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

July 31st, 2020

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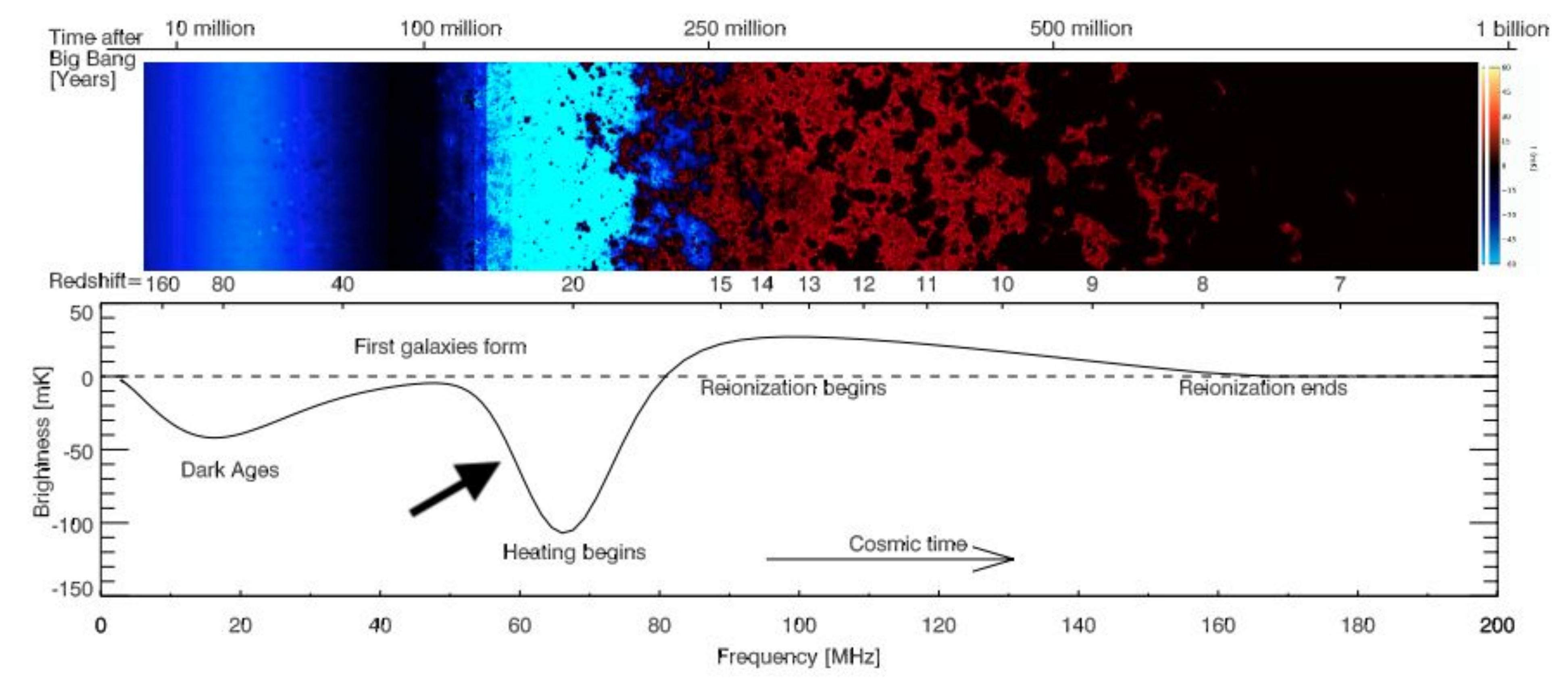
Image Credit: NASA/STScI

Outline

- Introduction to 21-cm Cosmology
- Current Limits of LWA-SV
- Recent Work and Changes
- Achromatic Beamforming

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.

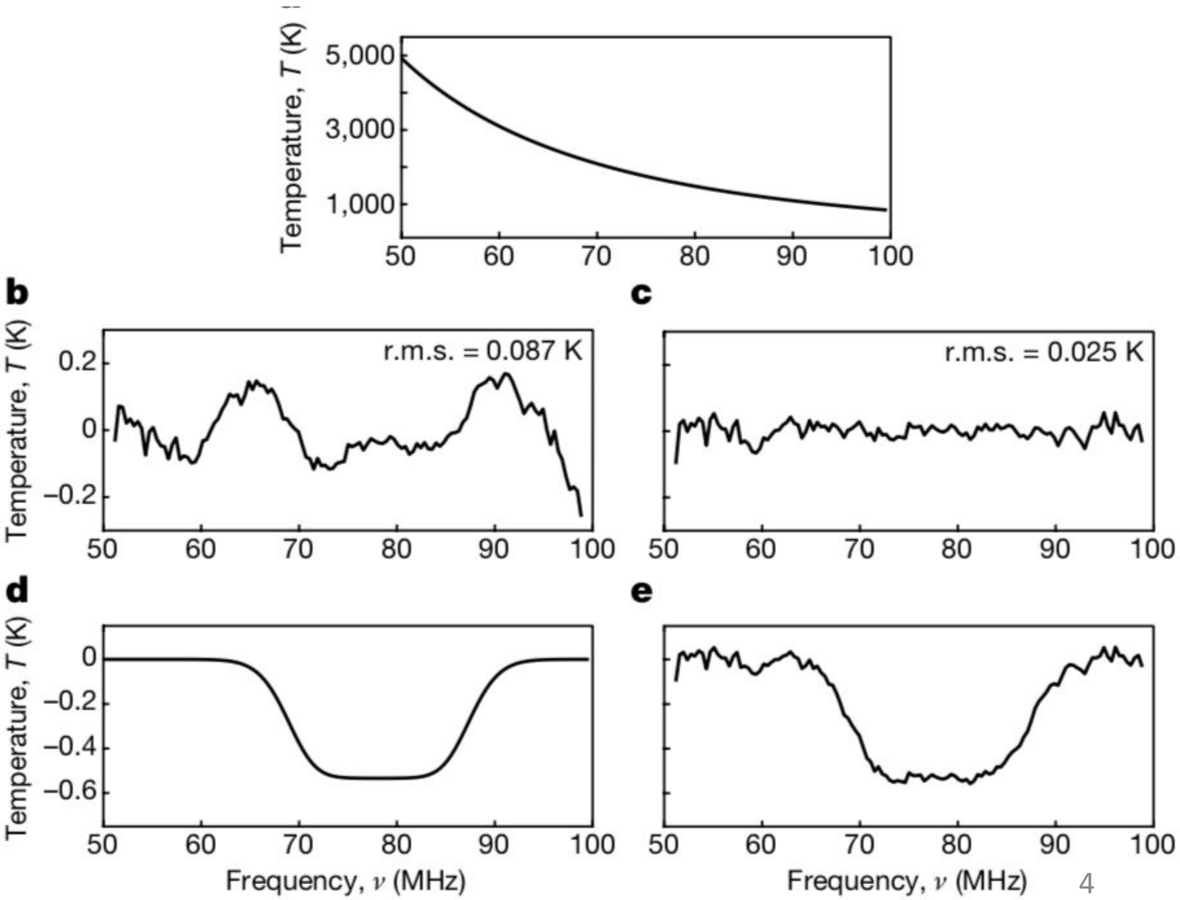
A Possible Detection! – Bowman et al. 2018

