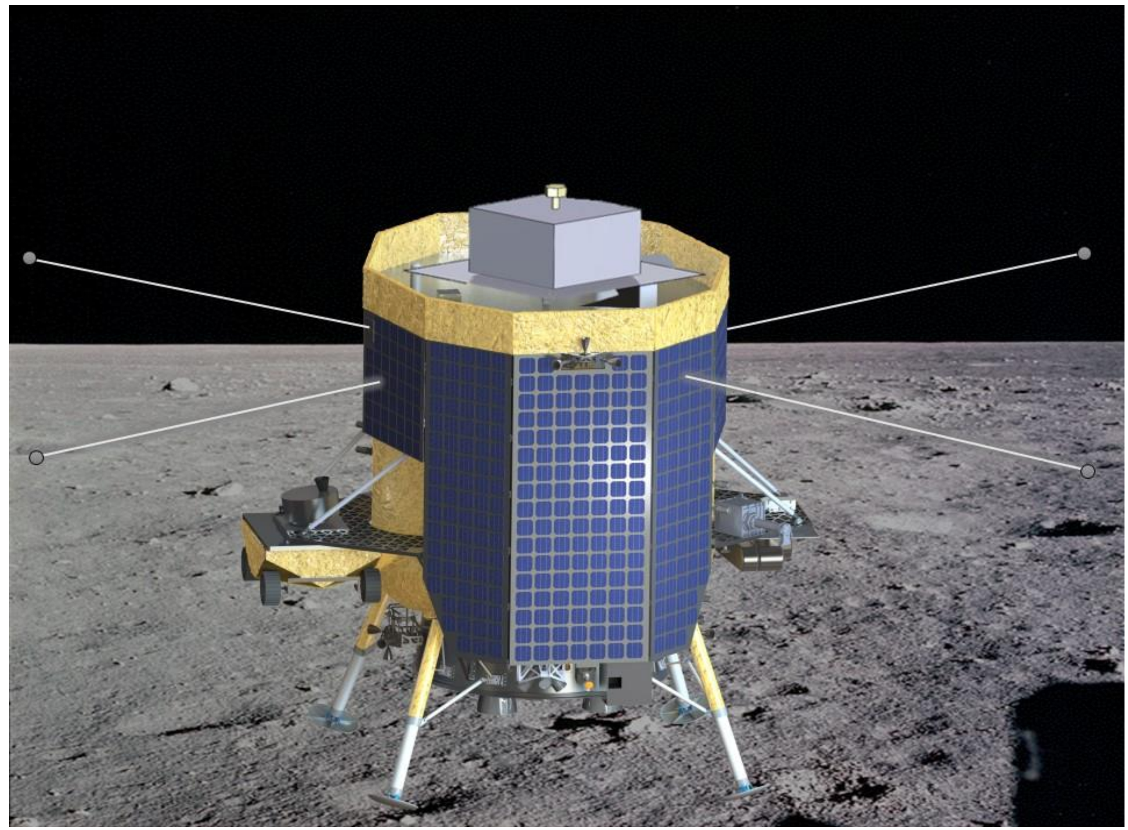
DAPPER

The Dark Ages Polarimeter PathfindER



Principal Investigator:
Jack Burns, University of Colorado Boulder

Co-Investigators:
Stuart Bale, U. California at Berkeley
Richard Bradley, NRAO

NASA Lead Center:
NASA Ames Research Center

Presented by: Keith Tauscher

DAPPER Project Team Members

1.	Jack Burns	PI	CU Boulder
2.	Rich Bradley	Deputy PI: Receiver; High-band Antenna	NRAO
3.	Thomas Squire	PM	NASA Ames
4.	Keith Tauscher	Co-I: Data Pipeline	CU Boulder
5.	David Rapetti	Co-I: Data Pipeline	NASA Ames
6.	Bang Nhan	Co-I: Antennas/receiver	NRAO
7.	Stuart Bale	Co-I: Instrument; Low-band Antenna	UC Berkeley
8.	Keith Goetz	Co-I: Antenna SE	U. Minn
9.	Marc Pulupa	Co-I: Receiver Engineer	UC Berkeley
10.	Neil Bassett	Data Pipeline	CU Boulder
11.	Joshua Hibbard	Data Pipeline	CU Boulder
12.	David Bordenave	Antennas/receiver	NRAO
13.	Jordan Mirocha	Collaborator	McGill
14.	Robert MacDowall	Collaborator	NASA Goddard
15.	Steve Furlanetto	Collaborator	UCLA

SCIENCE

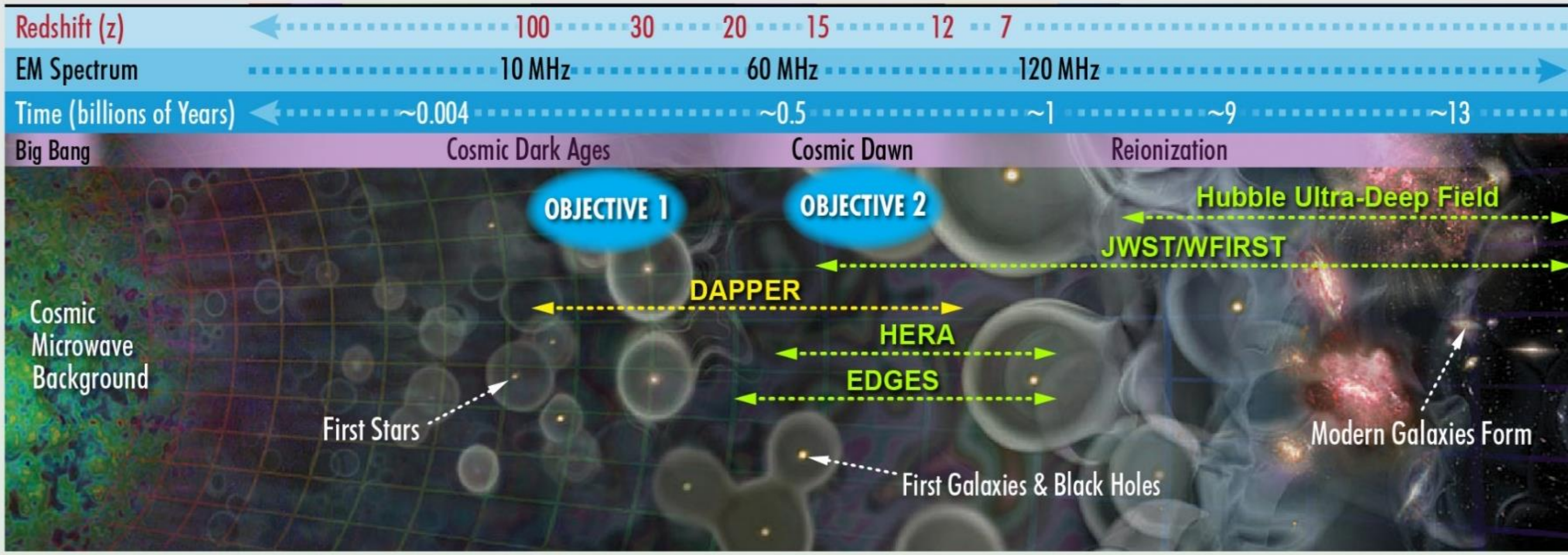
OBJECTIVE 1:

