Preparing for the Moon with EDGES

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Network for Exploration and Space Science
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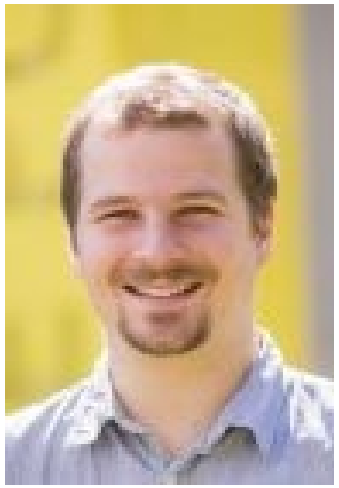

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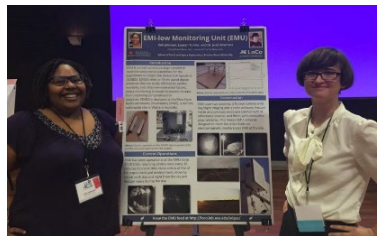
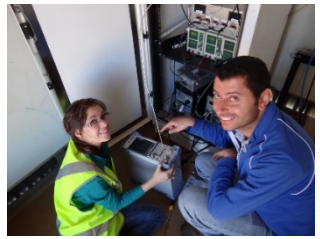
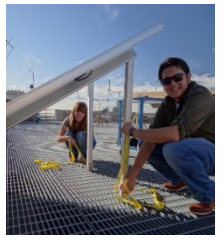
<u>Additional technicians/engineers</u>

- Mark Derome
- Hamdi Mani
- Jim Traffie
- Ken Wilson

And on-site support from the CSIRO MRO team



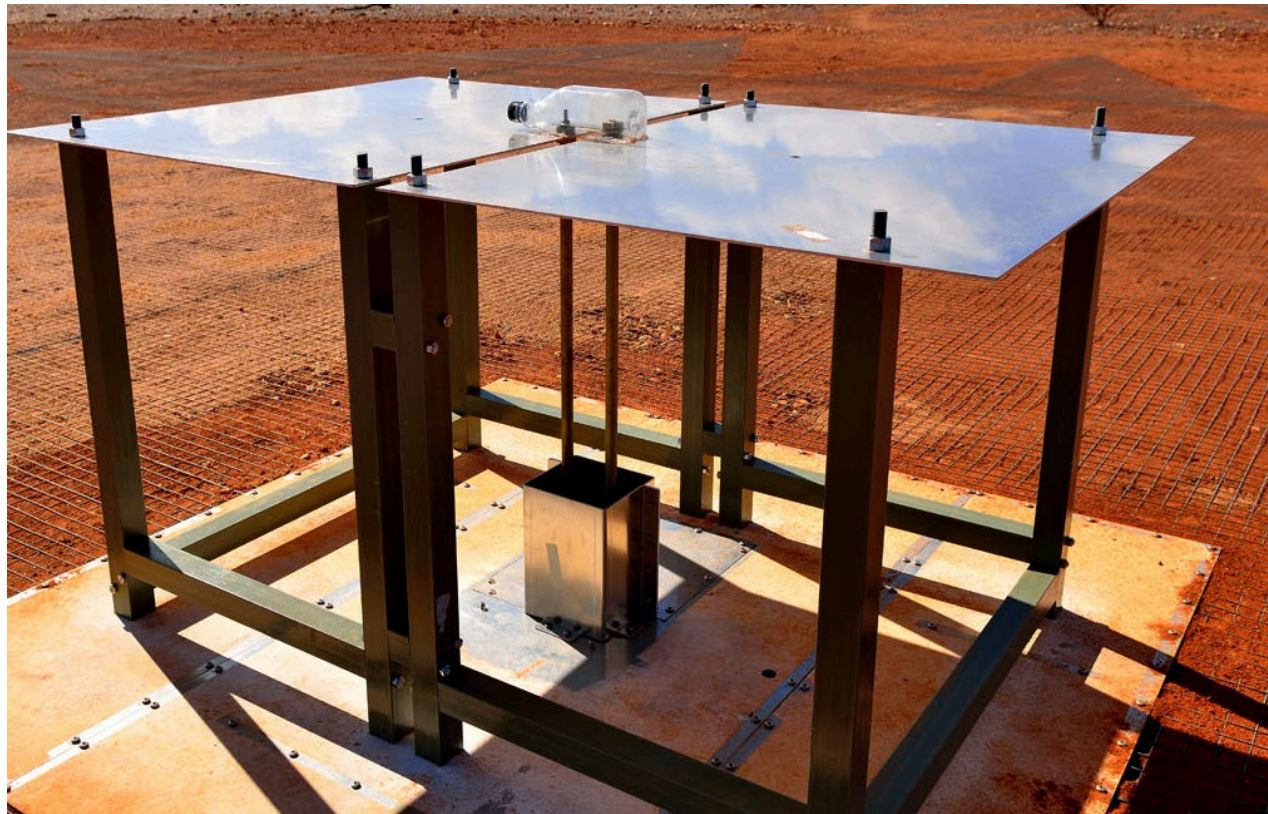




<u>Undergraduate students</u>: Kali, Lauren, Leroy, Sarah, Hamdi, Breana, Jose, Delani, Ethan

