Using the Long Wavelength Array to Search for Cosmic Dawn

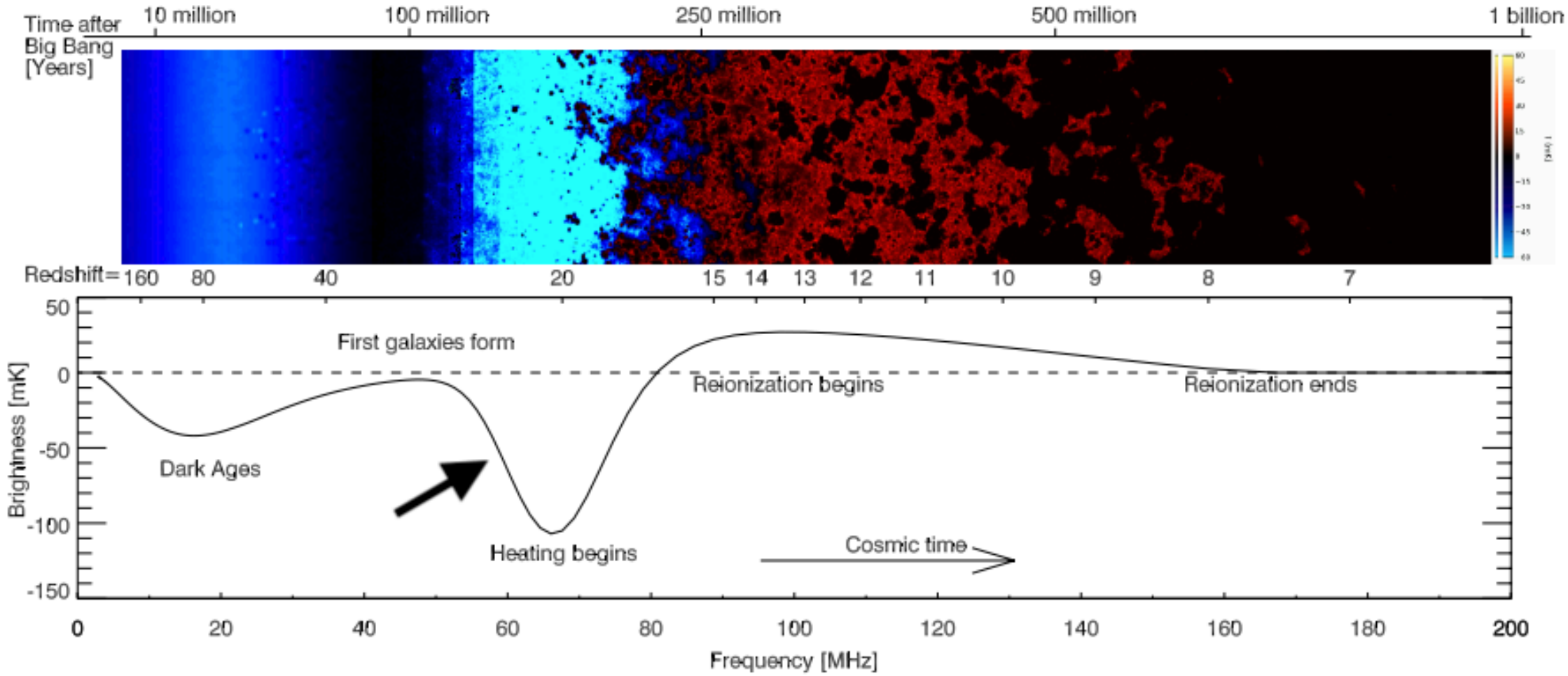
February 21st, 2020

Christopher DiLullo

With: Greg Taylor and Jayce Dowell

University of New Mexico

21-cm Cosmology



Pritchard, Jonathan R., and Abraham Loeb. "21 cm cosmology in the 21st century." *Reports on Progress in Physics* 75.8 (2012): 086901.

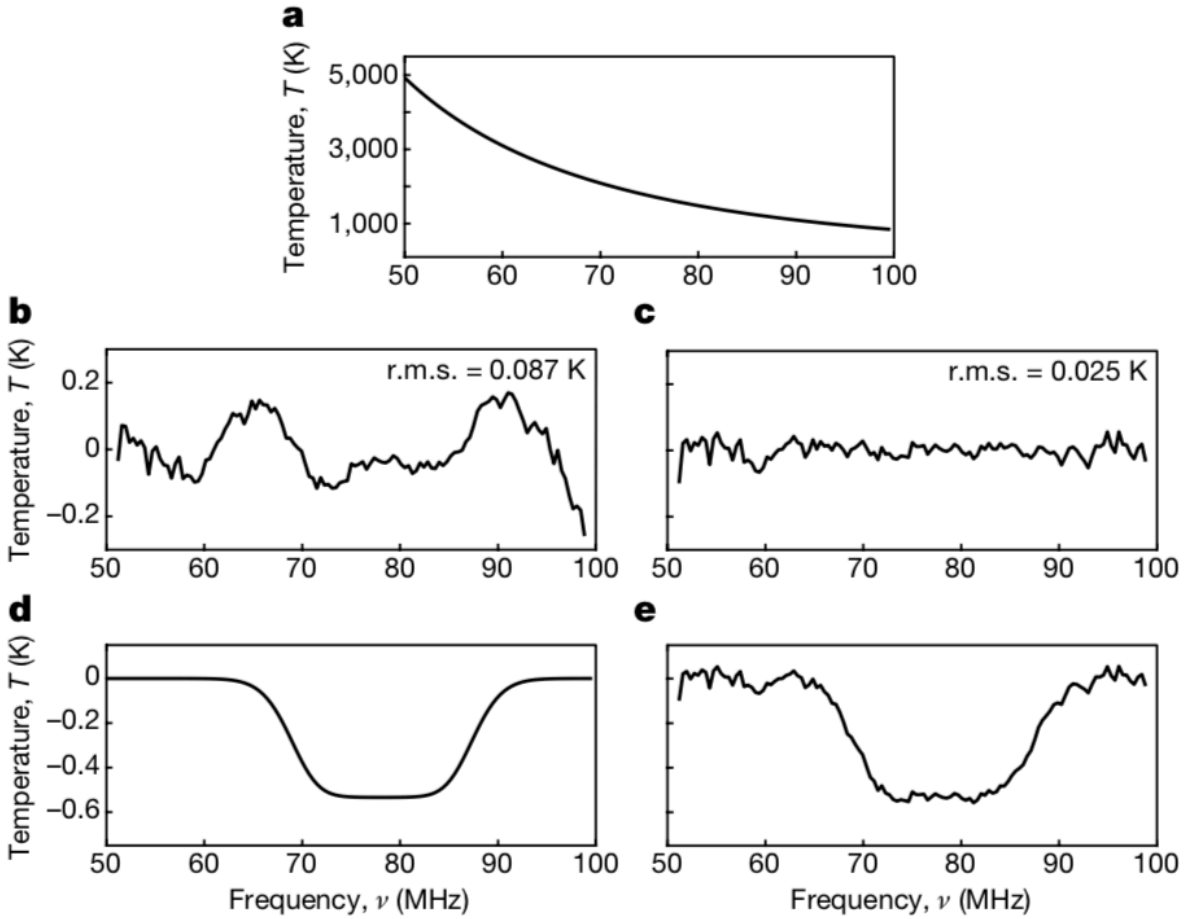
A Possible Detection! – Bowman et al. 2018