LETTER

doi:10.1038/nature25792

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

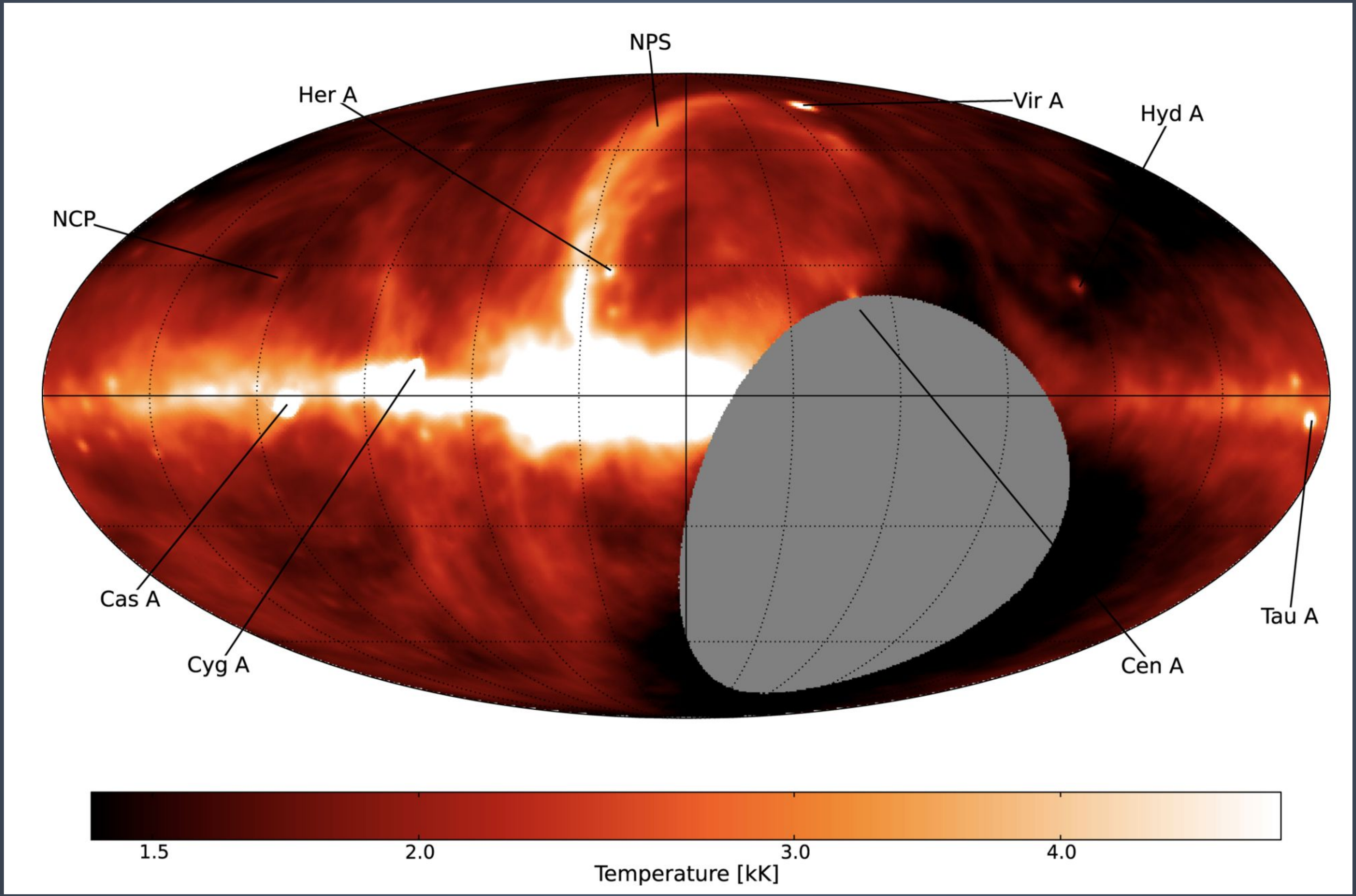
Judd D. Bowman[1], Alan E. E. Rogers[2], Raul A. Monsalve[1,3,4], Thomas J. Mozdzen[1] & Nivedita Mahesh[1]



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!
- Beamforming vs sky-averaged spectrum.

