Searching for the 21-cm Cosmic Dawn Absorption Signal with the LWA

August 2nd, 2019

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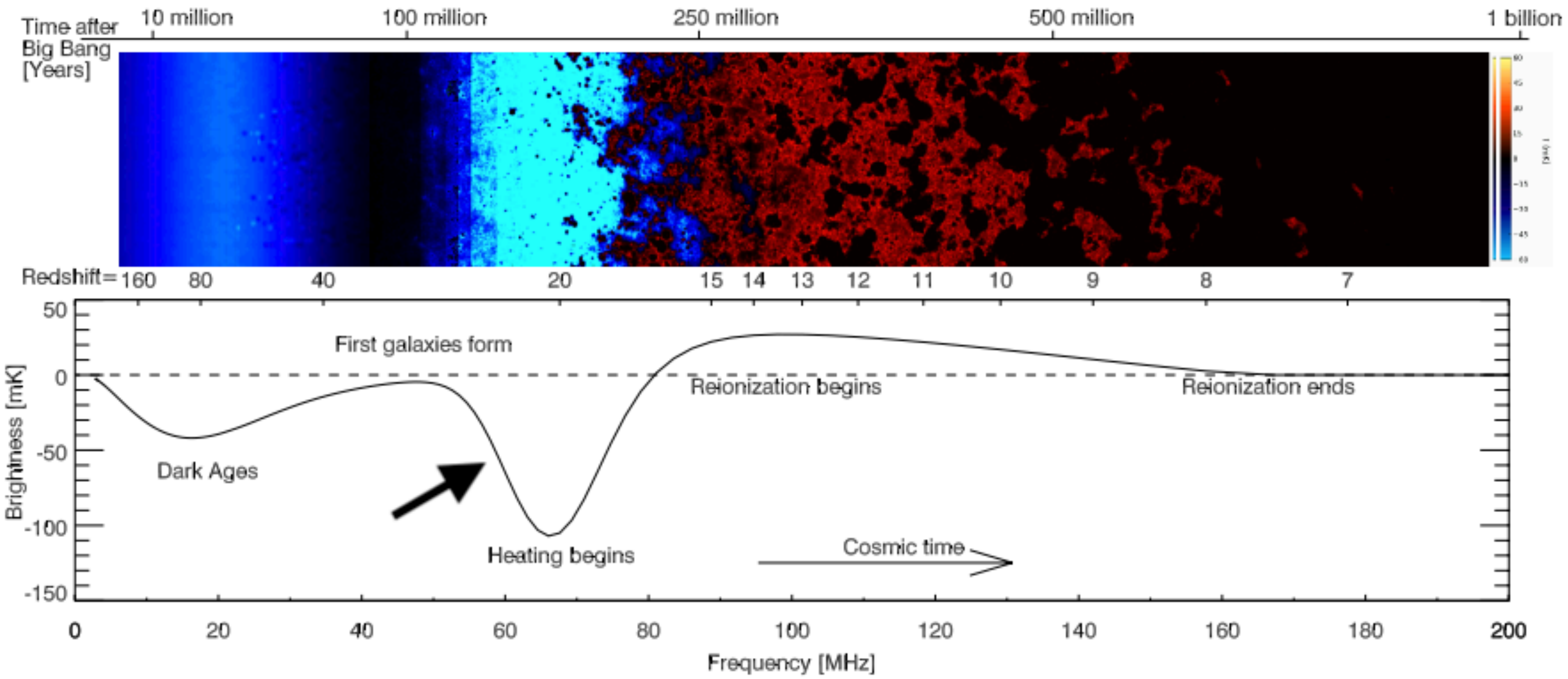
Outline

- 21-cm Cosmology
- Current Limits of the LWA
- Ongoing Improvement Efforts

21-cm Cosmology



Pritchard & Loeb 2012

- First stars emit Lyα which couples hydrogen spin temperature to gas temperature.
- $T_K < T_{CMB}$, so 21-cm signal seen in absorption.

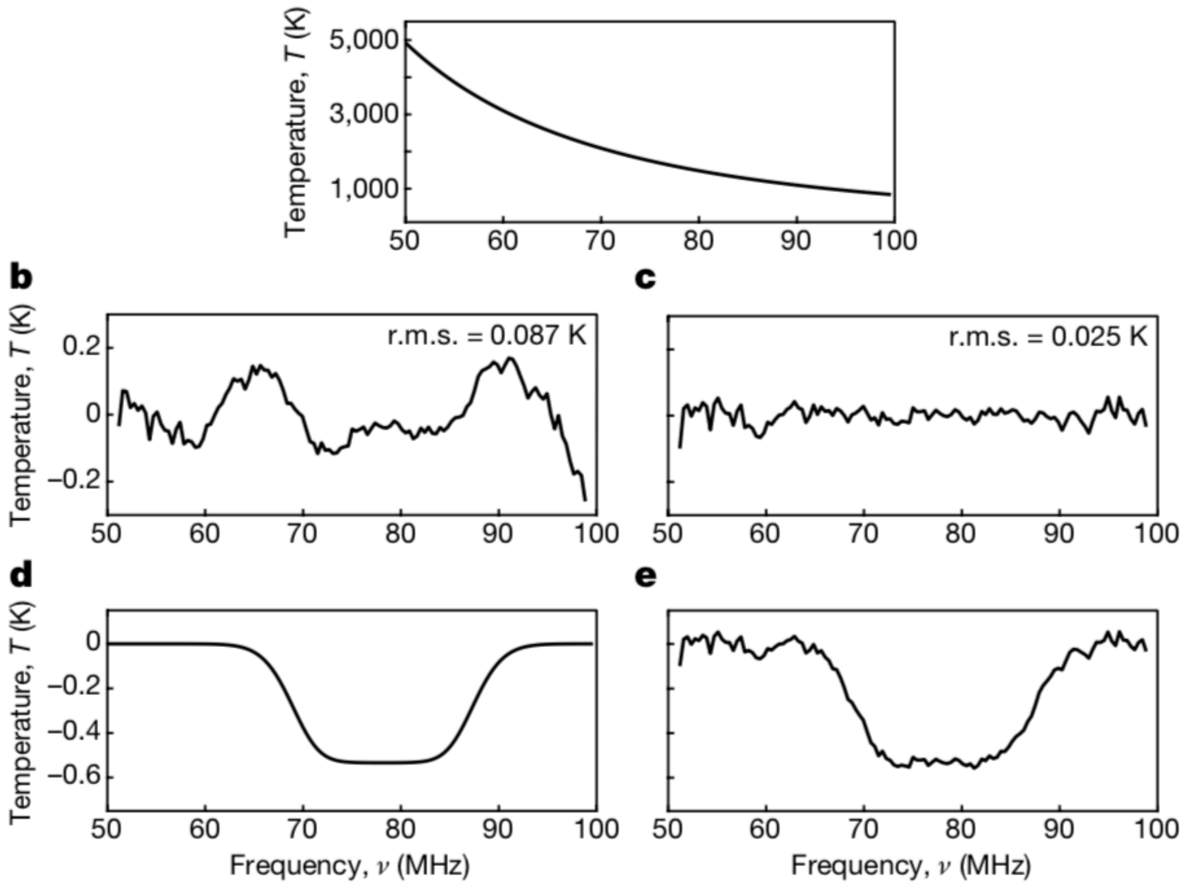
A Possible Detection! – Bowman et al. 2018

