It’s always darkest before the Cosmic Dawn

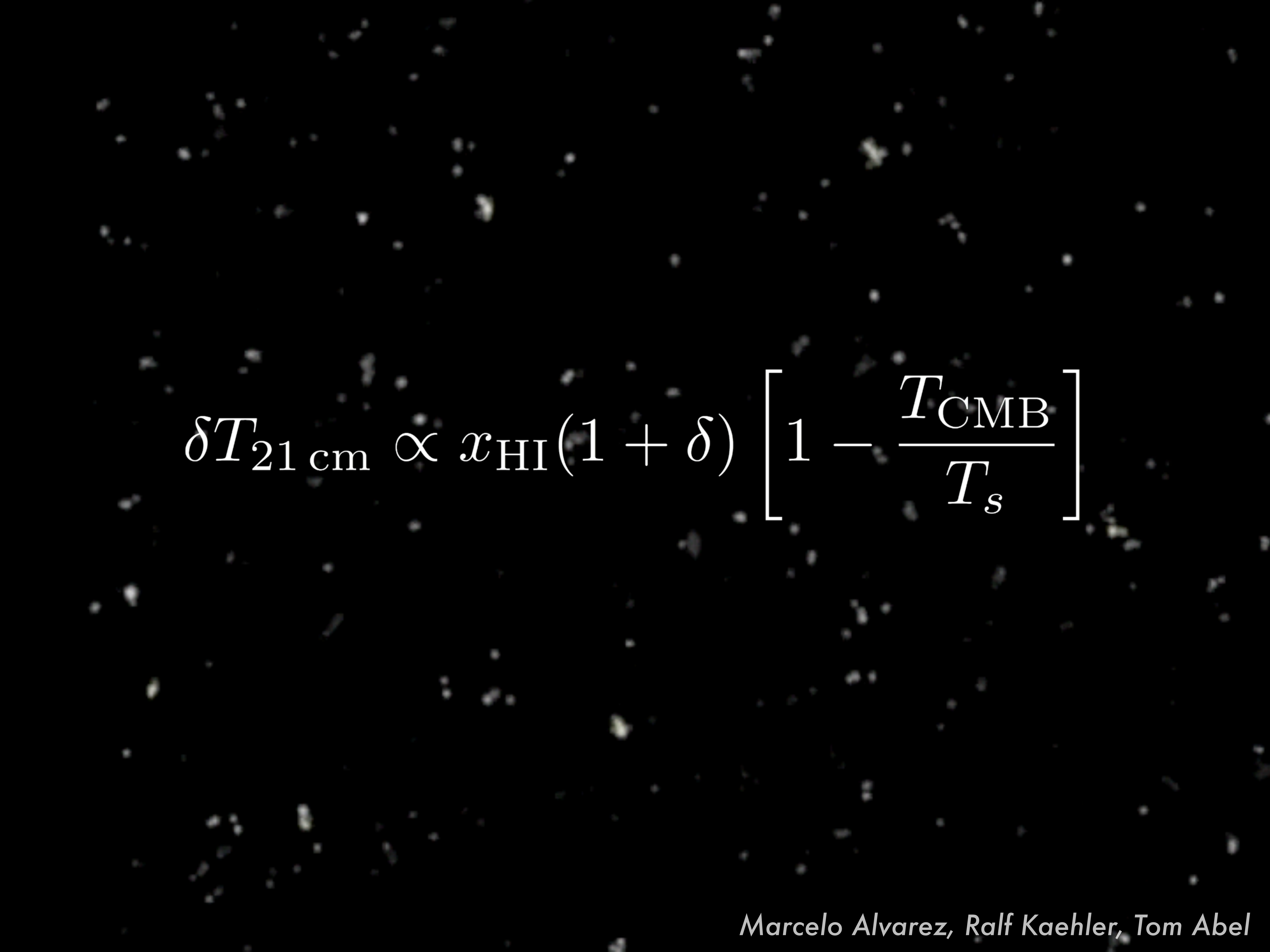
First generation 21 cm results and lessons for next-generation arrays

Josh Dillon
UC Berkeley

We all know the promise of 21cm cosmology...

Marcelo Alvarez, Ralf Kaehler, Tom Abel

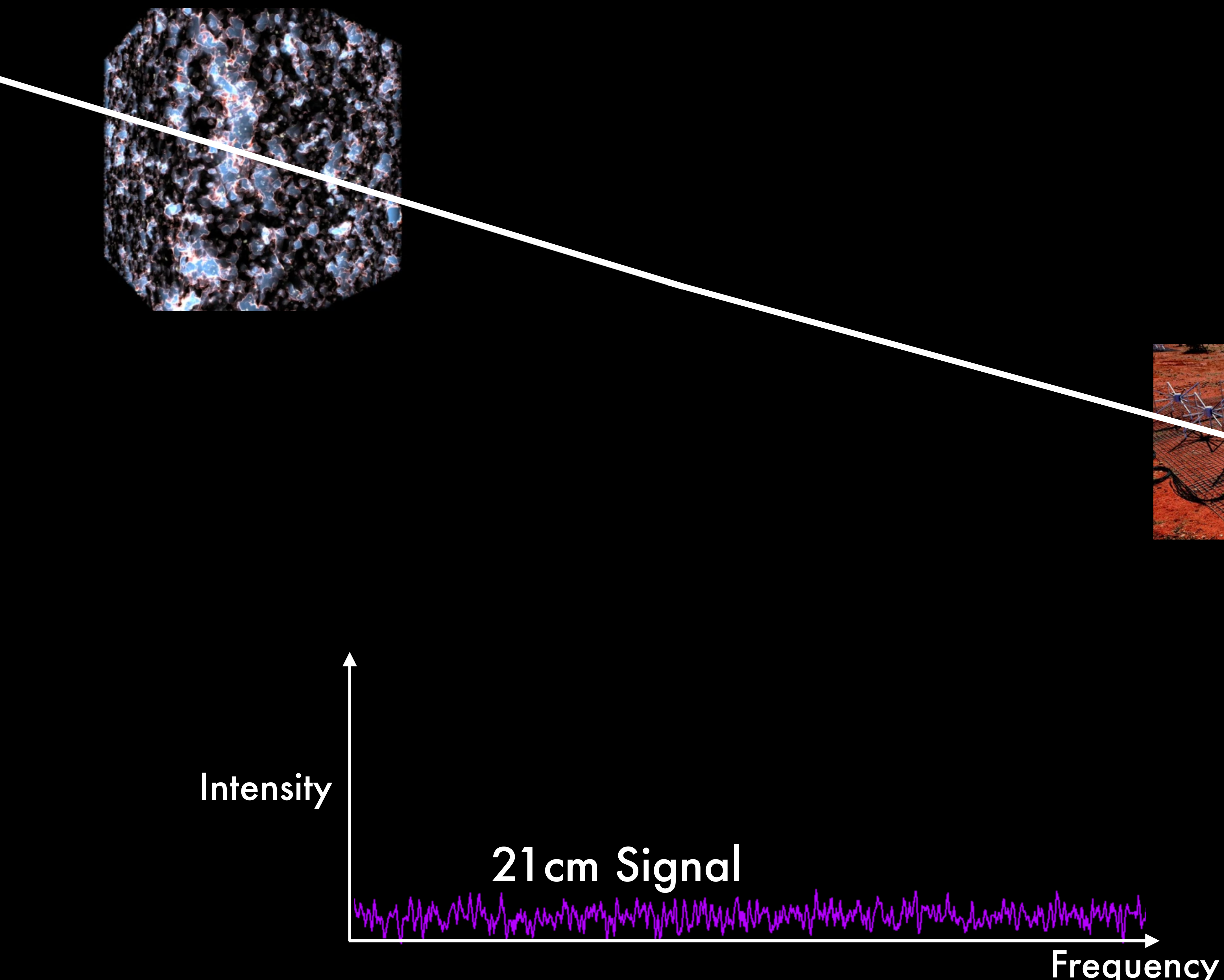

We all know the promise
of 21cm cosmology...
Marcelo Alvarez, Ralf Kaehler, Tom Abel



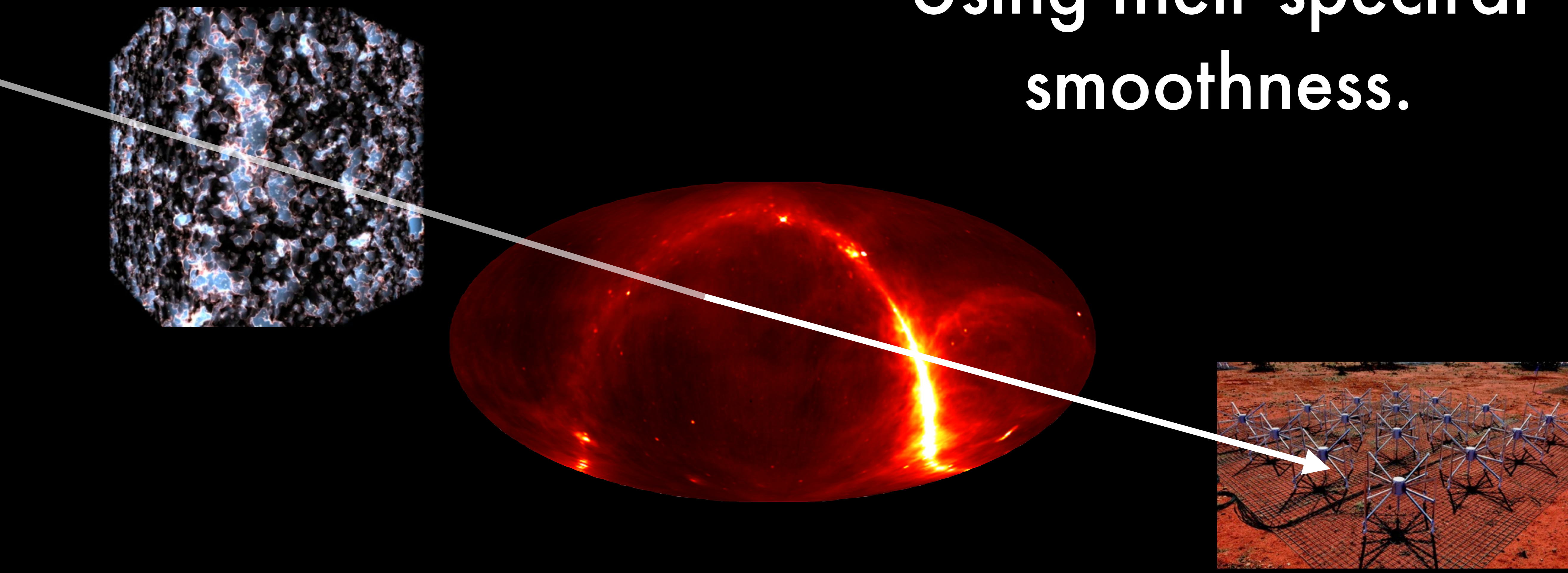
$$\delta T_{21\,\mathrm{cm}} \propto x_{\mathrm{HI}}(1+\delta)\left[1-\frac{T_{\mathrm{CMB}}}{T_s}\right]$$

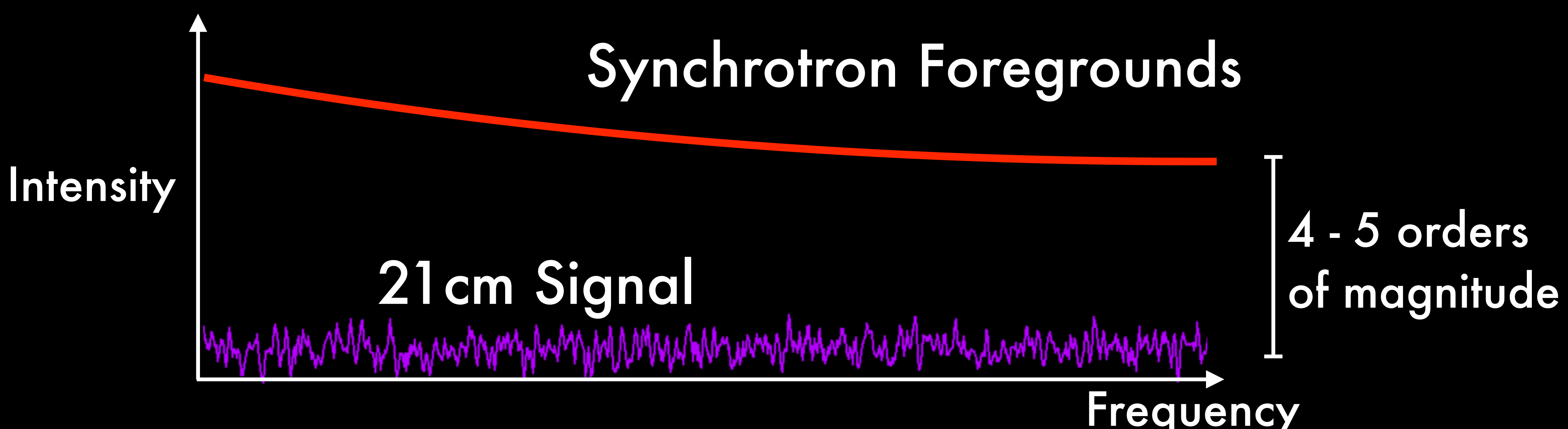
Marcelo Alvarez, Ralf Kaehler, Tom Abel


But how can we separate the signal from bright foregrounds to deliver on that promise?
Marcelo Alvarez, Ralf Kaehler, Tom Abel