LETTER

doi:10.1038/nature25792

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

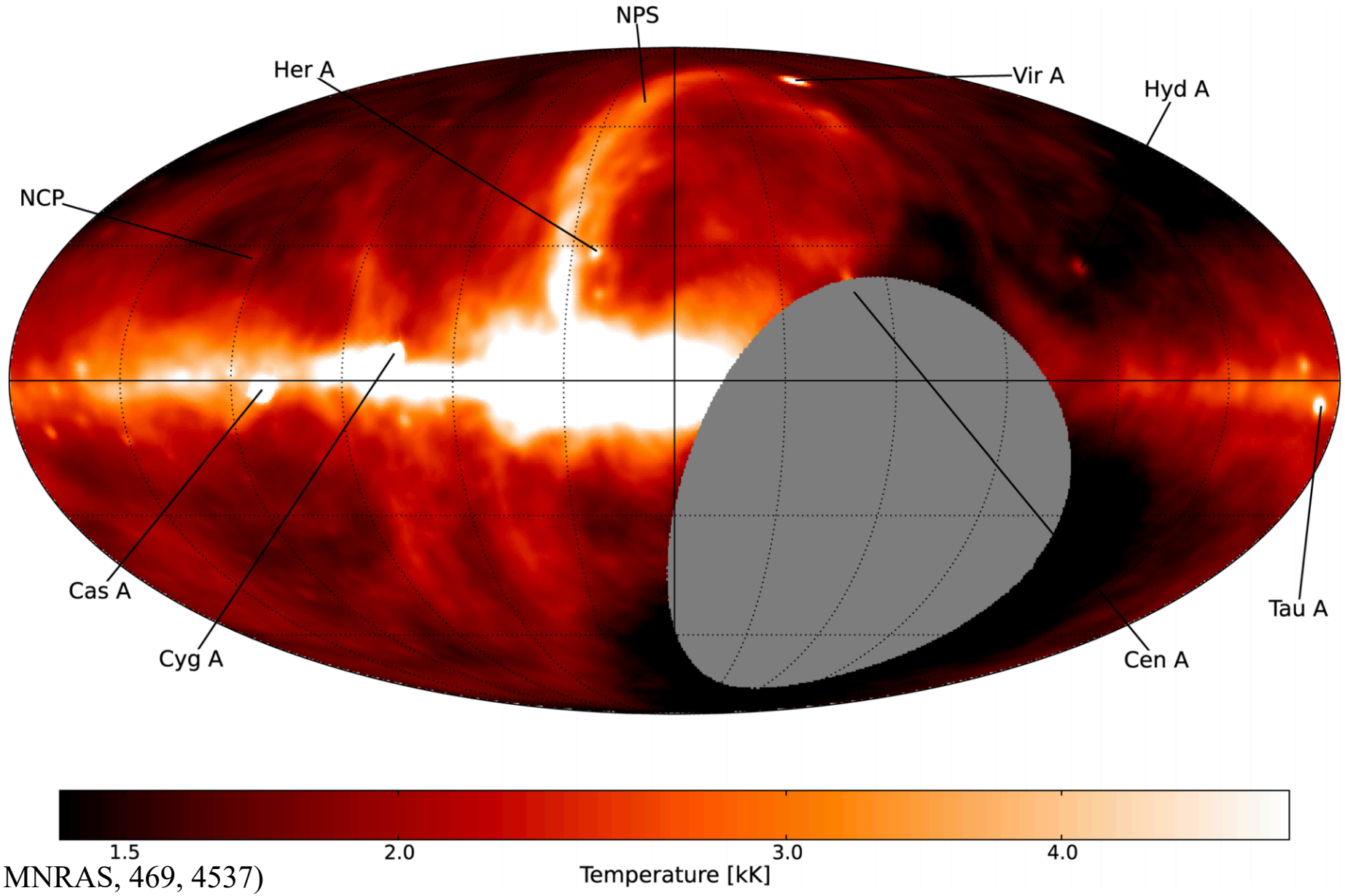
Judd D. Bowman[1], Alan E. E. Rogers[2], Raul A. Monsalve[1,3,4], Thomas J. Mozdzen[1] & Nivedita Mahesh[1]



LWA-SV

- 256 dual-pol antennas
- 100 m x 110 m ellipse oriented N/S
- 3 simultaneous beams
  - 2 tunings/beam
  - 20 MHz bandwidth / tuning
- Beamforming advantages
  - Spatial selection on the sky
  - *In situ* calibration via second beam

