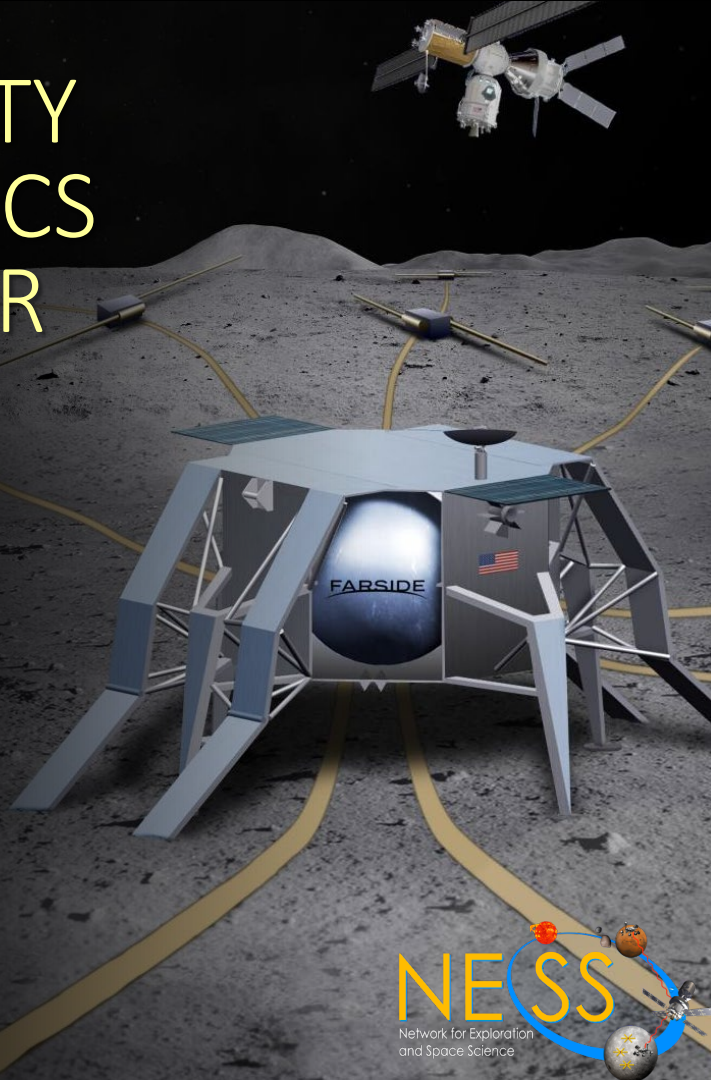
THE OPPORTUNITY FOR ASTROPHYSICS FROM THE LUNAR FARSIDE

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

AAS Splinter Session

Low Frequency Radio Astronomy for Cosmic Origins

13 January 2021



NESS
Network for Exploration and Space Science

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 of 2021 using Intuitive Machines Nova-C lander.

