RADIO SCIENCE FROM THE MOON ENABLED BY NASA COMMERCIAL LANDERS

Jack Burns, University of Colorado Boulder
on behalf of the *ROLSES, LuSEE, DAPPER* & *FARSIDE* teams

Using Commercial Lunar Payload Services to Achieve Lunar Biological and Physical Science Objectives

24 March 2021

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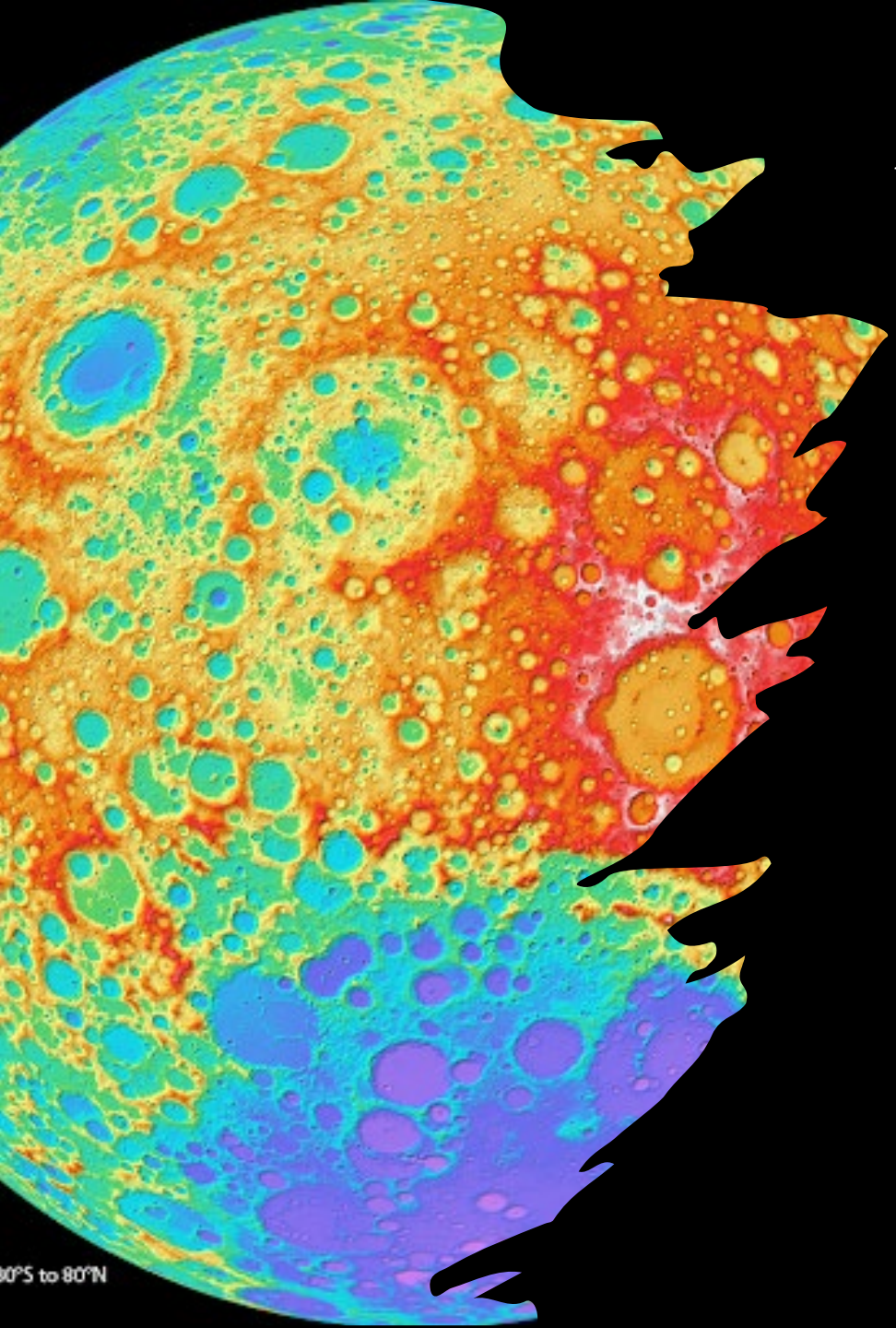
Burns et al., 2021, *Low Radio Frequency Observations from the Moon Enabled by NASA Landed Payload Missions*, Planetary Science Journal, 2:44, April 2021.

Compelling astrophysics that uniquely requires low frequency observations from the lunar farside

The Dark Ages

Magnetospheres and Space Environments of Habitable Planets

Burns, J.O. 2021, *Transformative Science from the Lunar Farside: Observations of the Dark Ages and Exoplanetary Systems at Low Radio Frequencies,* Phil. Trans. A Royal Society, 378, 20190564.



Access to the lunar farside provides an unparalleled opportunity to perform low radio frequency astrophysics & cosmology due to the

- unique radio-quiet,
- lack of a significant ionosphere,
- dry, stable environment.

NASA-PROVIDED LUNAR PAYLOAD: ROLSES

Radio wave Observations at the Lunar Surface of the photoElectron Sheath = ***ROLSES***

- Science Goals:
  - determine the photoelectron sheath density from ~1 to ~3 m above the lunar surface.
  - demonstrate detection of solar, planetary, & other radio emission from lunar surface
  - detect dust impacting NOVA-C lander or antennas
  - measure reflection of incoming radio emission from lunar surface and below
  - Measure RFI from terrestrial transmitters
  - Aid development of lunar radio arrays.

- Team: **Robert MacDowall**, William Farrell, Damon Bradley, Nat Gopalswamy, Michael Reiner, Ed Wollack, Jack Burns, David McGlone, Mike Choi, Scott Murphy, Rich Katz, Igor Kleyner

- Status: ROLSES scheduled to land on lunar nearside in Q4 2021 using Intuitive Machines Nova-C

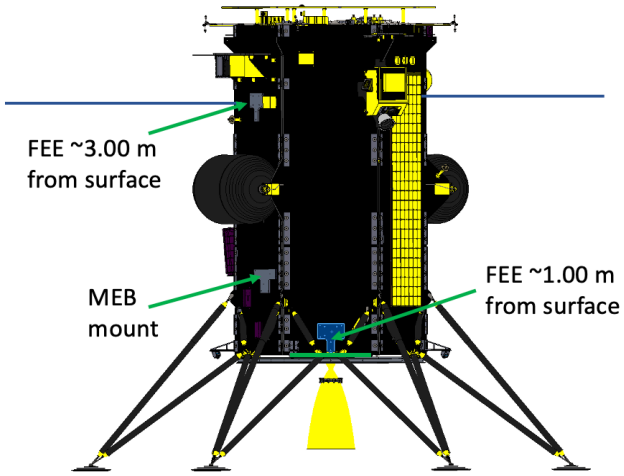


Diagram of the NOVA-C lander that will take the ROLSES payload to the lunar surface in late 2021.

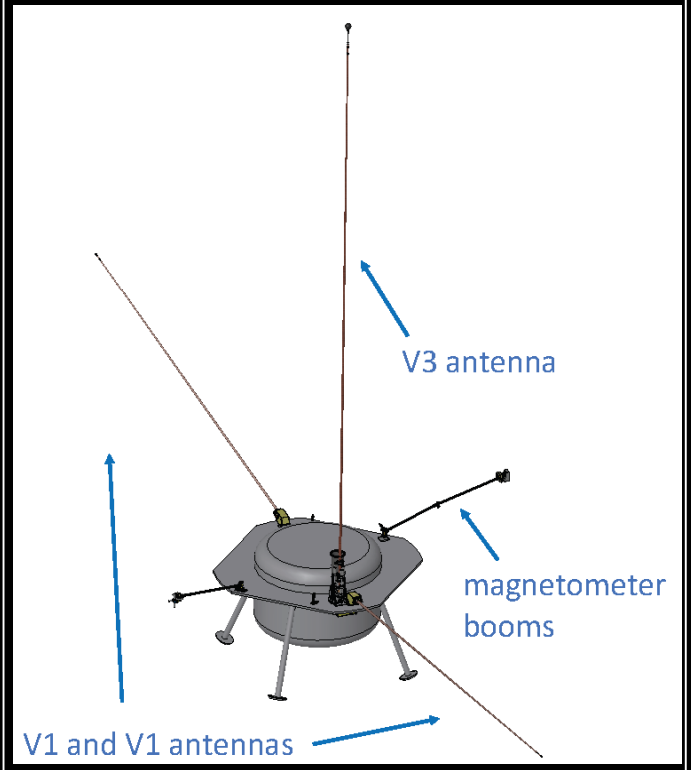
LUNAR SURFACE INSTRUMENT AND TECHNOLOGY PAYLOADS: LuSEE

Lunar Surface Electromagnetics Experiment = **LuSEE**

- Science Goals
  - measure DC electric & magnetic fields, including plasma waves
  - measure electrostatic signatures of dust impacts
  - measure radio emissions from the Sun, Earth and outer planets
  - address the interaction of the lunar surface with the solar wind
  - probe the structure and dynamics of the tenuous lunar exosphere

