



Validating Spectral Smoothness in 21cm Radio Experiments

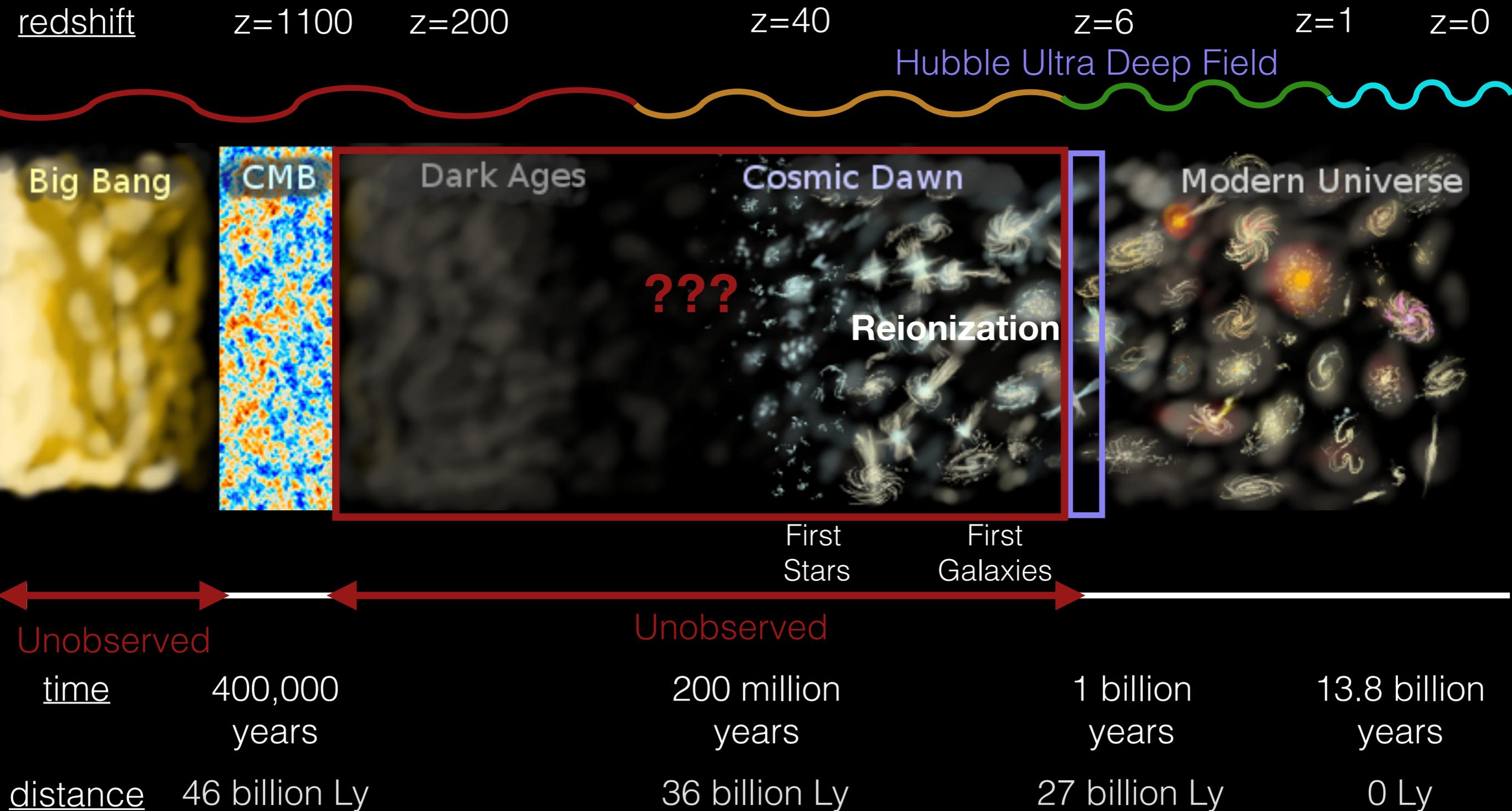
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NPP Fellow,
Jet Propulsion Laboratory, California Institute of Technology.



We are using 21 cm to fill in our cosmic timeline.

$$\lambda_{\text{observed}} = \lambda_{\text{emitted}}(1+z)$$



21cm Tomography

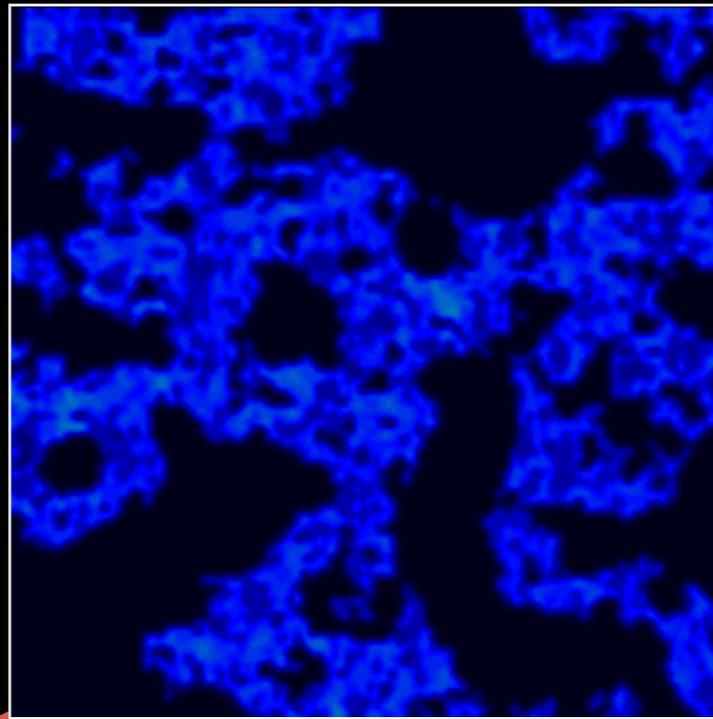
Lets us Observe the Impact of the first
Galaxies on Intergalactic Gas

