The Lunar Surface Electromagnetics Experiment

Stuart D. Bale

Physics Department and Space Sciences Lab

University of California, Berkeley

…for the entire LuSEE team

- LuSEE was **selected** in June 2019 by NASA in the Lunar Surface Instrument and Technology Payloads (**LSITP**) for the Commercial Lunar Payload Services (**CLPS**) program – *originally based on PSP/FIELDS flight spare hardware*

- Under contract by MSFC/PMPO and **in development**

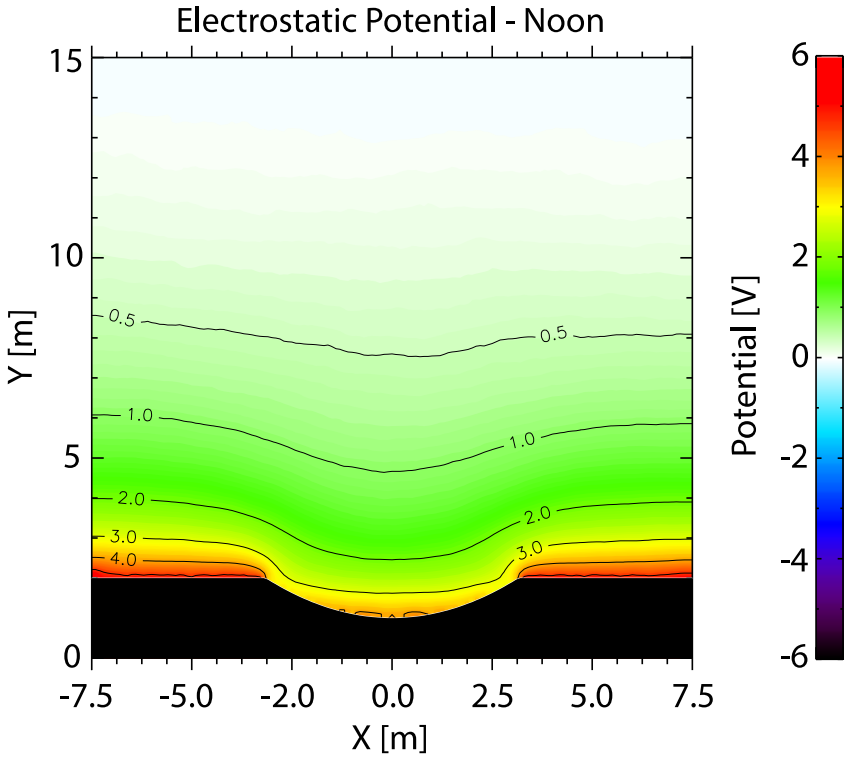
- LuSEE is a program **split into 2 payloads on 2 separate landers**

    - **LuSEE 'Lite'** to the Schrödinger Basin (south pole farside) in late 2024 on the CP-12 mission
        - Surface plasma physics and waves, DC electrostatic potentials, dust impacts, and coordination with LITMS/LMS (magnetotellurics)

    - **LuSEE 'Night'** to the farside mid-latitudes in 2025? on the CS-3 mission in a major collaboration with the US Department of Energy (**DOE**) – BNL and LBL
        - Low frequency radio astronomy (< ~50 MHz) with **standalone** operations through the lunar night
        - Lunar farside landing side, mid-latitudes
        - Operations through the lunar night, full EMI control

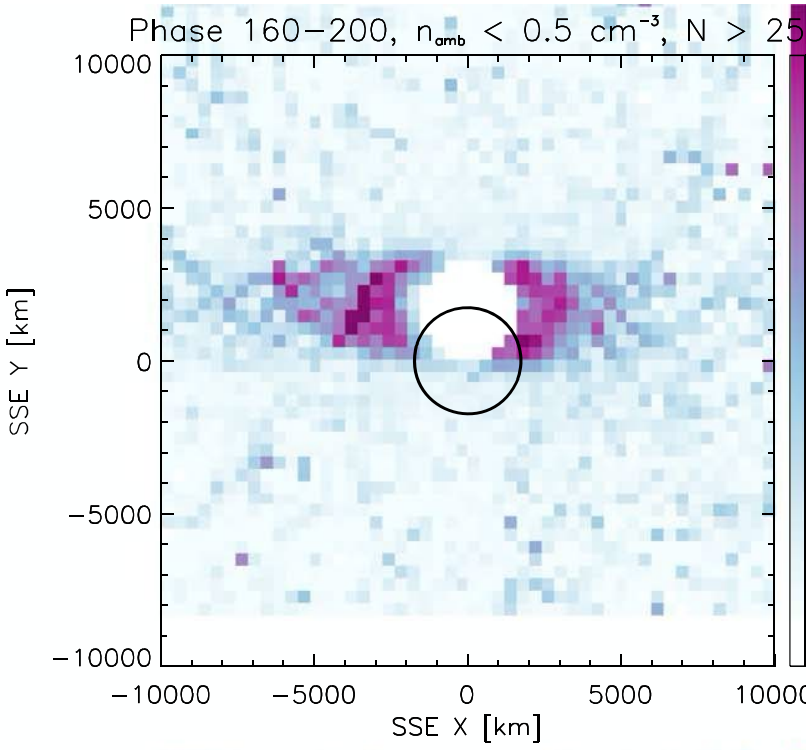
LuSEE 'Lite' Objectives and Measurements

- Lunar ionosphere - plasma waves
- Surface-geospace interactions - plasma waves
- Lunar surface electrostatic potential/sheath

