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Calibration Modeling Errors in the 21cm Power Spectrum

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Foreground Isolation Requires Smooth Gains

Real Space

Brightness

Fourier Space

g

s

gxs

F(g)

F(s)

F(g)✳F(s)

signal

f (MHz) ~ r (h^{-1}Mpc)

t (ns) ~ $k_{\parallel}$ (hMpc^{-1})

Two Options for Mitigating Spectral Structure

1. Design the Structure out of the Instrument (See Nithya's Talk).

2. Remove Residual Structure through Calibration (Nichole's talk, This talk, Josh Dillon's Talk).

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Calibration Tries to Solve the Following Equation

Measured Visibility Antenna Gains True Visibility

$$V_{ij}^{meas}(\nu) = g_i(\nu) g_j^*(\nu) V_{ij}(\nu)$$

In “Sky-based” Calibration, we assume a model for $V_{ij}(\nu)$

All Models of the Sky will be imperfect at Some Level

1. Source Confusion (due to finite resolution)
2. Primary Beam Modeling Errors

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What are the Consequences?

Smooth model errors -> Smooth gain errors

Incorrect

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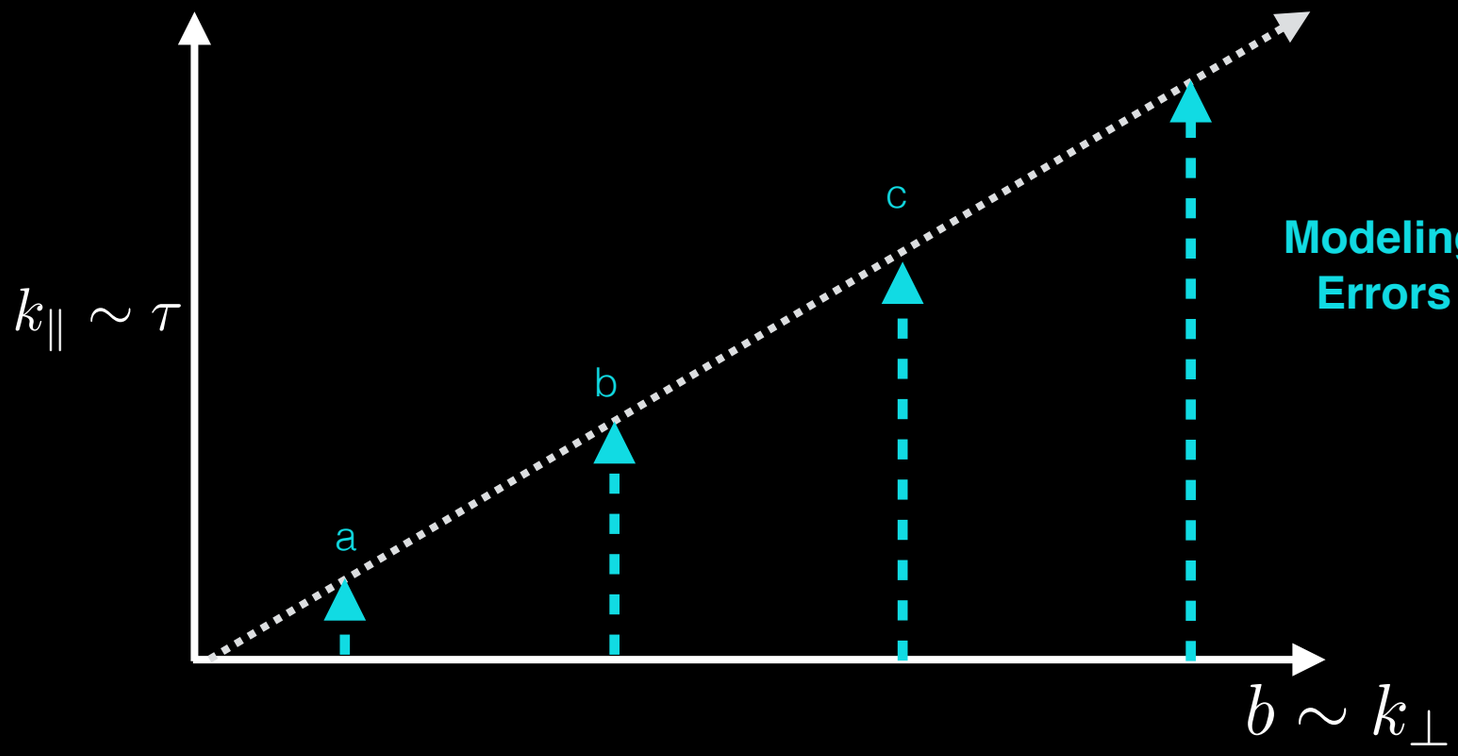
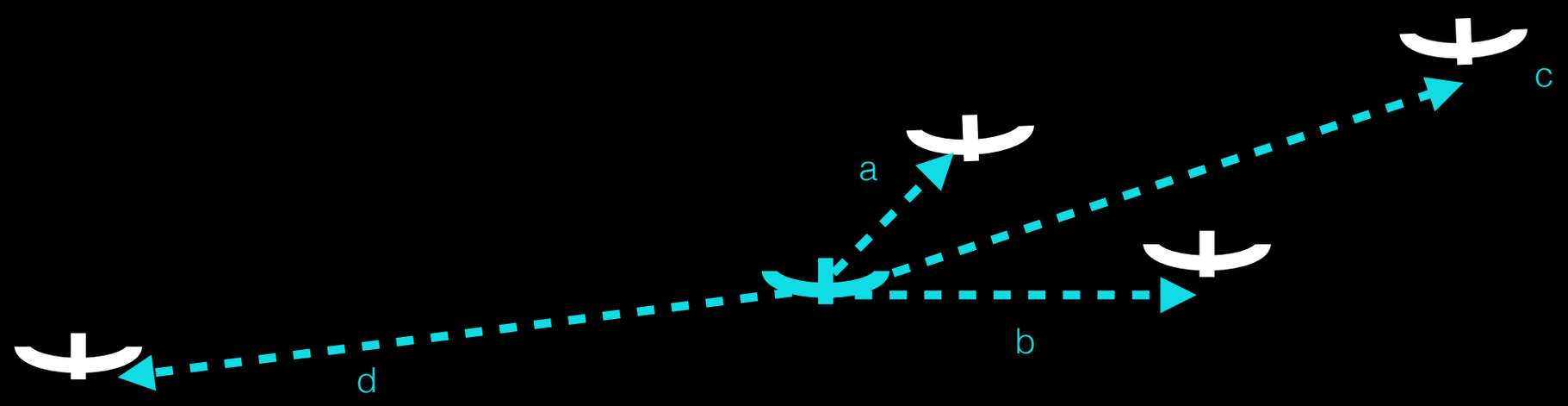
How Modeling Errors Contaminate the EoR Window