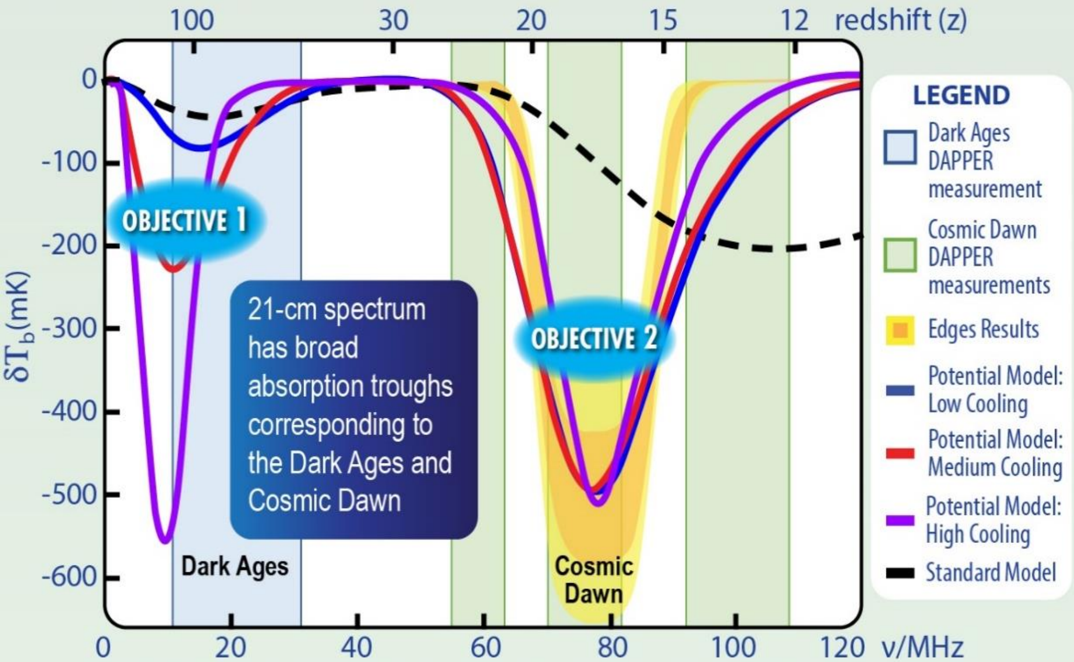
- Determine the level of (dis)agreement with the standard cosmological model caused by dark matter in the Dark Ages.

OBJECTIVE 2:

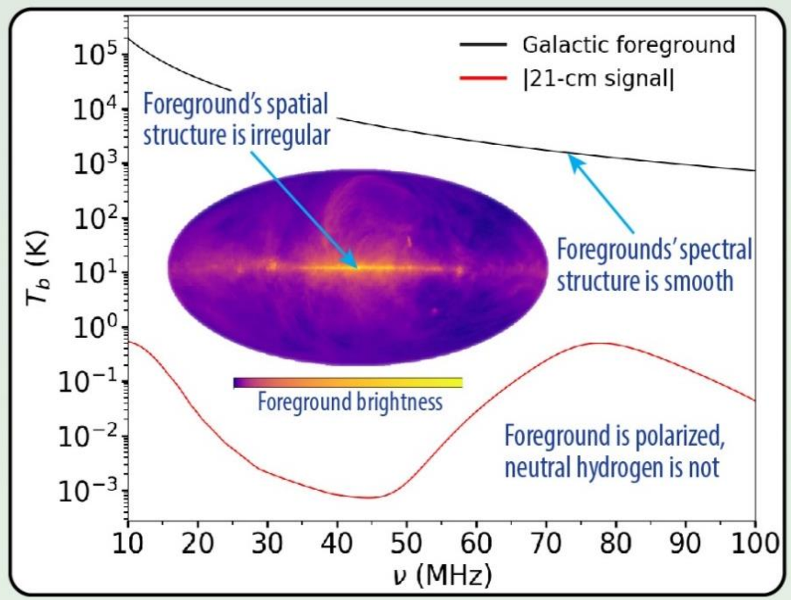
- Determine the level of excess cooling above the adiabatic limit for Cosmic Dawn.
- Determine when the first stars and black holes formed.

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





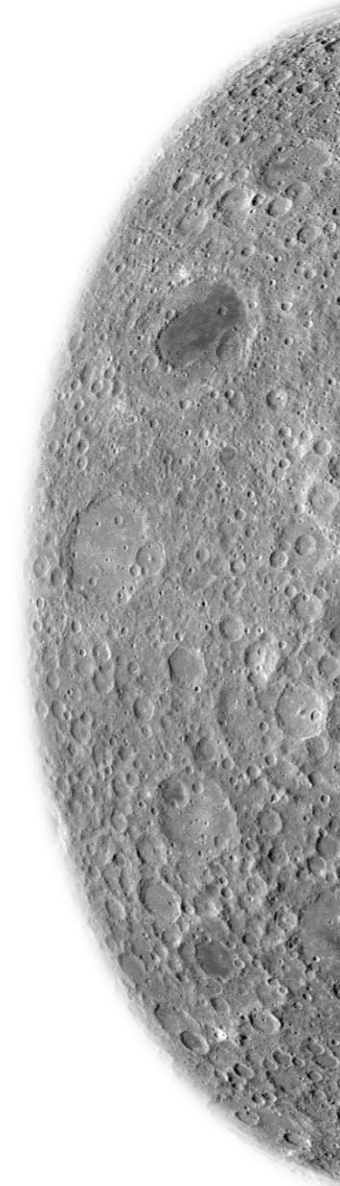
DAPPER uses the 21-cm all-sky signal to observe redshifts z = 83-12, associated with the Dark Ages and the Cosmic Dawn.



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

Mission Overview

- 2 Frequency Bands: 18-40 MHz and 60-110 MHz.
- Measure all 4 Stokes parameters.
- Proposed to be included on the same CLPS lander as LuSEE (Lunar Surface Electromagnetic Experiment) and with coordinated observations at the Schrodinger basin.
- Integration time: 240 hr of lunar day + more if lander can survive the night
- Zenith-pointing with time dependence given by sky drifting overhead.



See also Burns, J.O. 2020, *Phil. Trans. Roy. Soc. A*, in press, arXiv:2003.06881