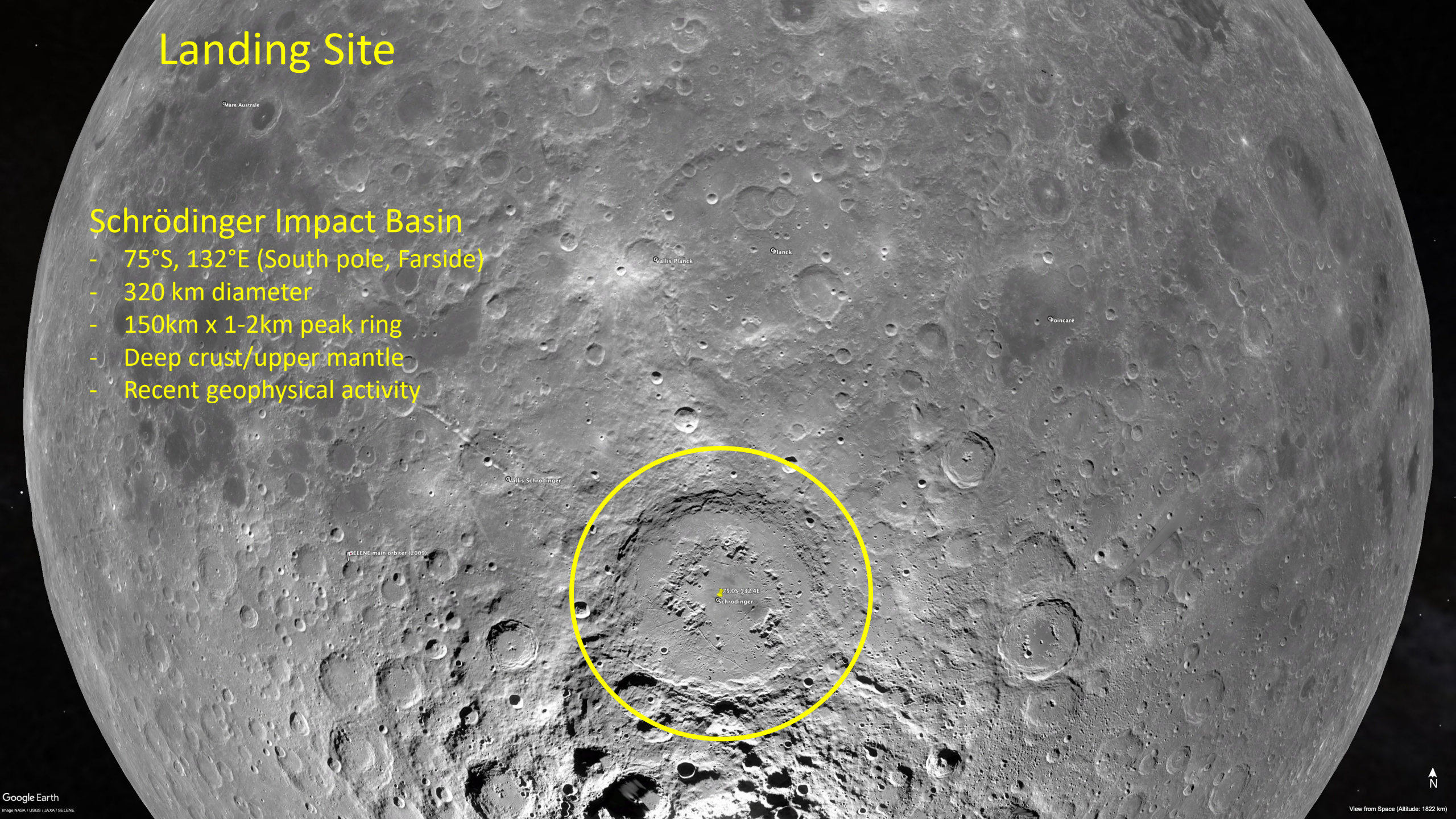


(Poppe)

- Dust/electrostatic field interactions
- Support for LMS/LITMS electromagnetic sounding
  - Electrical structure of the upper-mantle



