Spectral Leakage Mitigation in Delay Filtered PAPER 64 Visibilities using Foreground Subtraction

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PAPER 64 Background

PAPER dipole
Image taken from *http://eor.berkeley.edu/*

- Located in the Karoo Desert in South Africa
- 64 dipoles arranged for maximum redundancy (redundant calibration techniques)
- Bandwidth of 100-200 MHz
- Uses the delay spectrum approach for a statistical 21cm EoR power spectrum measurement

PAPER 64 Data Important Specs.

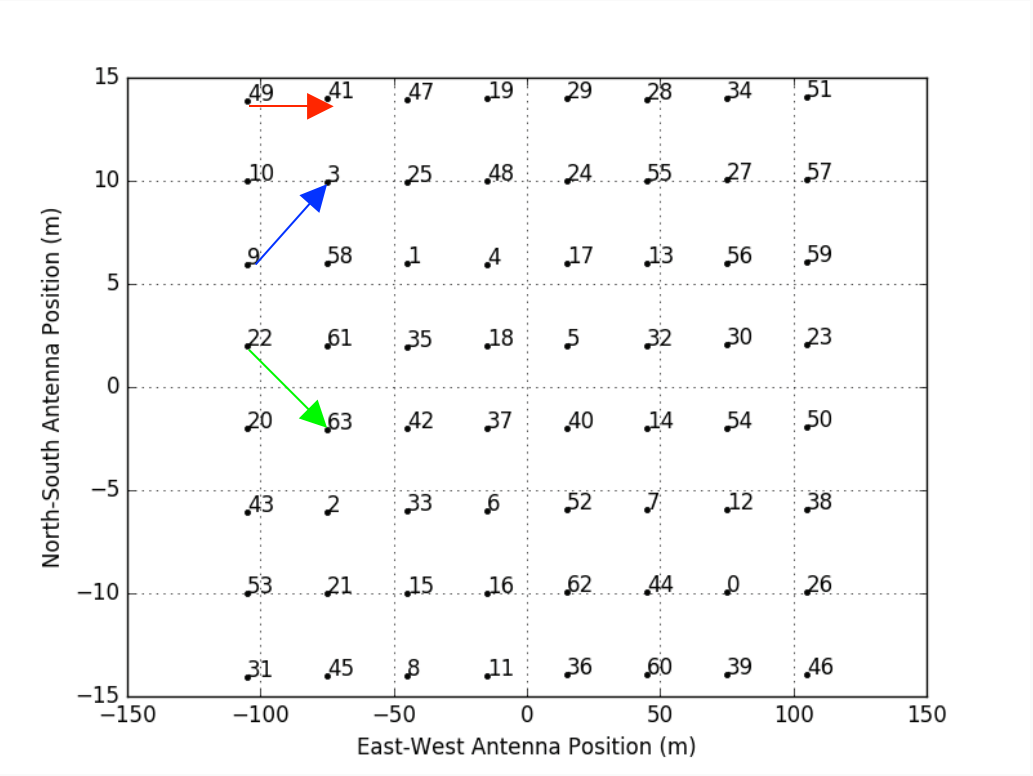
PSPEC Analysis uses 30m baselines: 3 Instantaneously redundant east-west orientation

