

Beamforming Errors in Murchison Widefield Array (MWA) Antenna Tiles and their Effects on Epoch of Reionization (EOR) Science

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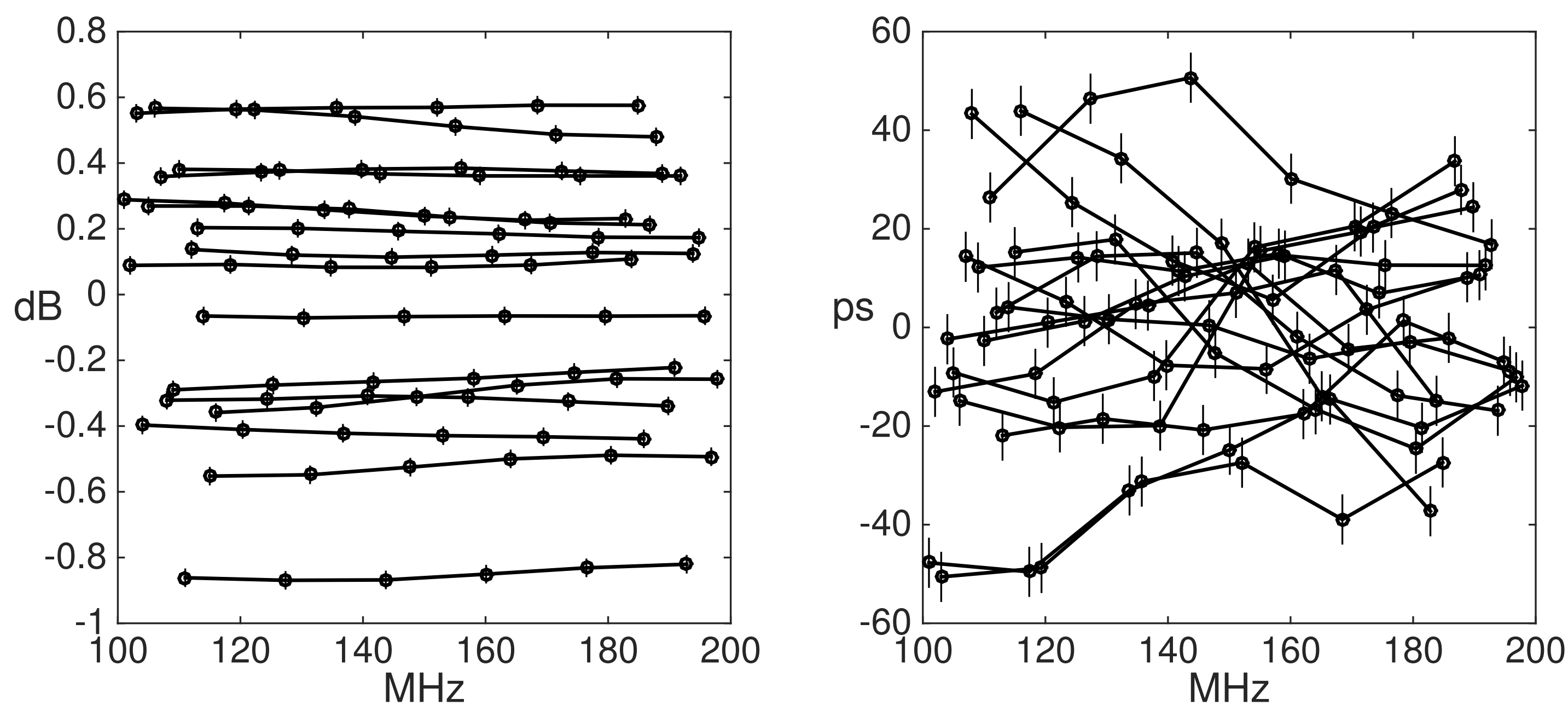
Beamforming errors in 21cm expts

- Faint EOR signal demands high dynamic range measurements & accurate beam models
- Advanced modeling and in situ measurements are improving mean MWA beam models [1,2]
- ...but antenna-to-antenna variation has remained unexplored
- We characterize this variation with lab measurements & Monte Carlo simulations
- ...and quantify effects on power spectrum measurements