LETTER

doi:10.1038/nature25792

An absorption profile centred at 78 megahertz in the sky-averaged spectrum

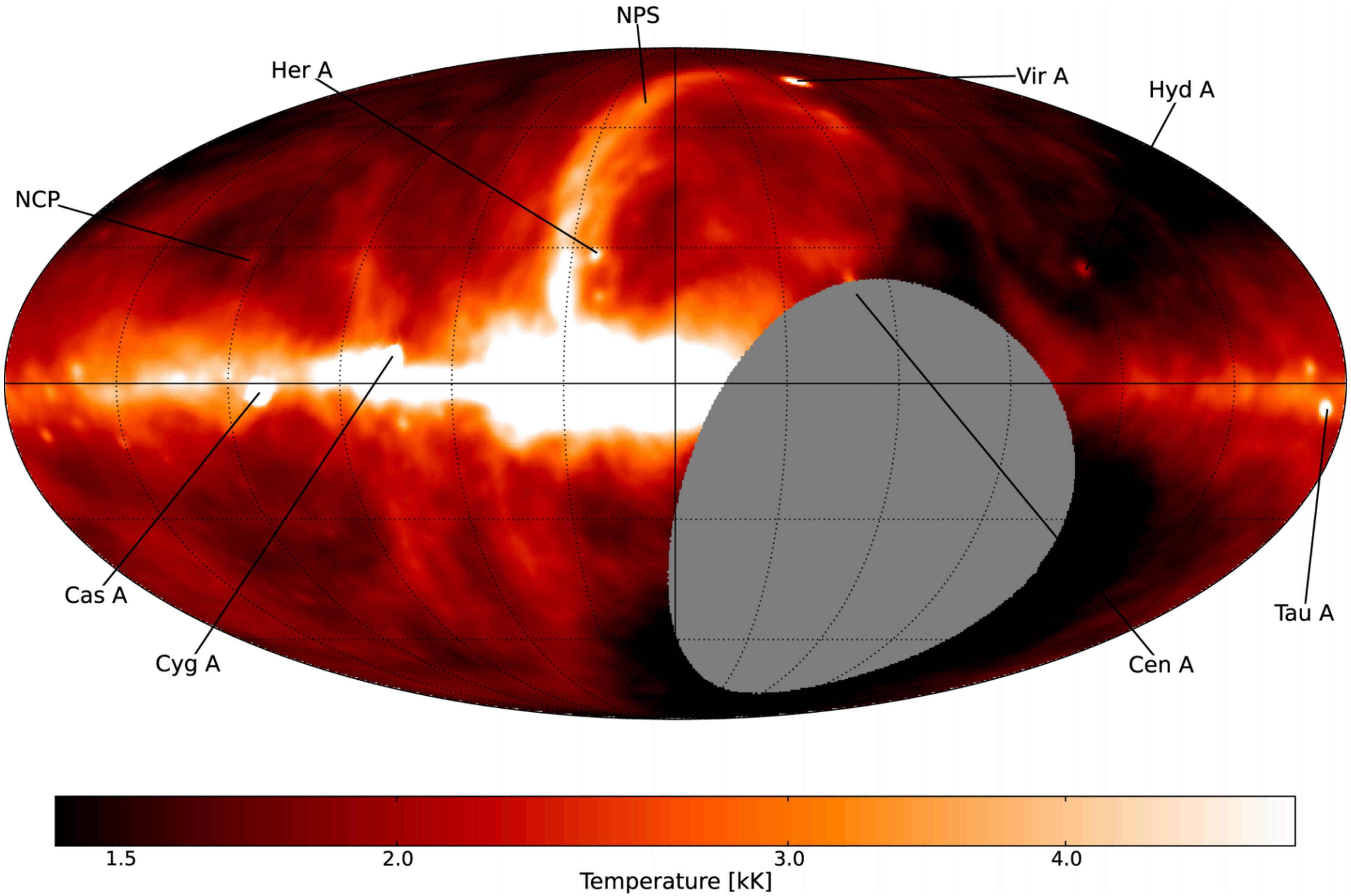
Judd D. Bowman[1], Alan E. E. Rogers[2], Raul A. Monsalve[1,3,4], Thomas J. Mozdzen[1] & Nivedita Mahesh[1]



EDGES vs LWA-SV

- EDGES is a single dipole → required hundreds of hours of integration.
- LWA-SV has 256 dipoles → needs much less time.
  - Should be detectable with an r.m.s. of 50 mK within 25 s!
- Beam forming vs sky-averaged spectrum.

