Calibration Requirements for Detecting the EoR Power Spectrum

N. Barry

Department of Physics
University of Washington

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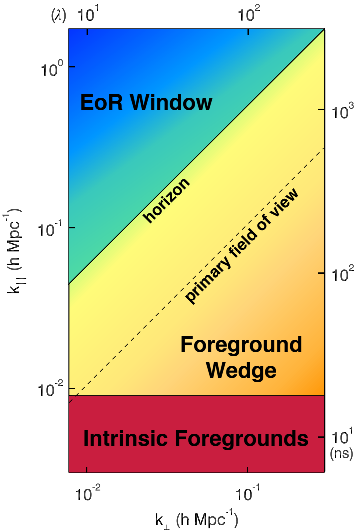
URSI

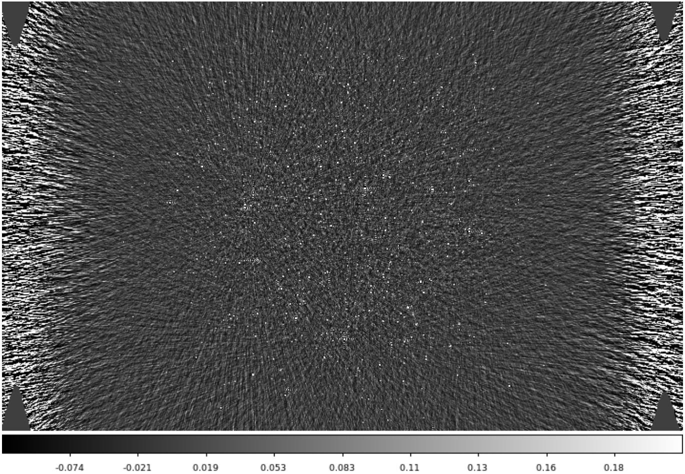
The 2D Power Spectrum



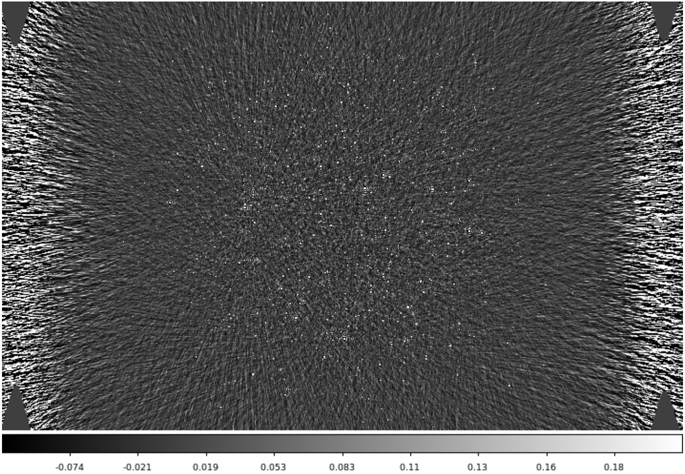
By Bryna Hazelton

Looking at the 2D Power Spectrum

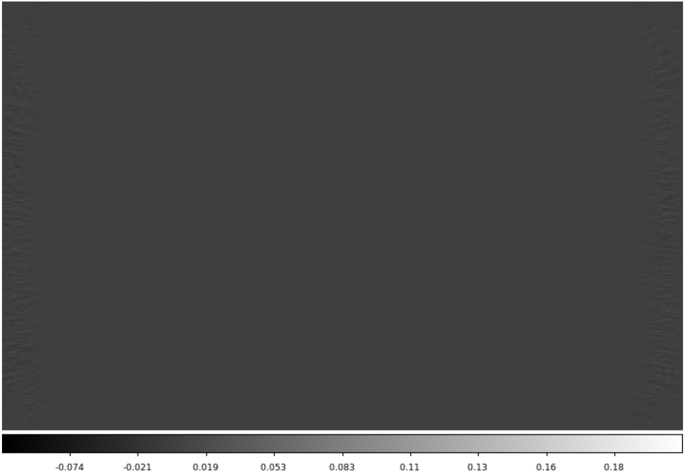
Dirty, calibrated (6950 sources)