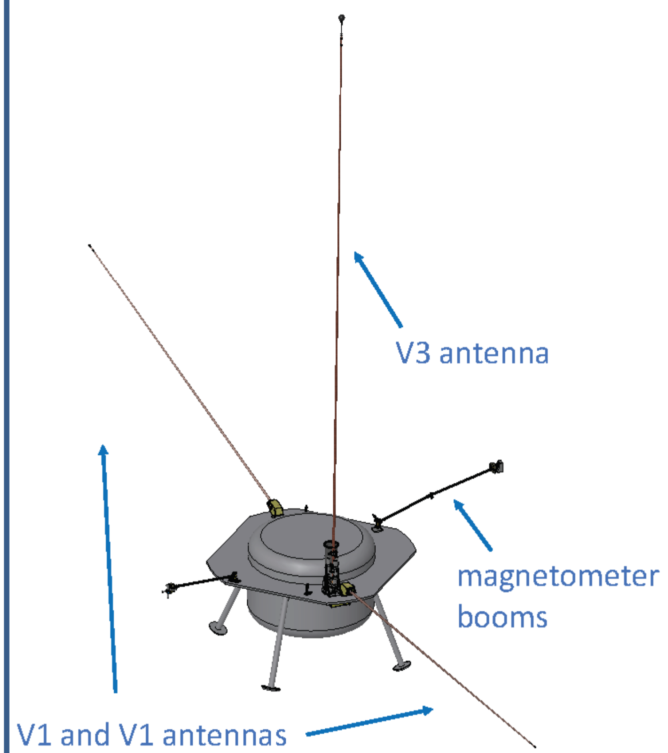
NASA LUNAR SURFACE INSTRUMENT AND TECHNOLOGY PAYLOADS: LuSEE

Lunar Surface Electromagnetics Experiment = **LuSEE**

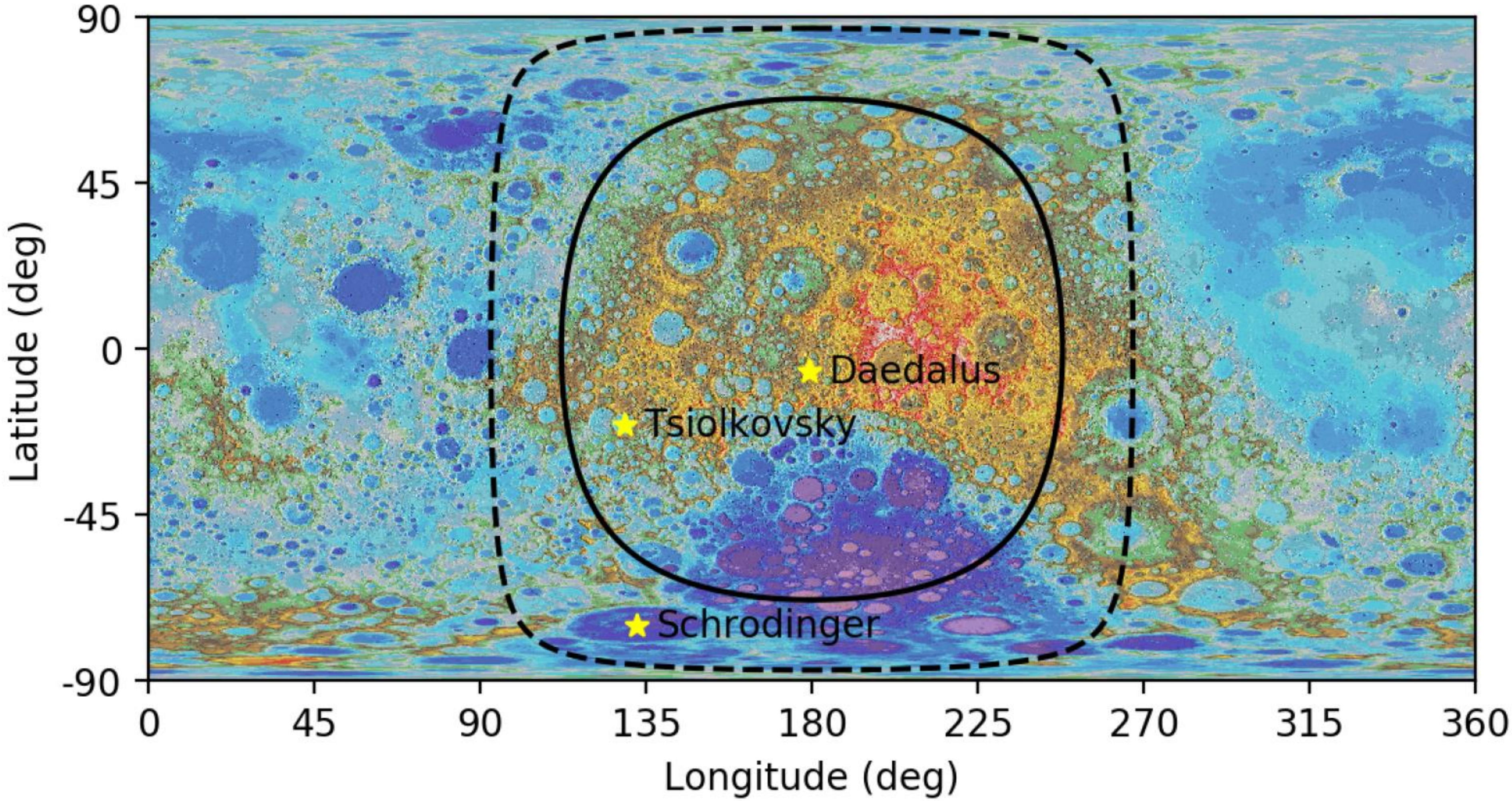
- <u>Science Goals</u>
  - measure DC electric & magnetic fields, including plasma waves
  - measure electrostatic signatures of dust impacts
  - measure radio emissions from the Sun, Earth and outer planets
  - address the interaction of the lunar surface with the solar wind
  - probe the structure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

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

- <u>Status</u>: LuSEE is currently scheduled to land in the Schroedinger impact basin on the lunar farside in 2024.



LuSEE sensors are 6-m stacer antennas (V1 & V2) deployed to form a ground plane. 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.



The Moon provides a shield from Anthropogenic Radio Frequency Interference (ARFI).

Solid line: -80 dB attenuation of kHz frequency ARFI, **Dashed line**: -80 dB attenuation of MHz frequency ARFI

High Band Patch Antenna Design

Baseline Design

A rendering of the baseline design made from solid dielectric materials is shown in Fig. 3 along with a cut-away view, where the middle layer of metal and the four terminal connections are visible.

Laminated Structure

Composite Dielectric

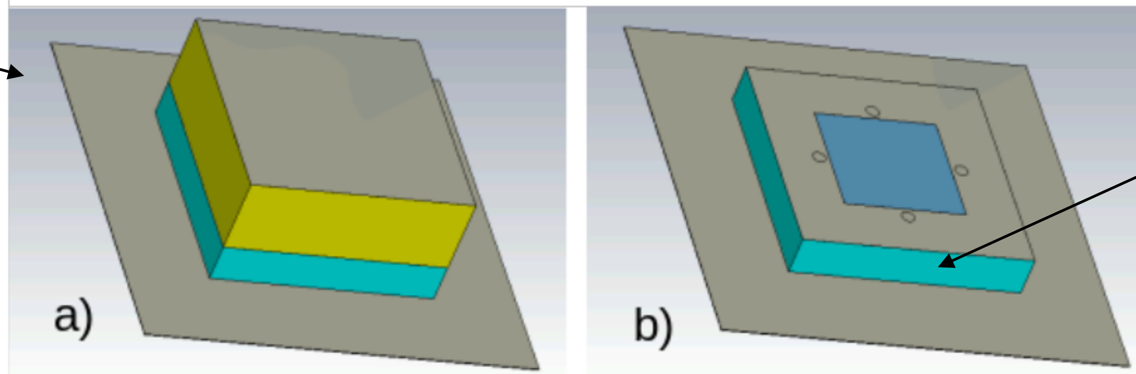
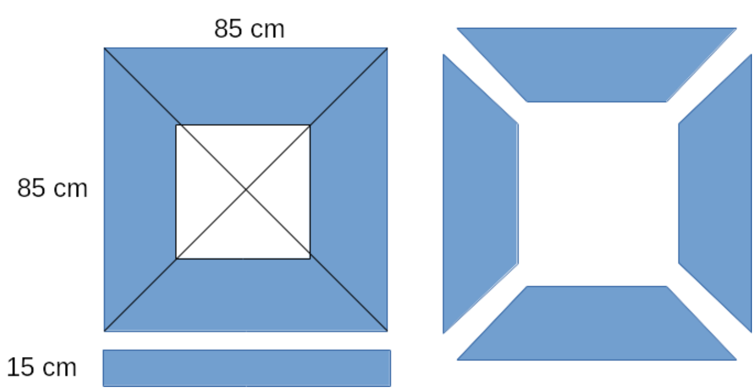


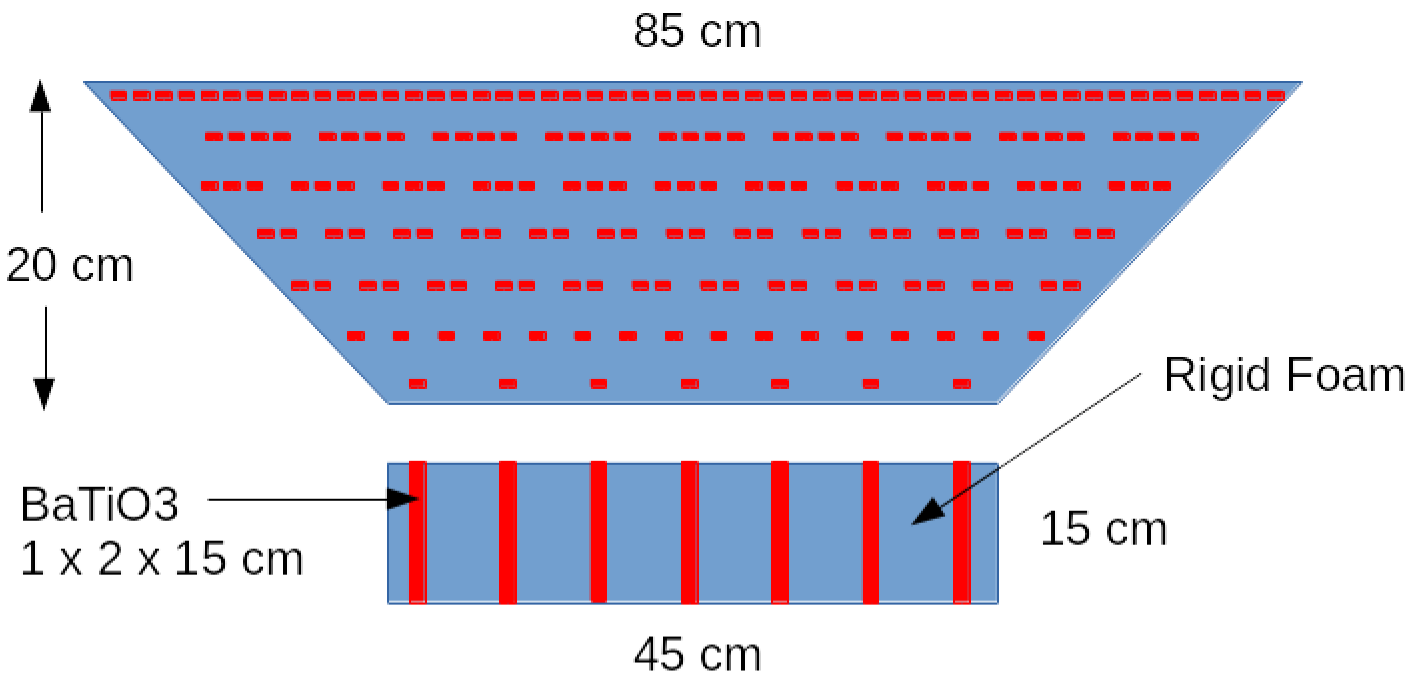
Figure 3: Rendering of the baseline patch antenna. Panel a) is an overall view, and b) is a cutaway showing the middle metal layer and feed connections.