EDGES

- **Measurement:** Sky-averaged radio spectrum below 200 MHz
- **Requirement:** Knowable instrument response at 0.01%
- **Instrument design:** Widefield, wideband radio spectrometer
  - Compact antenna and embedded receiver
  - Temperature controlled receiver with internal references to provide a time-invariant response through Dicke-switch scheme
- Instrument strategy now followed by other global 21cm experiments Well-matched to lunar surface or orbital missions
- Almost continuous remote operation since 2015 with three variations of antennas



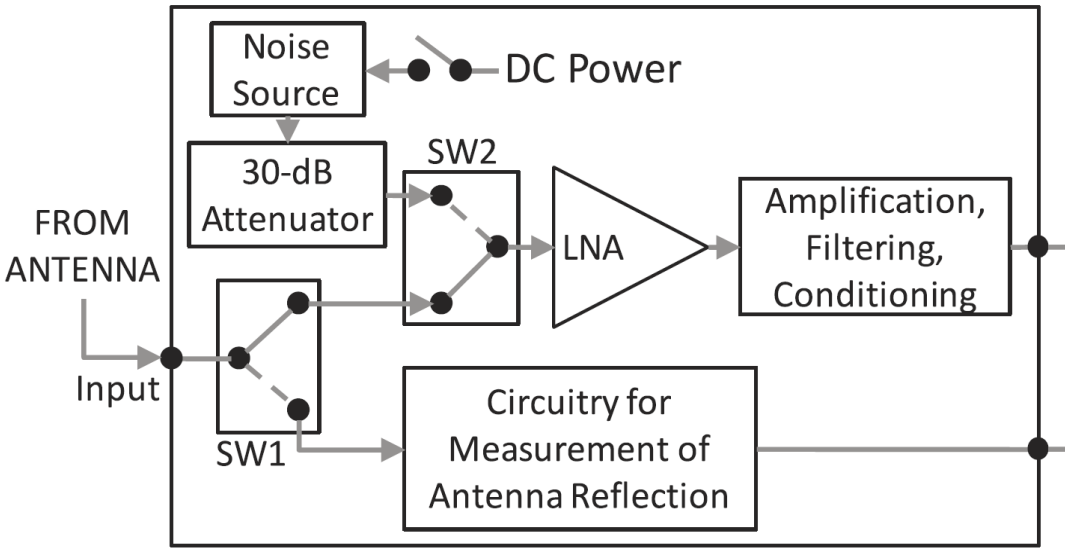
Preparing core techniques

Absolute calibration and antenna modeling

Calibration

- Measure response to known inputs in the laboratory to solve for absolute temperature scale
  - Absolute accuracy to 1%
  - Relative accuracy in band to < 0.01%
- In-situ measurement of antenna impedance
- Now commonly used by global 21cm experiments (e.g. SARAS-3, REACH, LEDA)
- Key contributions through NASA support:
  - NASA Roman Technology Fellowship
  - LUNAR and DARE: Integrating instrumental effects into analysis (e.g. Tauscher et al. 2018)
  - NESS: Developing joint Bayesian estimation of calibration and science parameters (see Steven Murray's talk)

