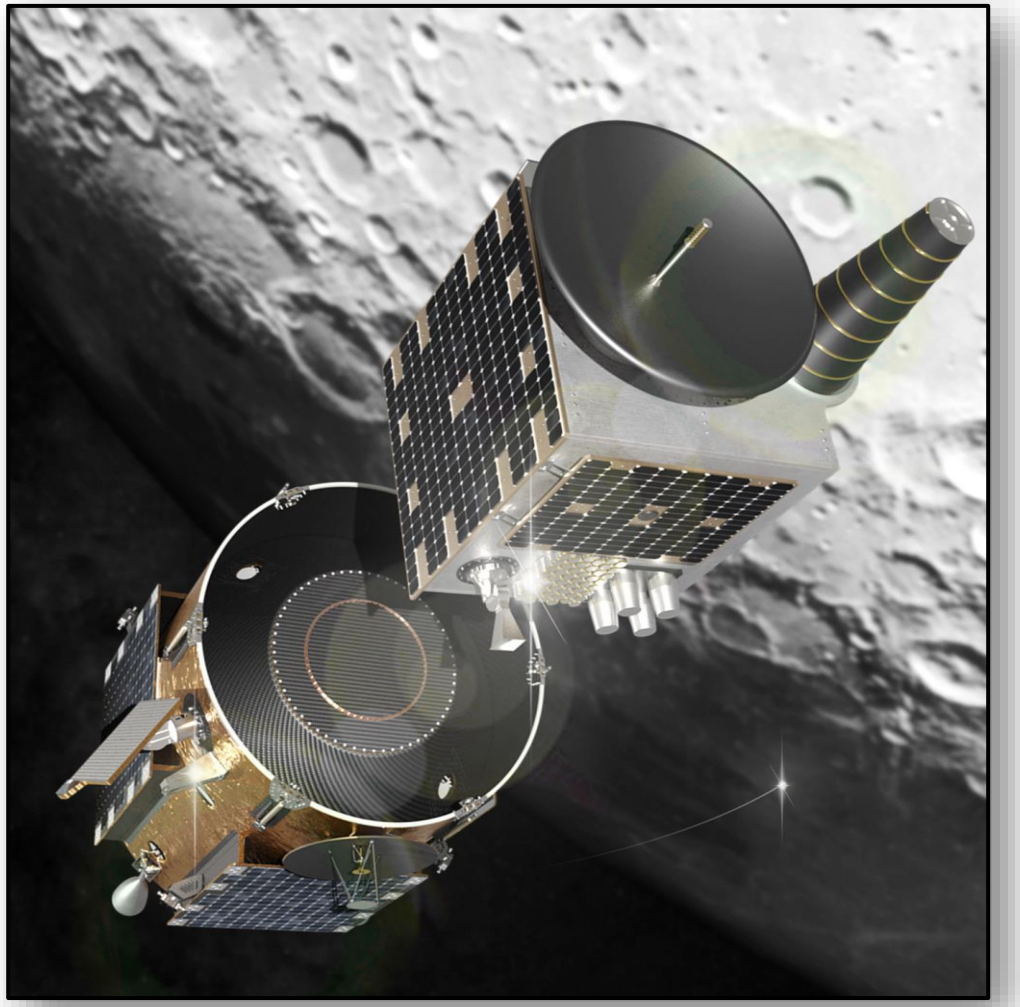
A: Dark Ages: test of standard cosmological model