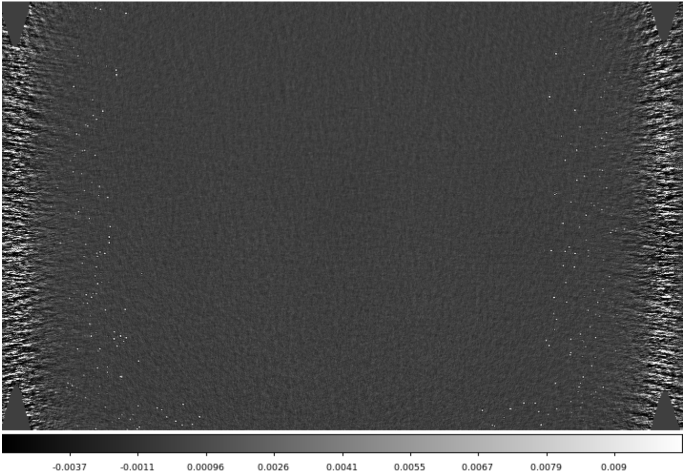
Model, 72% flux (4000 sources)



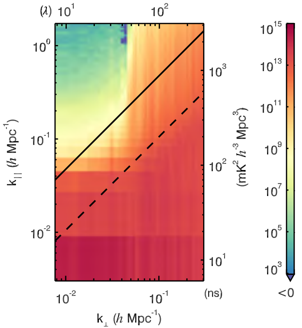
Residual, 28% flux (2950 sources)



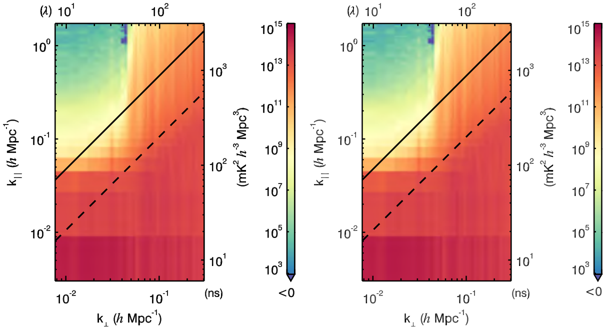
Residual, 28% flux (2950 sources)



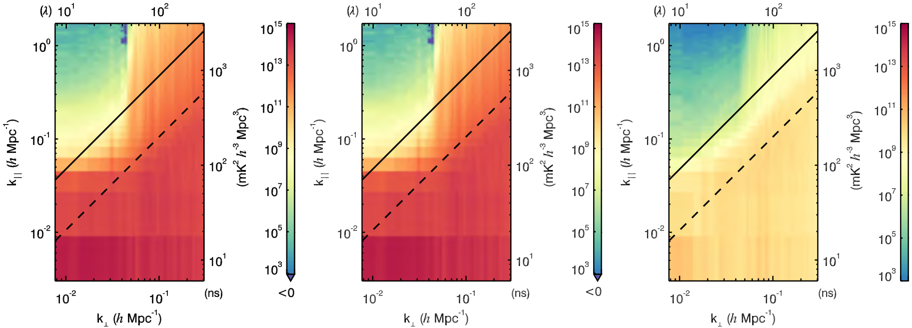
Residual PS


(λ) 10^1 10^2
$k_{||}$ (h Mpc^{-1})
10^0
10^{-1}
10^{-2}
10^3
10^2
10^1
(ns)
10^{-2} 10^{-1}
$k_\perp$ (h Mpc^{-1})
(mK^2 h^{-3} Mpc^3)
10^{15}
10^{13}
10^{11}
10^9
10^7
10^5
10^3
<0