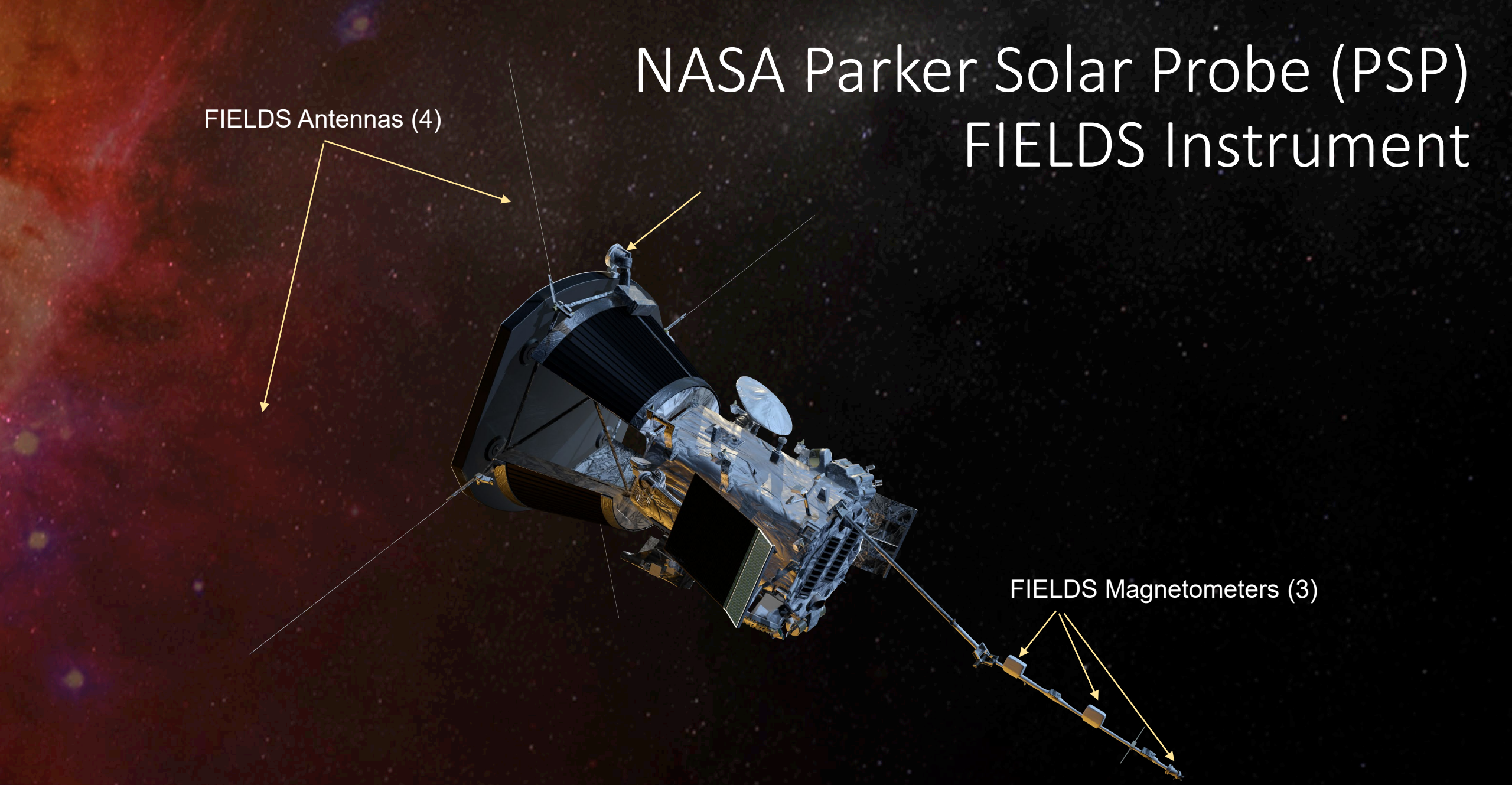
Landing Site



Schrödinger Impact Basin

- 75°S, 132°E (South pole, Farside)
- 320 km diameter
- 150km x 1-2km peak ring
- Deep crust/upper mantle
- Recent geophysical activity

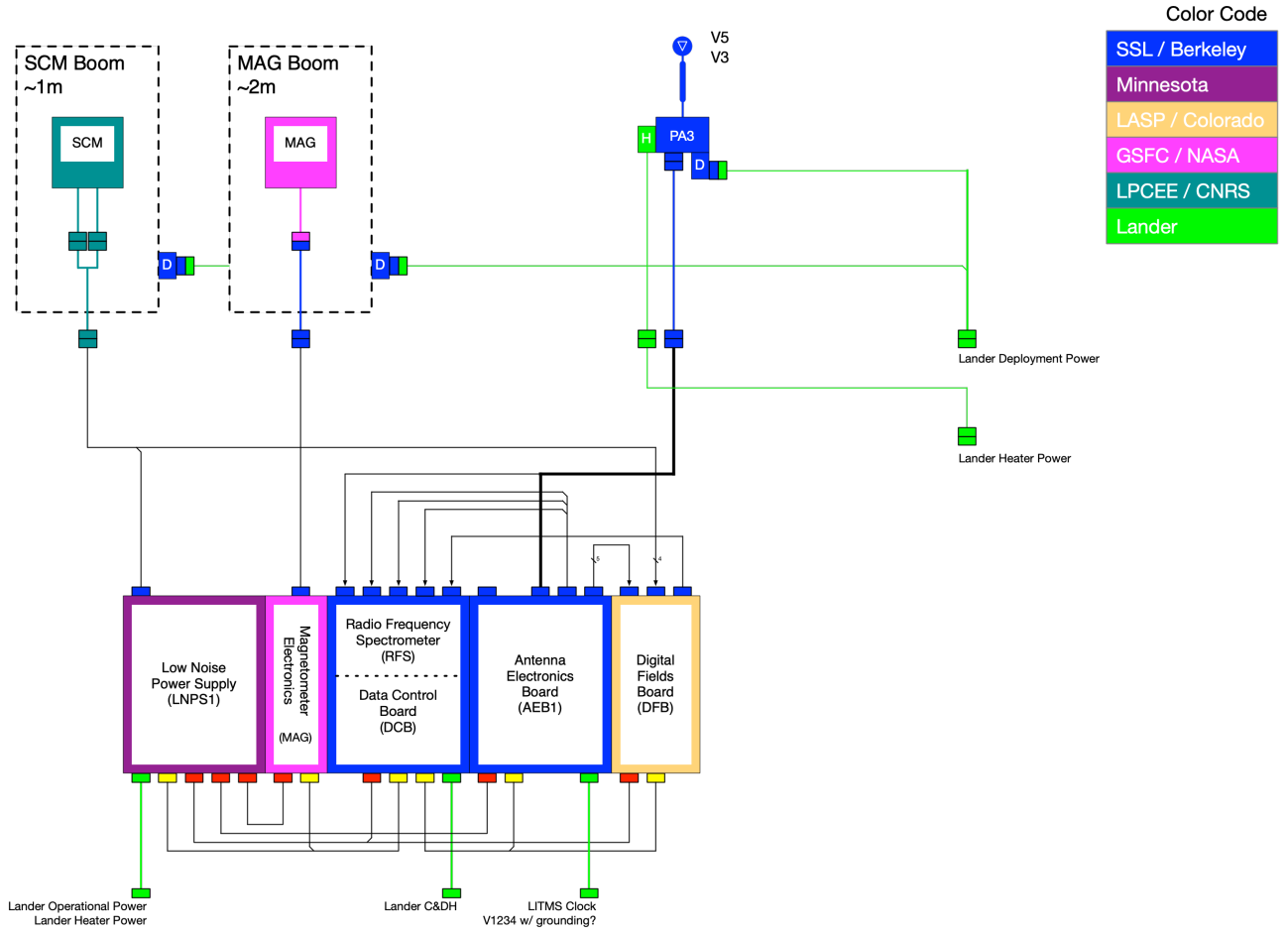
NASA Parker Solar Probe (PSP) FIELDS Instrument



LuSEE instrument hardware is FS/EM or derived from PSP/FIELDS (Bale et al., 2016; Pulupa et al., 2017)

LuSEE ‘Lite’ Block Diagram

- Vector 'DC’ magnetic field (fluxgate magnetometer)
  - 293 Sa/sec (146 Hz Nyquist)
- 3-d vector AC magnetic field (search coil magnetometer)
  - 293 Sa/sec (146 Hz Nyquist)
  - Burst mode to 150,000 Sa/sec
  - Spectra and cross spectra to 75 kHz
- 1-d AC magnetic field (search coil magnetometer)
  - Spectra and cross-spectra to 1 MHz
- 1 single-ended voltage with current-biasing & floating ground – from V3
- 4 single-ended voltages – from LITMS instrument electrodes
  - 293 Sa/sec (146 Hz Nyquist)
  - Burst mode to 150,000 Sa/sec
  - Spectra and cross-spectra to 75 kHz
- Quasi-thermal noise measurements to 1 MHz
- Radio emission spectra and cross-spectra to ~20 MHz