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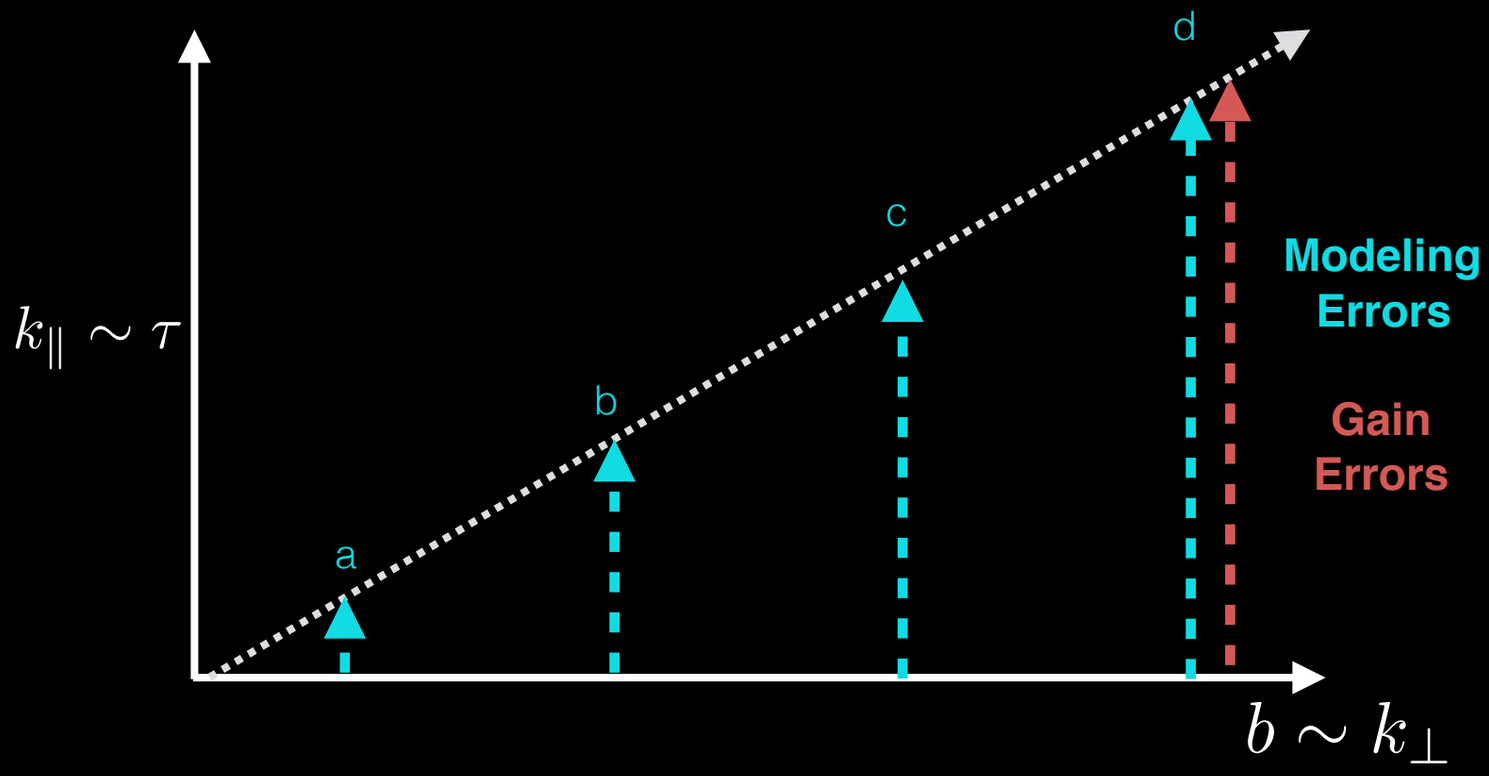