- Team: **Stuart Bale**, John Bonnell, Jack Burns, Jasper Halekas, Milan Maksimovic, Andrew Poppe, Marc Pulupa, Arnaud Zaslavsky, Keith Goetz, Robert MacDowall, David Malaspina, Peter Harvey

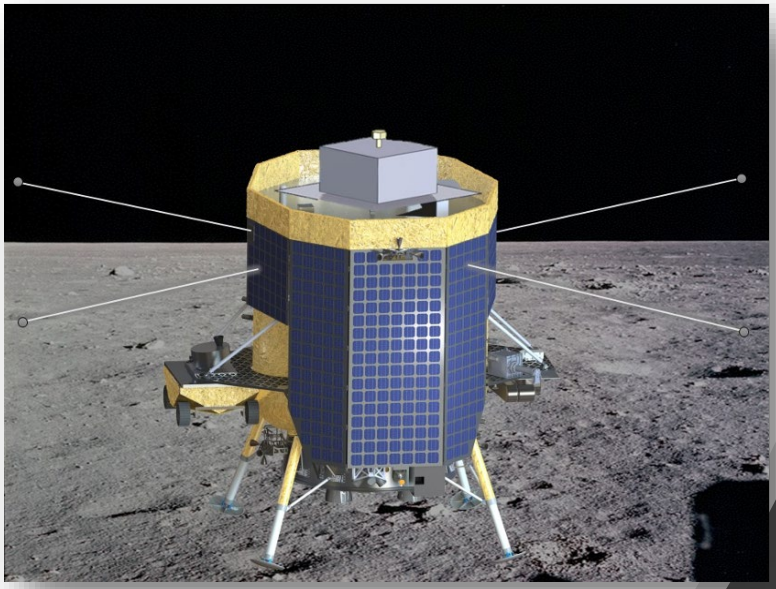
- Status: LuSEE is currently scheduled to land in the Schroedinger impact basin on the lunar farside in Q2 of 2024.



LuSEE sensors are 6-m stacer antennas (V1 & V2) deployed to form a dipole. V3 is a stacer with a spherical voltage probe used to measure the vertical electric field. Fluxgate and search coil magnetometers are mounted on 2-m and 1-m carbon fiber booms, respectively.

LuSEE + DAPPER on a NASA Commercial Lander

DAPPER
The Dark Ages Polarimeter PathfindER



- Artist concept of the DAPPER low radio frequency Patch antenna on the top deck of an Astrobotics Peregrine lander. Also shown are the LuSEE STACER cross-dipole antennas with the planned augmentation.
- Together, the LuSEE-DAPPER telescope suite will make the first cosmological observations from the farside of the Moon within the Schrödinger Basin.
- P.I. J. Burns, Deputy P.I. S. Bale, Instrument Scientist R. Bradley.

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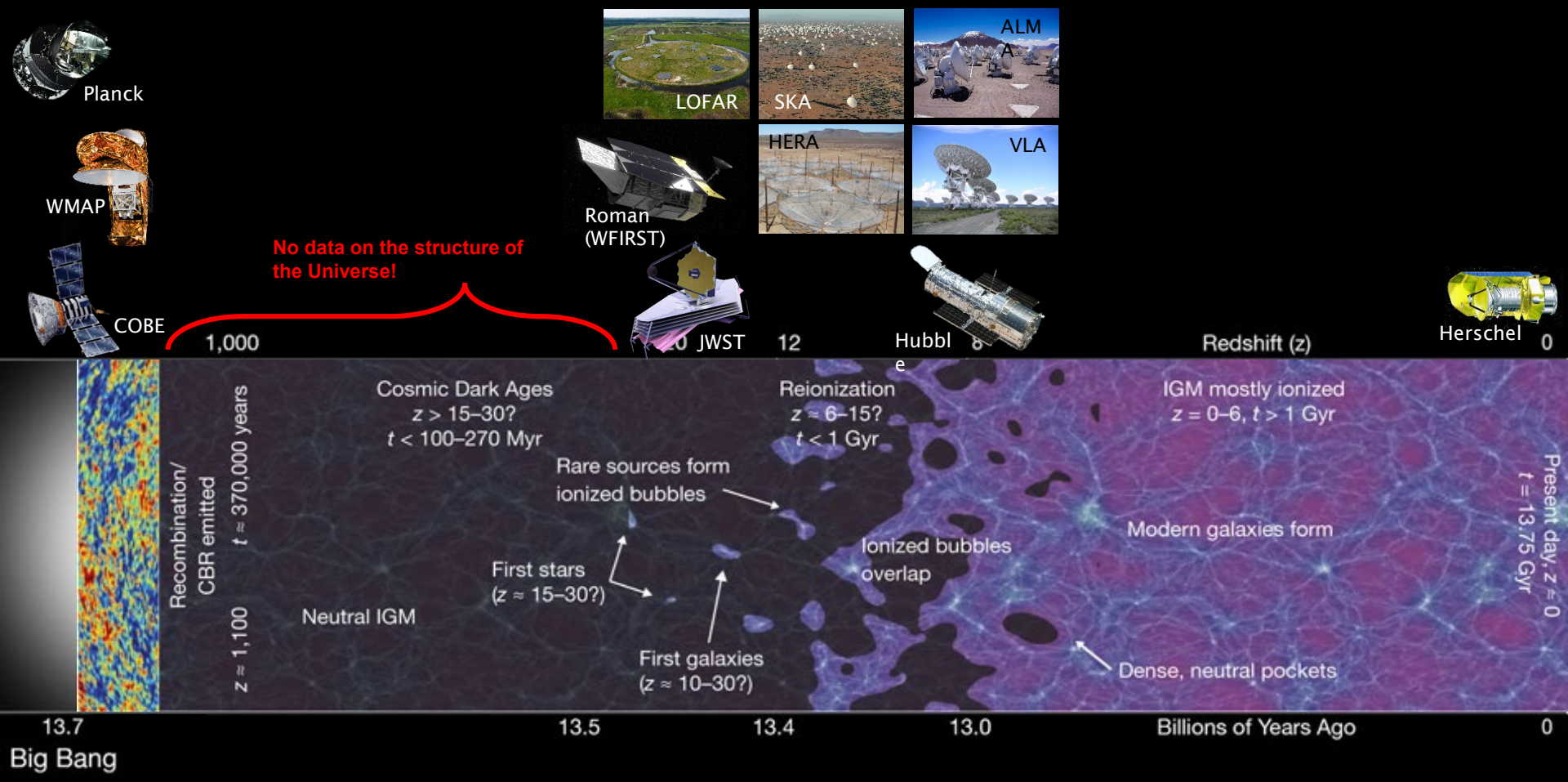
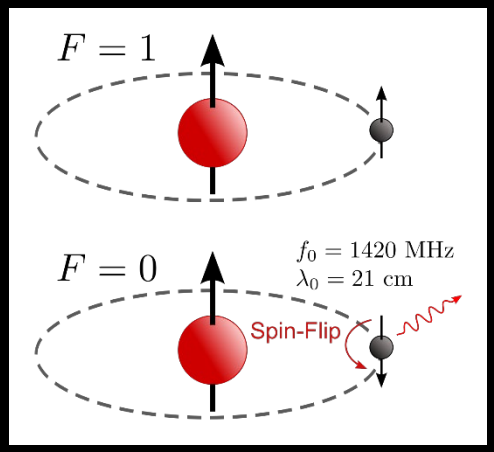
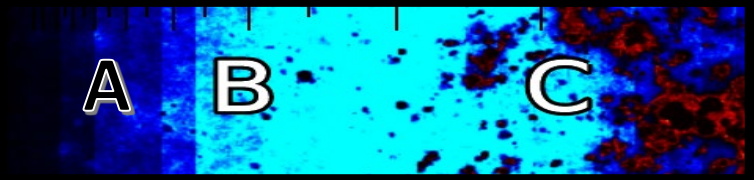
Evolution of the Universe