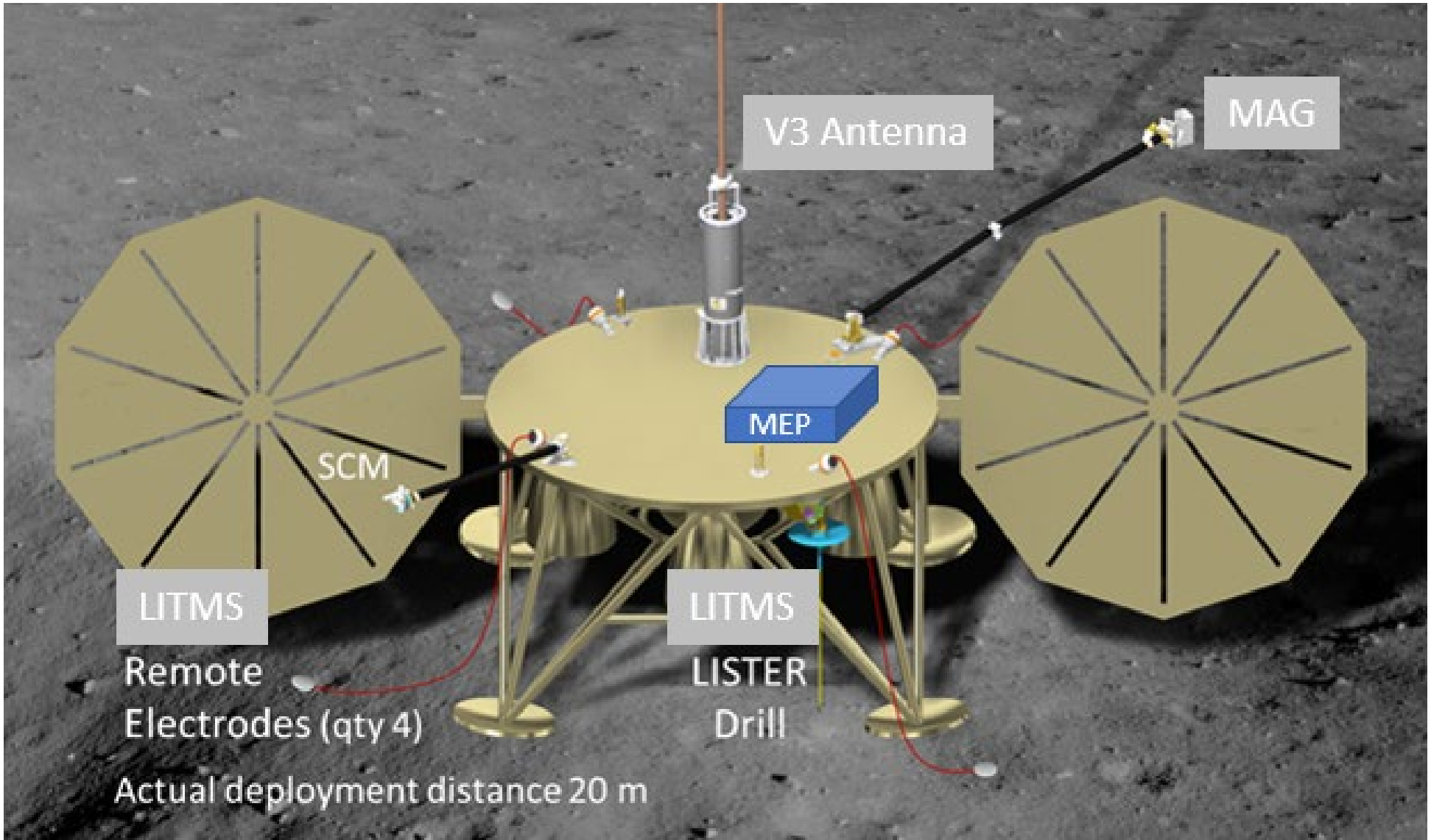
LuSEE-Lite Instrument Block Diagram

LuSEE ‘Lite’ will be integrated in Berkeley *this summer*

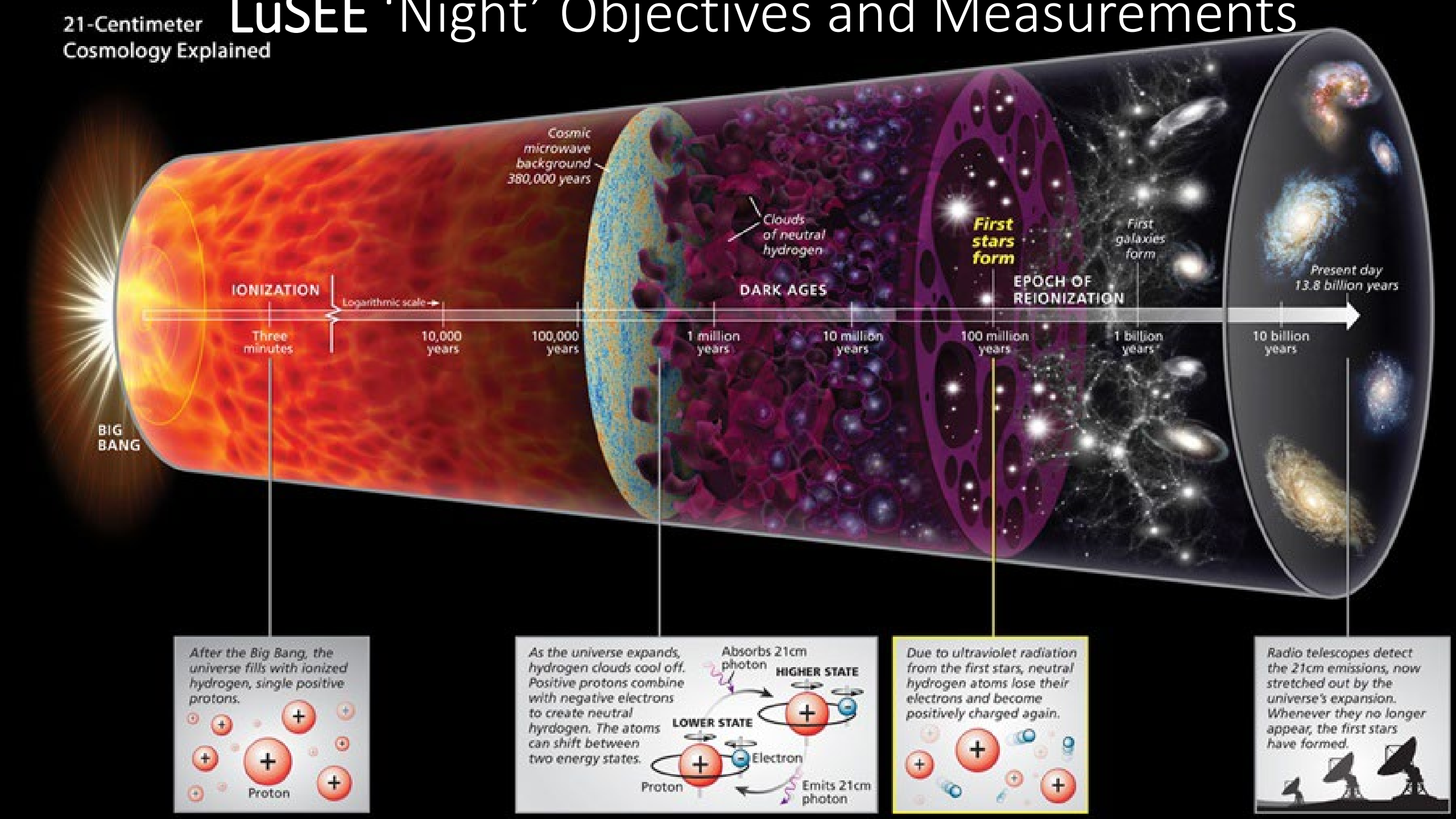
