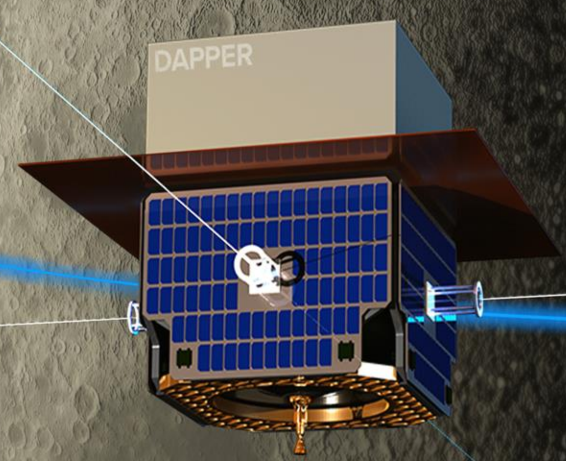
DAPPER

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



NASA · Ames Research Center · CU · NRAO · The University of California Berkeley 1868 · bradford space

DAPPER Project Team Members

1.	Jack Burns	PI	CU Boulder
2.	Neil Bassett	Data Pipeline	CU Boulder
3.	Joshua Hibbard	Data Pipeline	CU Boulder
4.	Keith Tauscher	Data Pipeline	CU Boulder
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7.	David Rapetti	Data Pipeline	NASA Ames
8.	Tim Snyder	S/C Engineer	NASA Ames
9.	Rich Bradley	Co-I: Receiver; High-band Antenna	NRAO
10.	David Bordenave	Antennas/receiver	NRAO
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14.	Keith Goetz	Antenna SE	U. Minn
15.	Lindsey Hayes	PM-UCB	UC Berkeley
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17.	Marc Pulupa	Receiver Engineer	UC Berkeley

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 October 2021 using Intuitive Machines Nova-C lander.

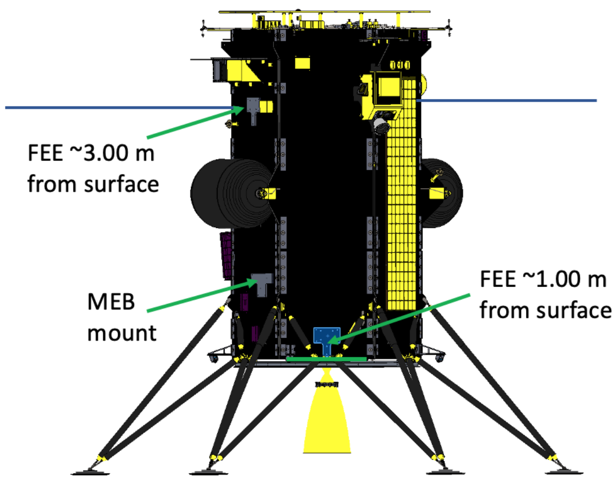


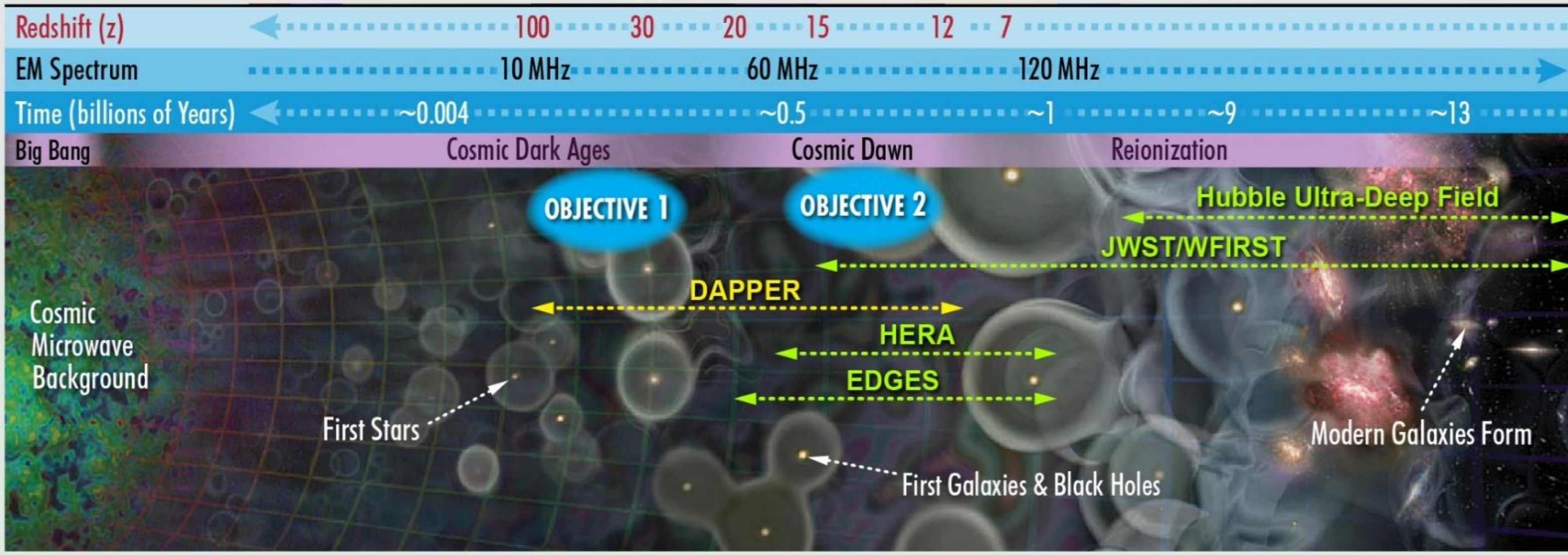
Diagram of the NOVA-C lander that will take the ROLSES payload to the lunar surface in 2021.

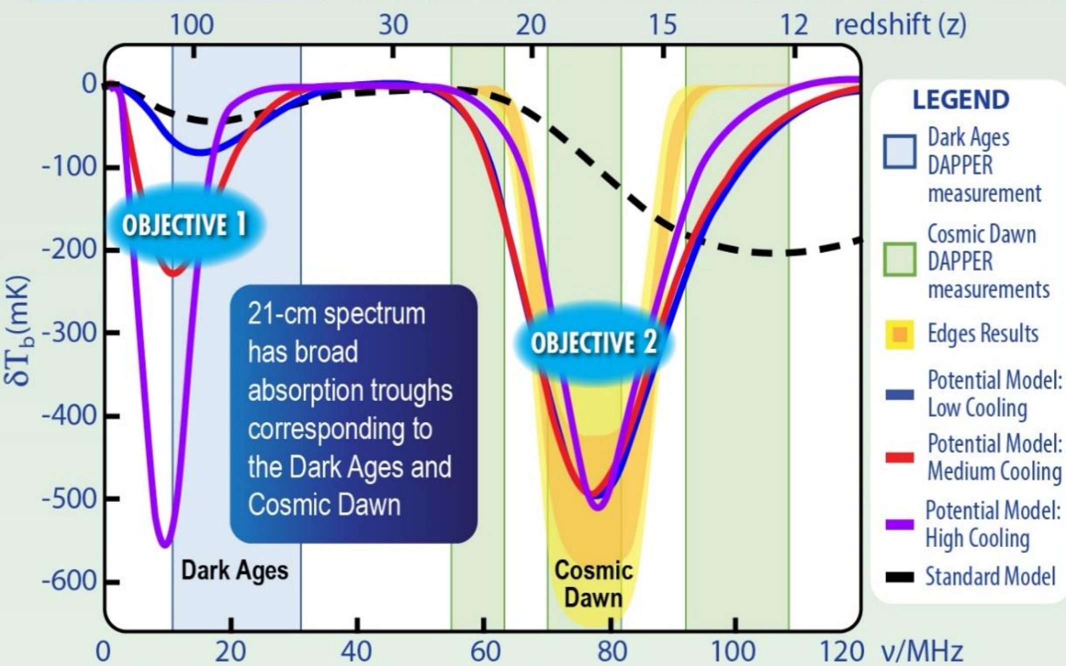
SCIENCE

OBJECTIVE 1:
- Determine the level of (dis)agreement with the standard cosmological model caused by dark matter in the Dark Ages.

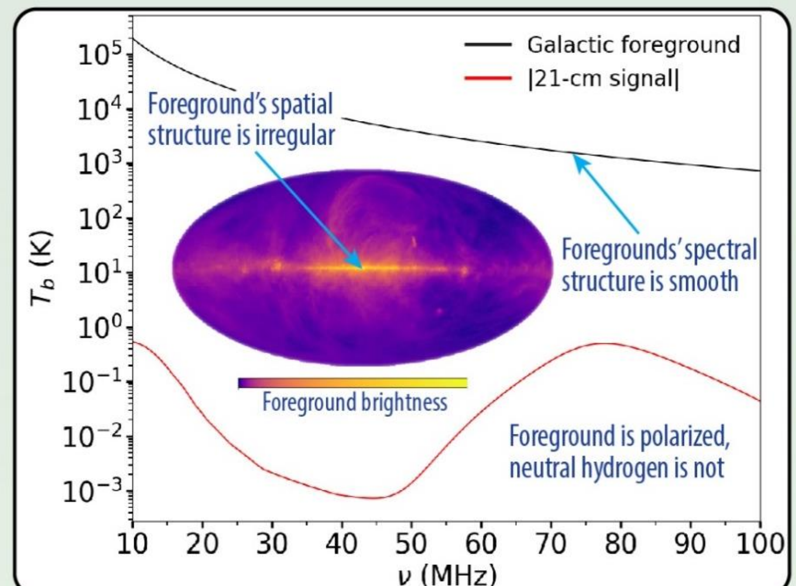
OBJECTIVE 2:
- Determine the level of excess cooling above the adiabatic limit for Cosmic Dawn.
- Determine when the first stars and black holes formed.