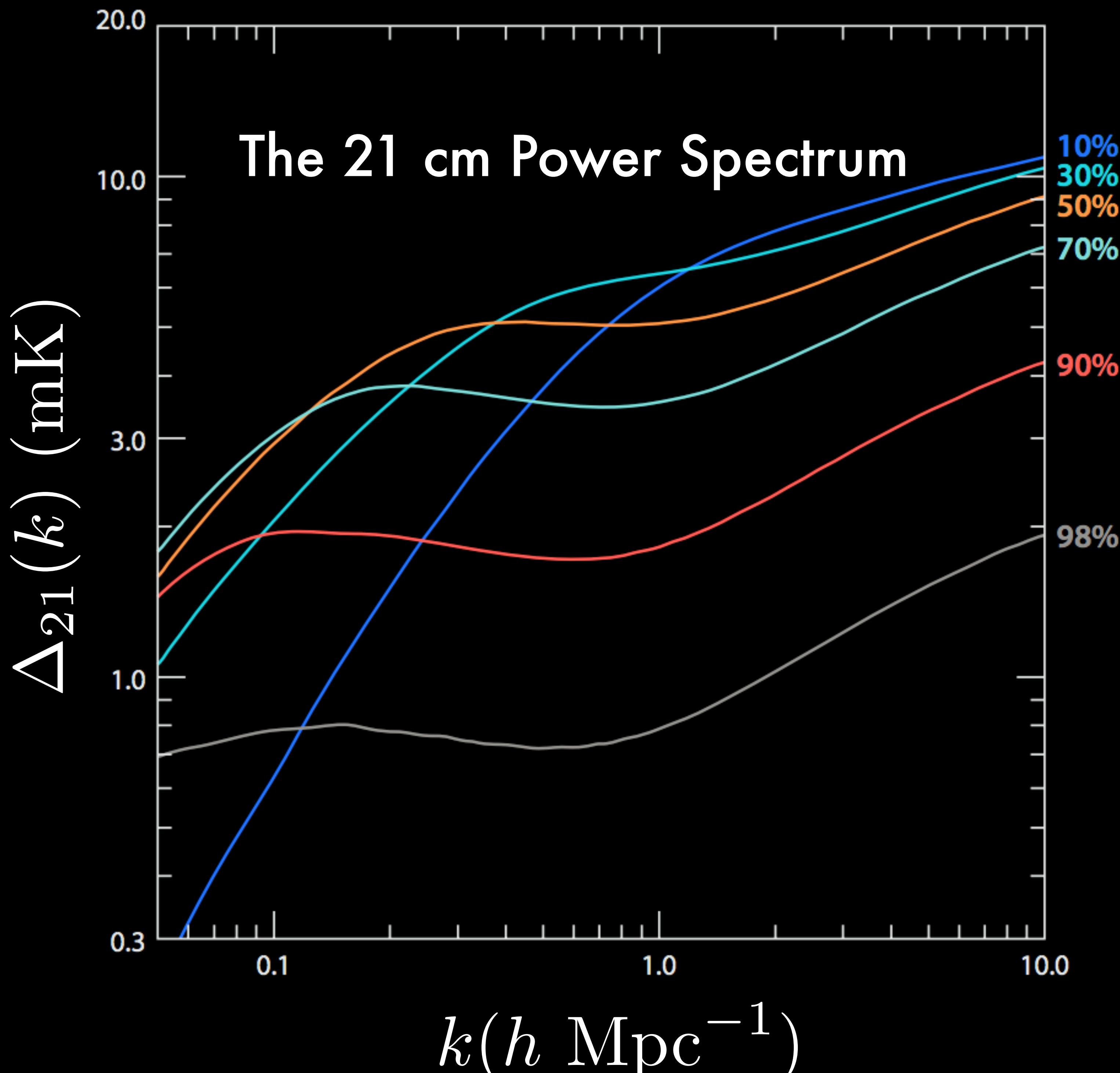

Intensity
21cm Signal
Frequency

Using their spectral smoothness.



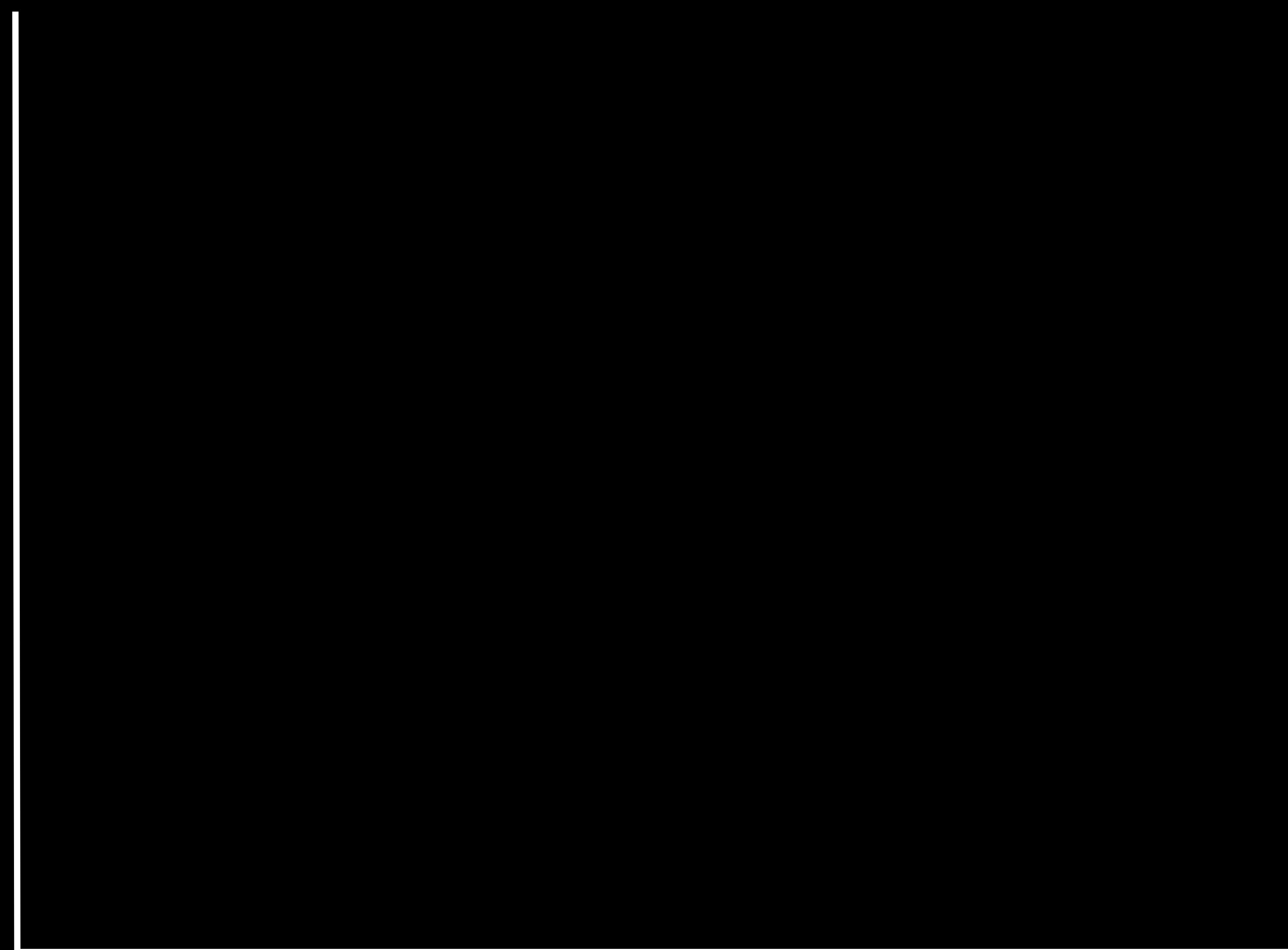


So instead of spherically averaged Fourier space...

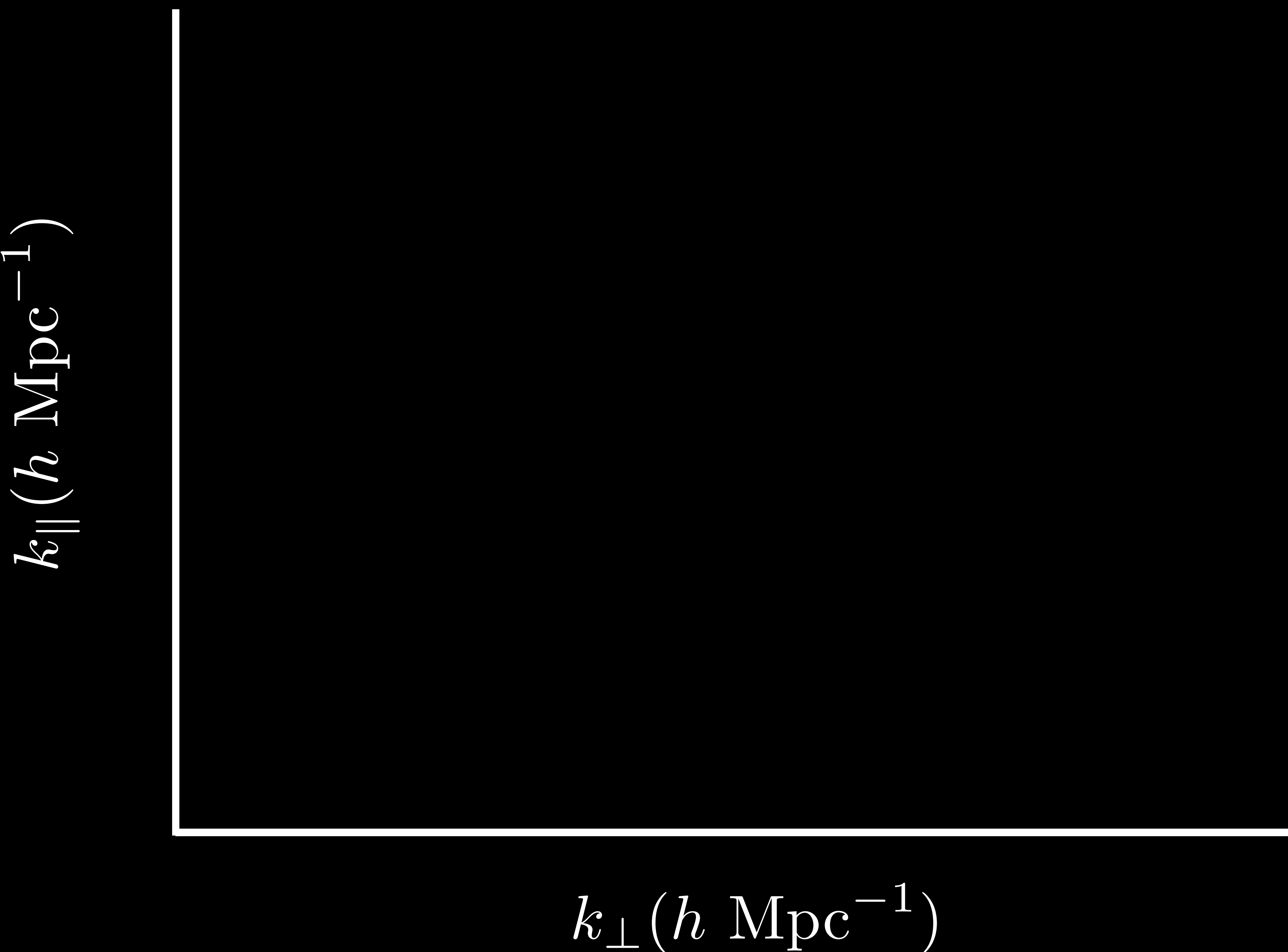


Barkana (2009), Morales & Wyithe (2010)

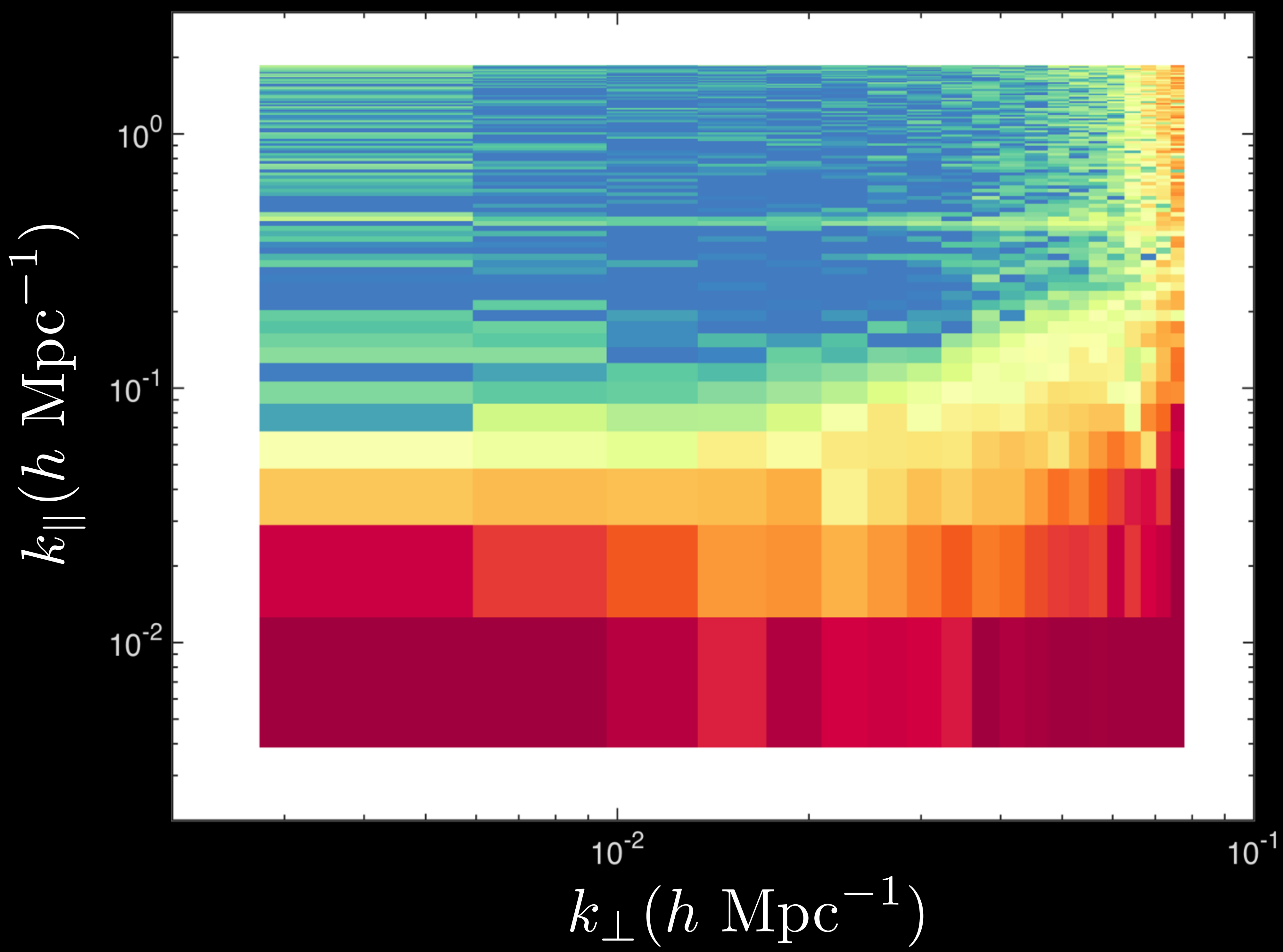
So instead of spherically averaged Fourier space…