Bottom Dielectric Material

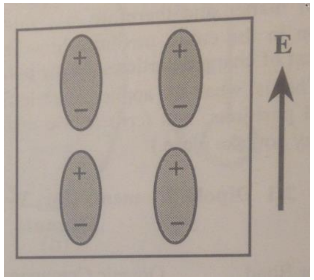


Four identical quadrants

DAPPER Patch Design

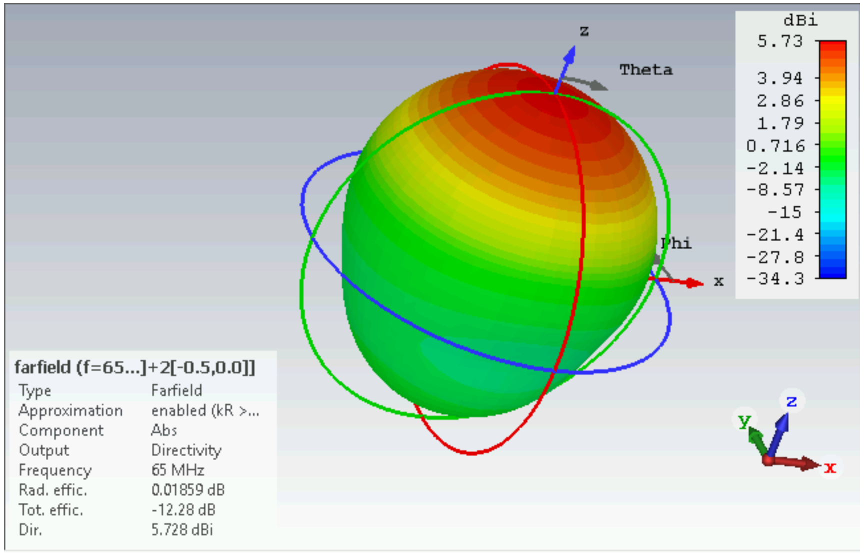


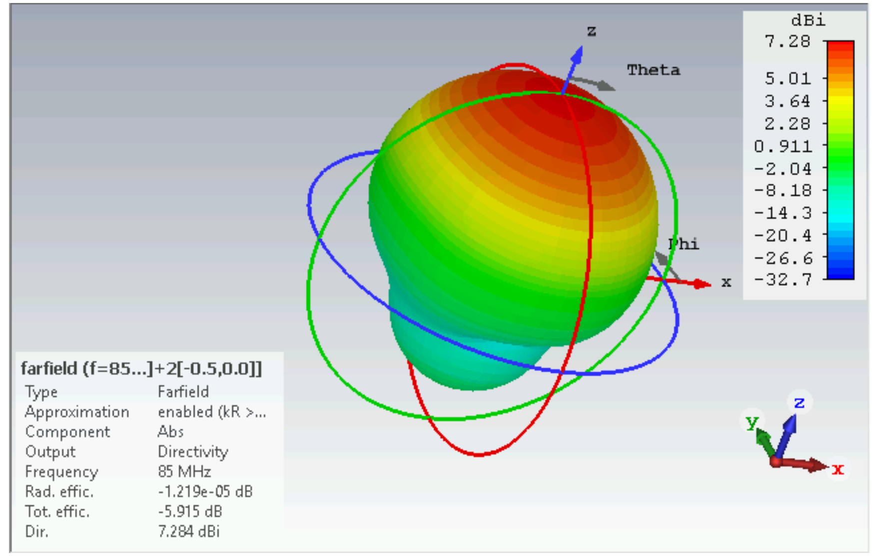
BaTiO3 is the most widely used ferroelectric material, and even sixty years after its discovery, it is the most important multilayer ceramic dielectric.

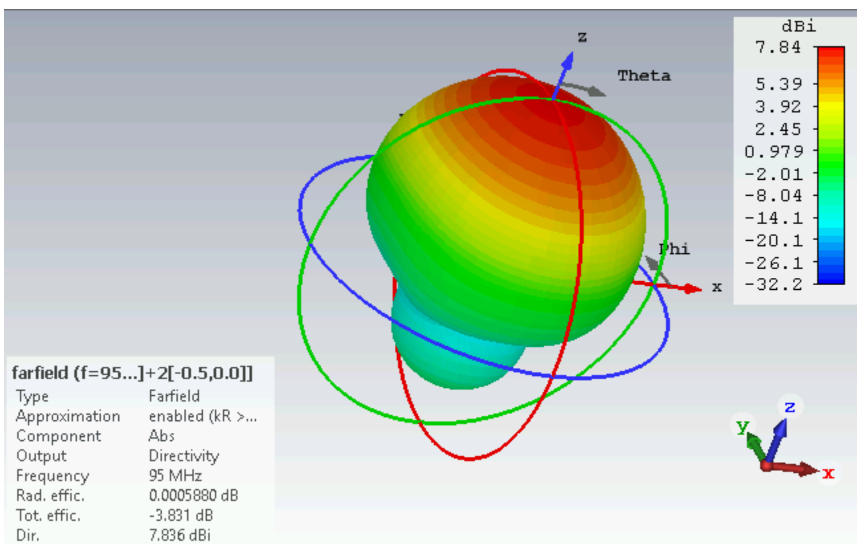


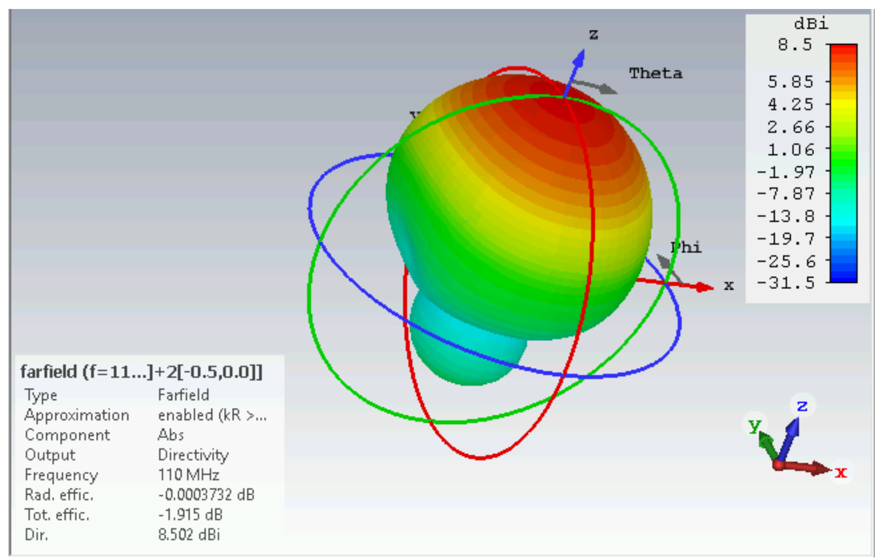
Molecular alignment leading to high dielectric constant of BaTiO3

Beam Patterns (65, 85, 95, 110 MHz)



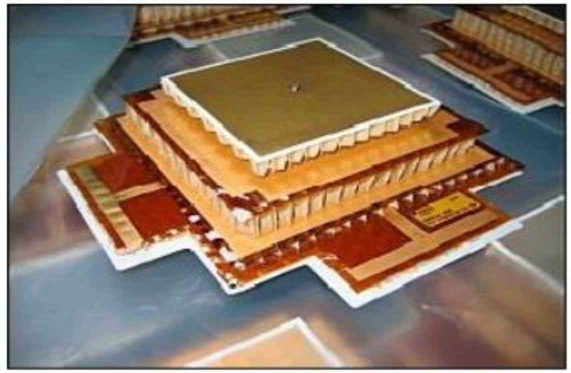






Patch Antenna Heritage

Galileo in-orbit patch. Four stacked layers of Kapton.



