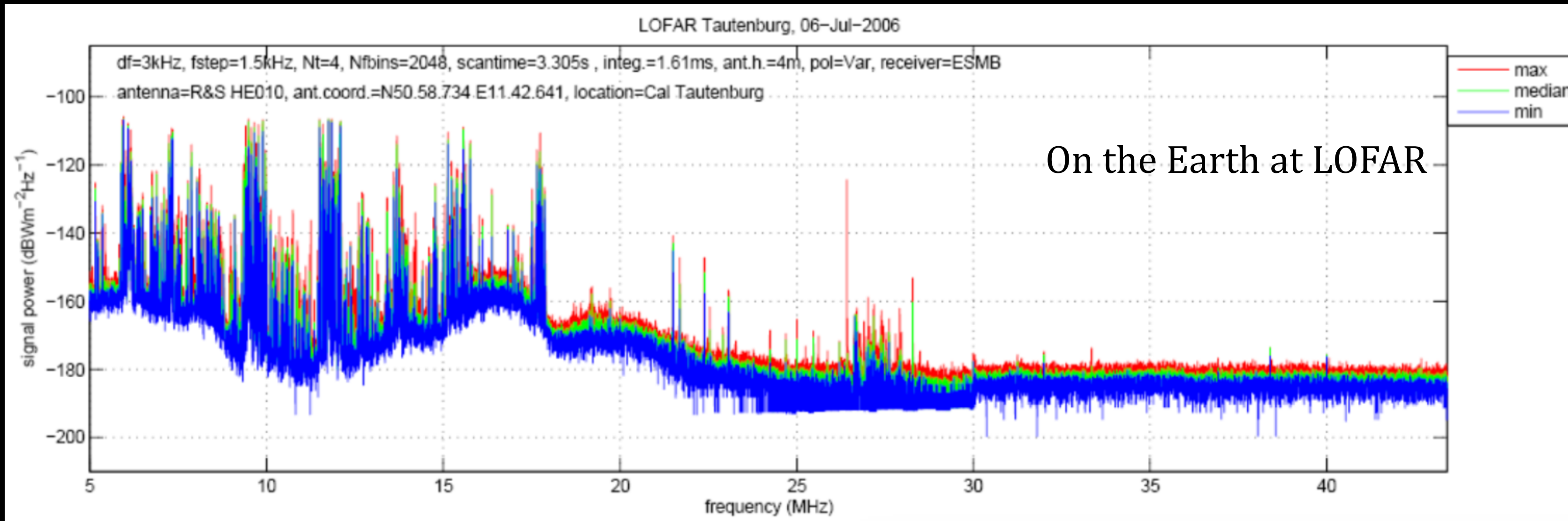
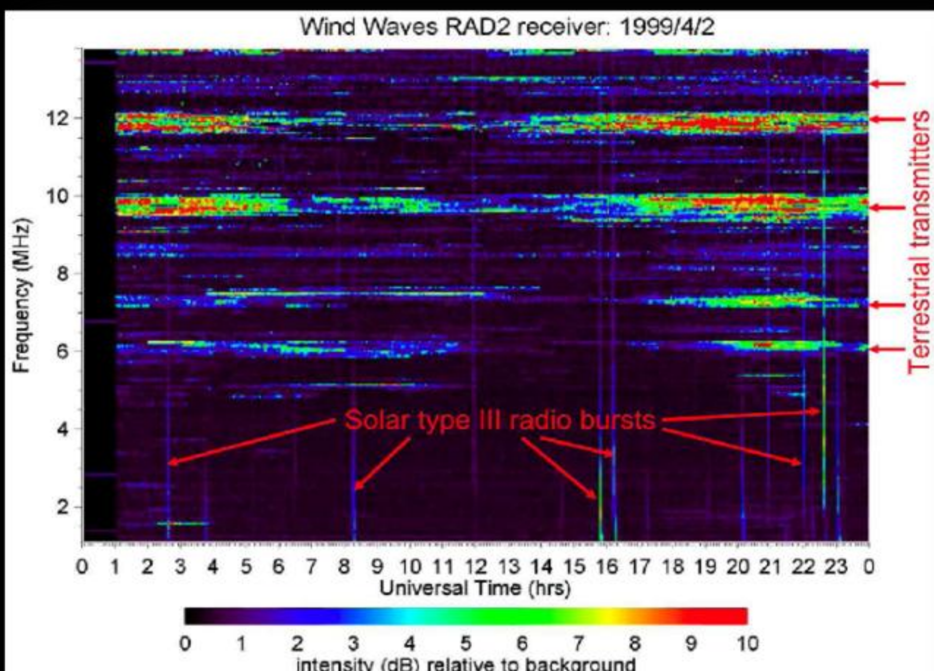
LOW RADIO FREQUENCY OBSEVATIONS FROM THE FARSIDE OF THE MOON

Jack Burns, University of Colorado

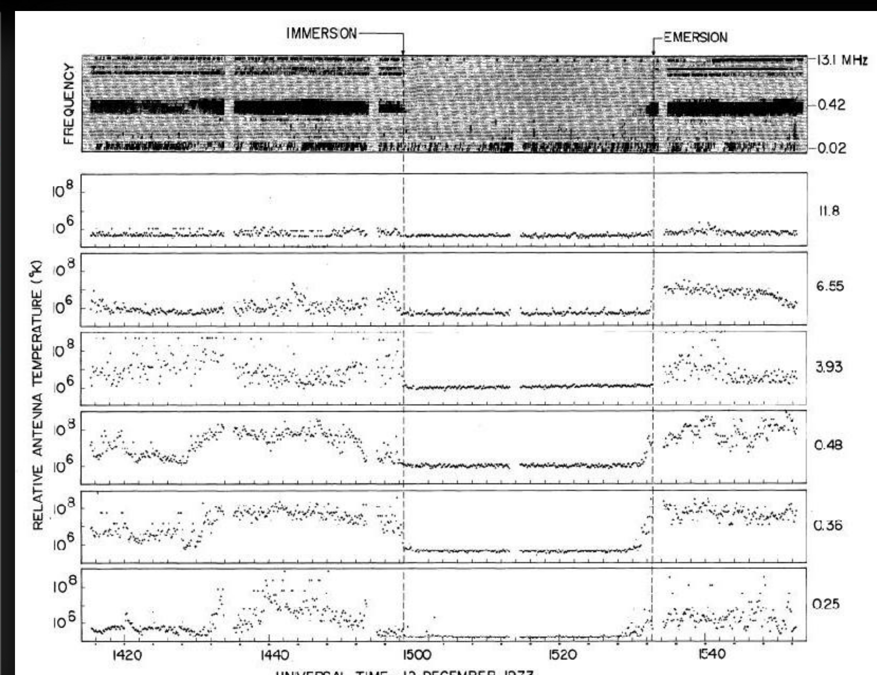
Moon Farside Negotiations Teleconference, 25 March 2020