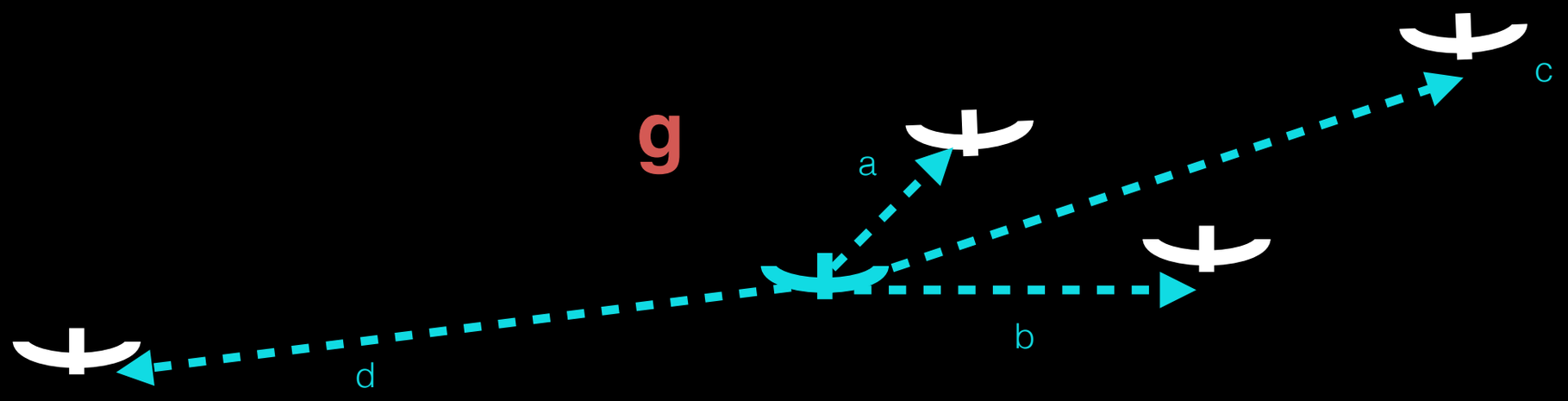

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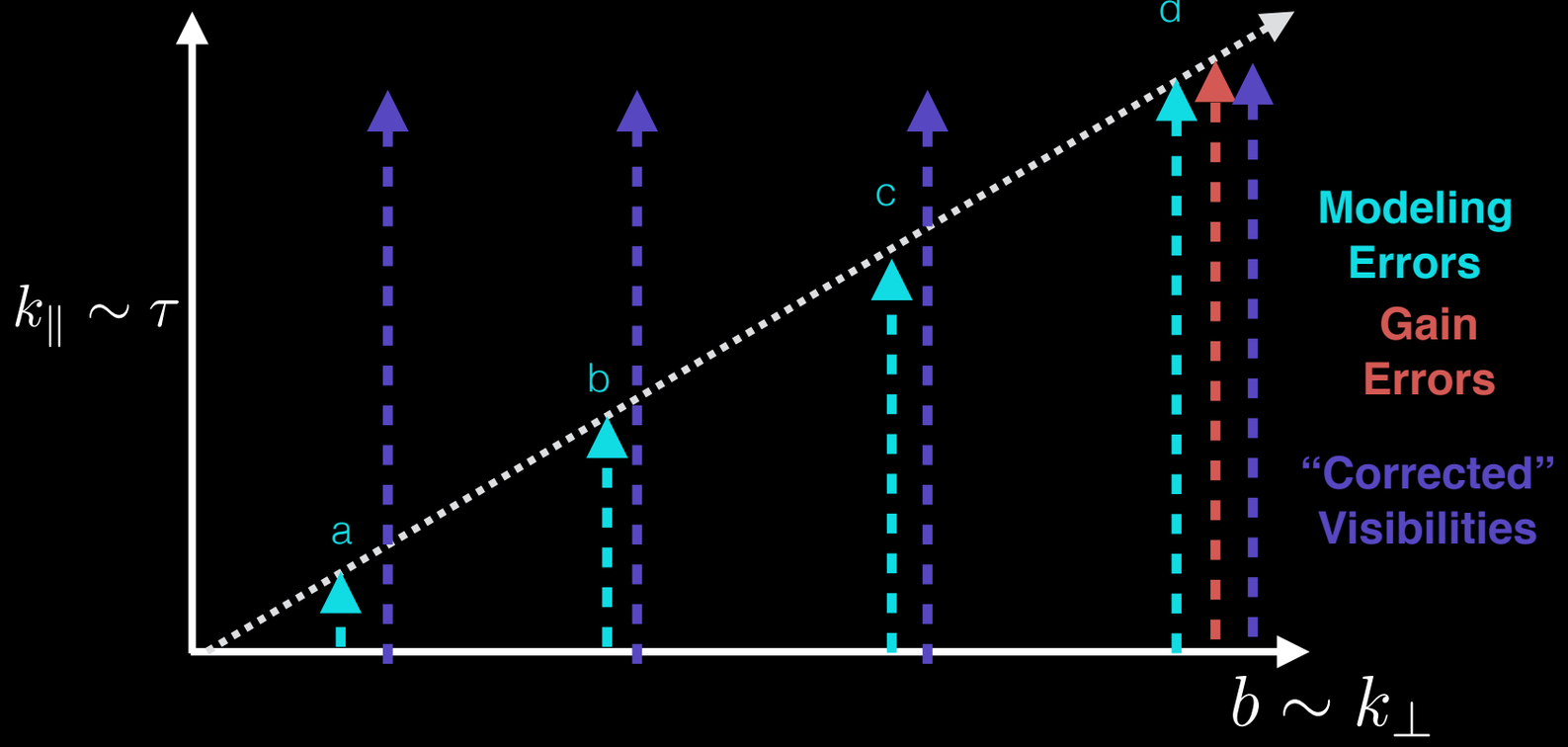