Patch antennas have been used primarily for TT&C and ISL applications

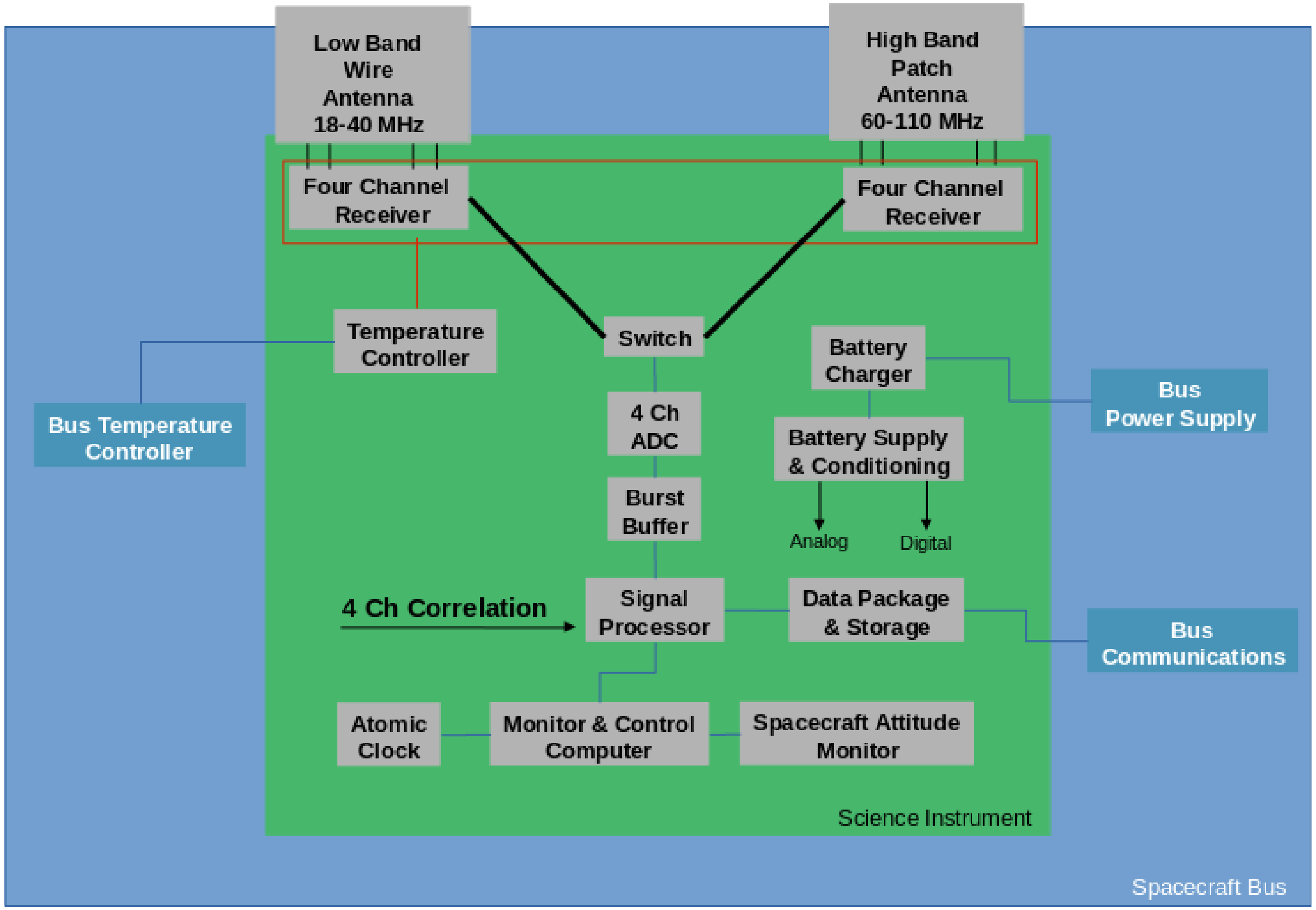
Table 79: Constellation ISL Comparison

Mission	Link	Band	Antenna type	Data-rate	Distance	Link margin
ROSETTA	Orbiter-Lander	S	Patch	16 kbps	150km	14,8 dB
	Lander-Orbiter	S	Patch	16,38 kbps	150 km	15,5 dB
PRISMA	RRFR	S	X-pole	12 kbps	30 km	18,1 dB
CanX 4&5	ISL	S	Patch	10 kbps	5 km	19,2 dB
NODES	ISL	UHF	Monopole	9,6 kbps	100 km	33,8 dB
TSX-TDX	P-P @90°@	S	Patch	31,25 kbps	1,25 km	12,0 dB
Sar-Lupe	Low rate	S	Patch	300 kbps	50 km	13,5 dB
	High Rate	S	Patch	6000 kbps	50 km	0,5 dB