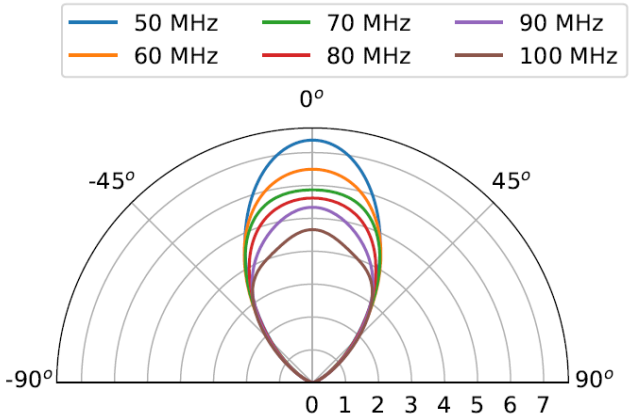
Block diagram of EDGES receiver

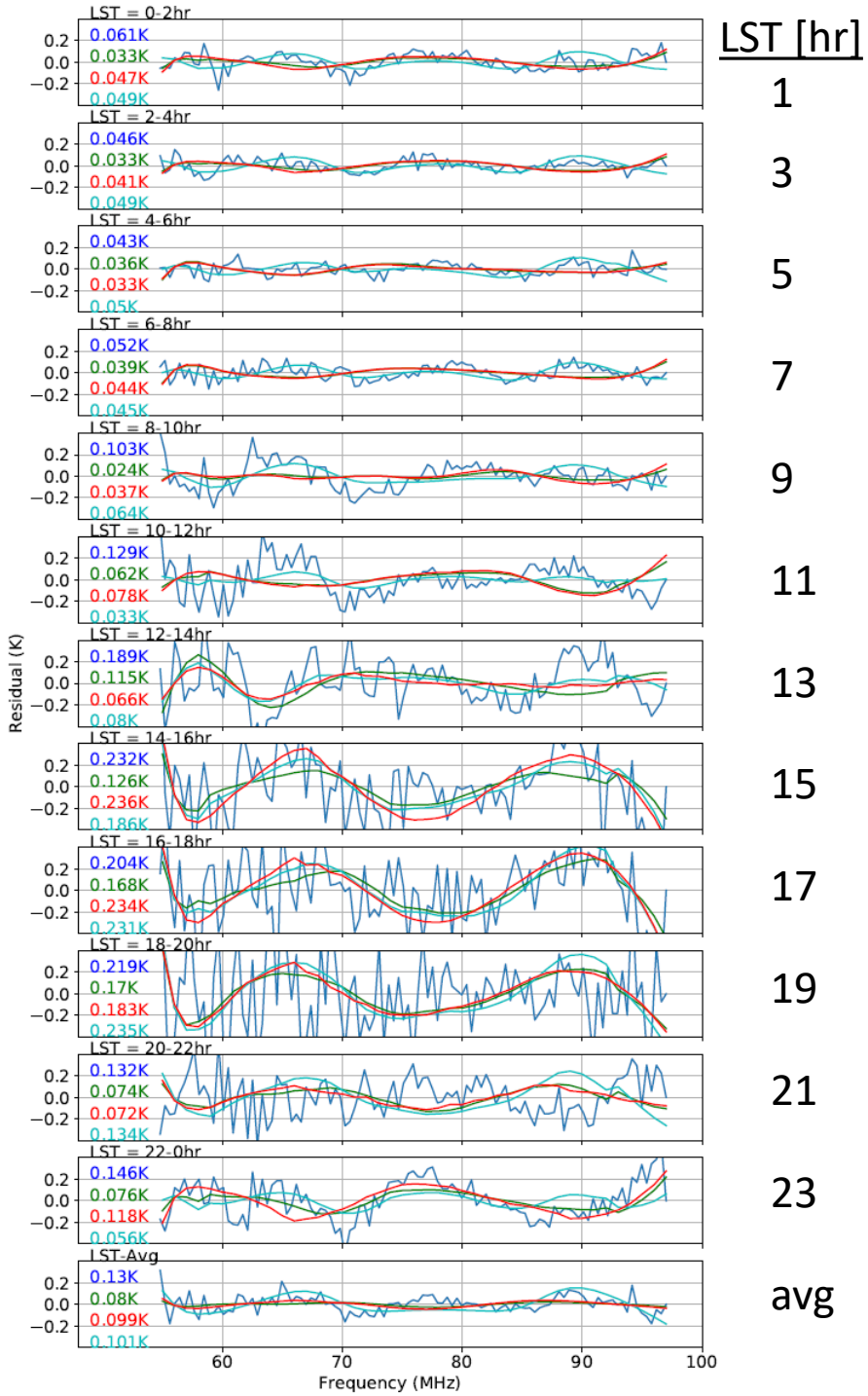


Monsalve et al. 2017, Rogers & Bowman 2012

Modeling Chromatic Antenna Beams

- Antennas are chromatic – their properties depend on frequency. This couples angular sky structure into observed spectrum
- Cannot presently measure antenna beam with sufficient accuracy
- Need extremely accurate electromagnetic antenna models to capture these effects
- Developed modeling techniques for EDGES and verified across three numerical solvers. Validated by comparing EDGES data and simulated observations
- **Results**: Uncertainty from sky model and antenna environment





Mahesh et al. (submitted)