~5000 Observations over 135 Days

Each observation is a 10 min. snapshot

Observing window of 0-8.5 hrs LST

PAPER 64 Array Layout



Foregrounds

- Galactic Synchrotron
- Extragalactic radio sources
- Supernova remnants

Foregrounds should be smooth spectrum, EoR is not

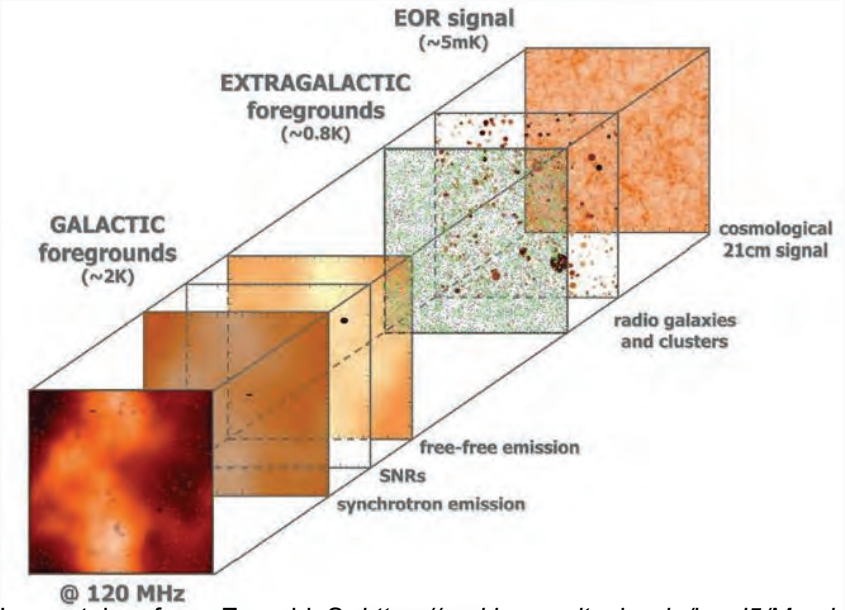


Image taken from: Zaroubi, S. *https://ned.ipac.caltech.edu/level5/March14/Zaroubi/Zaroubi5.html*

Goals of FG Subtraction/ Avoidance

What we're trying to investigate:

Reduce bright foregrounds leaking into the 21cm measurement window when using foreground avoidance and the delay spectrum approach.

Starting point:

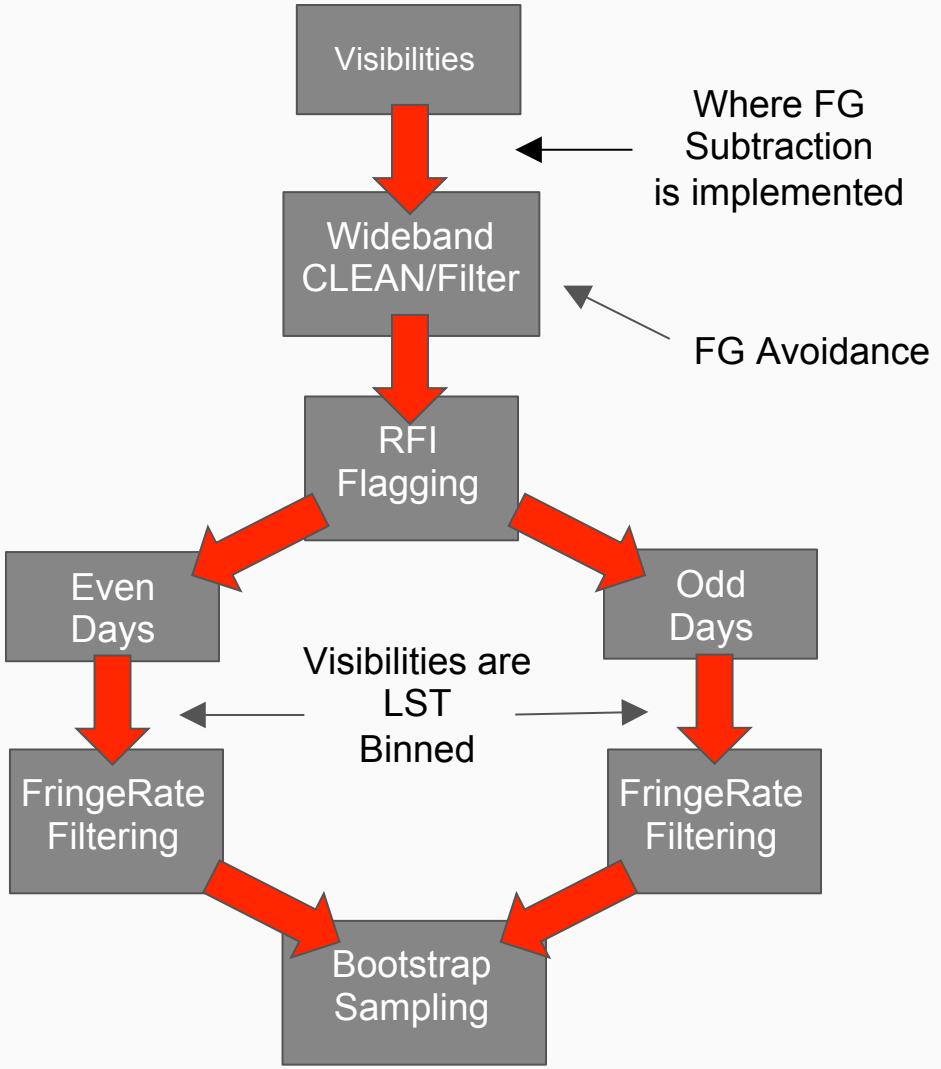
Working off the results of Ali et. al. (2015), using the PAPER 64 power spectrum pipeline (minus Inverse Covariance Weighting)