Residual PS

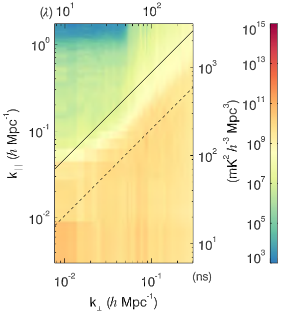

(λ) 10^1 10^2
10^0
10^{-1}
10^{-2}
$k_{||}$ (h Mpc^{-1})
10^3
10^2
10^1
(ns)
10^{-2} 10^{-1}
$k_\perp$ (h Mpc^{-1})
(mK^2 h^{-3} Mpc^3)
10^{15} 10^{13} 10^{11} 10^9 10^7 10^5 10^3
<0

Residual PS

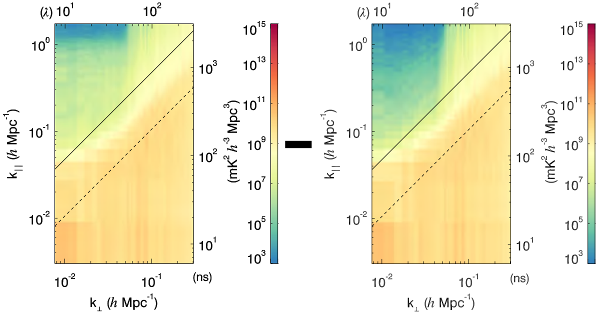


"perfect calibration" = no calibration errors

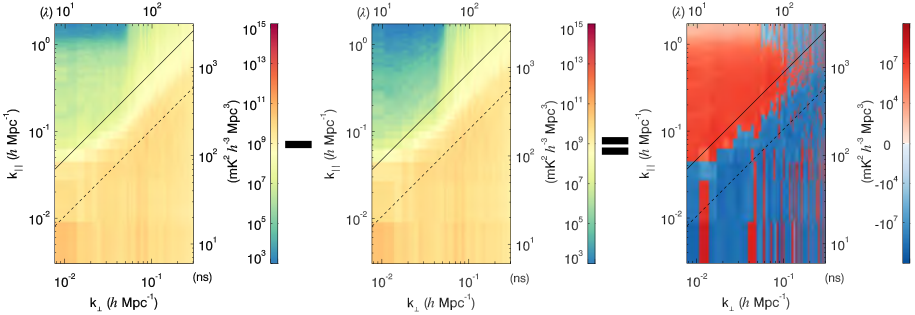
Difference – per freq, per pol, per antenna calibration



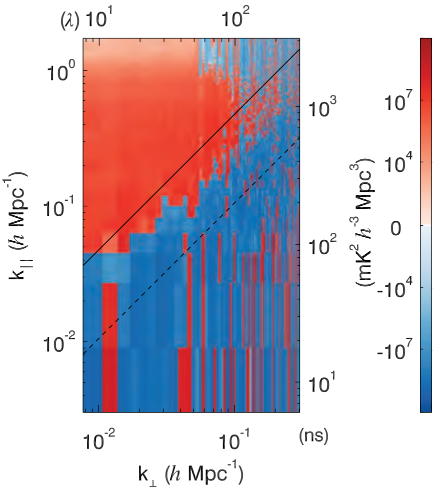
Difference – per freq, per pol, per antenna calibration

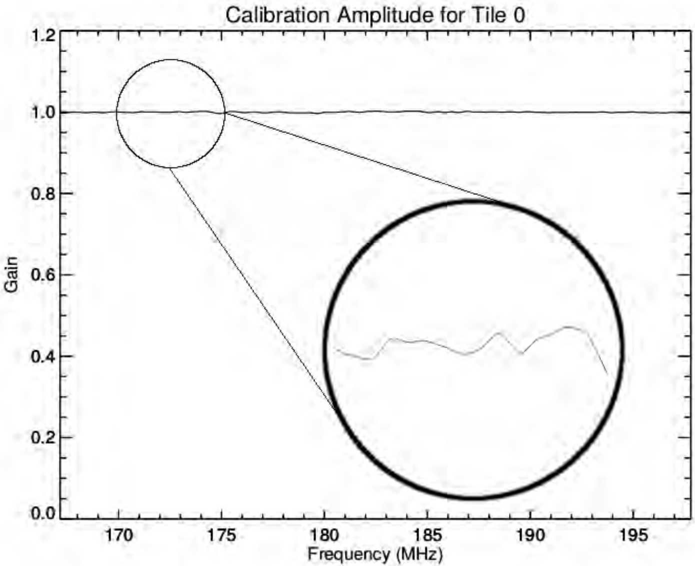


Difference – per freq, per pol, per antenna calibration



- Entire window saturated by 10^7, or an order of magnitude above the EoR
- Foreground wedge over fit
- Measurement of the EoR impossible!