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



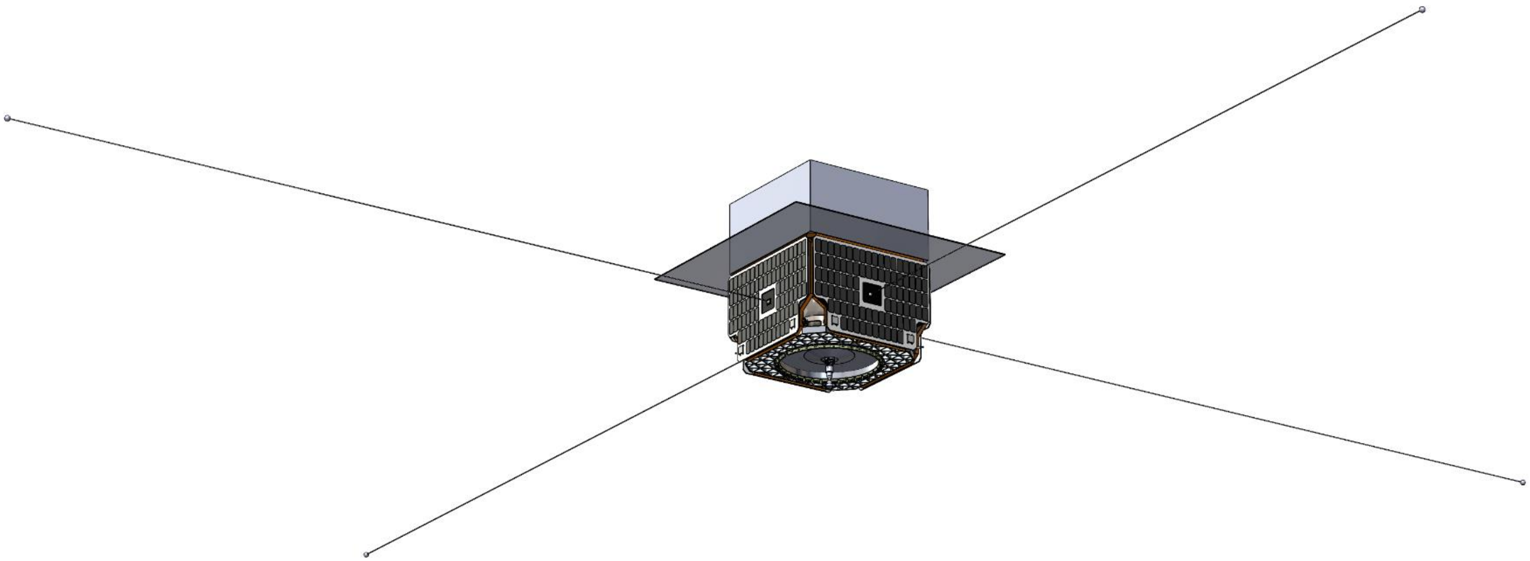


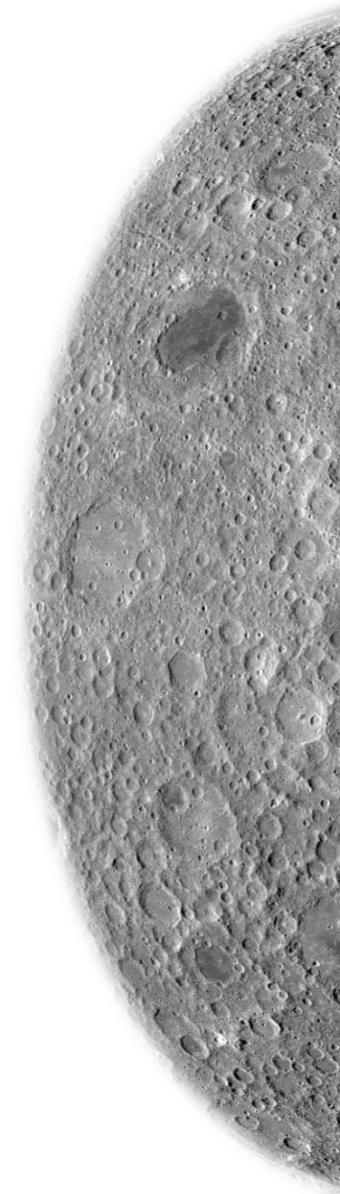
DAPPER uses the 21-cm all-sky signal to observe redshifts z = 83-12, associated with the Dark Ages and the Cosmic Dawn.



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

Mission Overview

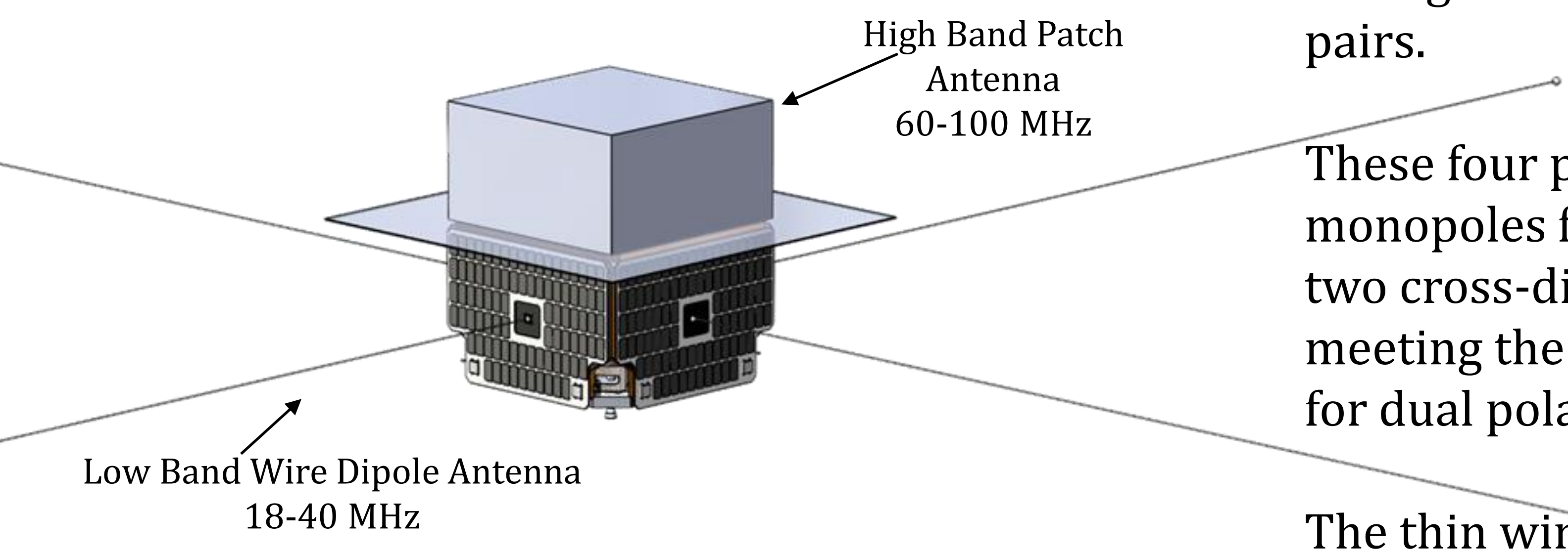




- 2 Frequency Bands: 18-40 MHz and 60-110 MHz.
- Measure all 4 Stokes parameters.
- Spin spacecraft at 2-5 rpm for dynamic polarimetry.
- Integration time: 5000 hrs at low band and 500 hrs at high band to achieve ~20 mK thermal noise.
- Low 50×125 km equatorial lunar orbit to maximize time in radio quiet cone.

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

DAPPER Low Band Antenna



Four deployable wire antenna units (~3.5-m length), arranged in two, orthogonal co-linear pairs.