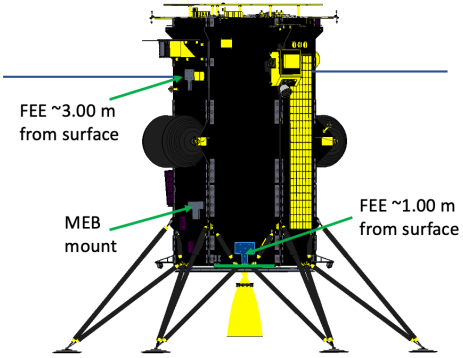
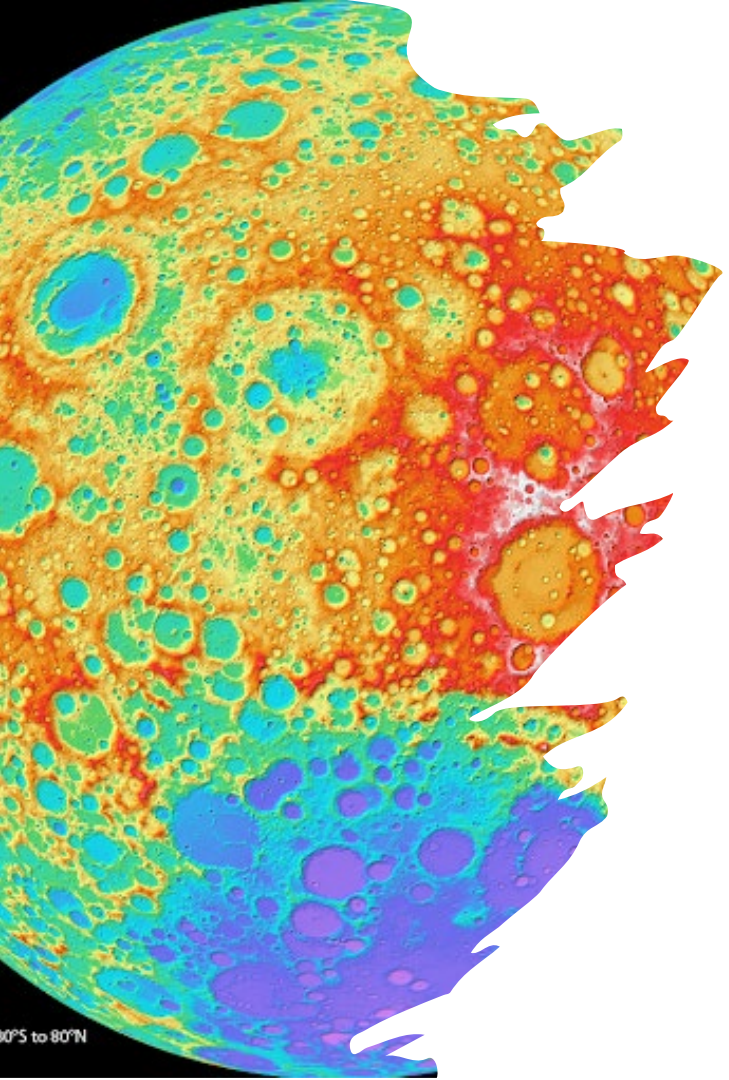


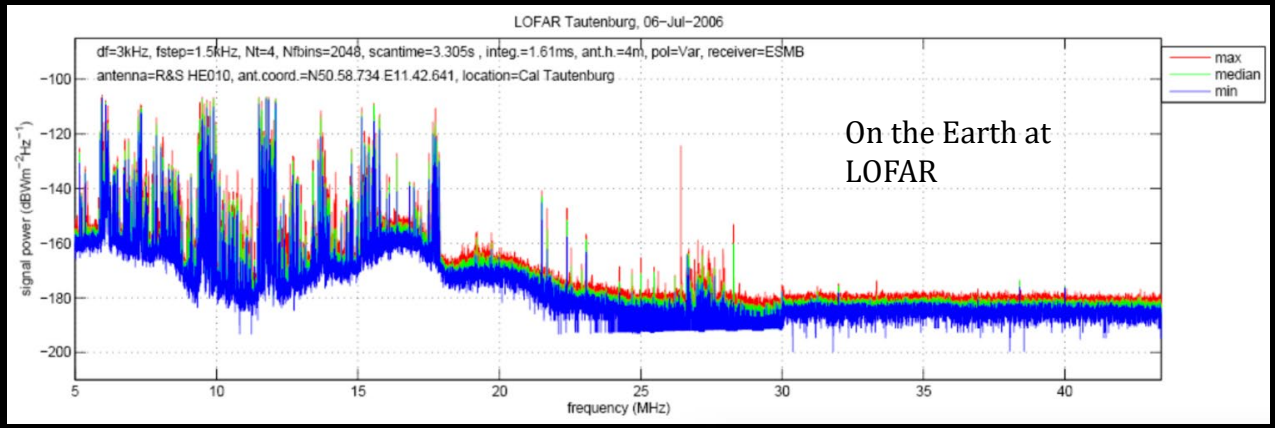
Diagram of the NOVA-C lander that will take the ROLSES payload to the lunar surface in 2021.