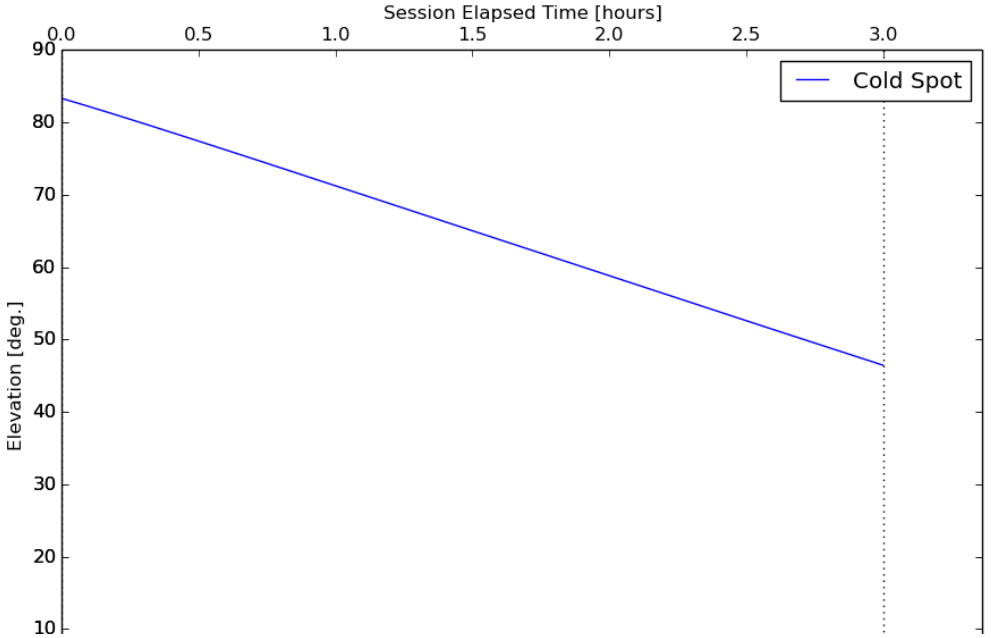
The Sky at 74 MHz

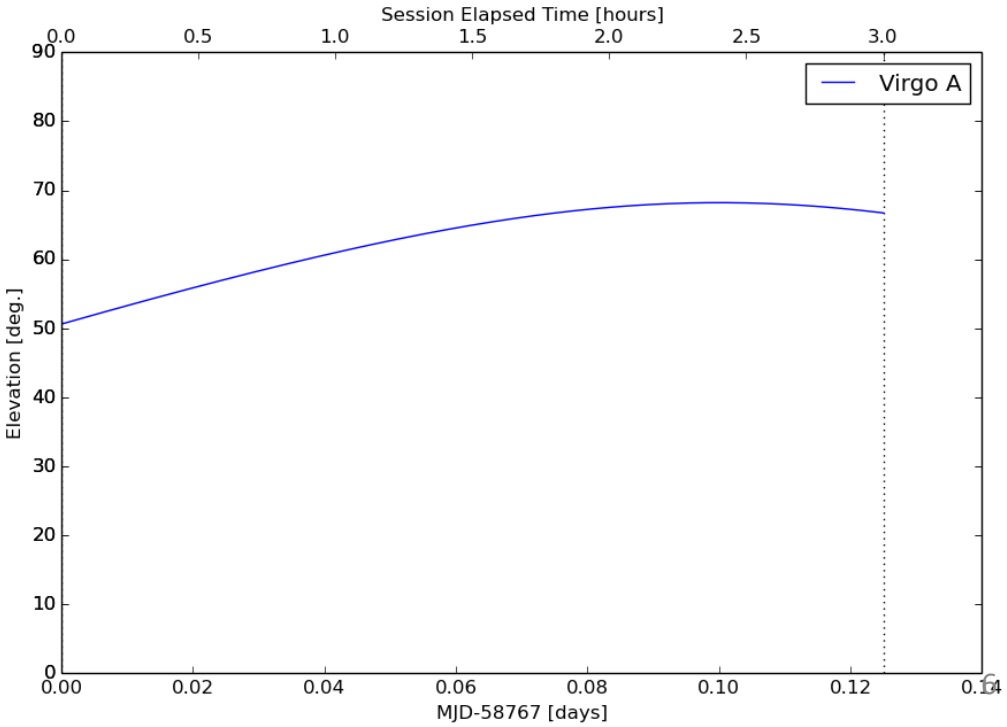


Dowell et al. (2017, MNRAS, 469, 4537)

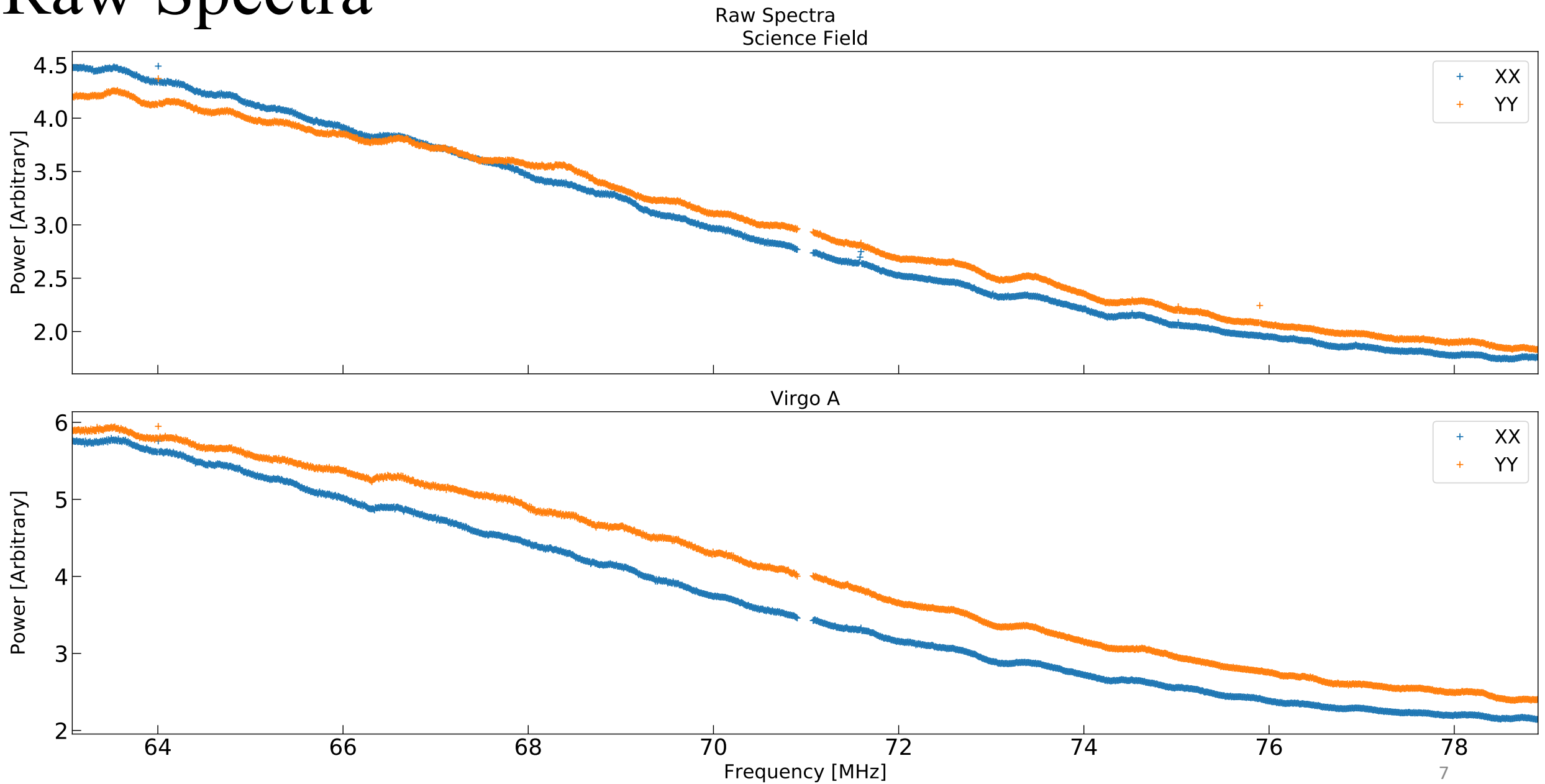
Observational Setup

- 2 simultaneous beams on Virgo A and Science Field
- 3 hr runs with tuning centers at 67 and 75 MHz.
- Spectrometer mode with 1024 9.57 kHz channels and 80 ms time resolution.
- RFI excision using a pseudo-spectral kurtosis flagging criterion.