PAPER 64 PSPEC Abridged Pipeline

Fore more information on Fringe Rate Filtering see:

Parsons 2015, Optimized Beam Sculpting with

Generalized Fringe-Rate Filters



Per Baseline Delay Transform

$$\widetilde{V}(\tau) = \int A(\nu)W(\nu)I(\nu)e^{2\pi i\nu(\tau_g-\tau)}d\nu = \widetilde{A} * \widetilde{W} * \widetilde{I} * \delta(\tau_g - \tau)$$

$A(\nu) = Antenna\ Response$
$W(\nu) = Window/Sample\ Function$
$I(\nu) = Specific\ intensity\ of\ source$
$\tau_g = Geometric\ delay\ of\ source$

$$\tau_g = \frac{\vec{b}\cdot\hat{s}}{c}$$

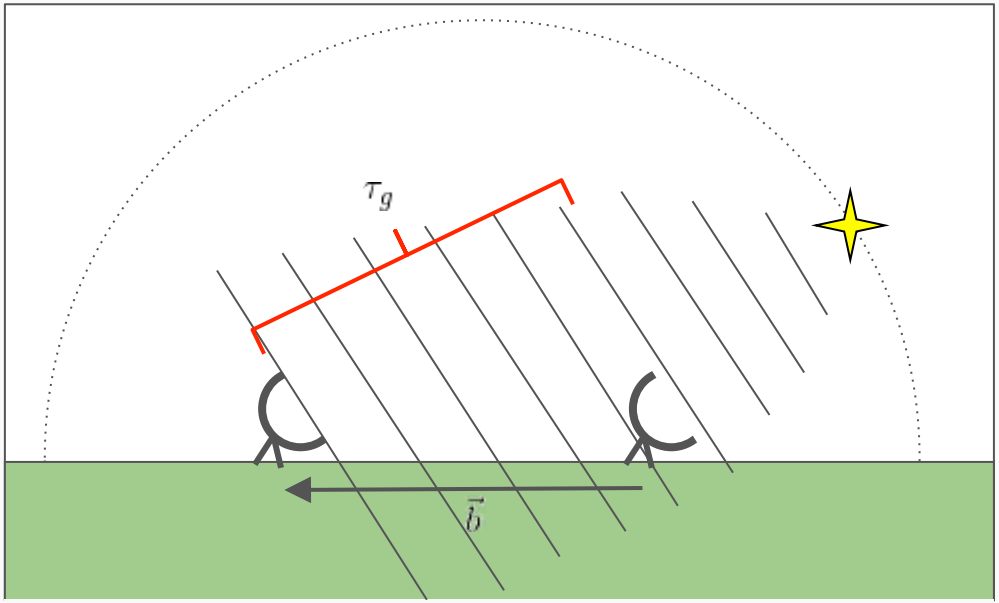
For more information see: *A Per-Baseline, Delay-Spectrum Technique for Accessing the 21cm Cosmic Reionization Signature*, Parsons et. al, Ap.J 2012

Source / Fractional Source near Horizon Example

Point source on the celestial sphere, with a single baseline.