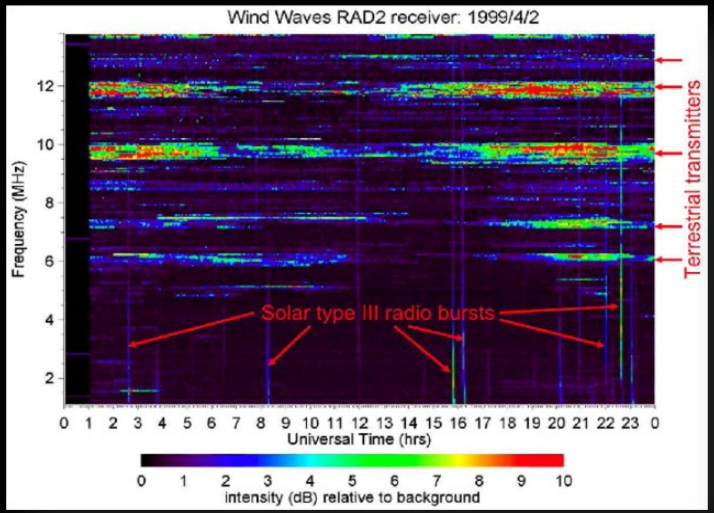


Access to the lunar farside provides an unparalleled opportunity to perform precision 21-cm cosmology due to the

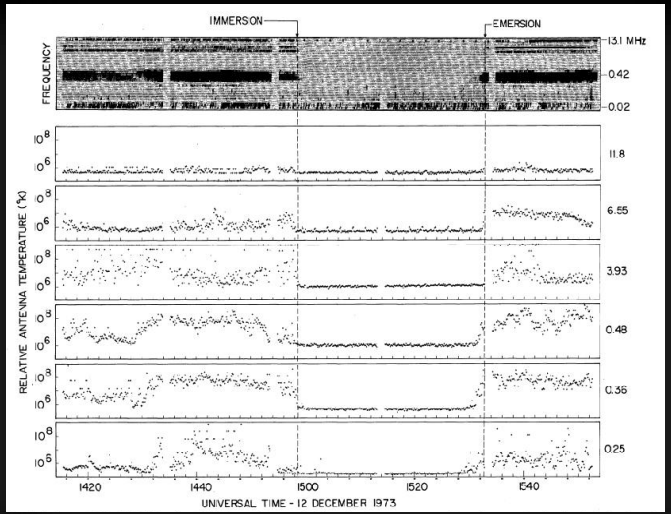
- unique radio-quiet,
- lack of a significant ionosphere,
- dry, stable environment.

Anthropogenic radio-frequency interference





Wind/Waves data near the Moon in



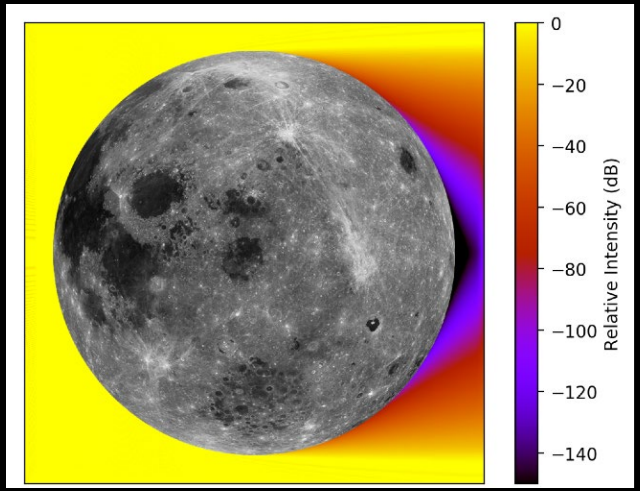
NASA RAE-2 occultation of Earth in 1972

Terrestrial RFI is bad everywhere except lunar farside

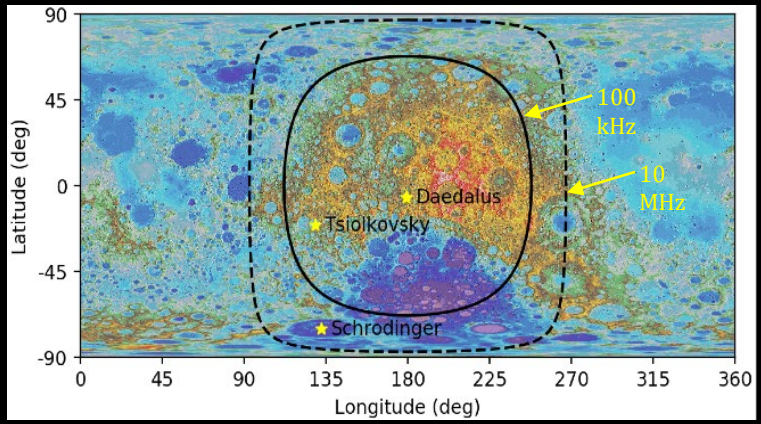
- "Quantifying excess power from radio frequency interference in Epoch of Reionization measurements", Wilensky et al., MNRAS 498, 265–275 (2020)
  - "We conclude that relatively low levels of RFI contamination are sufficient to overwhelm the EoR signal in the 21-cm power spectrum."
- "Characterizing the Radio Quiet Region Behind the Lunar Farside for Low Radio Frequency Experiments", Bassett et al., ASR 66 (6), 1265-1275 (2020)
  - Temperature of RFI from lunar nearside is 750,000 K.