Direct heritage from NASA Parker Solar Probe and ESA Solar Orbiter

LuSEE ‘Lite’ Deployed

(notional lander)



LuSEE 'Night' Objectives and Measurements



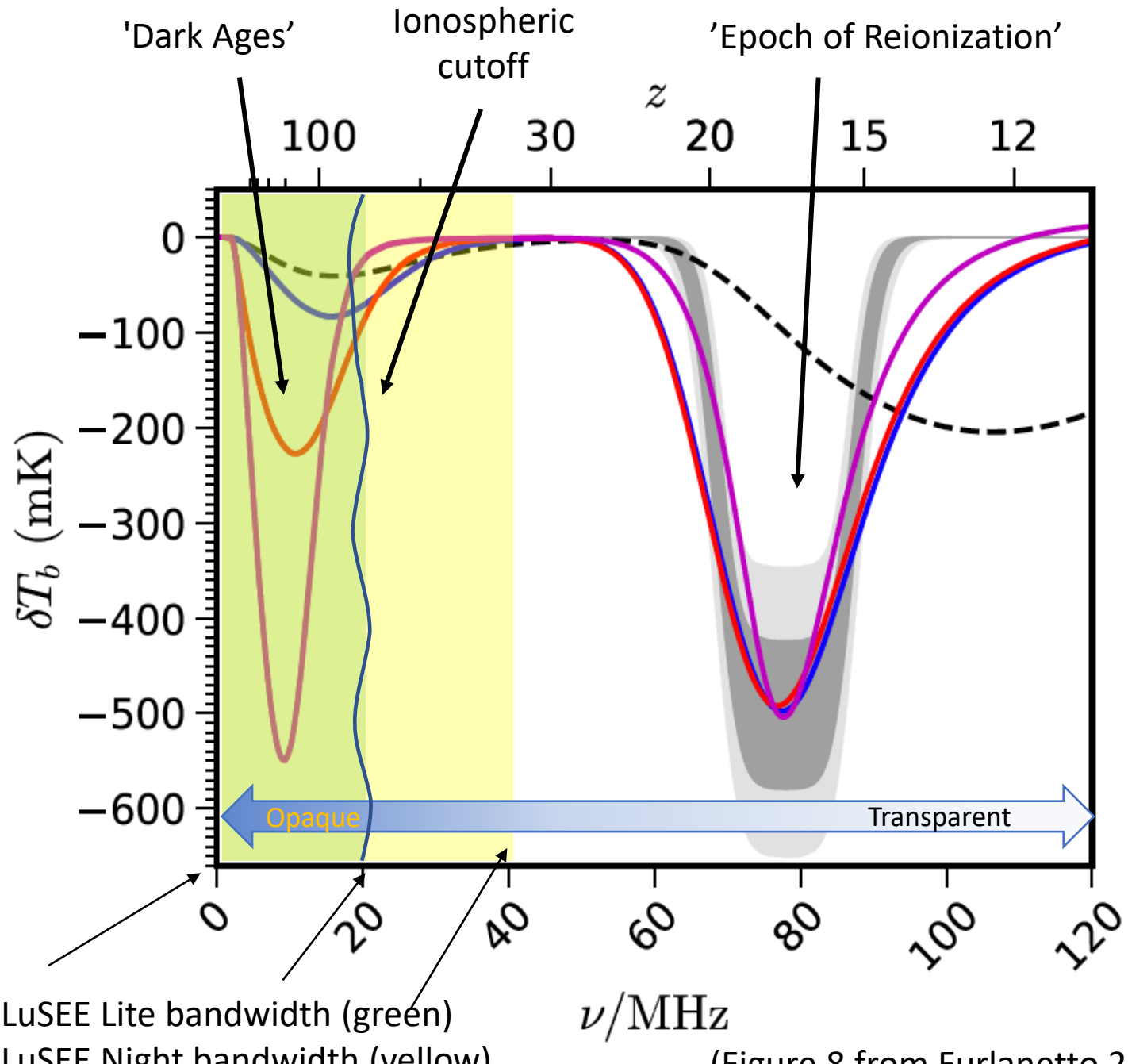
Why go to space?