The Sky at 74 MHz



Dowell et al. 2017

Current Work

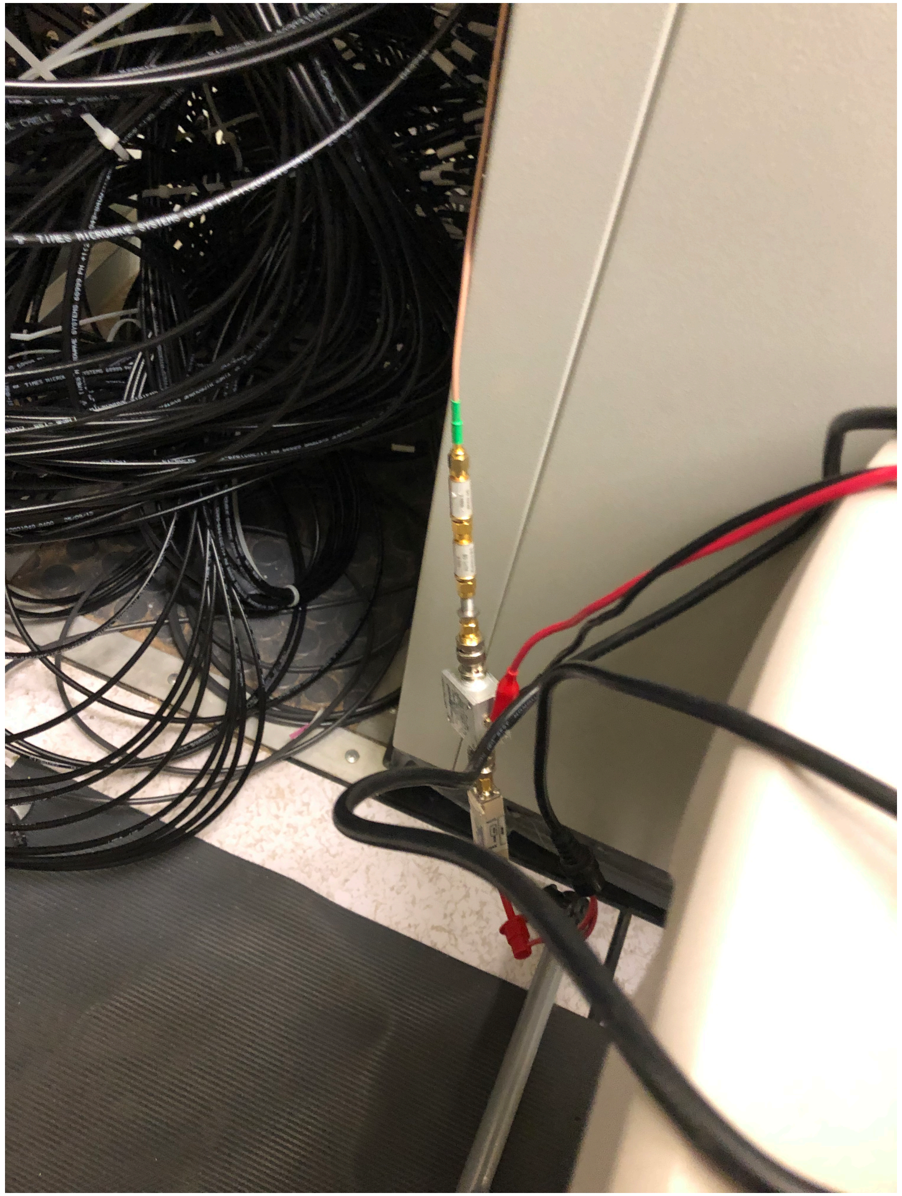
Calibration

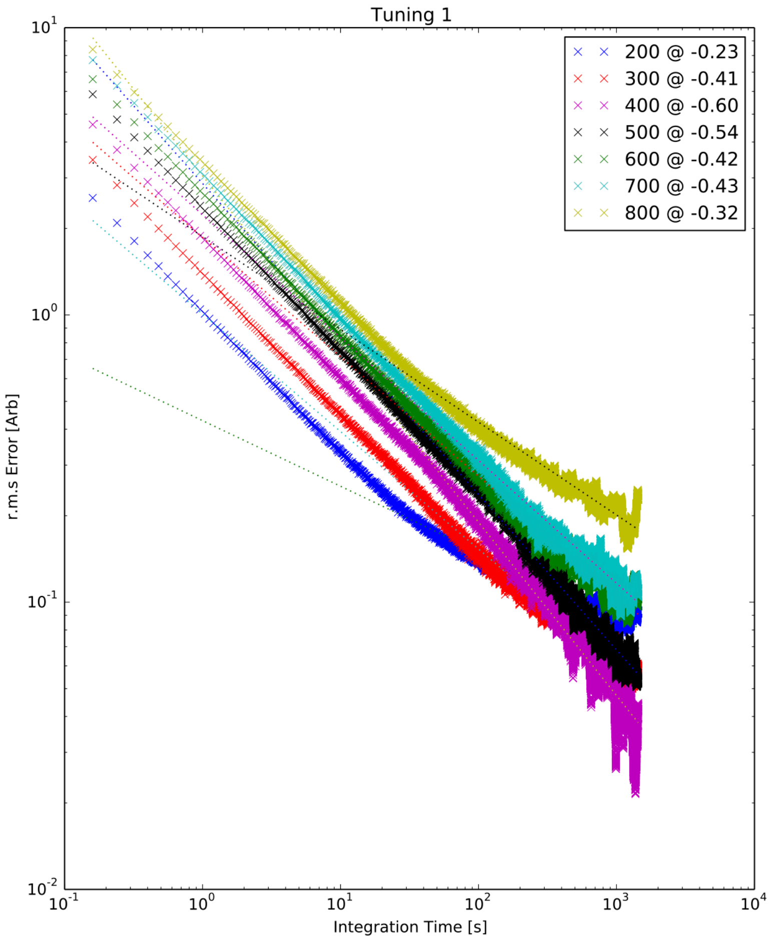
- Accurately describe the instrumental response of LWA-SV.
- Determine the current integration limitations of LWA-SV.
- Develop an accurate temperature calibration scheme.

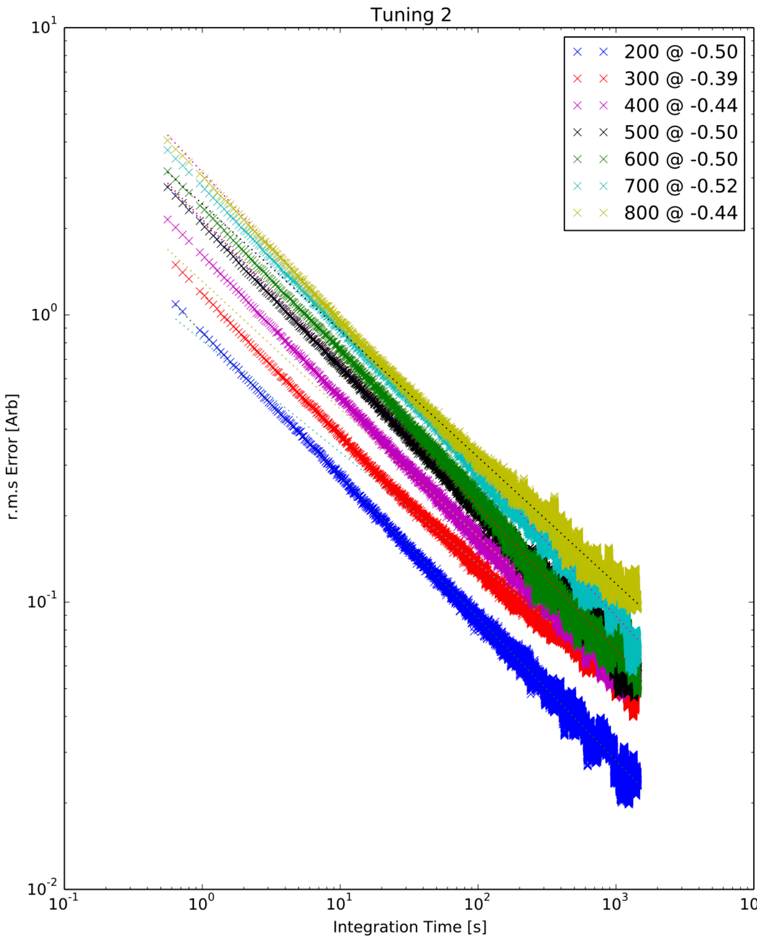
Modelling

- Accurately model foregrounds.
    - Physically motivated polynomials.
    - Maximally Smooth Functions
- Be careful not to over model and remove the 21-cm signal.

