LWA Long Wavelength Array | The University of New Mexico | ONR Office of Naval Research | NPP NASA Postdoctoral Program | Goddard Space Flight Center | JPL Jet Propulsion Laboratory California Institute of Technology | NSF

The LWA1 Low Frequency Sky Survey

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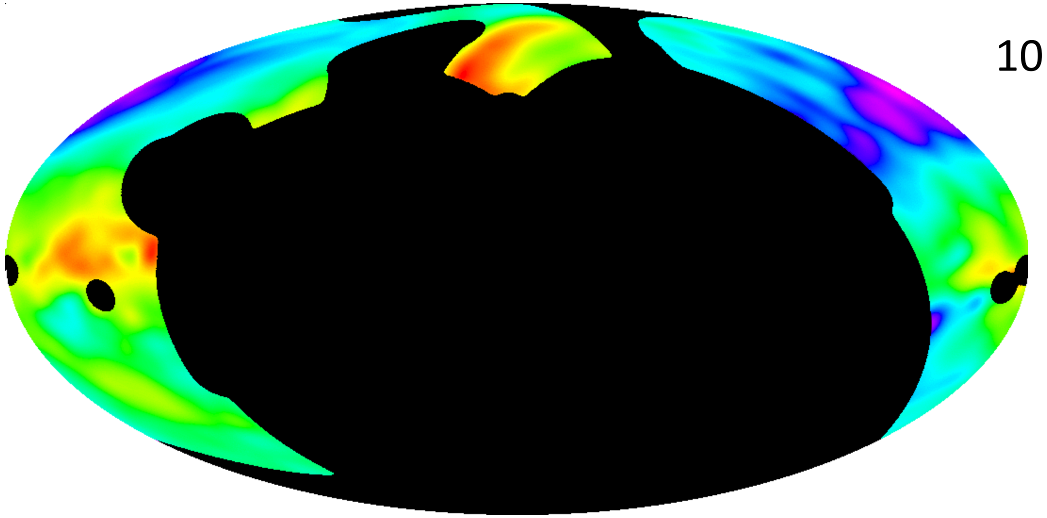
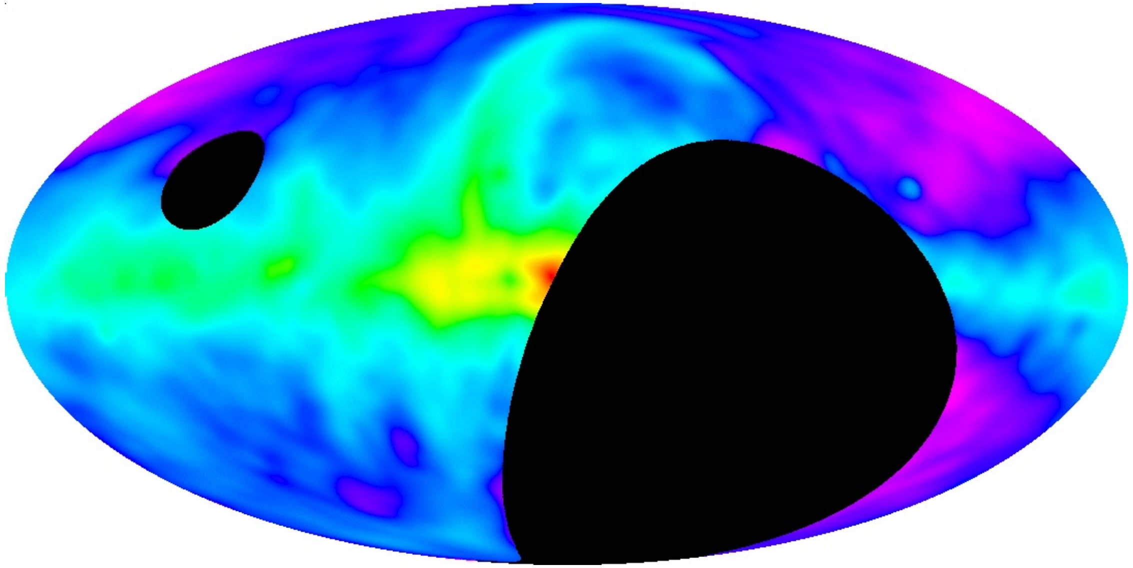
Outline

- Motivation
- LWA1 Low Frequency Sky Survey (Dowell et al. 2017)
  - LWA1
  - Data collection and calibration methodology
  - Results
- The Radio Background Below 100 MHz (Dowell & Taylor 2018)
- Current Efforts
- Summary

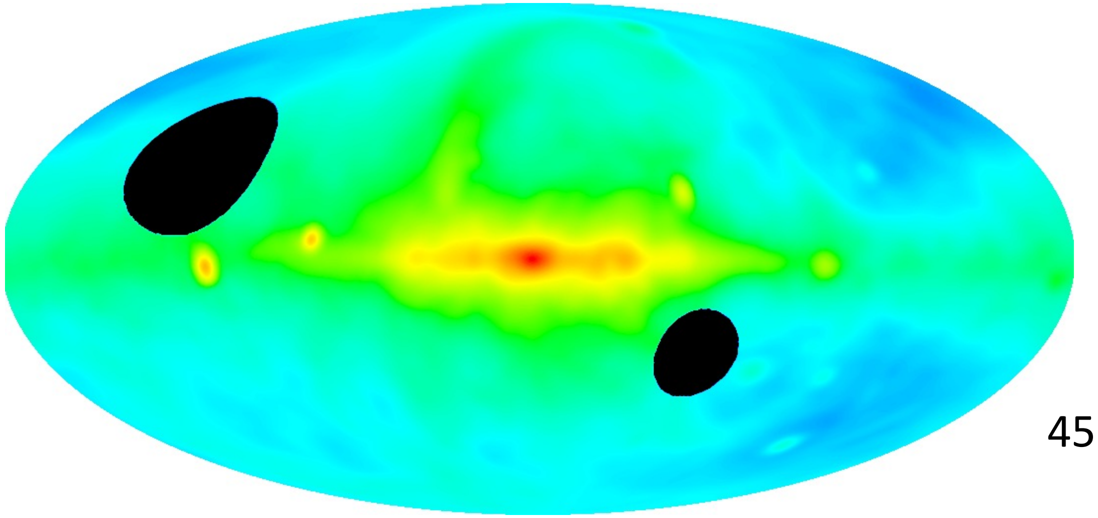
Why Low Frequency Maps of the Sky?