- Cosmology predicts two 21cm absorption features in the highly-redshifted CMB spectrum.
  - Recombination at z ~ 100-200 (ν ~ 20-10 MHz)
  - Dark Ages
  - The Epoch of Reionization (or 'Cosmic Dawn') at z ~ 15-20 (ν ~ 80-70 MHz)

- Exoplanet radio emission? Discrete sources? The quiet corona?

- The Earth's ionosphere starts to become opaque below ~20 MHz. Measurements of the z~100 absorption spectrum *must* be made in space.

- An initial measurement of the EoR feature has been made from Earth and several facilities are currently attempting to verify.



LuSEE Lite bandwidth (green)
LuSEE Night bandwidth (yellow)

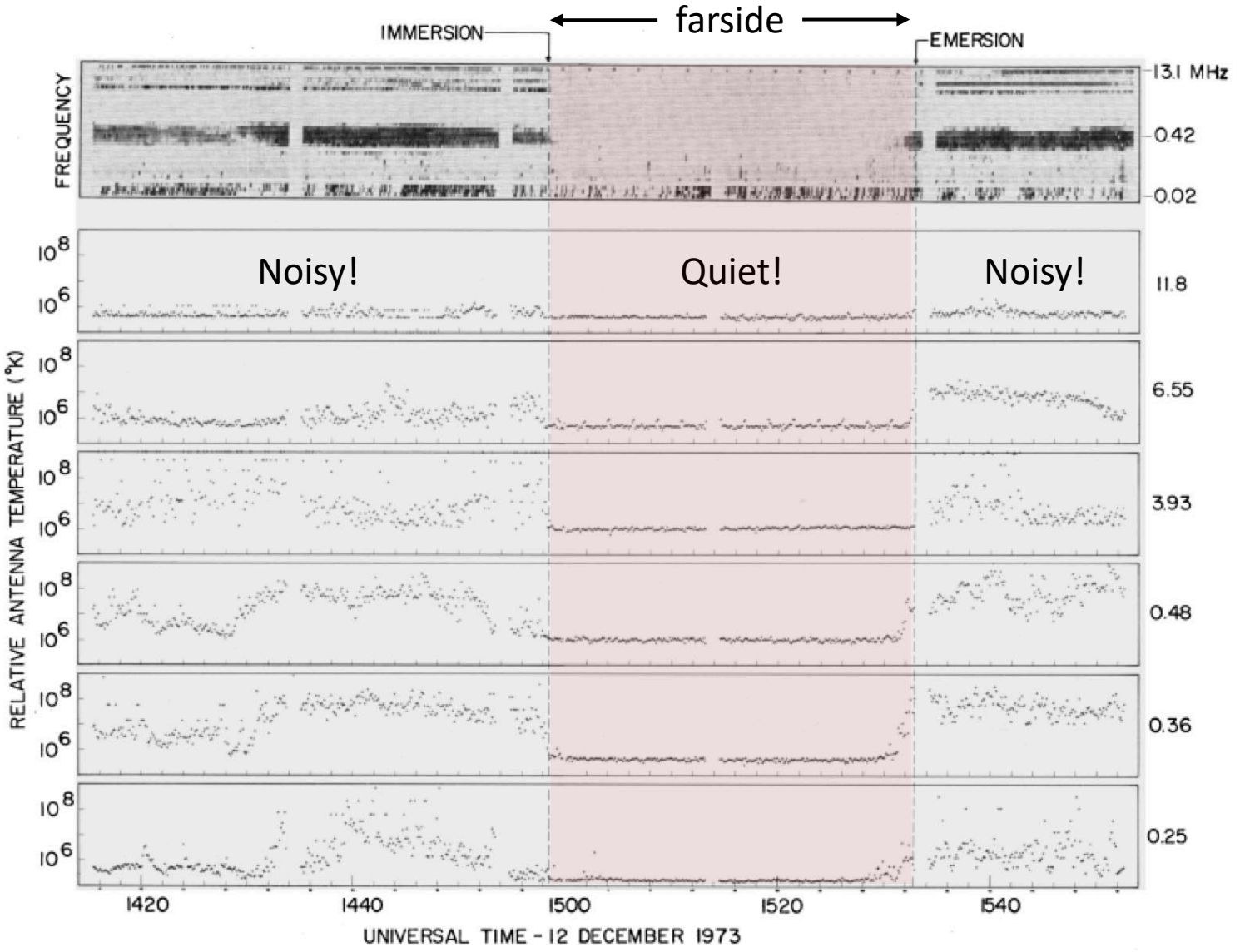
(Figure 8 from Furlanetto 2019)

Why the Moon?

- The Earth is noisy and the ionosphere is opaque < ~20 MHz
  - AKR at < 1 MHz
  - Shortwave radio stations, all across the band
- The Sun is noisy
  - Solar radio bursts from flares, CME shocks, etc. This is our solar science
  - Solar blackbody radiation
- The outer planets are noisy
  - Jovian decametric emission
  - Saturnian emissions

The lunar farside (*still*) offers radio-quiet intervals shielded from Earth (always) and the Sun (monthly) and outer planets (regularly).