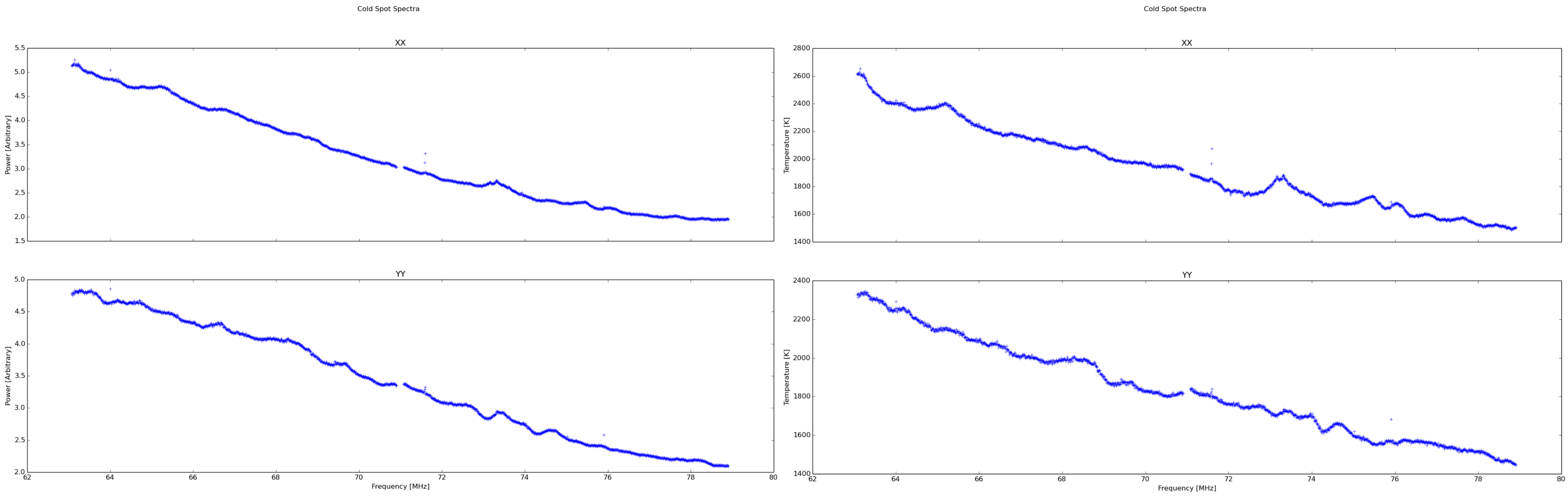
Current Limitations







Setting a Temperature Scale



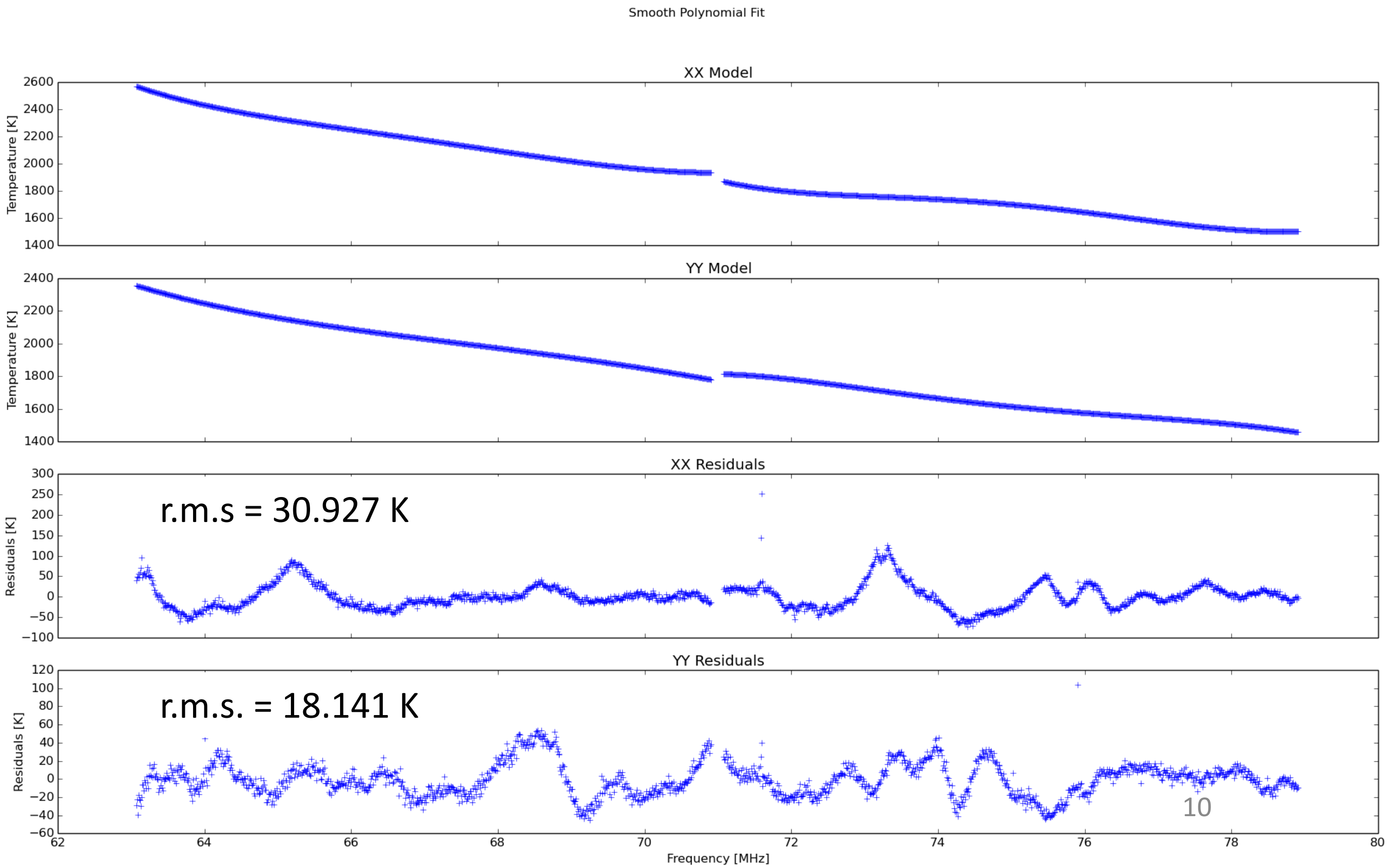
- Use Virgo A as a calibrator to obtain frequency dependent scaling by comparing to the Global Sky Model.
- Apply this scaling to cold spot spectrum.