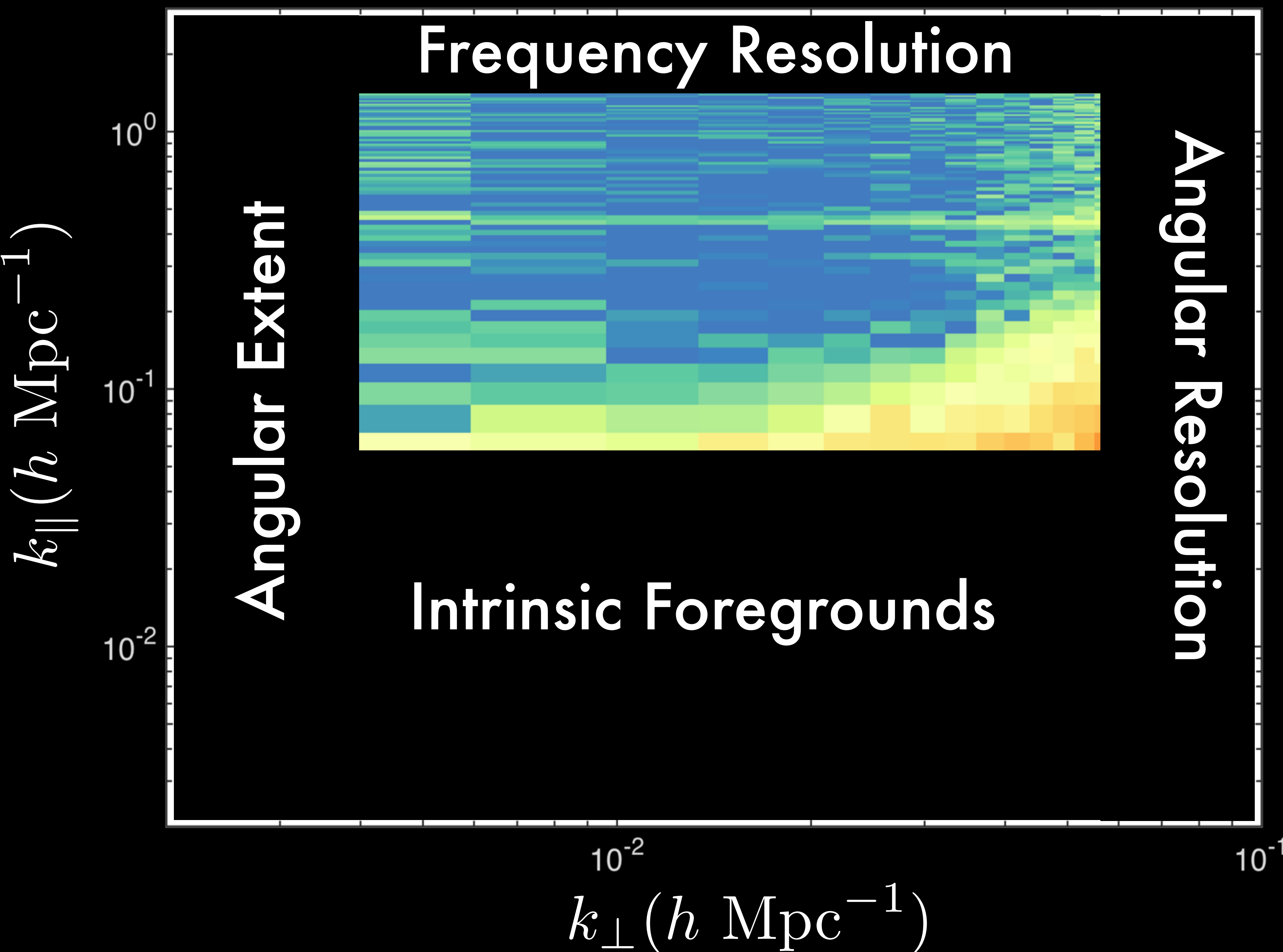
We separate out Fourier modes parallel and perpendicular to the line of sight.



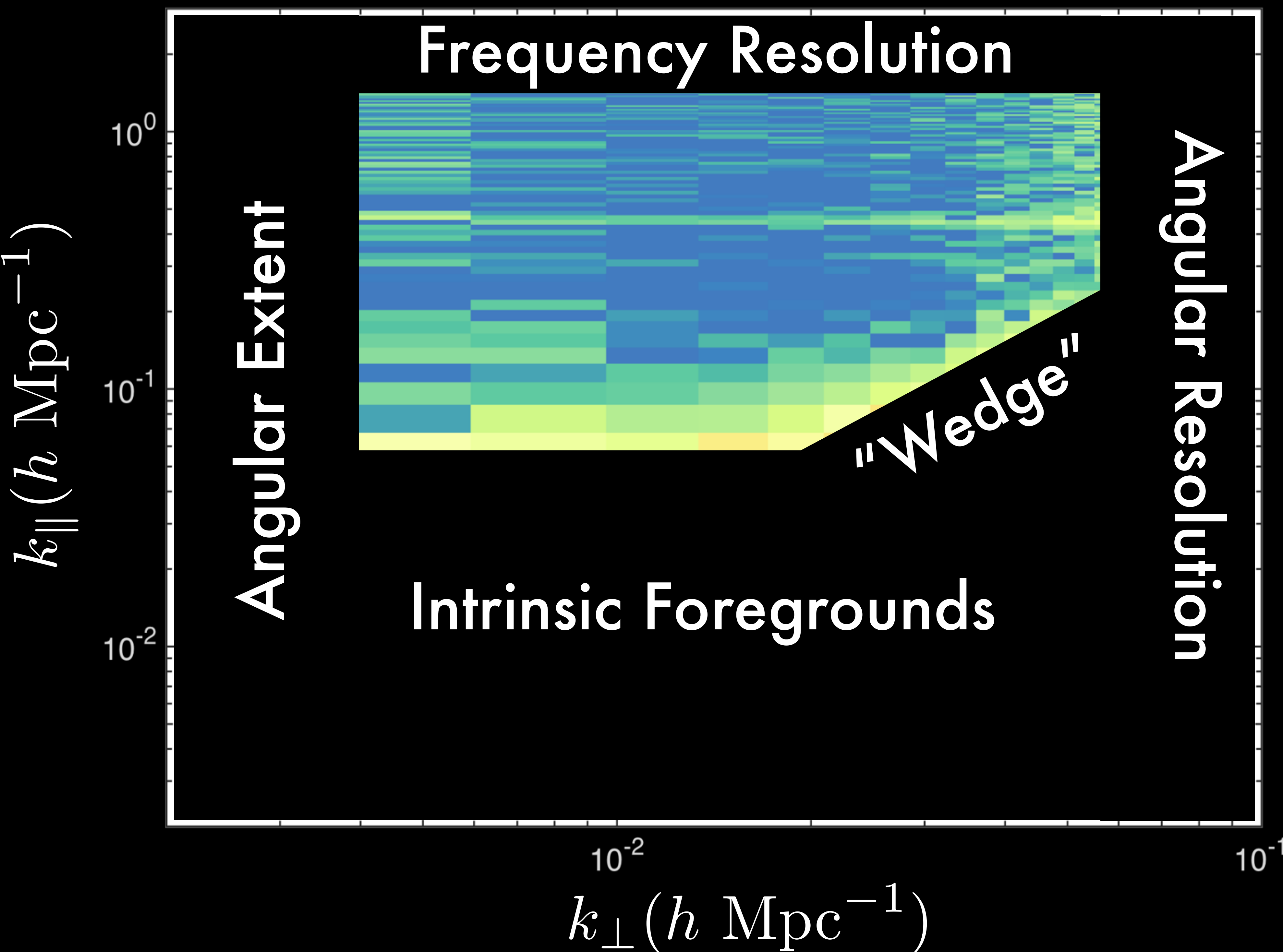
And we find an "EoR Window."



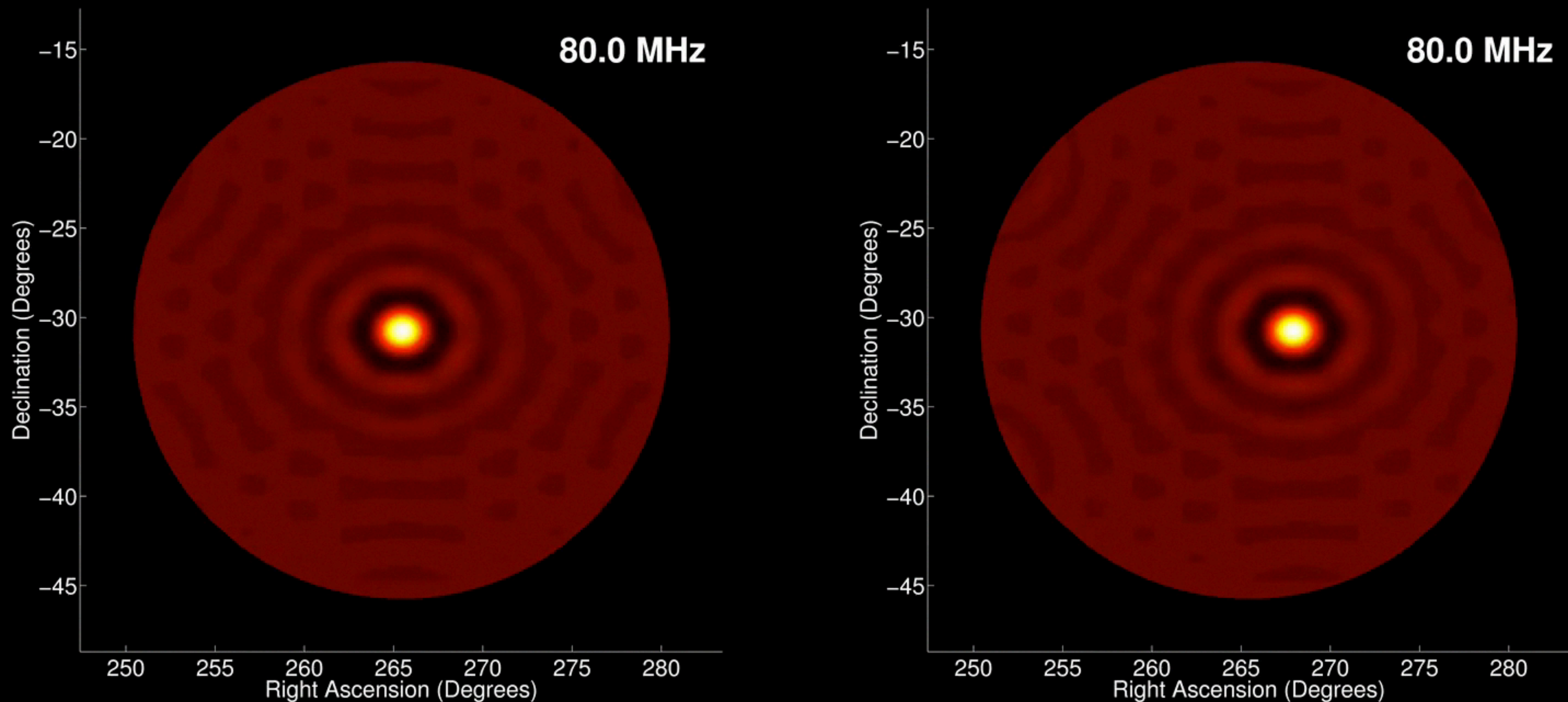
And we find an "EoR Window."



And we find an “EoR Window.”

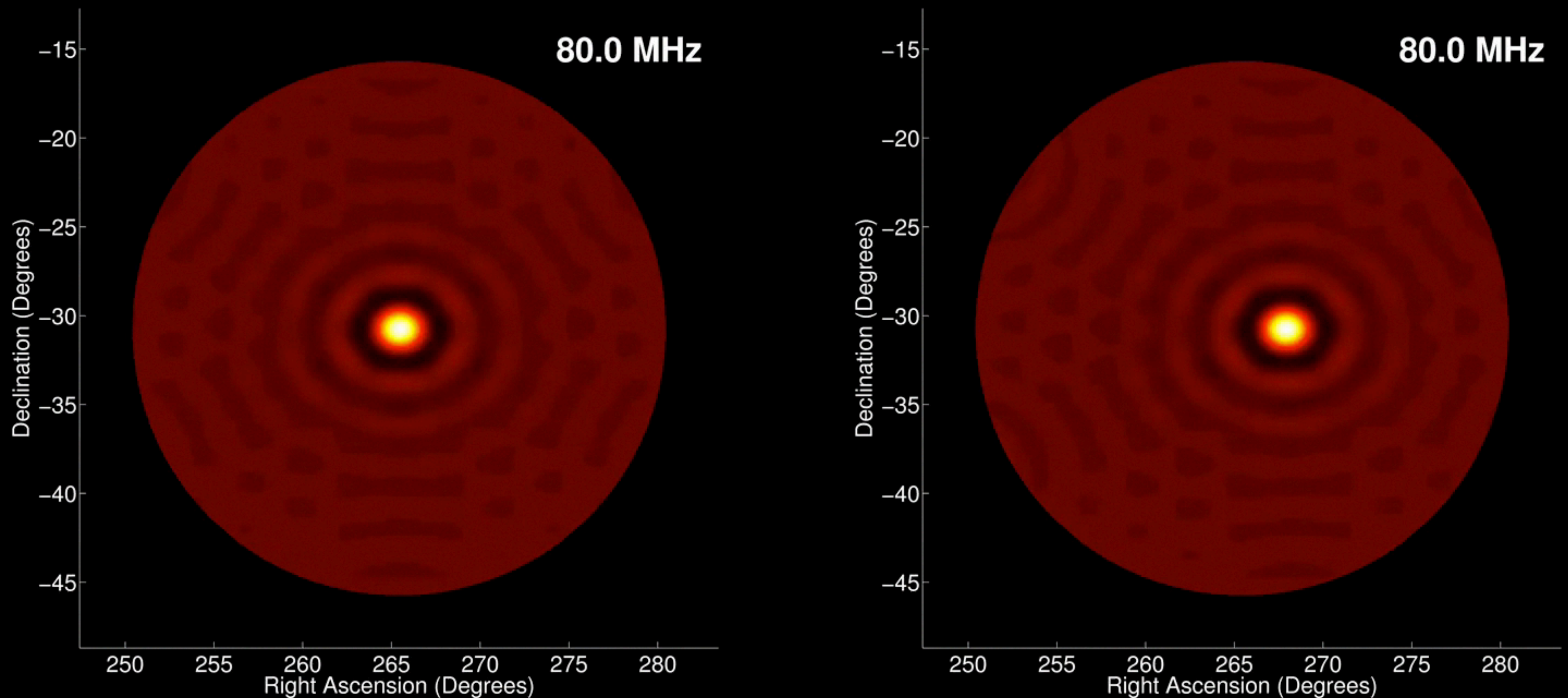


The "wedge" arises from the frequency-dependent point spread function creating spectral structure in spectrally smooth foregrounds.