10 MHz (Caswell 1976)

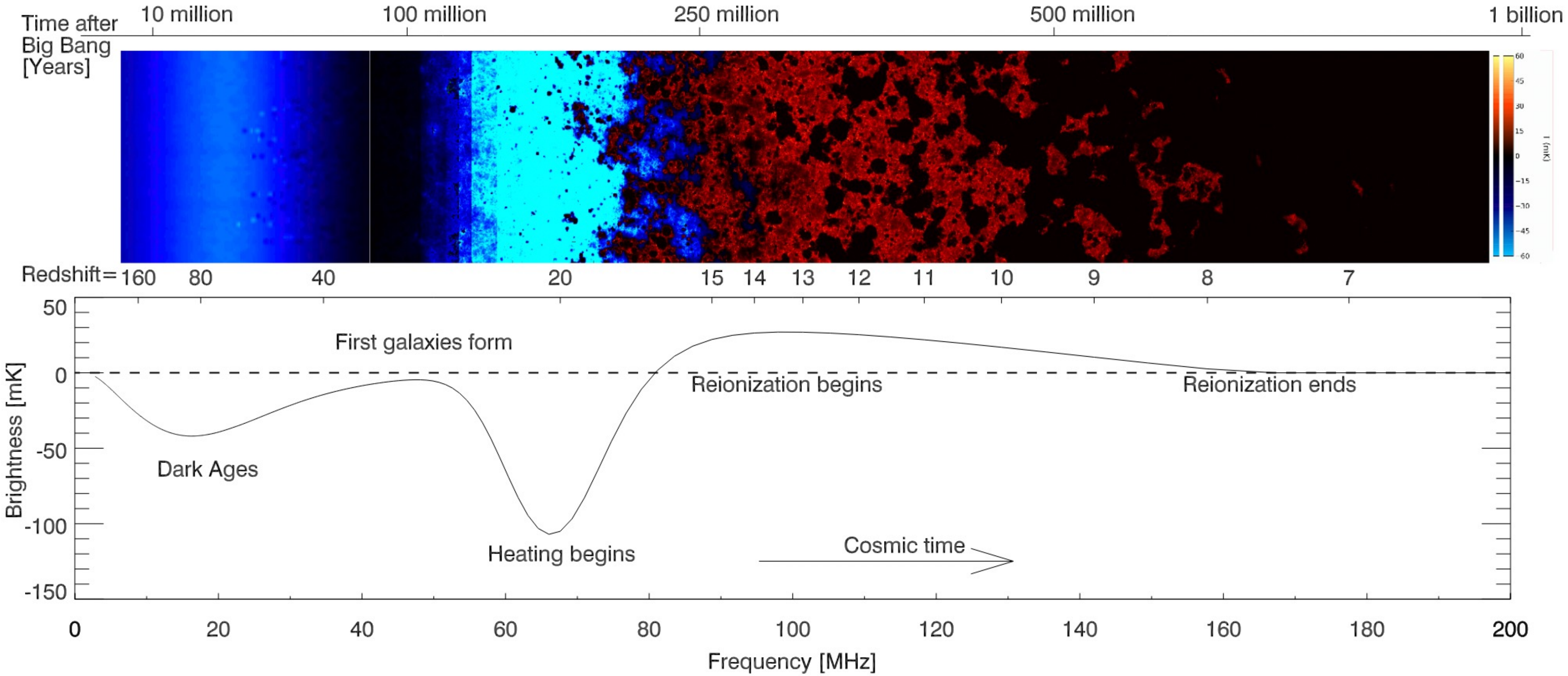


22 MHz (Rogers et al. 1999)



45 MHz (Alvarez et al. 1997; Maeda et al. 1999)

Why Low Frequency Maps of the Sky?

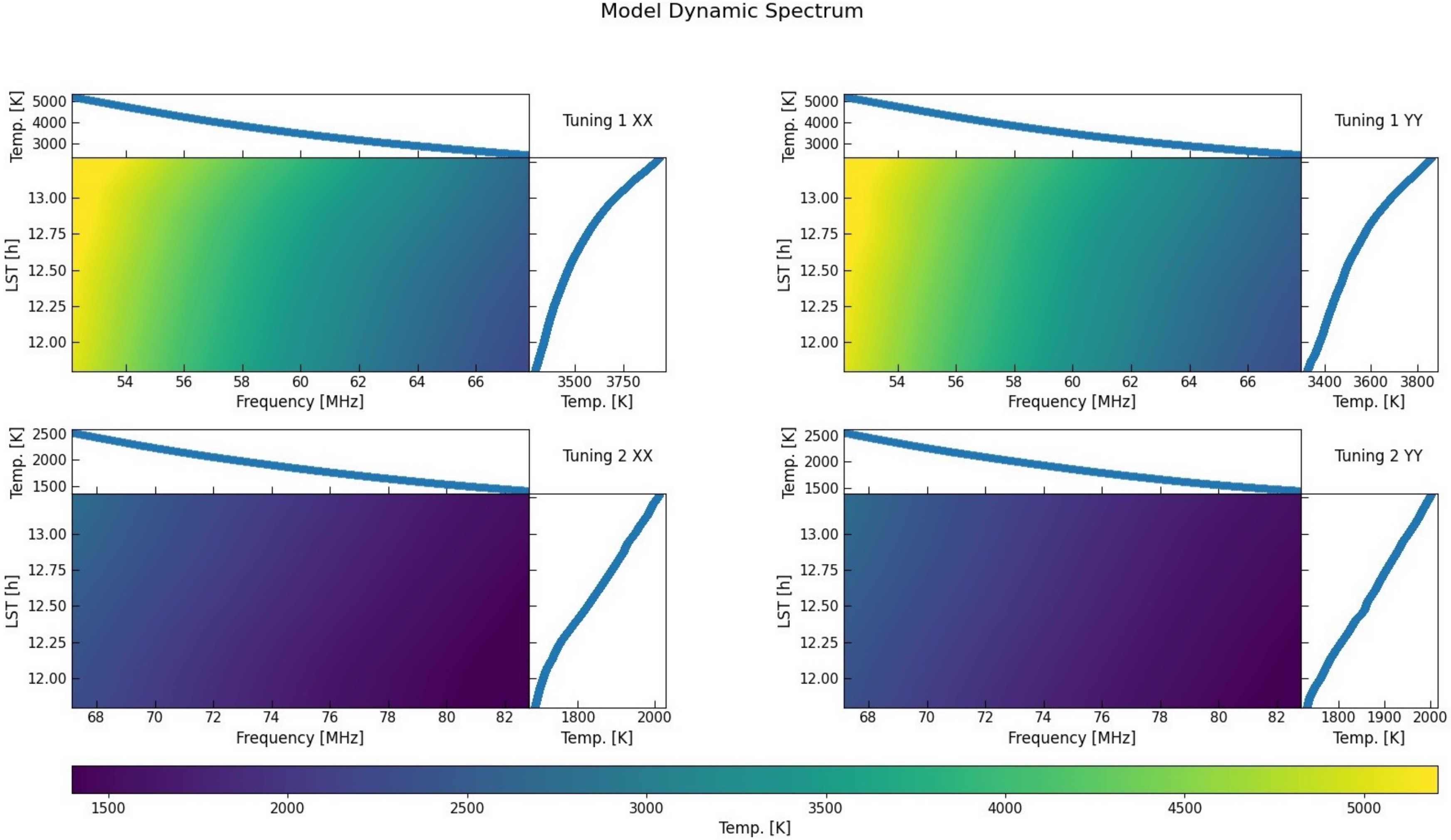


Pritchard & Loeb (2012)

Why Low Frequency Maps of the Sky?