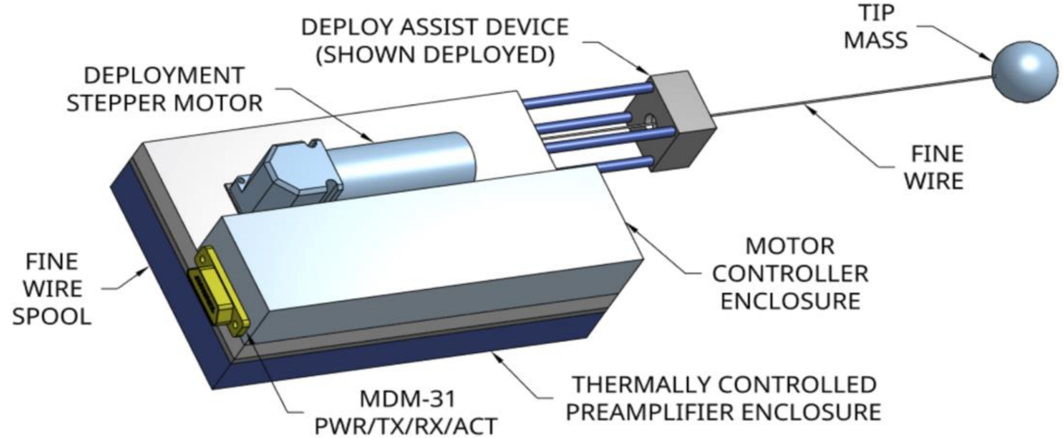
These four physical monopoles function as two cross-dipoles, meeting the requirement for dual polarization.

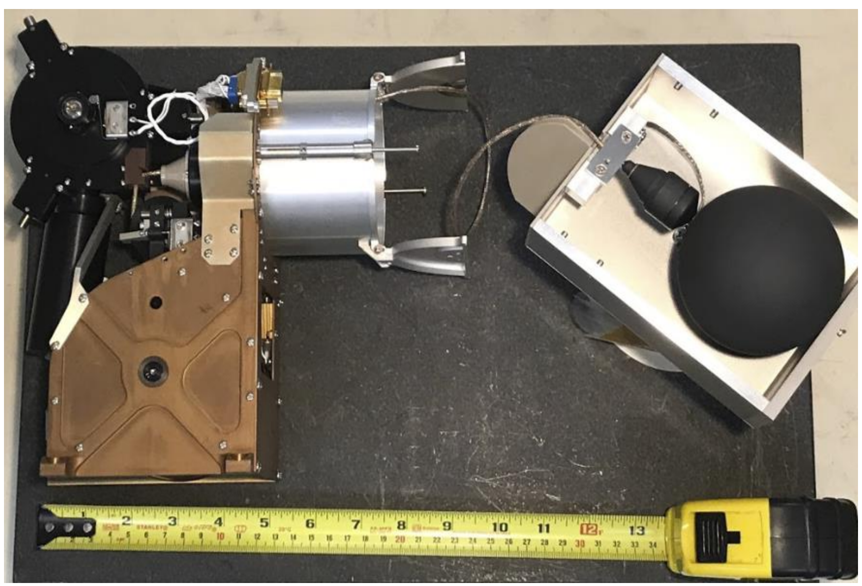
The thin wire antennas are wound on spools and deployed by commanded motor-drive in the spin-plane of the spacecraft.

Low Band Wire Antenna Heritage

DAPPER will use fine wire, rather than a wire harness, simplifying the design.

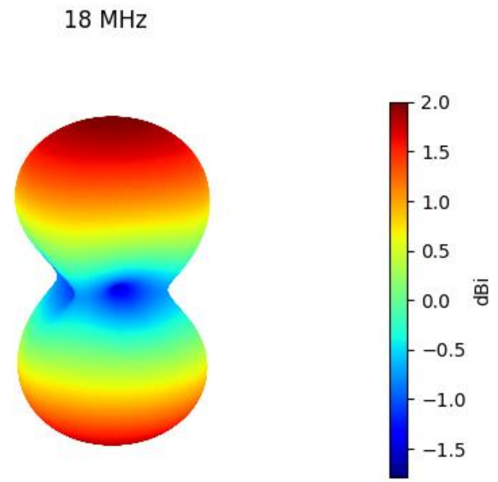
The DAPPER antenna enclosure will be designed to optimize antenna impedance.

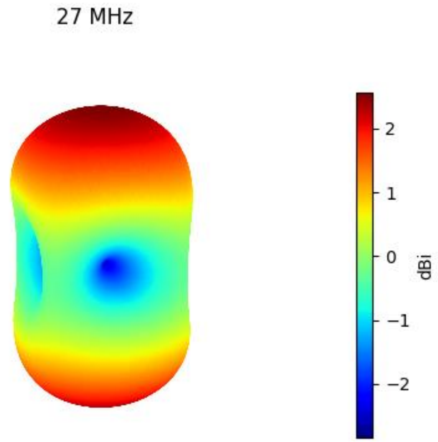


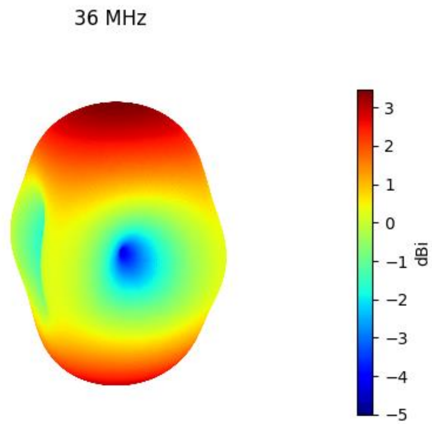


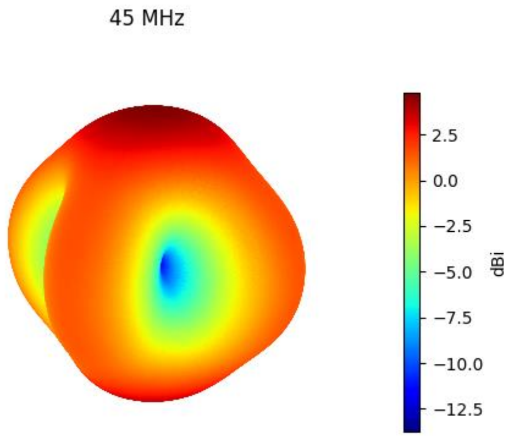
A THEMIS/EFI spin plane boom system. The THEMIS mission successfully deployed 20 of these units on orbit. The DAPPER wire boom antennas derive directly from the THEMIS/EFI and Van Allen Probe (RBSP) units

Low Band Wire Antenna Beams









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.

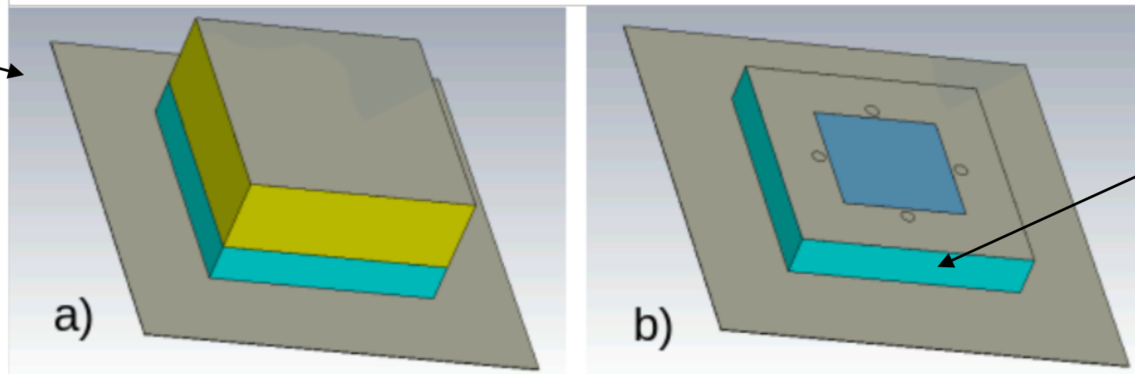
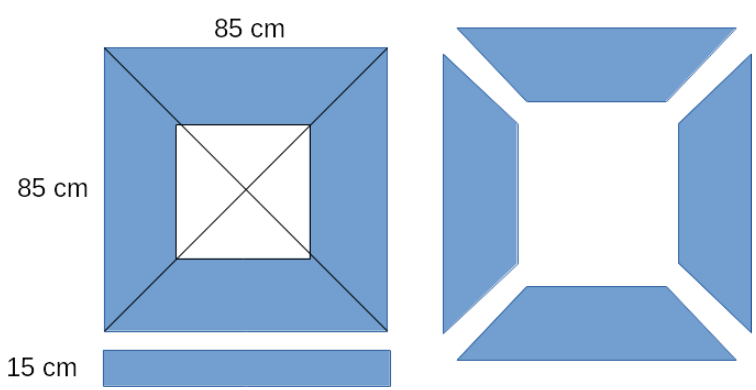
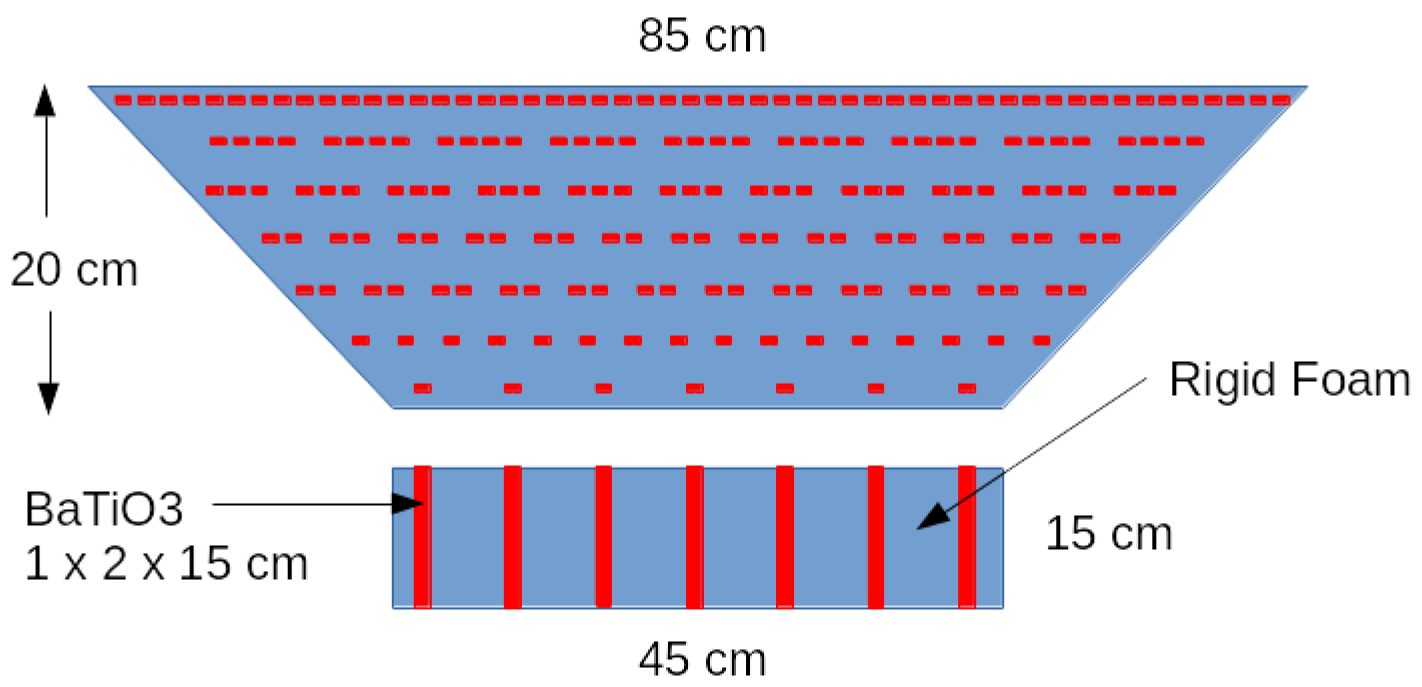