$\lambda = 21\text{cm}$
 $f = 1420\text{ MHz}$



21cm Tomography

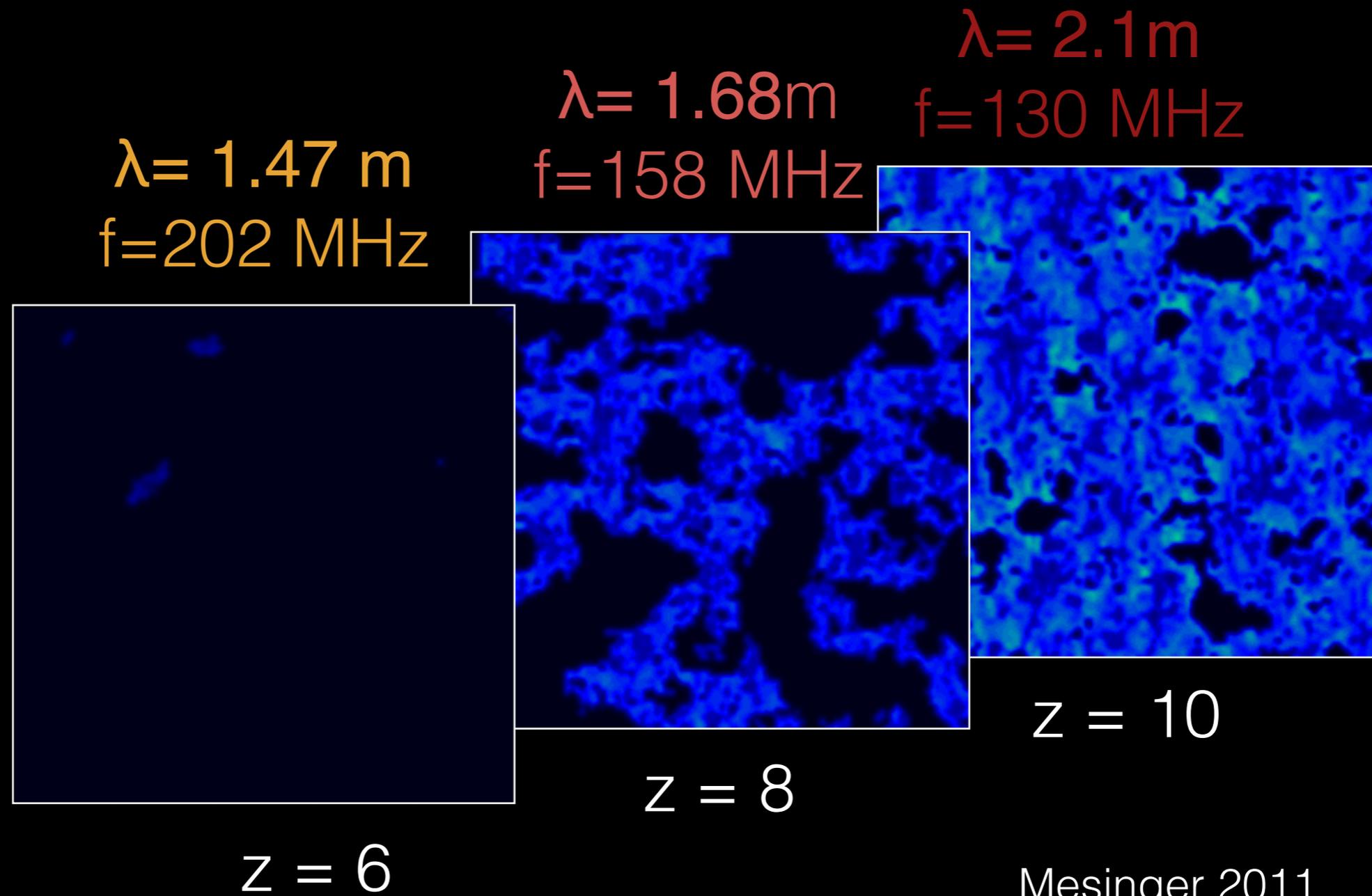
$\lambda = 1.68\text{m}$
 $f = 158\text{ MHz}$