The radio-frequency environment



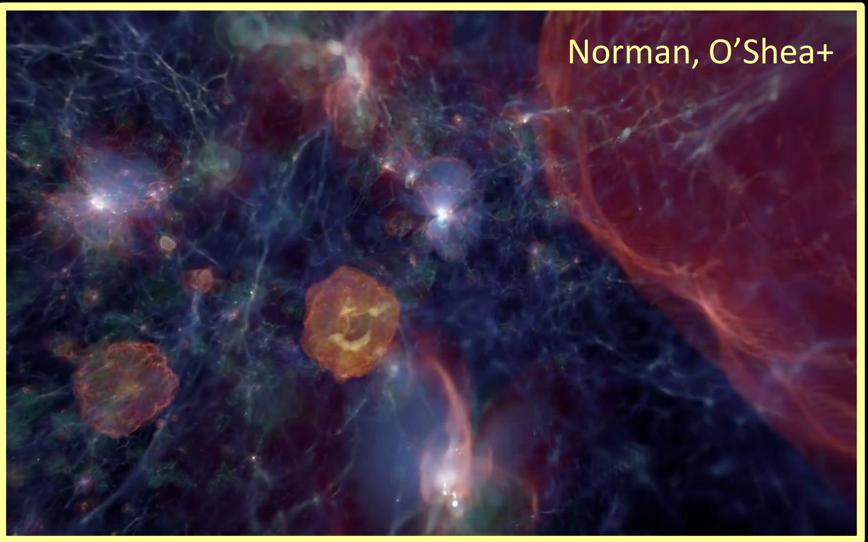


Wind/Waves data near the Moon in 1999



NASA RAE-2 occultation of Earth in 1972

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



The Dark Ages

Magnetospheres and Space Environments of Habitable Planets

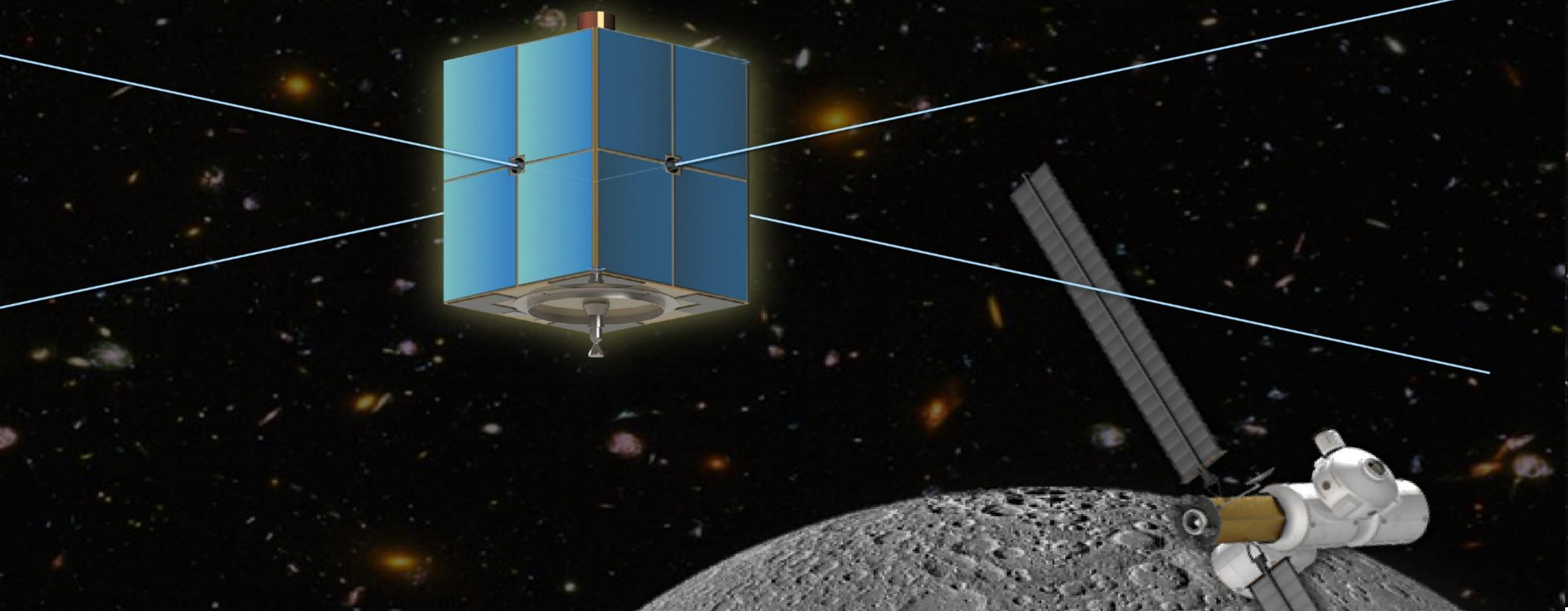
DAPPER

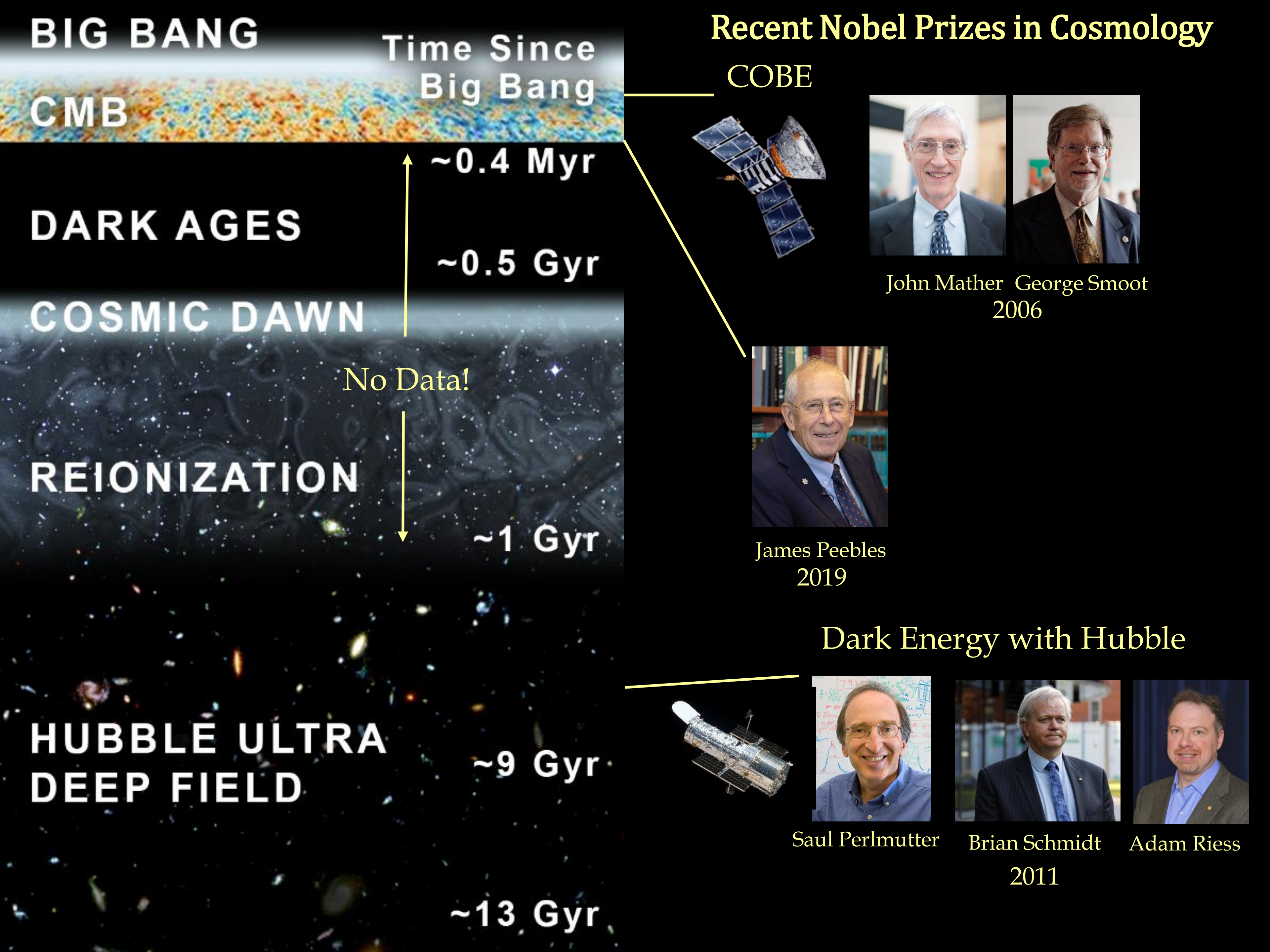
The Dark Ages Polarimeter PathfindER

Principal Investigator:
Dr. Jack Burns, University of Colorado Boulder

Co-Investigators:
Dr. Stuart Bale, University of California at Berkeley
Dr. Richard Bradley, National Radio Astronomy Observatory

NASA Lead Center:
NASA Ames Research Center




Recent Nobel Prizes in Cosmology
BIG BANG
CMB
Time Since Big Bang
~0.4 Myr
DARK AGES
~0.5 Gyr
COSMIC DAWN
No Data!
REIONIZATION
~1 Gyr
HUBBLE ULTRA DEEP FIELD
~9 Gyr
~13 Gyr
COBE
John Mather
George Smoot
2006
James Peebles
2019
Dark Energy with Hubble
Saul Perlmutter
Brian Schmidt
Adam Riess
2011

DAPPER

Dark Ages Polarimeter PathfindER

DARK COSMOLOGY: INVESTIGATING DARK MATTER IN THE DARK AGES

SCIENCE

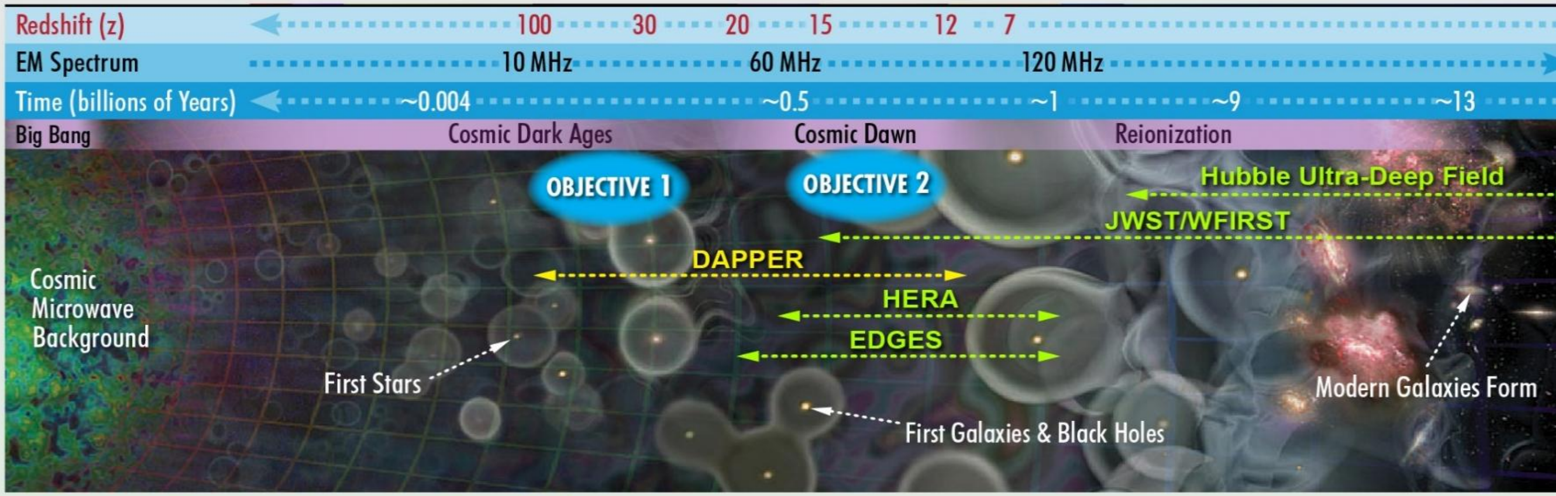
OBJECTIVE 1:

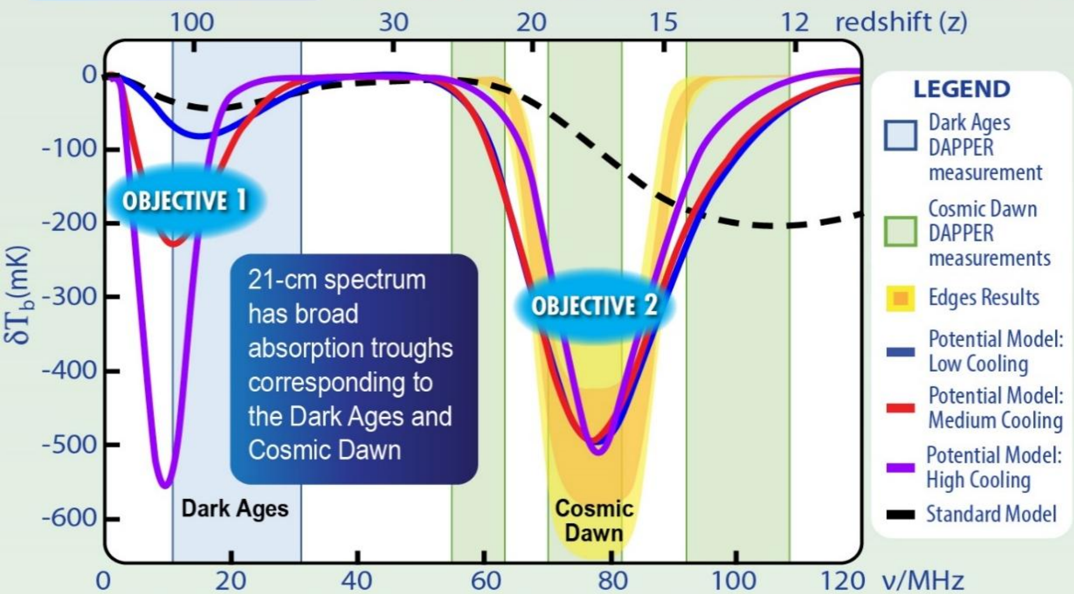
- Determine the level of (dis)agreement with the standard cosmological model caused by dark matter in the Dark Ages.

OBJECTIVE 2:

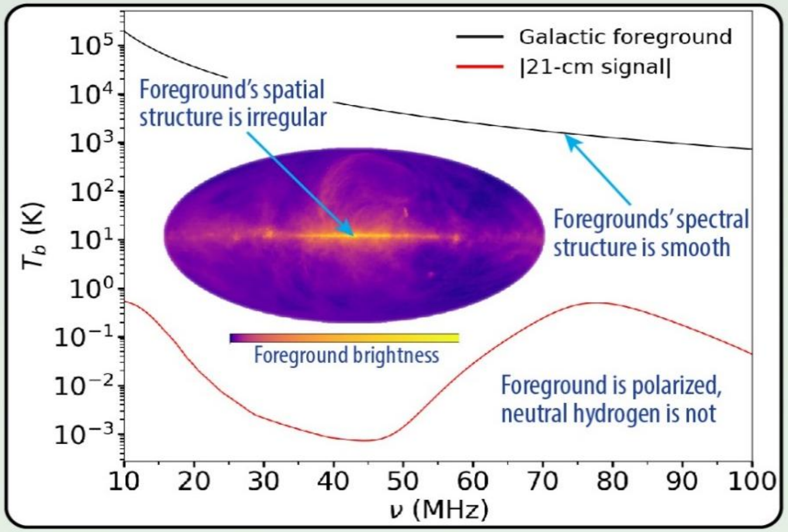
- Determine the level of excess cooling above the adiabatic limit for Cosmic Dawn.
- Determine when the first stars and black holes formed.

Will the observed behavior of redshifted neutral hydrogen redefine the standard cosmological model?