Effects on power spectrum analysis

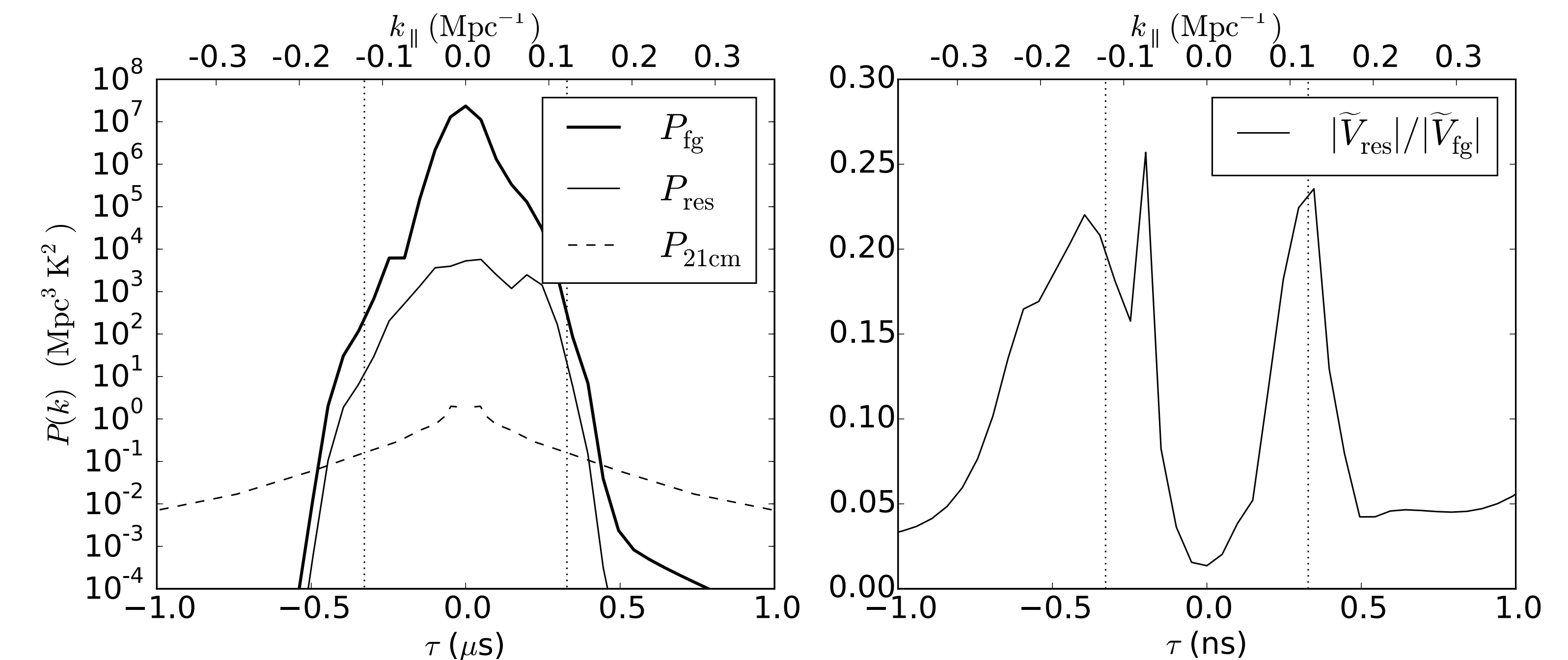
- We simulate visibilities with beamforming errors ($\pm 50\text{ps}$, $\pm 0.5\text{dB}$, $\pm 0.3^\circ$, & $\pm 5\text{ps/MHz}$) for a 100m baseline
- ...then subtract otherwise perfect foreground model with unmodeled beamforming errors
- ...and compute power spectrum with delay transform [3]
- Residuals dominate EOR signal in the wedge, but do not corrupt EOR window