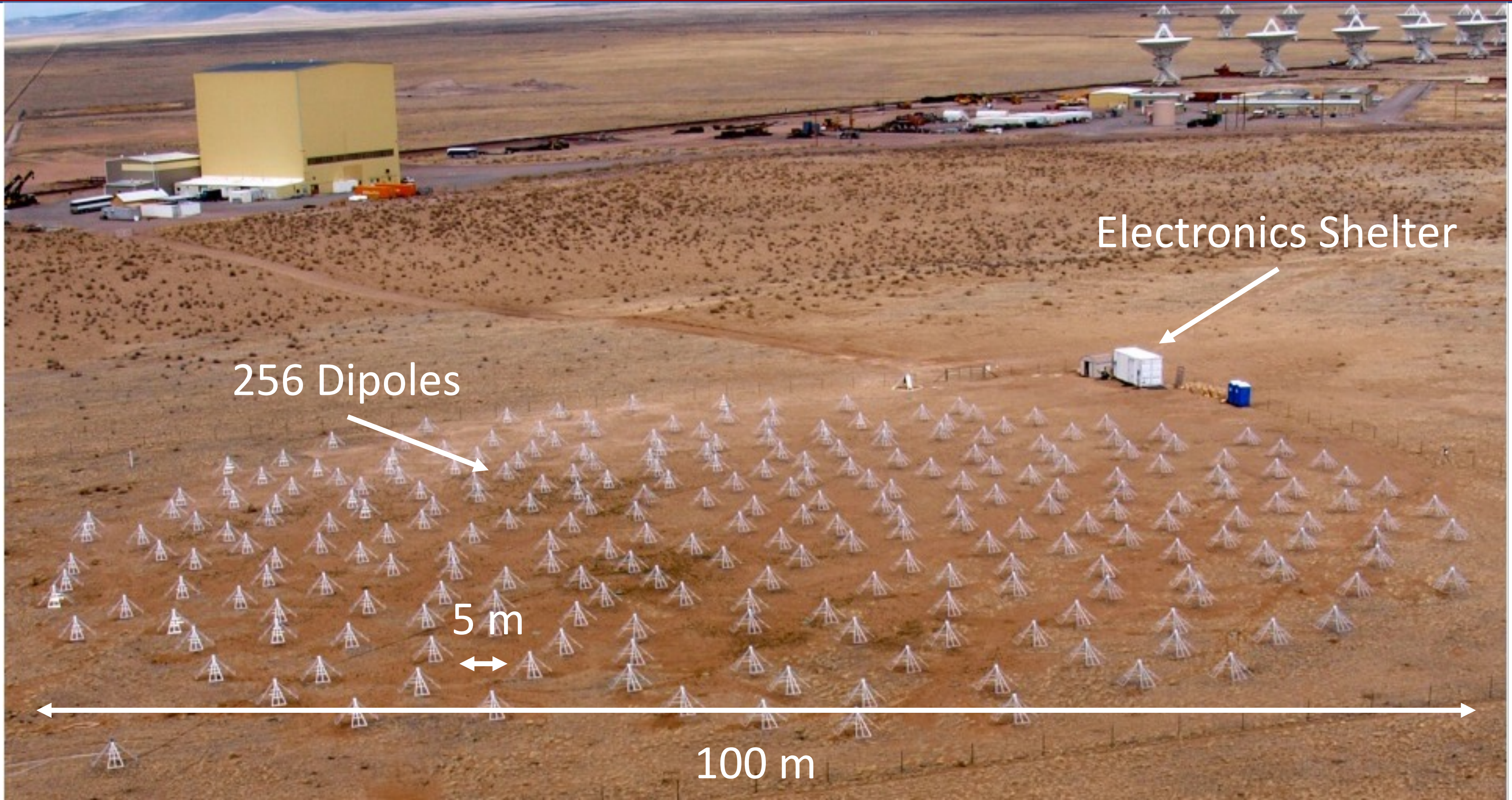
LWA Beam Pattern
+
Sky Model

=

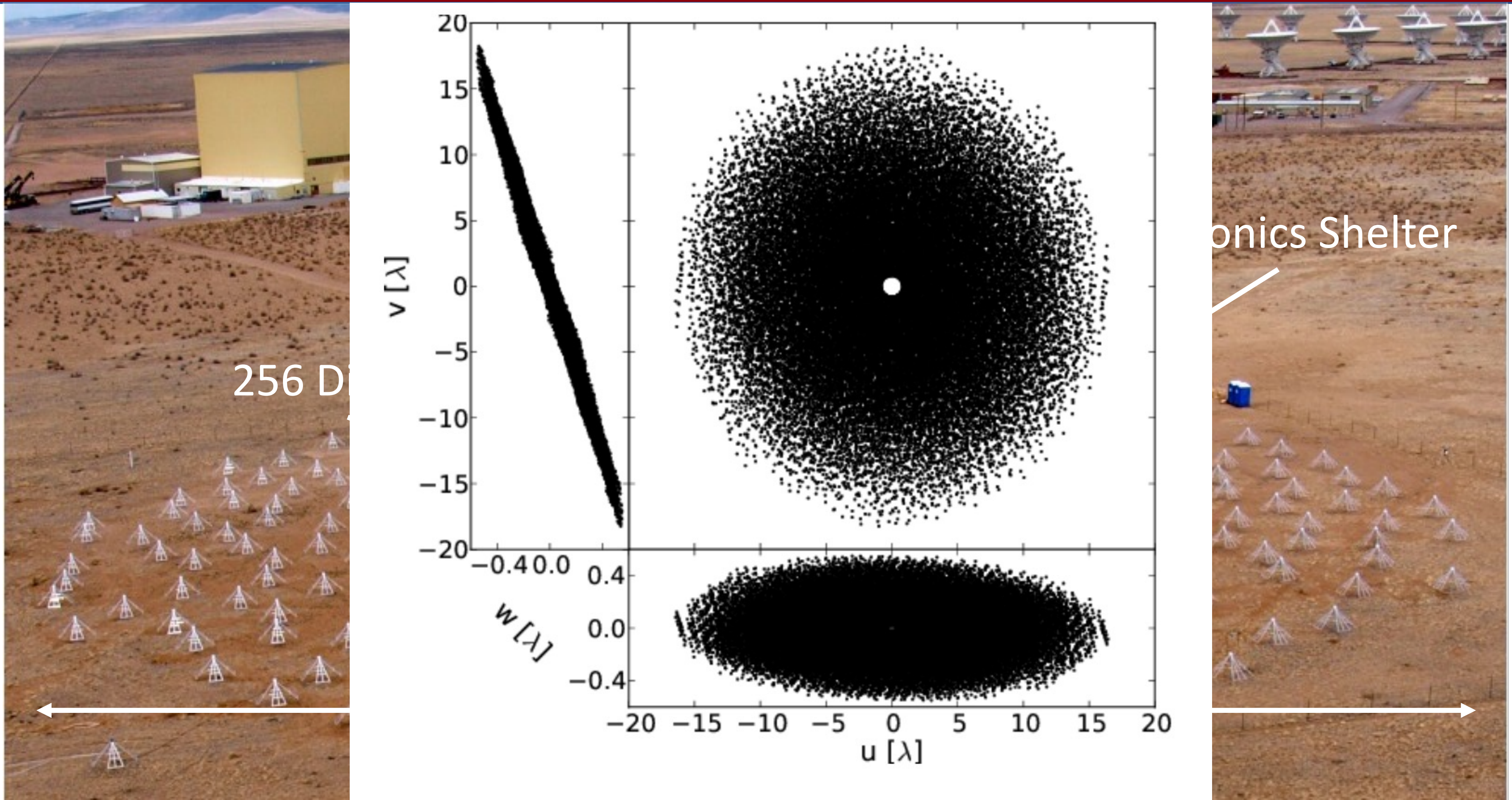


DiLullo et al. (2021)

The Long Wavelength Array (LWA1)



The Long Wavelength Array (LWA1)



LWA1 Low Frequency Sky Survey (LFSS)