Calibration Amplitude for Tile 0
Gain
Frequency (MHz)
1.2
1.0
0.8
0.6
0.4
0.2
0.0
170
175
180
185
190
195

Modulation

$$h(\nu) = f(\nu)\left(1 + \Delta g \cos \eta_0 \nu\right) \quad (1)$$

The modulation theorem results in the Fourier transform

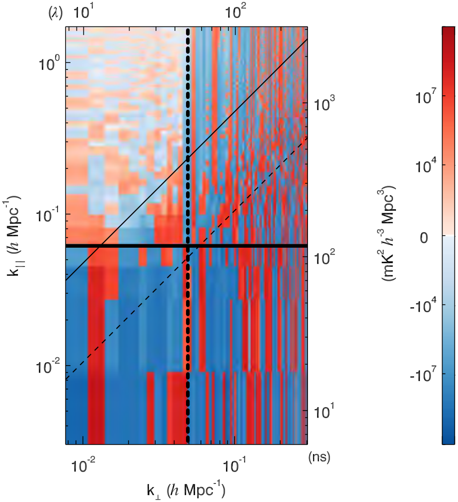
$$H(\eta) = \frac{\Delta g}{2} F(\eta - \eta_0) + \frac{\Delta g}{2} F(\eta + \eta_0) + F(\eta) \quad (2)$$

An order of magnitude estimate of the positive power spectrum of this modified signal is

$$\mathcal{O}(|H(\eta)|^2) \approx \mathcal{O}(|F(\eta)|^2) + \mathcal{O}\left(\left|\frac{\Delta g}{2} F(\eta \pm \eta_0)\right|^2\right) \quad (3)$$

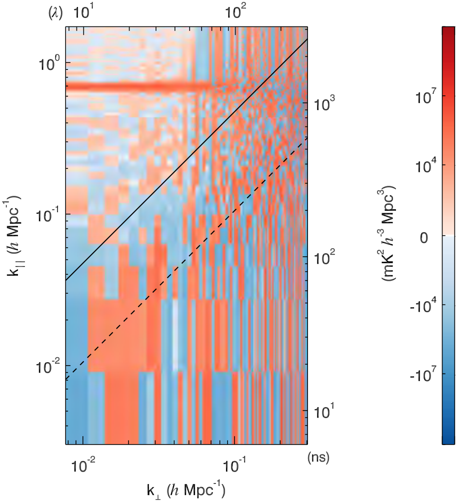
Difference – smooth calibration

- Fit a 2nd order gain polynomial and linear phase to the previous calibration solutions
- A good approximation if only full-band instrumental effects existed
- Noise-like in window, no bias