Measured **gains** (left) and **group delays** (right) of an MWA beamformer

Simulating imperfect beams

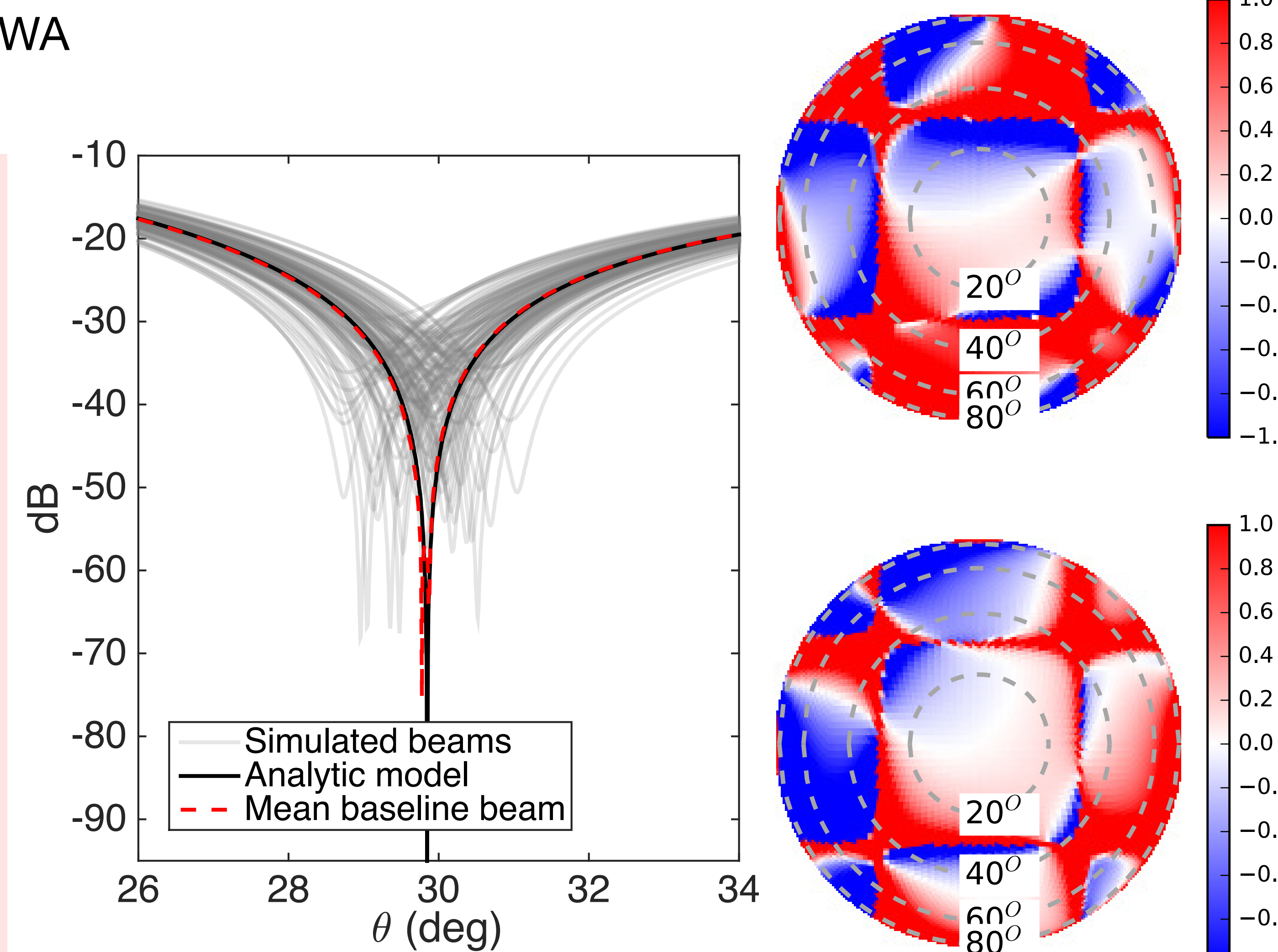
- Simulated 128 beams with random gain/delay/alignment errors from error budget
- 10-20% fluctuations observed near edge of main lobe ($>20^\circ$) and in sidelobes at 150MHz
- Complex beam errors partly cancel out in dirty images, but alter PSF and limit deconvolution accuracy



Simulated **EOR measurement** after subtracting otherwise perfect foreground model with unmodeled beamforming errors (left)

Lab measurements of beamforming errors

- Conducted VNA gain/delay measurements through beamformer paths (shown above), cables, and LNAs
- Achieved high precision using few cables, custom connectors, and ground plates
- Found significant gain/delay variation compared to measurement uncertainties
- Final beamforming error budget: $\pm 50\text{ps}$, $\pm 0.5\text{dB}$, $\pm 0.3^\circ$



Discussion and implications

- Even with freq-dependent beamforming errors, foregrounds confined to wedge & EOR window remains clean
- Accessing EOR in wedge requires foreground subtraction with per-antenna beams
- Building on [4], future work will study beamforming errors in full array simulation

1. Sutinjo et al., Radio Sci., 50, 52
2. Neben et al., Radio Sci., 50, 614
3. Parsons et al., ApJ, 756, 165
4. Thyagarajan et al., ApJ, 804, 14

We are preparing a paper to submit to Radio Science.