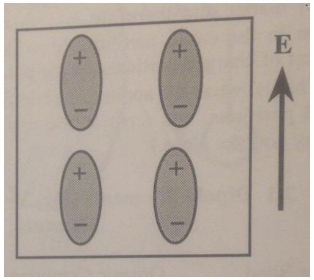
Figure 3: Rendering of the baseline patch antenna. Panel a) is an overall view, and b) is a cutaway showing the middle metal layer and feed connections.



DAPPER Patch Design

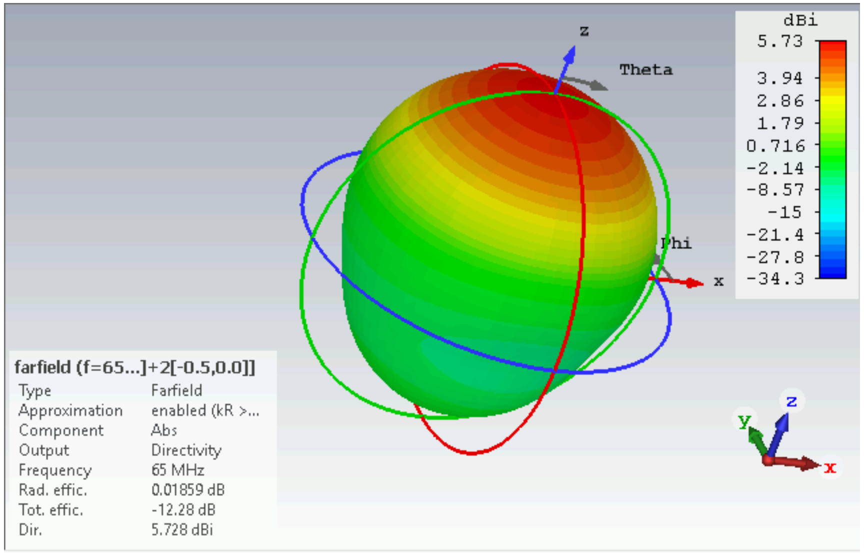


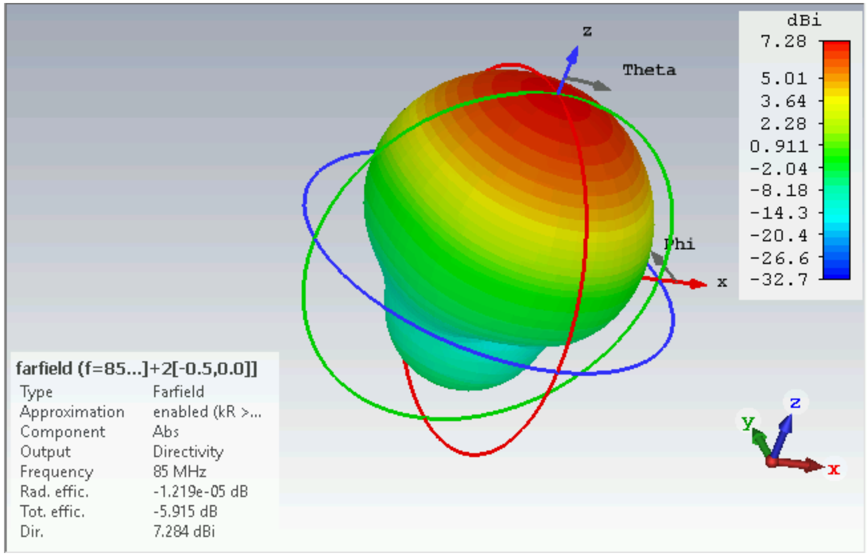
BaTiO3 is the most widely used ferroelectric material, and even sixty years after its discovery, it is the most important multilayer ceramic dielectric.

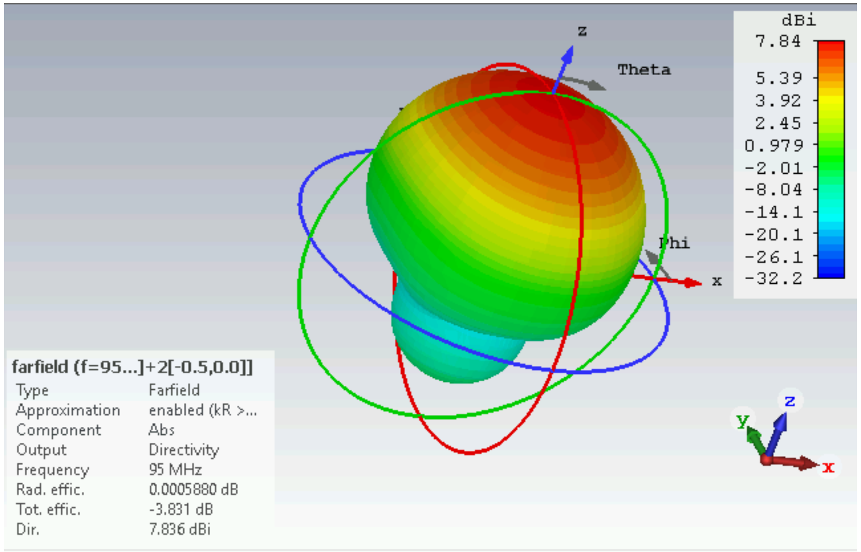


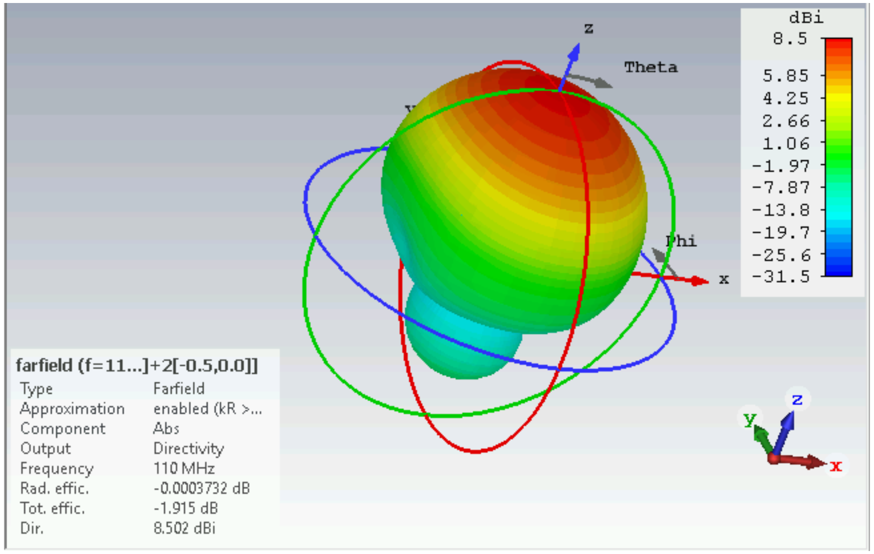
Molecular alignment leading to high dielectric constant of BaTiO3