Simulations of the Radio Environment of the Moon

Bassett et al. 2020, *Advances in Space Research*, 66, 1265.



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

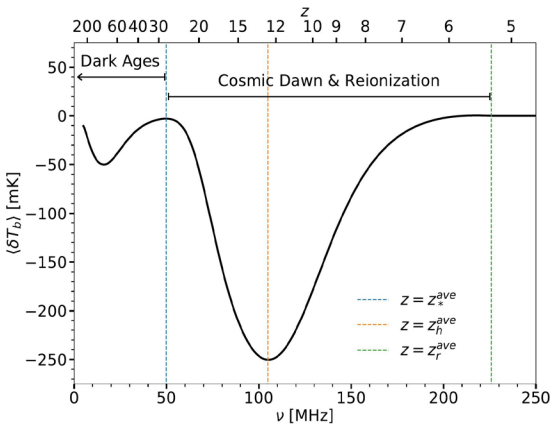


The “radio quiet” region at 100 kHz (solid) and 10 MHz (dashed) defined by ≥ 80 dB attenuation plotted over a map of the lunar surface.

Ionospheric effects

"Quantifying Ionospheric Effects on Global 21 cm Observations", Shen et al., submitted to MNRAS, arXiv:2011.10517

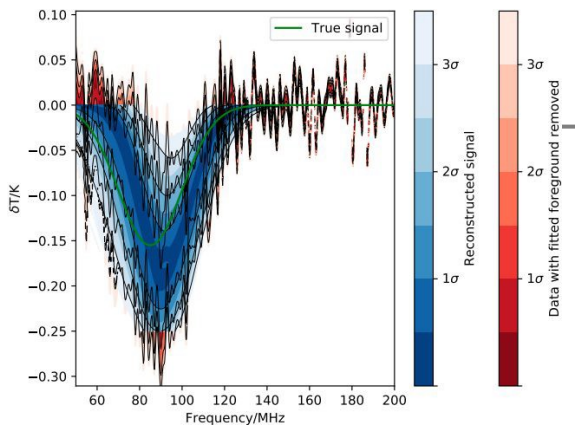
- "It is observed that the ionospheric effects do not cancel out over time". D-layer absorbs & F-layer refracts radio waves.
- "[...] **it is clear that the ionospheric effects have great potential to bury a weak global 21-cm signal of amplitude $\lesssim$ 0.6 K in an otherwise smooth foreground**"
- "[...] a precise knowledge of the ionospheric condition is not currently achievable". Need direction-dependent ionospheric calibration system that is well beyond current capability.



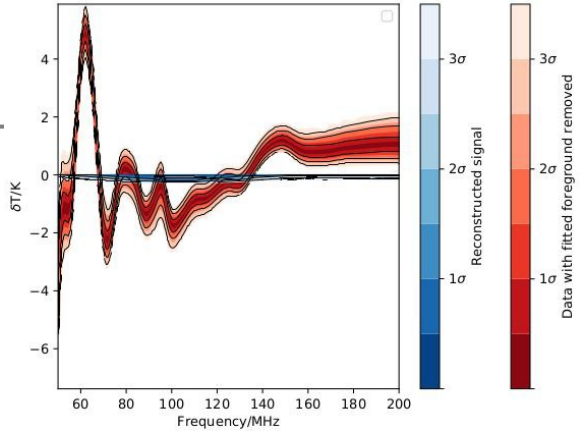
Ionospheric effects (cont.)