$z = 8$

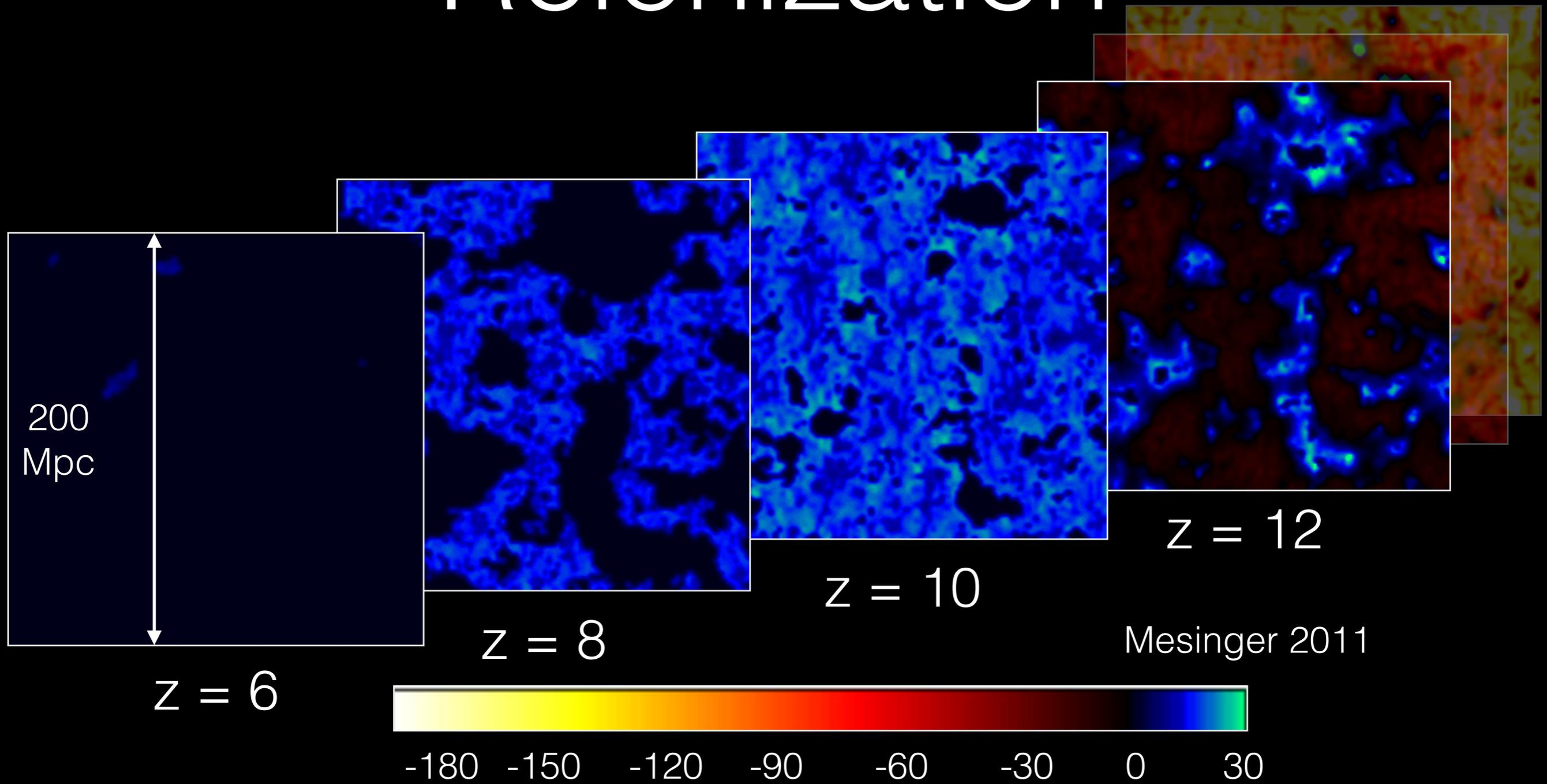
Mesinger 2011

21cm Tomography

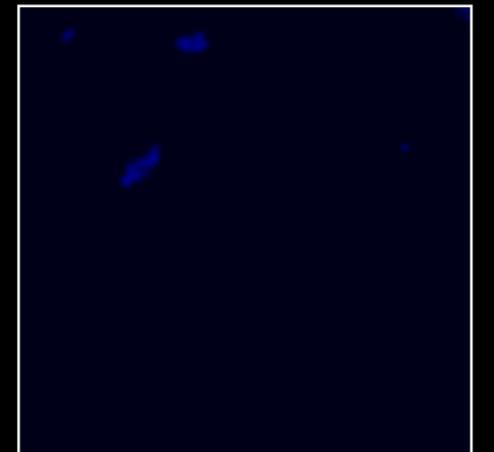