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



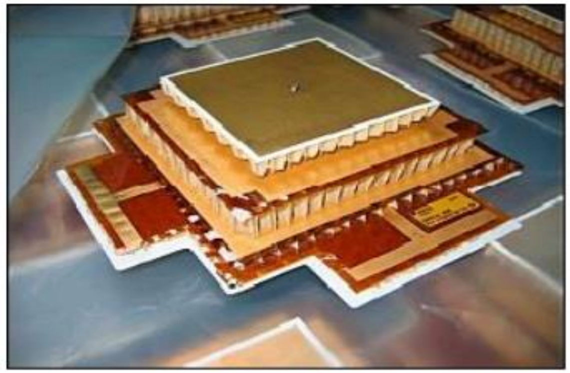






Patch Antenna Heritage

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



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

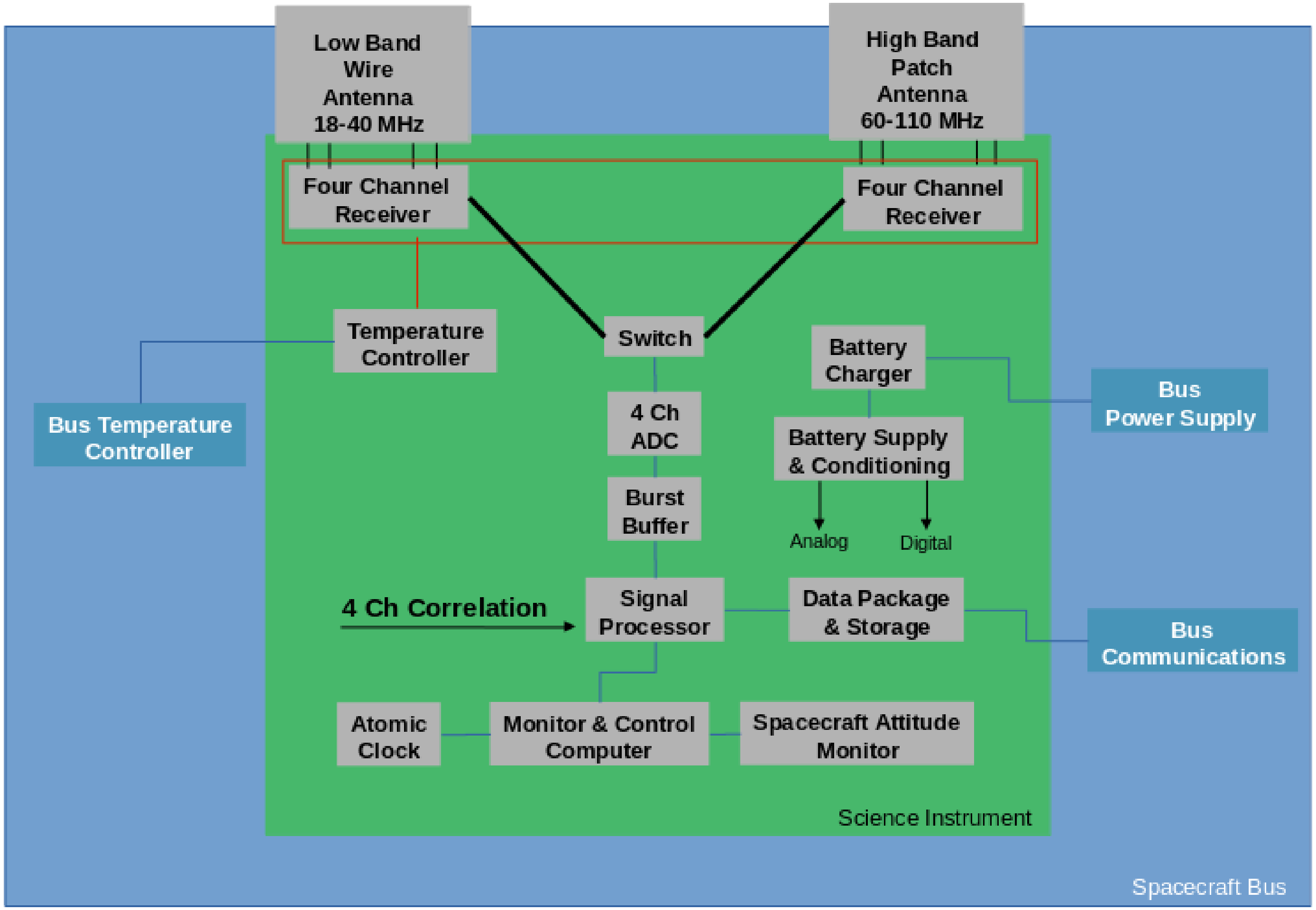
Table 79: Constellation ISL Comparison

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

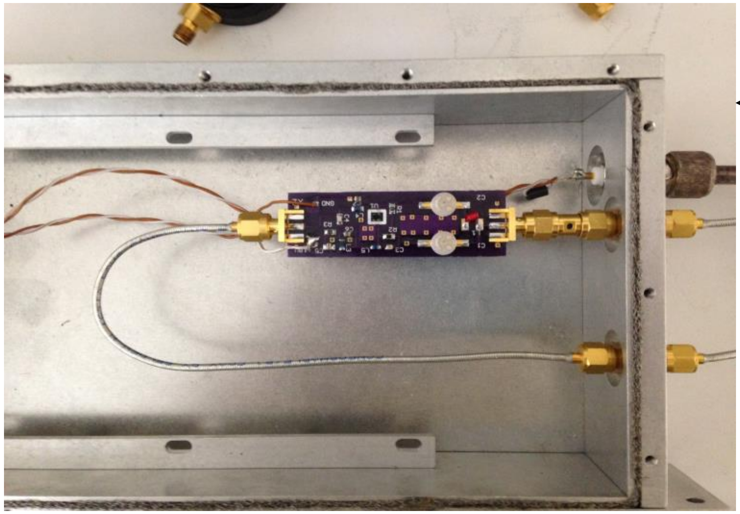
Four Channel Correlation Receiver



Receiver Concept

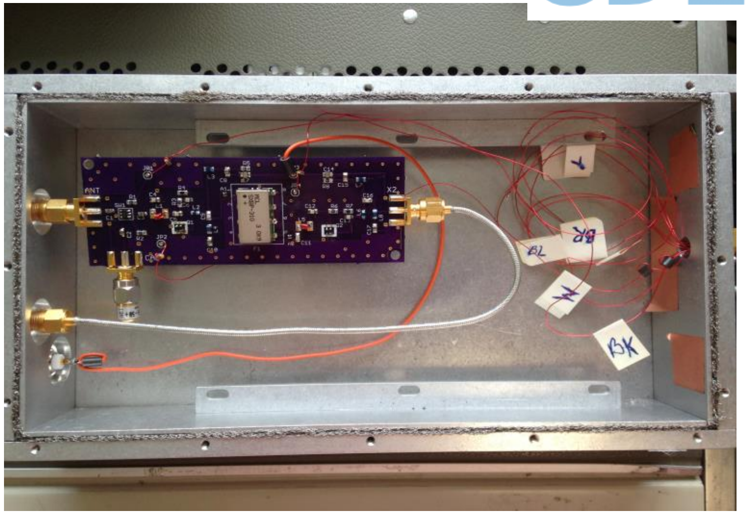
Current Status

CDL

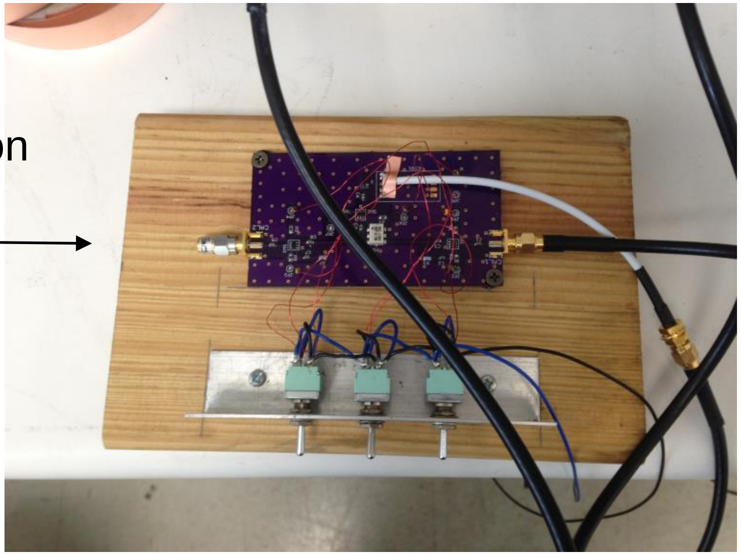


LNA

Receiver



Calibration Board



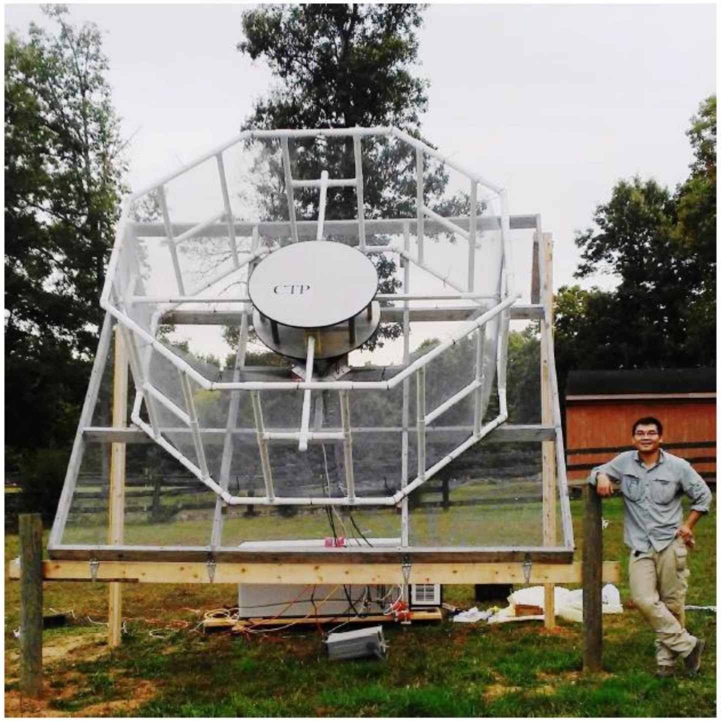
Status

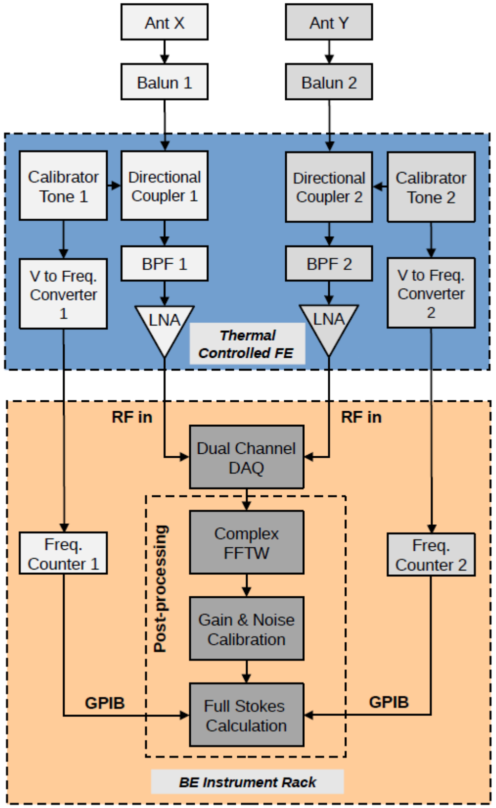
- Initial test of 310 MHz POC completed
- First set of ADS models completed
- Final 310 MHz Rcvr board completed