Only smooth spectrum sources should be confined to within the horizon limit, which is the maximum geometric delay allowable by the horizon.

$$\tau_g = \frac{\vec{b} \cdot \hat{s}}{c}$$

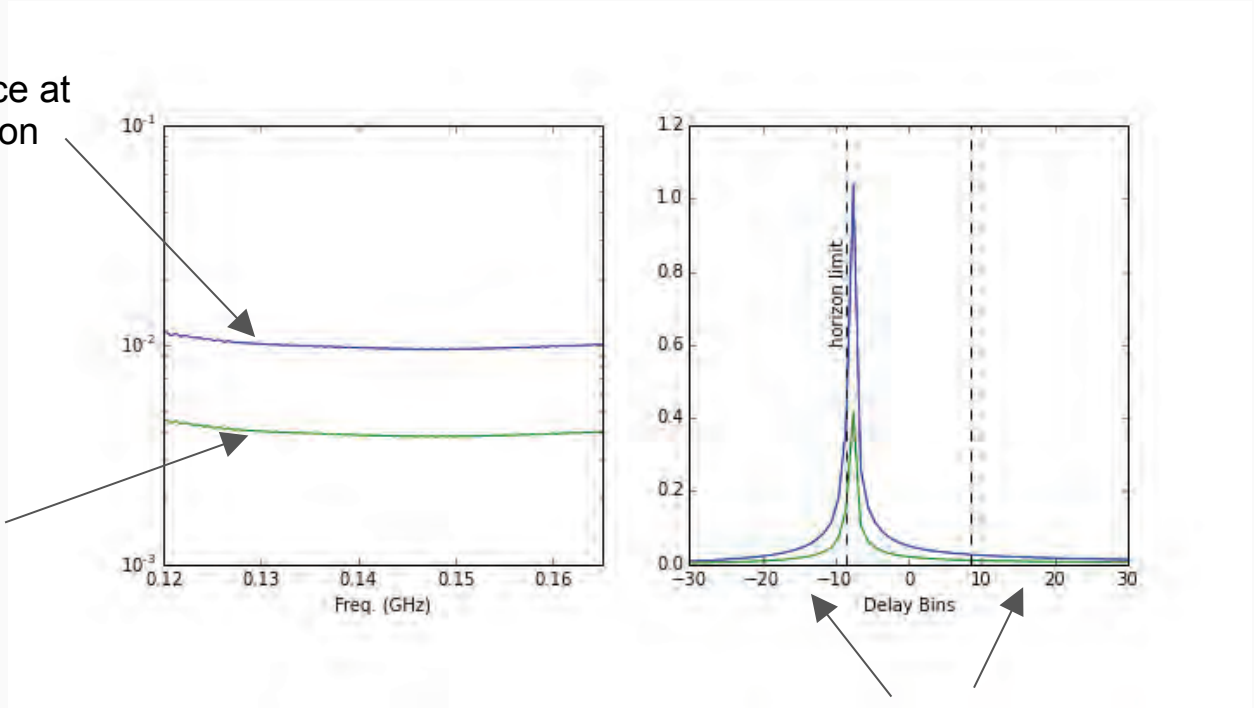


Recreated from A Per-Baseline, *Delay-Spectrum Technique for Accessing the 21cm Cosmic Reionization Signature*, Parsons et. al, Ap.J 2012