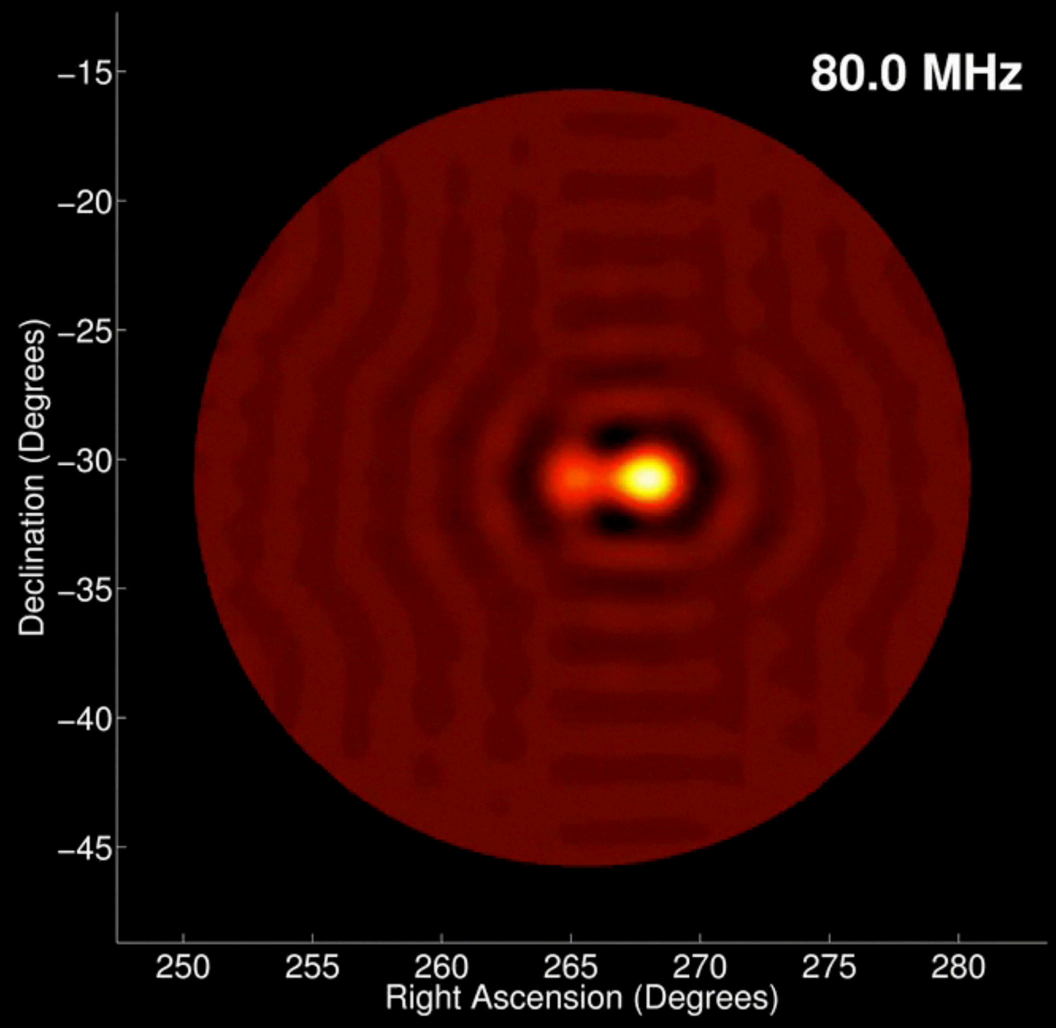
Dillon et al. (2015)

The "wedge" arises from the frequency-dependent point spread function creating spectral structure in spectrally smooth foregrounds.



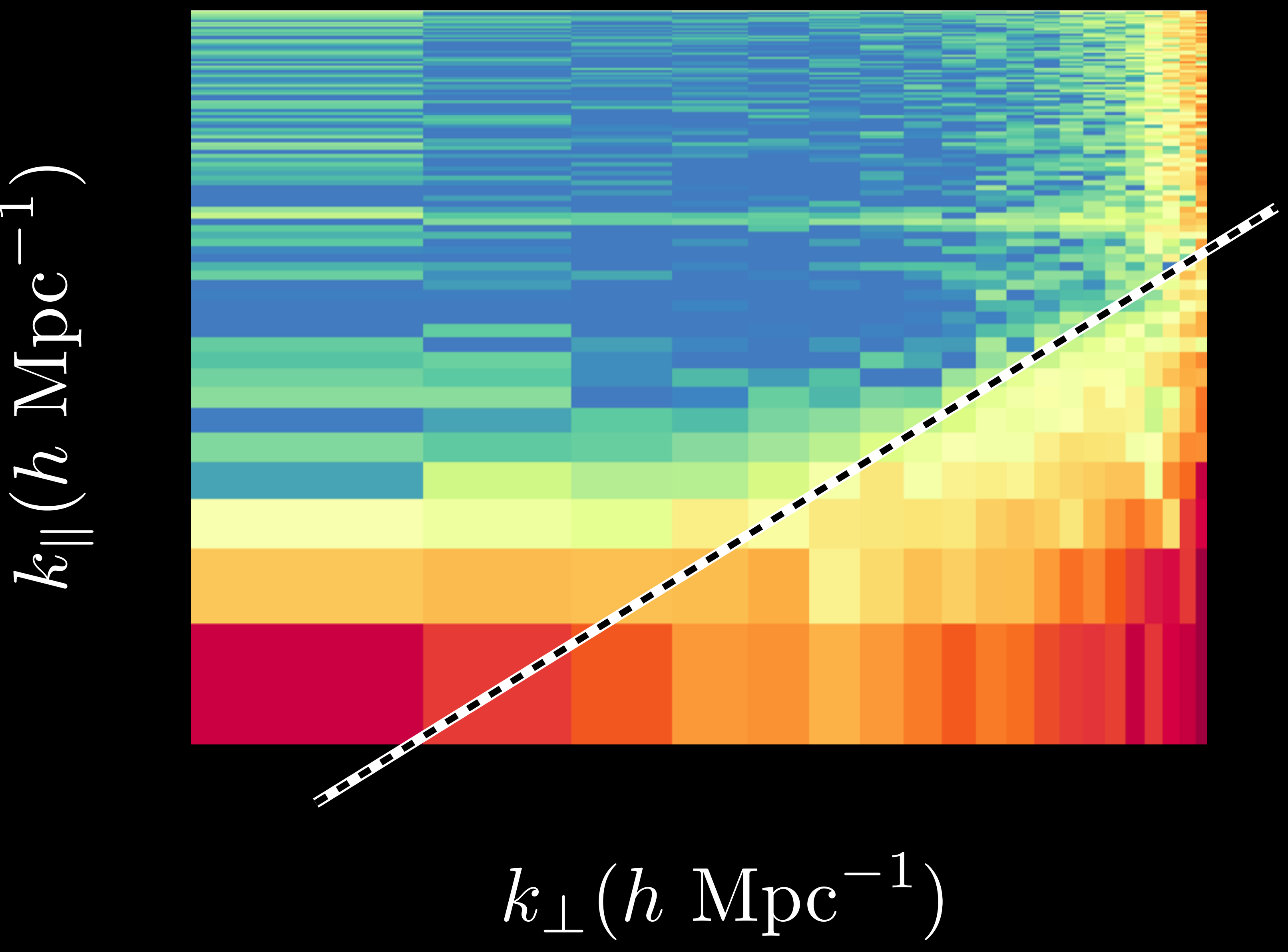
Dillon et al. (2015)

The "wedge" arises from the frequency-dependent point spread function creating spectral structure in spectrally smooth foregrounds.

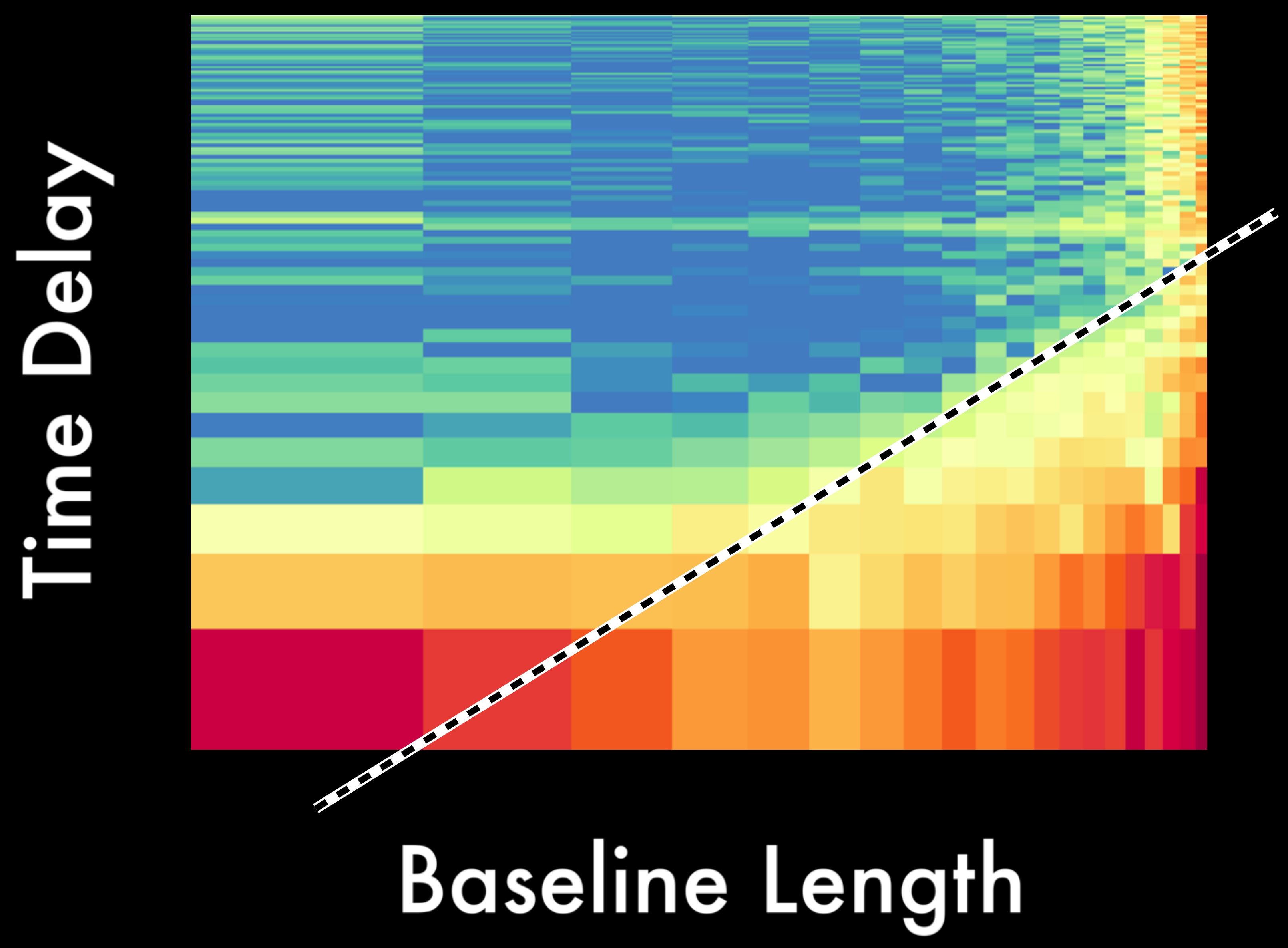


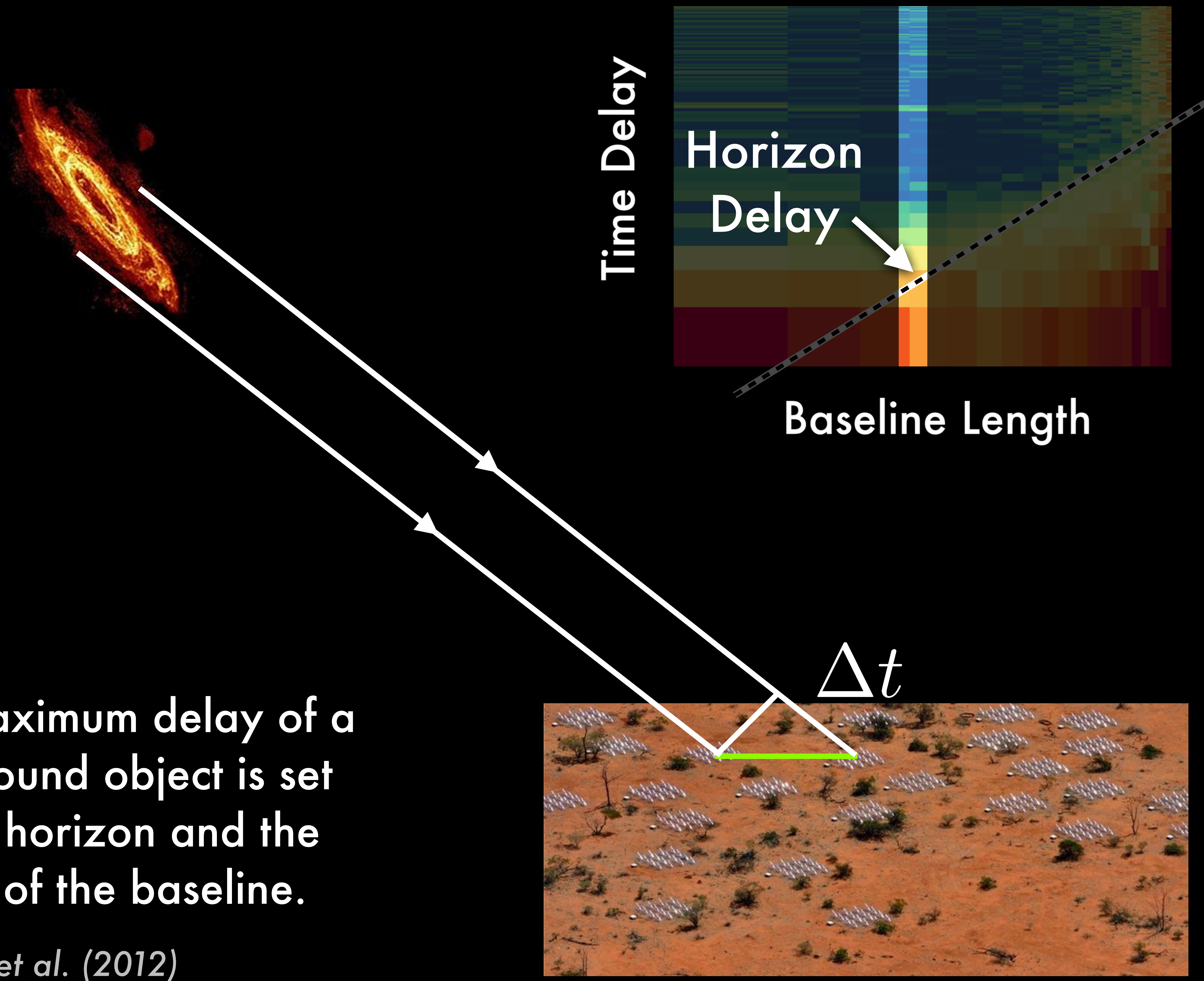
Dillon et al. (2015)

The wedge is limited by geometry.