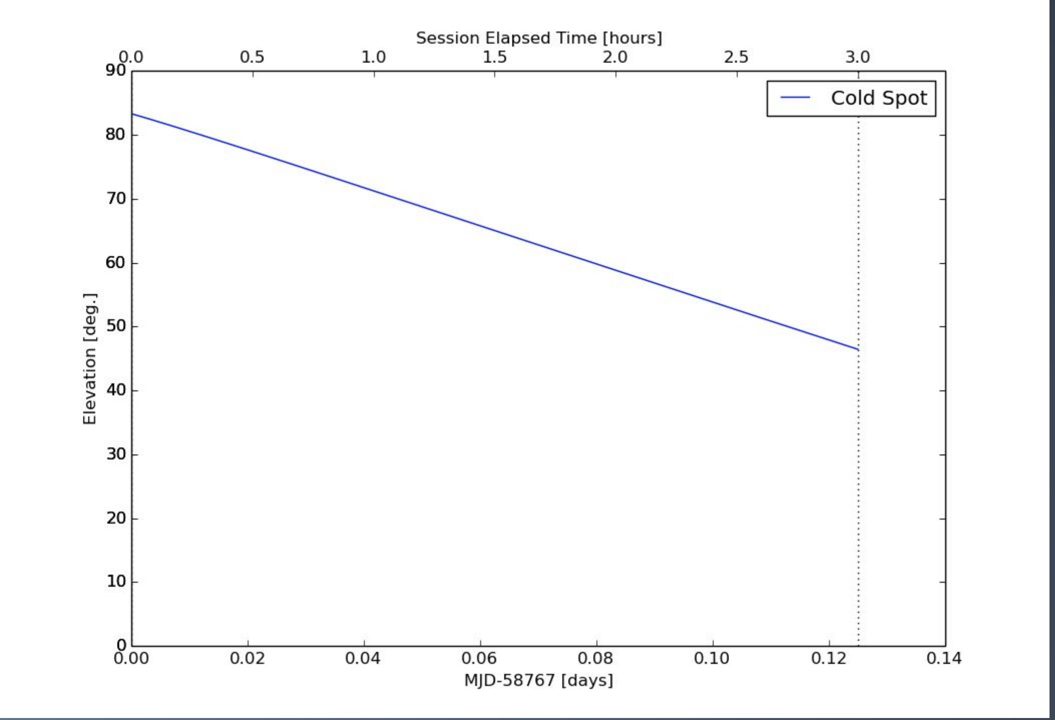
The Sky at 74 MHz

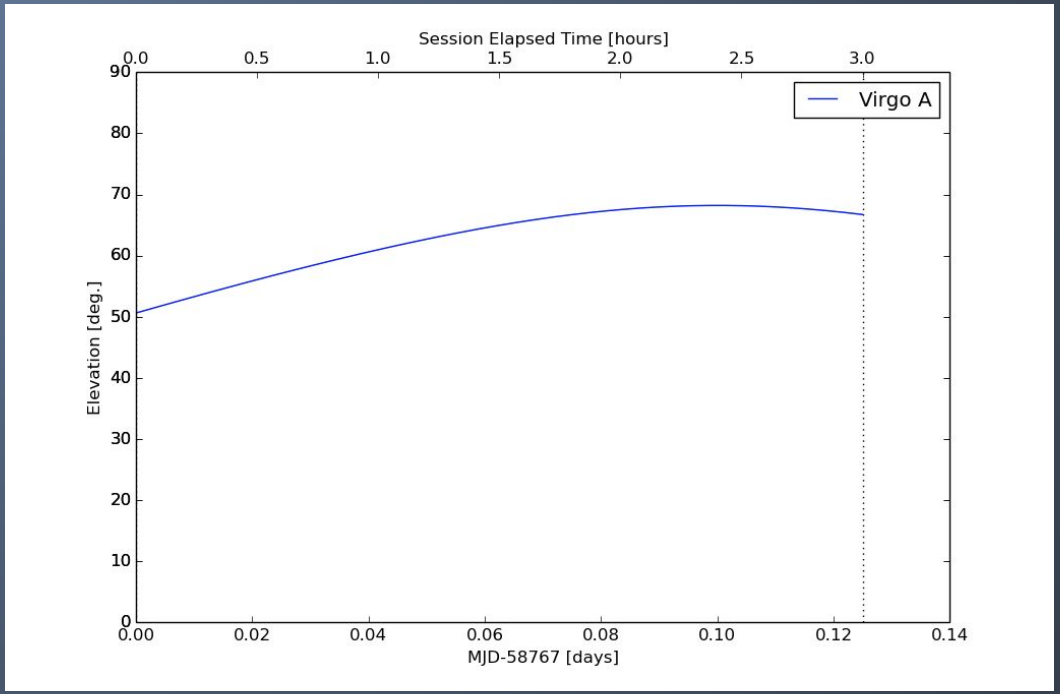


Dowell et al. (2017)

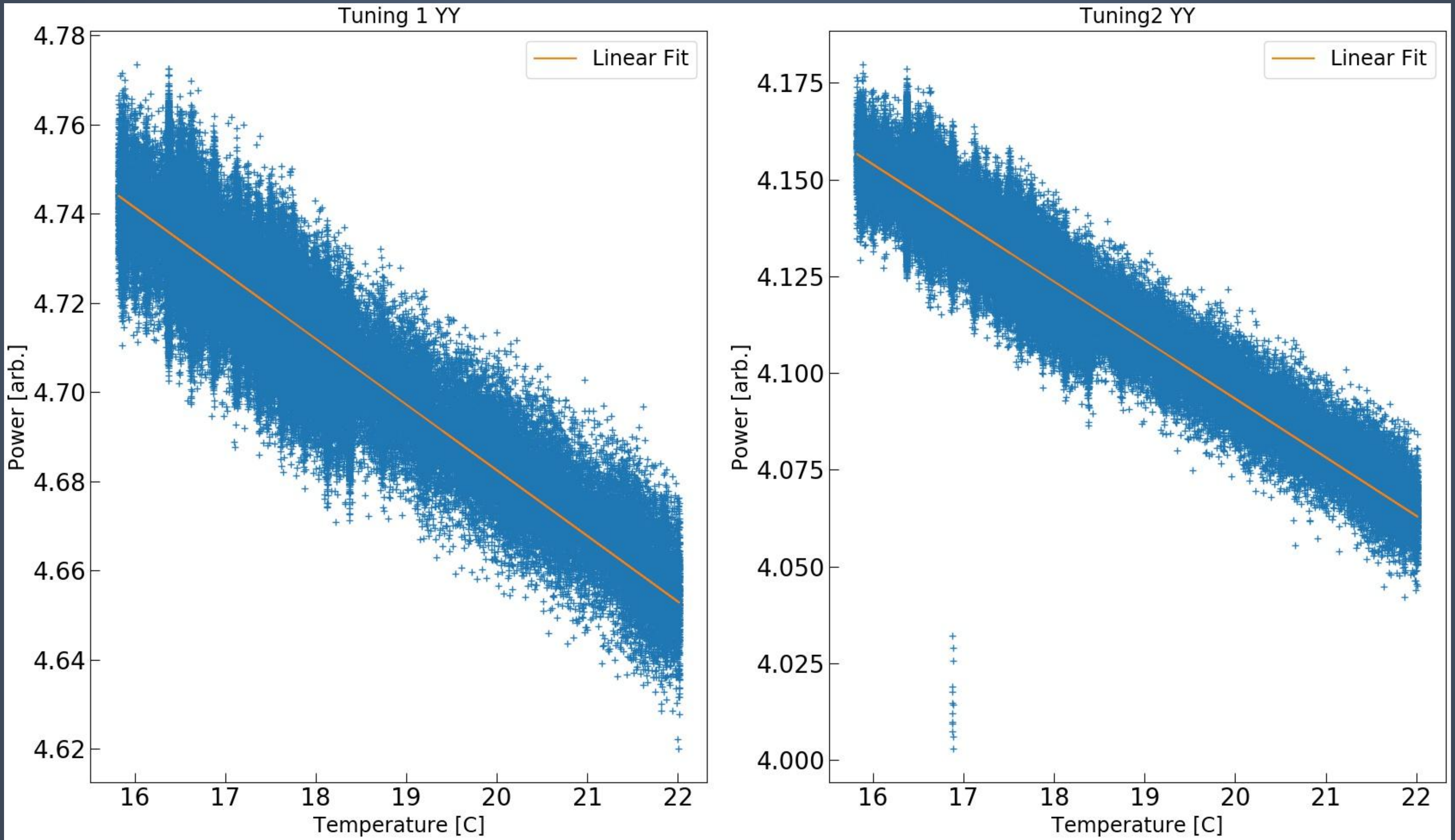
Observational Setup

- 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 via pseudo-spectral kurtosis flagging.