B: Cosmic Dawn: First stars ignite

C: Black hole accretion begins



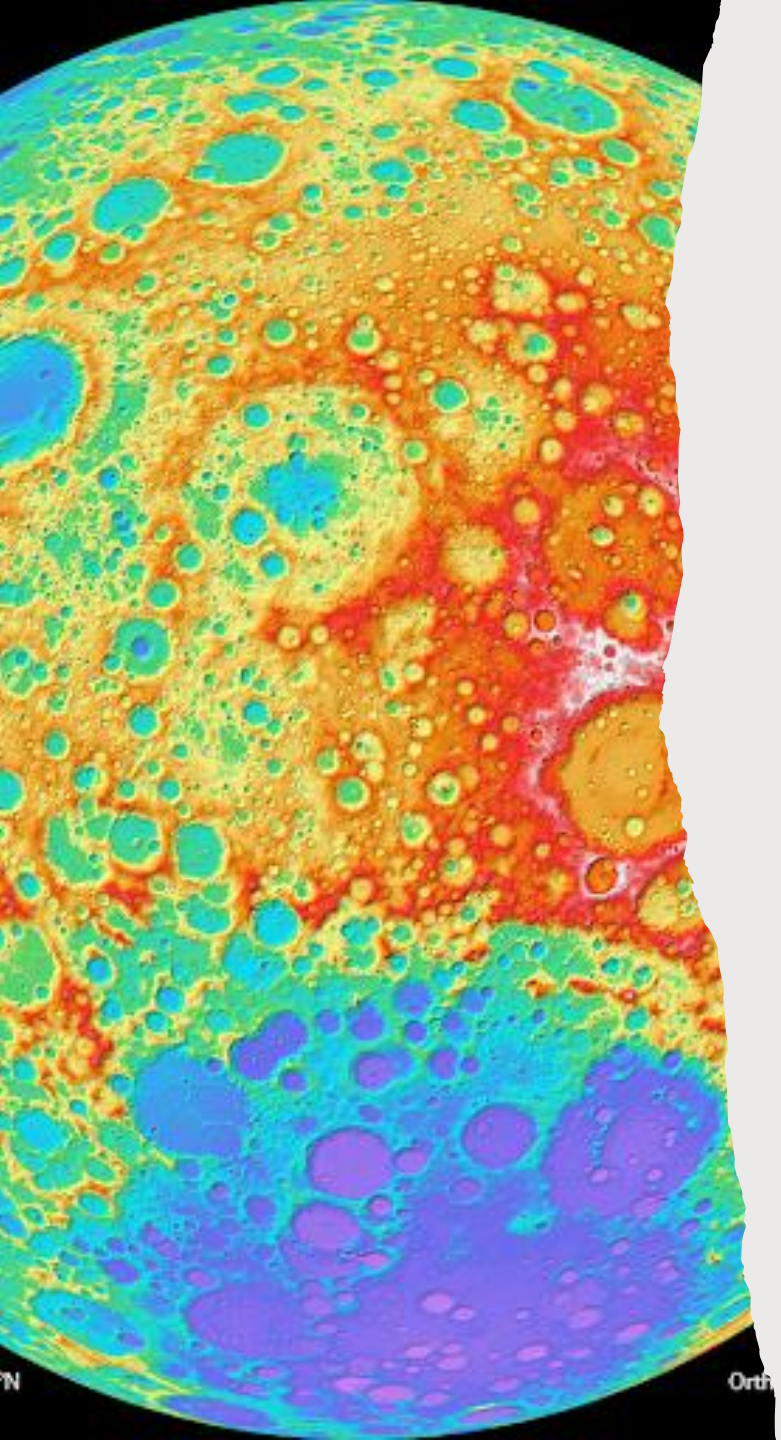




Deployment of *Lunar Pathfinder* communications satellite as part of LuSEE-Night mission.
Courtesy of NASA