REACH (Shen et al. 2021) pipeline results:

Without ionosphere



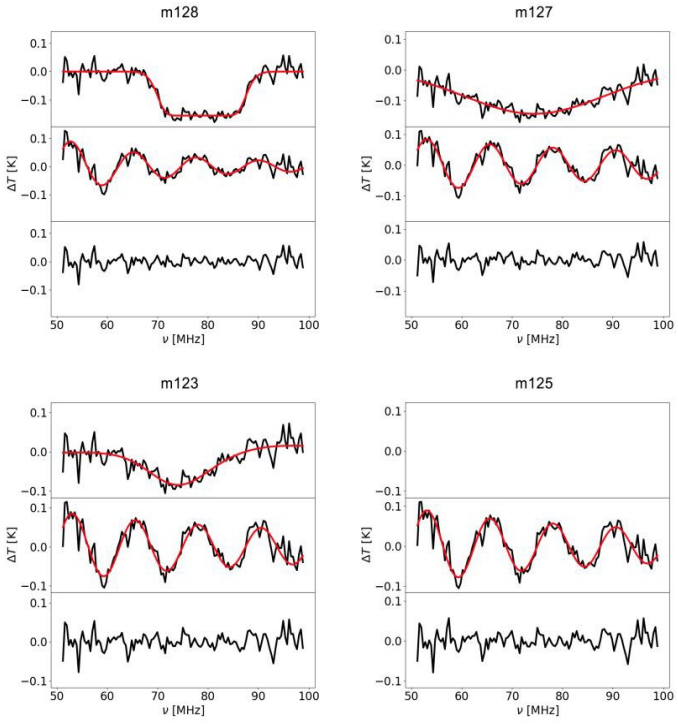
With ionosphere



Environmental Effects: Systematics, physical modeling & assumptions

"Testing for calibration systematics in the EDGES low-band data using Bayesian model selection" Sims and Pober, MNRAS, 492, 22 (2020)

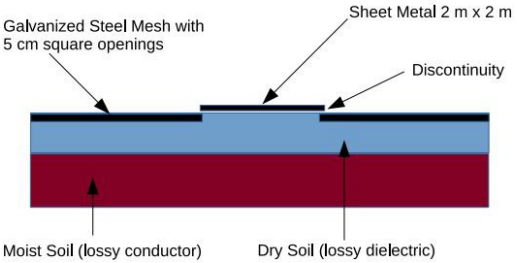
=>EDGES data equally well explained (approximately equal Bayesian evidence) by many different fits, many with a sine-wave systematic assumed to be caused by beam chromaticity.



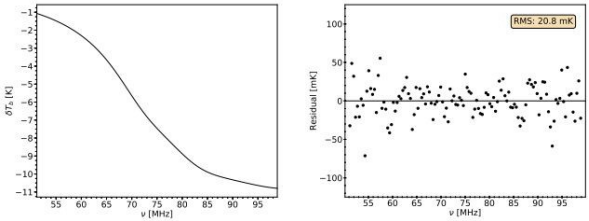
EDGES trough has other possible explanations

"A Ground Plane Artifact that Induces an Absorption Profile in Averaged Spectra from Global 21 cm Measurements, with Possible Application to EDGES", Bradley et al., ApJ 874, 2, 153 (2019):

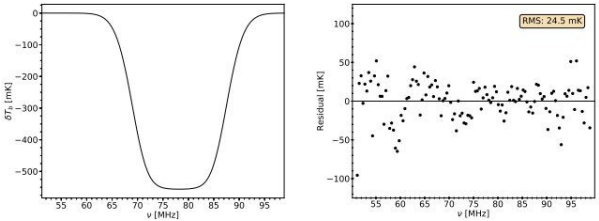
=>A ground plane resonance caused by the combination of dry and moist soil beneath the EDGES instrument could cause the detection of the trough