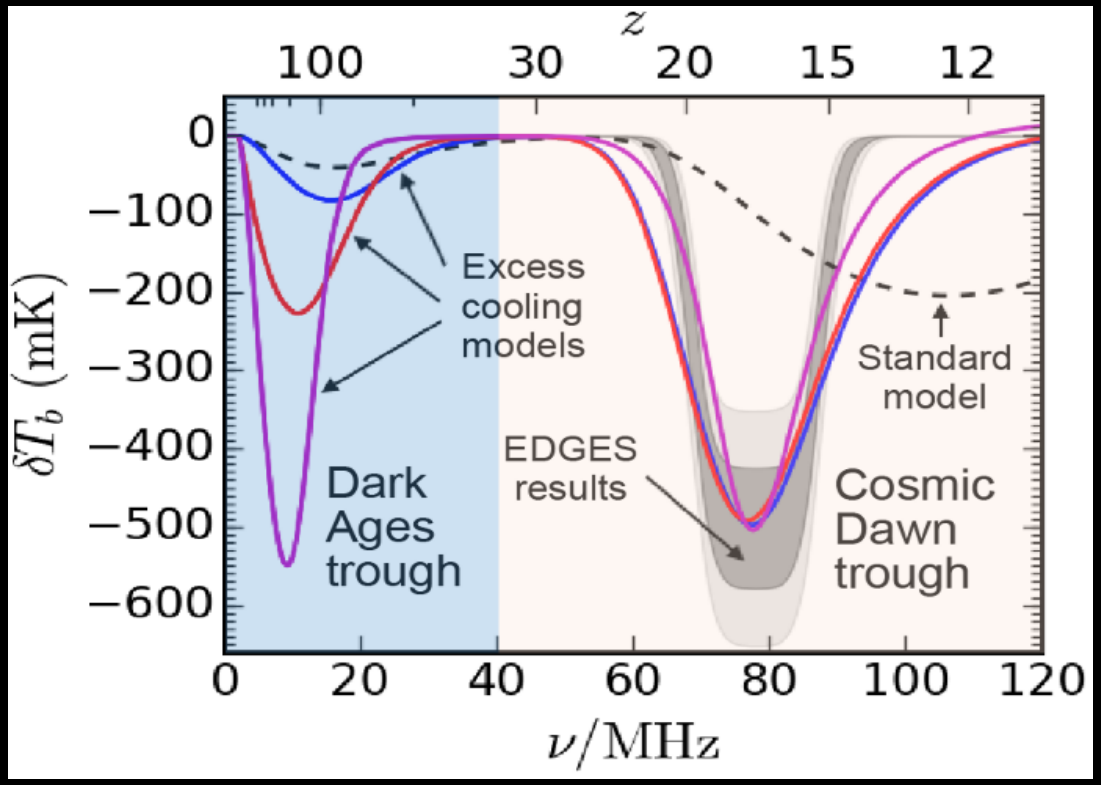


The Global 21-cm signal

Spectral Features







A: Dark Ages: test of standard cosmological model

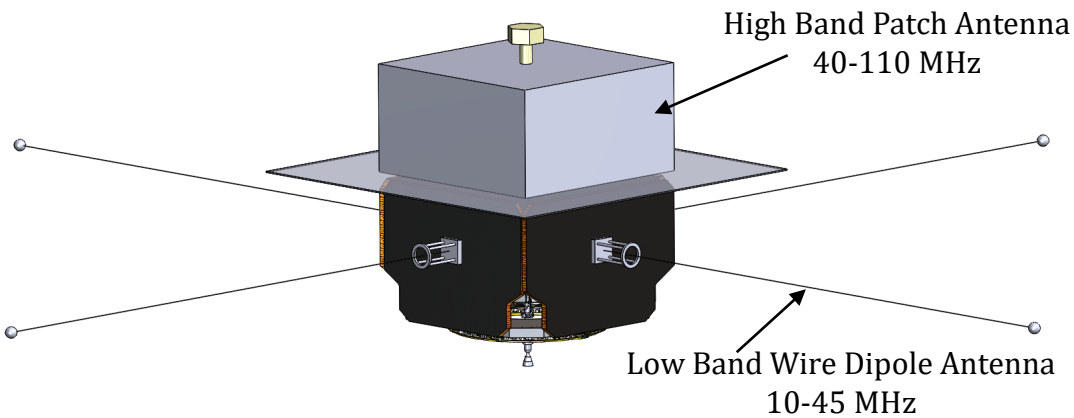
B: Cosmic Dawn: First stars ignite

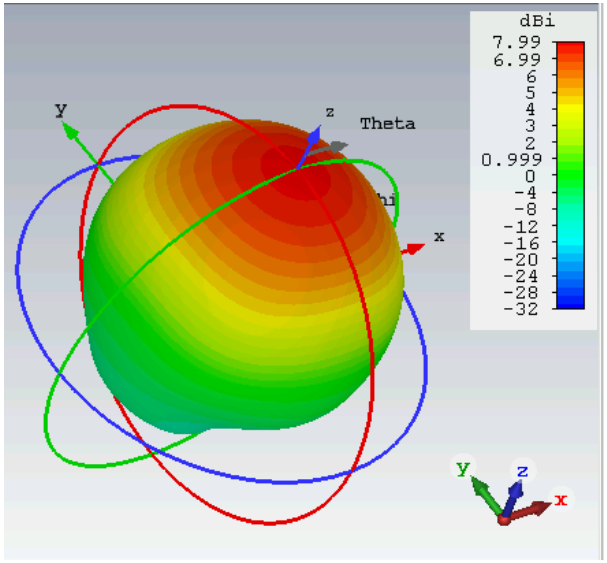
C: Black hole accretion begins

DAPPER

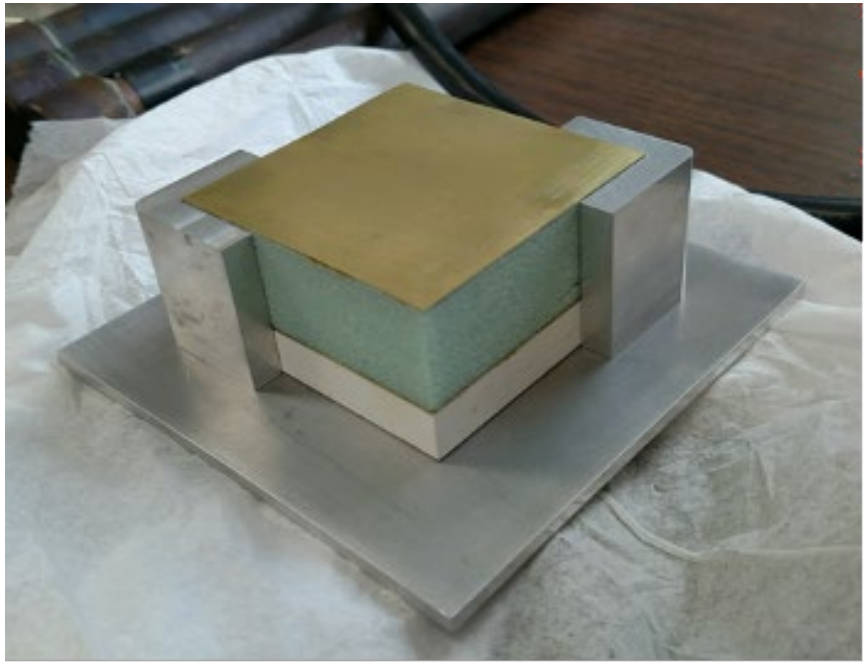
Dark Ages Polarimeter PathfindER

DARK COSMOLOGY:
INVESTIGATING DARK MATTER IN THE DARK AGES





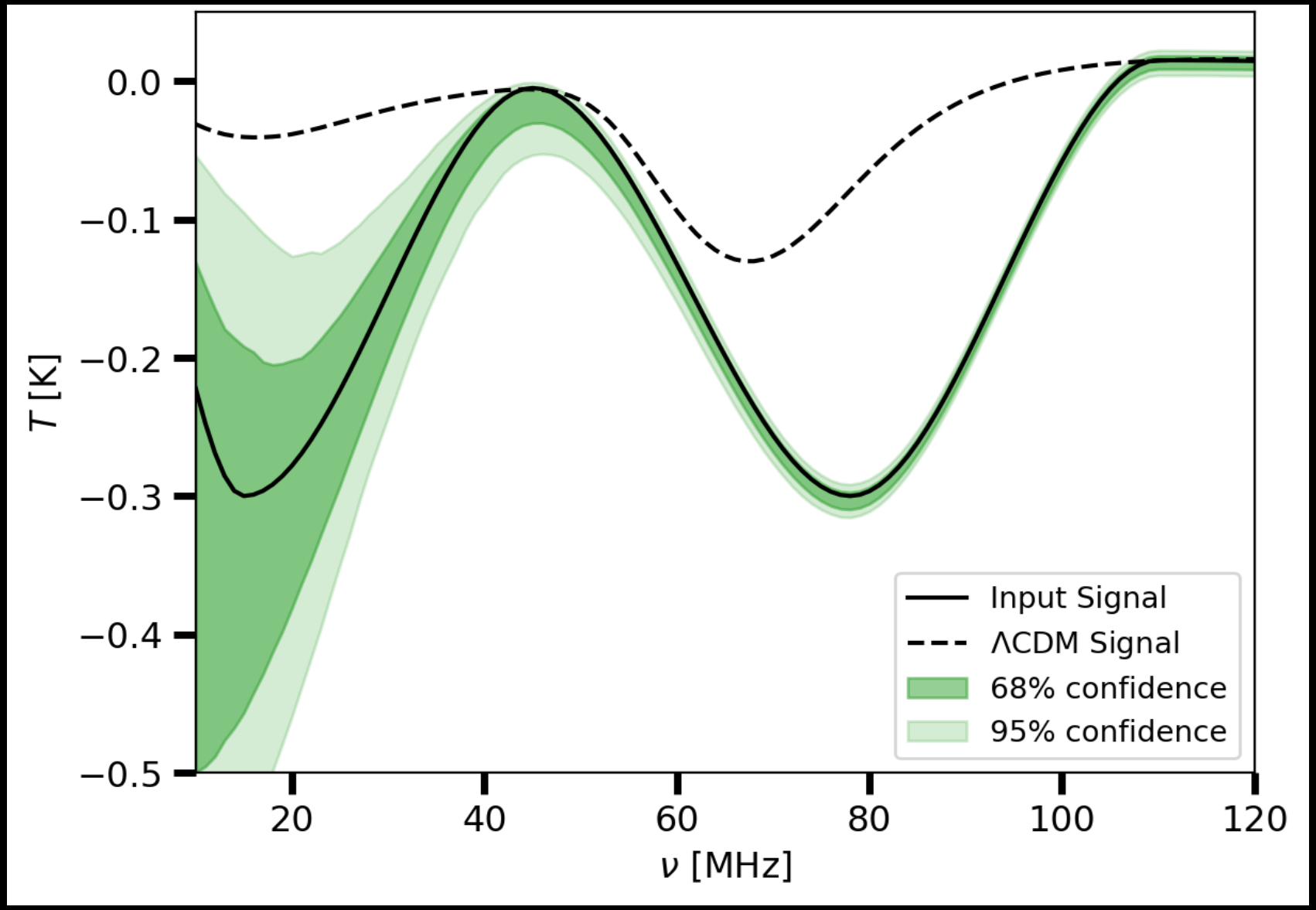
Patch antenna beam at 75 MHz.



This 1/15th-scale Patch antenna is a stacked structure with two square pieces of thin brass sheet stock separated by dielectric materials. Coaxial radio frequency connections are attached under the base, with the center conductor extending through the lower dielectric and bonded to the central metal sheet.

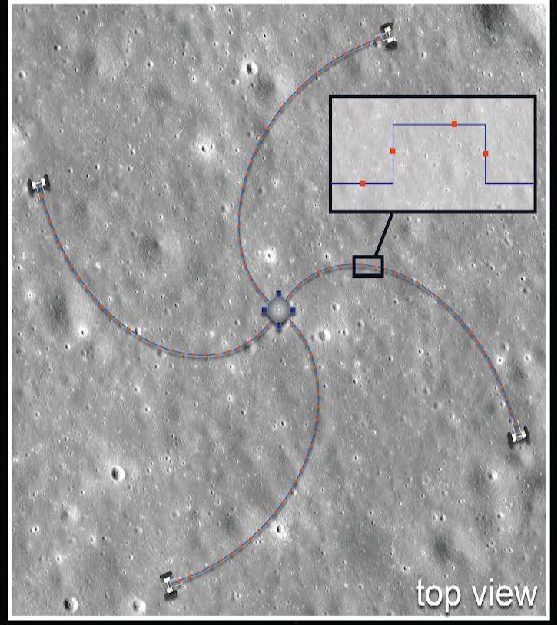
Image: R. Bradley, NRAO

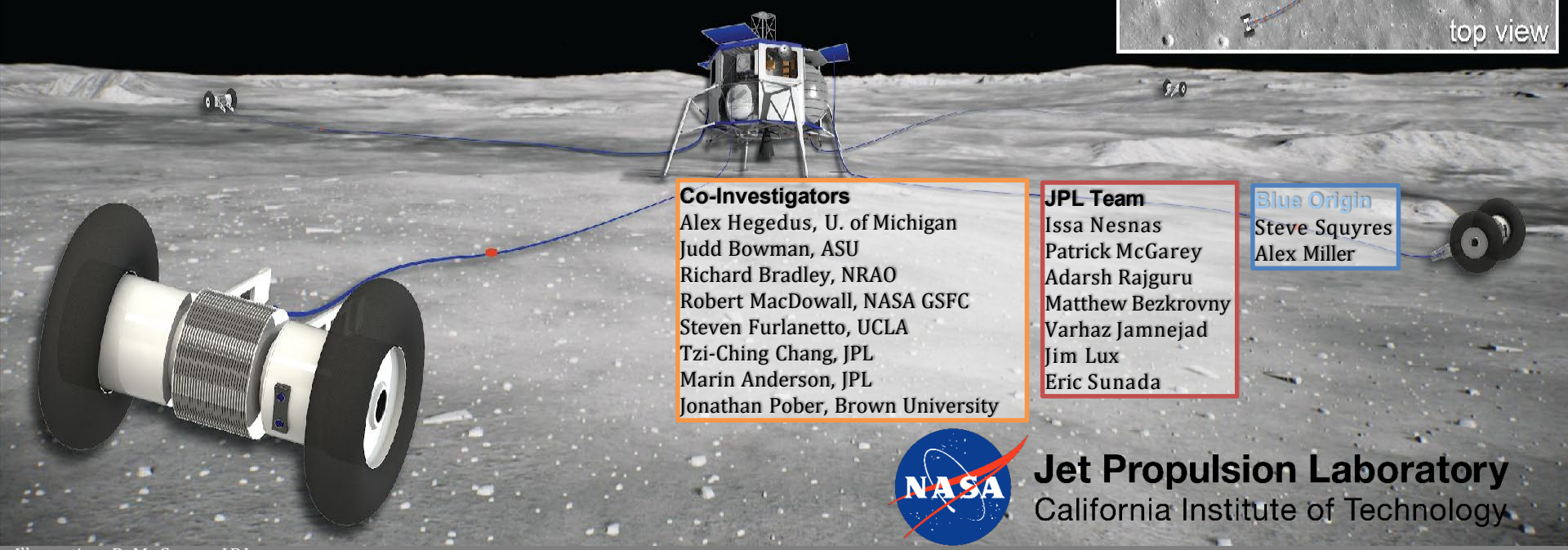
LuSEE + DAPPER constraints



FARSIDE: Farside Array for Radio Science Investigations of the Dark ages and Exoplanets

Principal Investigator: Jack Burns, University of Colorado Boulder
Deputy P.I.: Gregg Hallinan, Caltech
Study Lead: Lawrence Teitelbaum, JPL





Co-Investigators
Alex Hegedus, U. of Michigan
Judd Bowman, ASU
Richard Bradley, NRAO
Robert MacDowall, NASA GSFC
Steven Furlanetto, UCLA
Tzi-Ching Chang, JPL
Marin Anderson, JPL
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JPL Team
Issa Nesnas
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Varhaz Jamnejad
Jim Lux
Eric Sunada

Blue Origin
Steve Squyres
Alex Miller

Jet Propulsion Laboratory
California Institute of Technology

Illustration: P. McGarey, JPL

This presentation has been reviewed and determined not to contain export controlled technical data.

Burns, MacDowall, Bale, Hallinan, Bassett, Hegedus, 2021, *Low Radio Frequency Observations from the Moon Enabled by NASA Landed Payload Missions,* Planetary Science Journal, 2:44, arXiv:2102.02331