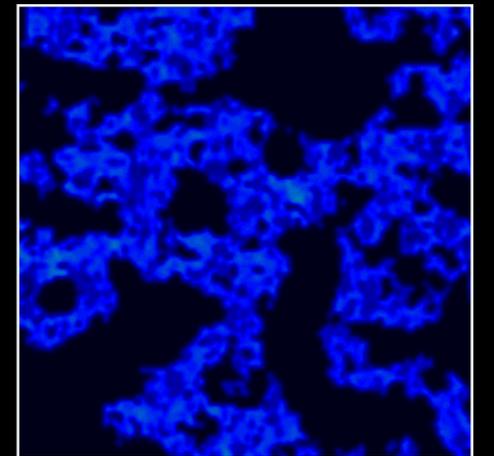
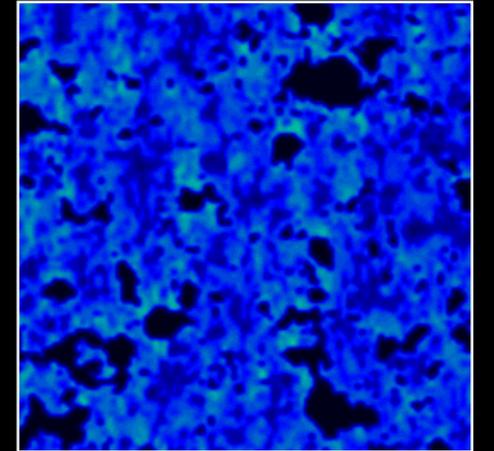
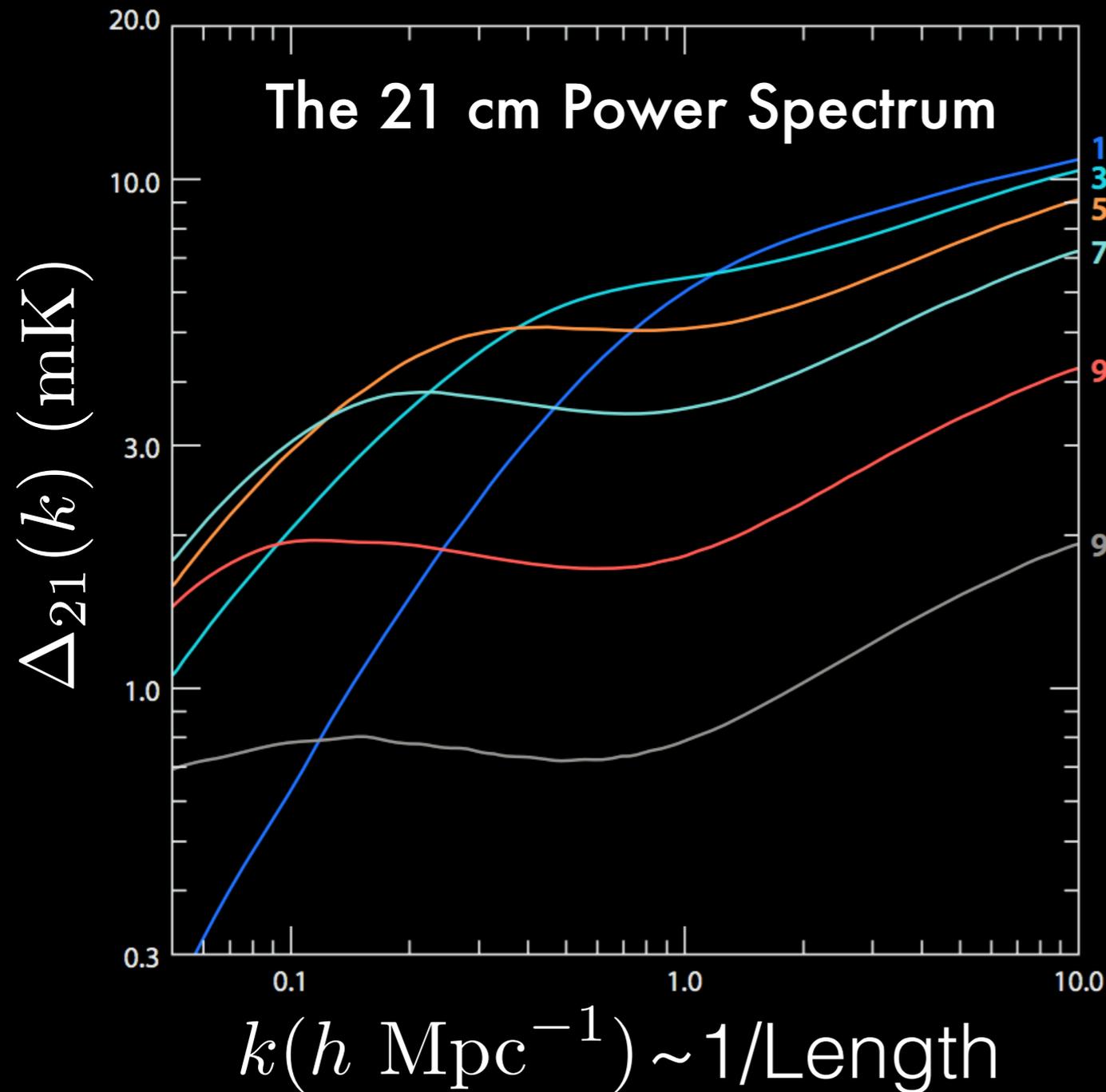