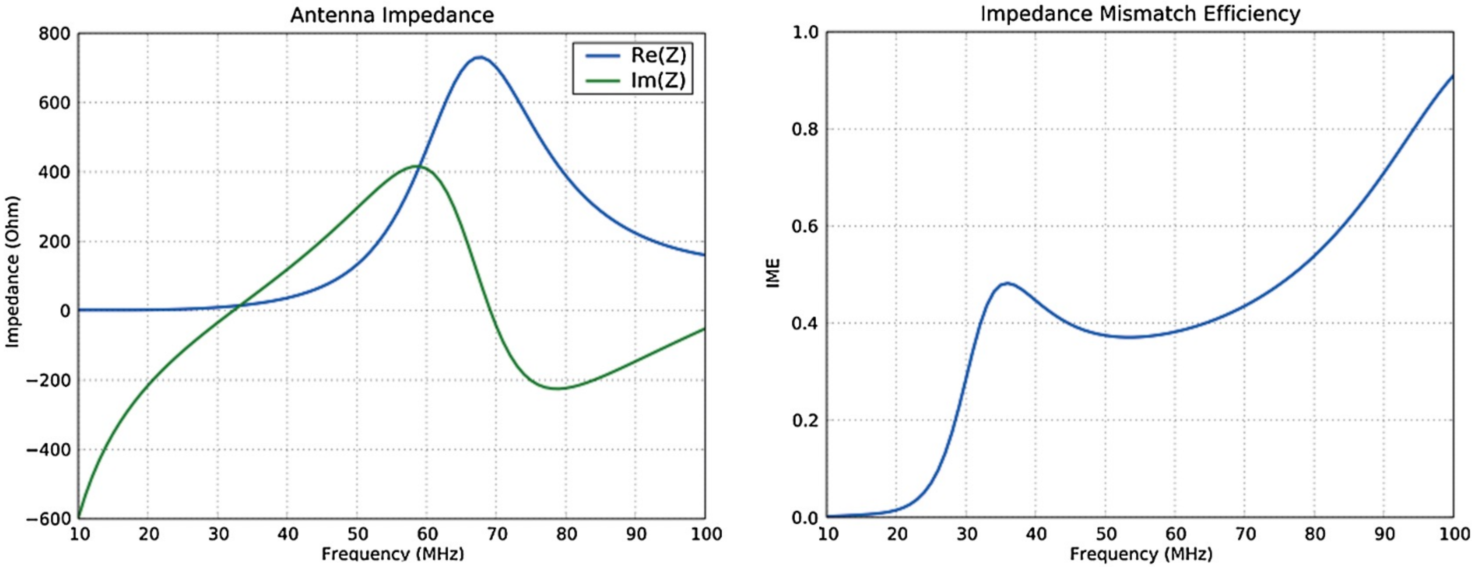
Data Acquisition

- TBW mode
  - 61 ms time resolution
  - 80 MHz bandwidth
- Snapshot every 15 min over 48 hr period (≈11.6 s of data)
- Multiple observing epochs to remove Sun and RFI

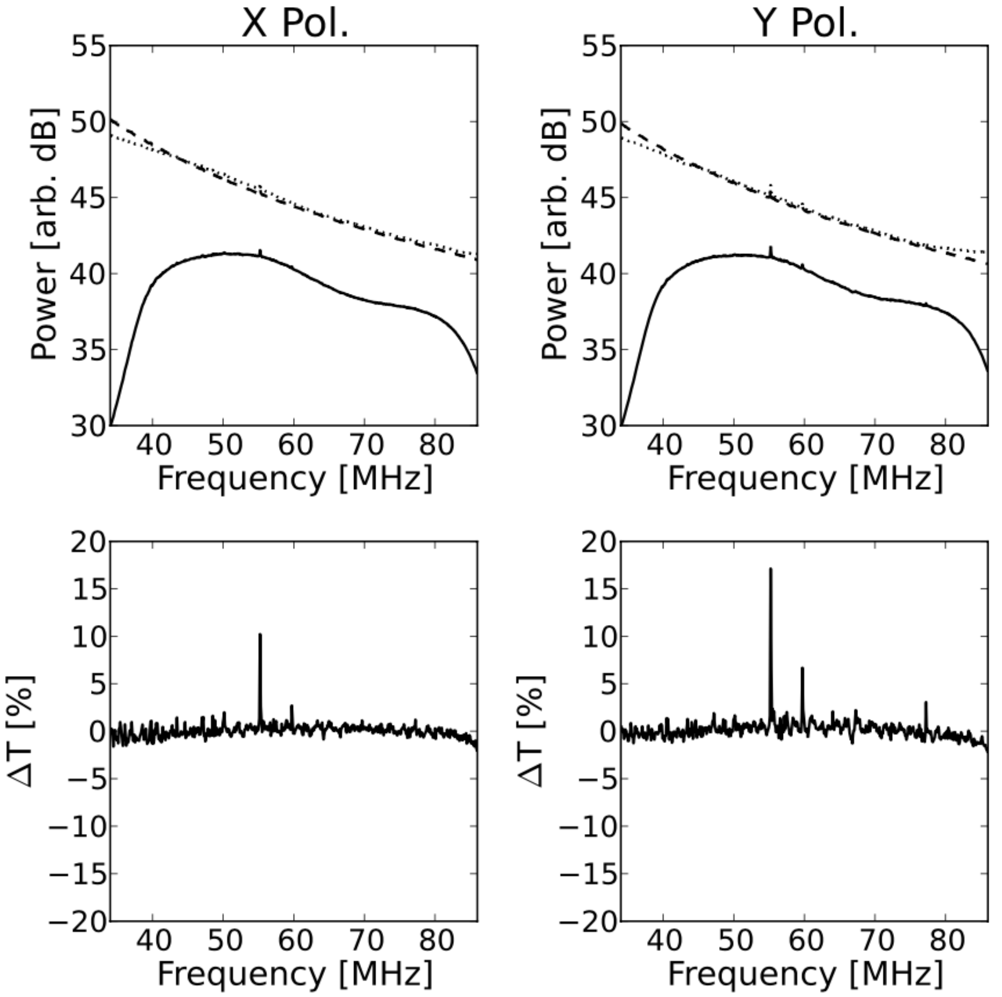
Calibration

- Impedance mismatch (simulation)
- Front End Electronics (FEE) and Analog Receiver (ARX) corrections (lab)
- Delay and flux calibration ("A Team")
- Temperature calibration
  - Custom LEDA front ends

Impedance Mismatch and Electronics Response



Hicks et al. (2012)



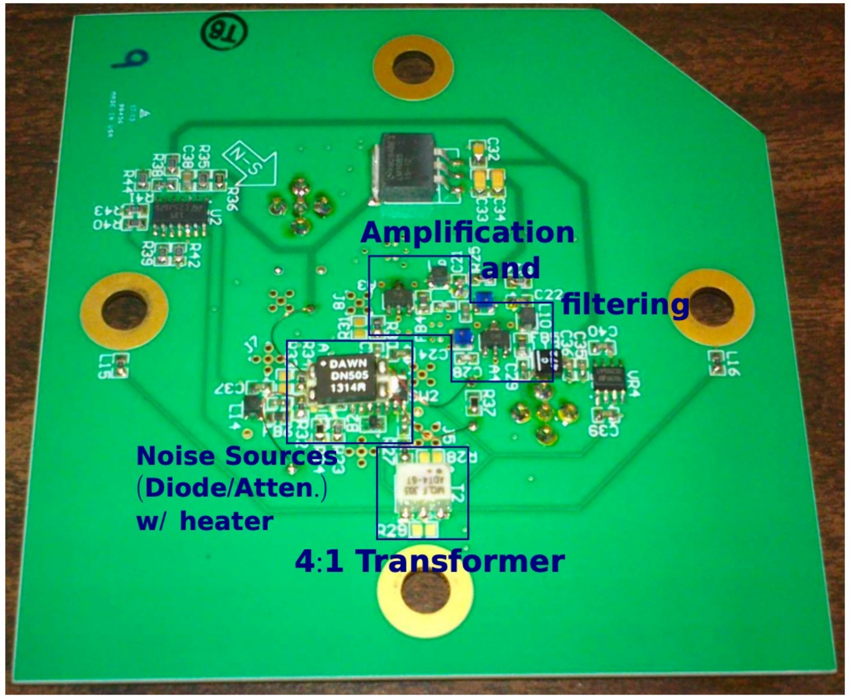
- Impedance mismatch (IMM) corrected via simulation (Hicks et al. 2012)
- FEE and ARX corrected through lab measurements
  - Removes bandpass structure
- Below 45 MHz, residual correction required
  - Probably due to IMM simulation limitations and ground losses
  - Fit simple power law with curvature to represent sky response

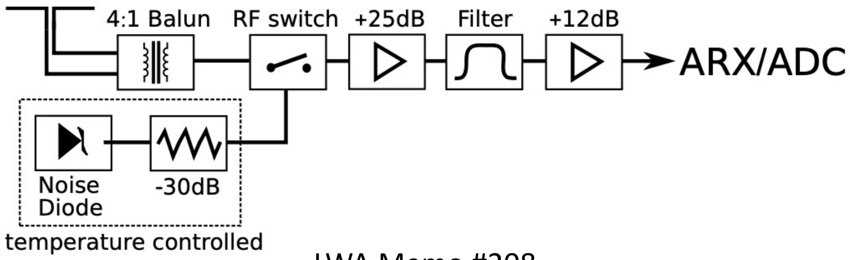
Delay and Flux Calibration

- Delays updated by imaging Cygnus A near transit and using self calibration solutions to update complex visibility phases
- Flux calibration is 3-part:
  - IMM correction and FEE/ARX corrections
  - LWA dipole gain pattern simulations (Ellingson 2010, Dowell 2011) and 1-D empirical correction for elevation-dependent variations
  - Set flux scale to Baars et al. 1977 using "A Team" sources
    - Local sky subtraction to account for different beam sizes
    - Estimated uncertainty of ≈20%