ASP Temperature Variations



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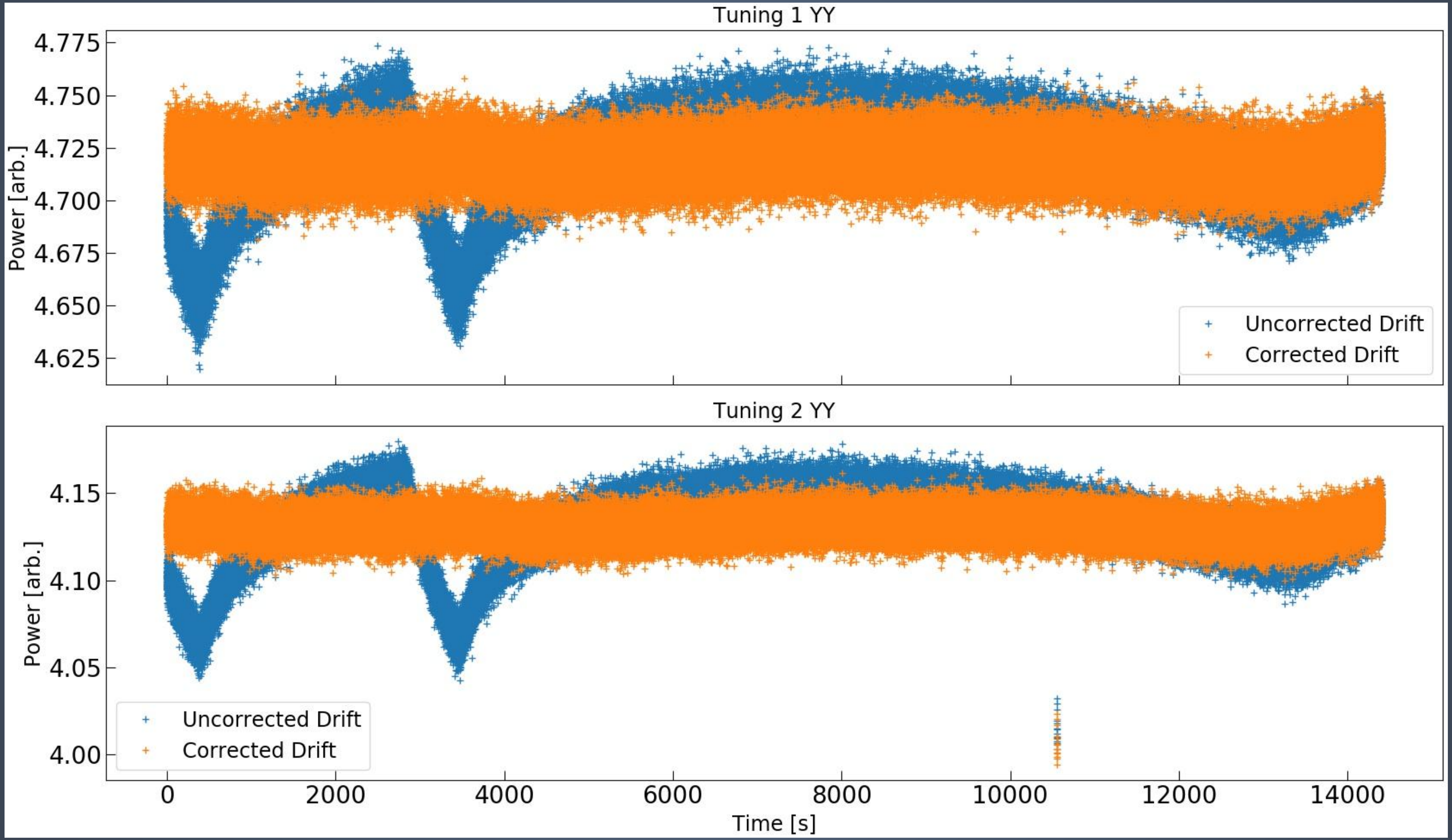
ASP Temperature Variations



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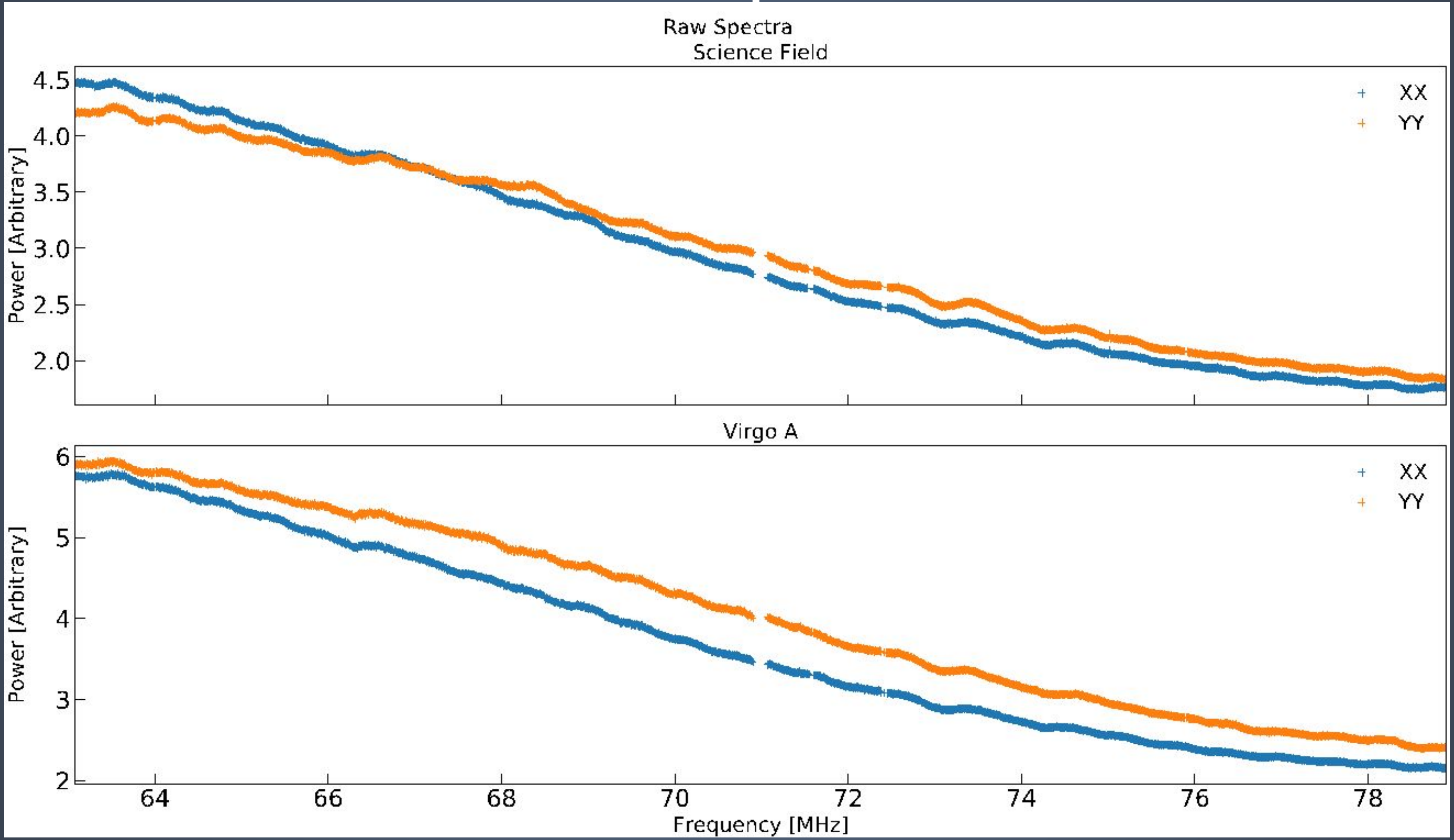
Raw Spectra