Example Single/Fractional Source in Freq./Delay Space

Source at Horizon

Partially Removed Source at Horizon



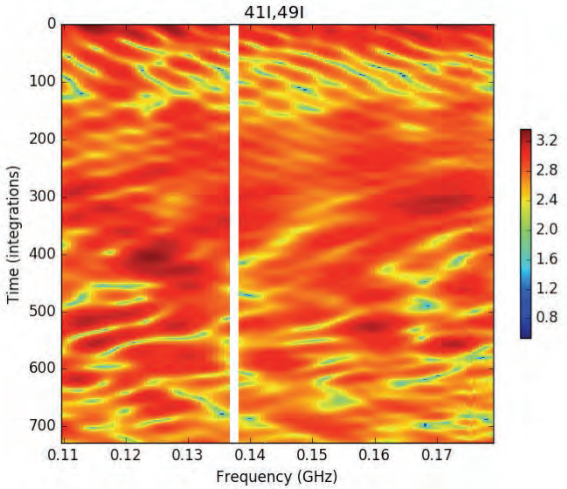
Reduced Leakage outside of horizon limits

PAPER 64 Delay Spectrum

8 hrs of LST Binned Dirty and Residual Visibilities

Observation window has Fornax A and Pictor A as our brightest sources

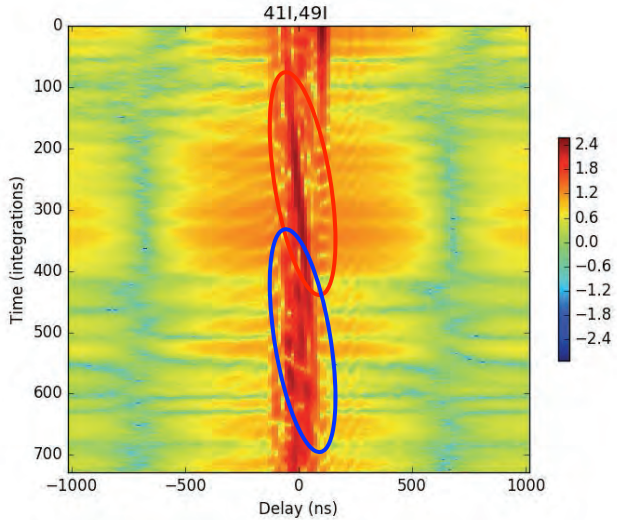
All sources are assumed point, PAPER 64 lacks ability to properly resolve extended sources



Missing data at freq. 138 MHz has been flagged due to constant RFI.

High Delays have high spectral leakage due to bright sources.

Fornax A - Red Oval
Pictor A - Blue Oval



Fast Holographic Deconvolution (FHD)

- Developed and maintained by the UW Astro group
- FHD has several current functions: Simulation, Deconvolution, and ‘Firstpass’ mode
- Firstpass mode allows for extragalactic catalogs to be modeled and subtracted from observational data

For more information see: *Fast Holographic Deconvolution: A New Technique for Radio Interferometry,* Sullivan, I. et. al. 2012

Galactic and Extragalactic All Sky MWA Survey (GLEAM)

GLEAM contains ~300k radio sources over 72-231 MHz.

GLEAM catalog was used with 30k point sources with focus on Fornax A and Pictor A