Temperature Scaling and Missing Spaces Correction

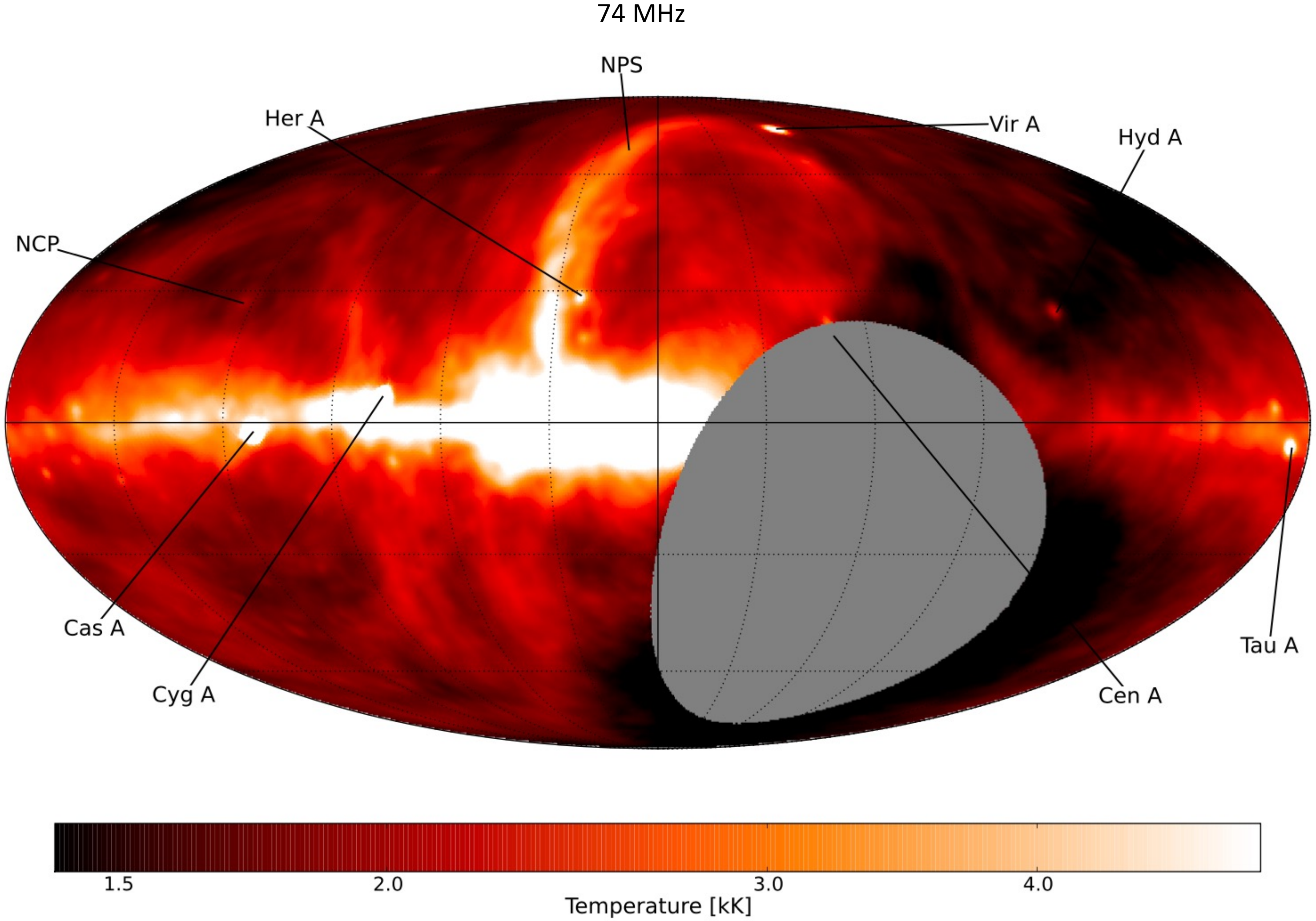
- LEDA frontends at LWA1 used to convert to temperature
- 24-hr LEDA total power observations from 2014 yield global scale factor to convert autocorrelations into temperature
- Compare sky averaged temperature in snapshots to expected value from autocorrelations to estimate missing emission
- Forward modeling (sky model + dipole gain pattern) to estimate missing scales