Example of Antenna Environment

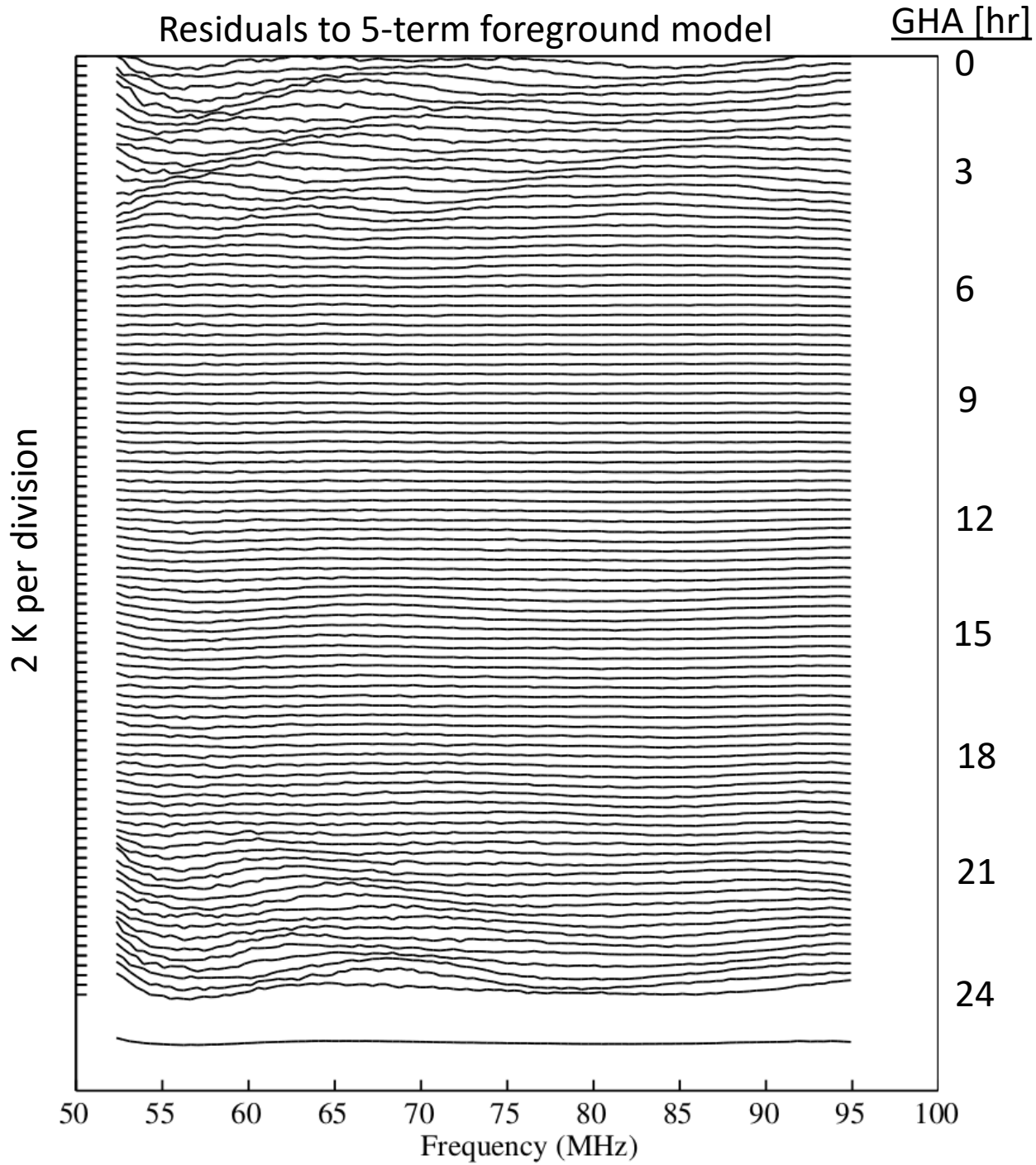
- Many factors have significant impact
  - Multipath/reflections
  - Soil properties
  - Ambient weather conditions
  - Unmodelled imperfections in ground plane

Residuals to **5-term** foreground model

15-min bins across 24 hr

Residuals **increase toward GHA=0 hr** (Galactic Center transit)

Studying structure seen at ~22 hr, which could correspond to scattering by object tens of meters from antenna