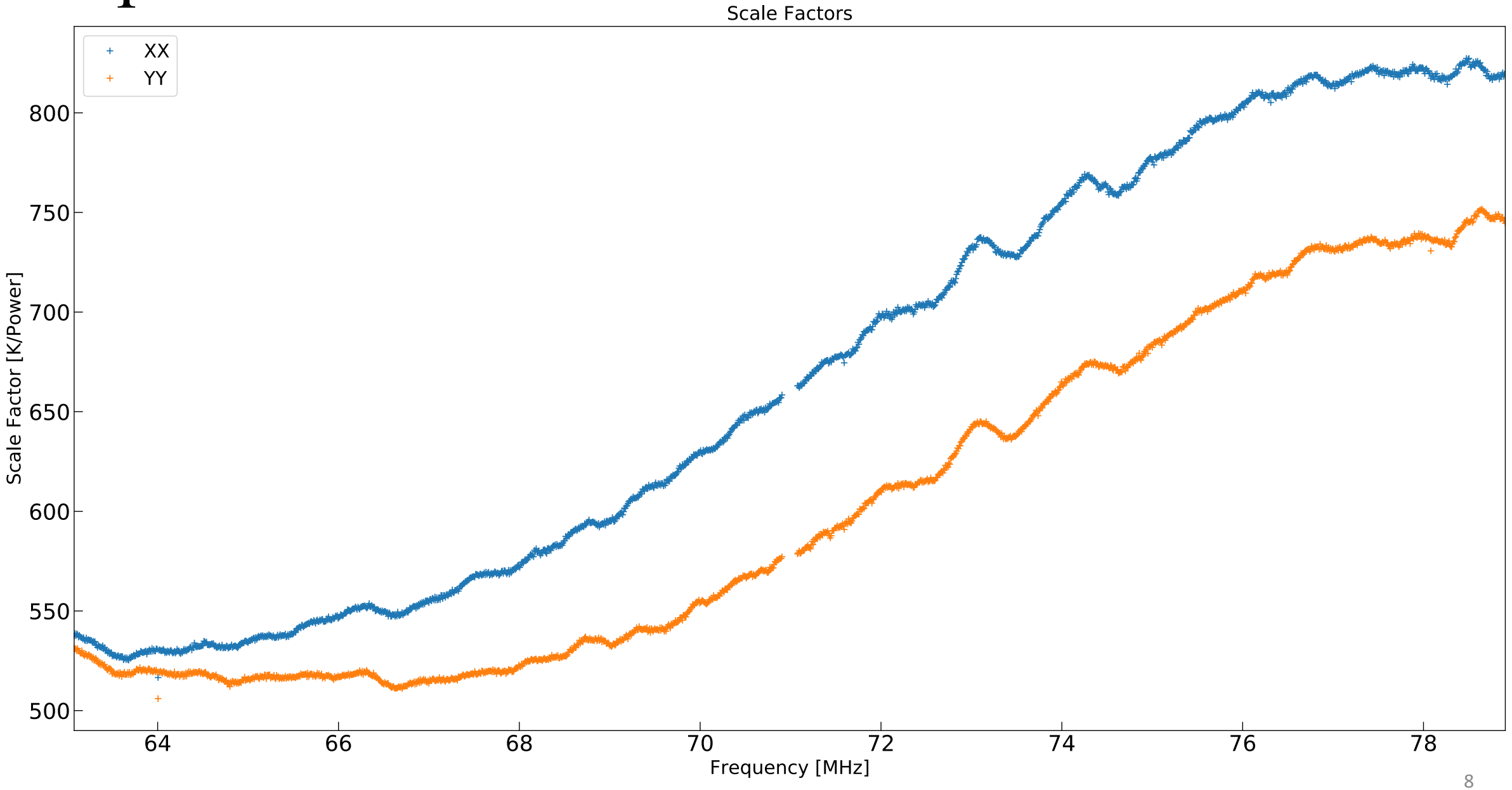




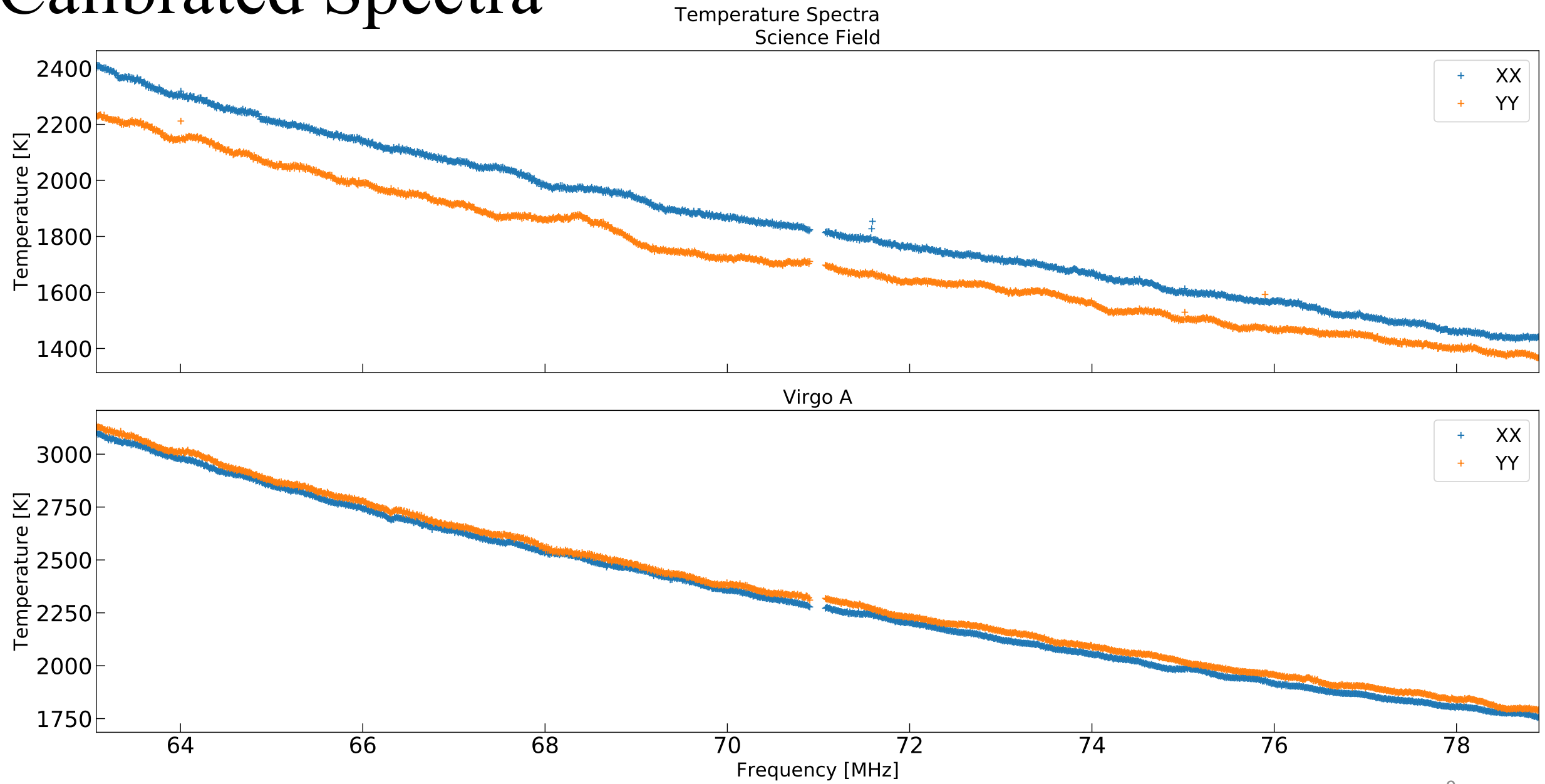
Raw Spectra


Raw Spectra
Science Field
Power [Arbitrary]
4.5
4.0
3.5
3.0
2.5
2.0
XX
YY
Virgo A
Power [Arbitrary]
6
5
4
3
2
XX
YY
64
66
68
70
72
74
76
78
Frequency [MHz]