Following from https://directory.eoportal.org/

DAPPER Receiver Design

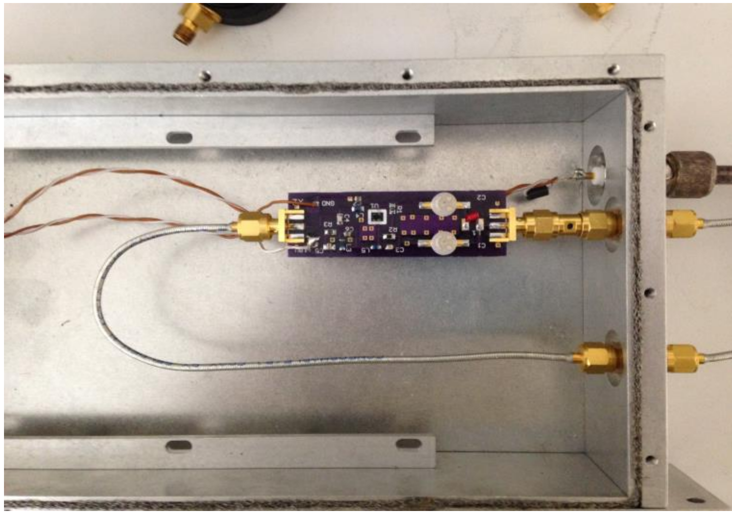
Four Channel Correlation Receiver



Receiver Concept

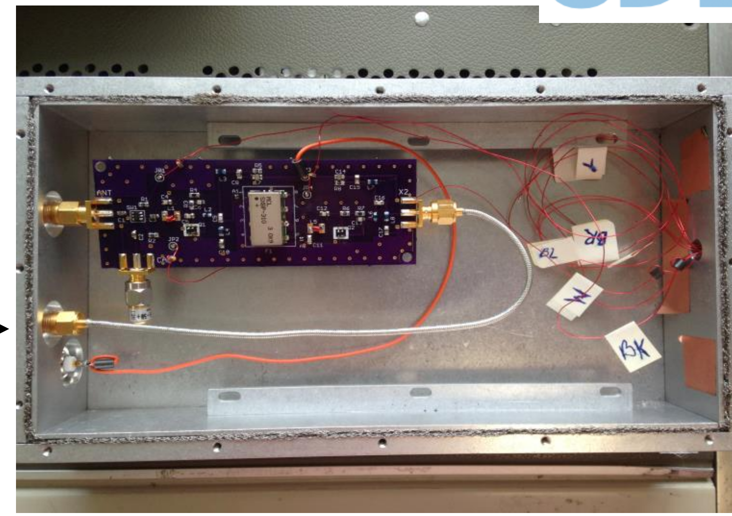
Current Status

CDL

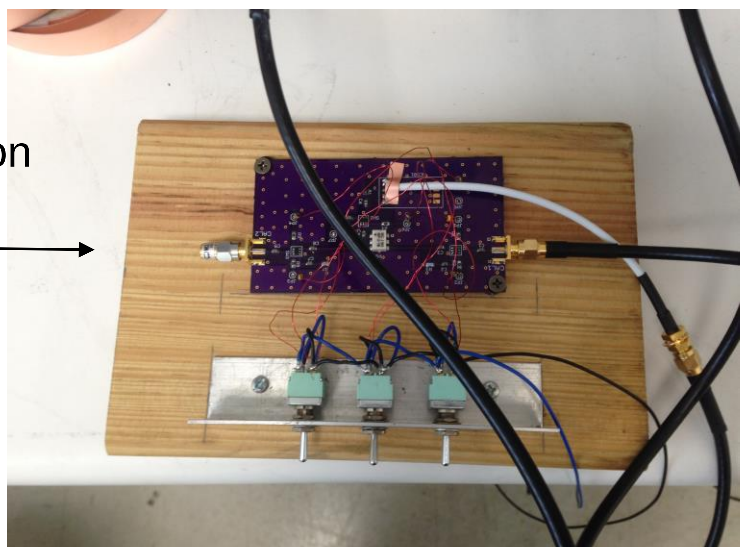


LNA

Receiver



Calibration Board



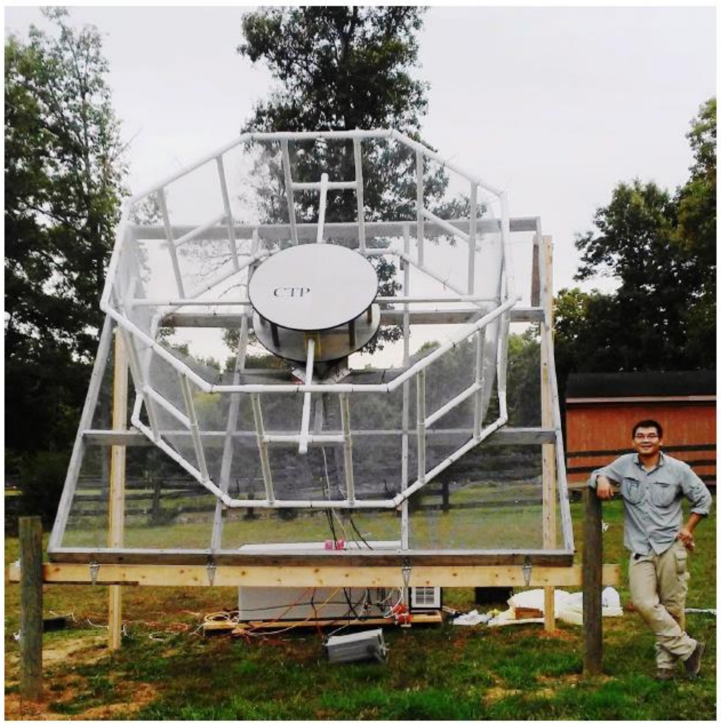
Status

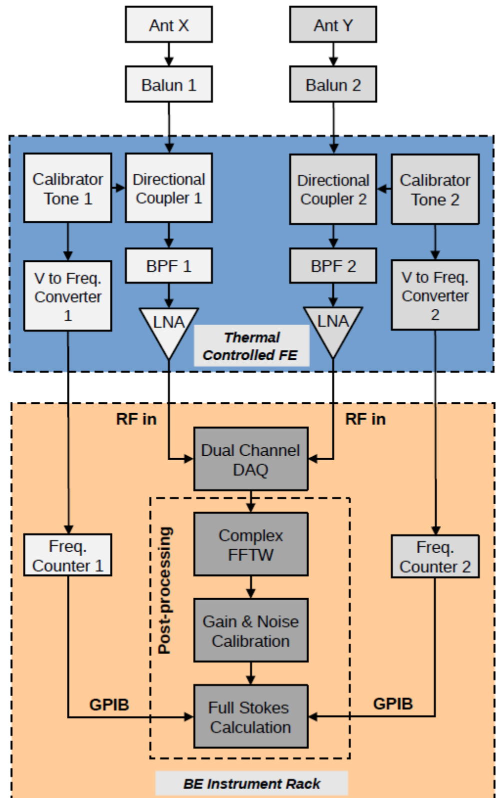
- Initial test of 310 MHz POC completed
- First set of ADS models completed
- Final 310 MHz Rcvr board completed
- Correlation tests to begin shortly
- Initial 60-110 MHz Rcvr design started

DAPPER Heritage

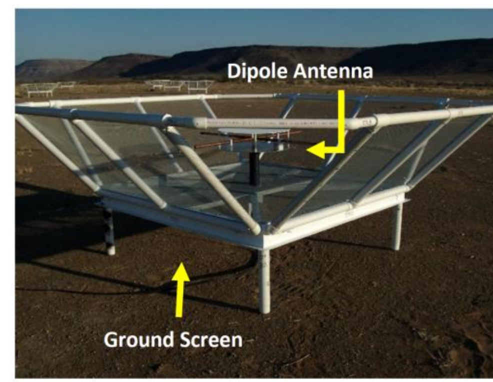
Cosmic Twilight Polarimeter – Initial Tests of Dynamic Polarimetry

CTP-1





CTP-2

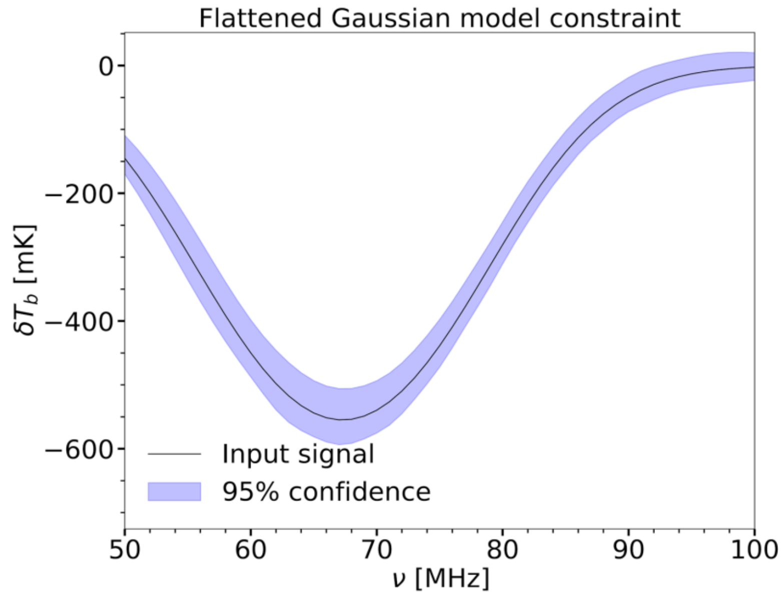


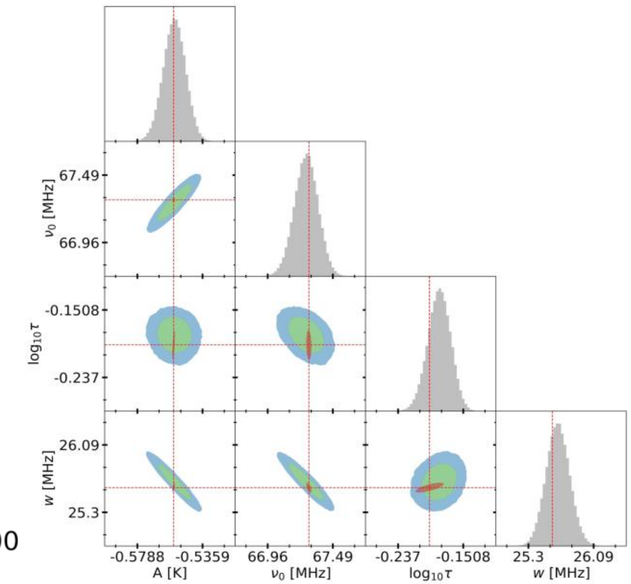
Nhan, Bordenave, Bradley, Burns, Tauscher, Rapetti, Klima, 2019, ApJ, 883, 126

DAPPER
Dark Ages Polarimeter PathfindER

DARK COSMOLOGY:
INVESTIGATING DARK MATTER IN THE DARK AGES

Signal Extraction and Parameter Constraints





Observation strategy (polarization and time dependence; Paper III)