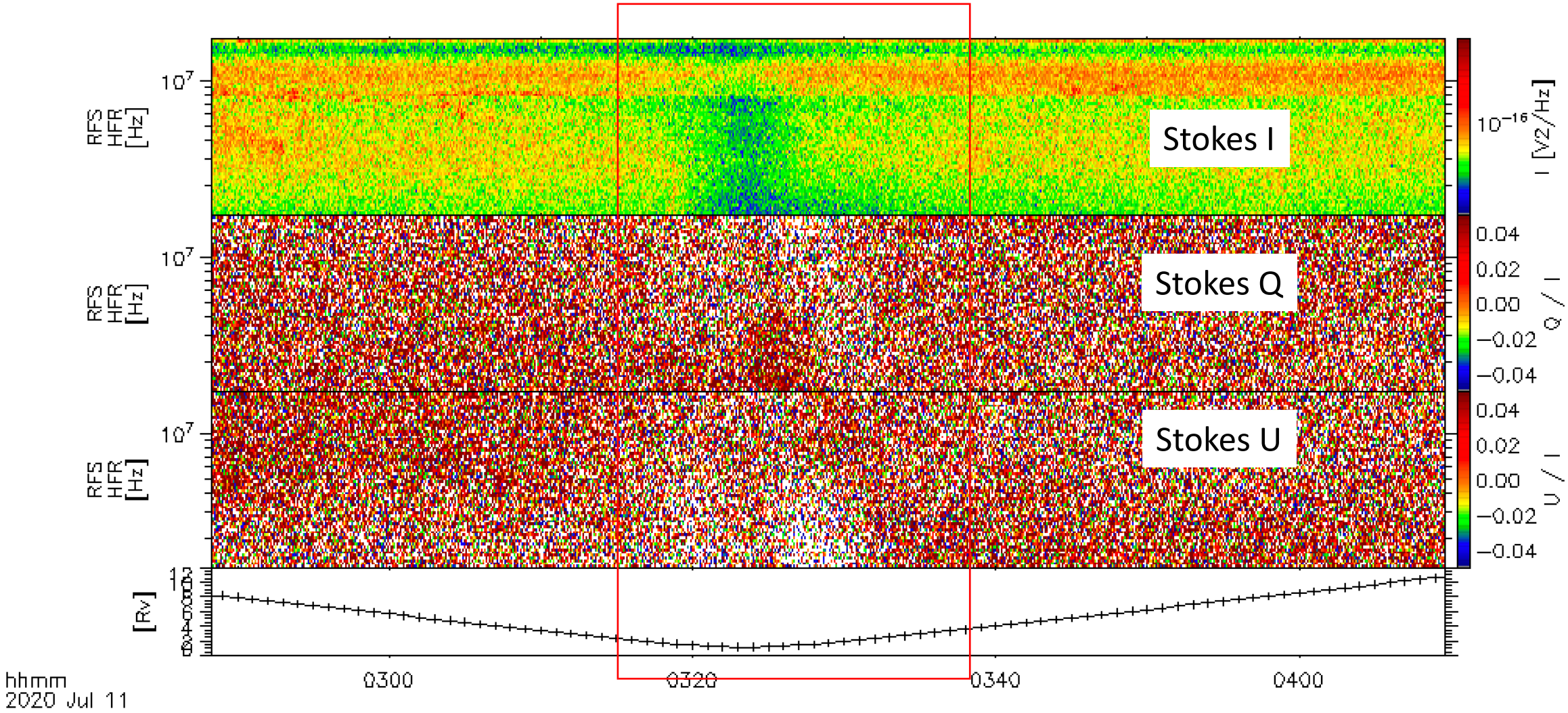
- A long history of concepts.
- The Chinese Chang'e 4 Instrument



(RAE-2 spacecraft, Alexander et al., 1975)

Why the Moon?

Galactic foreground intensity and polarization are modified



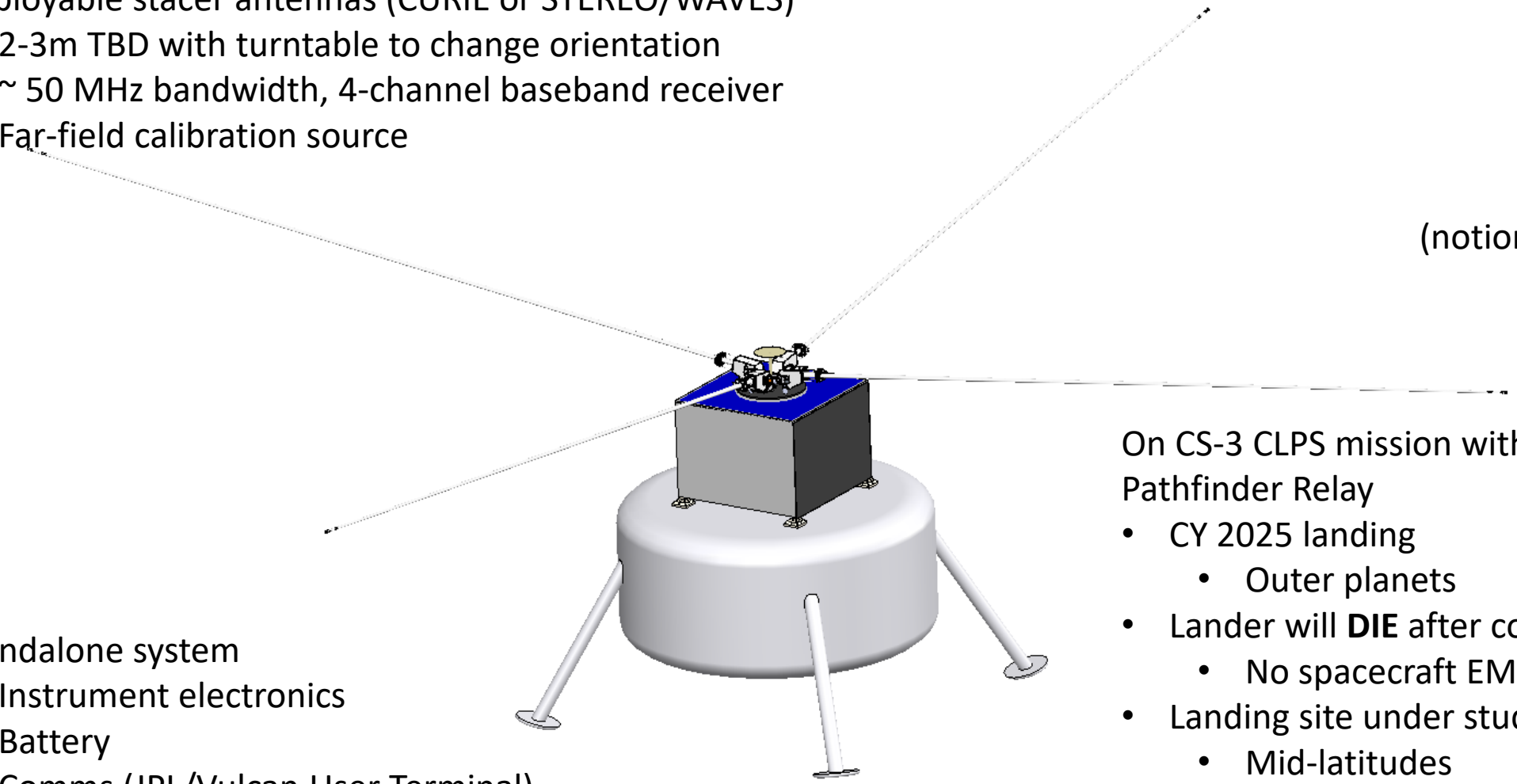
Parker Solar Probe flyby of Venus – planet acts as an occulting disk