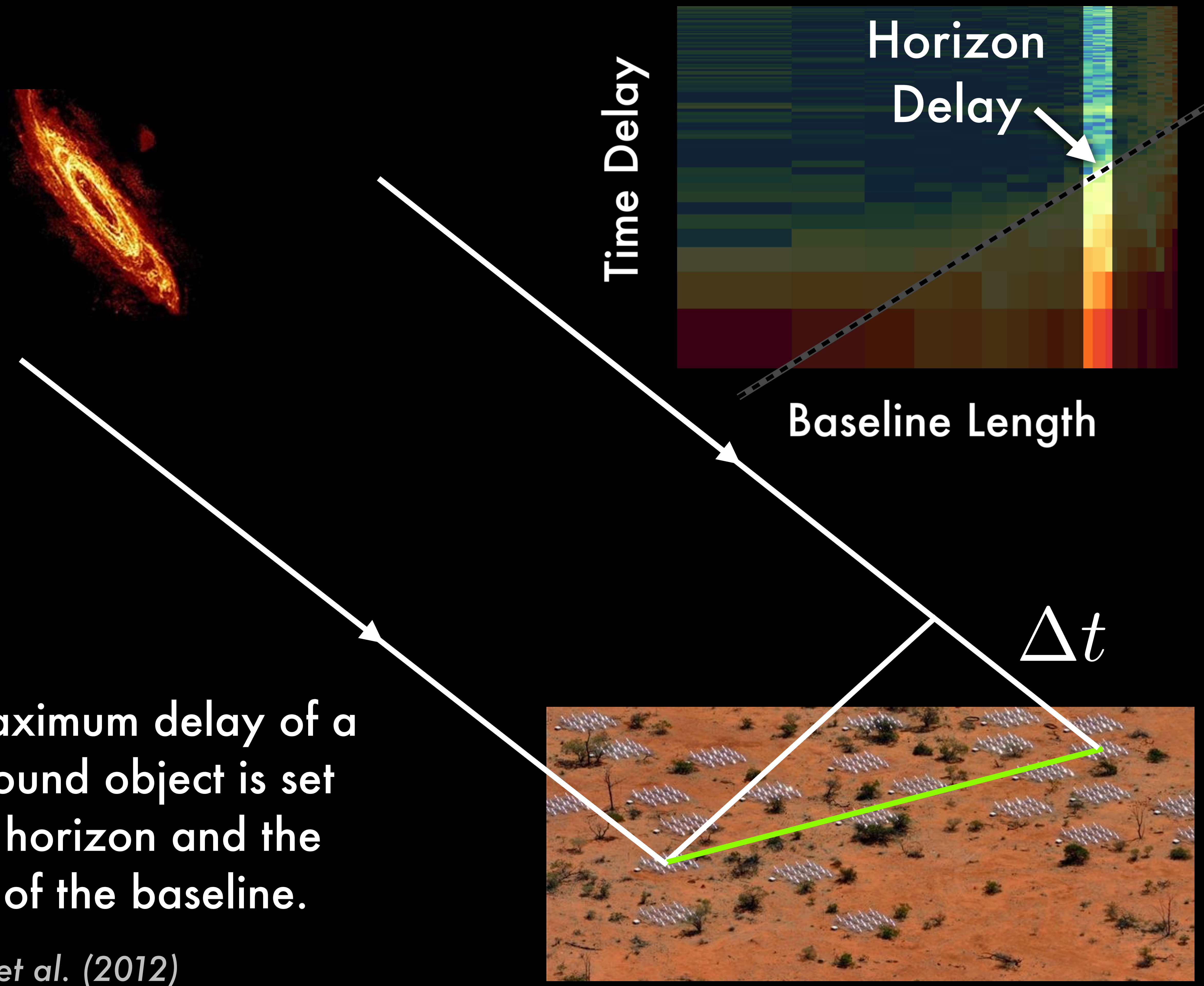
The wedge is limited by geometry.





The maximum delay of a foreground object is set by the horizon and the length of the baseline.

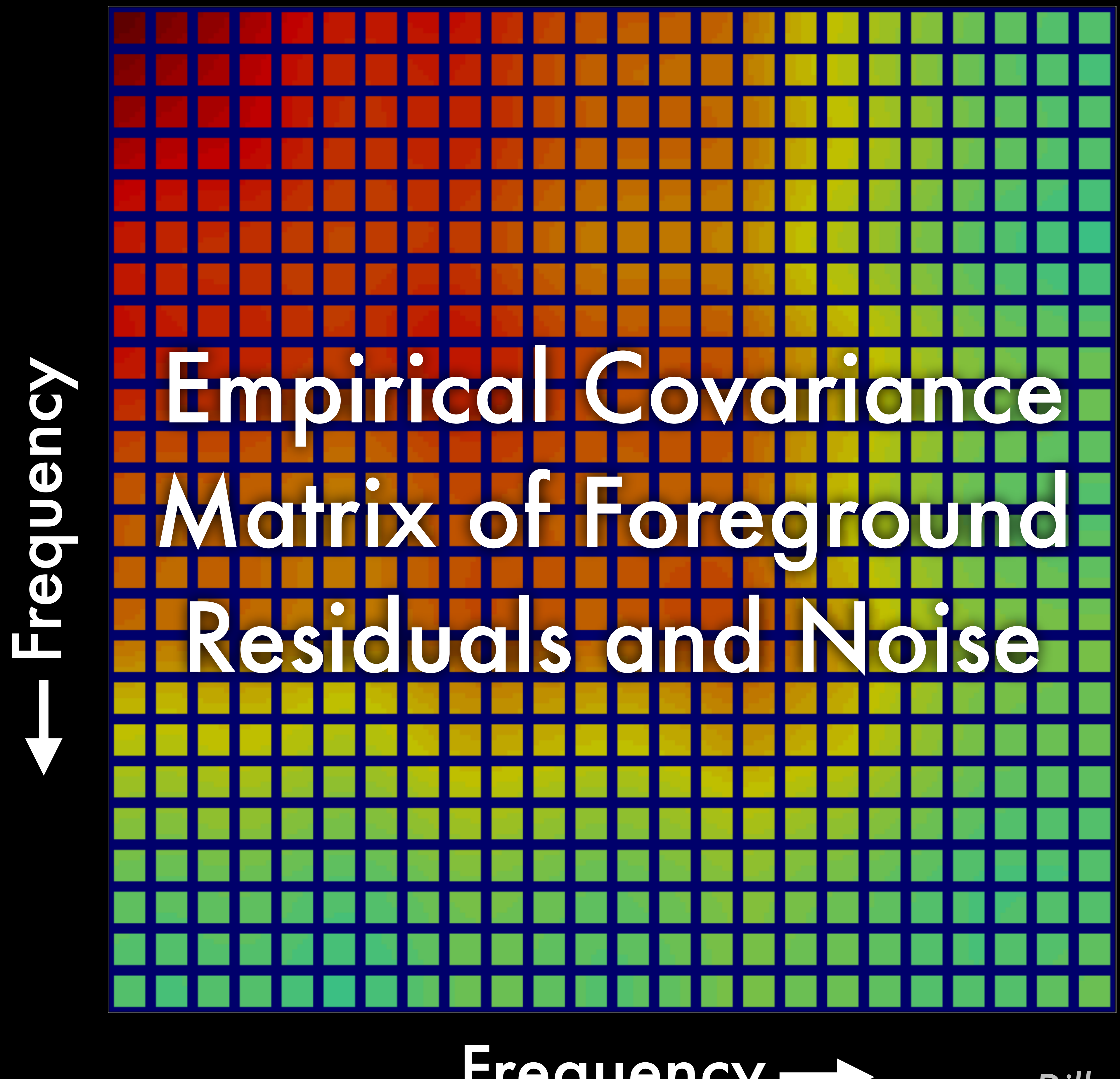
Parsons et al. (2012)



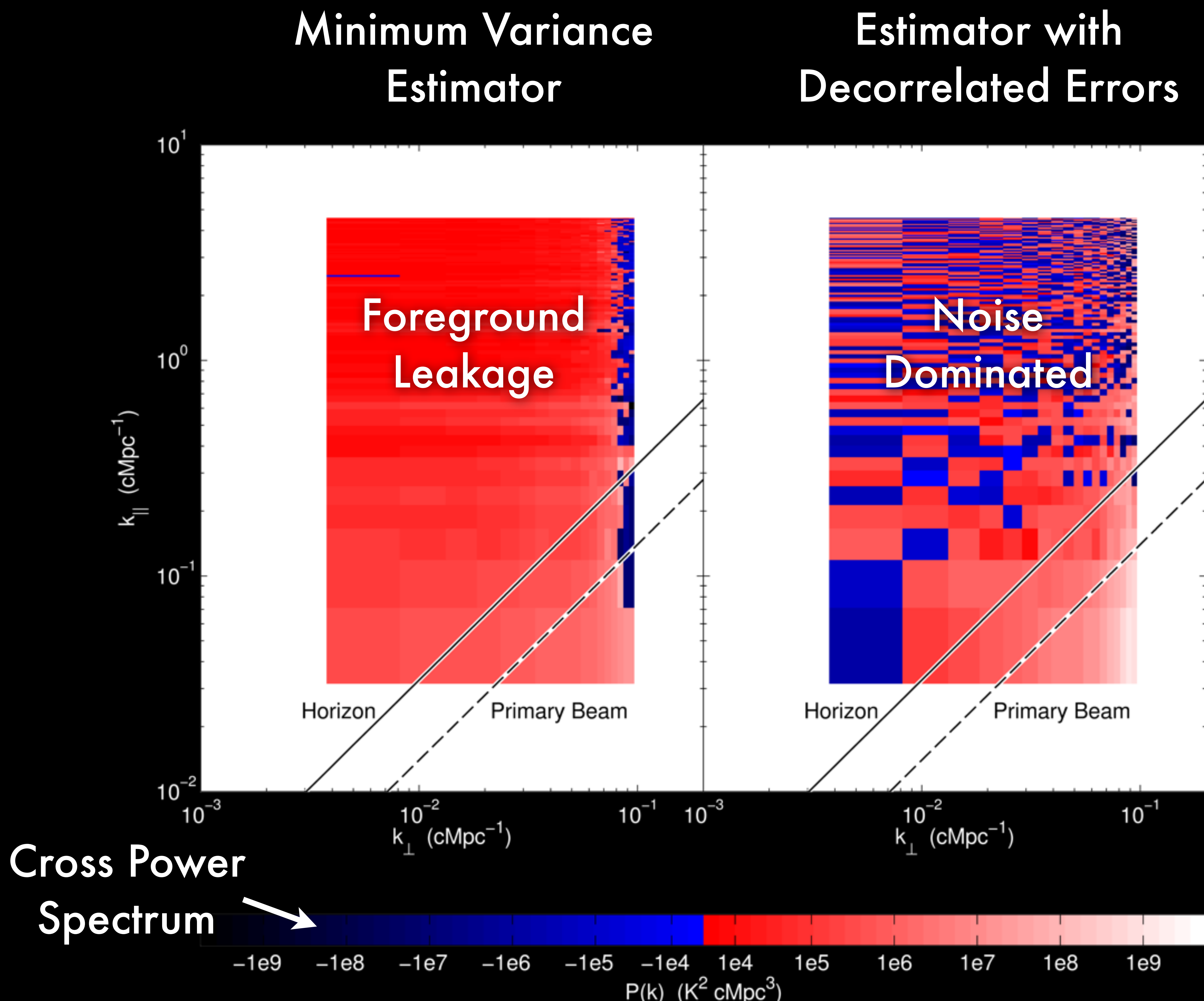
The maximum delay of a foreground object is set by the horizon and the length of the baseline.

Parsons et al. (2012)

Good estimators are essential to preserving the EoR window.

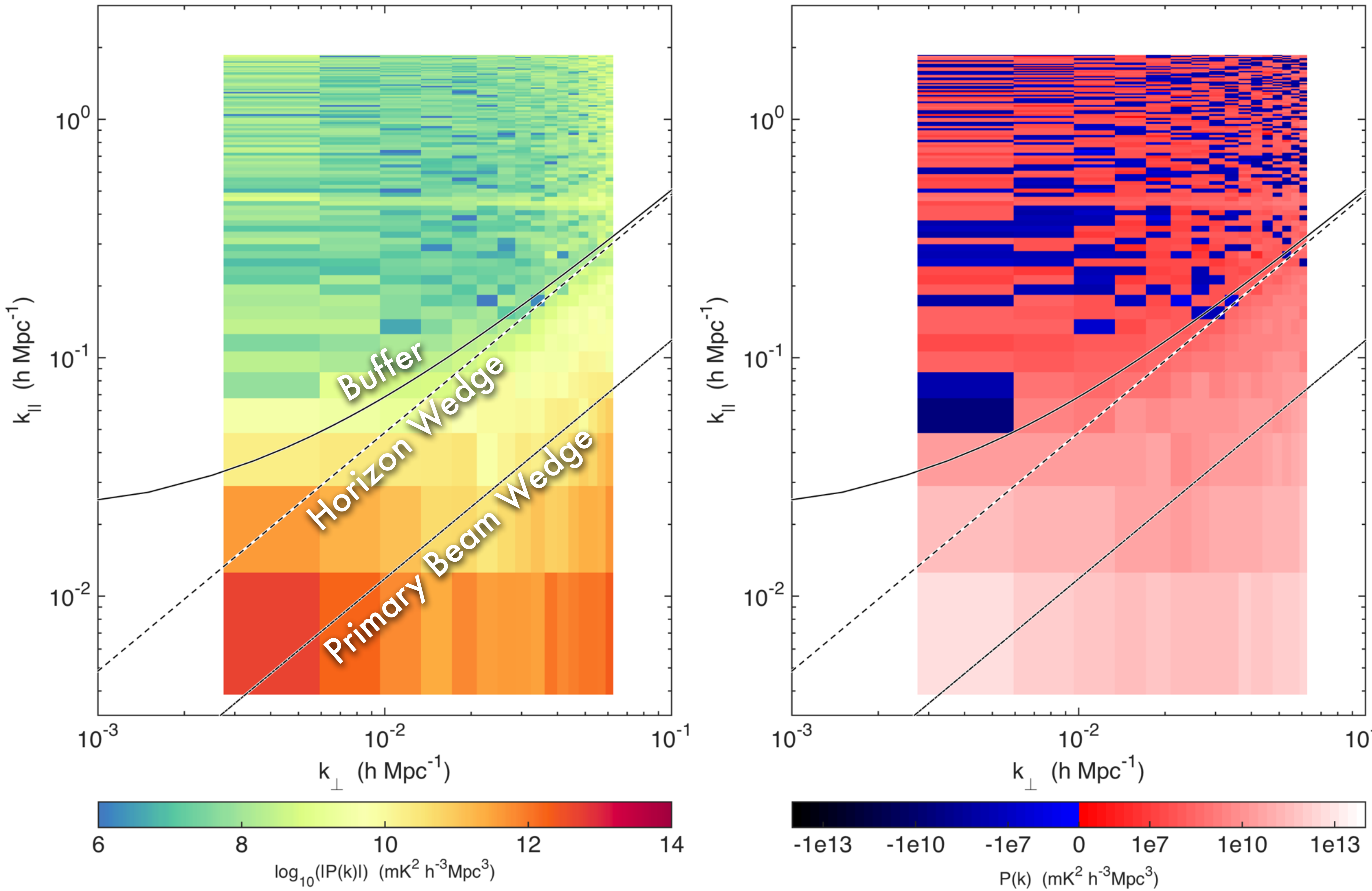


Dillon et al. (2015b)