Measured data

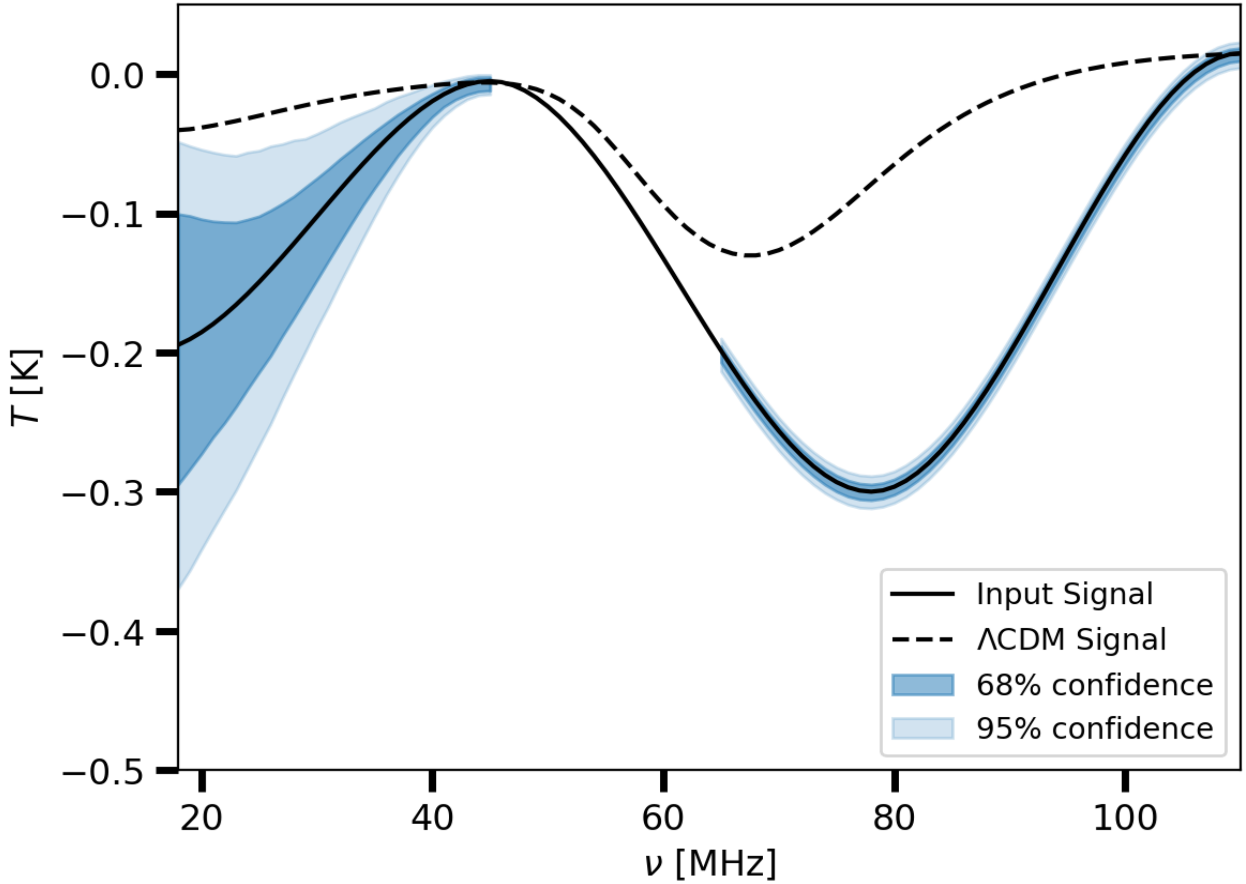
Frequency space signal fitting using training sets (Paper I)

Parameter space signal fitting using MCMC (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.

See also Workshop talks by Rapetti, Tauscher, Bassett, & Hibbard

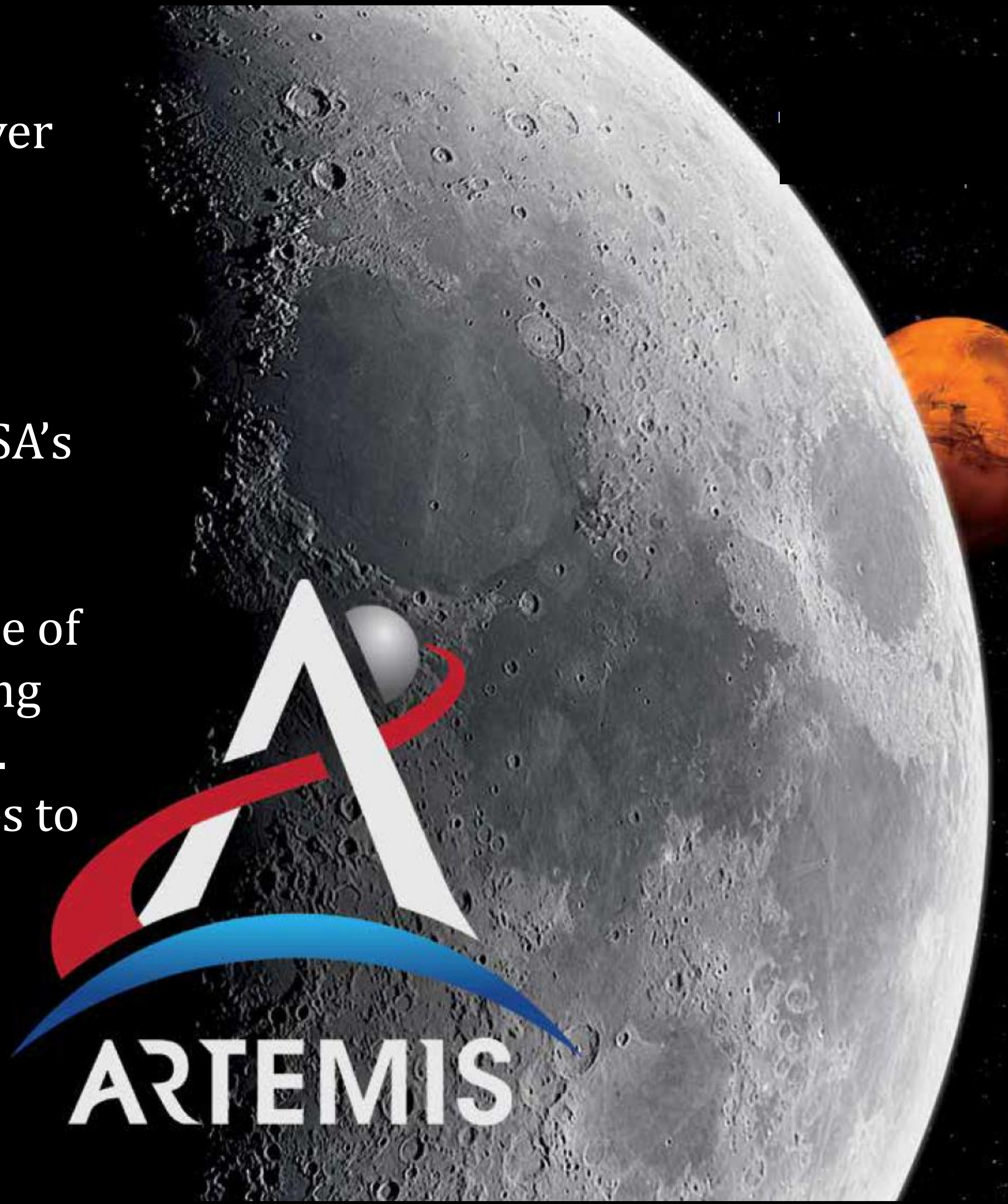
End-to-End Simulated DAPPER Observations



Simulated DAPPER observations including statistical plus systematic uncertainties. DAPPER will distinguish between a standard cosmology model and exotic physics models with high confidence.