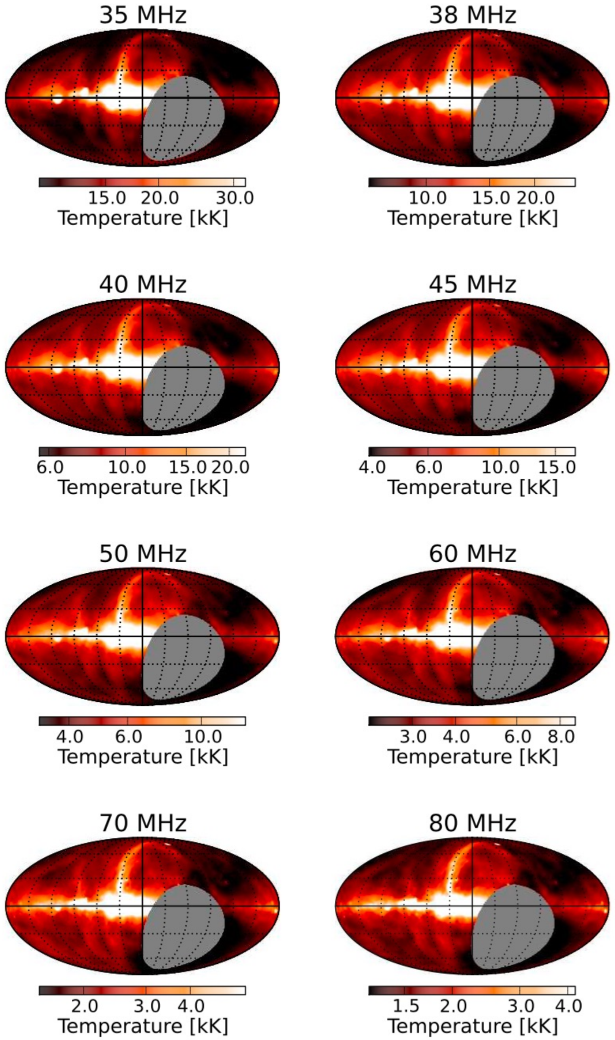




LWA Memo #208

Results: Maps

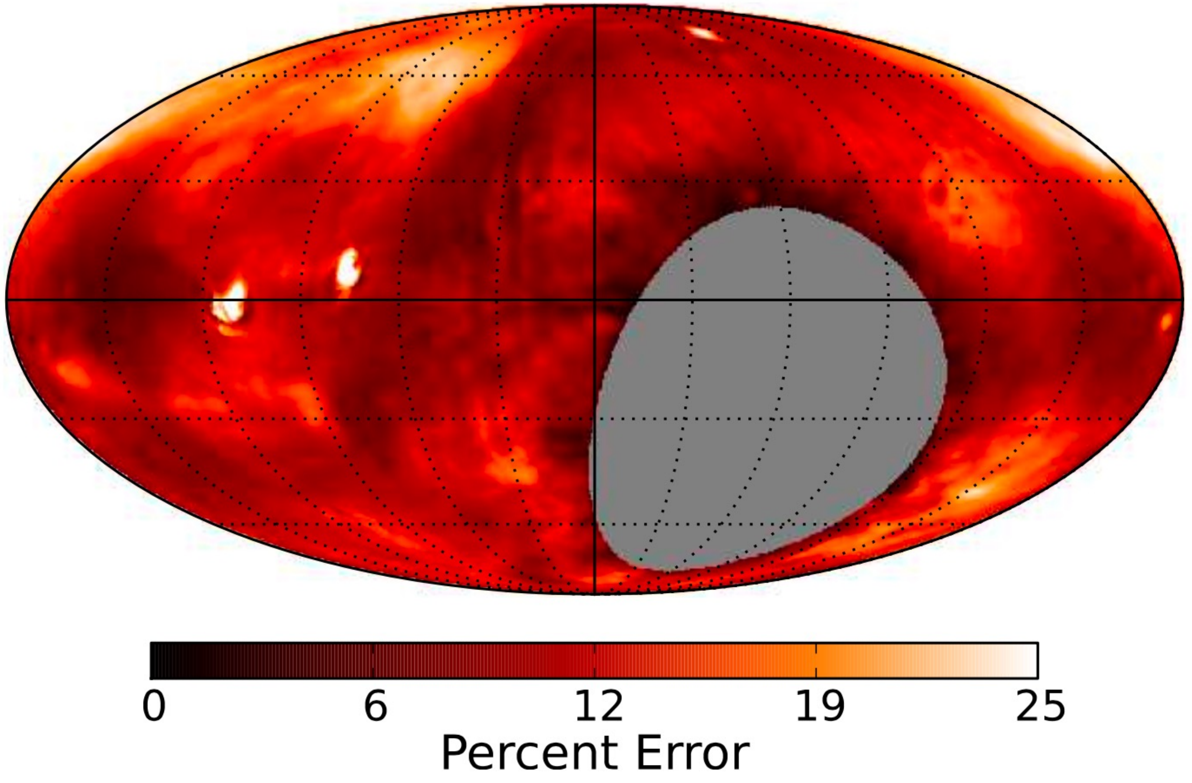




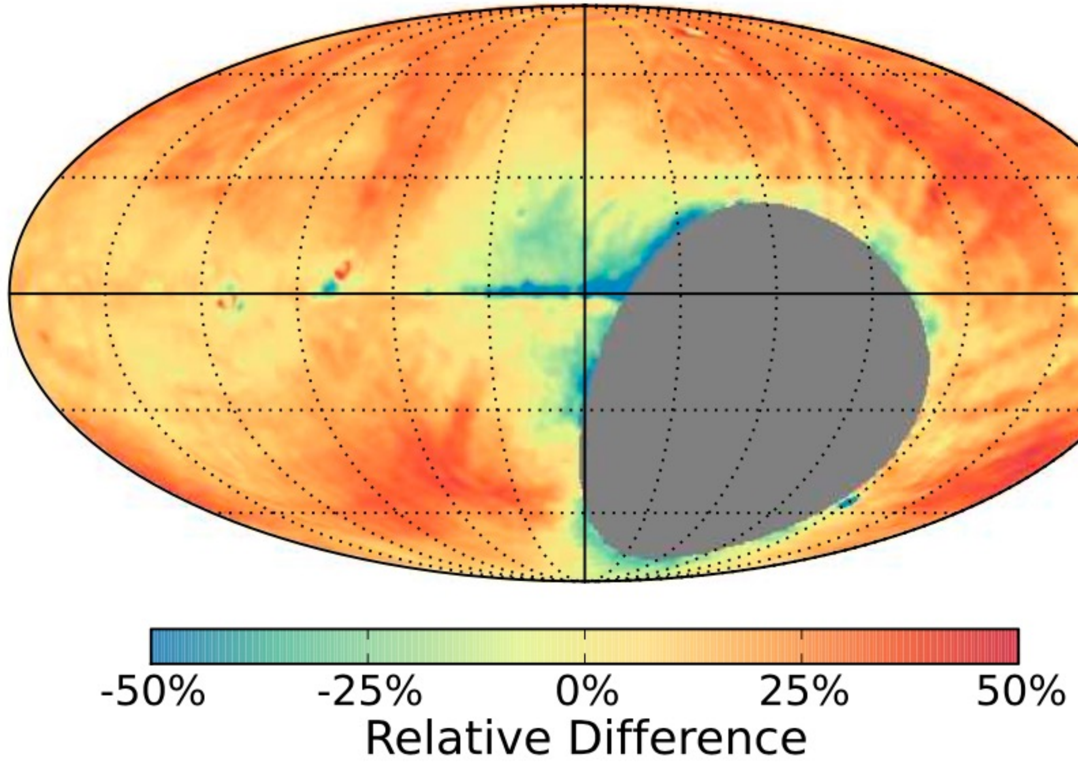
Results: Uncertainty Maps and Comparison to GSM