A. Rogers and R. Monsalve

Preparing knowledge of the sky

Three examples

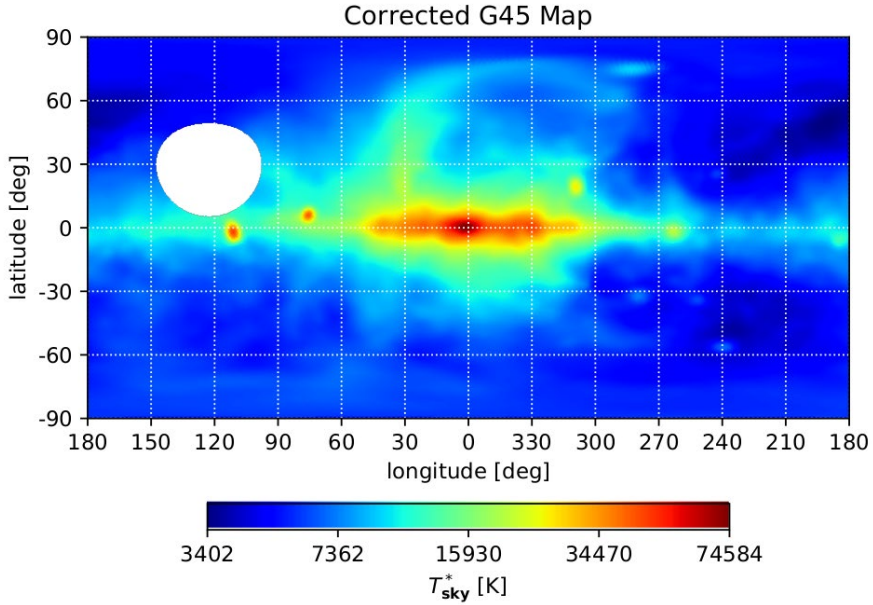
Flux calibration of sky maps

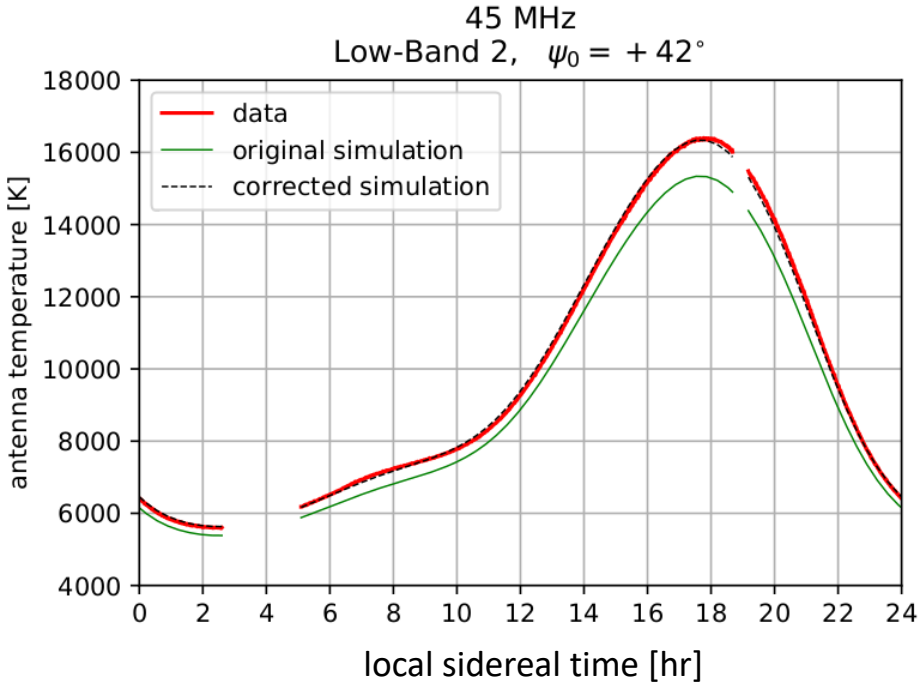
- Accurate sky maps are critical for including antenna chromatic effects in analyses
- Existing maps are calibrated to only about 10% accuracy.
- Using EDGES observations to improve flux calibration of Guzman (45 MHz) and Landecker & Wielebinski (150 MHz) sky maps.

Correction factors

Scale: **+7.6 %** +/- **3.4 %** (2σ)

Zero-level: **-160 K** +/- **78 K** (2σ)