- Correlation tests to begin shortly
- Initial 60-110 MHz Rcvr design started

DAPPER Heritage

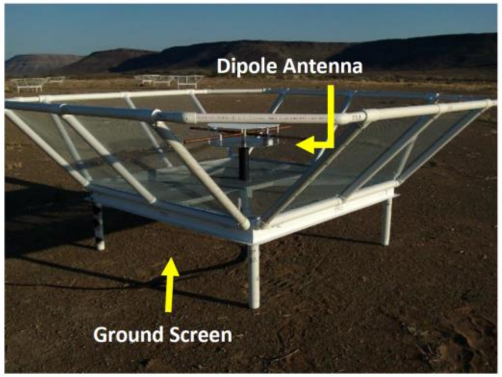
Cosmic Twilight Polarimeter – Initial Tests of Dynamic Polarimetry

CTP-1





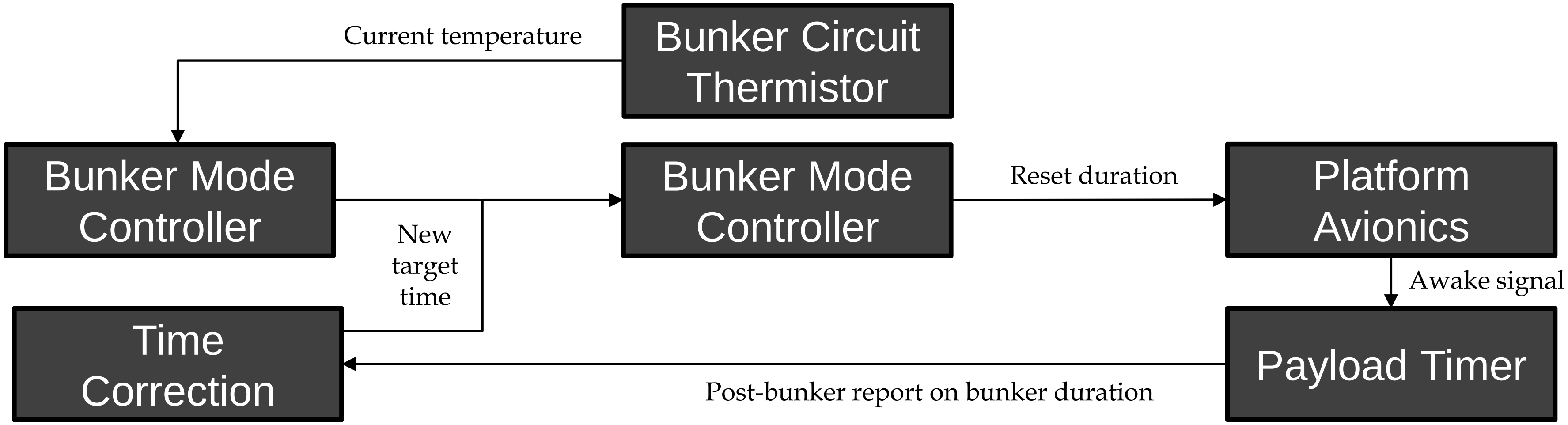
CTP-2



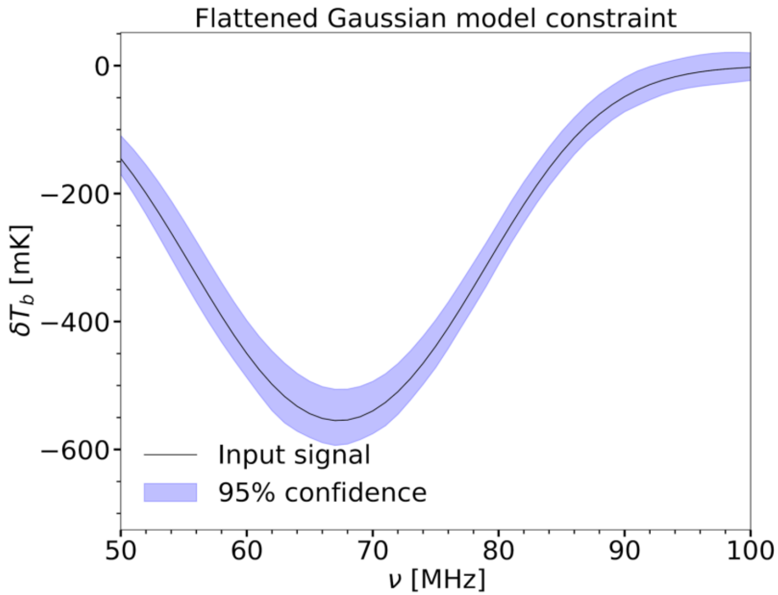
Nhan, Bordenave, Bradley, Burns, Tauscher, Rapetti, Klima, 2019, ApJ, 883, 126

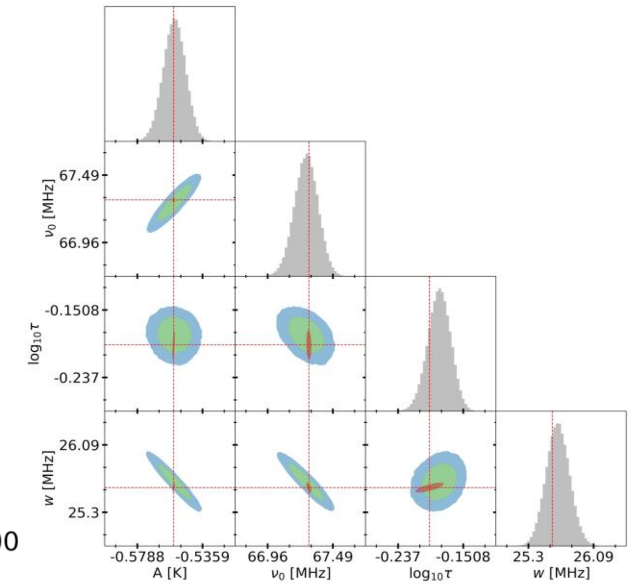
Bunker Mode - Diagram

- In order to correct for long-duration drifts in timing, a closed-loop controller is proposed
- Between each set of observations, the controller will adjust the
- Duration of the previous bunker mode is timed by the payload



Signal Extraction and Parameter Constraints





Observation strategy (polarization and time dependence; Paper III)