Uncertainty Map

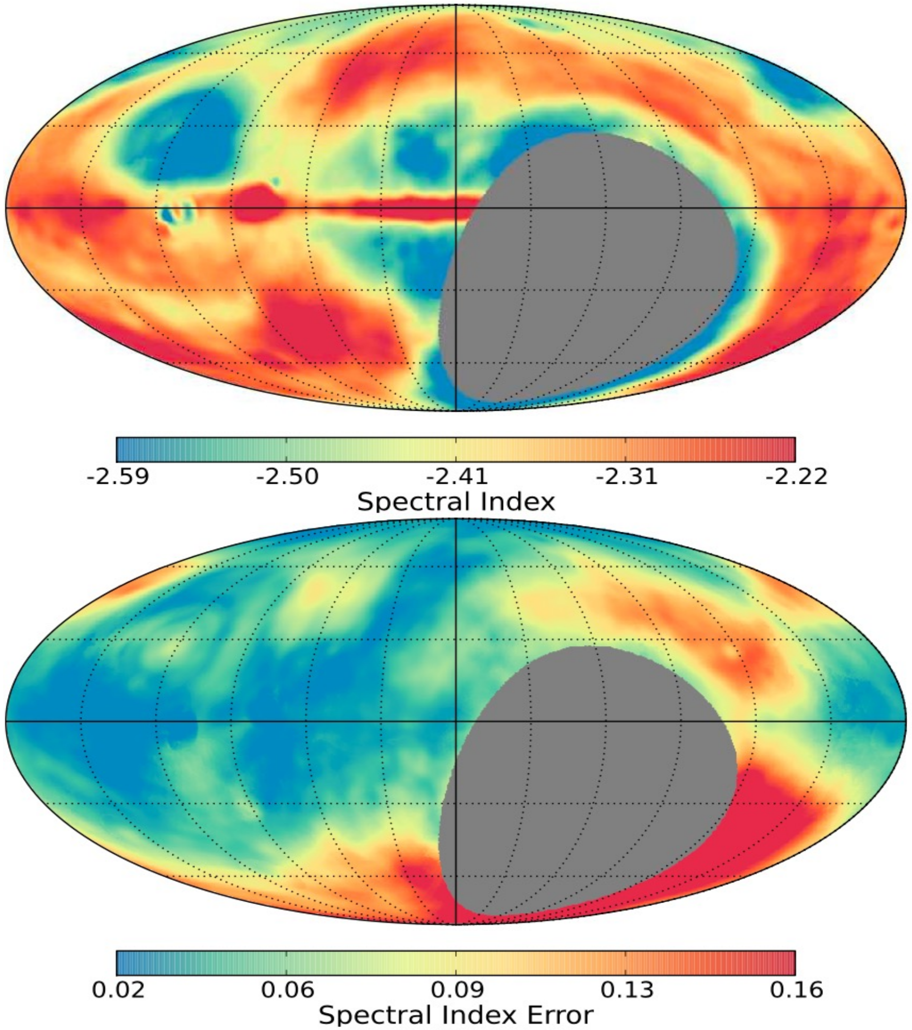
45 MHz



Comparison between 74 MHz LFSS map and the GSM at 74 MHz

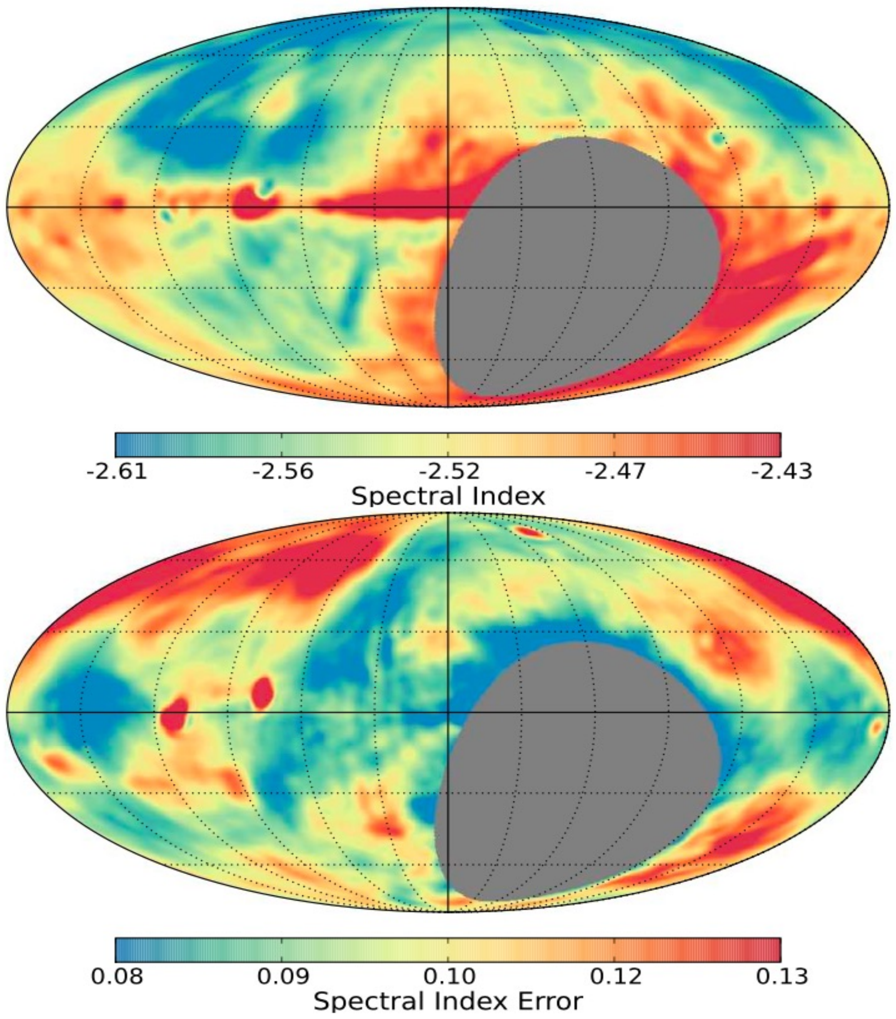


Results: Spectral Index Maps



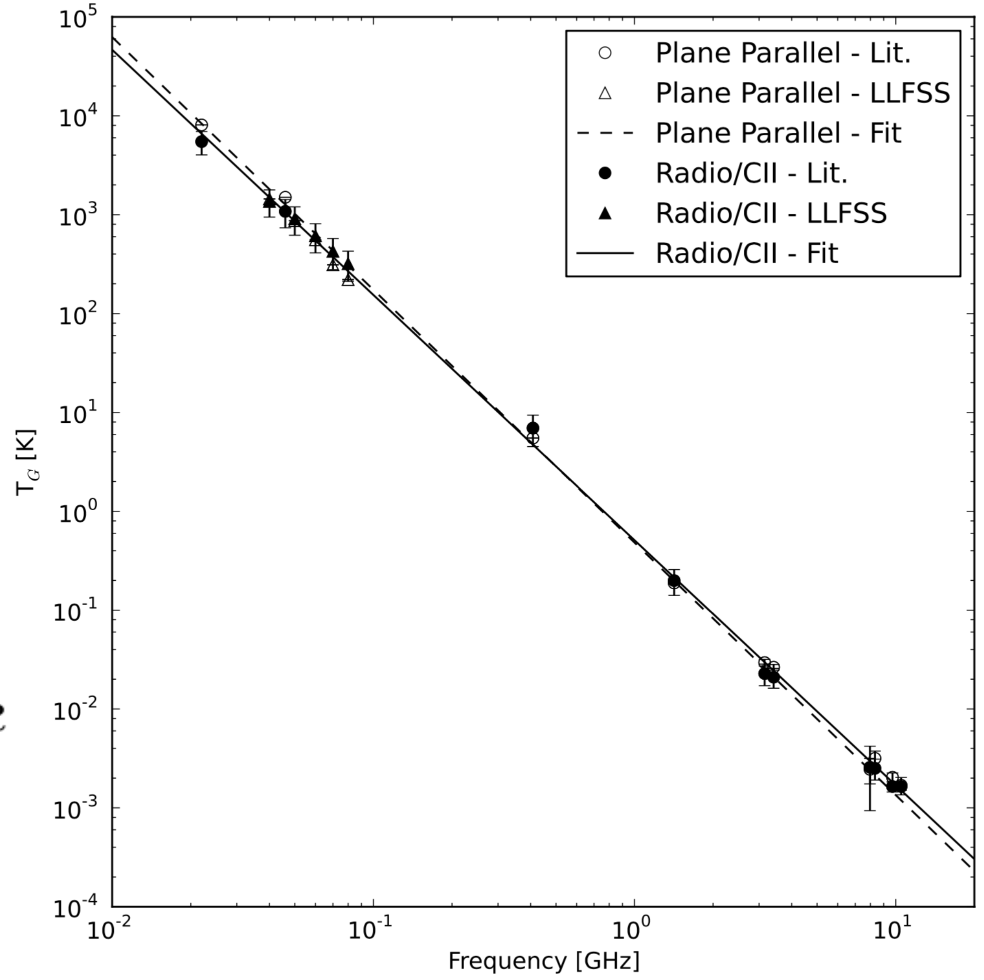
All 9 Maps Included

LFSS 45 MHz and reprocessed 408 MHz map (Remazeilles et al. 2015)



The Radio Background Below 100 MHz

- Combine 40, 50, 60, 70, and 80 MHz LFSS maps with literature data
- Remove Galaxy contribution
  - Plane parallel model: $T(\nu) = T_0(\nu) + T_G(\nu) \times \csc|b|$
  - Synchrotron/CII Correlation: $\langle T_G(\nu) \rangle = a(\nu) \langle \sqrt{I_{CII}} \rangle$
  - Results fit with power law: $T_G(\nu) = T_{Gal}\,(\nu/\nu_0)^{\beta_{Gal}}$
- Residuals are fit with a combination of the CMB and a power law: $T(\nu) = T_{CMB} + T_R\,(\nu/\nu_0)^{\beta}_{R}$