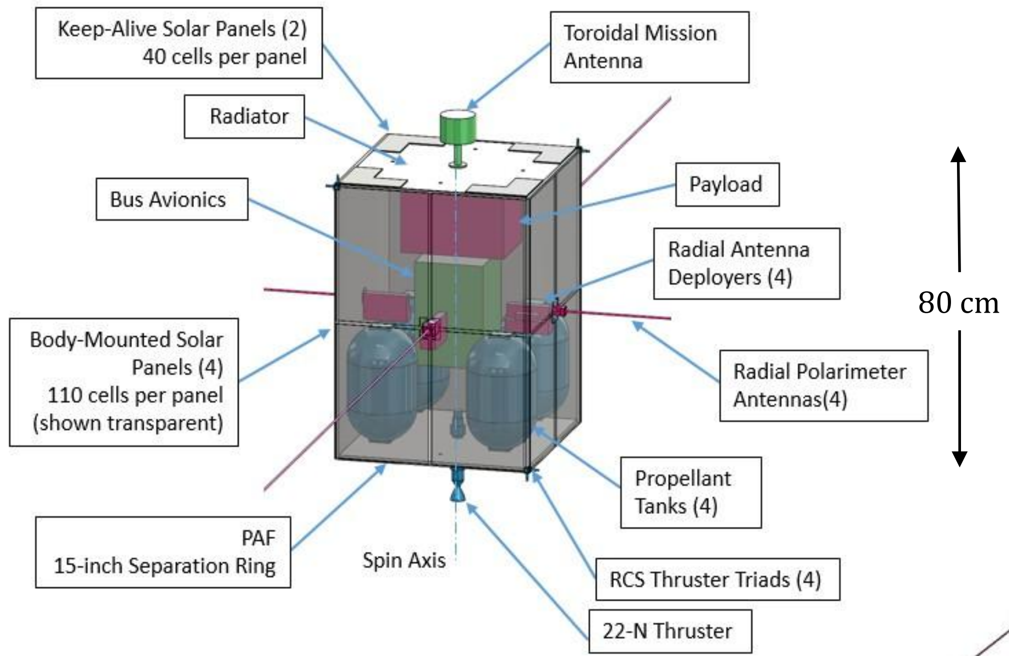
DAPPER uses the 21-cm all-sky signal to observe redshifts z = 83-12, associated with the Dark Ages and the Cosmic Dawn.



DAPPER separates Galaxy foreground from 21-cm signal using differences in spectral shapes, spatial structure, and polarization.

DAPPER
Dark Ages Polarimeter PathfindER

DARK COSMOLOGY:
INVESTIGATING DARK MATTER IN THE DARK AGES

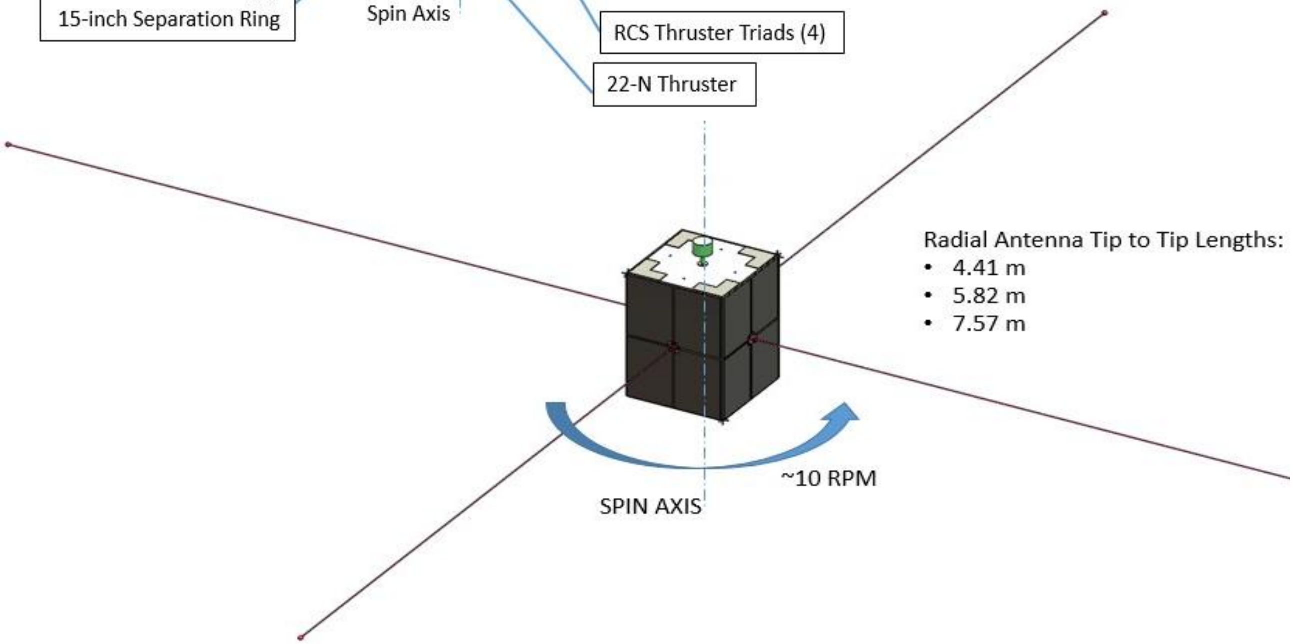


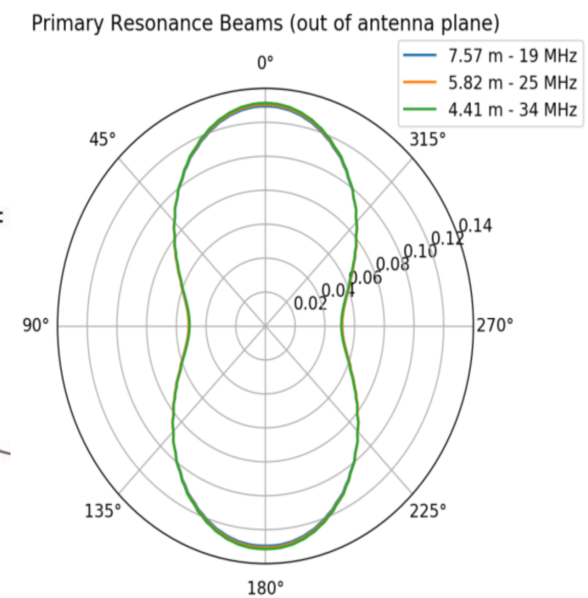
Spacecraft

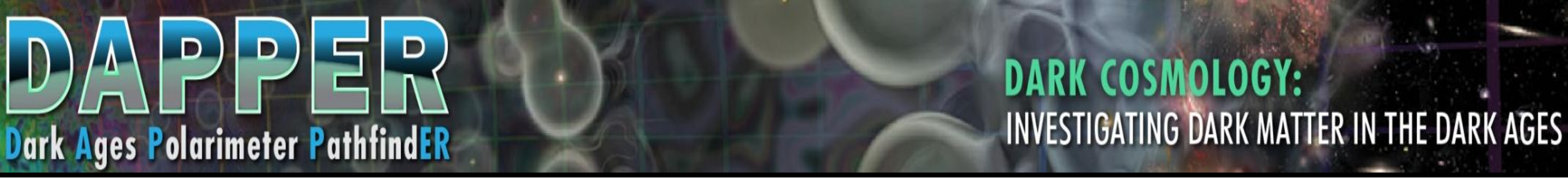
- Deep Space bus.
- High impulse, high ΔV.

Antennas

- Deployable, spinning, wire boom antennas arranged in 2 orthogonal, co-linear pairs.
- 3 length deployments to “tune” instrument to 17-38 MHz.

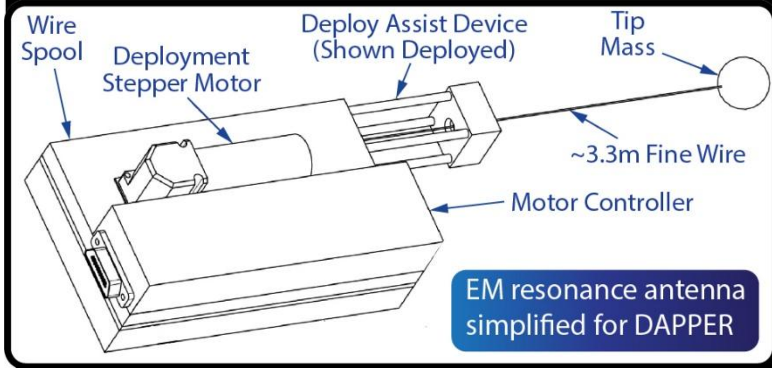


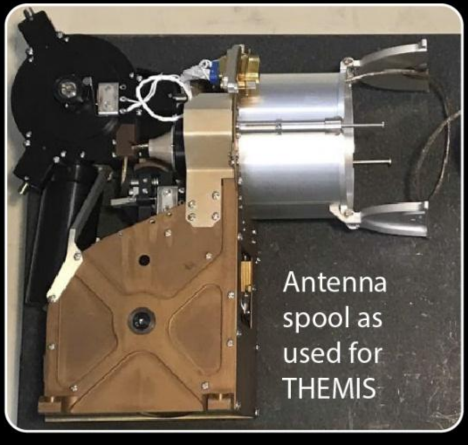




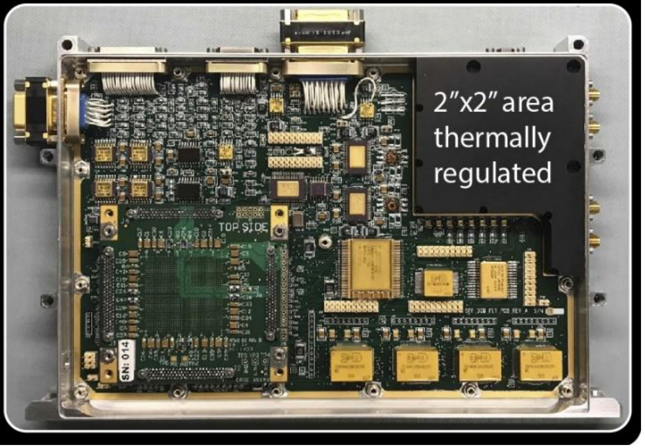
INSTRUMENT

Thermally robust antennas have been deployed in near-sun environment and in deep space.