Modelling

- Smooth polynomial model:

$$T(\nu) = \sum_{n=0}^{N-1} a_n \left(\frac{\nu}{\nu_c}\right)^{n-2.5}$$

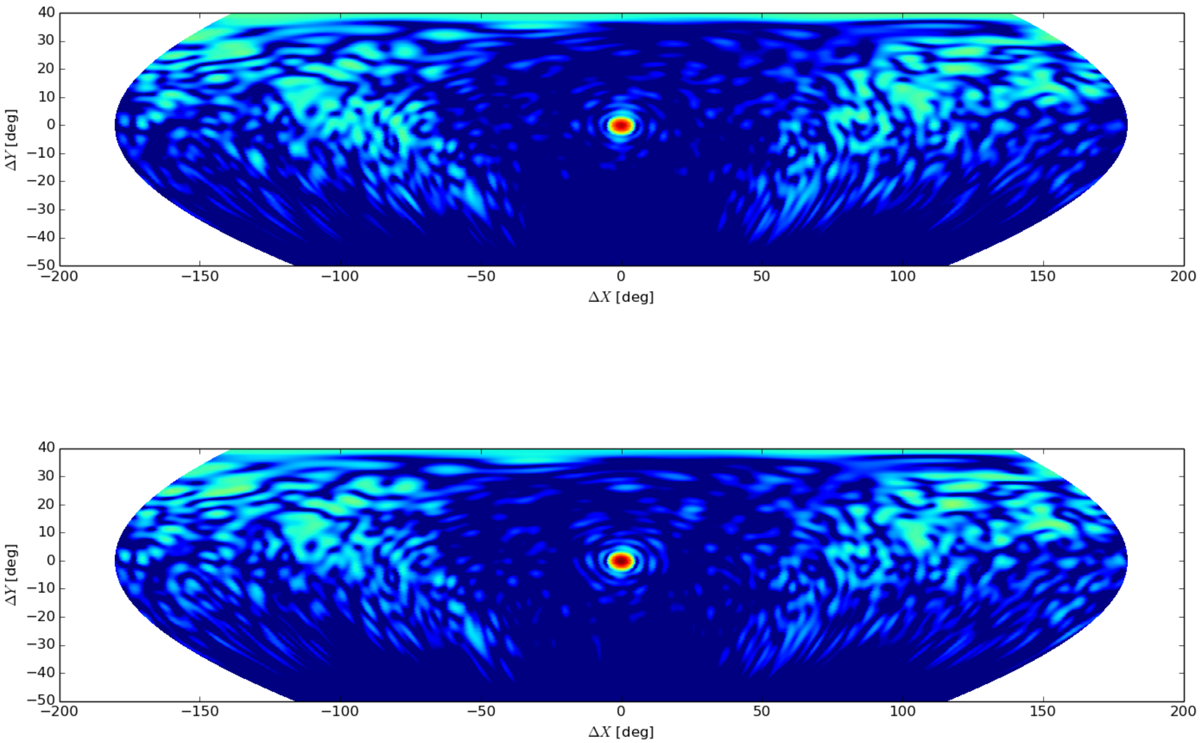
a_n	Fit (x 10^6)	σ (x 10^6)
a_0	8.37	1.00
a_1	-33.5	4.01
a_2	50.3	6.03
a_3	-33.5	4.03
a_4	8.38	10.1