Mesinger 2011

Reionization



Early Detections of 21cm will be Statistical



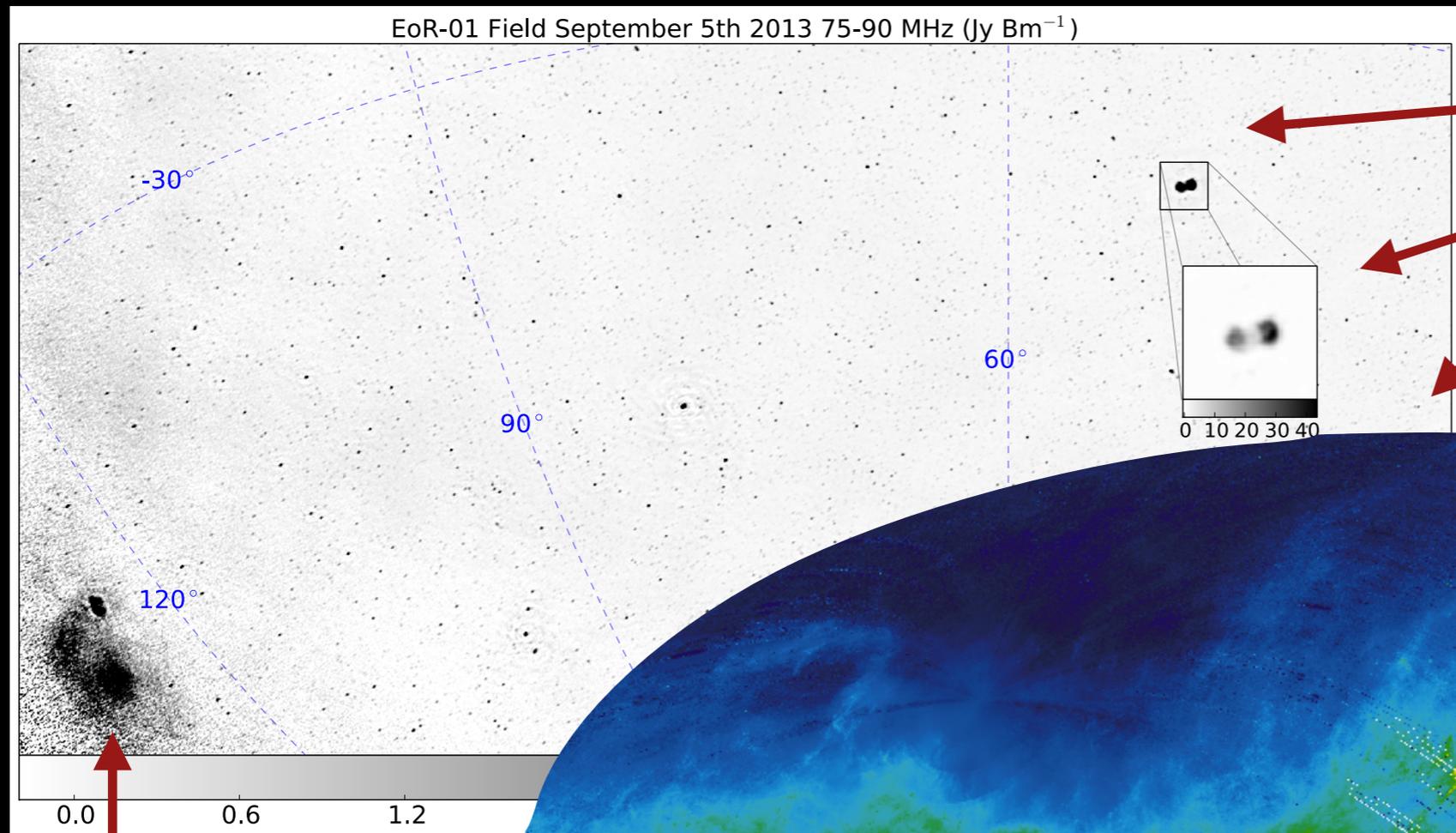
“All you need is paperclips and a supercomputer”

-Don Backer

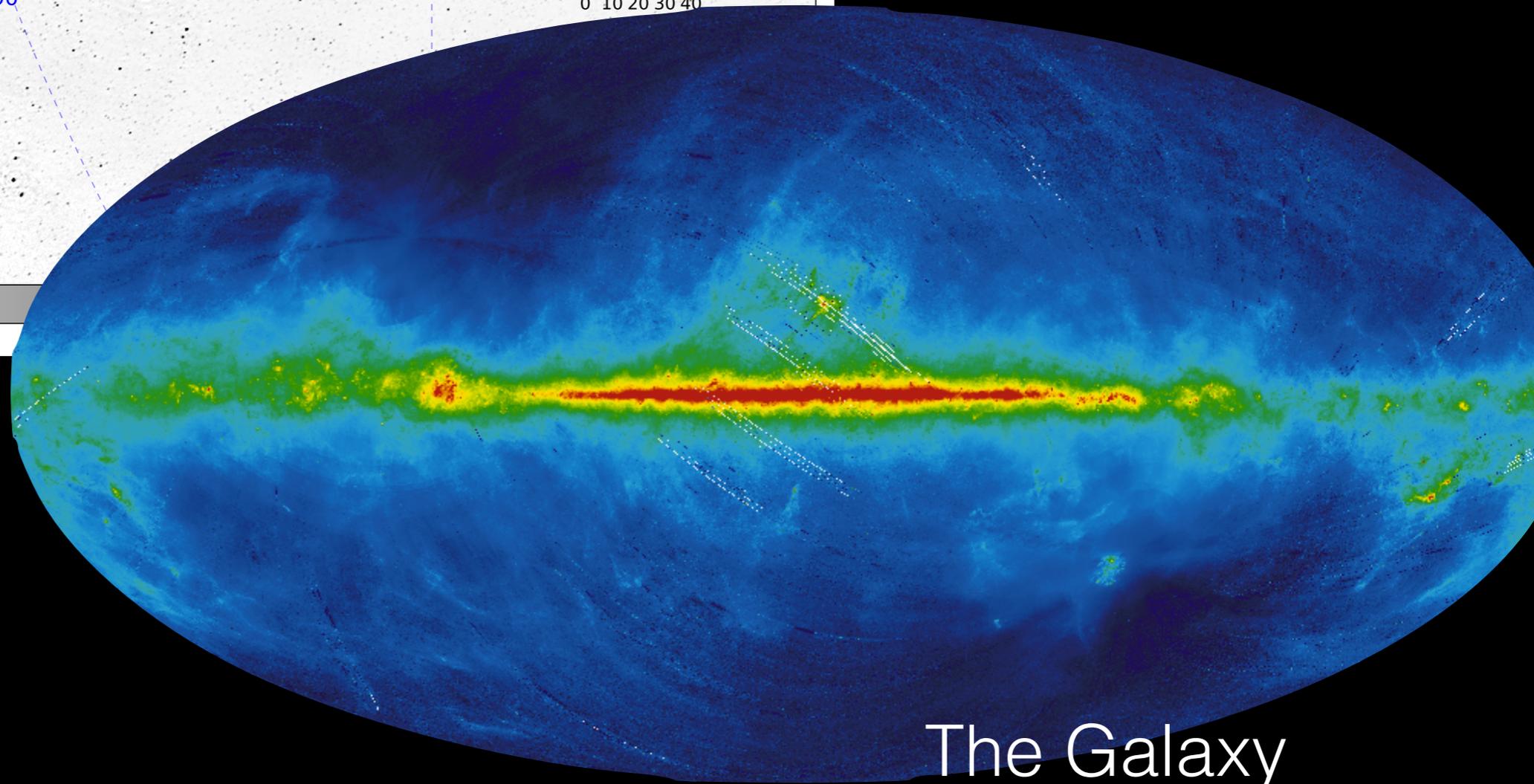
LOFAR



Radio Foregrounds: $\sim 10^4 \times$ the signal level!