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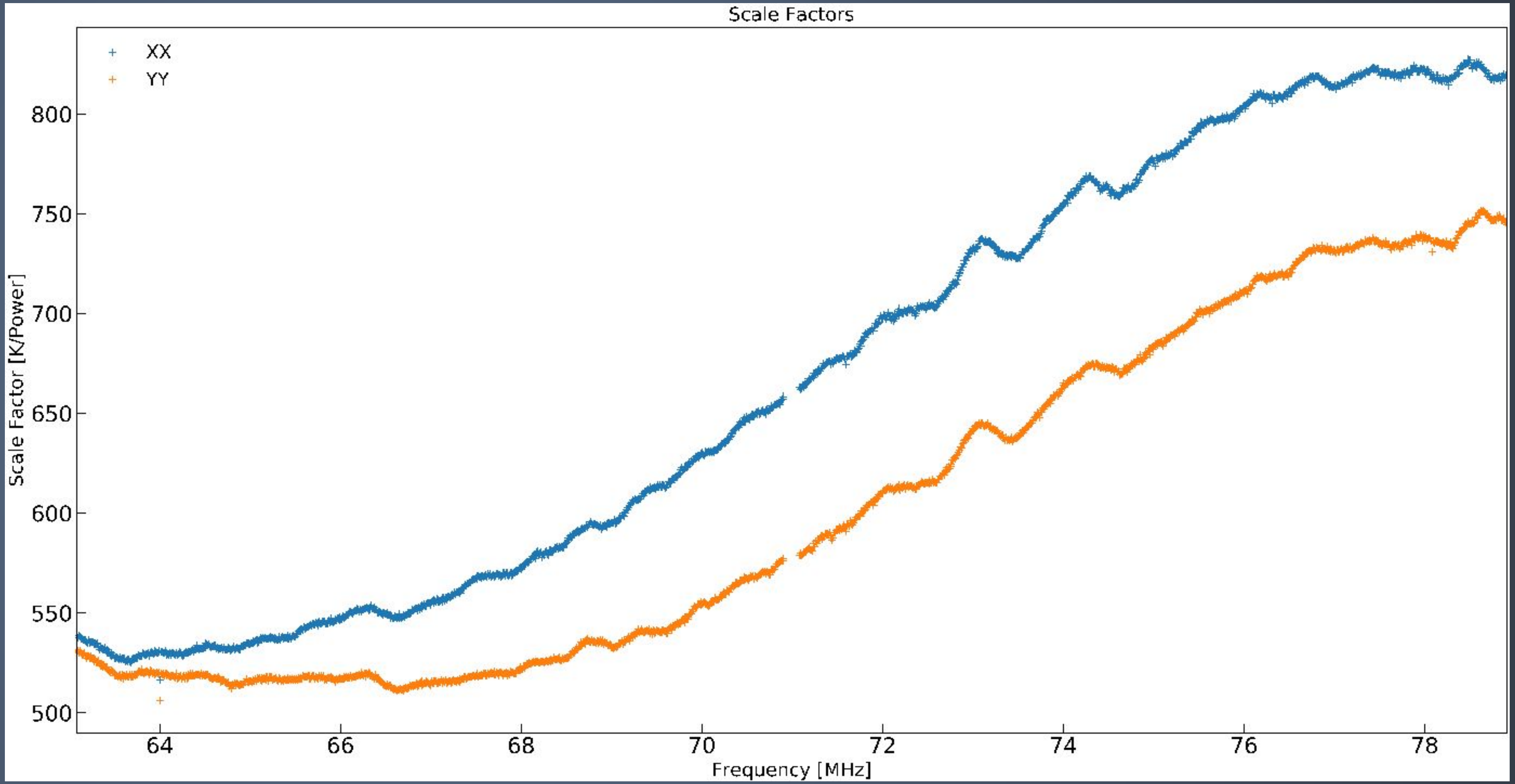
Astronomical Temperature Calibration

- Derive scaling of Virgo A via the Global Sky Model.
- Integrated ∼4 minutes of data.
- Apply scaling to raw Science Field spectra.



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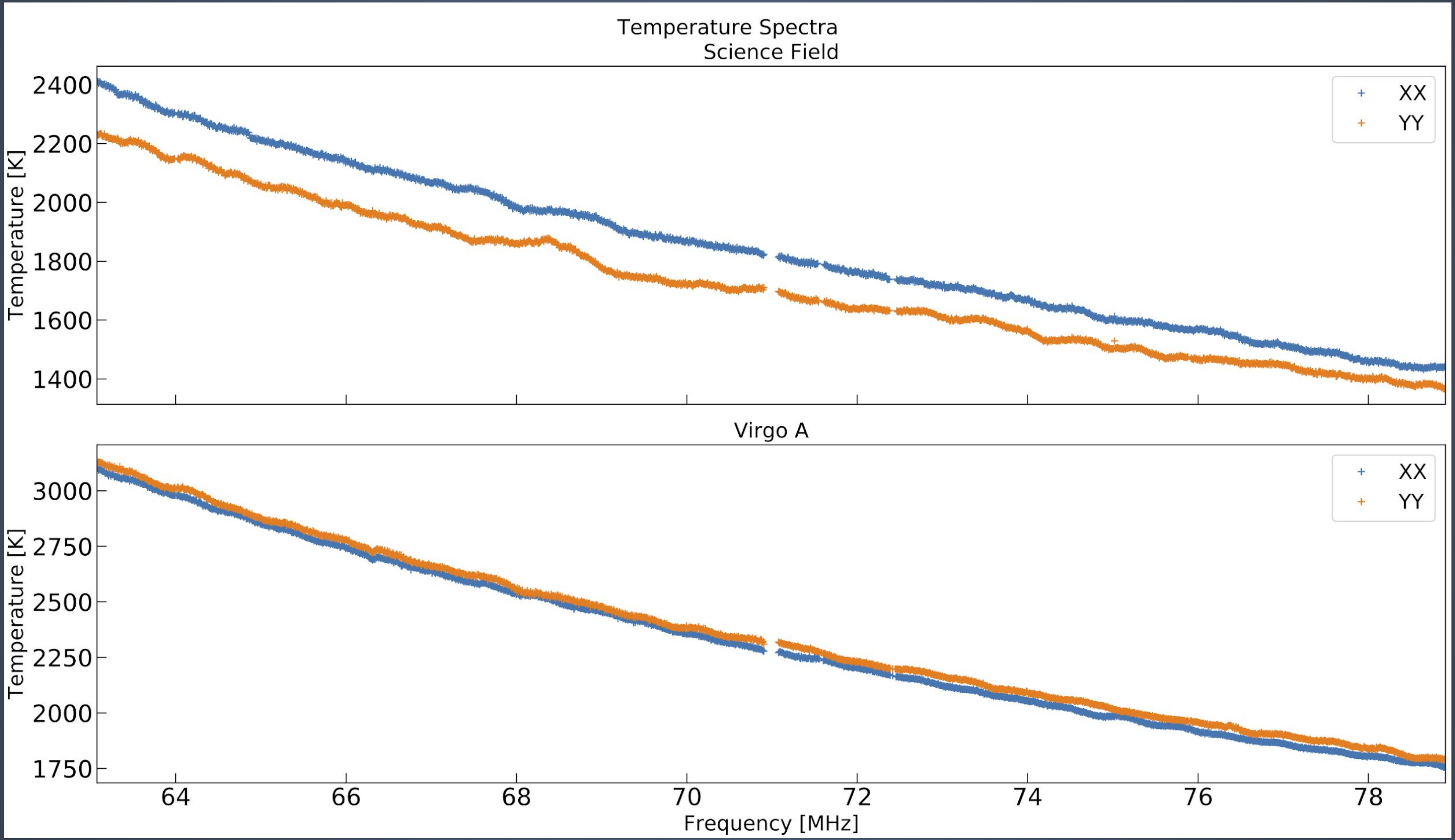
Calibrated Spectra