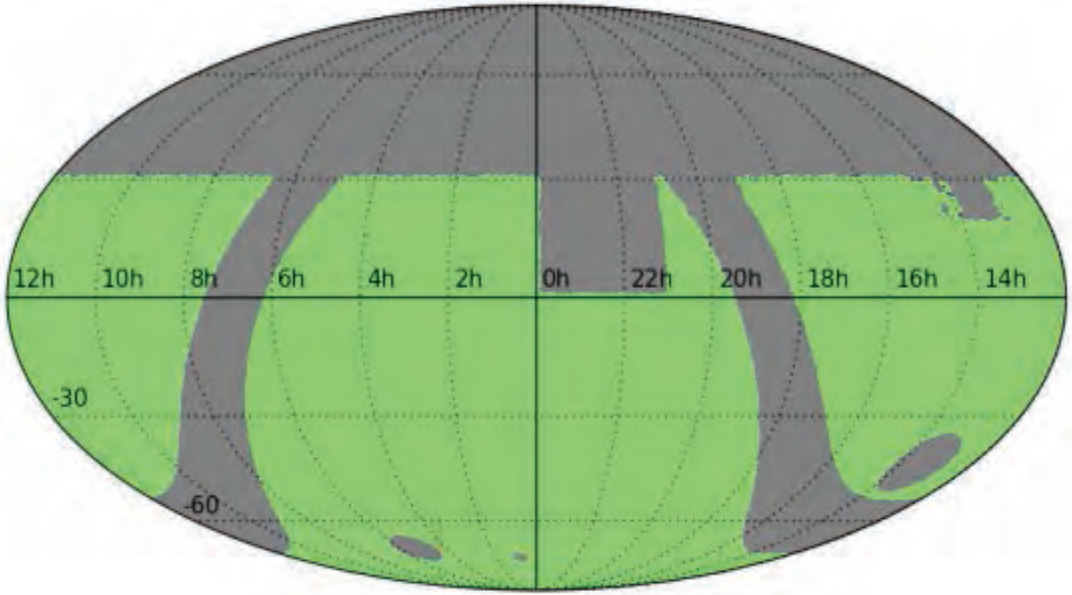
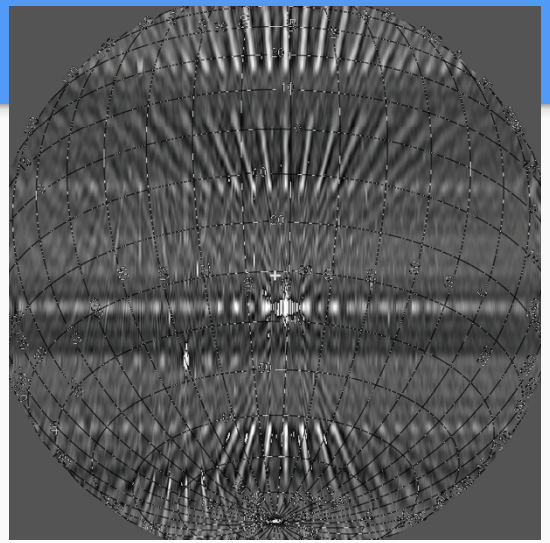
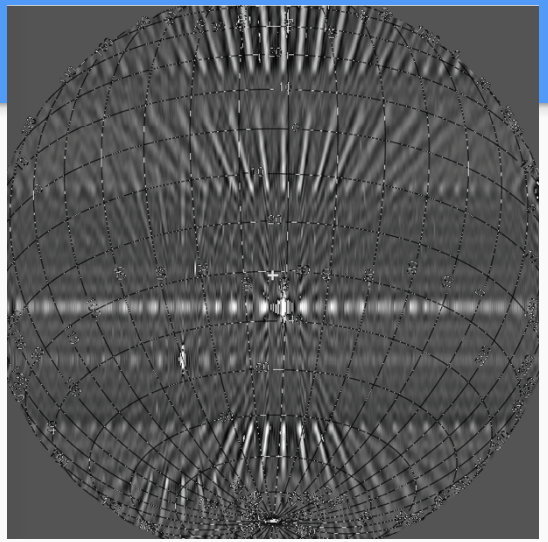


Image taken from *GaLactic and Extragalactic All-sky Murchison Widefield Array (GLEAM) survey I: A low frequency extragalactic catalogue*, Hurley-Walker et. al. , MNRAS 2016

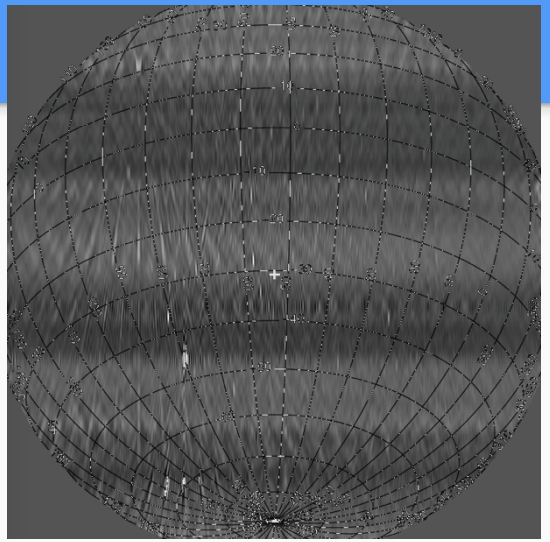
FHD Observation Images



DIRTY



MODEL



RESIDUAL

Fornax A at the center of the FoV (xx polarization);
modeled in FHD as a point source.