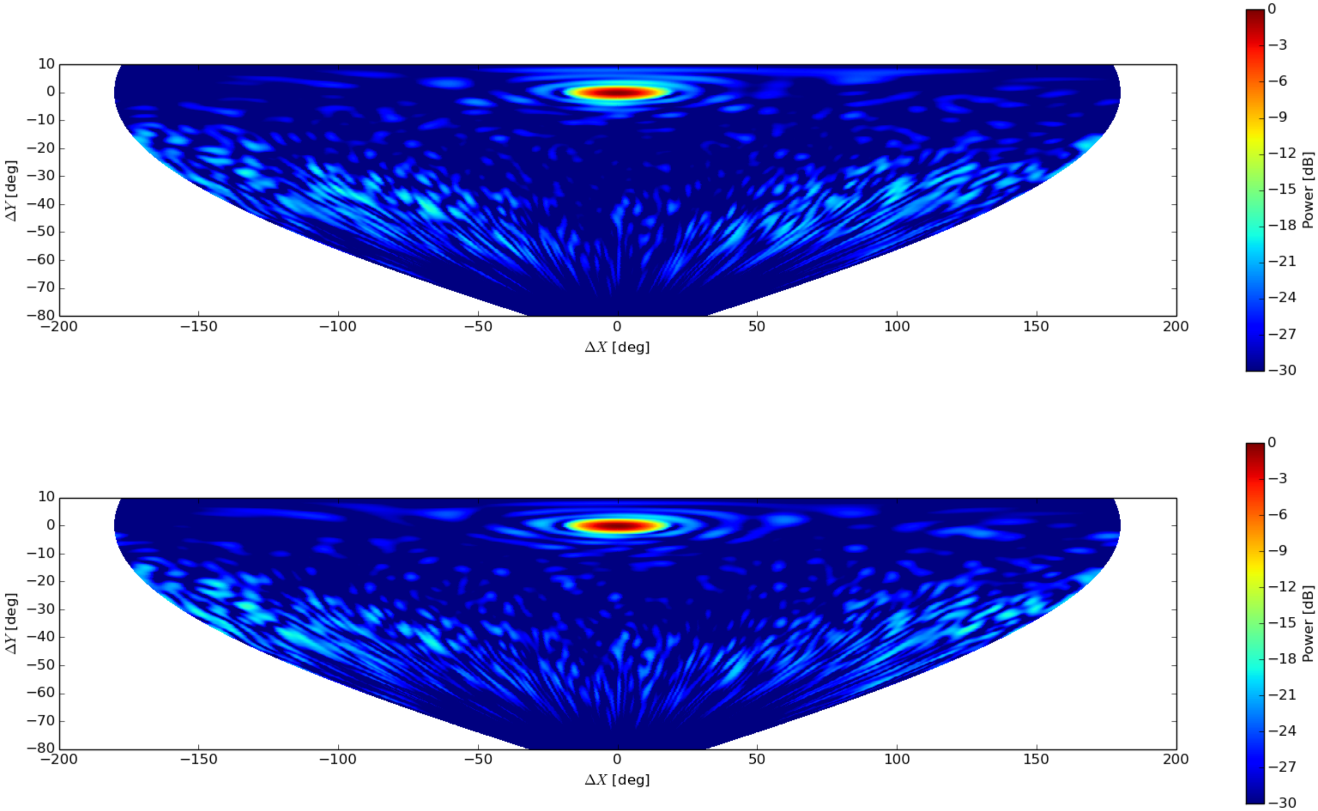


An Idea for Improvement: Custom Beam Forming

- Sets the size/shape of the beam.
  - Make the beam achromatic.
- $Y(\theta, \varphi) = R(\theta, \varphi) \times (\mathbf{W} \cdot \mathbf{V}(\mathbf{k}))$
  - R – antenna gain pattern
  - **W** – weighting vector
  - **V** – steering vector
- Down-weight certain dipoles to shape the beam.
- Limited by the resolution of the lowest frequency.