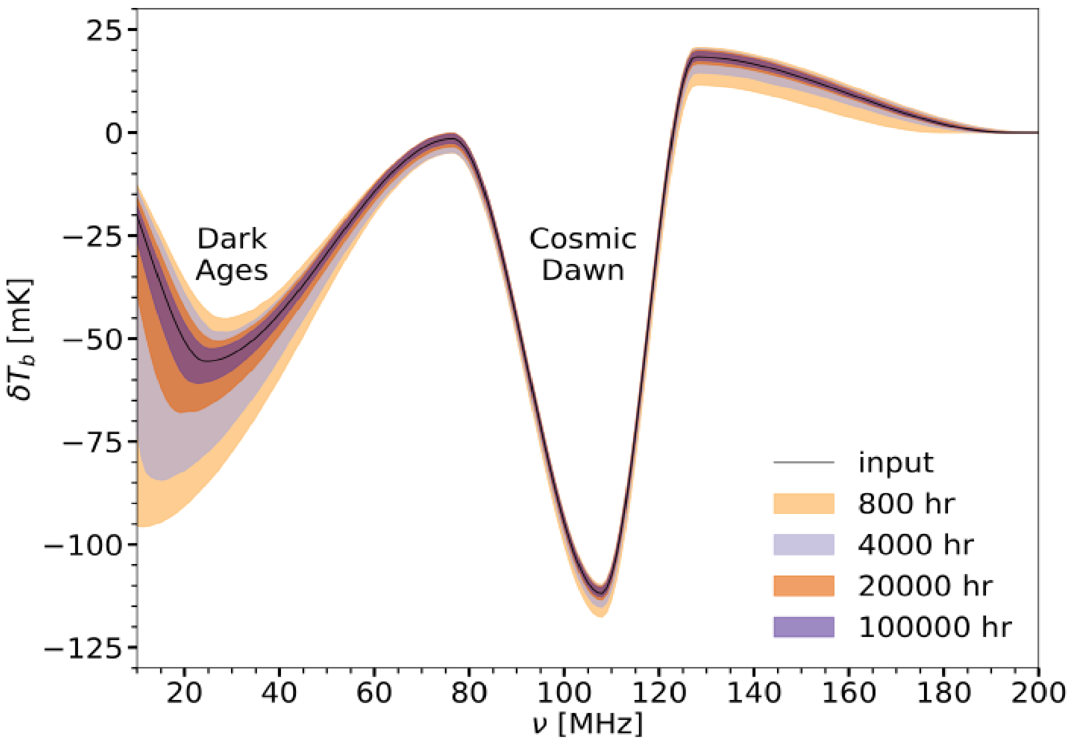


Spectrometer/Polarimeter used for Parker Solar Probe



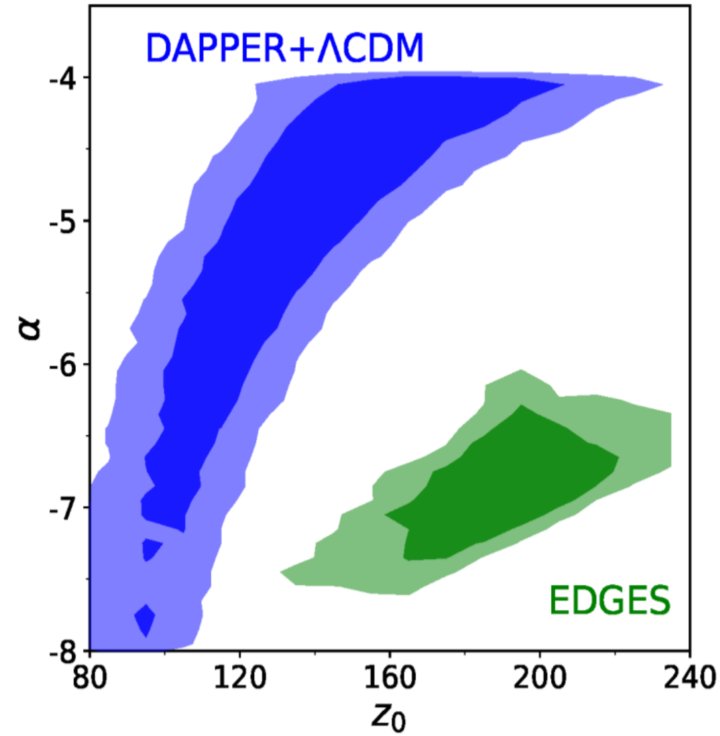
DAPPER Instrument

- High heritage from Parker Solar Probe, THEMIS, Van Allen Probes.
- Receiver gain variations:
  - Measured with high fidelity by frequency tones.
  - Controlled by stabilizing temperatures to $\pm 1°C$.
- Calibration:
  - Pre-launch lab measurements.
  - In-flight verification.
  - Fitting receiver characteristics using pattern recognition/MCMC pipeline.



Results for simulated DAPPER observations using our SVD/MCMC pipeline including statistical plus systematic uncertainties for four evenly increasing integration times from 800-10^5 hours.

Rapetti, Tauscher, Mirocha, Burns, 2020, *Global 21-cm Signal Extraction from Foreground and Instrumental Effects II: Efficient and Self-Consistent Technique for Constraining Nonlinear Signal Models,* arXiv:1912.02205.



DAPPER will distinguish at $>5\sigma$ between a standard ΛCDM model (blue) and an added cooling model as suggested by EDGES (green). α is the cooling rate and z_0 is the redshift where cooling begins.

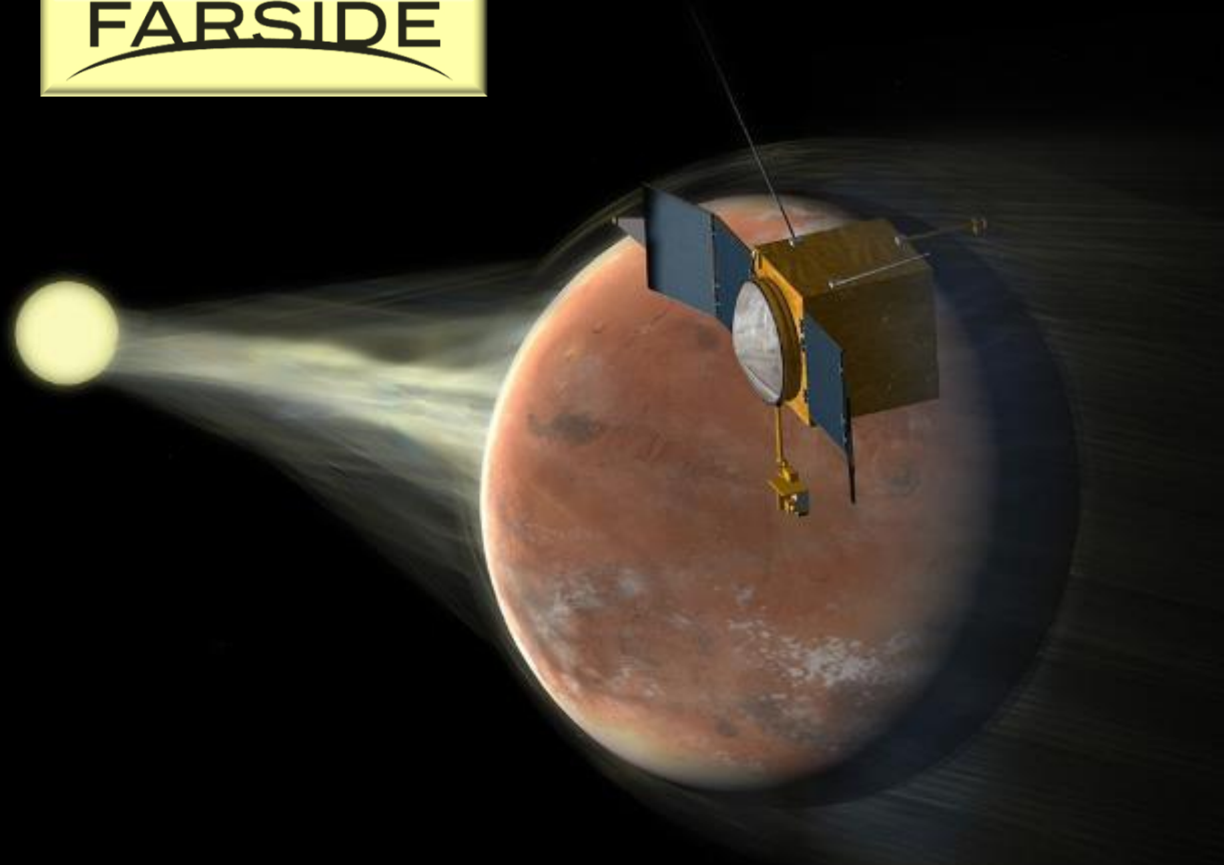
FARSIDE: Farside Array for Radio Science Investigations of the Dark ages and Exoplanets

P.I. J. Burns, Co-P.I. G. Hallinan (Caltech), & JPL Team-X

Image credit: Robin Clarke, JPL

FARSIDE

Young Mars was warmer
and wetter

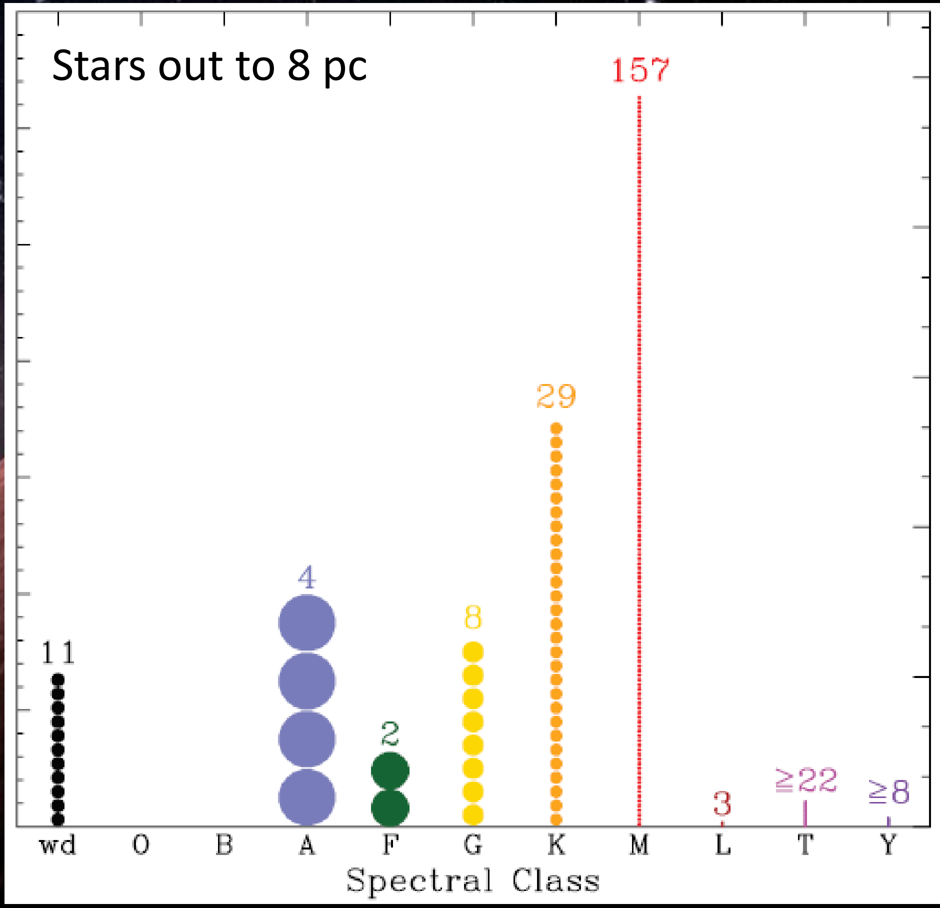


Jakosky et al. 2015

Flares – higher X-ray and ultraviolet radiation flux –>
drives photochemistry and thermal escape

Particle flux - CMEs and SEPs –>
can erode atmosphere – eg. ion pick-up erosion (Kulikov 2007)