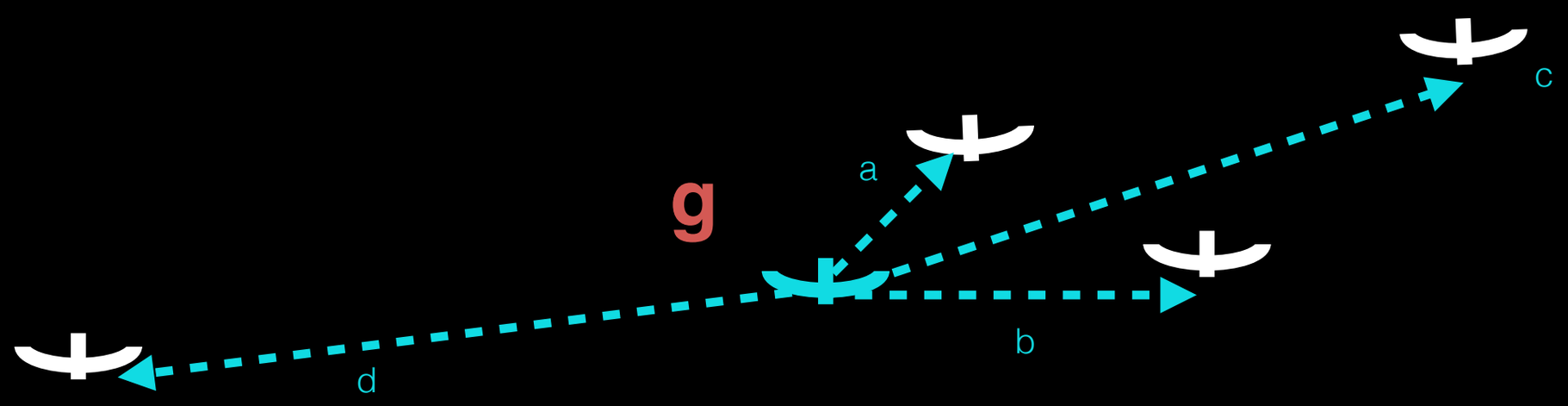

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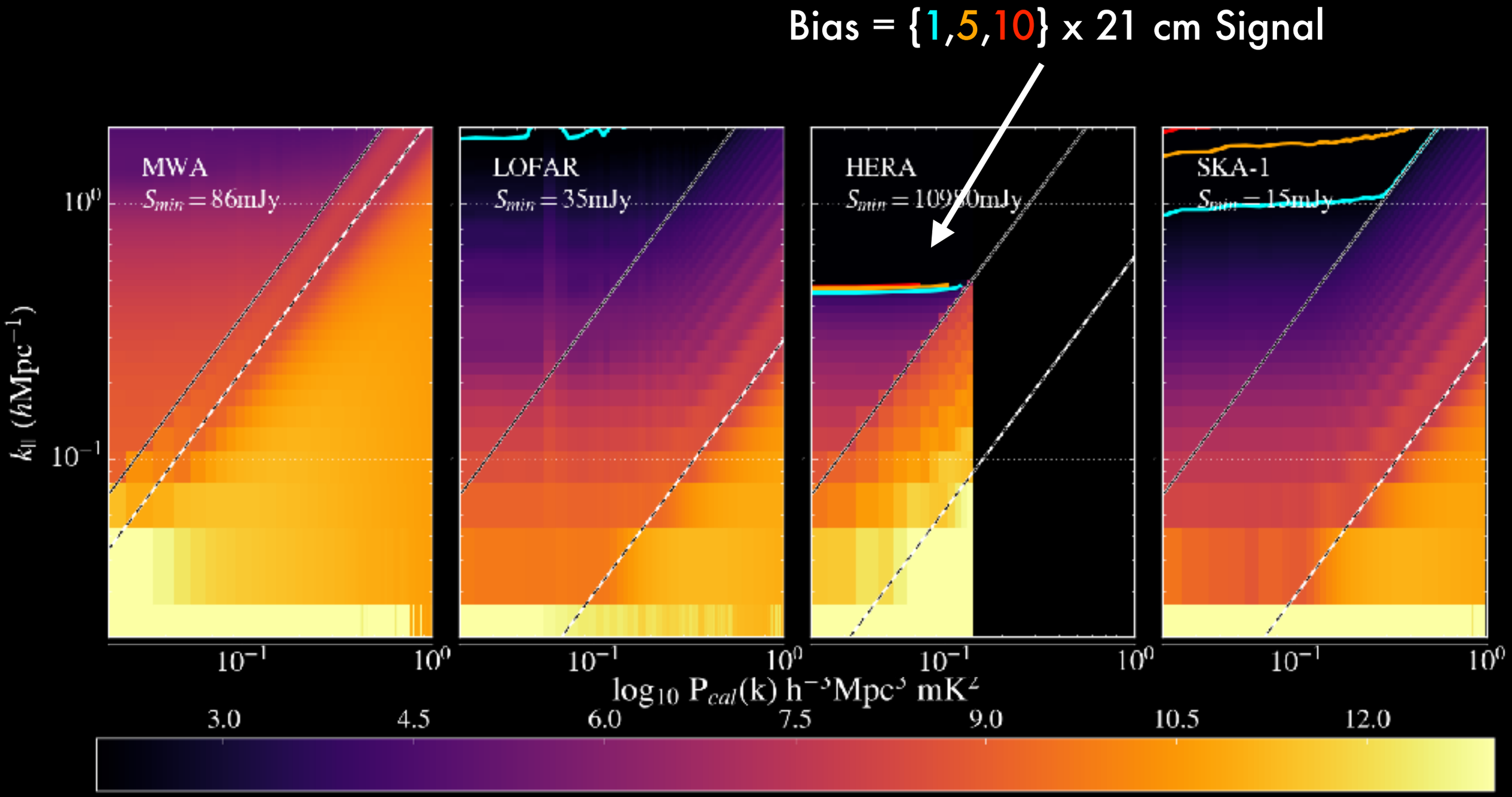
At Core Confusion Limits, Signal is Completely Masked