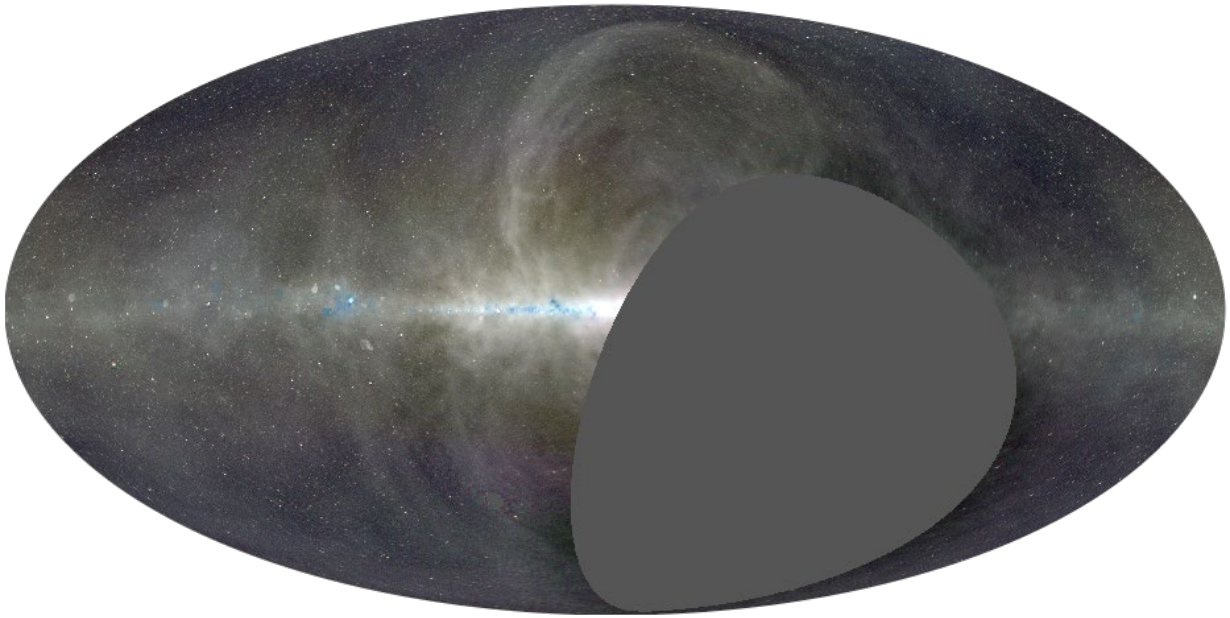


Monsalve et al. (submitted)

High resolution sky maps

- OVRO-LWA has created high-resolution sky maps for northern hemisphere for 35-80 MHz (Eastwood et al. 2018)

- EDGES team pilot program using Murchison Widefield Array (MWA) in Australia to apply same imaging technique to fill in southern sky

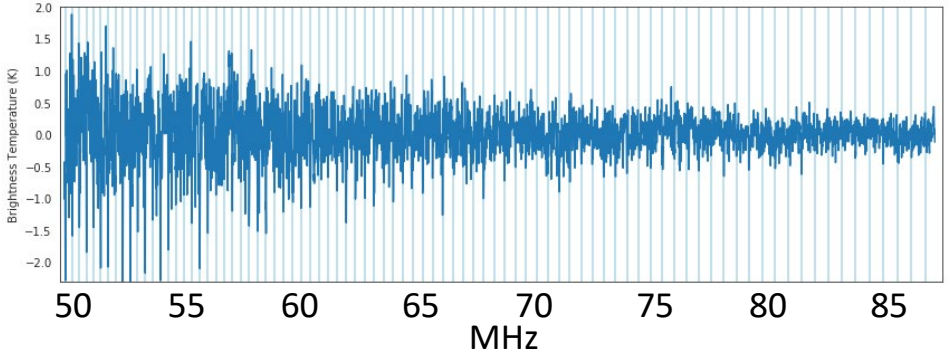


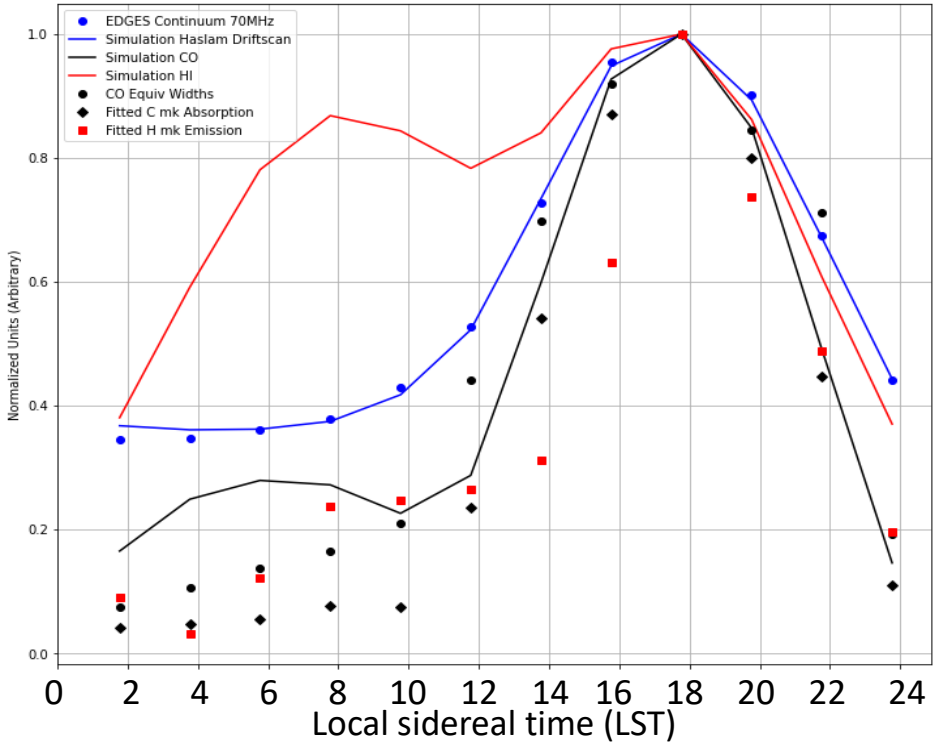
Three-color composite image of the long wavelength radio sky. The 36.5, 52.2, and 73.2 MHz data are represented as red, green, and blue respectively. https://lambda.gsfc.nasa.gov