LuSEE ‘Night’ Concept

Major involvement from US **DOE** (BNL and LBL)

Deployable stacer antennas (CURIE or STEREO/WAVES)

- 2-3m TBD with turntable to change orientation
- ~ 50 MHz bandwidth, 4-channel baseband receiver
- Far-field calibration source



(notional lander)

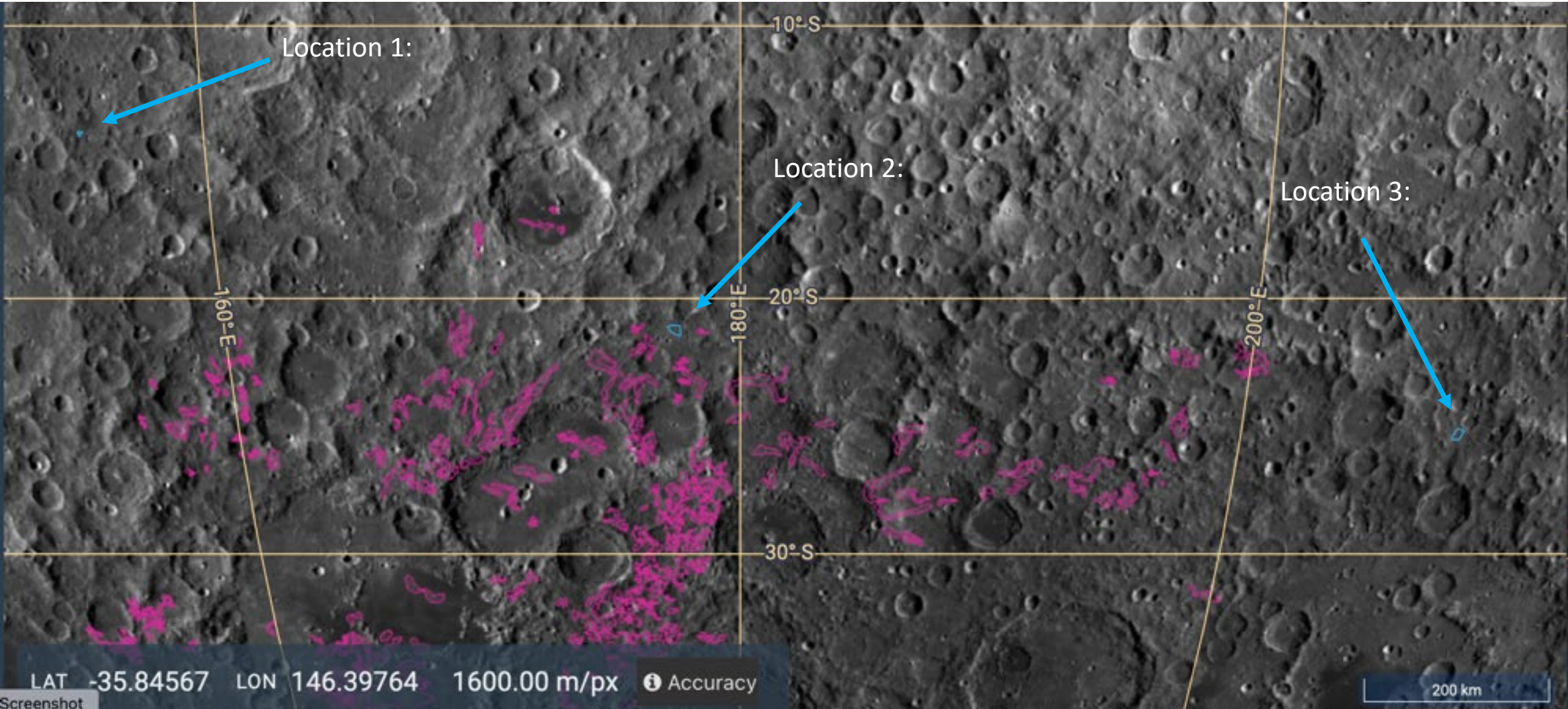
Standalone system

- Instrument electronics
- Battery
- Comms (JPL/Vulcan User Terminal)
- PRISM FSS-like (JPL PALETTE) thermal design

On CS-3 CLPS mission with ESA Lunar Pathfinder Relay

- CY 2025 landing
  - Outer planets
- Lander will **DIE** after commissioning
  - No spacecraft EMI!
- Landing site under study
  - Mid-latitudes
  - Farside
  - Slightly south?

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



Conclusions

- **LuSEE Lite is ready to be integrated at SSL/Berkeley**
  - Delivery ‘in place’ this year and to a CP-12 lander once selected
  - Delivery to Schroedinger Basin (South pole) in CY 2024.
  - Lunar surface plasma physics, ionosphere, dust, and support for E/M subsurface sounding

- **LuSEE Night is in active development in partnership with DOE**
  - Brookhaven National Lab and Lawrence Berkeley Lab under DOE MIE
  - CS-3 lander to the lunar farside, mid-latitudes in 2025 – manifested with ESA Lunar Pathfinder
  - Radio astrophysics/cosmology pathfinder
    - Quiet corona, galactic foreground, discrete sources and outer planets, cosmology
    - 50 MHz bandwidth Stokes polarization measurements
    - Antenna modeling work in progress
    - Thermal design (w/ JPL) in progress