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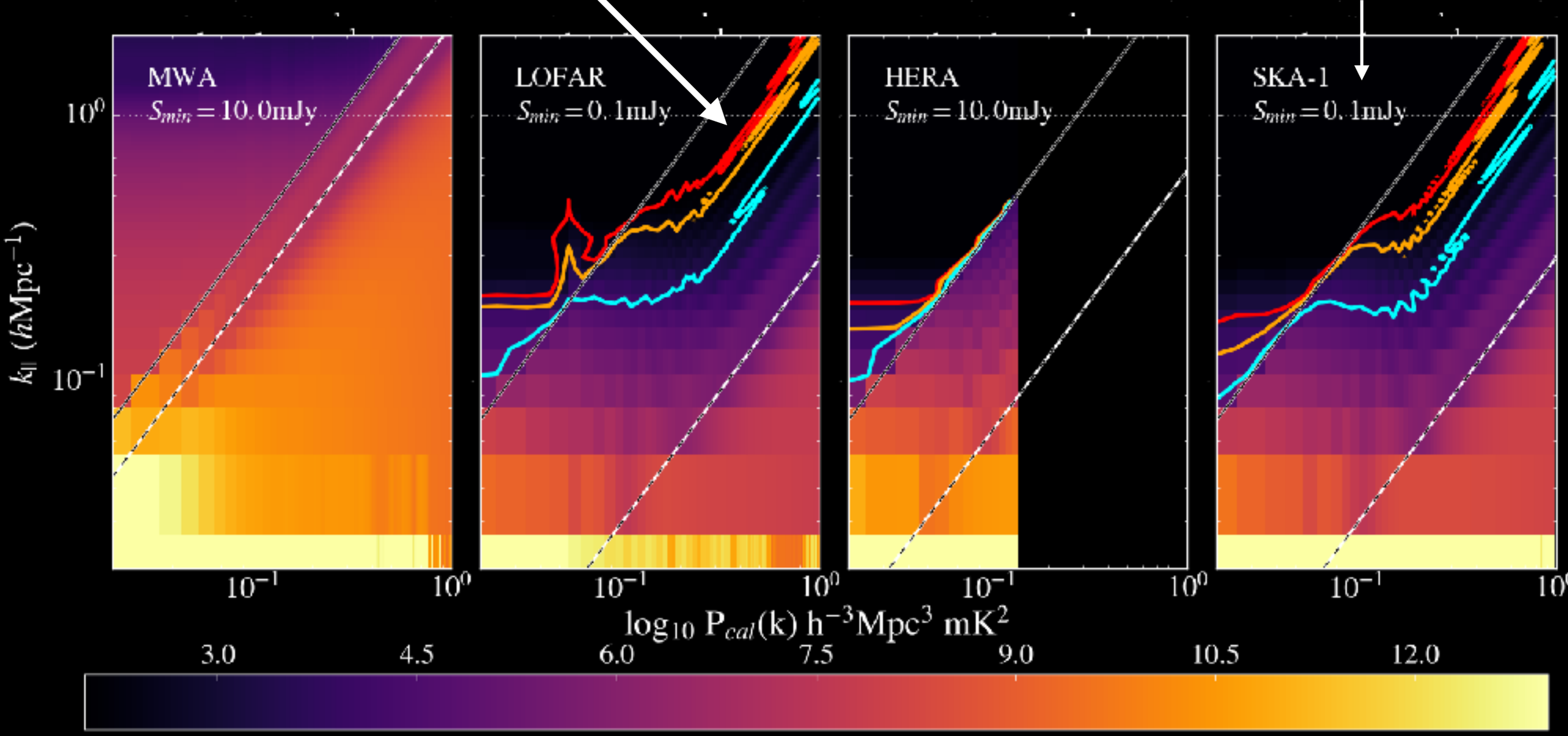
The Situation Improves Dramatically With Source Modeling from Outrigger Antennas