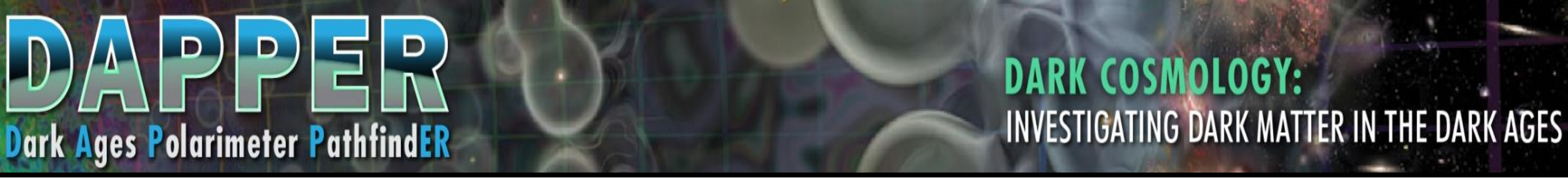
Measured data

Frequency space signal fitting using training sets (Paper I)

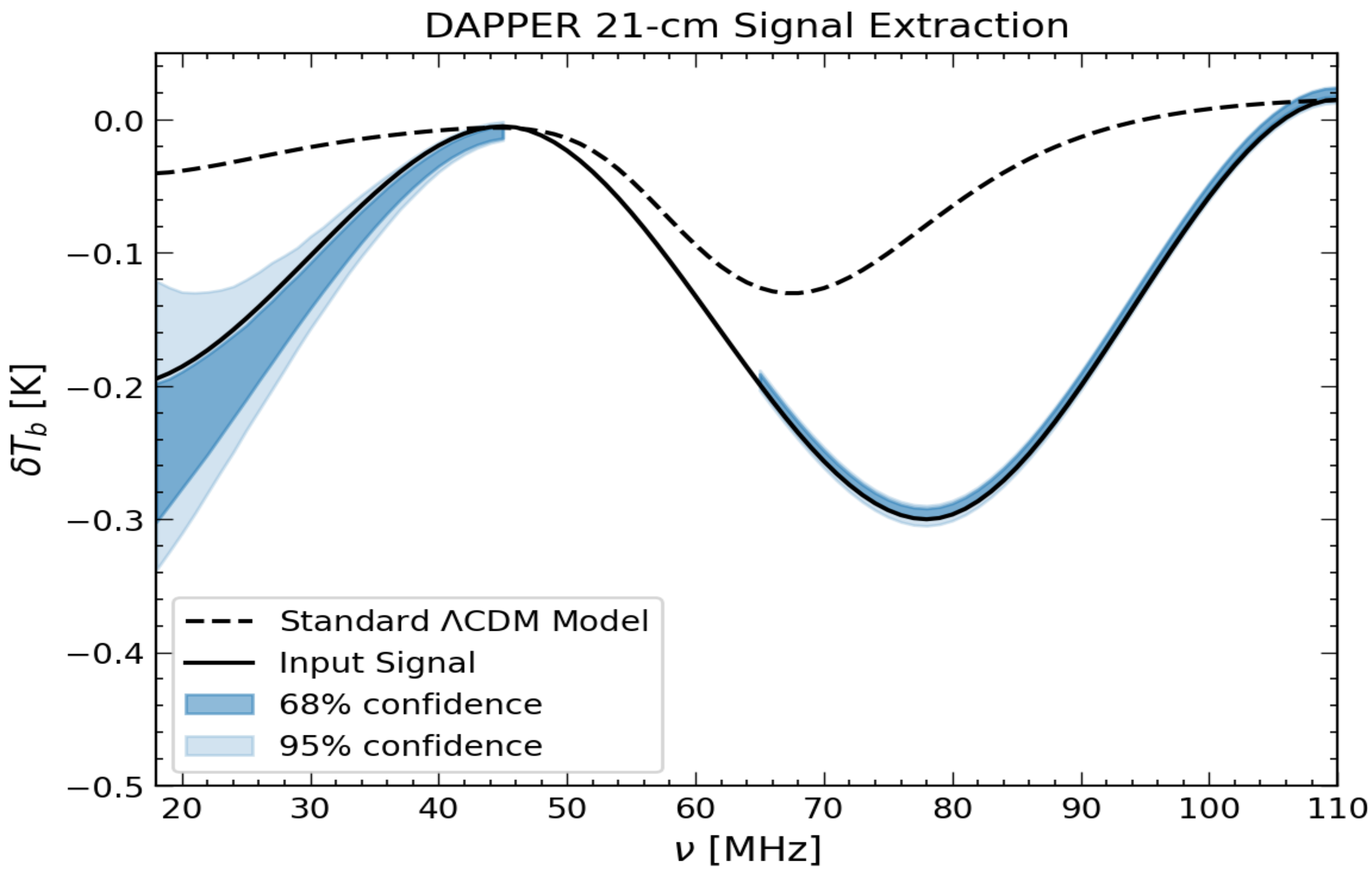
Parameter space signal fitting using MCMC (Paper II)

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, Basset, & Hibbard



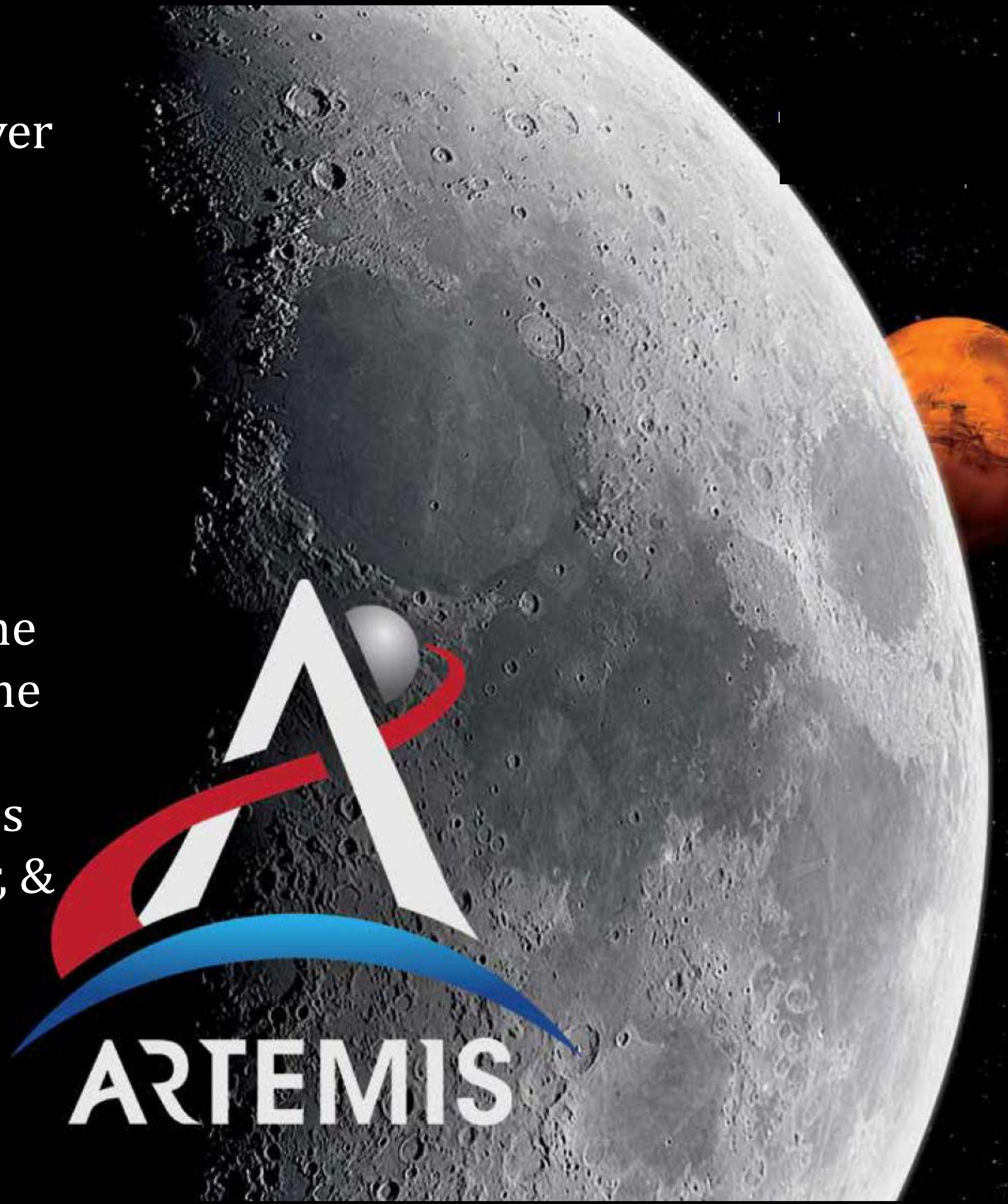
End-to-End Simulated DAPPER Observations



Simulated DAPPER observations including statistical plus systematic uncertainties. DAPPER will distinguish at >5σ between a standard cosmology model and exotic physics models.