FARSIDE



Kirkpatrick et al. 2012

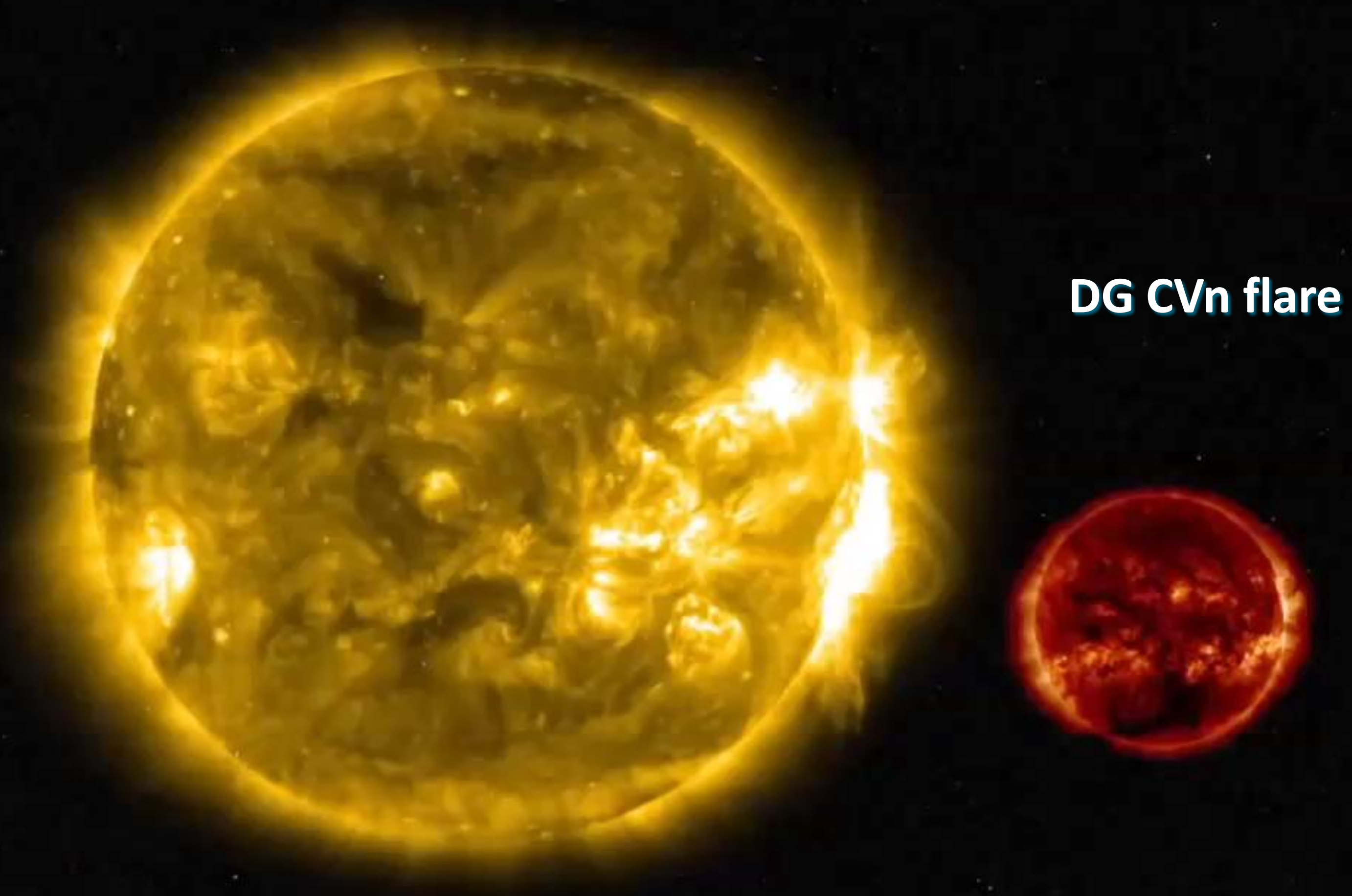
The M Dwarf Opportunity

Rocky planets are particularly frequent around M dwarfs (Dressing & Charbonneau 2013, 2015)

The nearest "habitable" planet likely orbits an M dwarf within a few pc

FARSIDE

Largest solar flare – November 4th 2003

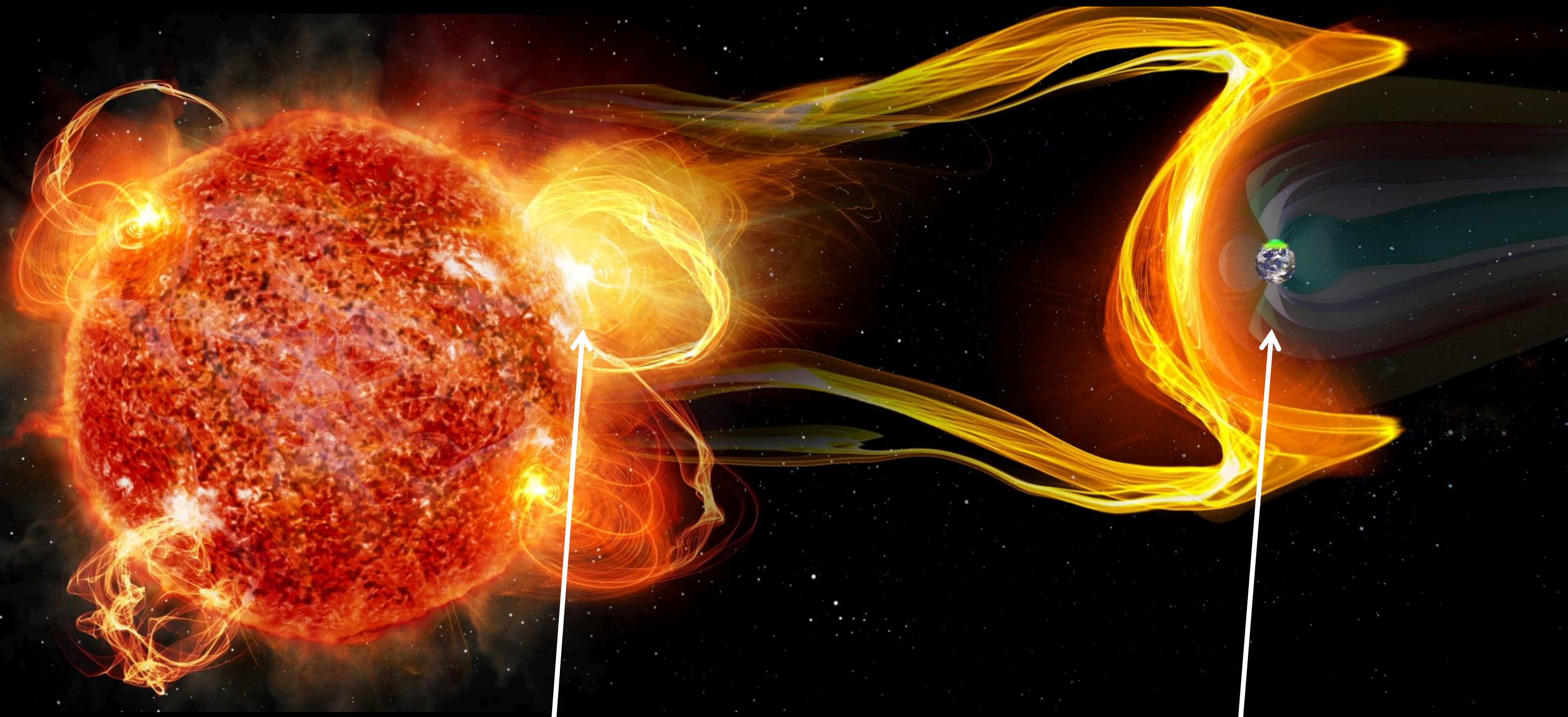


DG CVn flare – April 23rd 2014

FARSIDE

Low Frequency Radio Emission

Credit: Chuck Carter / Caltech / KISS



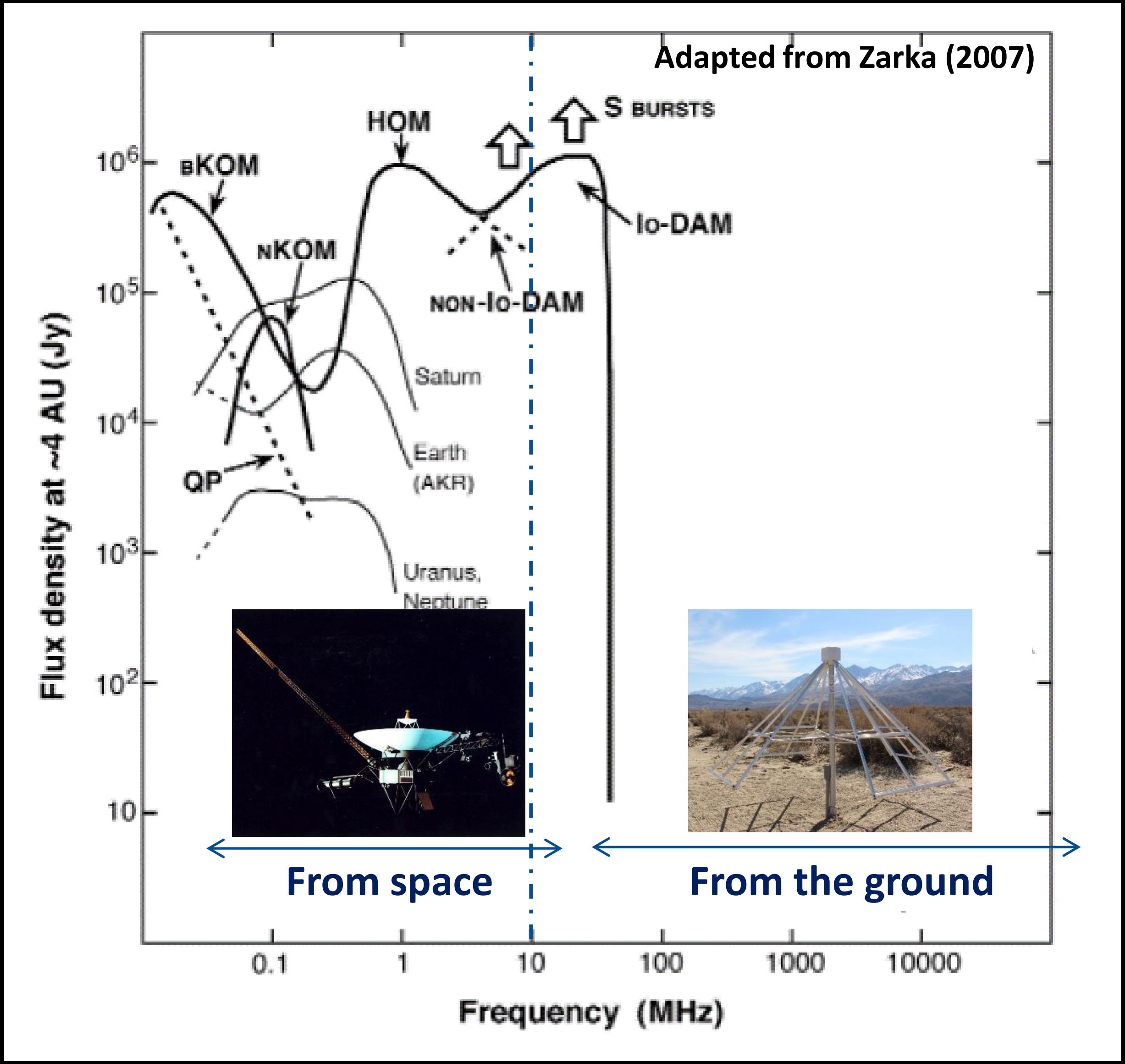
Type II radio bursts
traces density at CME shock

Auroral radio emission
measures magnetic fields

Why Low Frequencies?