Uniform Weighting Scheme





67 MHz, 180° azimuth, 50° elevation

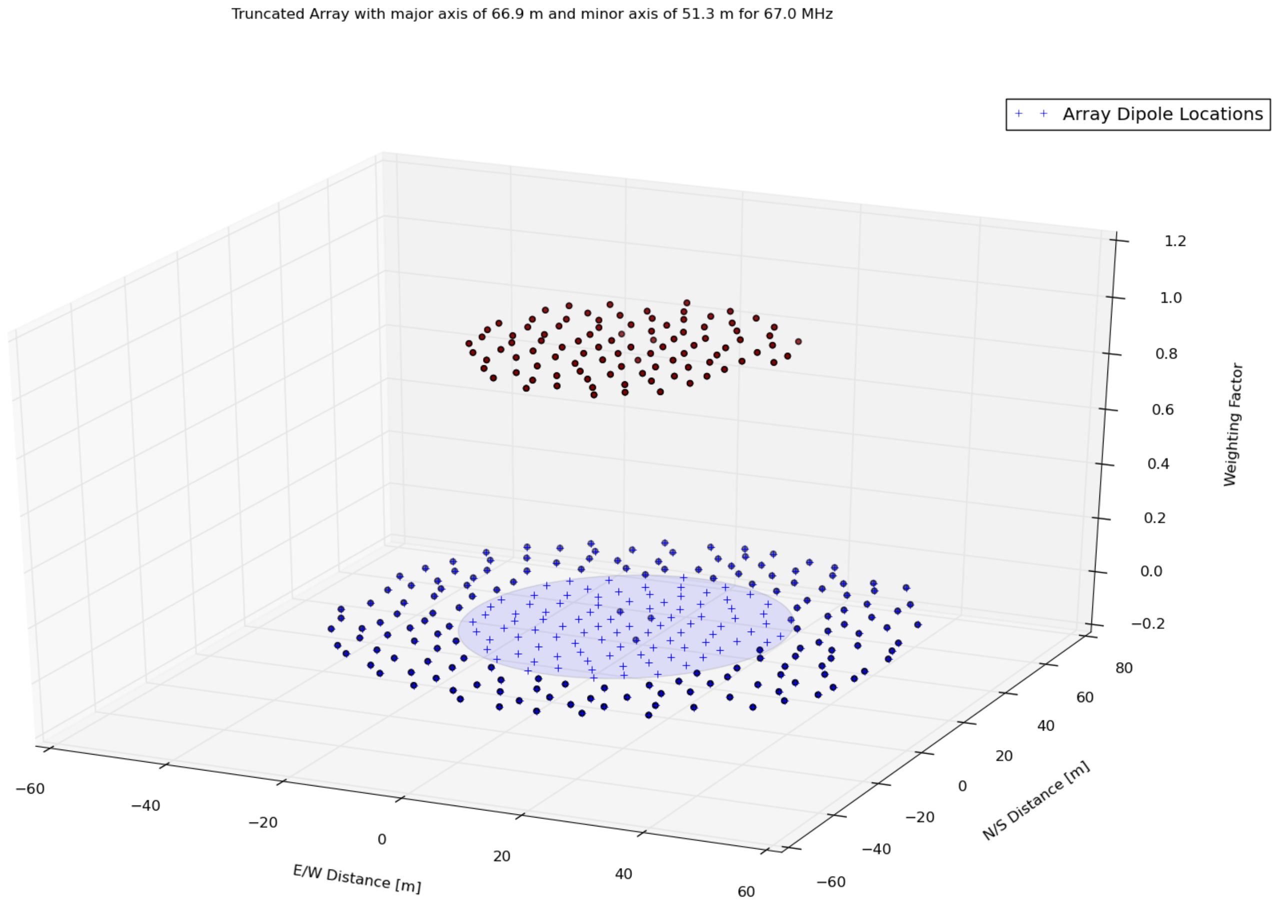
2.9° ✕ 3°

67 MHz, 180° azimuth, 80° elevation

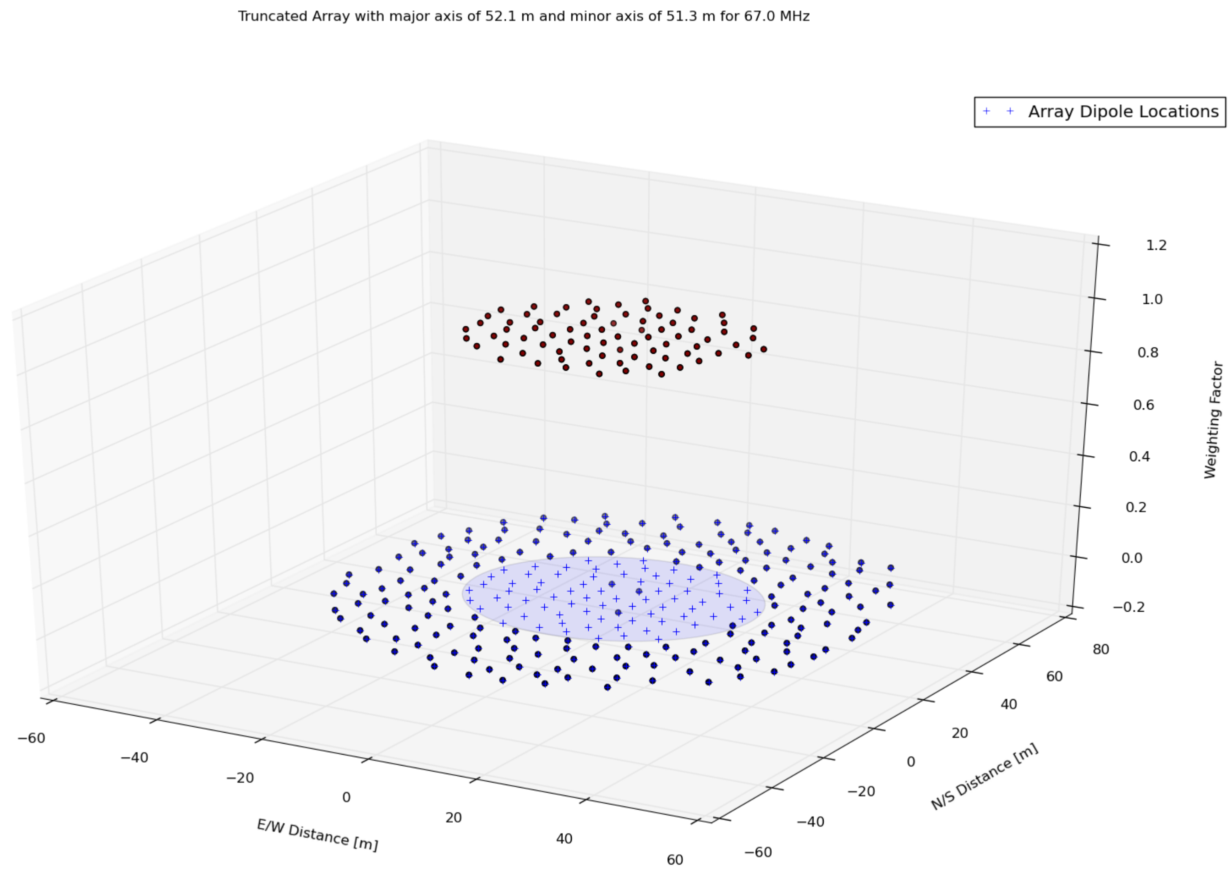
2.9° ✕ 2.4°

Truncated Weighting Scheme

$$D_{\perp} = \frac{c}{\nu \cdot \theta} \qquad D_{\parallel} = \frac{D_{\perp}}{\sin(e)}$$