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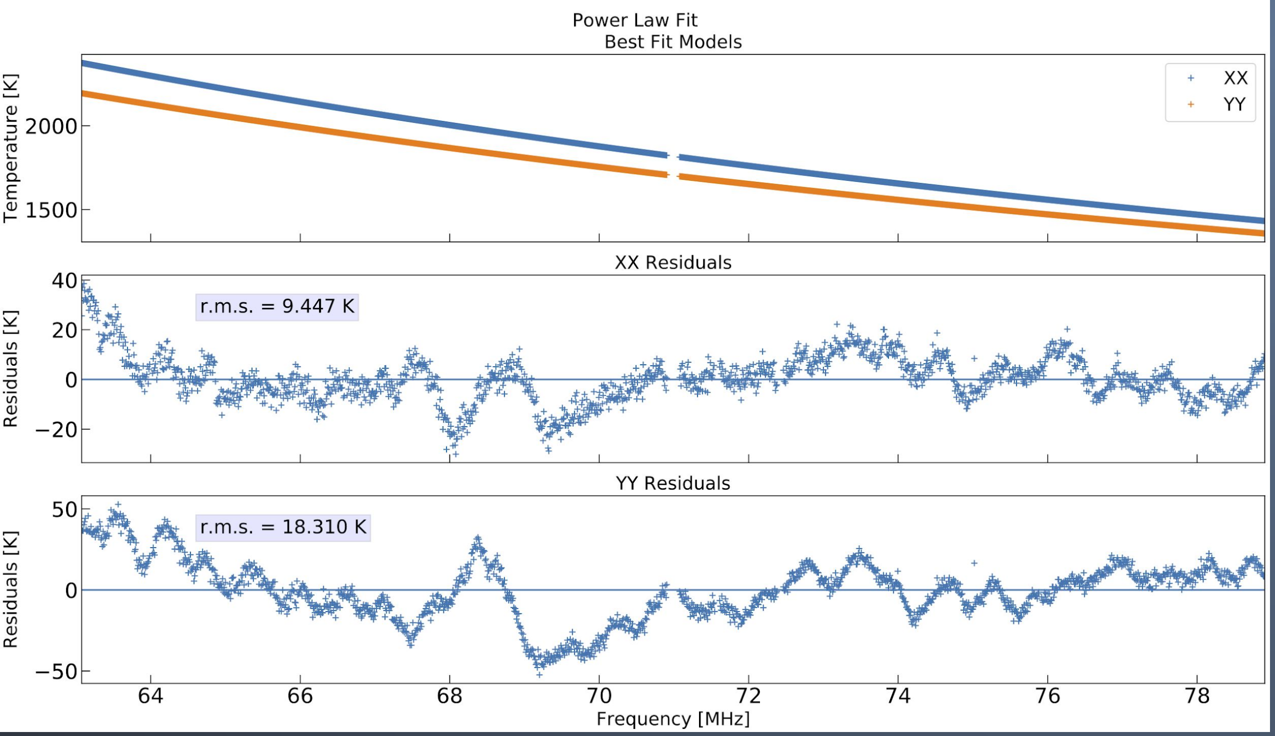
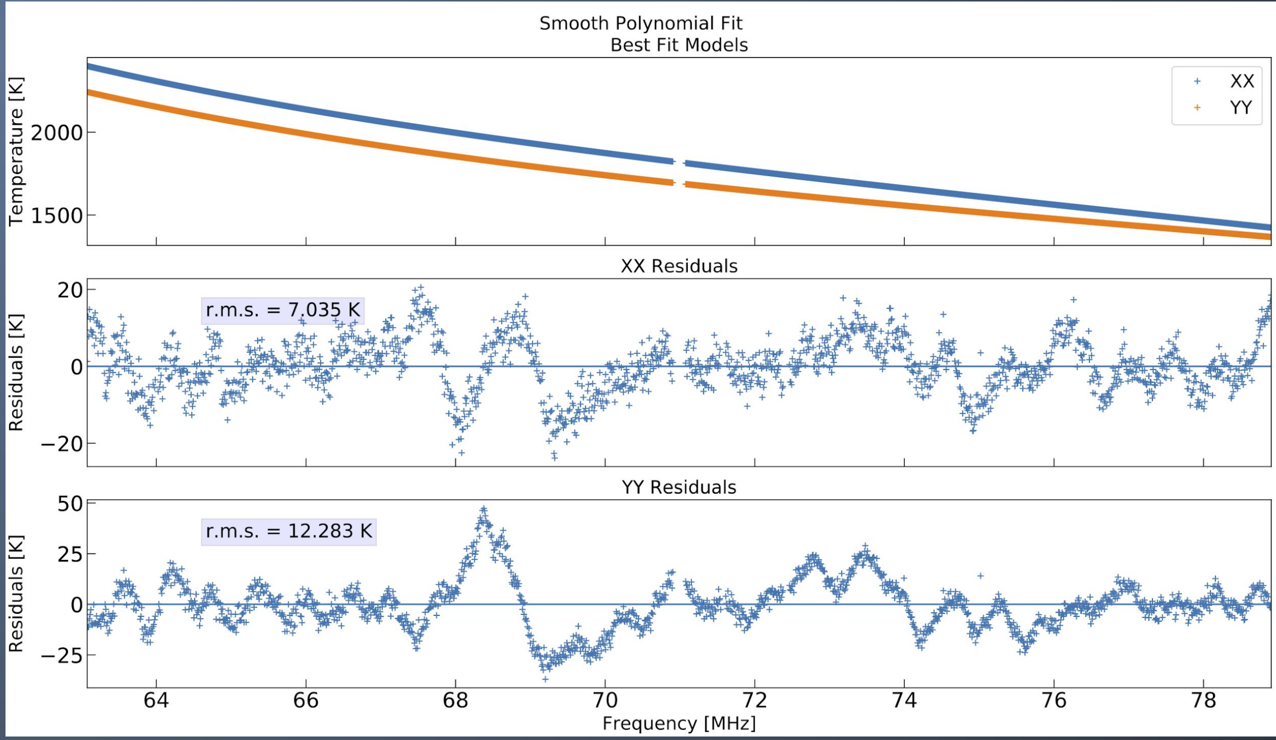
Foreground Modelling

- Fit two foreground models
- Power Law: $T(\nu) = k\left(\frac{\nu}{\nu_0}\right)^{\alpha}$
- 5-term Smooth Polynomial: $T(\nu) = \sum_{n=0}^{4} a_n \left(\frac{\nu}{\nu_0}\right)^{n-2.5}$