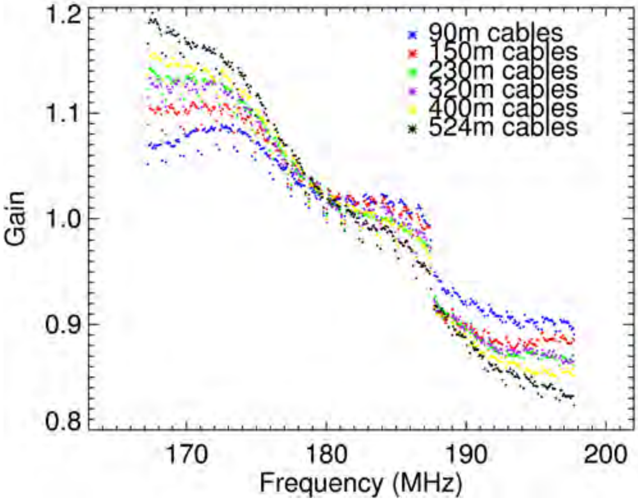


Difference – cable reflection fit

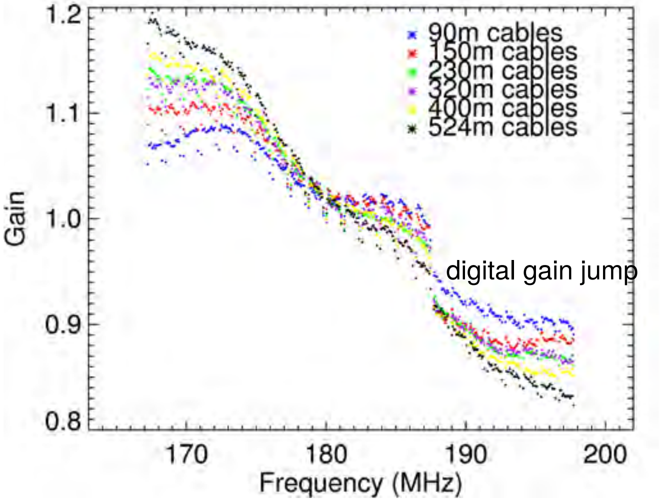
- A DFT fit of a 150m cable reflection, present only in real data
- Necessary to fit individually due to variability
- Excess power as bad as the per frequency, per tile, per polarization calibration