Temperature Calibration

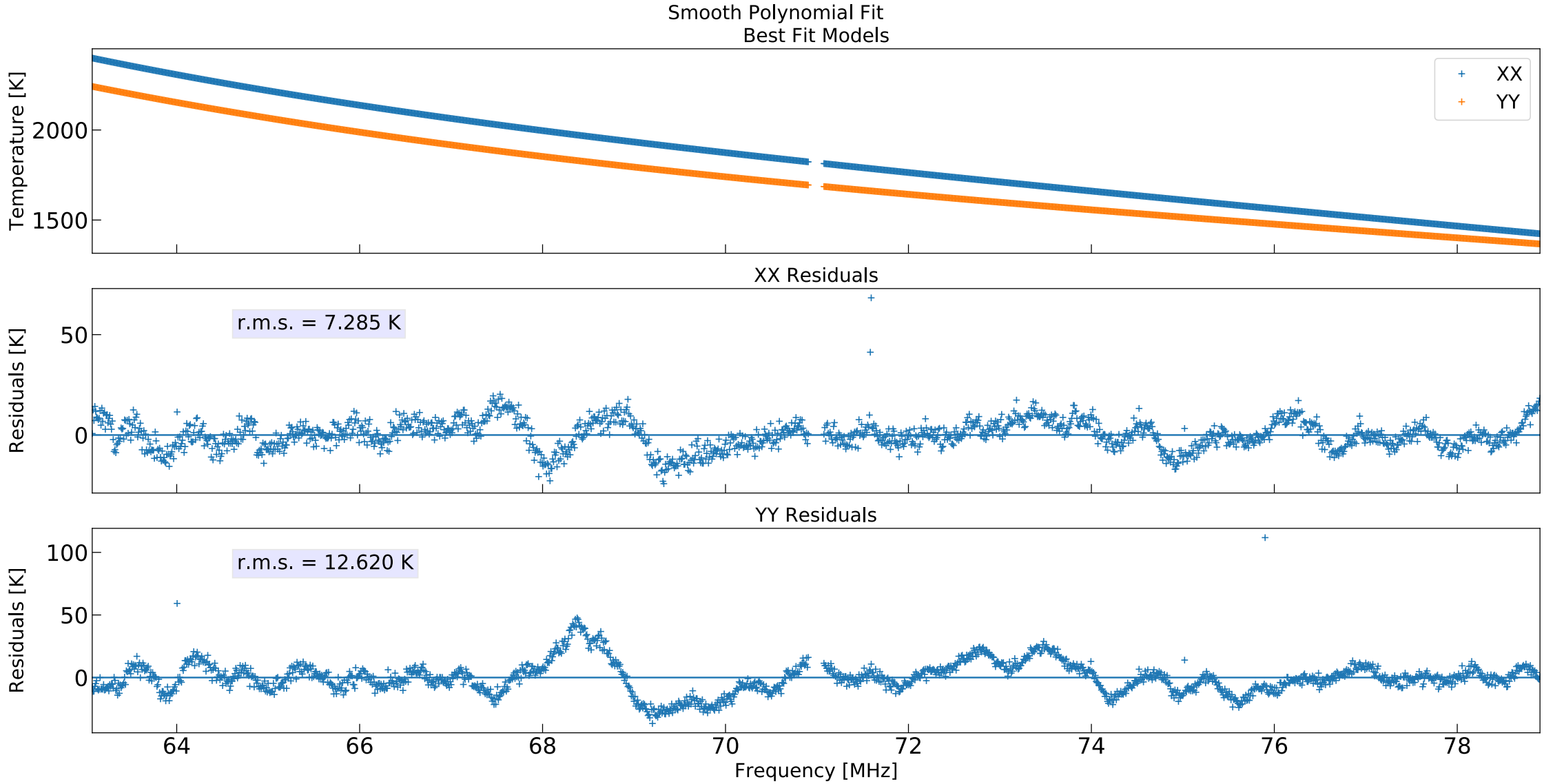


Calibrated Spectra

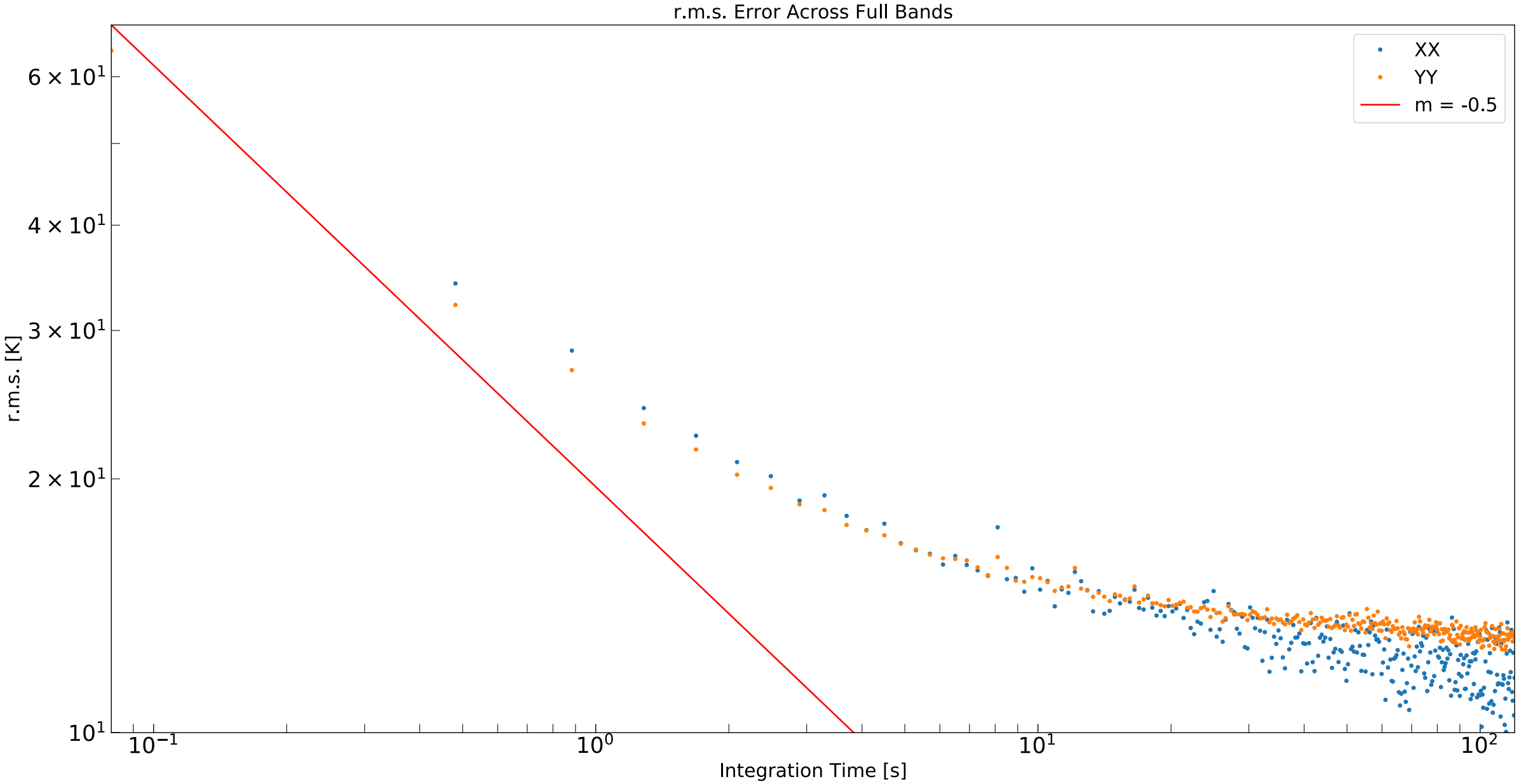


Modelling

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



r.m.s. vs. Integration Time



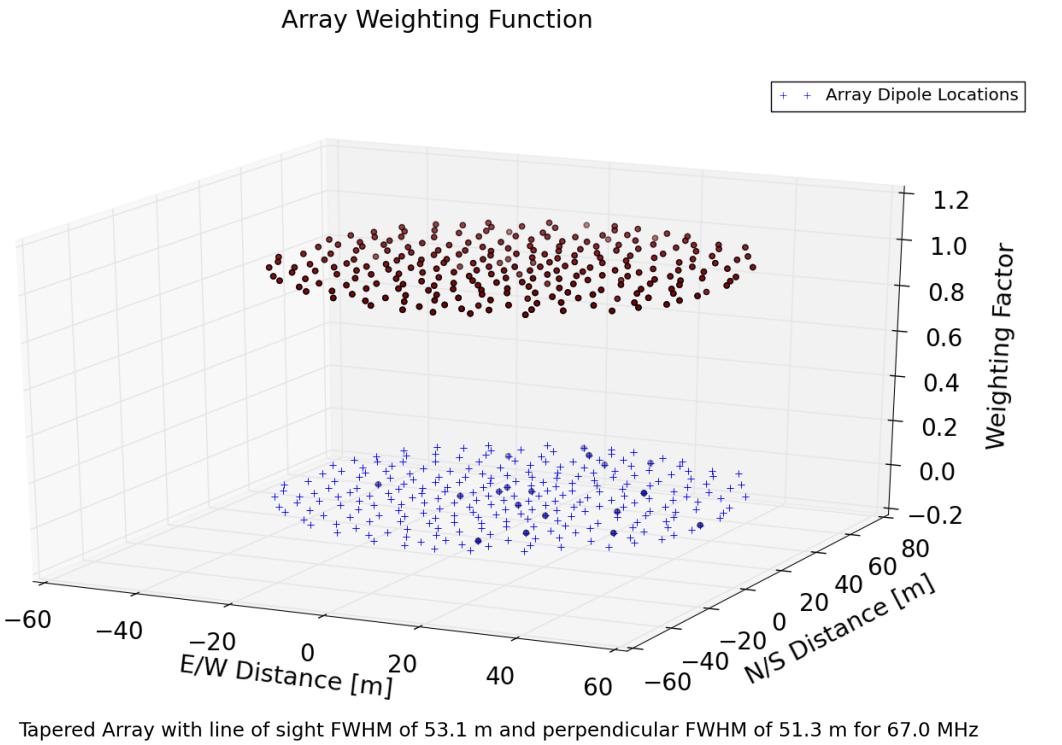
Custom Beamforming

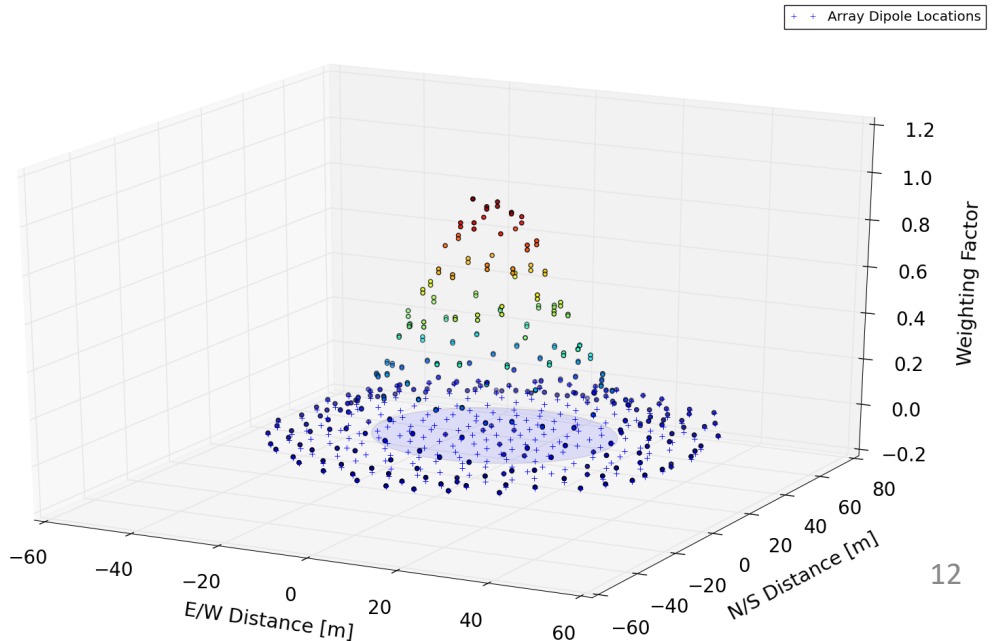
- $Y(\theta, \varphi) = R(\theta, \varphi) \times (\mathbf{W} \cdot \mathbf{V}(\mathbf{k}))$