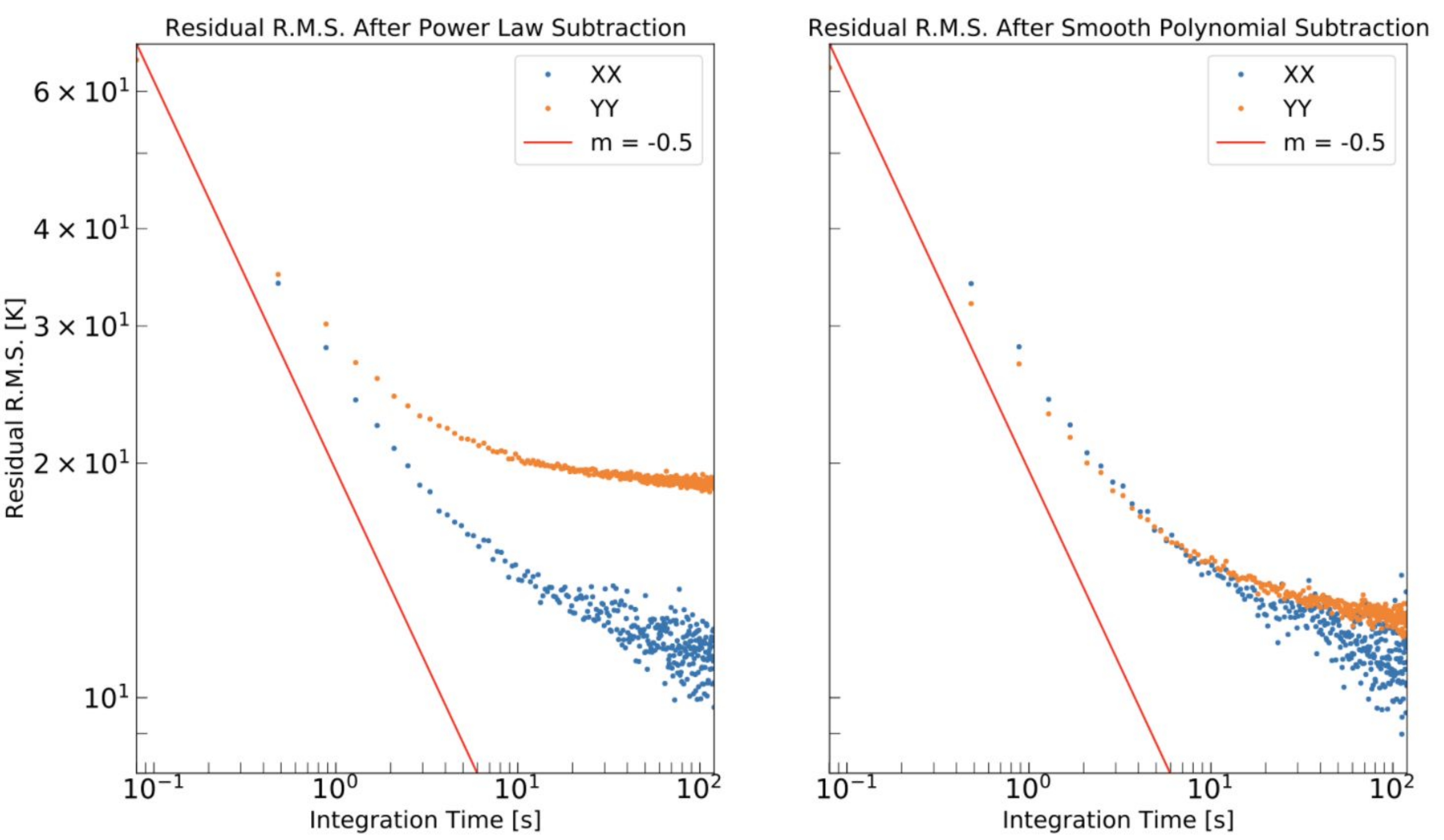
Table 2. Foreground Model Best Fit Parameters

Model	Parameter	XX Polarization	YY Polarization
N=5 Smooth Polynomial	a_0	$7.49 \times 10^4 \pm 1.43 \times 10^4$	$2.29 \times 10^4 \pm 2.51 \times 10^4$
	a_1	$-2.69 \times 10^5 \pm 5.78 \times 10^4$	$-5.96 \times 10^4 \pm 1.01 \times 10^5$
	a_2	$3.66 \times 10^5 \pm 8.74 \times 10^4$	$5.21 \times 10^4 \pm 1.53 \times 10^5$
	a_3	$-2.18 \times 10^5 \pm 5.86 \times 10^4$	$-1.10 \times 10^4 \pm 1.02 \times 10^5$
	a_4	$4.81 \times 10^4 \pm 1.47 \times 10^4$	$-2.72 \times 10^3 \pm 2.57 \times 10^4$
Power-Law	α	$-2.26 \pm 1.89 \times 10^{-3}$	$-2.14 \pm 3.83 \times 10^{-3}$
	k	$3.26 \pm 5.36 \times 10^{-5}$	$3.23 \pm 1.09 \times 10^{-4}$





RMS vs Integration Time



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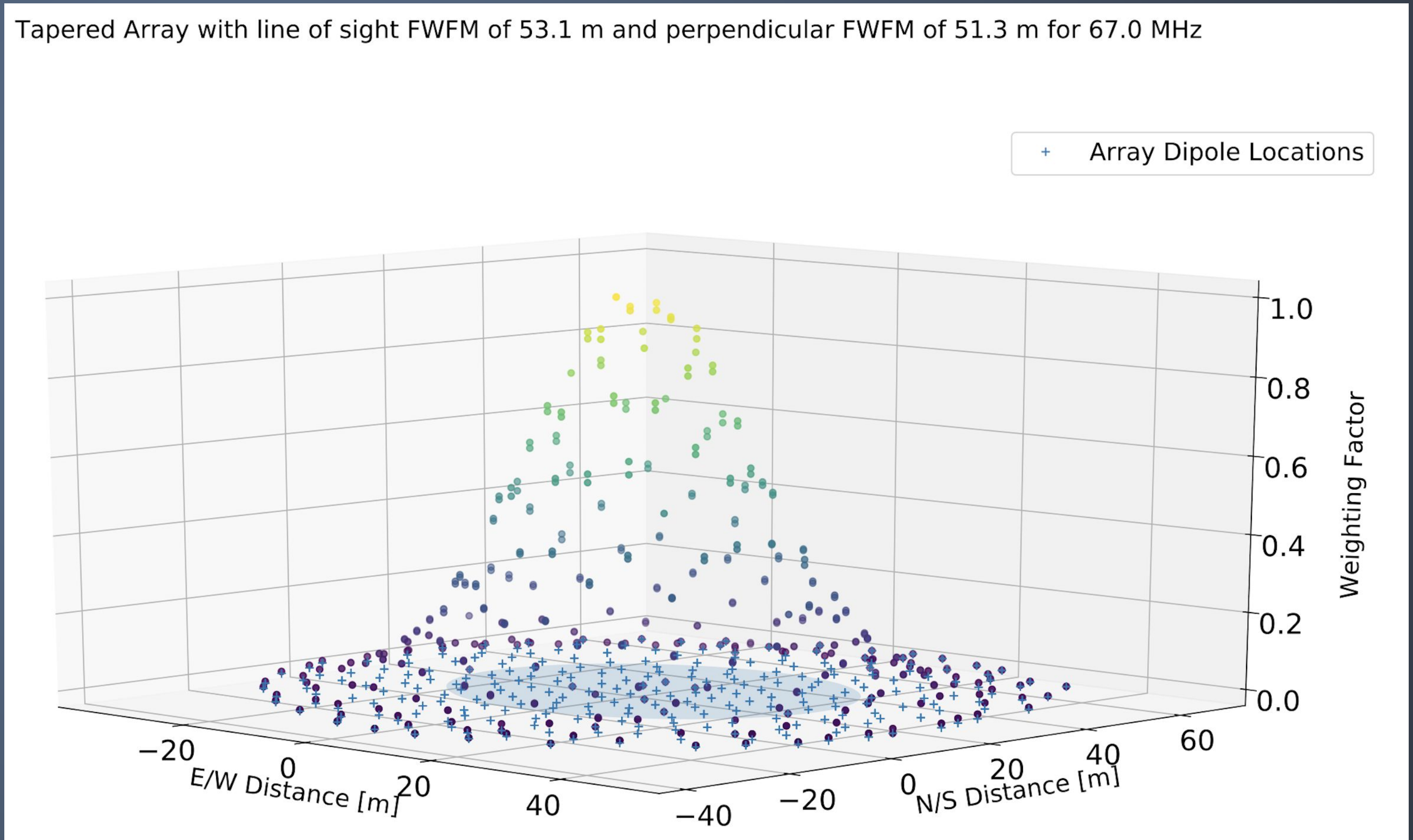
Recent Work and Changes