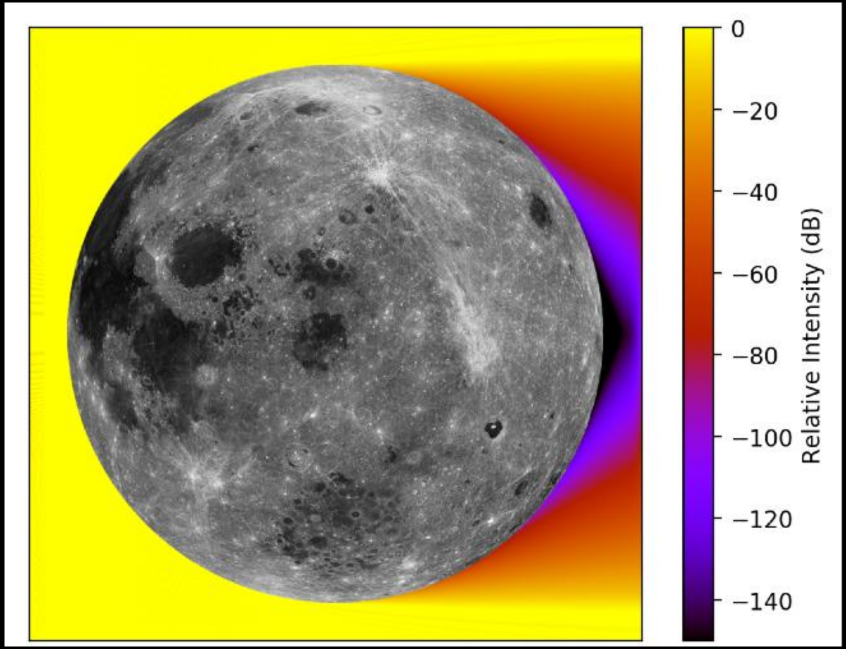
Electron cyclotron maser emission

Frequency (MHz) = B_{Gauss} x 2.8

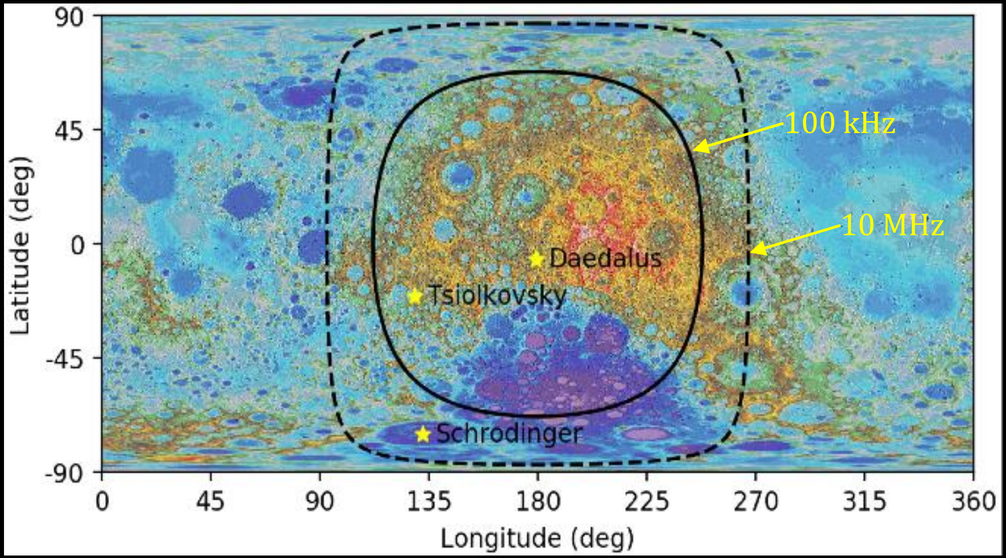


Simulations of the Radio Environment of the Moon

Bassett, Burns, et al. 2020, submitted to *Advances in Space Research*



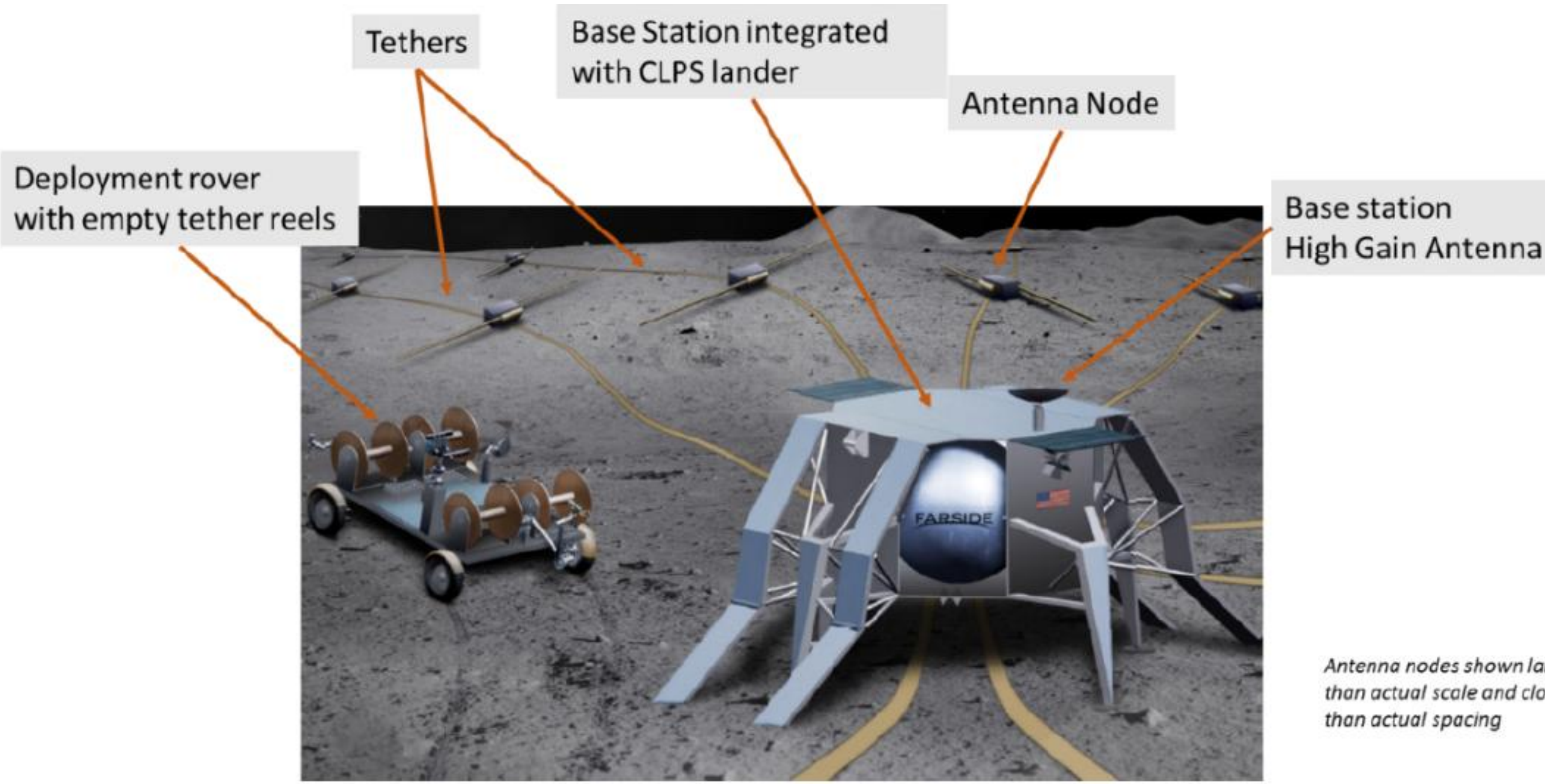
Two-dimensional numerical electrodynamics simulations show that the relative intensity of terrestrial radio waves incident on the Moon is highly attenuated behind the farside.



The "radio quiet" region at 100 kHz (solid) and 10 MHz (dashed) defined by ≥ 80 dB attenuation plotted over a map of the lunar surface.