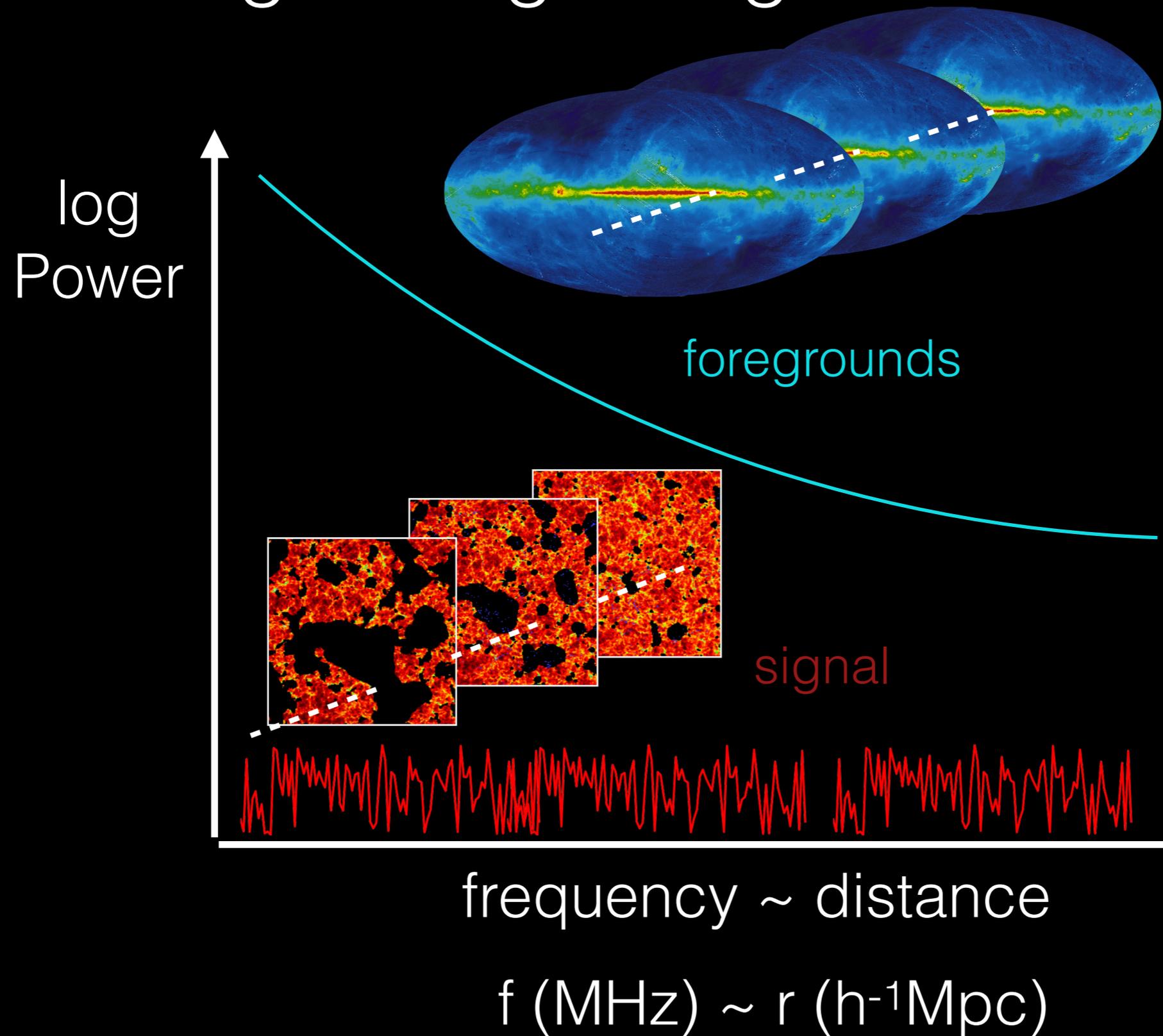
Active Galactic
Nuclei



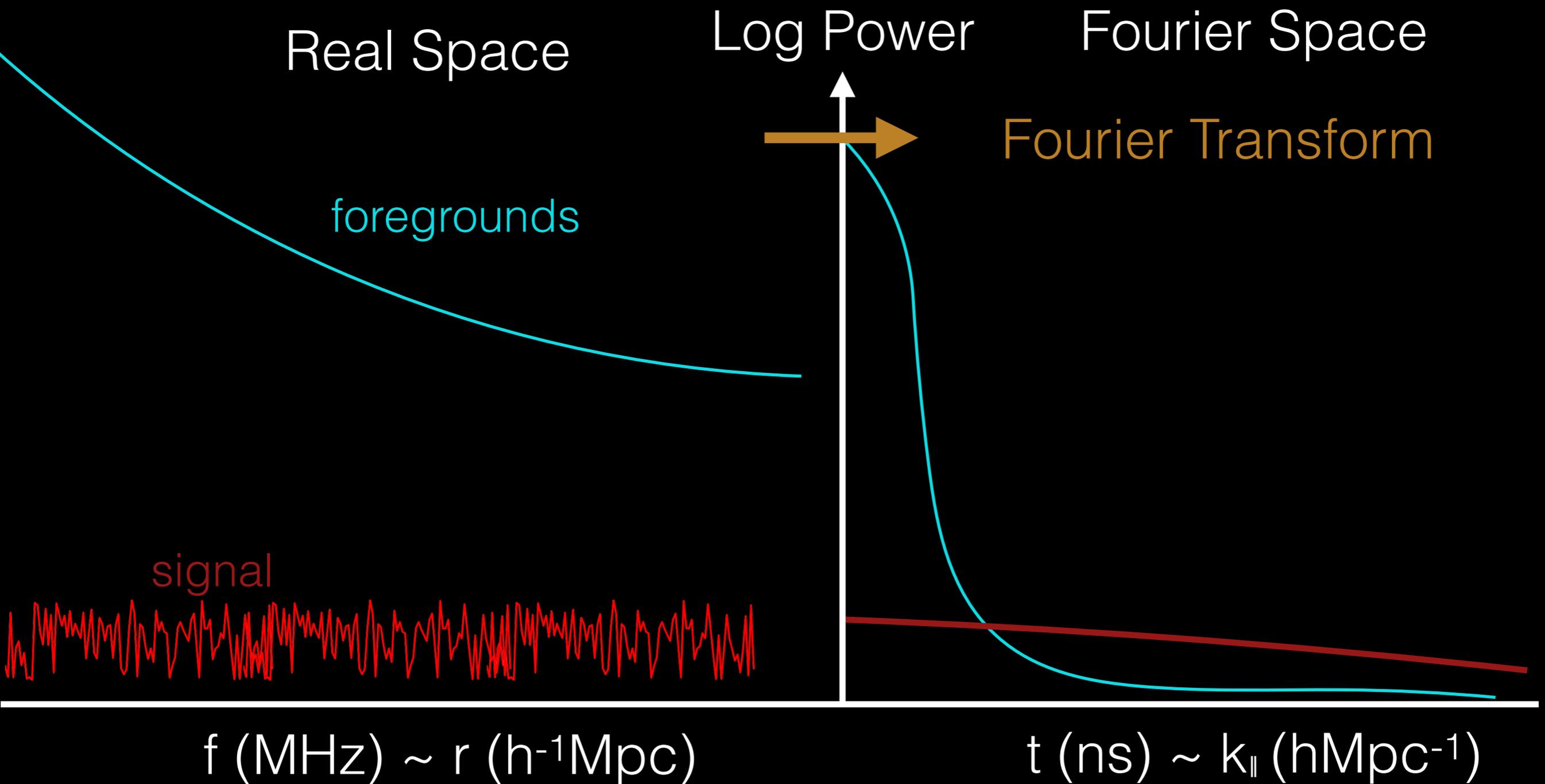
Supernova
Remnant

The Galaxy

Distinguishing Foregrounds from Signal



Isolating Foregrounds Using the Fourier Transform



This is all well and good ...

If your instrument is
Spectrally Smooth

If we have Instrumental Spectral Structure
Avoidance Fails!