Low Frequency Radio Emission

Credit: Chuck Carter / Caltech / KISS

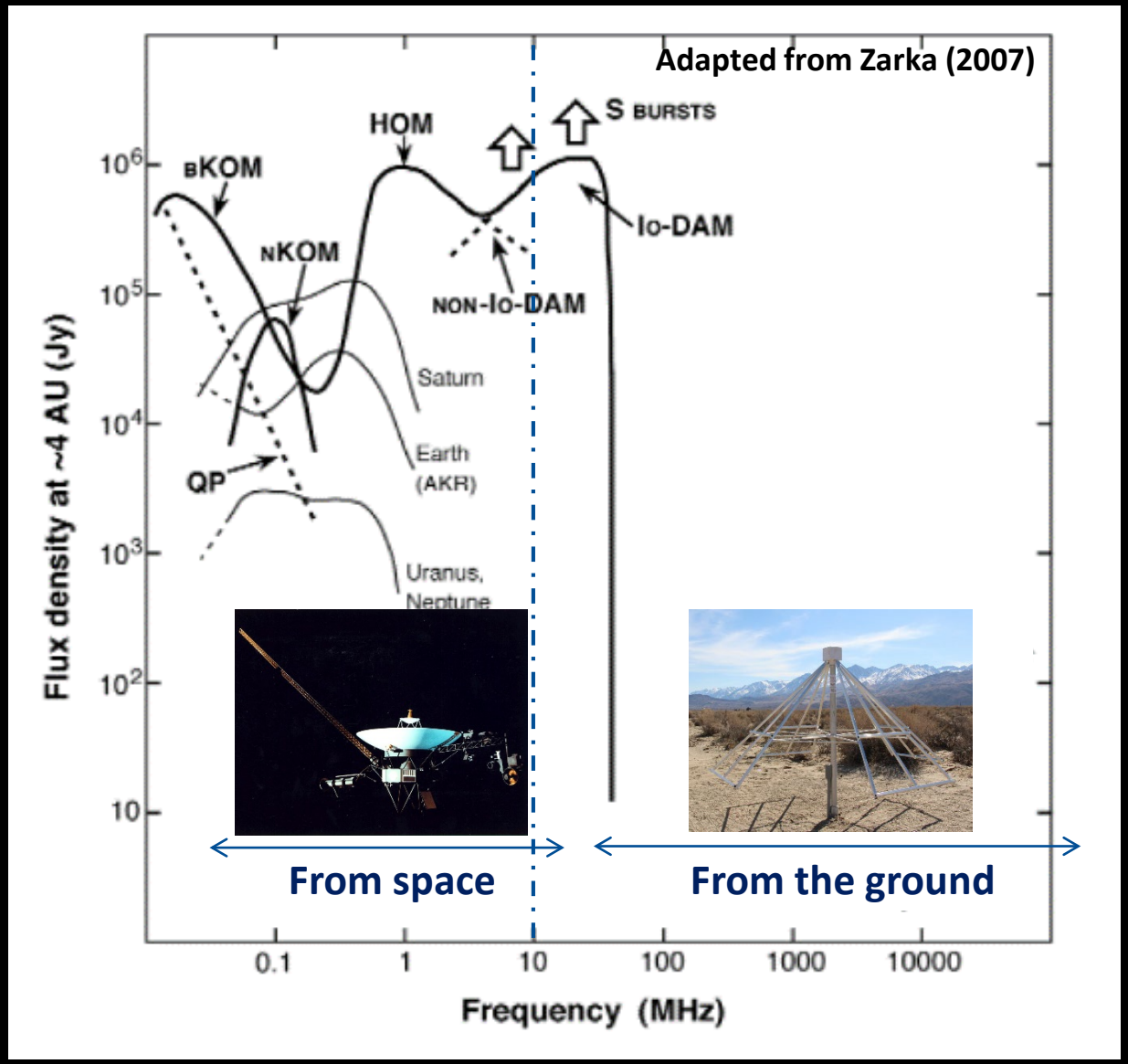
Type II radio bursts
traces density at CME shock

Auroral radio emission
measures magnetic fields

Why Low Frequencies?