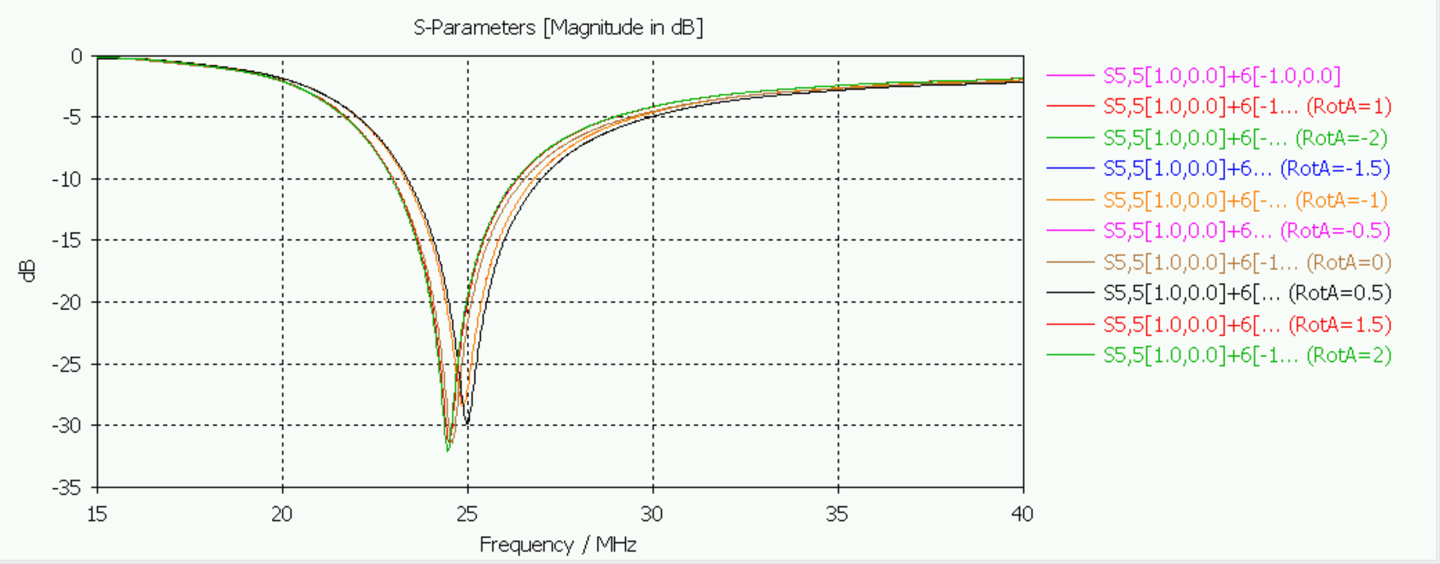
Summary & Conclusions

- 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 lunar orbit of the Dark Ages & Cosmic Dawn using the highly redshifted 21-cm signal.
- Instrument development continues to refine antenna designs, receiver, & data pipeline.

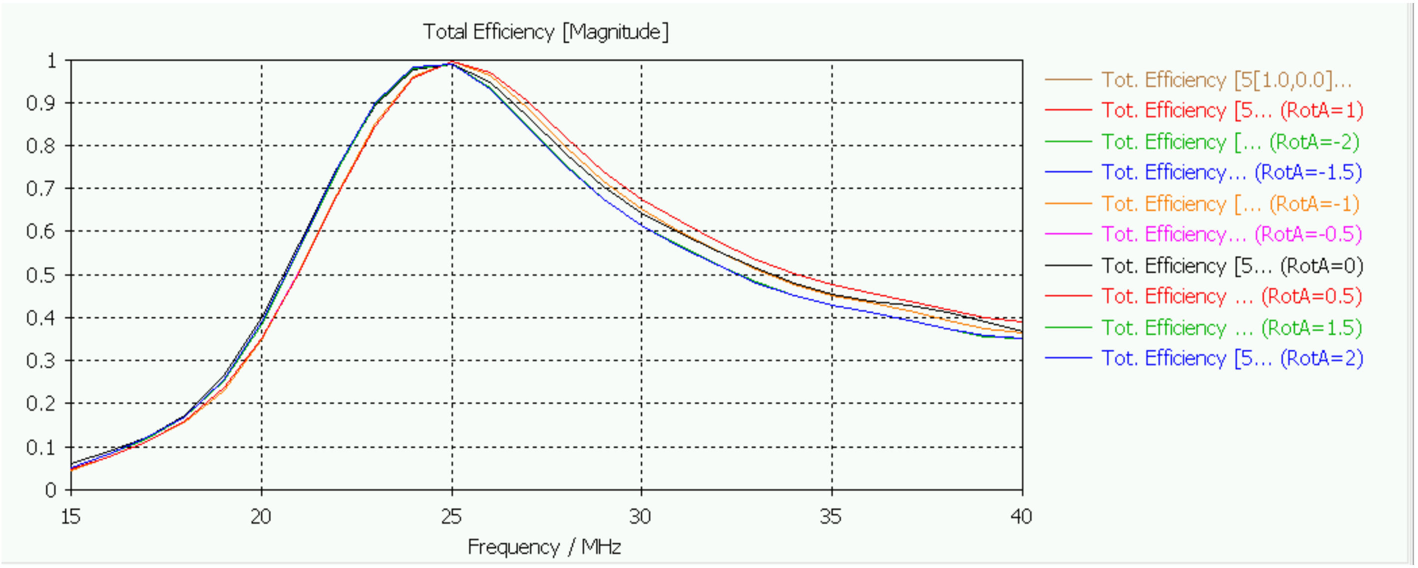


NESS
Network for Exploration and Space Science

Mechanical Mode Effects on Electromagnetic Performance: Tuning

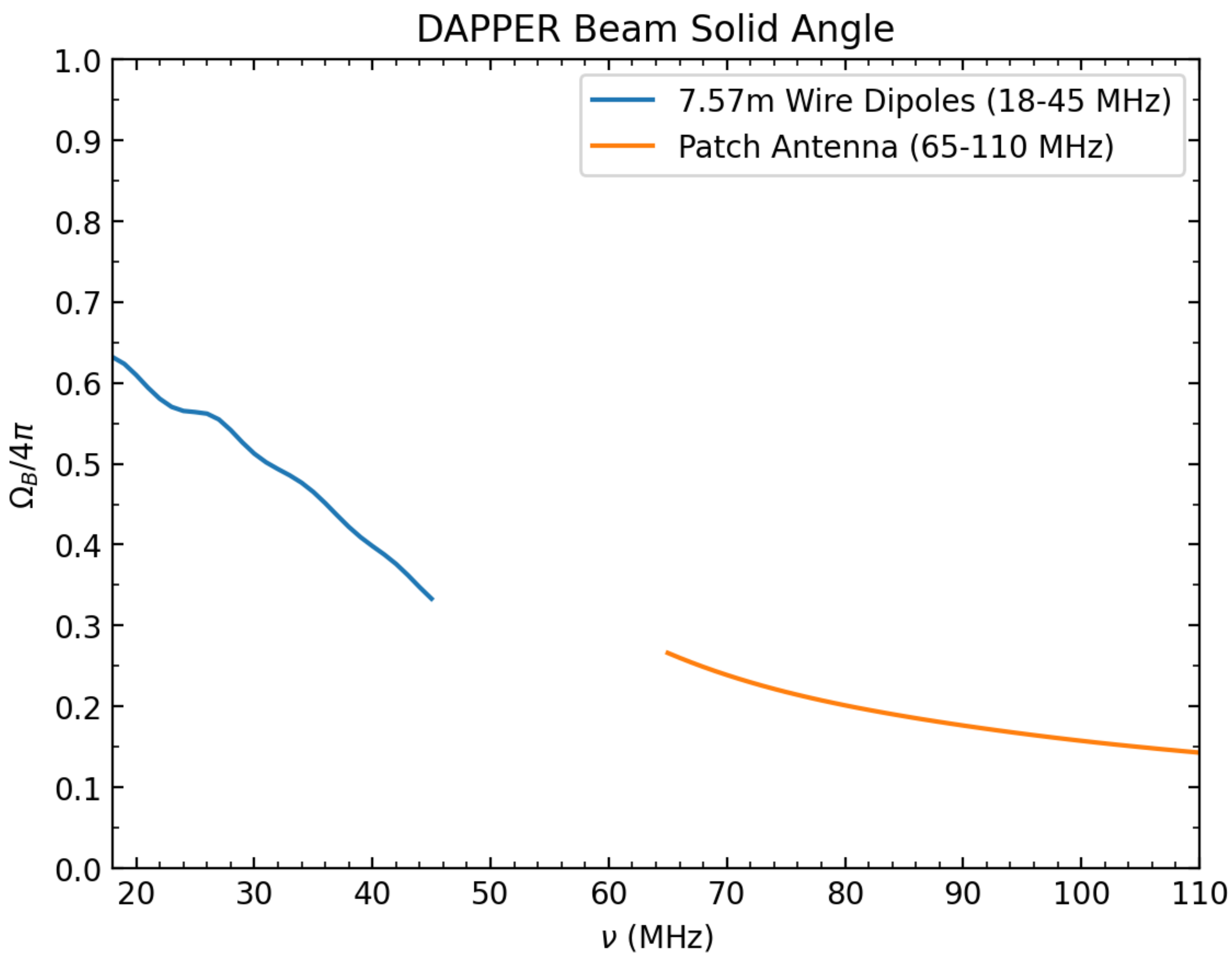


Antenna Tuning for several wire twist angles



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