FARSIDE Mission Concept

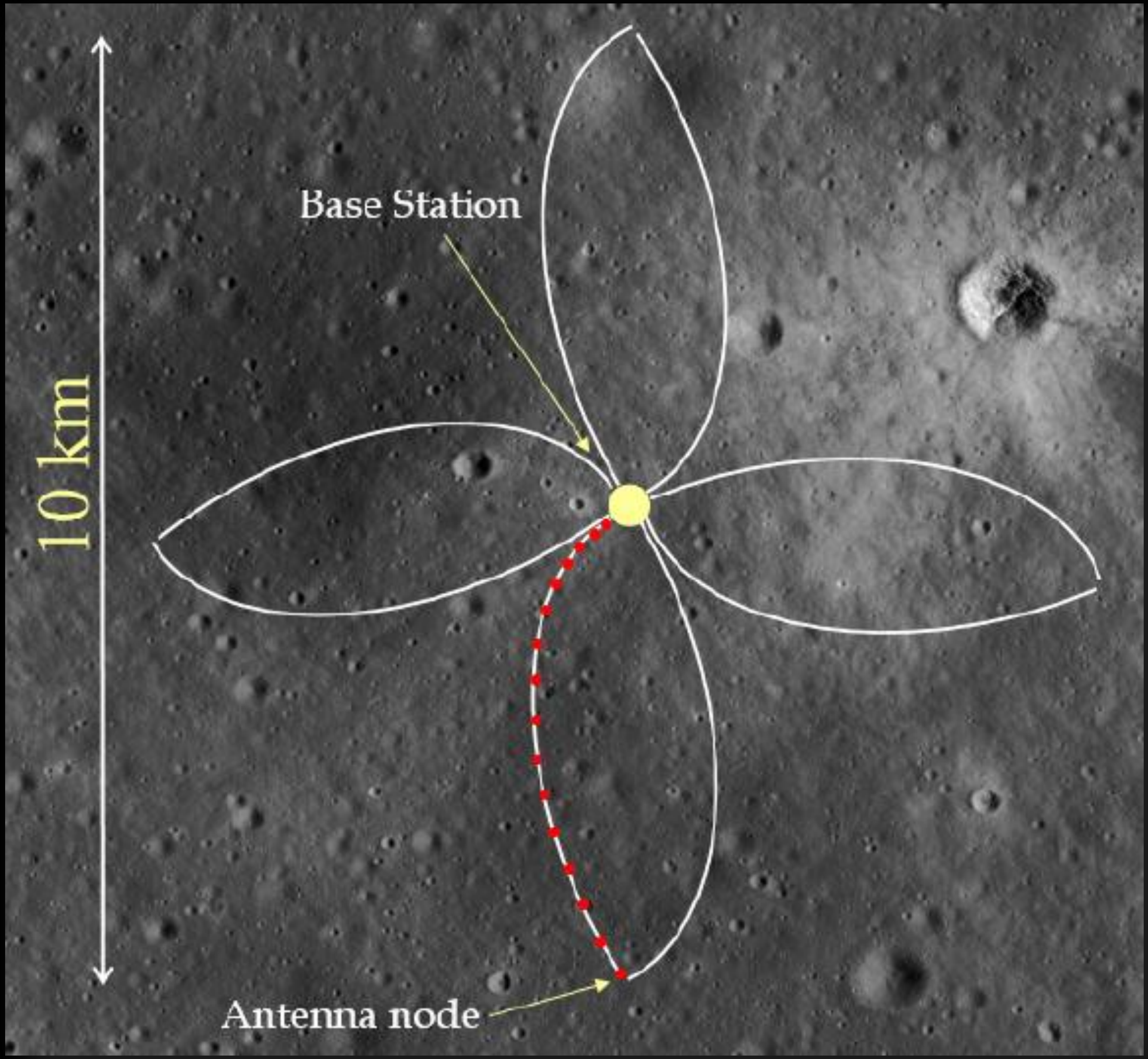
Frequencies: 100 kHz to 40 MHz



Antenna nodes shown larger than actual scale and closer than actual spacing

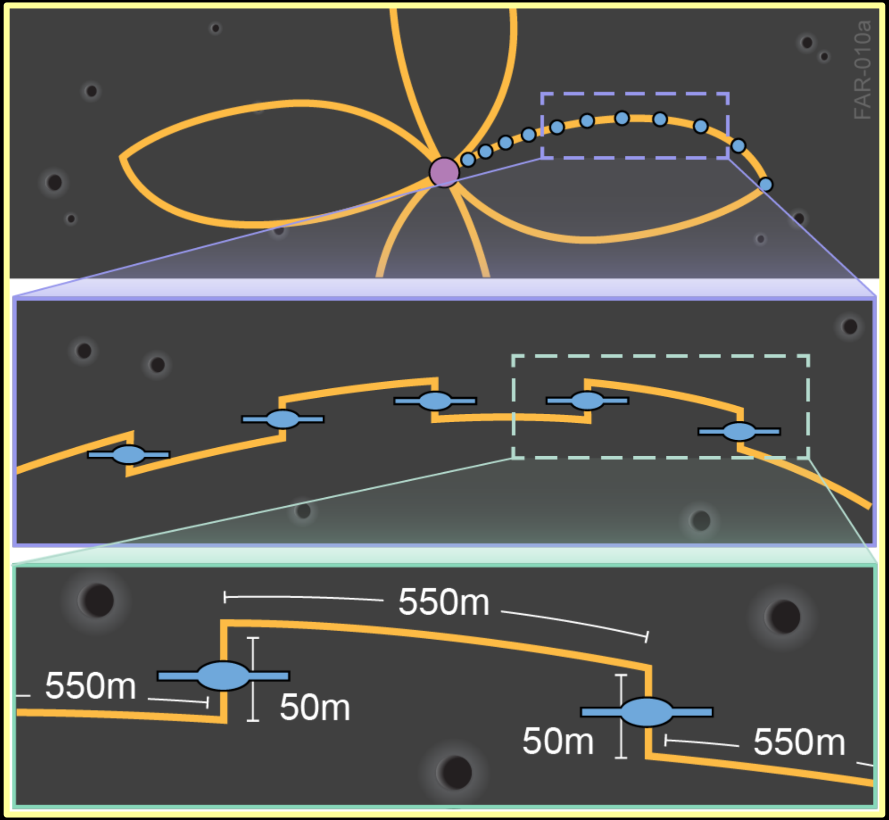
FARSIDE

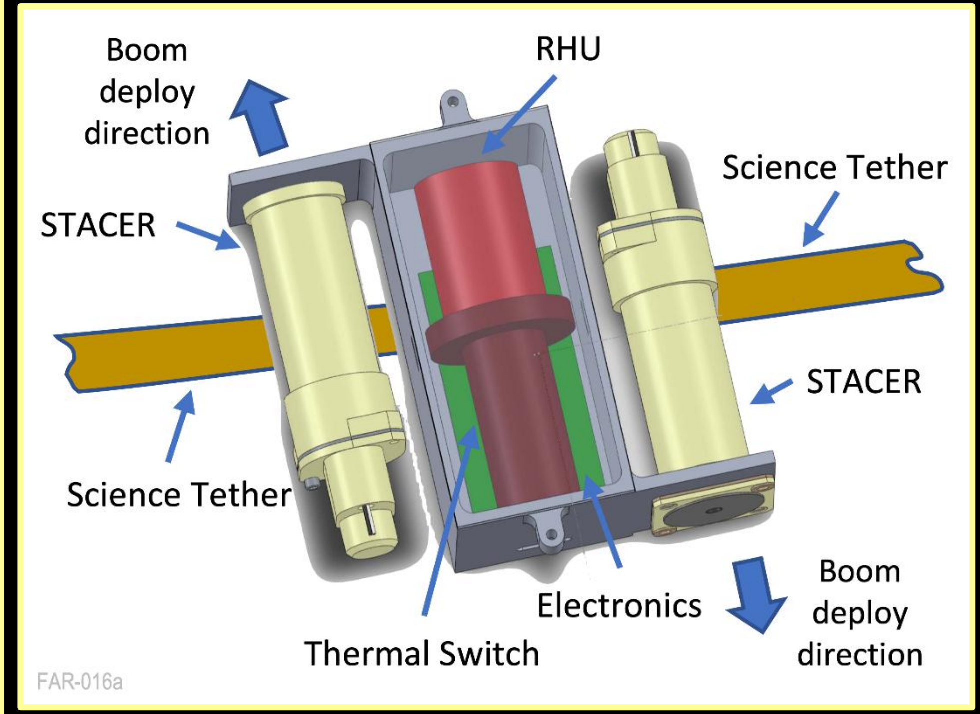
FARSIDE Configuration



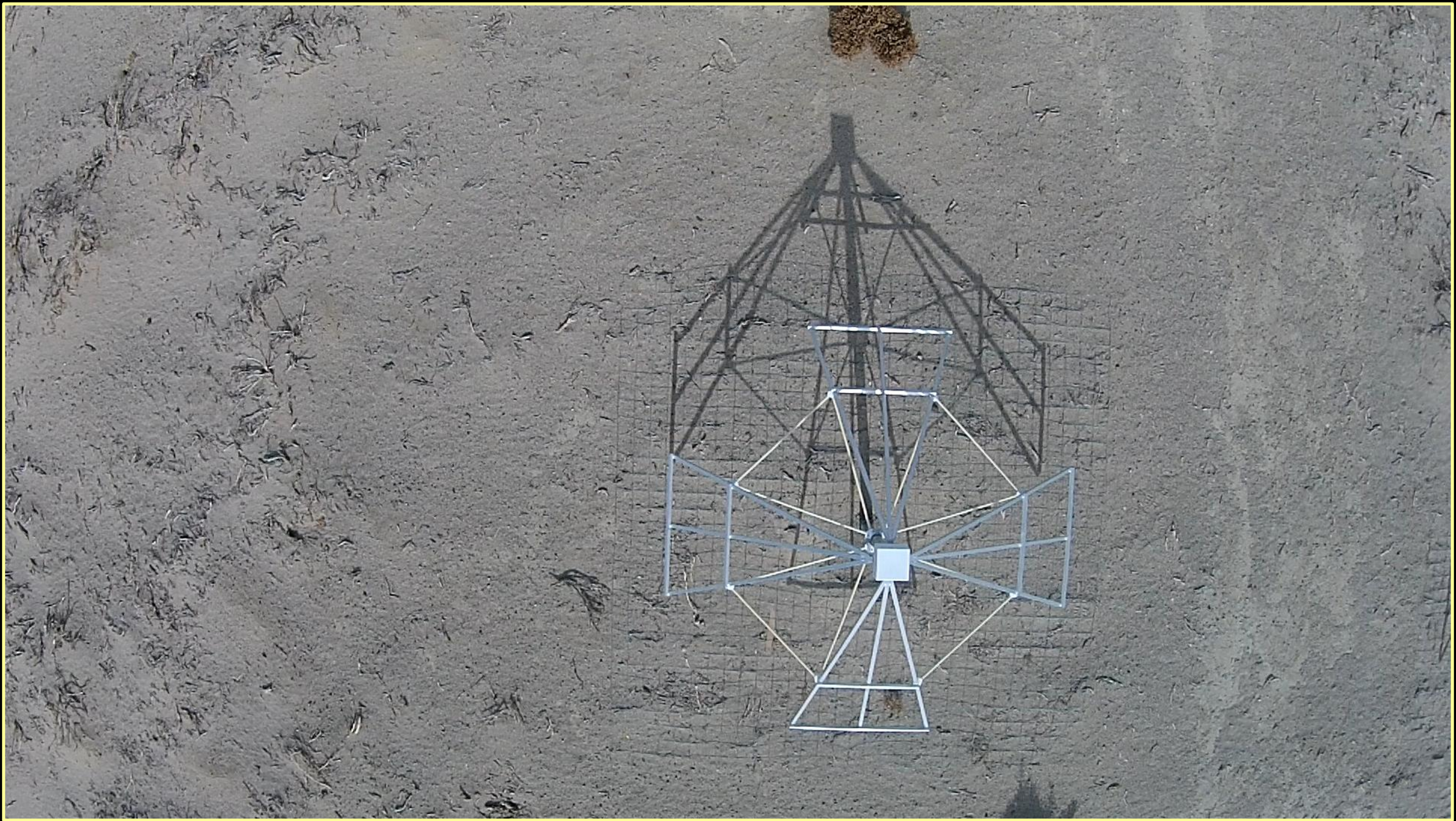
FARSIDE

FARSIDE Antenna Node



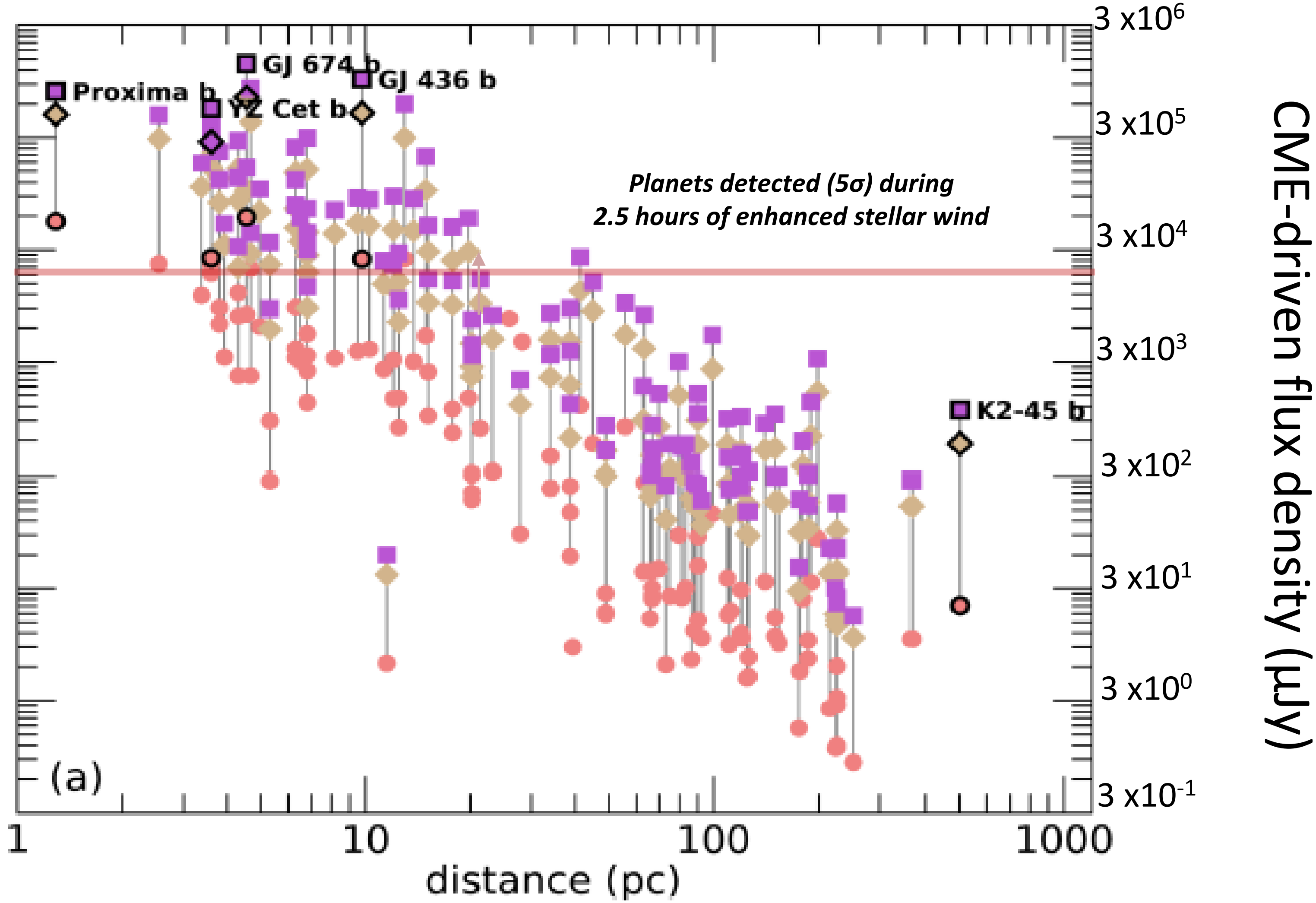


The OVRO-LWA

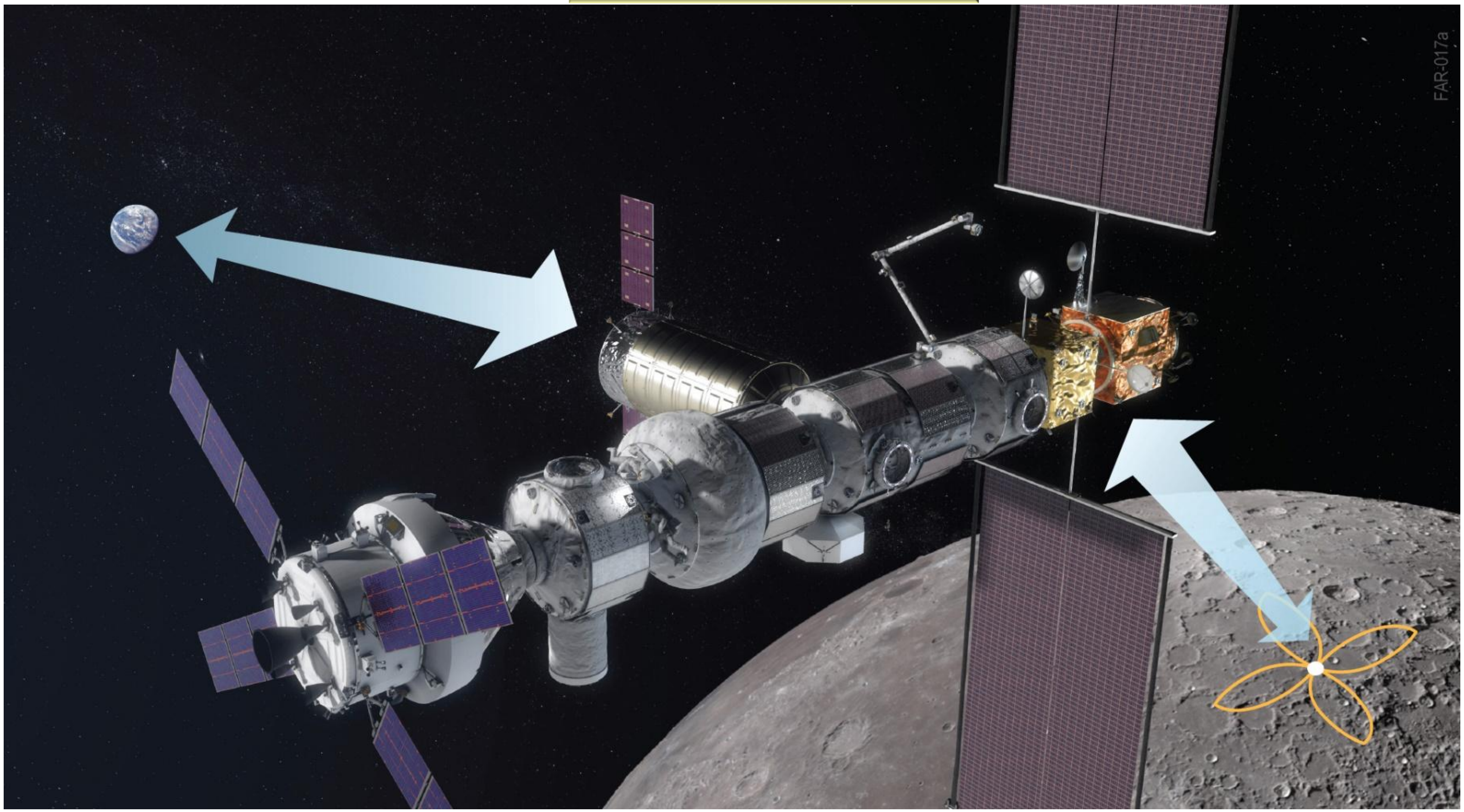


FARSIDE architecture benefits from OVRO-LWA heritage

FARSIDE



Adapted from Vidotto et al. 2019



Assumed Lunar Gateway Communications Support	
Rover forward link (Ku-band)	16 kb/s