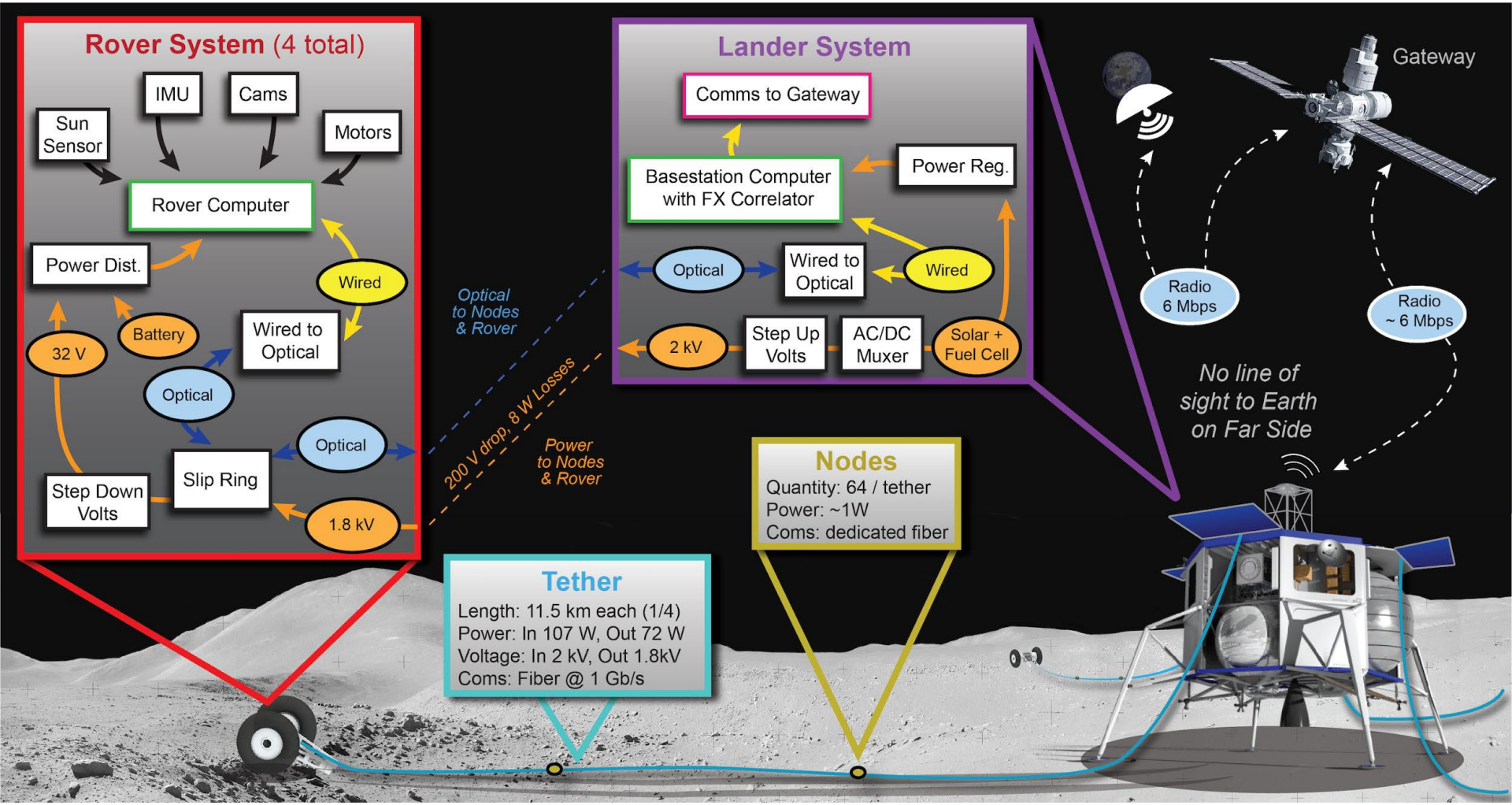
Electron cyclotron maser emission

Frequency (MHz) = B_{Gauss} x 2.8



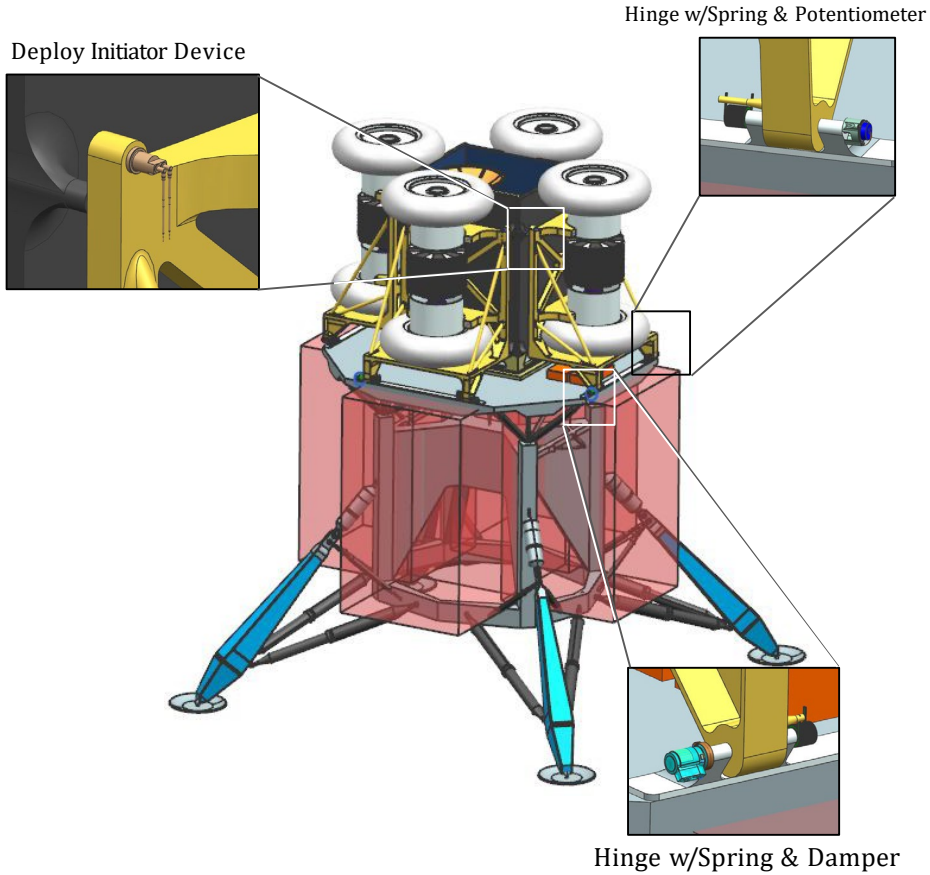
FARSIDE Mission Architecture

Frequencies: 100 kHz to 40 MHz

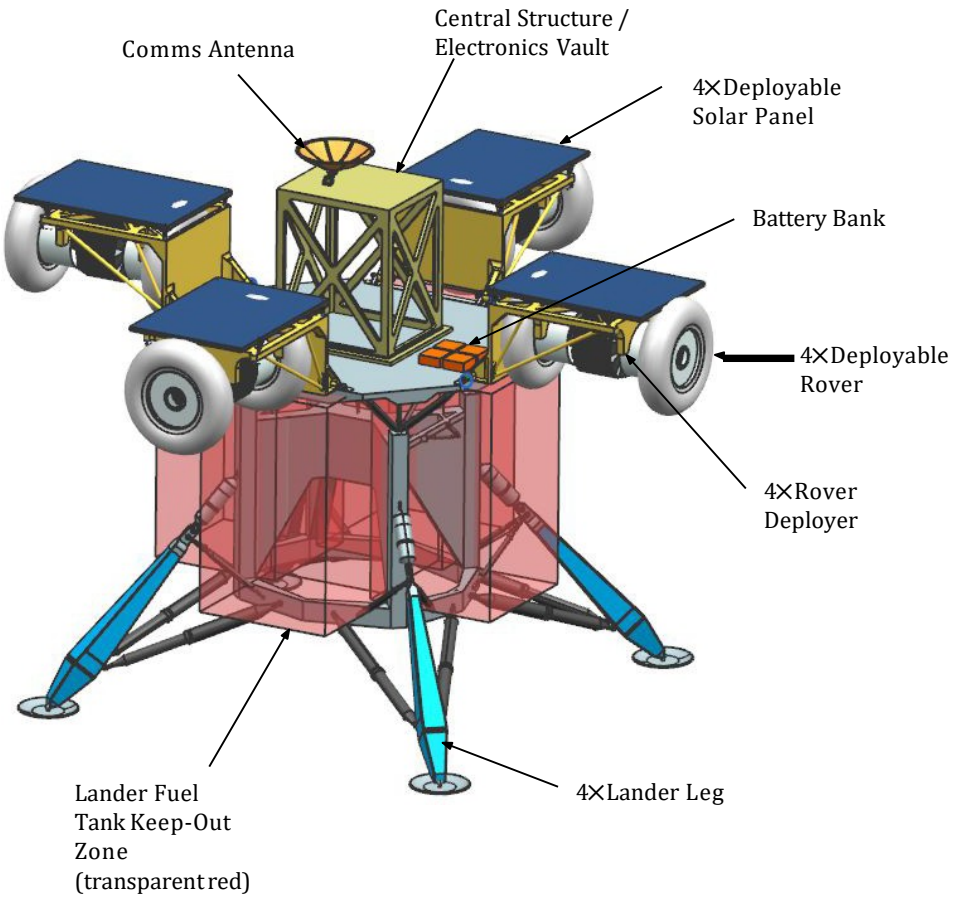


Lander/Rover Configuration Overview

Stowed/Landing Configuration



Mid-Deploy Configuration



Design Strategy

Node Sizing

↓

Node / Tether Integration

↓

Spool Deployment Strategy

↓

Spool Sizing

↓

Rover Design

↓

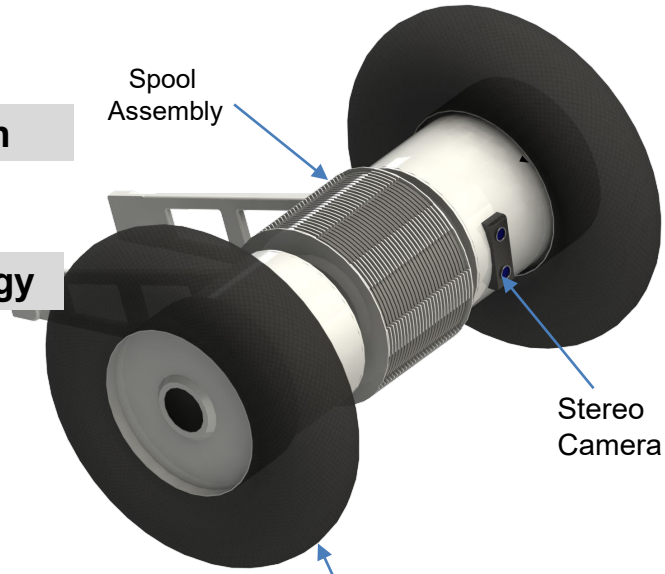
Egress Strategy

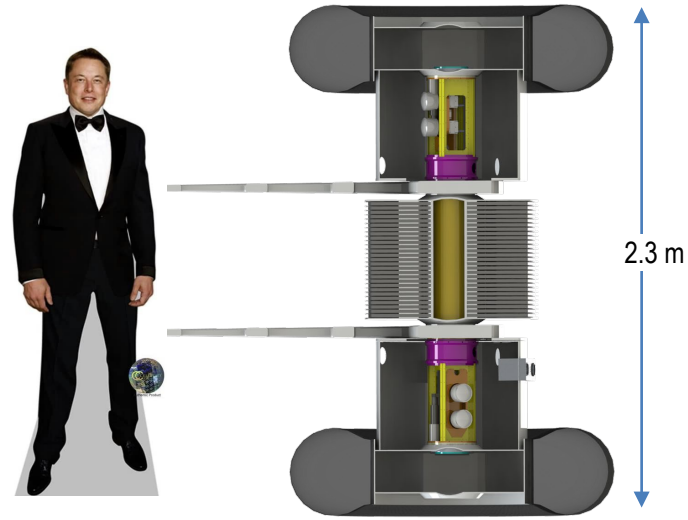
↓

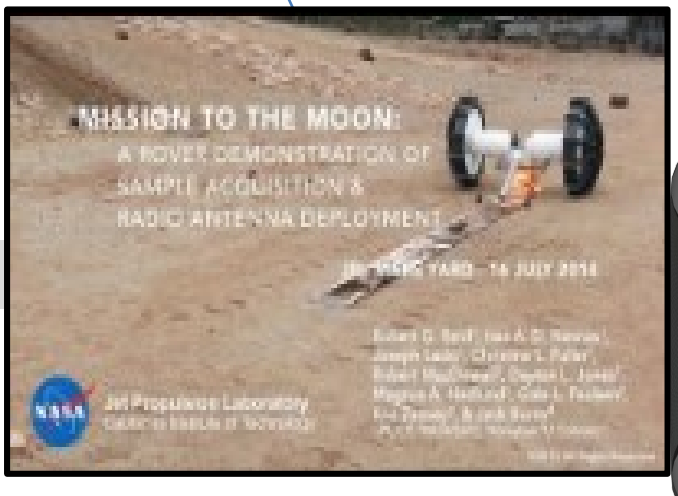
Lander Accommodations

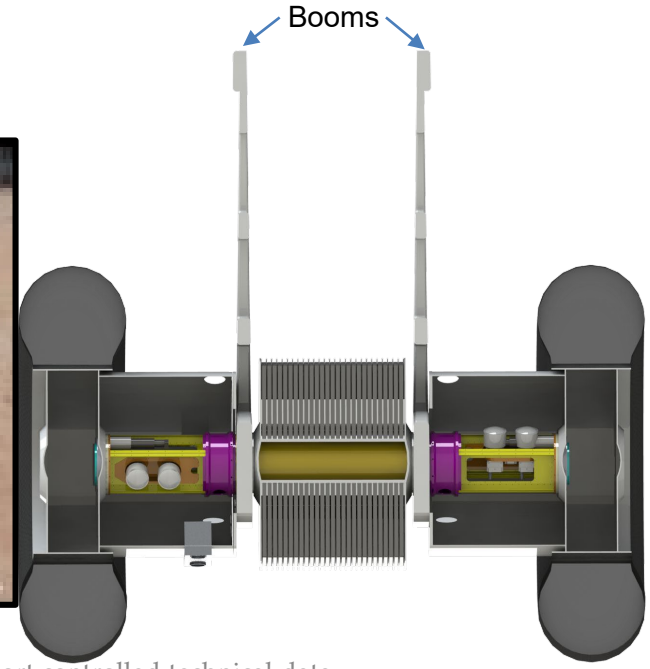
↓

Lander Configuration









FARSIDE Science Cases

Imaging Type II/III Solar Radio Bursts

Auroral Radio Emissions from Saturn, Uranus, & Neptune; lightning; Planet 9?