Eastwood et al. 2018

New limits on Radio Recombination Lines

- Radio recombination lines (RRLs) are possible foregrounds for 21cm power spectra during Dark Ages and Cosmic Dawn
- Easily detected on Galactic plane, but poorly constrained off plane
- Using EDGES observations to place limits on these lines across the sky





Beam average across 0-4 hr LST

Carbon: >33 mK
Hydrogen: 6-24 mK

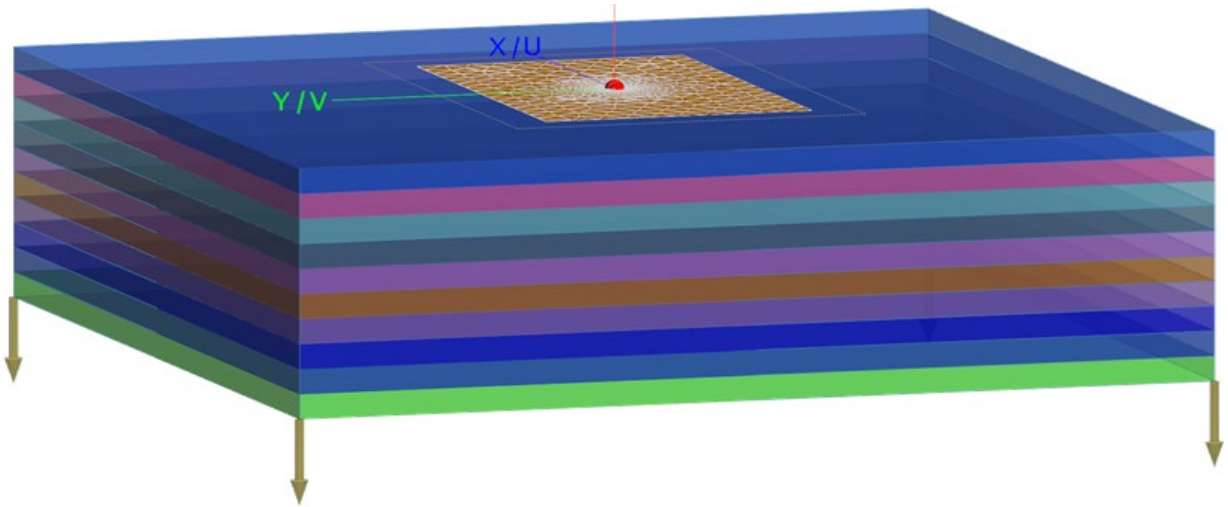
David Lewis et al. (in prep, applying to grad schools!)

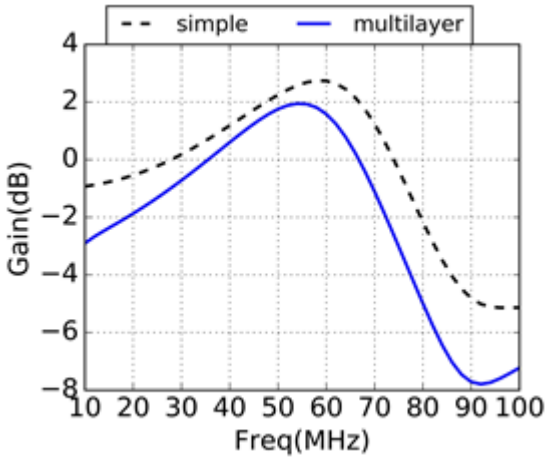
Applying lessons learned

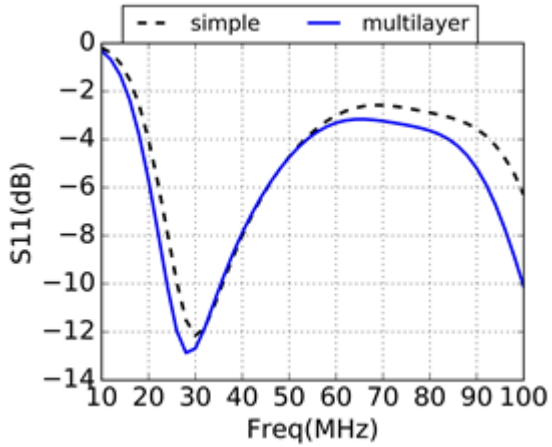
Lunar surface and EDGES-3

Lunar Surface

- To minimize susceptibility to soil and nearby objects, need either:
  - Very uniform soil properties to 10s of meters depth
  - To use a large metal ground plane (ideally 100 meter diameter)
- Does a lunar surface dipole need a metal ground plane?
- Modeling effects of regolith to assess feasibility