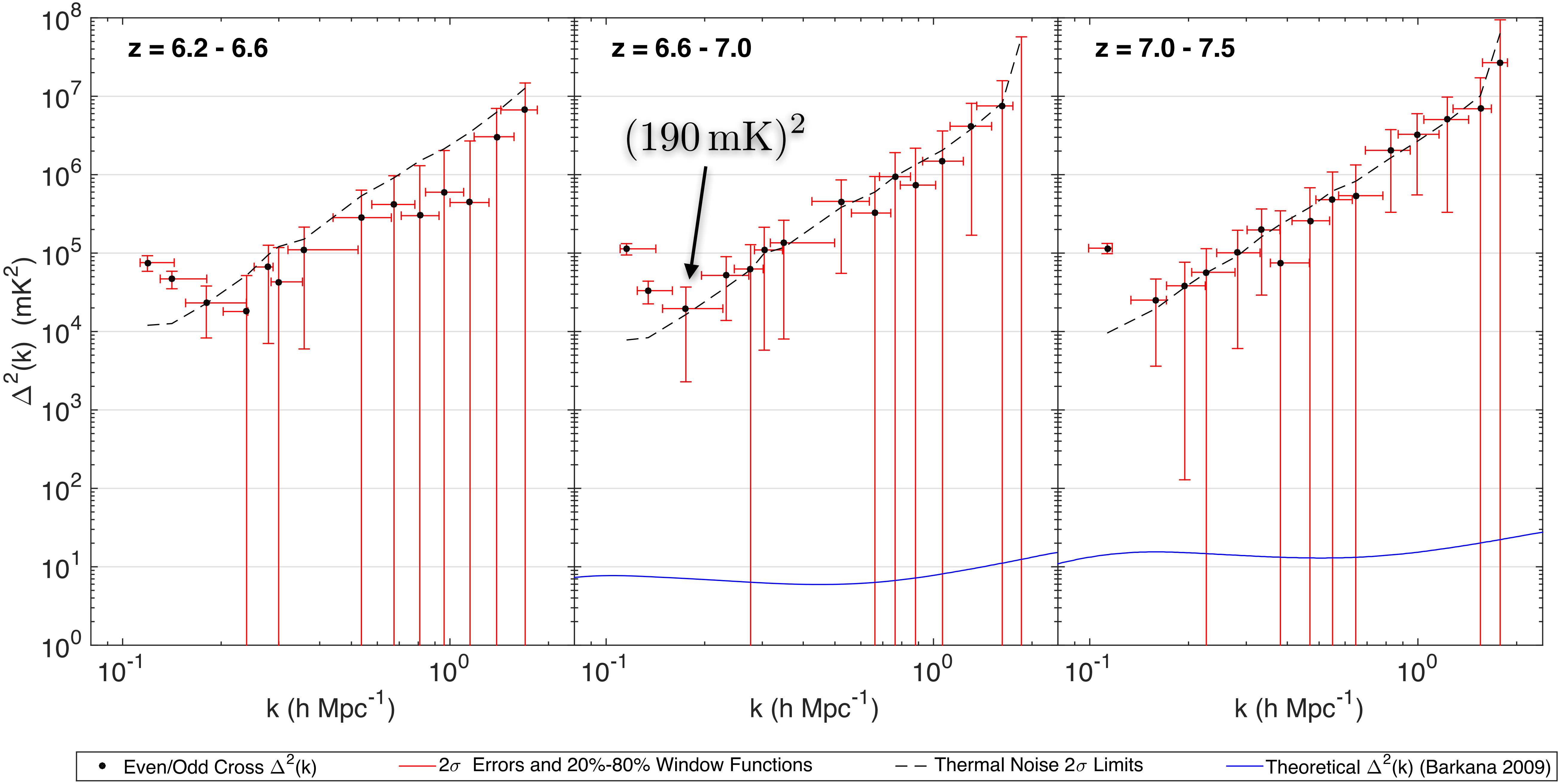
Dillon et al. (2014)

3 Hour MWA Observations at z ≈ 7



Dillon et al. (2015b)

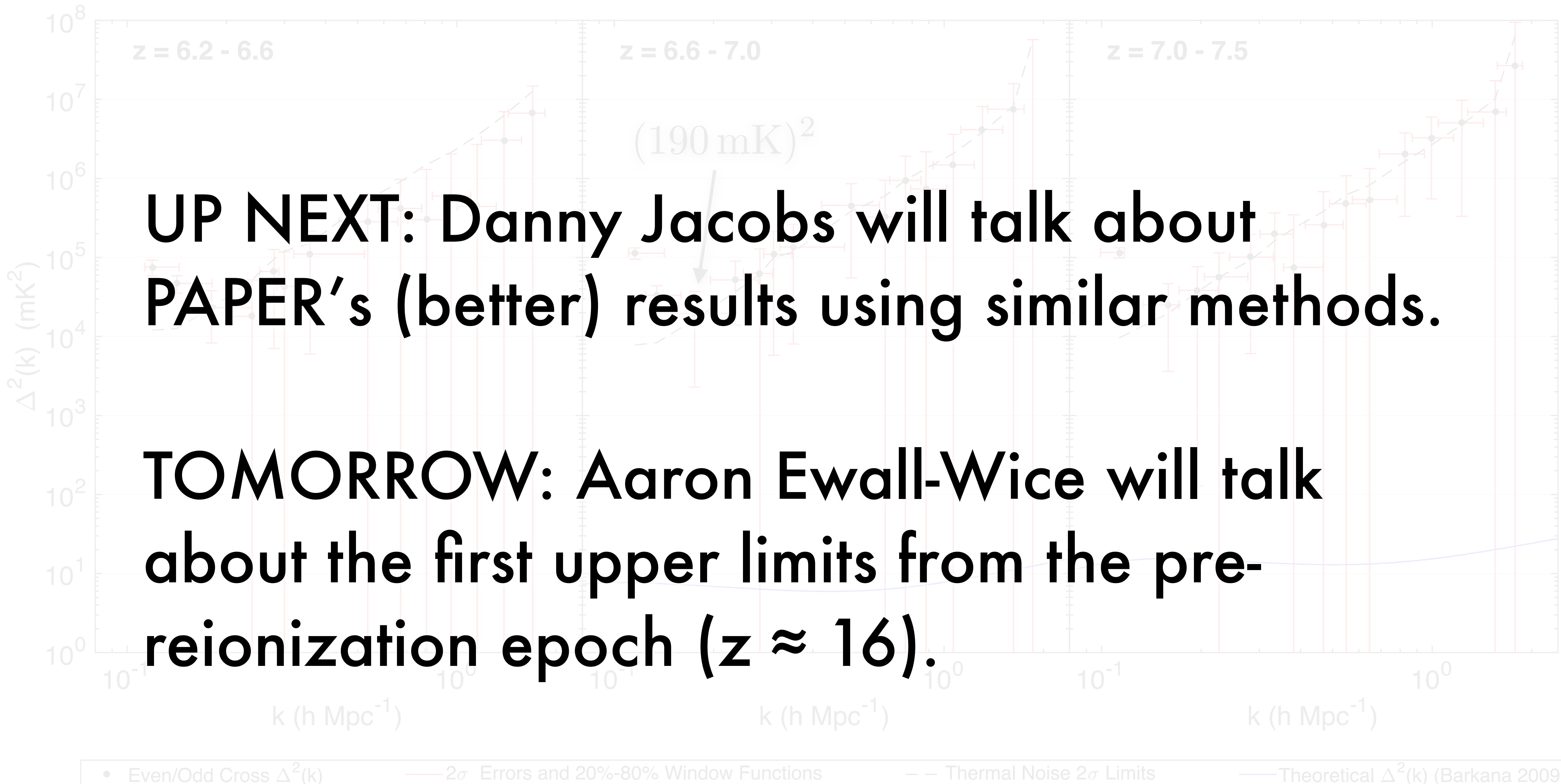
3 Hour MWA Observations at z ≈ 7



Deeper integrations are coming (look for Beardsley et al. and Neben et al. this year.)

Dillon et al. (2015b)

3 Hour MWA Observations at z ≈ 7



UP NEXT: Danny Jacobs will talk about PAPER's (better) results using similar methods.

TOMORROW: Aaron Ewall-Wice will talk about the first upper limits from the pre-reionization epoch (z ≈ 16).

Deeper integrations are coming (look for Beardsley et al. and Neben et al. this year.)

Dillon et al. (2015)

However, PAPER and the MWA can only achieve a marginal EoR detection, at best.

However, PAPER and the MWA can only achieve a marginal EoR detection, at best.

We need to think bigger.


HERA
The Hydrogen Epoch
of Reionization Array

CAL POLY POMONA

UNIVERSITY OF WASHINGTON

UNIVERSITY OF CALIFORNIA BERKELEY

ARIZONA STATE UNIVERSITY

UNIVERSITY OF KWAZULU-NATAL

SKA AFRICA
SQUARE KILOMETRE ARRAY

HARVARD

UCLA

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

UNIVERSITY of the WESTERN CAPE

NRAO

SCUOLA NORMALE SUPERIORE

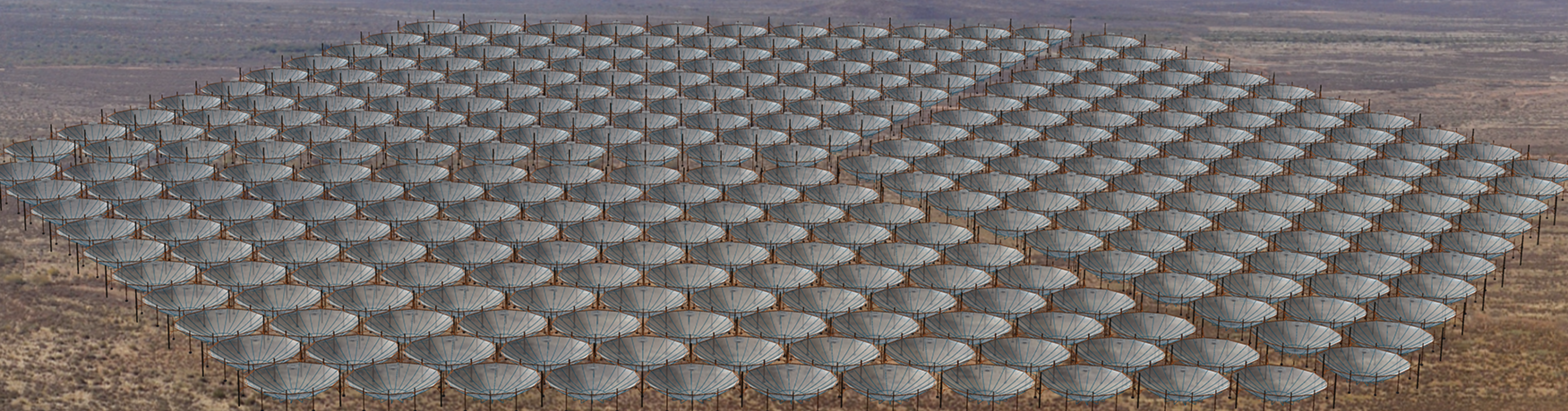
UNIVERSITY OF CAMBRIDGE

HERA

Penn
UNIVERSITY of PENNSYLVANIA

BROWN

The Hydrogen Epoch of Reionization Array



HERA will have:

- 350 stationary dishes that vastly increase sensitivity, enabling high significance detections.


The first 19 HERA elements in South Africa are now taking data.
14 m diameter dishes

We'll have the collecting area to confidently detect the EoR.