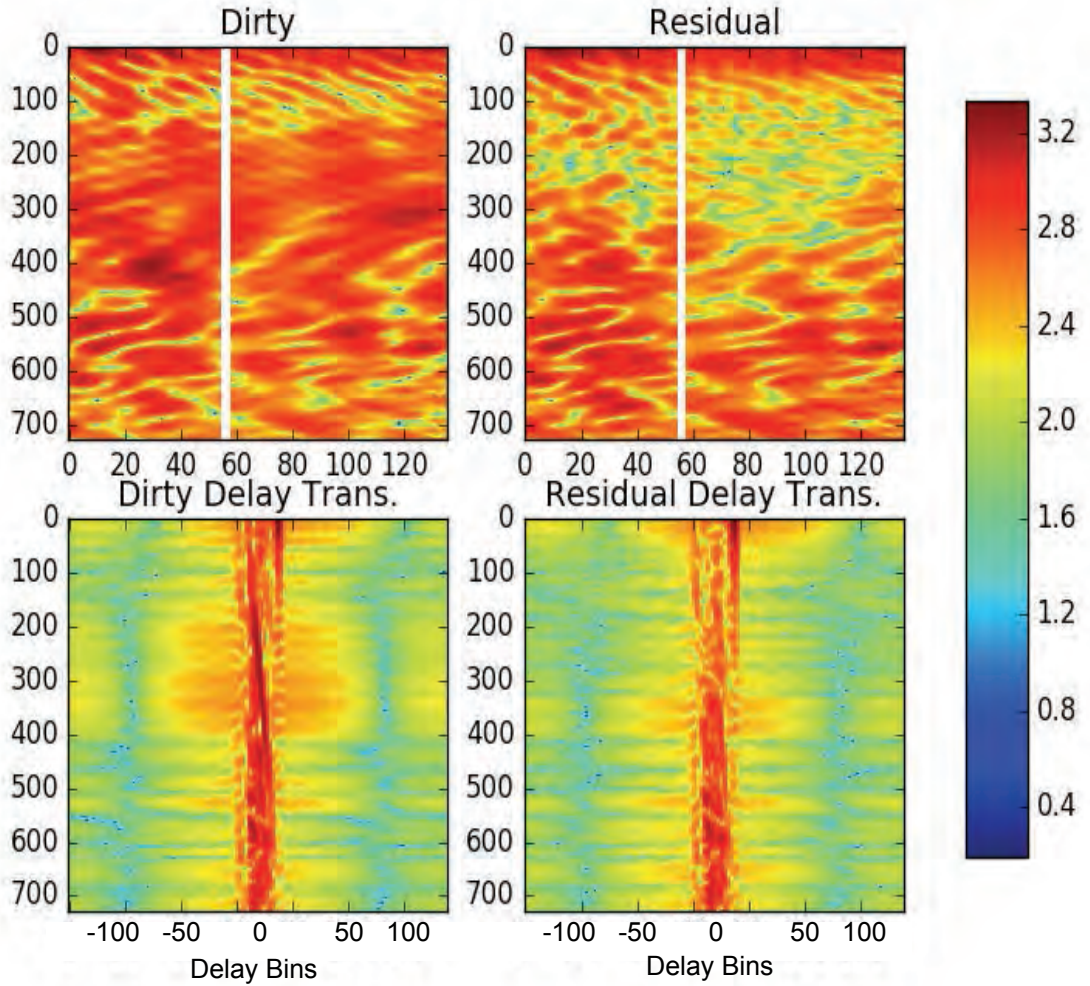
PAPER 64 FHD Subtracted Visibilities

Dirty and Residual LST binned visibilities from ~65 even days of observation

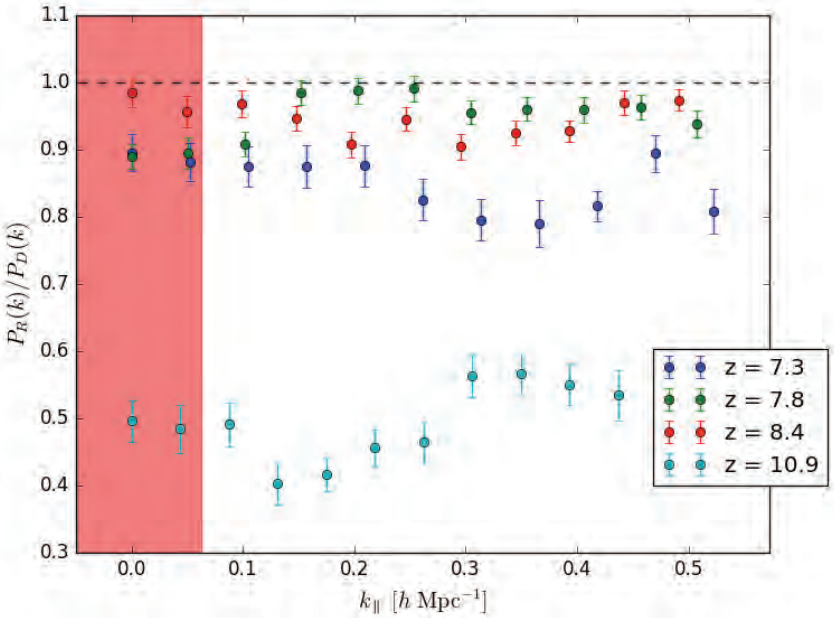
30 m East-West baseline

Majority of power removed is from Fornax A and Pictor A

Analysis is based on 2-6 hrs LST, where the GLEAM catalog is most effective



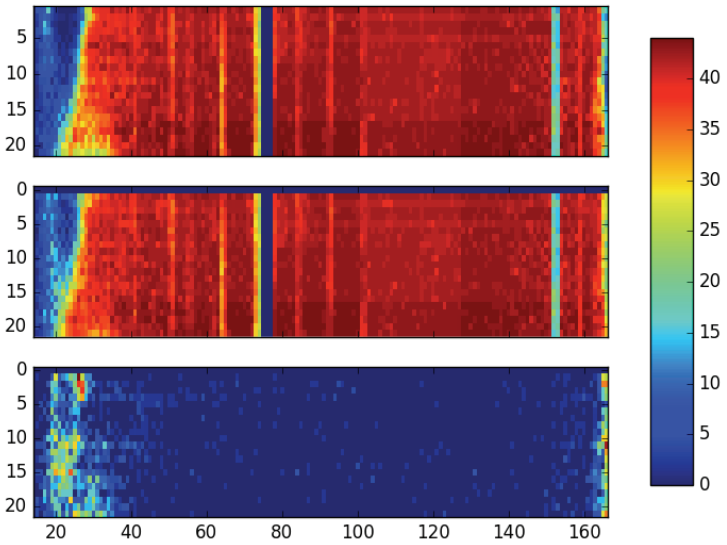
FG Subtraction + PAPER PSPEC Pipeline vs. PAPER PSPEC Pipeline



FG Subtraction offers up to an additional ~10% of FG power removal in the center of the band, z = 8.4.

Potential of up to 50% of power removal at band edges. (This can vary depending on window function selection for the Wideband CLEAN/ Filter.)

Preserved Data at Band Edges



RFI flagging in the PAPER PSPEC pipeline is done by flagging visibility data that is above some nσ threshold.

Foreground subtracting beforehand reduces this misidentification at band edges.

Any Questions?

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