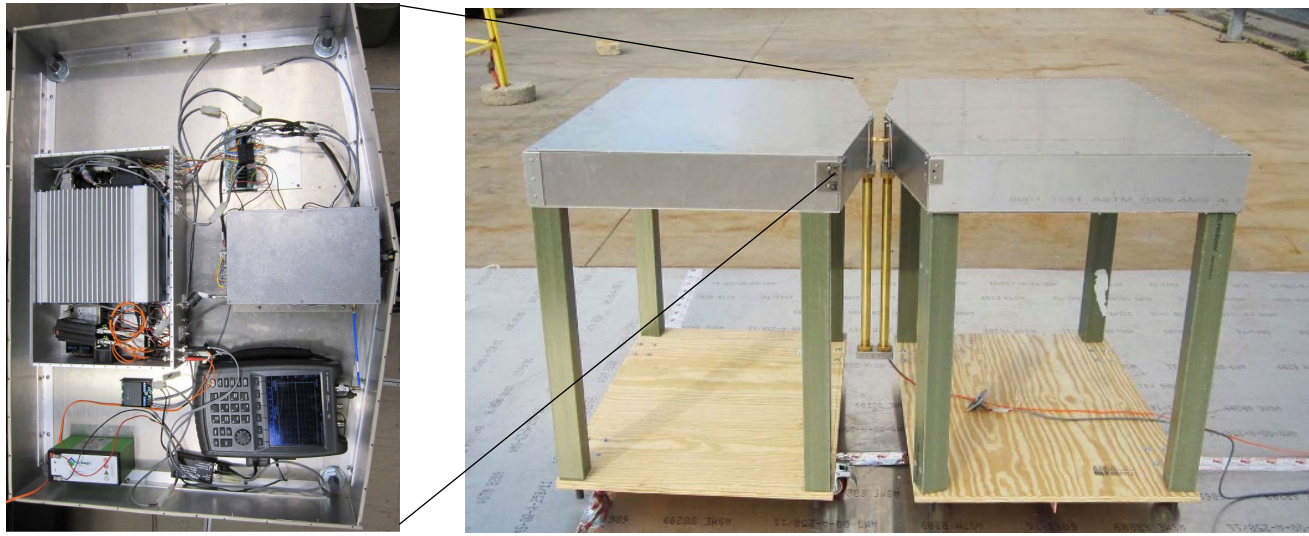




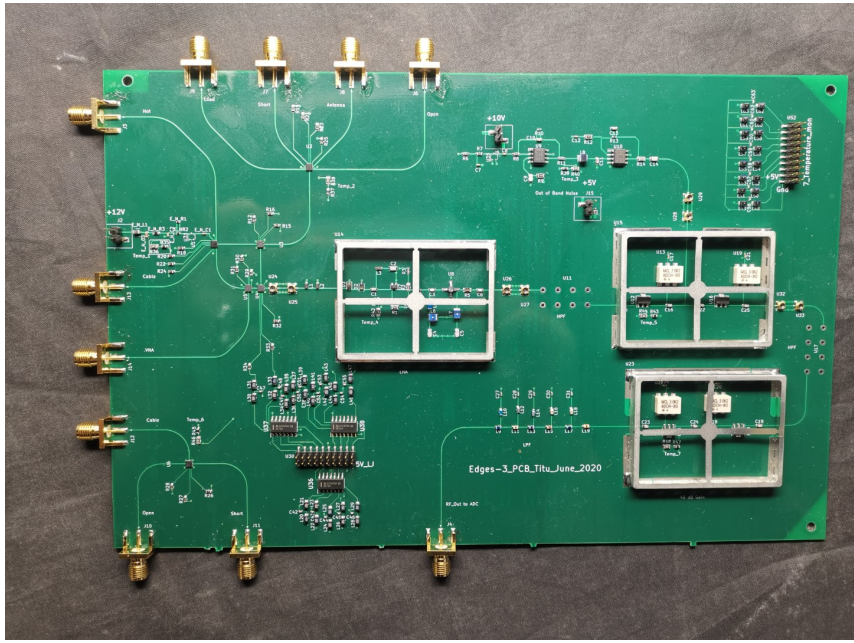


EDGES-3

- Apply lessons learned to create next-generation instrument
- 50-meter (or no) ground plane to improve antenna beam effects
- Integrate receiver *into* antenna to minimize electrical path length
- Integrate calibration standards into system
- Combine calibration and science inference for full error propagation
- Open source software and public data
- Pathfinder for flight hardware
  - Replacing mechanical switches with solid state
  - Integrating into compact printed circuit board
  - Reducing size for better thermal management



EDGES-3 antenna



EDGES-3 test PCB

T. Samson and A. Rogers

Summary

- EDGES has paved the way for lunar 21cm global missions
  - Established fundamental instrument design and calibration techniques
  - Developed accurate instrument and antenna modeling
  - Identified need for knowledge of environment and sky

- Preparing next-generation EDGES-3 and lunar instrument designs based on this validated foundation

- NASA supported collaboration has provided critical advances for EDGES and global 21cm experiments, including core calibration techniques and sophisticated analysis strategies