Rover return link (Ka-band)	5 MB/s
Lander forward link (Ku-band)	16 kb/s
Lander return link (Ka-band)	10 Mb/s

FARSIDE: Possible Lander

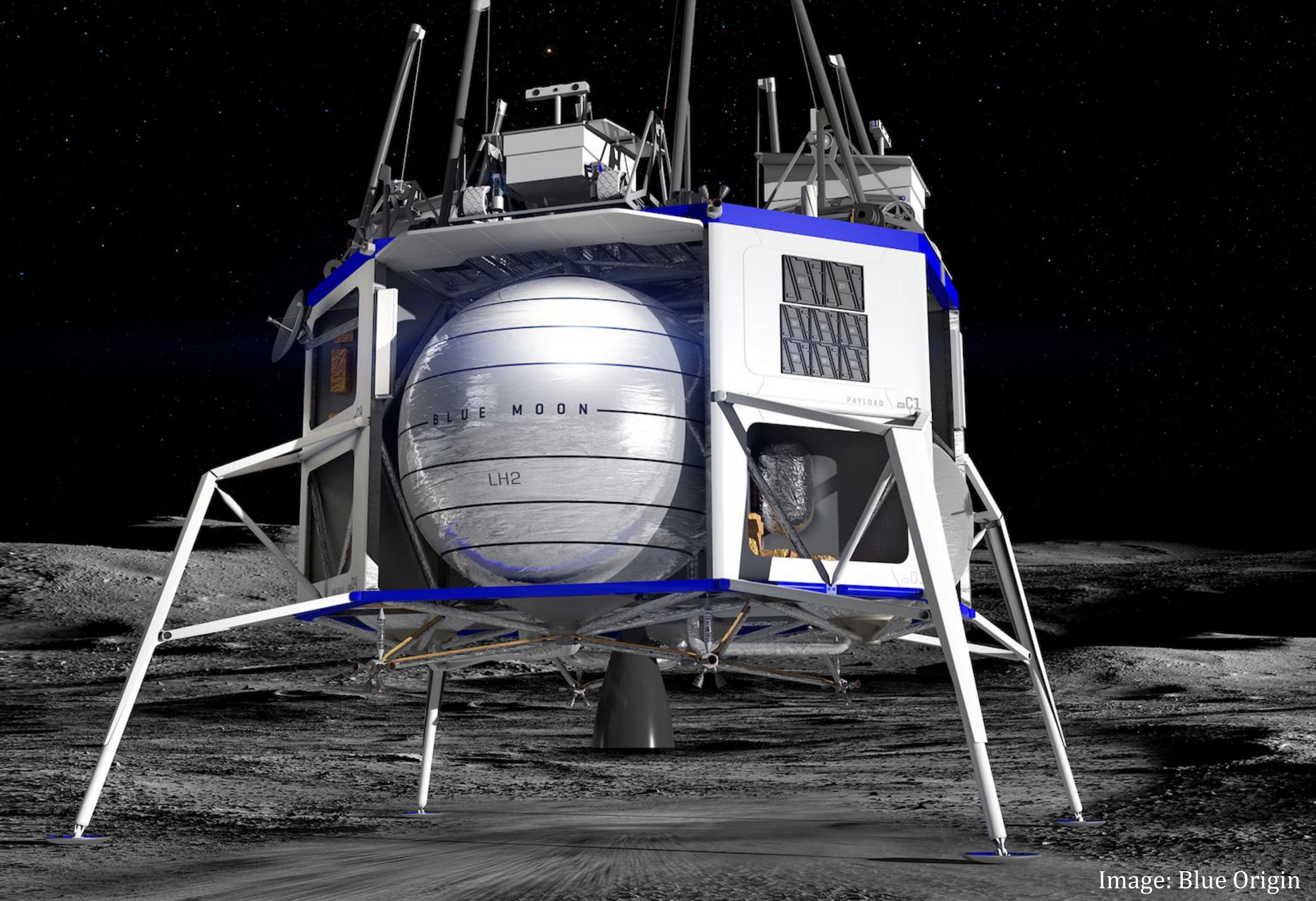
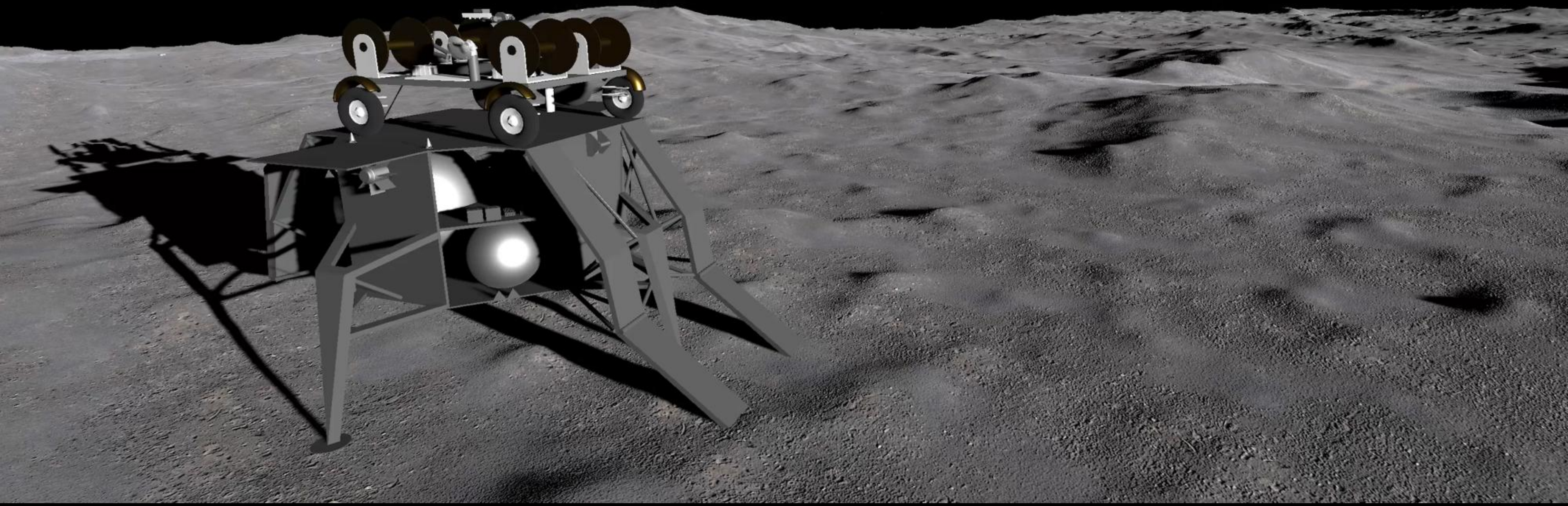


Image: Blue Origin

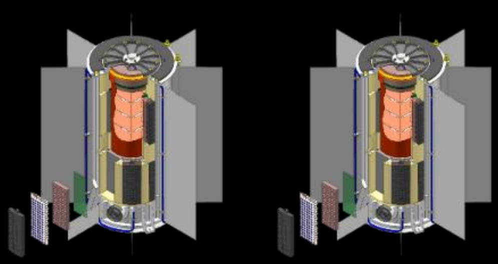
FARSIDE

FARSIDE Configuration

Rover with Blue Moon Lander



video credit: M. Walker, J. Burns, D. Szafir
University of Colorado Boulder



Power: 2 x EMMRTGs

<u>Base Station</u>
Correlator
Power
Telecom
Command and Data Handling

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 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.