- LWA-SV now supports 3 beams with 20 MHz bandwidth per tuning.
  - Now have continuous coverage from 52 - 83 MHz.
- New weather station installed at LWA-SV.
  - Expanding calibration to account for outside temperature variations which affect FEE response.
- Switched observing strategies.
  - New Science Field center pointing, same large cold region on the sky.
  - Both Science Field and Virgo A take the same track along the sky.
  - We no longer simultaneously observe the SF and Virgo A, but instead focus on observing at times when they have the same position on the sky.
  - Stepped observations give us more control over what the system does.

An Idea for Improvement: Custom Beam Forming

- Sets the size/shape of the beam.
  - Make the beam achromatic.
- $Y(\theta, \phi) = R(\theta, \phi) \times (\mathbf{W} \cdot \mathbf{V}(\mathbf{k}))$
  - R – antenna gain pattern
  - **W** – weighting vector
  - **V** – steering vector



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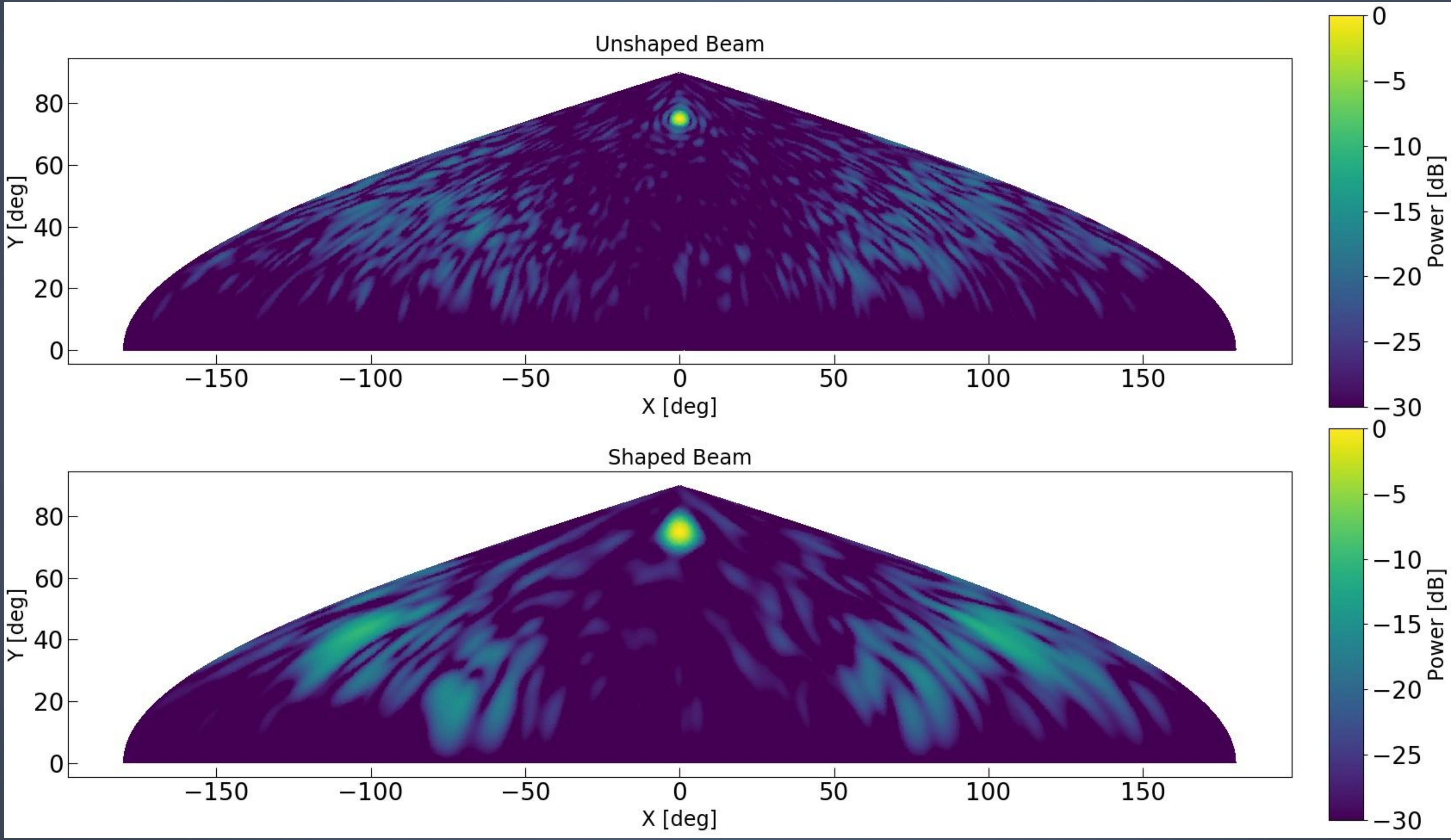
Custom Beams



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Achromatic Beams

Main Ideas:

- Modified version of the DRX pipeline within ADP.
- Predetermine the gains needed for each frequency at each pointing.
- Access the gains as needed throughout the observation.

Current Work:

- Static achromatic beam at 180° az 83.5° el → Cygnus A transit
- Compare shape of the drifts at each end of the band to see if they match.

Summary

- Detection of cosmic dawn is a **very sensitive** measurement.
- Current **RMS limit** of LWA-SV is **∼10 K**, but we need **50 mK**.
- LWA-SV offers **beamforming advantages** over single element radiometers.
- Currently developing **achromatic beamforming** via a modified version of the DRX pipeline.

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