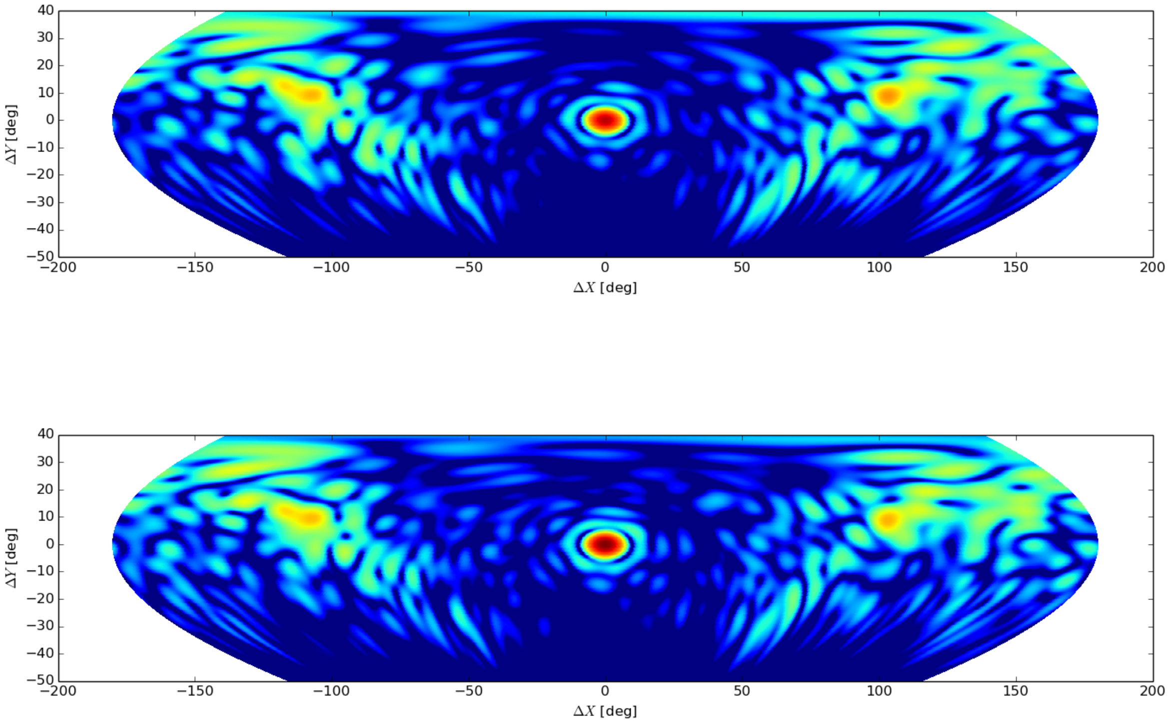


50° elevation

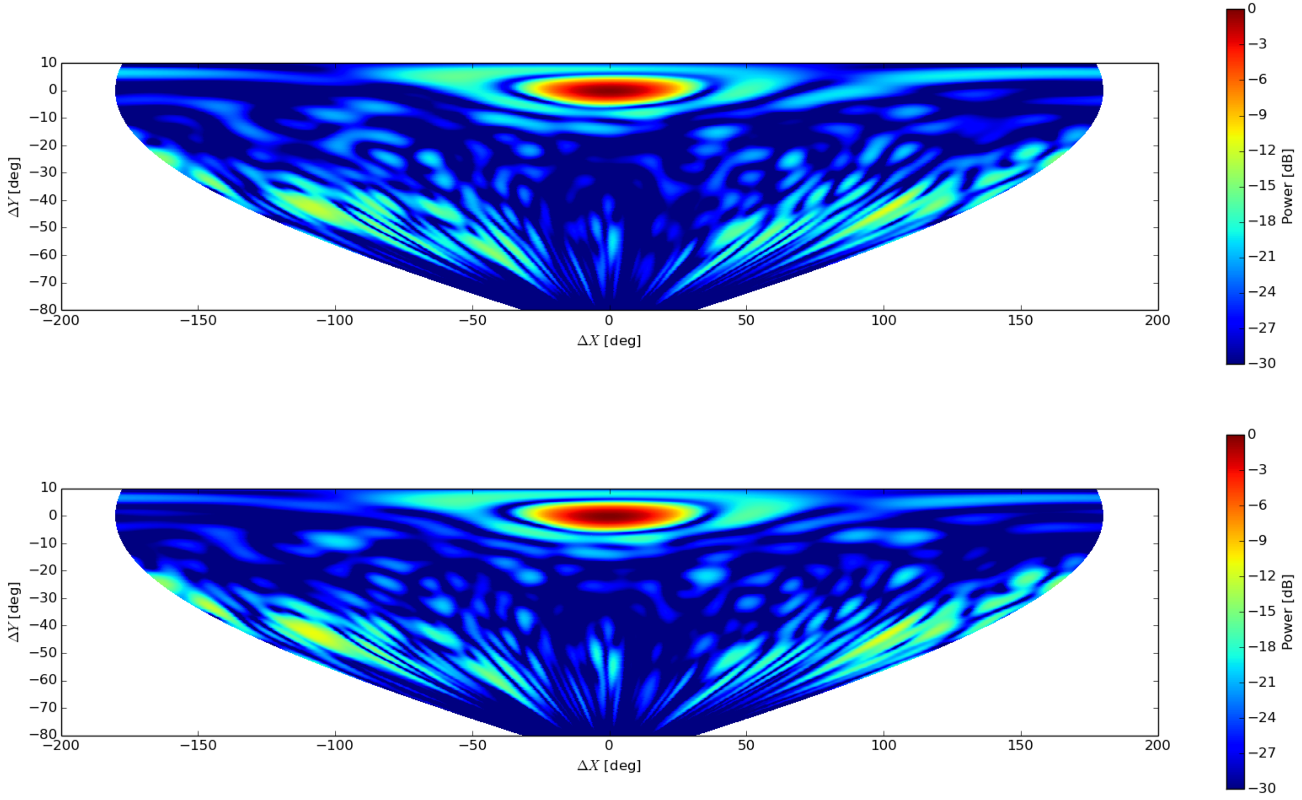


80° elevation

5° Circular Beams! (I promise)

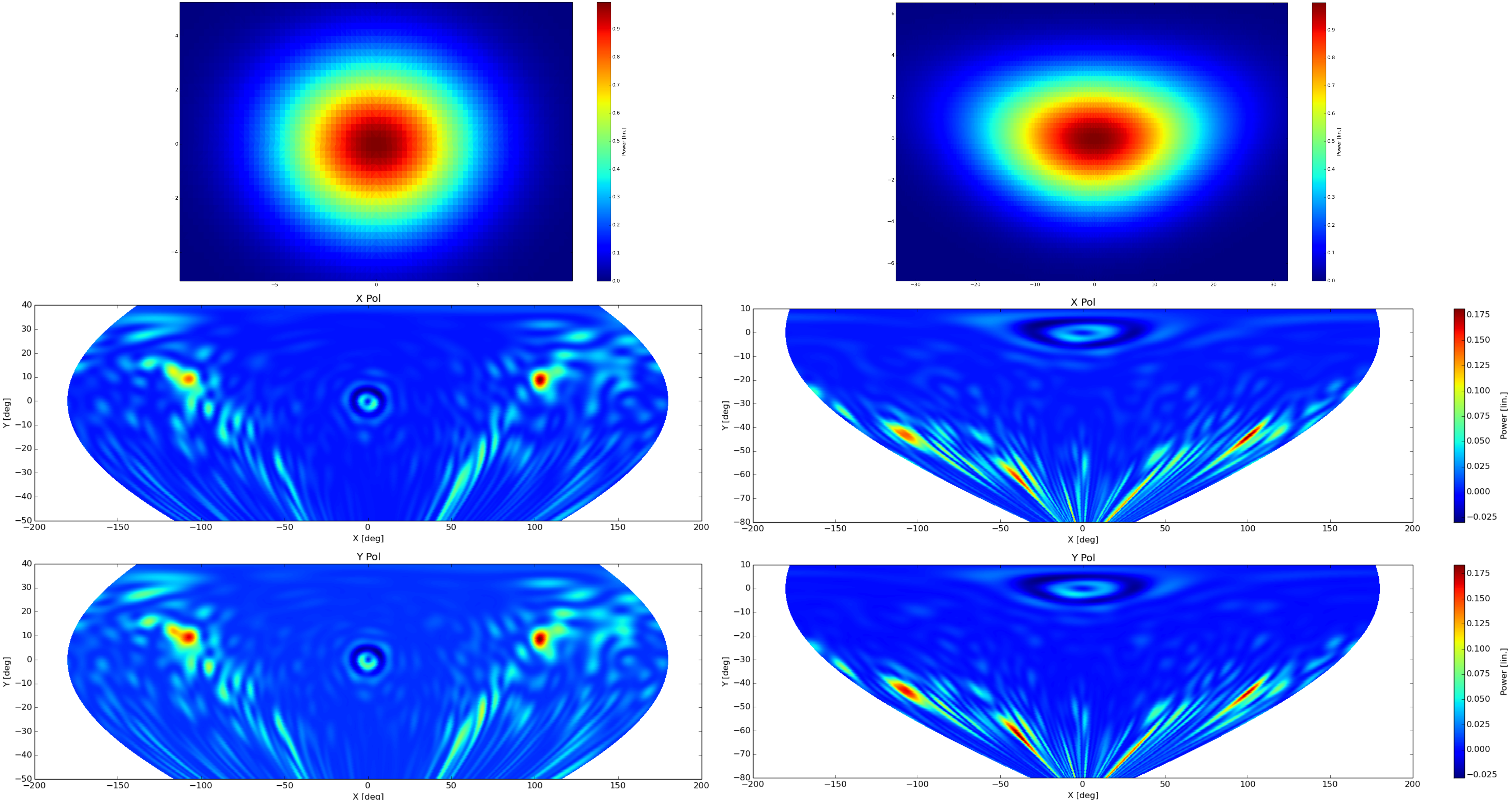


50° elevation



80° elevation

Residuals



Summary

- Detection of cosmic dawn is a **very sensitive** measurement.
- Requires **dynamic range** on the order of 10^4.
- LWA-SV offers **unique advantages** over single element radiometers.
- Currently developing **customizable beamforming methods**.

Far from a significant detection, but future improvements (custom beamforming, 2x 20 MHz bandwidth at SV) should help.