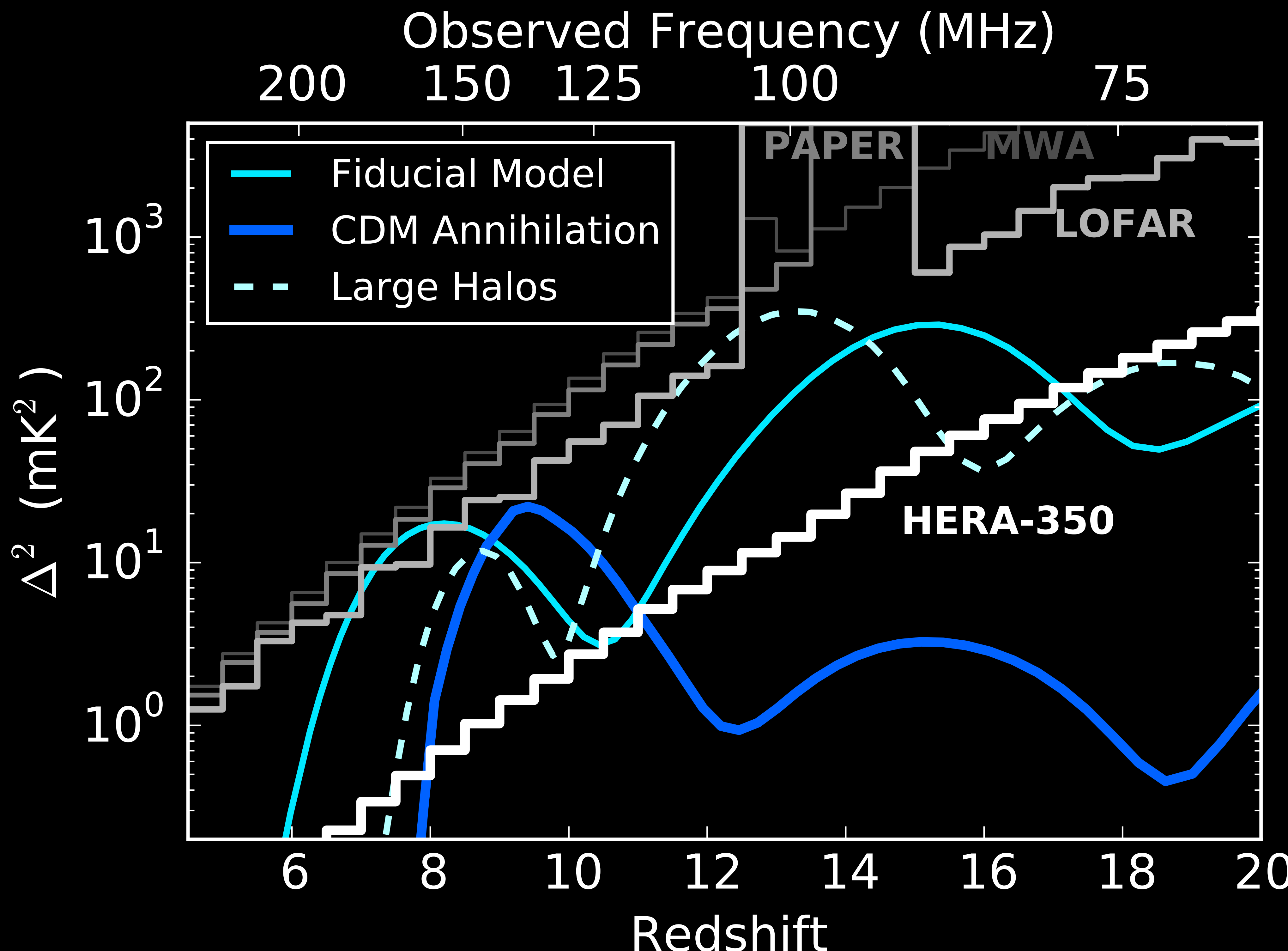
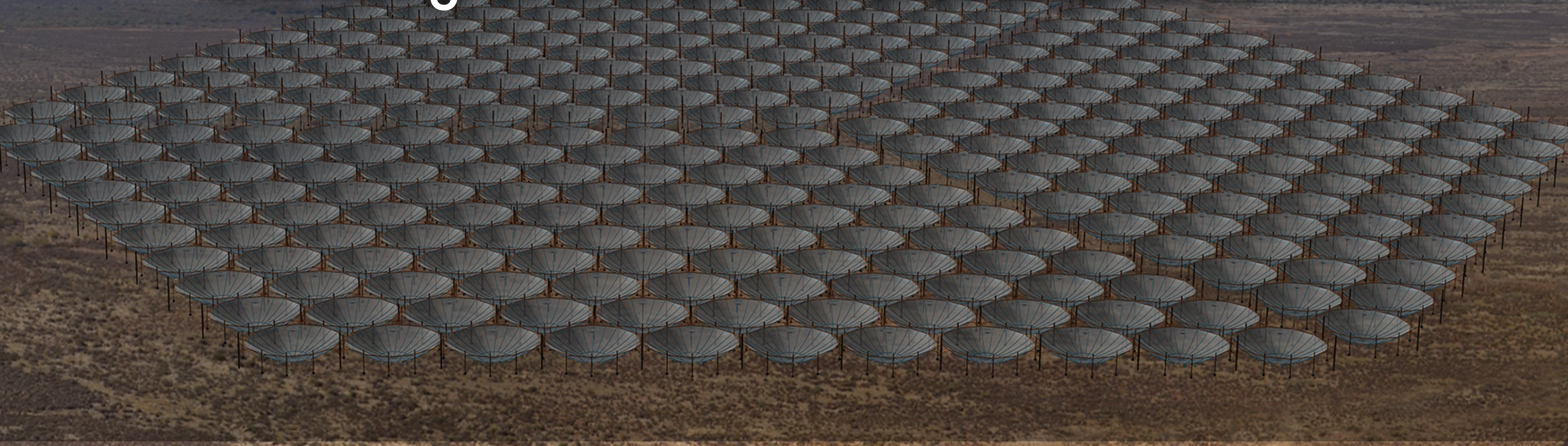


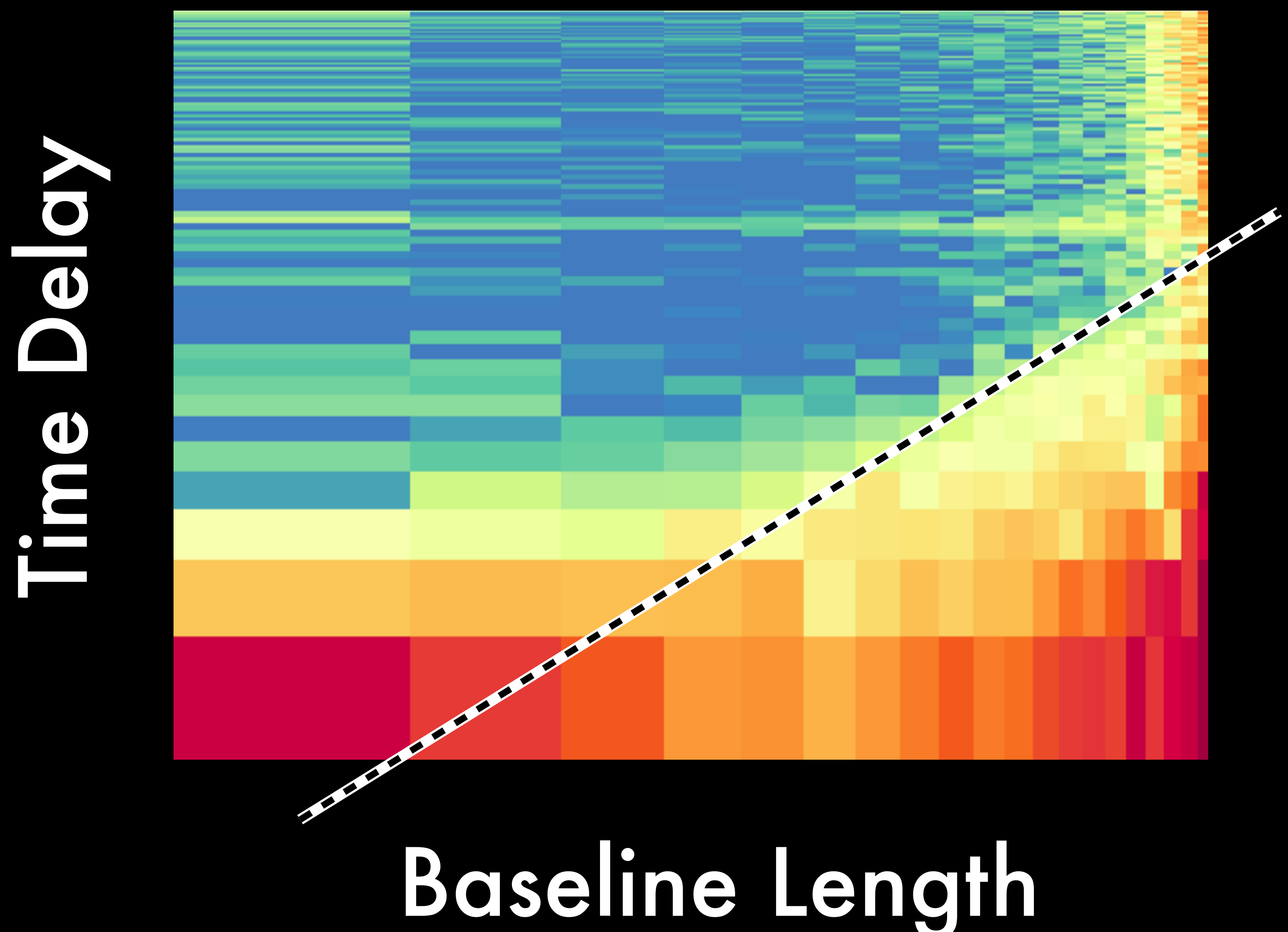
Figure: Aaron Ewall-Wice

HERA will have:

- 350 stationary dishes that vastly increase sensitivity, enabling high significance detections.
- Compact design with high sensitivity to short, less foreground-contaminated baselines.



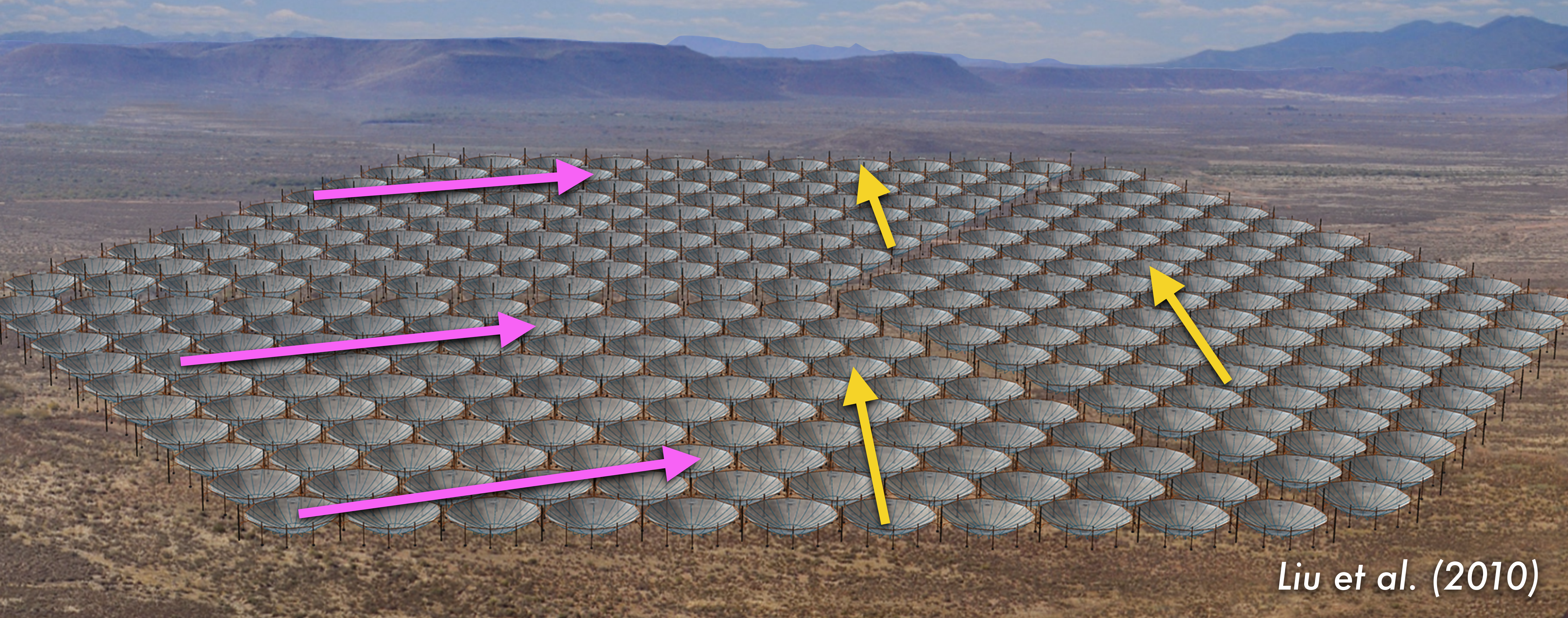
Recall, shorter baselines have “less wedge” in them.



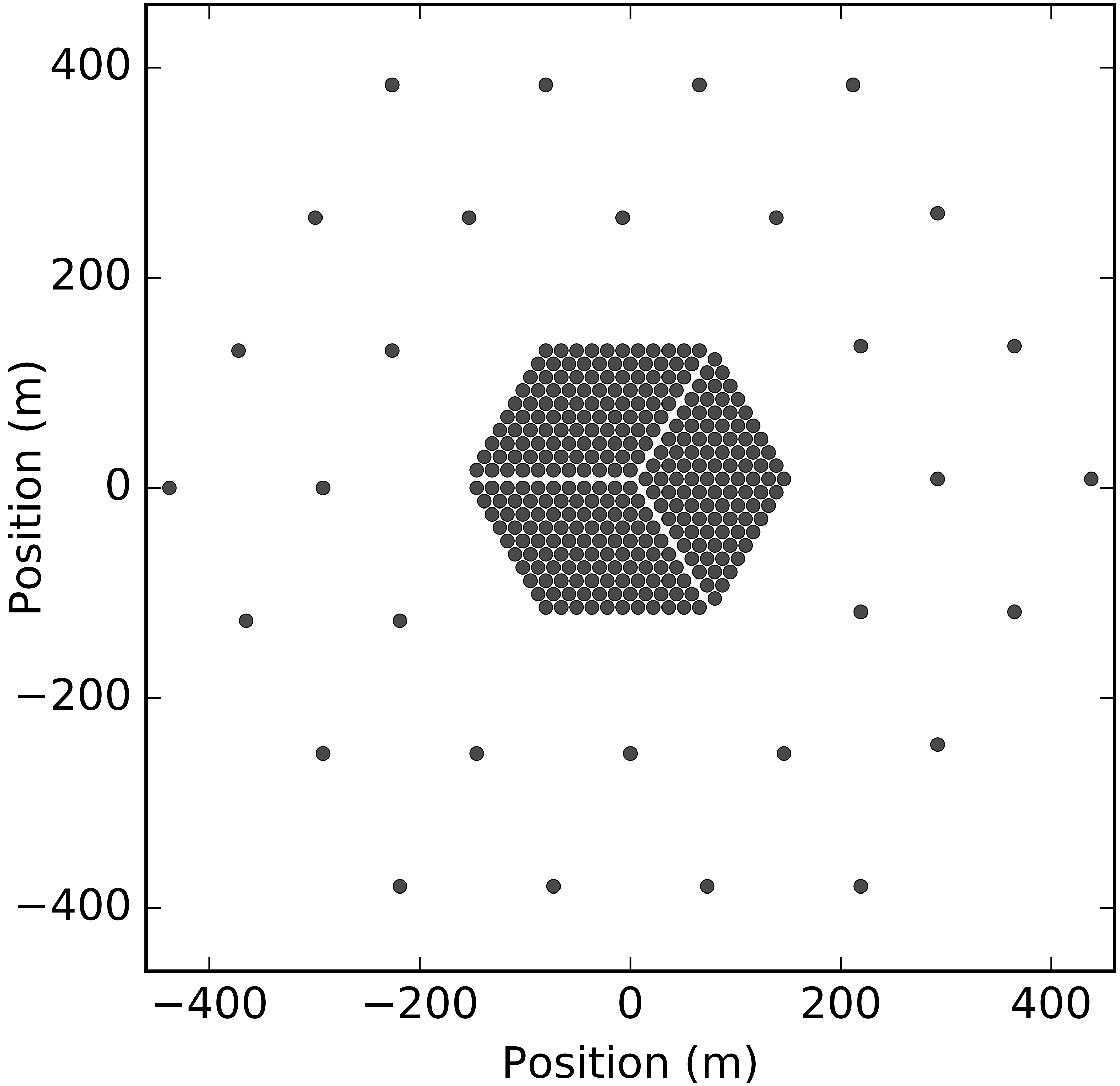
HERA will have:

- 350 stationary dishes that vastly increase sensitivity, enabling high significance detections.
- Compact design with high sensitivity to short, less foreground-contaminated baselines.
- A configuration that enables both precise redundant calibration and widefield imaging.