But only use the core to calibrate!

Bias = {1,5,10} x 21 cm Signal

Pradoni+Seynmour 2015
0.1mJy at 150MHz on SKA-1



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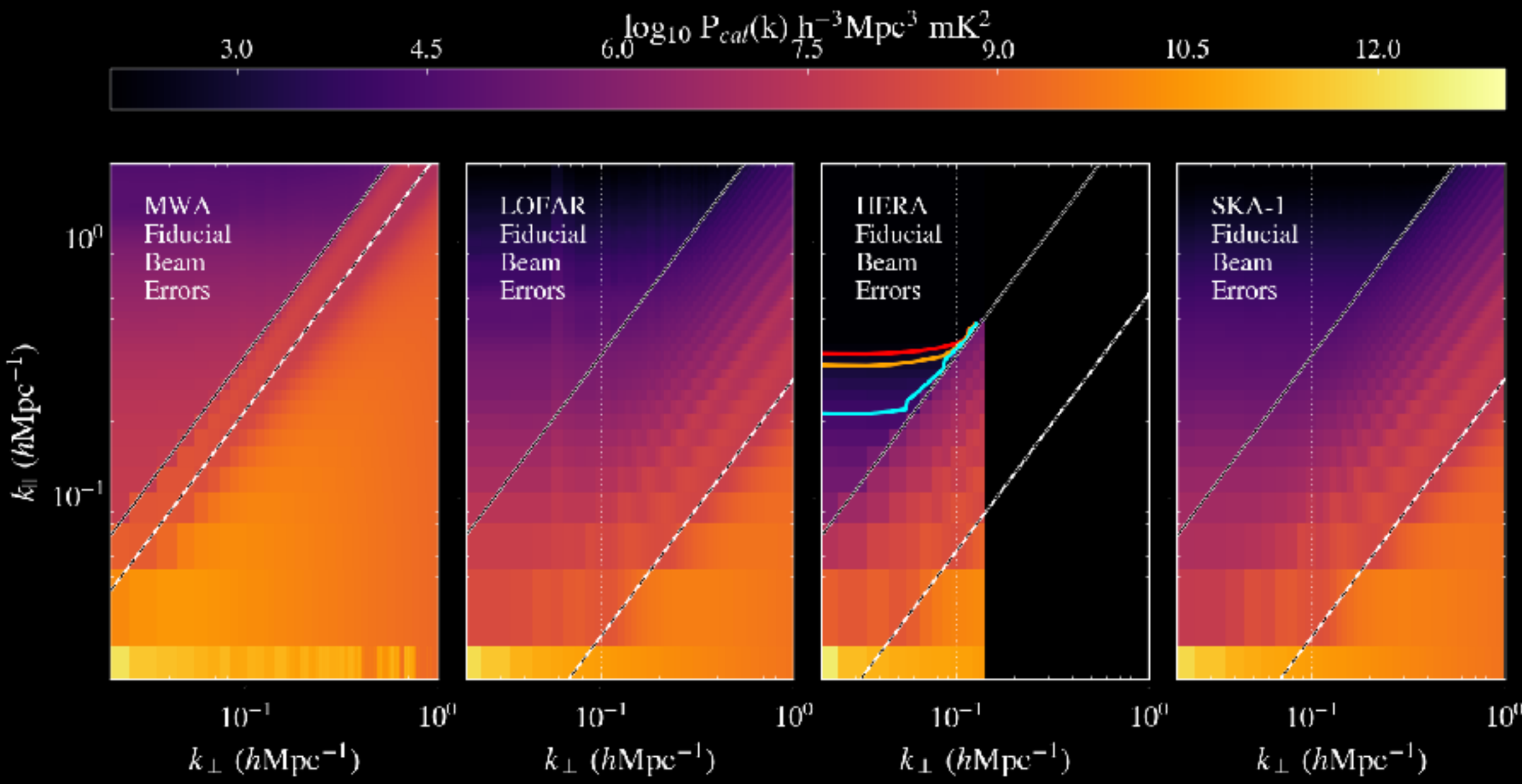
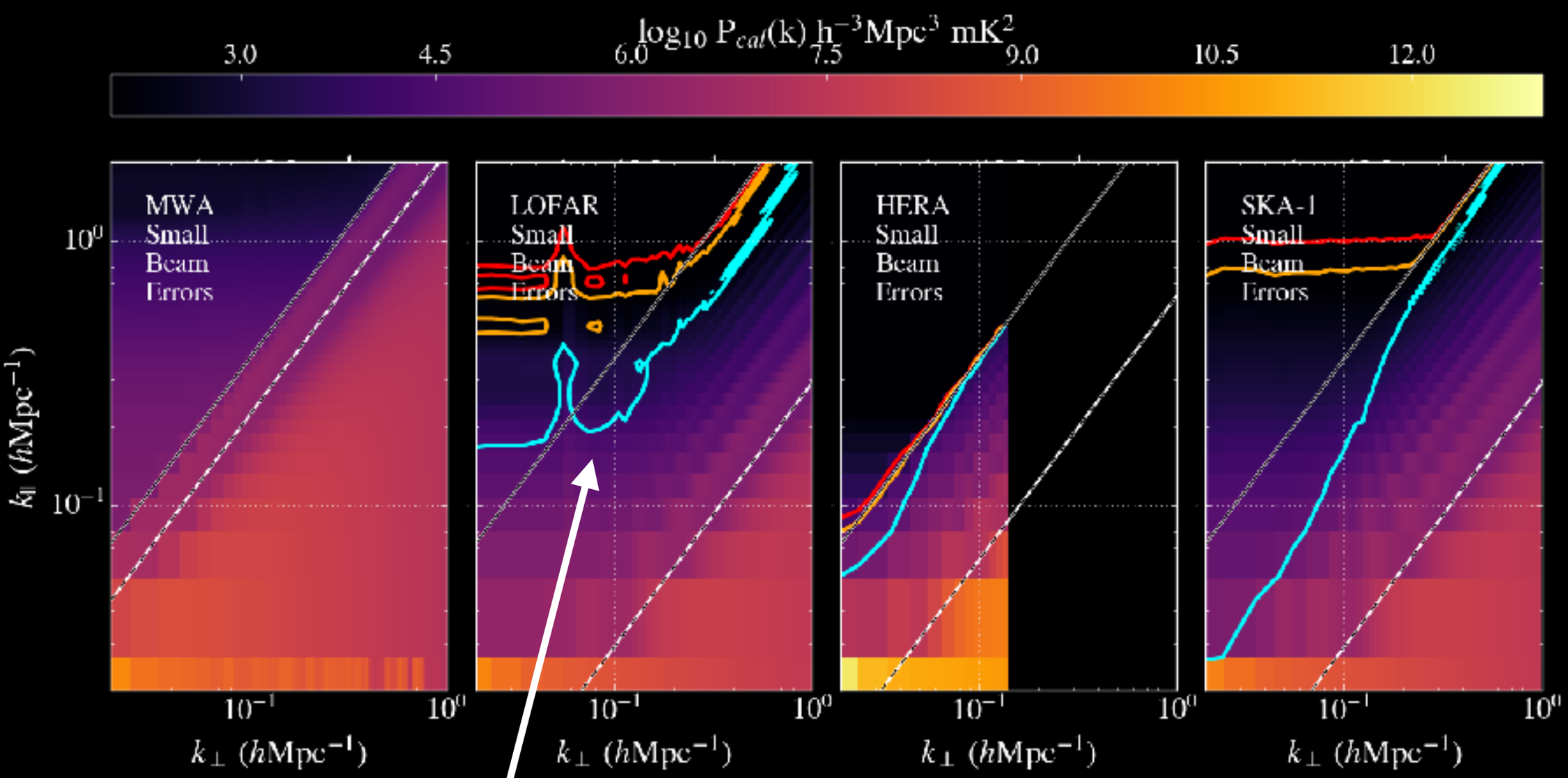
Even with a Perfect Sky Model, Current Beam modeling knowledge is not enough.