  - $Y(\theta, \varphi)$ – array response
  - $R(\theta, \varphi)$ – antenna gain pattern
  - $\mathbf{V}(\mathbf{k})$ – steering vector

- Change array beam response via weighting vector, **W**.

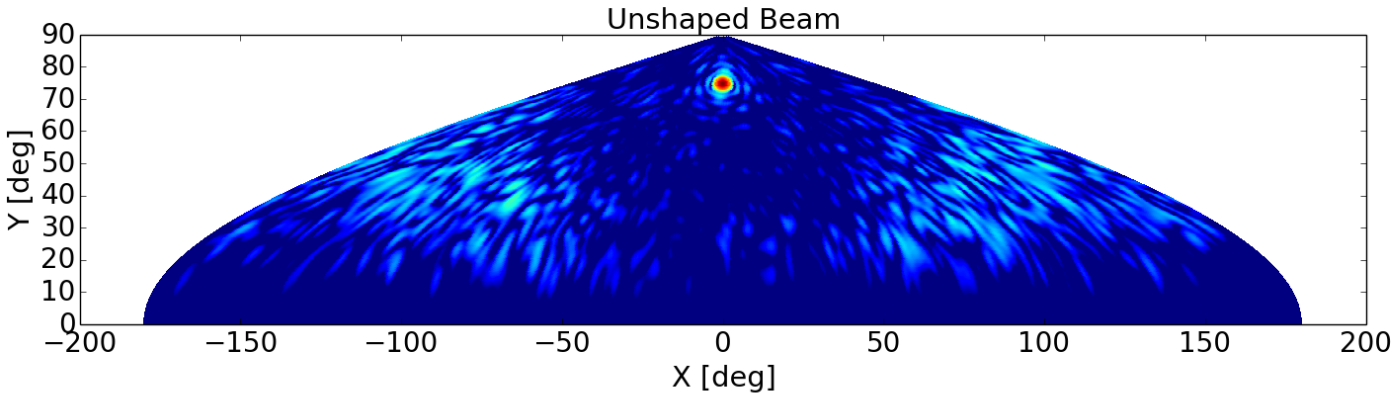
- Beam shape can be made independent of frequency and pointing direction.

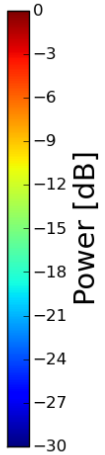
- Lose sensitivity as more antennas are down-weighted.