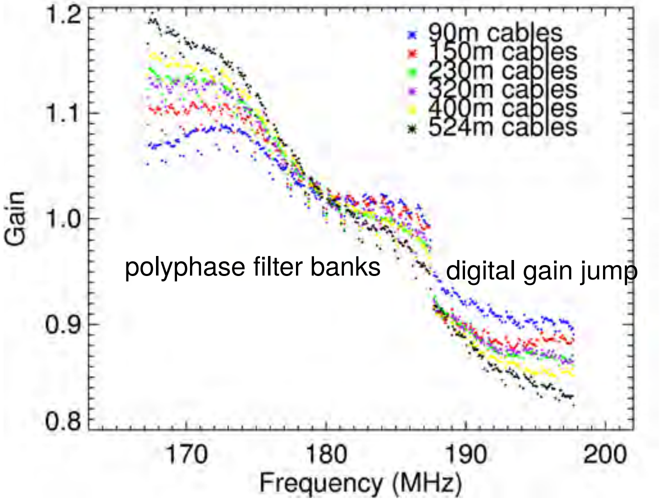
Real data calibration solutions



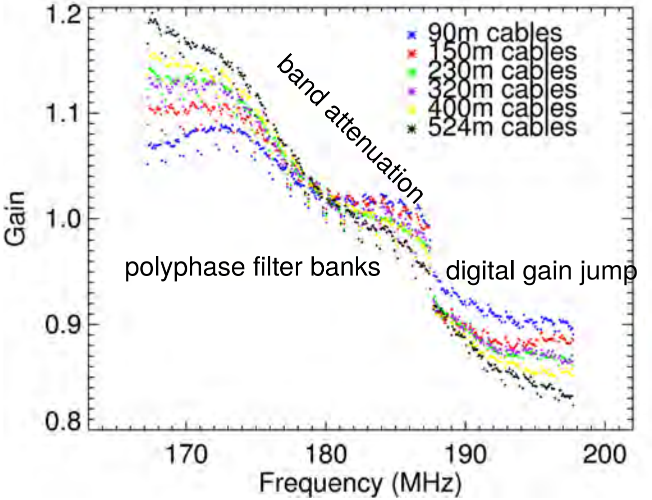
Real data calibration solutions



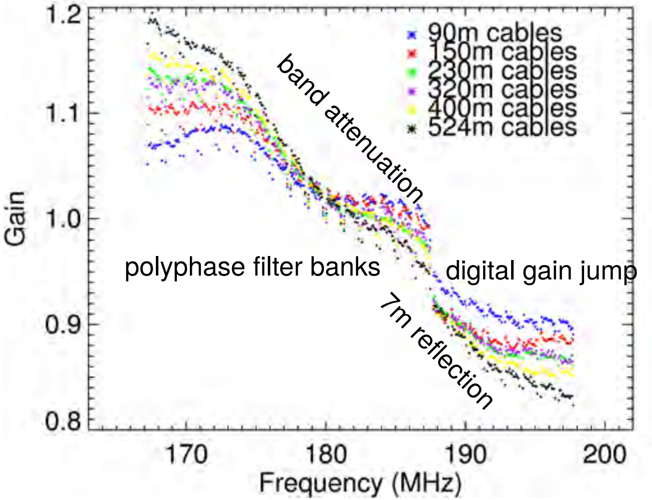
Real data calibration solutions



Real data calibration solutions

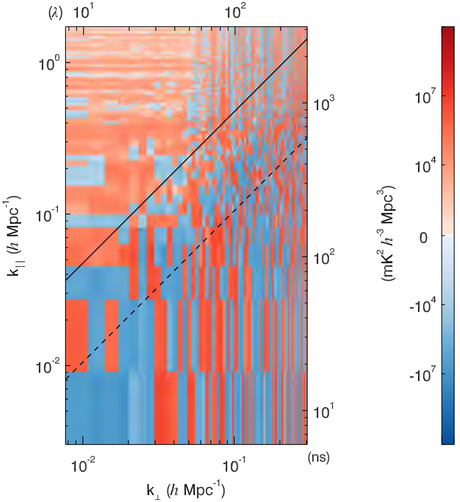


Real data calibration solutions

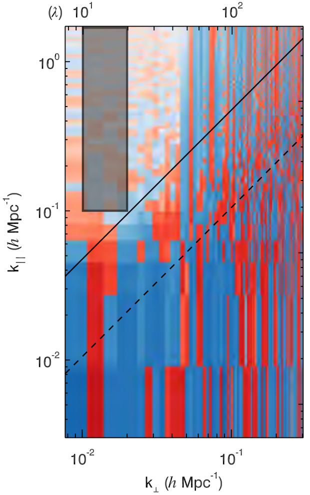


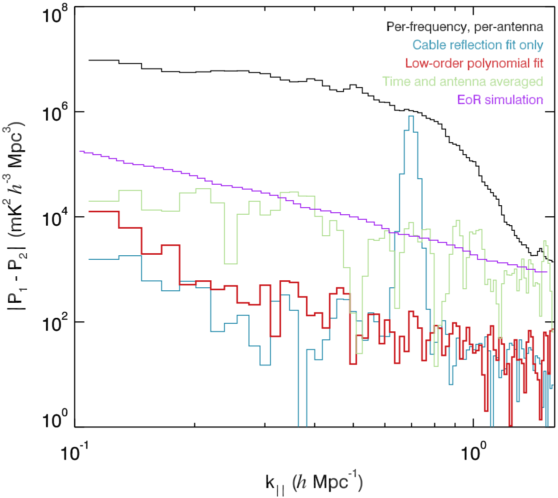
Difference – averaging calibration

- Averaged over all Local Sidereal Times and antennas
- Captures instrumental frequency-dependent effects
- Excess power 10^5, or about the level of the EoR



Final 1D comparison





Recommendations

- No frequency structure faster than 8 MHz (125 ns) in instrument
- Frequency structure lower than 1 part in 10^5
- Validation of calibration techniques
  - **in the space of the measurement**
  - **using incomplete models**

For more information...

- Barry N., Hazelton B., Sullivan, I. Morales M. F., Pober J. C., 2016 , MNRAS, doi:10.1093/mnras/stw1380
- Trott C. M. and Wayth R. B., 2016, PASA, 33, e019 doi:10.1017/pasa.2016.18.
- Patil A. H., Yatawatta S., Zaroubi S., Koopmans L. V. E., de Bruyn A. G., Jelić V., Ciardi B., Iliev I. T., Mevius M., Pandey V. N., Gehlot B. K., 2016, MNRAS, doi:10.1093/mnras/stw2277
- Ewall-Wice A., Dillon J. S., Liu A., Hewitt J., 2016, MNRAS, submitted