Redundant baselines enable precision calibration without a good sky model.

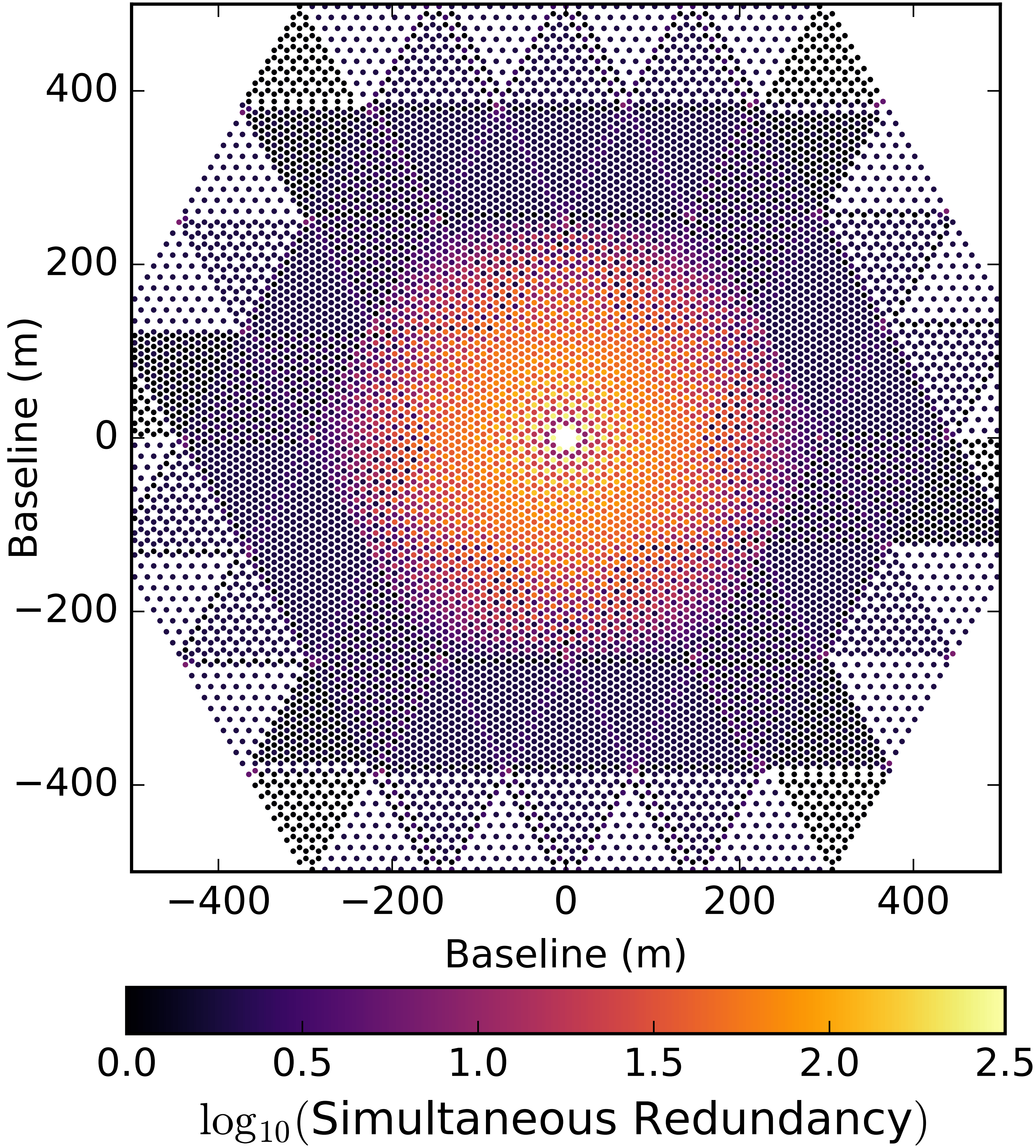


Liu et al. (2010)

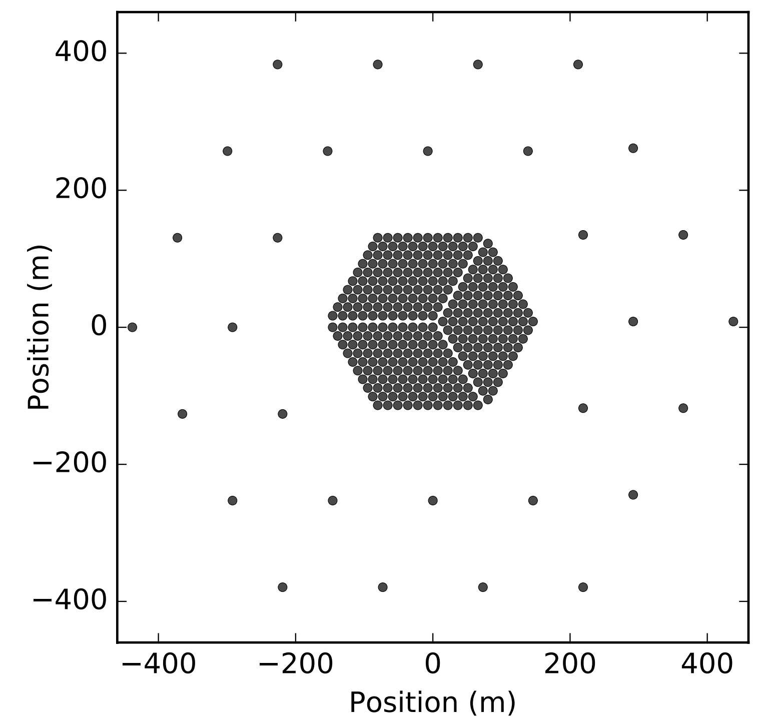


HERA's split configuration enables

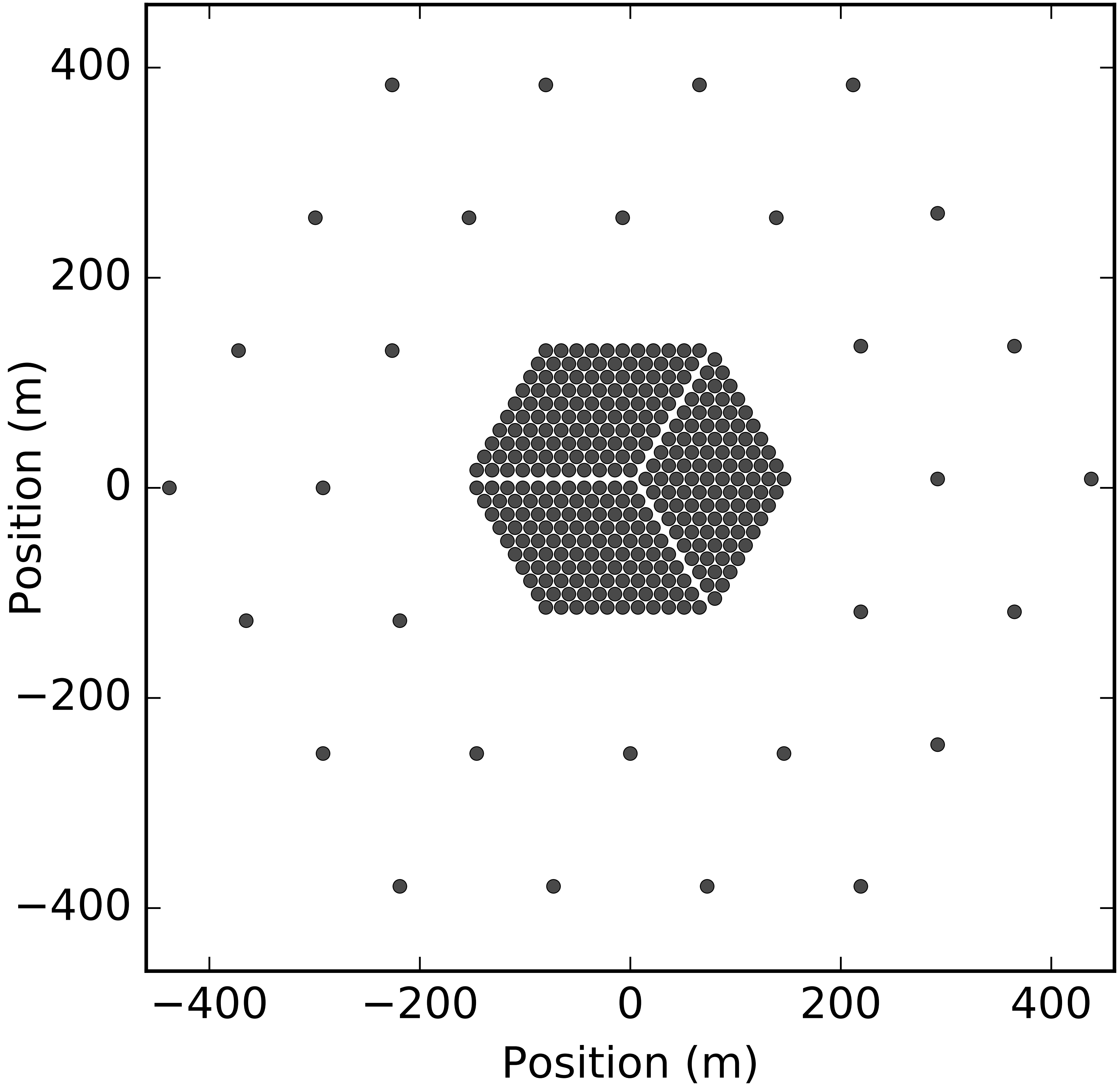
Dillon & Parsons (2016)



HERA's split configuration enables both good widefield imaging

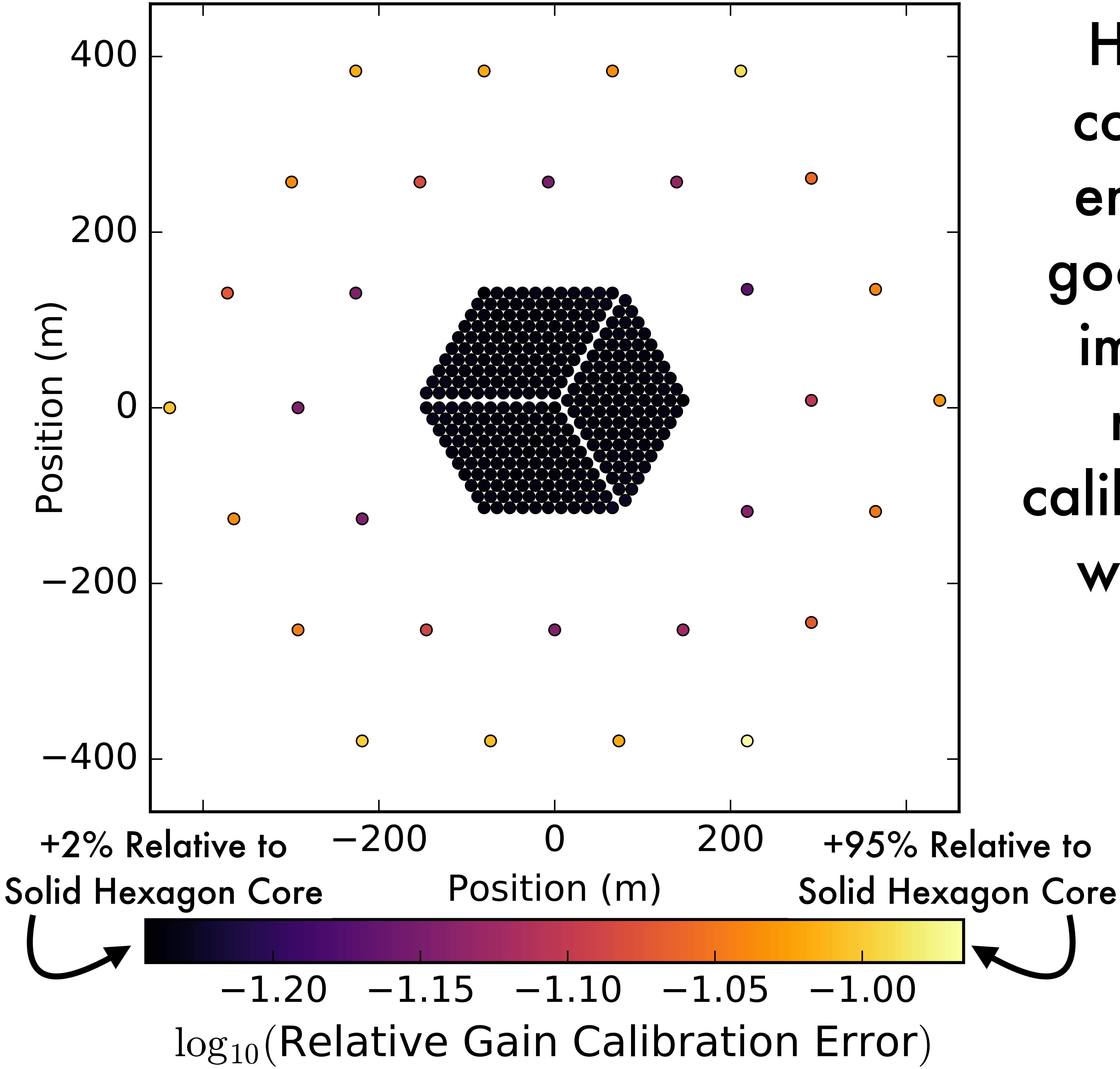


Dillon & Parsons (2016)



HERA's split configuration enables both good widefield imaging and redundant calibration of the whole array.

Dillon & Parsons (2016)



HERA's split configuration enables both good widefield imaging and redundant calibration of the whole array.

Dillon & Parsons (2016)

Coming up…

- NEXT: Danny Jacobs on PAPER power spectrum limits and HERA instrumental progress
- LATER TODAY: Nithya Thyagarajan on instrument and foreground simulations for HERA
- LATER TODAY: Adrian Liu on HERA constraint forecasts for reionization astrophysics, tau, and cosmology
- TOMORROW: Aaron Ewall-Wice on MWA limits on and HERA forecasts for the pre-reionization epoch

Photo Credit: Carina Cheng