Magnetospheres & Space Weather Environments of Habitable Exoplanets

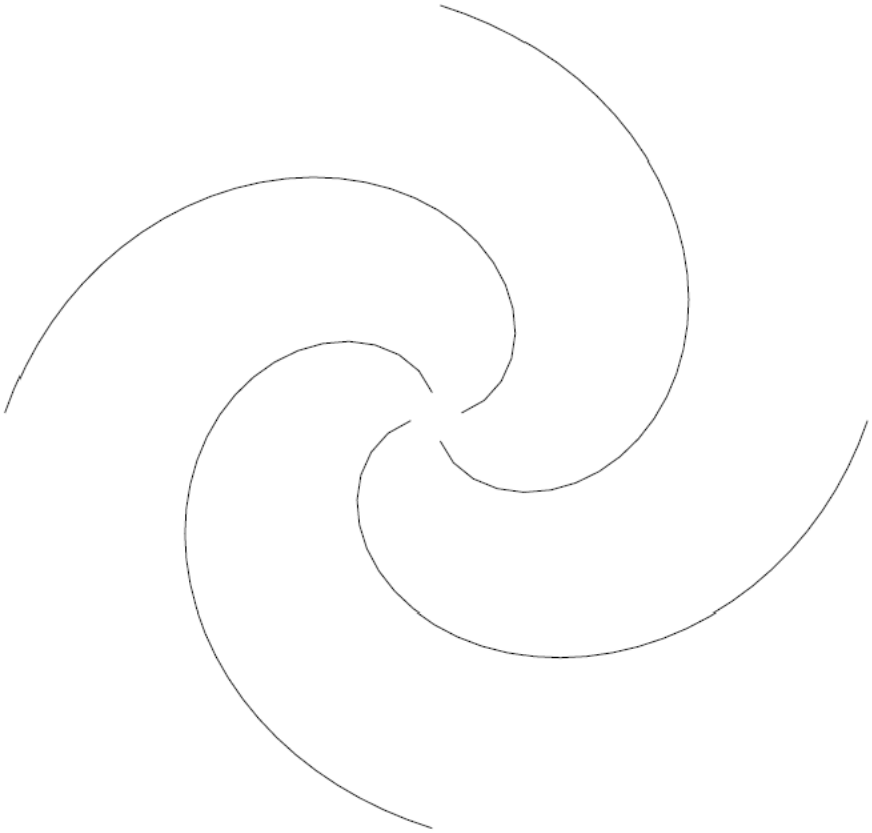
Sounding of the Lunar Subsurface

Measuring farside lunar quakes with Distributed Acoustic Sensing.

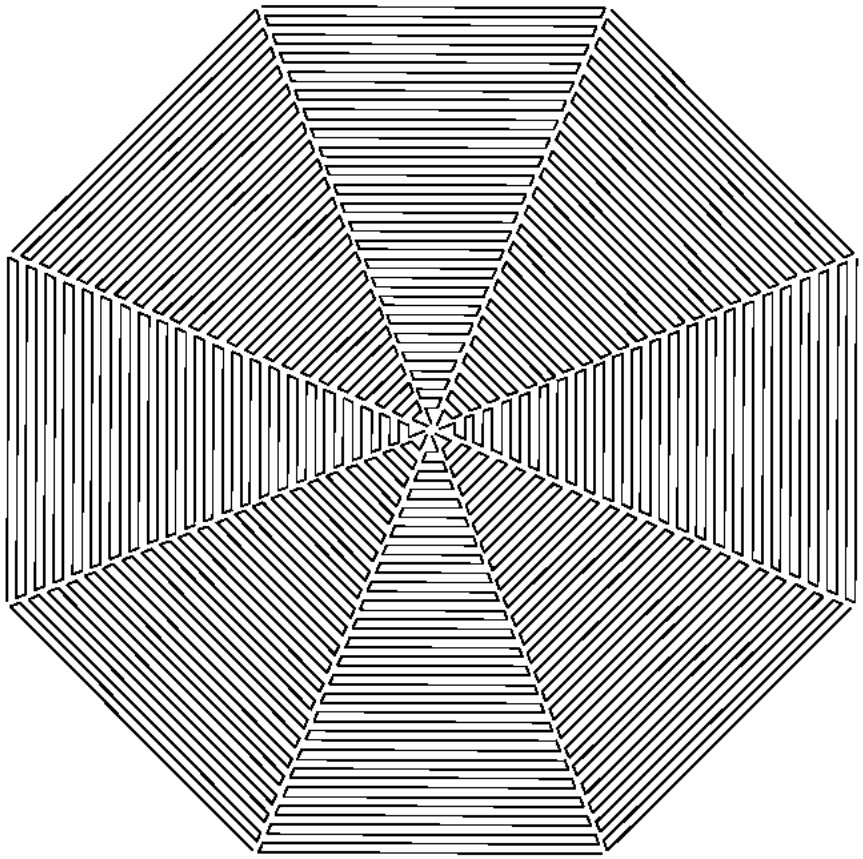
Tomography of the ISM

Dark Ages Hydrogen Cosmology

FarView: A radio array of 100,000 dipoles



FARSIDE
128 dual polarized antennas - 100m per polarization
4 rovers - 8.9 km per rover



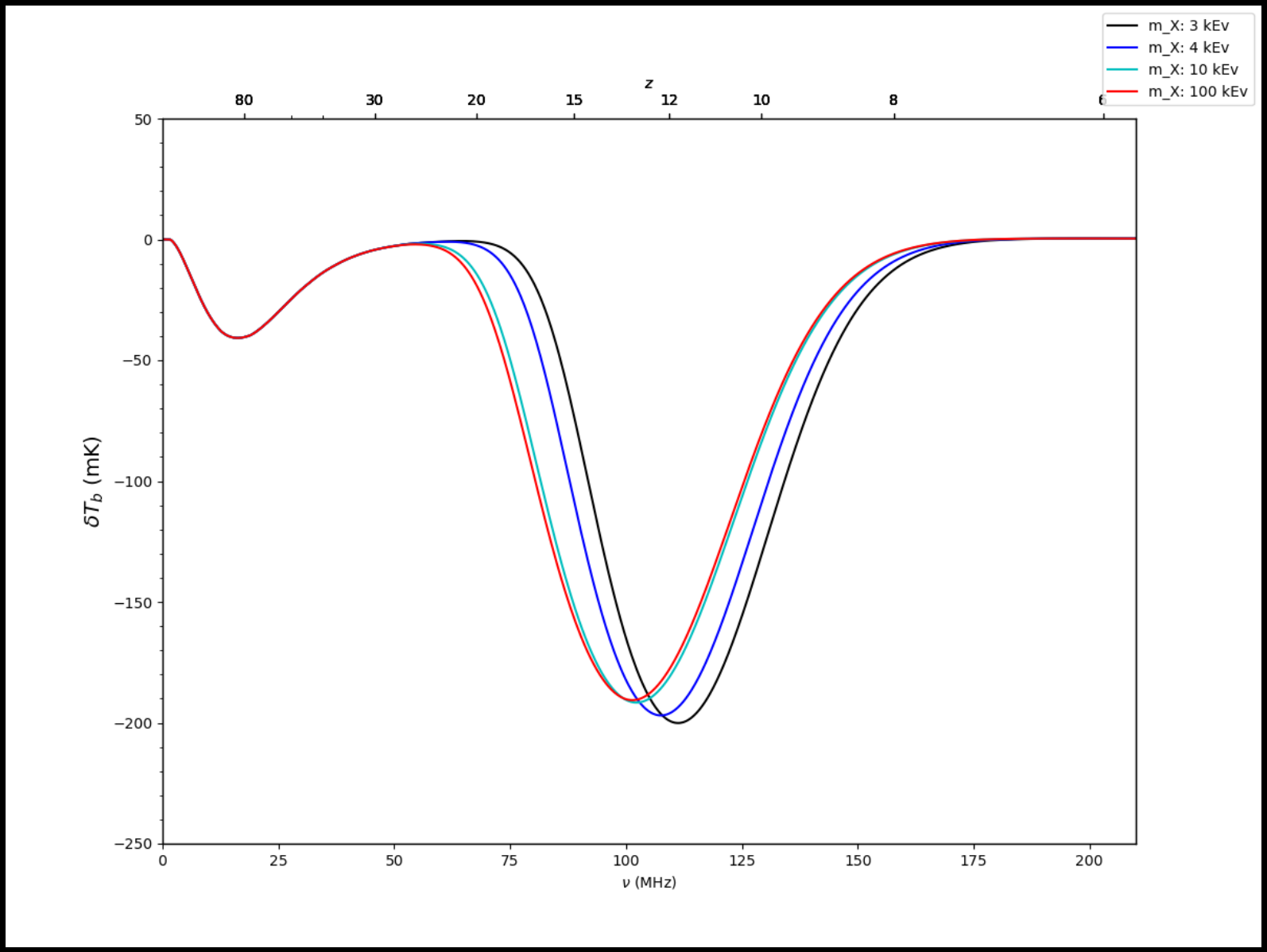
Farview
100,000 dual polarized antennas - 5m per polarization
8 rovers - 125 km per rover