With ground plane systematics



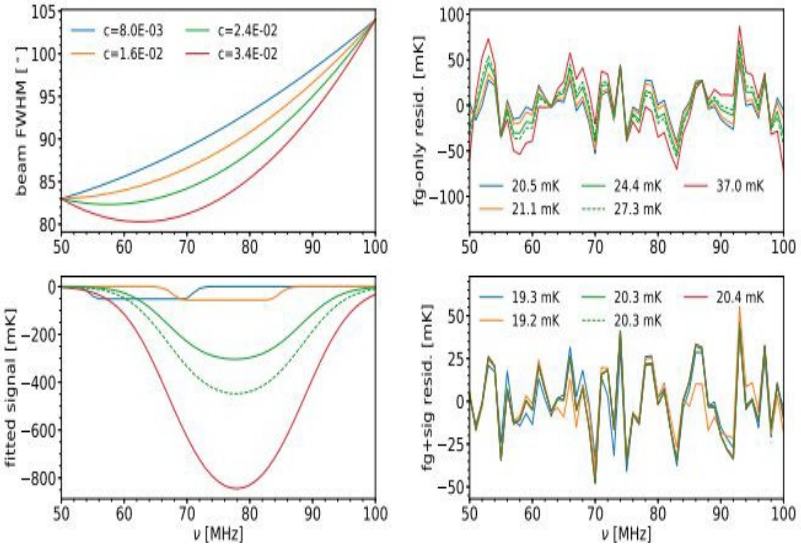
With flattened Gaussian trough



EDGES trough has other possible explanations

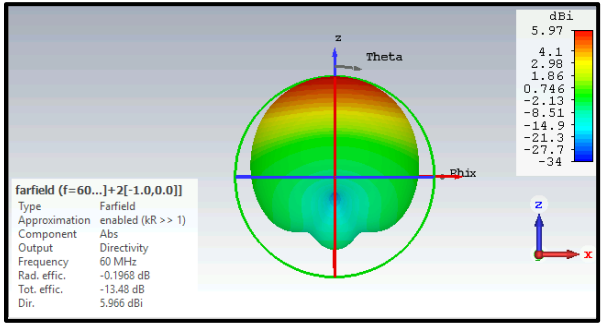
"Formulating and Critically Examining the Assumptions of Global 21 cm Signal Analyses: How to Avoid the False Troughs That Can Appear in Single-spectrum Fits", Tauscher et al., ApJ, 897, 2, 132 (2020):

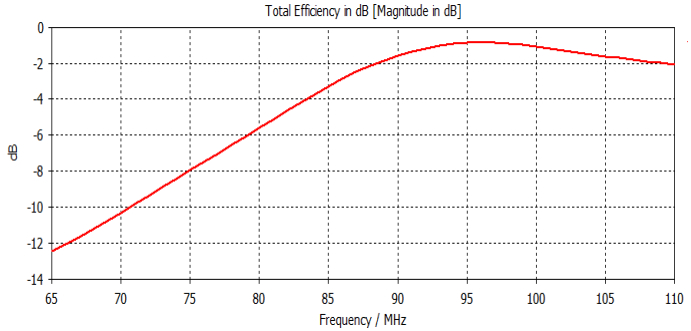
=>A flattened Gaussian trough like that reported by EDGES could be visible in the foreground spectrum alone



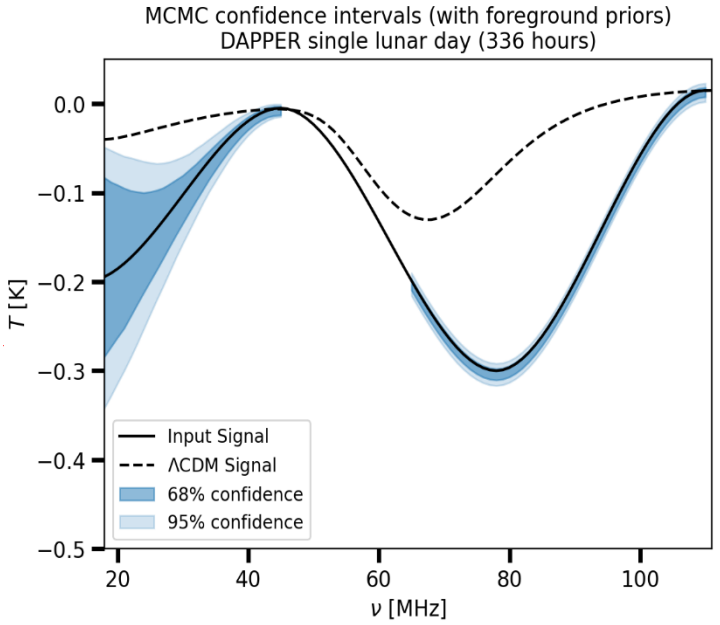
The potential of the lunar farside

- Without time varying environmental effects and with a stable instrument, the antenna would measure a consistent sky spectrum that can be separated between foreground and signal.
- Cosmic Dawn provides a lever arm to help detect Dark Ages





CST simulations by R. Bradley & B. Nhan



Simulations by Bassett, Rapetti, Tauscher, Burns