10% Main-Lobe Errors, 100% Side-Lobe Errors (Neben+ 2015,Jacobs+ 2016)

Significant Biases Exist with 1% Beam Errors and a Perfect Catalog



Bias = {1,5,10} x 21 cm Signal

When minimizing χ2 to fit gains, weight each i-j visibility contribution by

$$W_{ij} = e^{\frac{-b_{ij}^2}{2\sigma_w^2}}$$

baseline length

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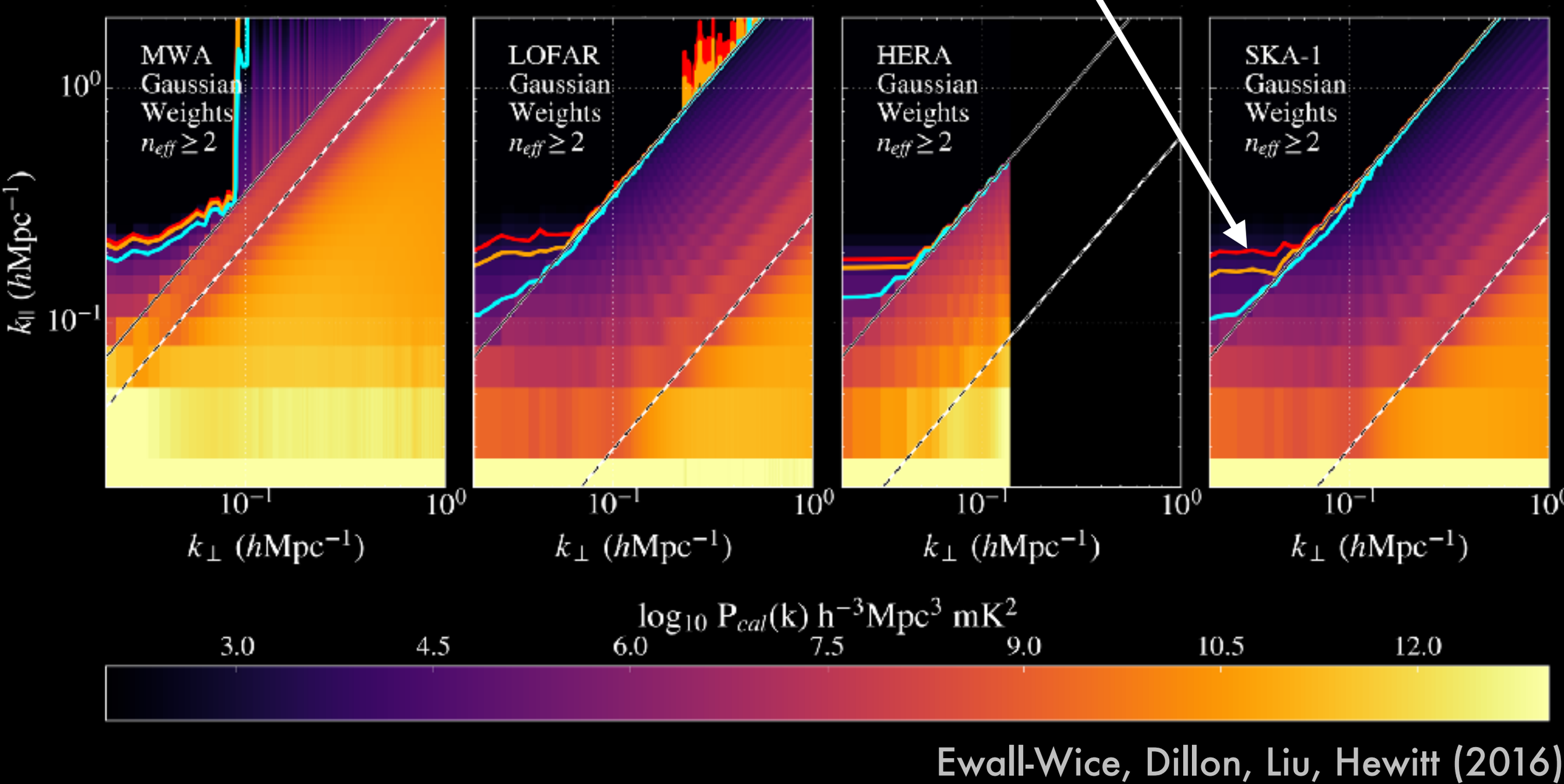
After the Application of Gaussian Weighting



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Take Aways

1. Traditional sky-model based calibration leaks foregrounds into the EoR window due to the wedge.

2. Calibrating a Compact Core of large Apertures with a deep (<~0.1 mJy) catalog brings noise below 21cm signal

3. But primary beam modeling must also be achieved at the <~1% level (Depending on Array Compactness).

4. Weighted Baseline Calibration may Enable Deep 21cm Limits in Existing Instruments (MWA and LOFAR), requiring decent diffuse models.

All of this is Necessary for “Foreground Avoidance”.
“Foreground Subtraction” will be much harder.