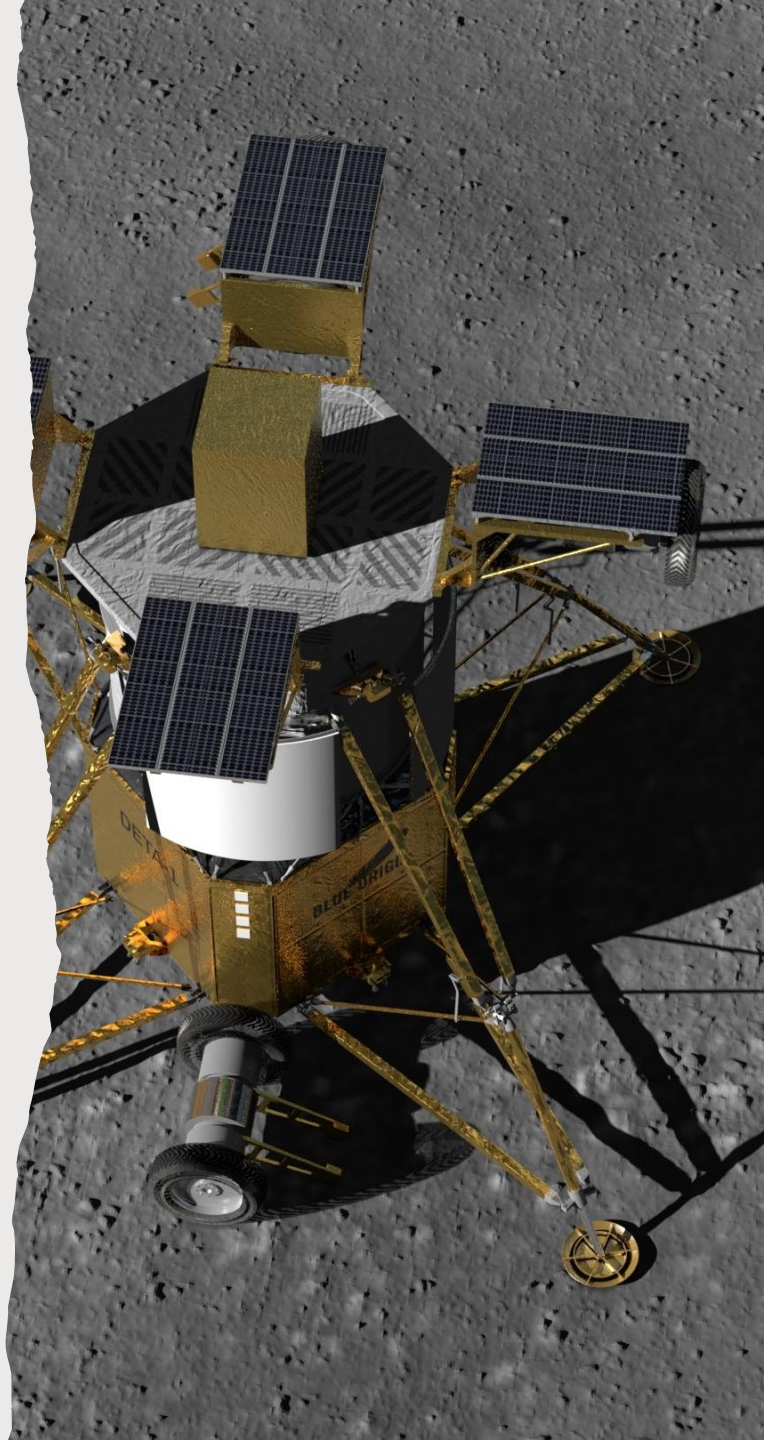
The Path Forward

- NASA's CLPS program is a high risk/high reward program that could be a game-changer with regular access to the lunar surface 2-3 times per year.
- The first NASA radio science payload, *ROLSES*, is planned to land at the South Pole in mid-2023. It will measure the electron plasma sheath near the surface, the Galaxy spectrum at <30 MHz, and the EM interaction with the dielectric lunar subsurface.
- *ROLSES* will inform the design & observational strategy for *LuSEE-Night*. *LuSEE-Night* will make the first nighttime observations of the radio band corresponding to the early Universe's Dark Ages.
- These CLPS radio science missions will prepare the way for a future array of low frequency radio antennas on the lunar surface.



The lunar far side is an enabling site for Low Frequency Radio Astronomy & Cosmology:

- uniquely radio-quiet,
- lacks a significant ionosphere,
- dry, stable environment.



Landing site candidates driven by terrestrial EMI, thermal constraints, and relay downlink