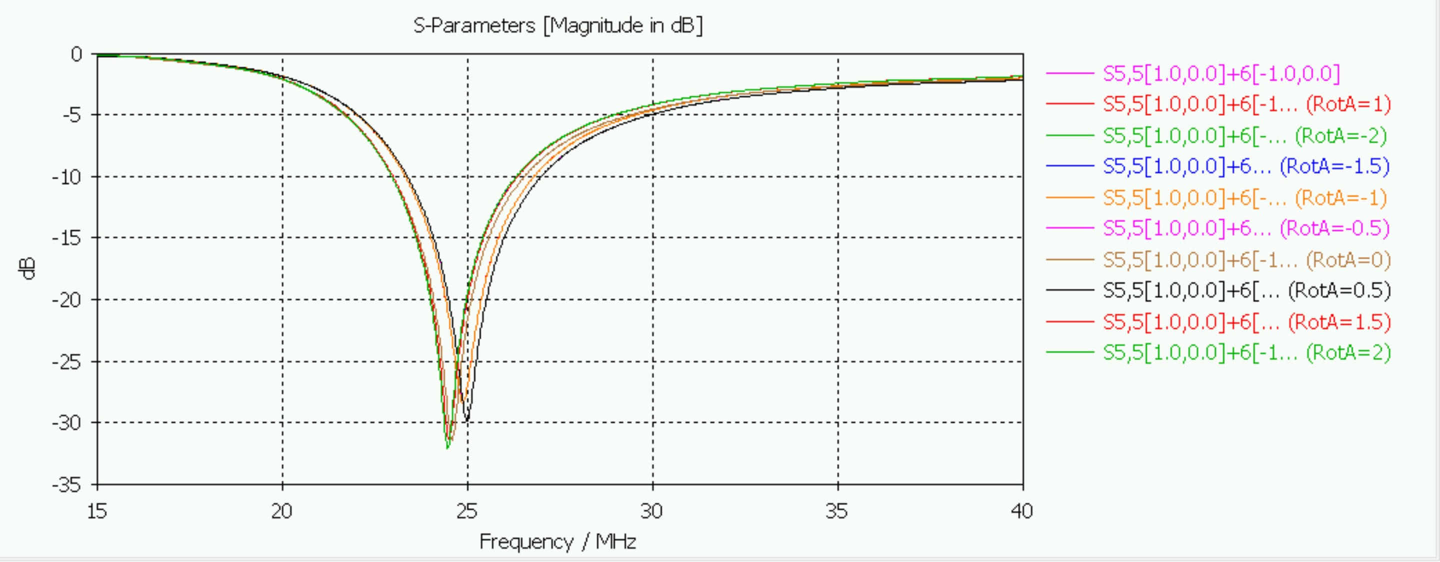
Summary & Conclusions

- NASA Commercial Lunar Payload Services (CLPS) program will deliver radio science payload to the lunar surface next year (ROLSES).
- DAPPER will take advantage of transportation & communication infrastructure associated with NASA's Artemis.
- DAPPER will make spectral observations from the lunar farside of the Dark Ages & Cosmic Dawn using the highly redshifted 21-cm signal.
- Instrument development continues to refine antenna designs, receiver, & data pipeline.

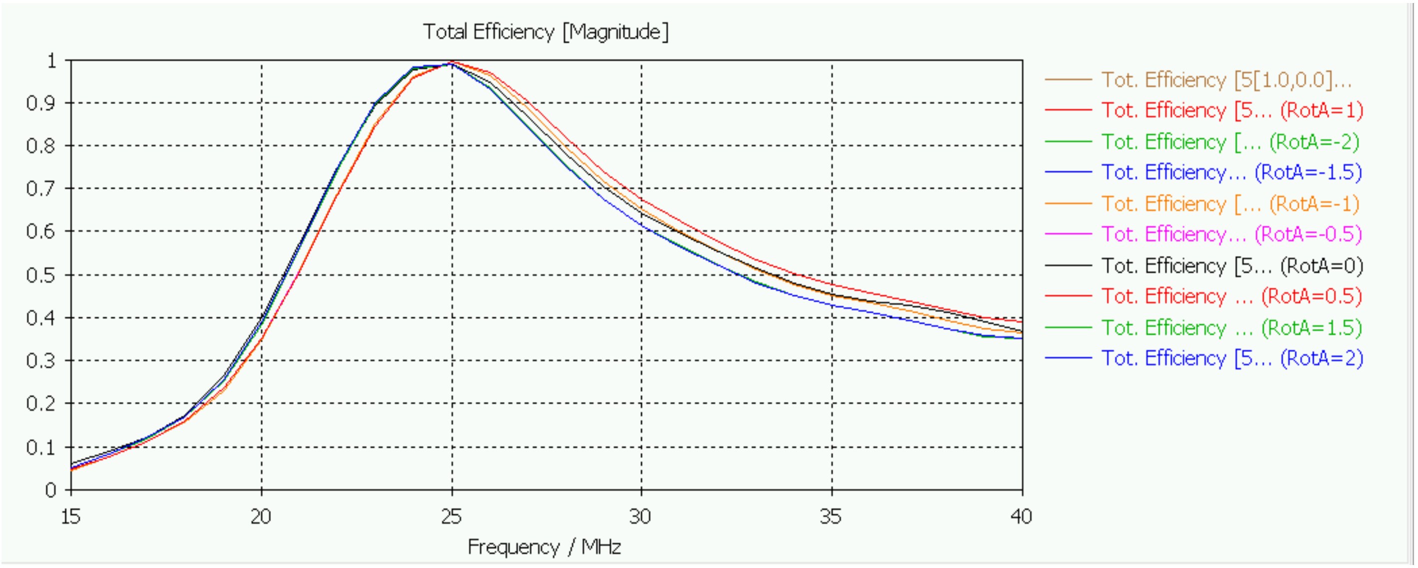


NESS
Network for Exploration and Space Science

Mechanical Mode Effects on Electromagnetic Performance: Tuning

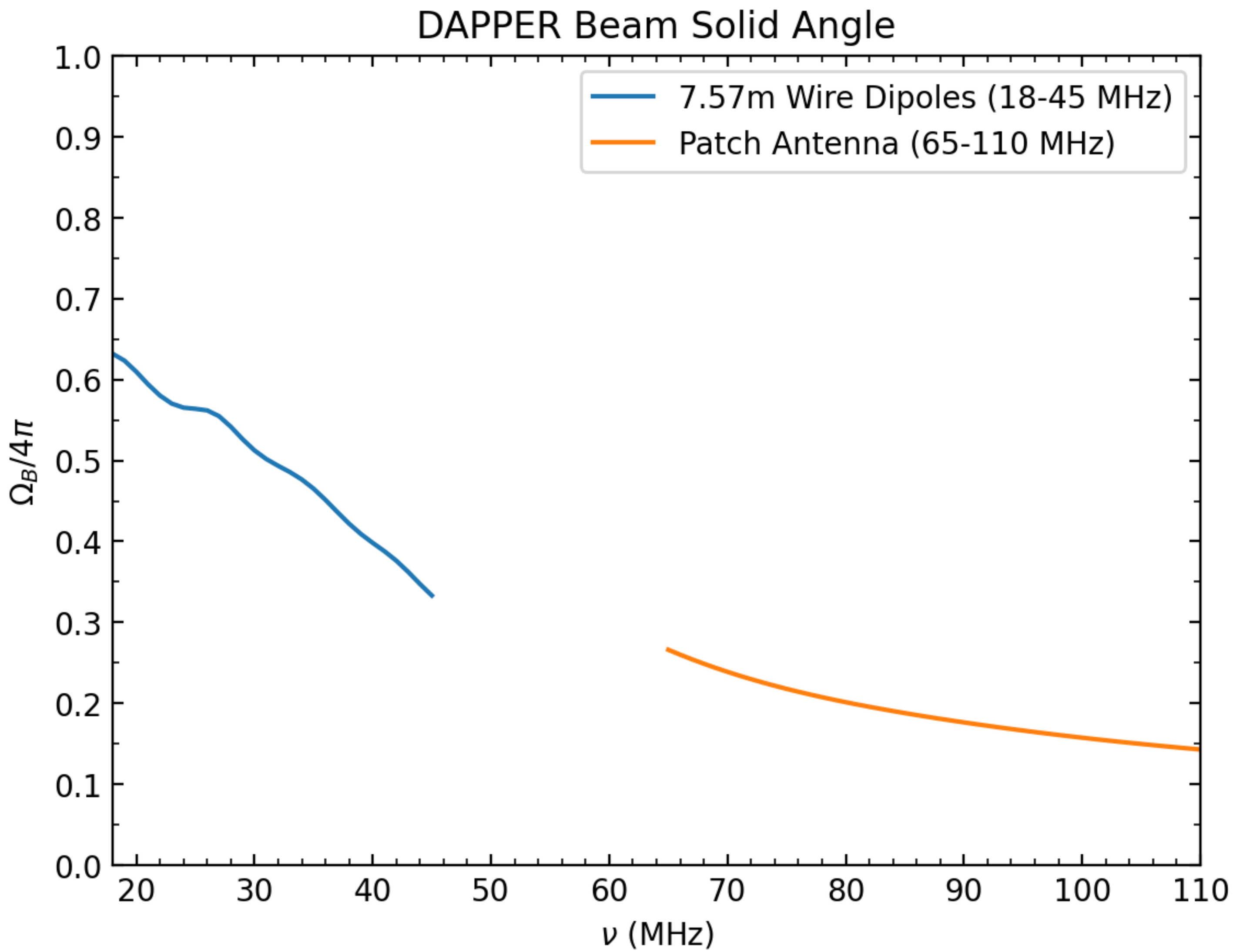


Antenna Tuning for several wire twist angles



Efficiency for several wire twist angles

Chromaticity of the DAPPER Antennas



The 21-cm Global signal

Spectral Features:

A: Dark Ages: test of standard cosmological model

B: Cosmic Dawn: First stars ignite

C: Black hole accretion begins