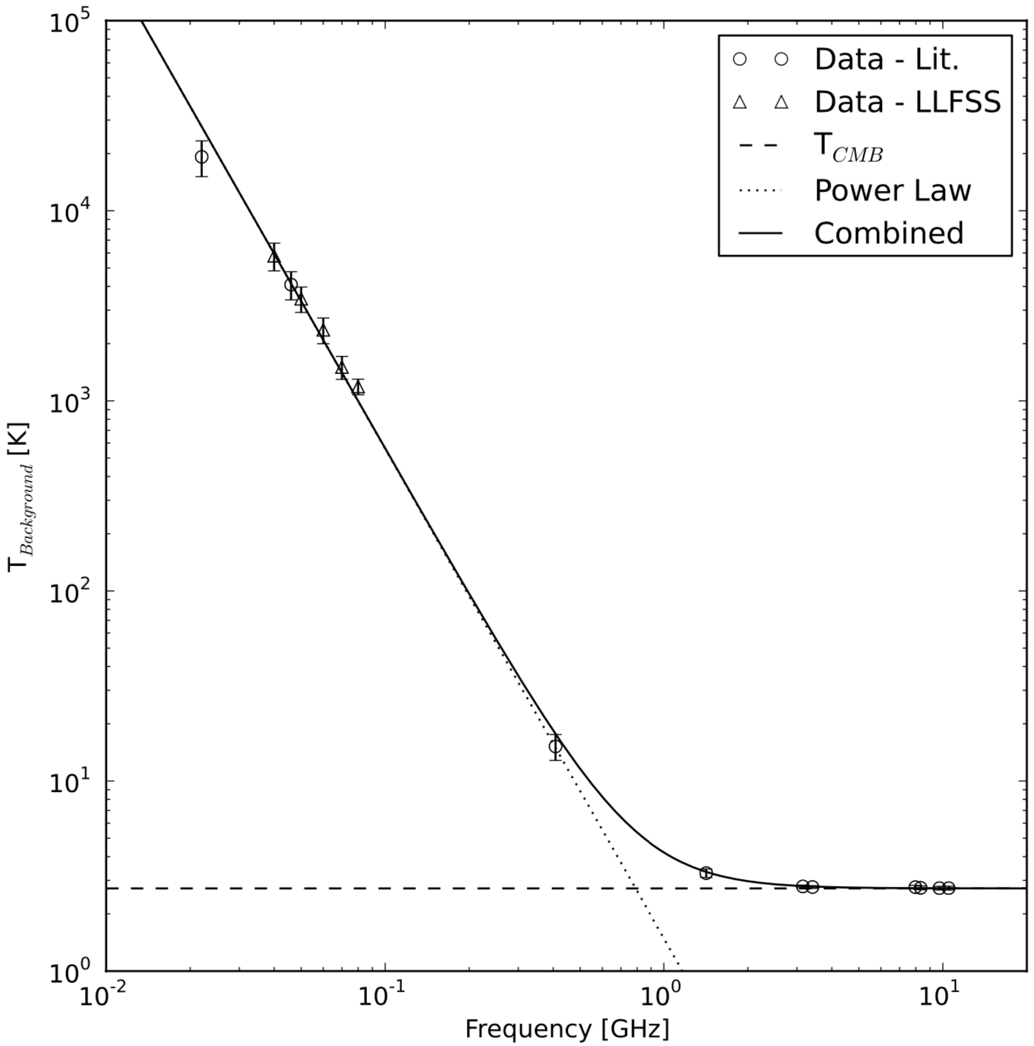


The Radio Background Below 100 MHz

Table 2. Mean Extragalactic Background Temperature

Frequency [GHz]	Map Source	Temperature[a] [K]	Uncertainty[b] [K]
0.022	Roger et al. (1999)	19212	4095
0.040	LLFSS; Dowell et al. (2017)	5792	963
0.046	Alvarez et al. (1997); Maeda et al. (1999)	4090	691
0.050	LLFSS; Dowell et al. (2017)	3443	526
0.060	LLFSS; Dowell et al. (2017)	2363	365
0.070	LLFSS; Dowell et al. (2017)	1505	208
0.080	LLFSS; Dowell et al. (2017)	1188	112
0.408	Haslam et al. (1982); Remazeilles et al. (2015)	15.20	2.37
1.419	Reich (1982); Reich & Reich (1986); Reich et al. (2001)	3.276	0.167
3.150	ARCADE 2; Fixsen et al. (2011)	2.788	0.045
3.410	ARCADE 2; Fixsen et al. (2011)	2.768	0.045
7.970	ARCADE 2; Fixsen et al. (2011)	2.764	0.060
8.330	ARCADE 2; Fixsen et al. (2011)	2.741	0.062
9.720	ARCADE 2; Fixsen et al. (2011)	2.731	0.062
10.490	ARCADE 2; Fixsen et al. (2011)	2.731	0.065

[a] The temperatures shown here have been converted to from antenna to thermodynamic temperature.
[b] Estimated from the five different combinations of Galaxy removal method and line-of-sight.



Current Efforts

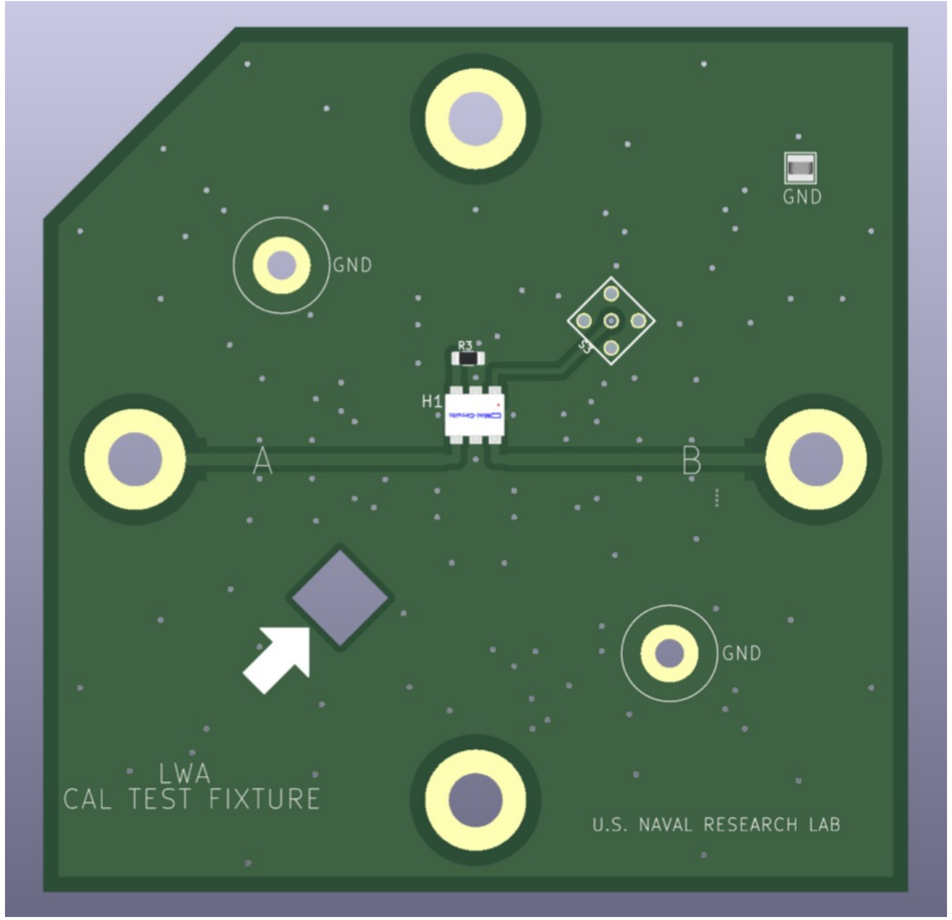
Need better characterization of the LWA antenna:

1. Dipole beam pattern
   - External Calibrator for Hydrogen Observatories (ECHO; Jacobs et al 2017)
   - Unsuccessful run in 2019, but future runs planned
2. Impedance Mismatch
   - Need actual measurements, not just simulations. Ongoing work with improved results coming soon (hopefully!)

New Sky Survey:

1. TBW data every 3 minutes between 2 AM – 6 AM local time
2. Trying to push frequency coverage below 20 MHz

Current Efforts



Custom calibration fixtures designed by Brian Hicks (NRL) and Whitham Reeve

In situ measurements of the LWA antenna impedance using a VNA

Summary

- The LWA1 Low Frequency Sky Survey
  - Nine frequency bands between 35 – 80 MHz
  - Absolutely calibrated LWA1 data
  - Low Frequency Sky Model (LFSM), not covered in this talk, but available
- The Extragalactic Radio Background Below 100 MHz
  - Data from the LWA1 LFSS combined with other experiments suggest that there is an unaccounted component to the extragalactic radio background
  - Consistent with the ARCADE 2 results between 3-10 GHz
  - 21 cm rest frame temperature is 603 mK with a spectral index of -2.58
- Current efforts are focusing on better measuring the LWA dipole gain pattern and the impedance mismatch between the antenna and front end electronics
- Major goal is to have new sky maps with consistent calibration to yield a physically motivated sky model