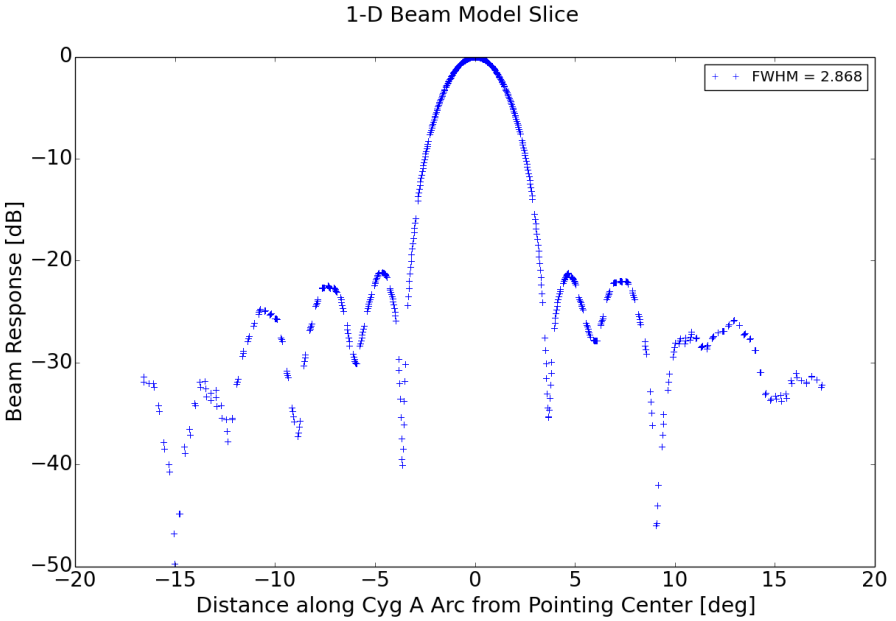


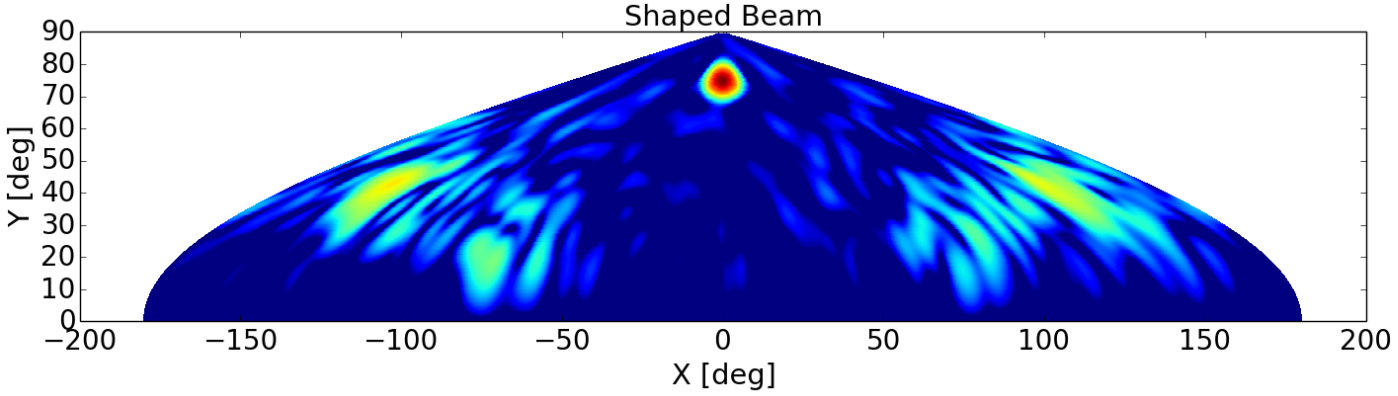


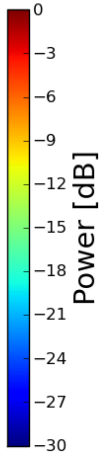
Custom Beamforming

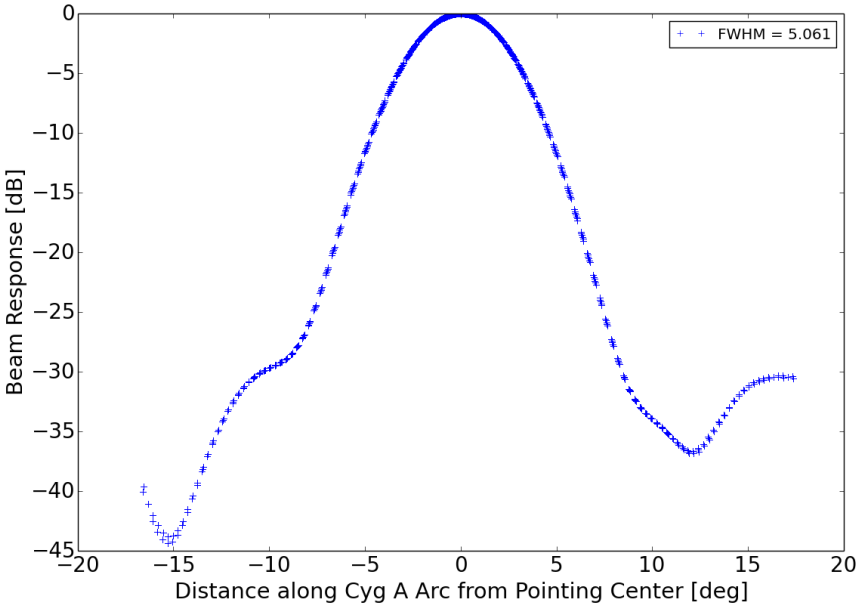




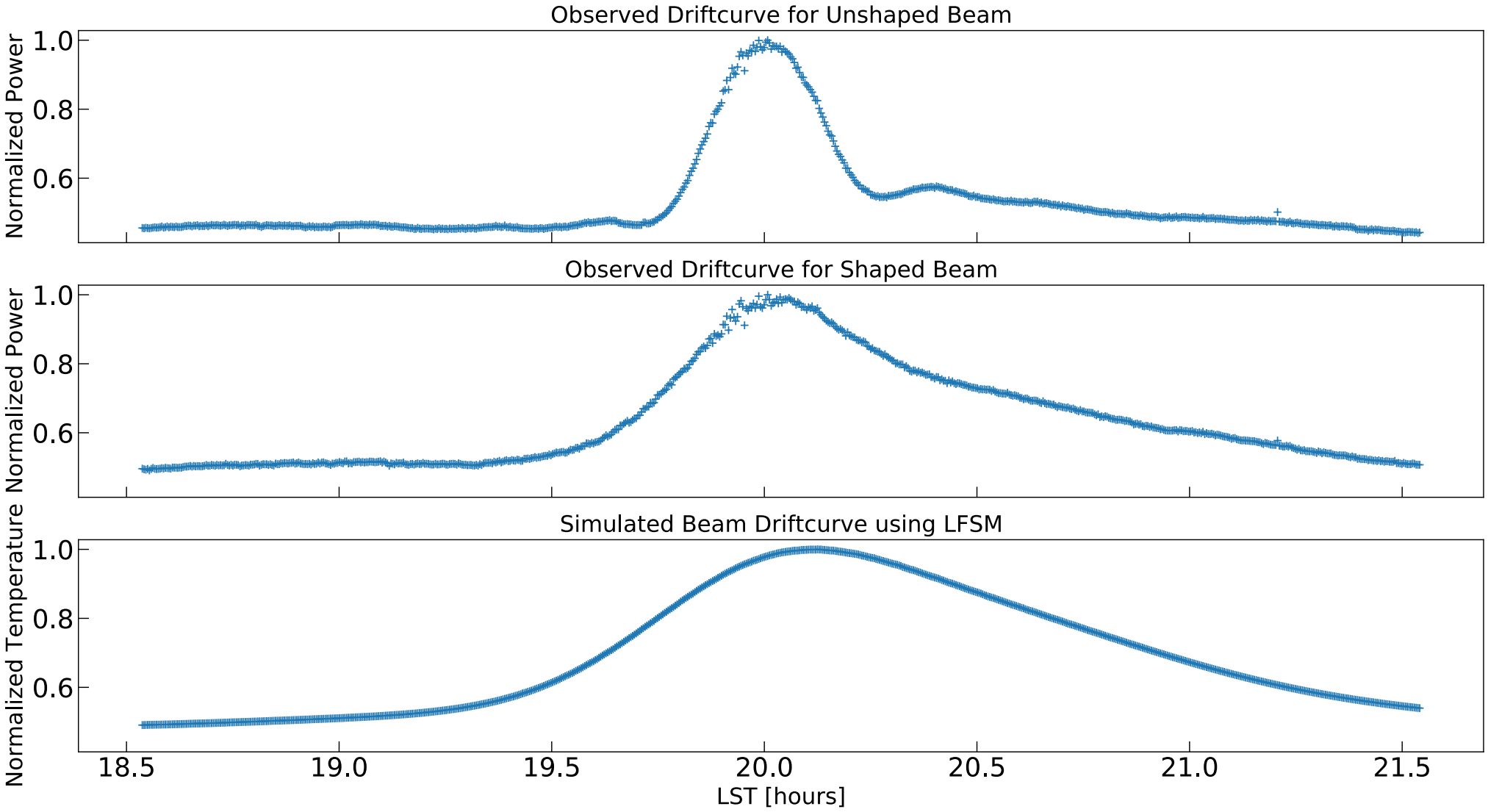








Custom Beamforming – 5° Results



Summary

- Beamforming offers a different method to detect the global 21-cm absorption signal.
- LWA-SV currently is limited to a residual r.m.s. of order ~ 7 K within 2 minutes of integration.
- Custom beamforming could control sidelobes and avoid chromatic effects.
- Challenging, but progress is being made.

Contact: Chris DiLullo
cdilullo@unm.edu