NIAC P.I. Ron Polidan, Lunar Resources,
Co-Is: J. Burns, E. Carol, A. Ignatiev

Summary & Conclusions

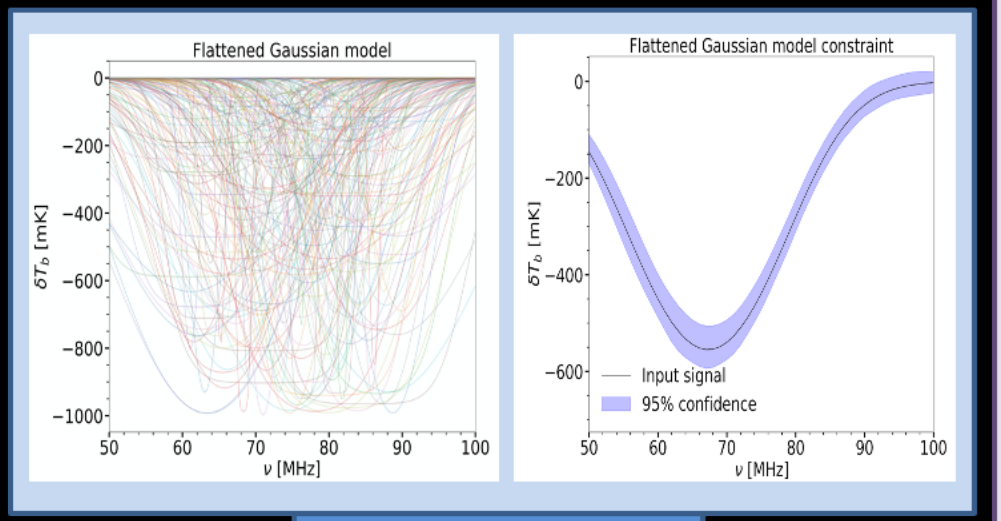
- NASA, ESA, & other space agencies are committed to new explorations of the Moon in this decade.
- NASA Commercial Lunar Payload Services (CLPS) program will deliver science payloads to the surface of the Moon beginning in Q4 2021.
- DAPPER and FARSIDE will take advantage of the transportation and communication infrastructure associated with NASA's Artemis.
- DAPPER will make first observations of the Dark Ages using the highly redshifted 21-cm signal.
- FARSIDE will detect radio bursts from CMEs for stars out to 25 pc & measure exoplanet B-fields using AKR energized by space weather.

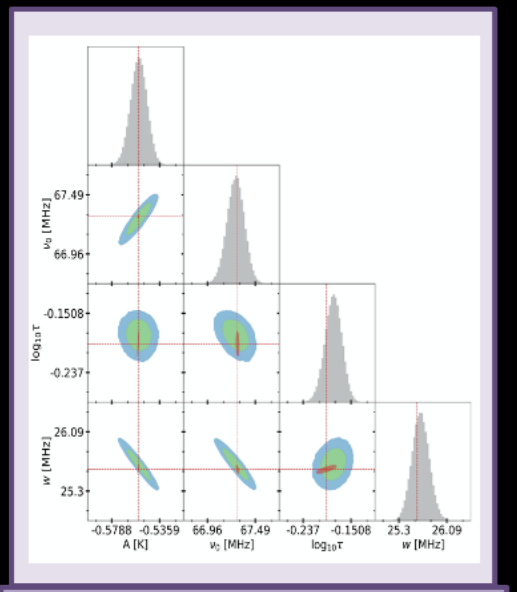
Warm vs. Cold Dark Matter



DAPPER Data Analysis Pipeline

Observation strategy: time dependence and polarization, as discussed in Paper III





Observed or synthetic data

Frequency space signal fitting using model sets following the method of Paper I

Parameter space signal fitting via MCMC sampling as described in Paper II

Paper I – Tauscher, Rapetti, Burns, Switzer, 2018, ApJ, 853, 187.
Paper II – Rapetti, Tauscher, Mirocha, Burns, 2020, ApJ, 897, 174.
Paper III – Tauscher, Rapetti, Burns, 2020, ApJ, 897, 175.

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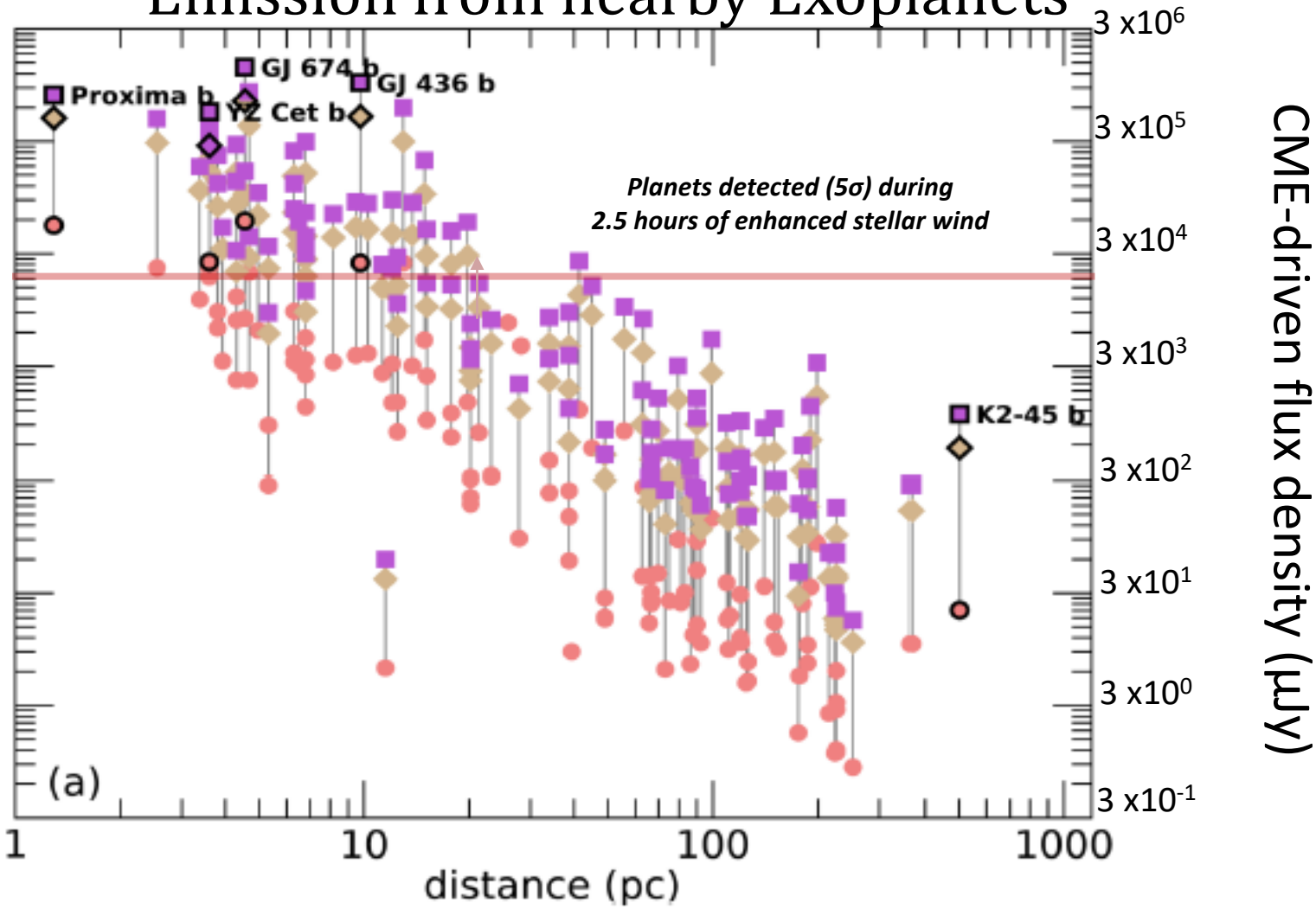
Projected Detections of Auroral Radio Emission from nearby Exoplanets



Adapted from Vidotto et al. 2019