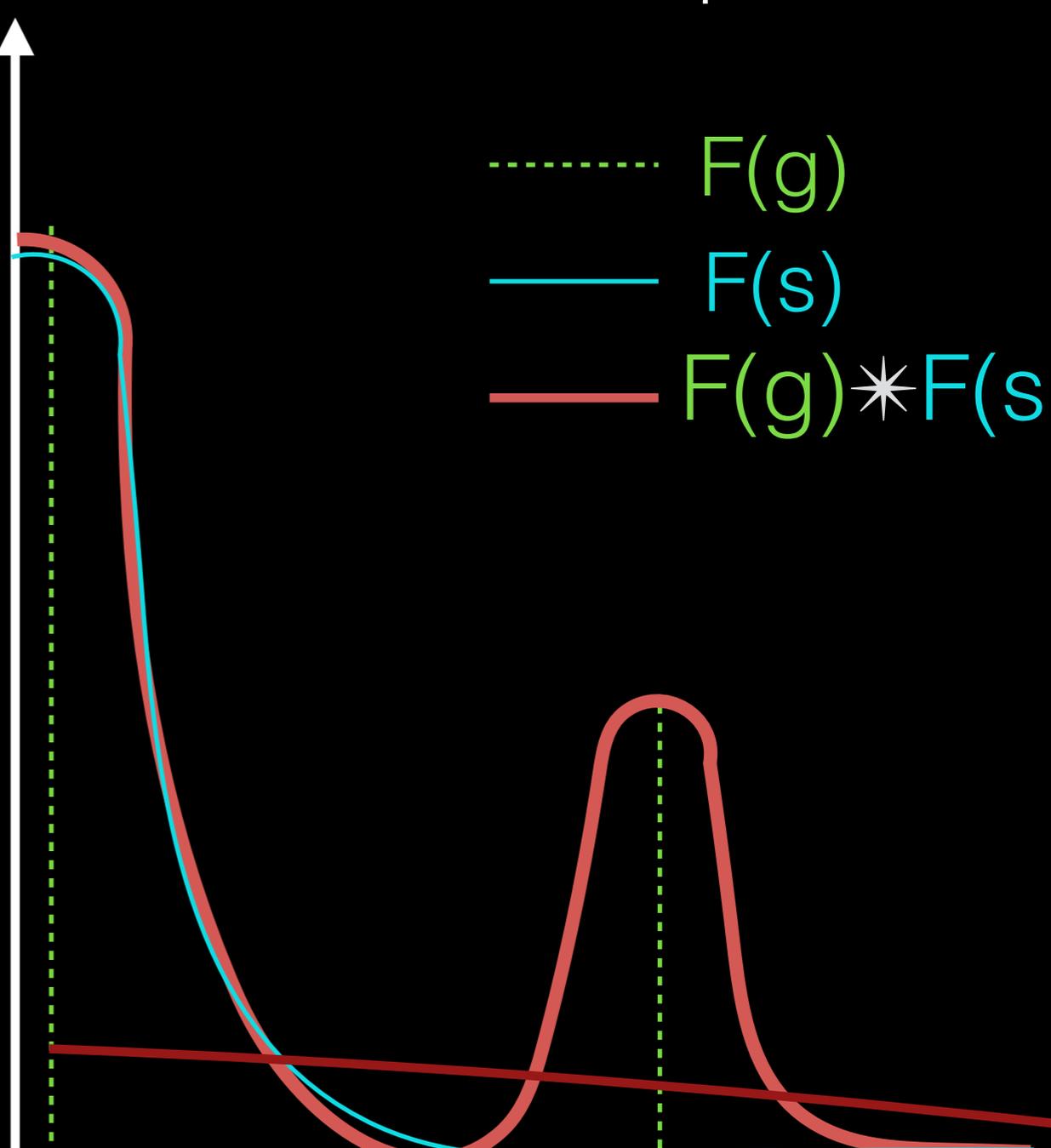
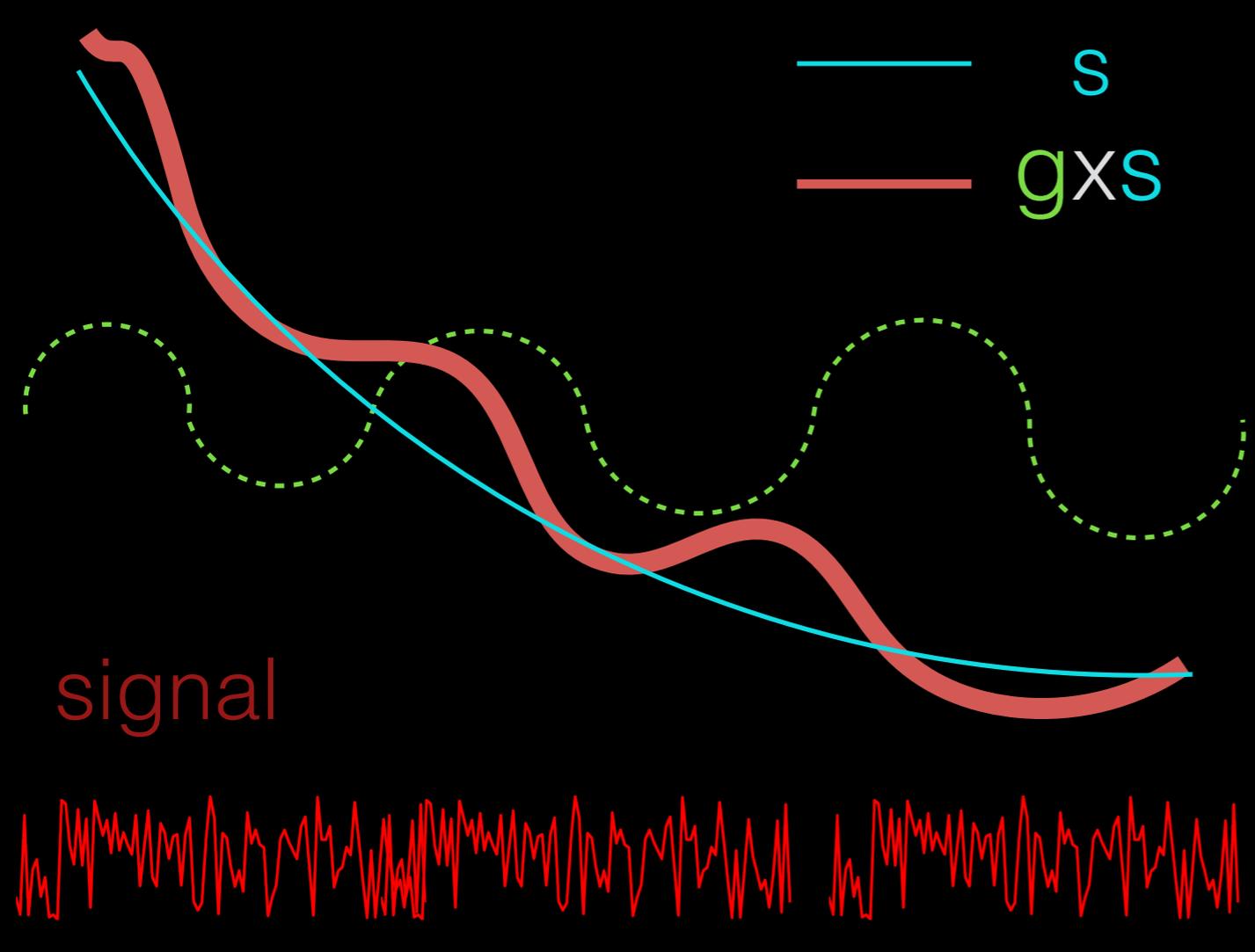
Real Space

Power

Fourier Space

----- g
----- s
----- gxs

----- F(g)
----- F(s)
----- F(g)*F(s)

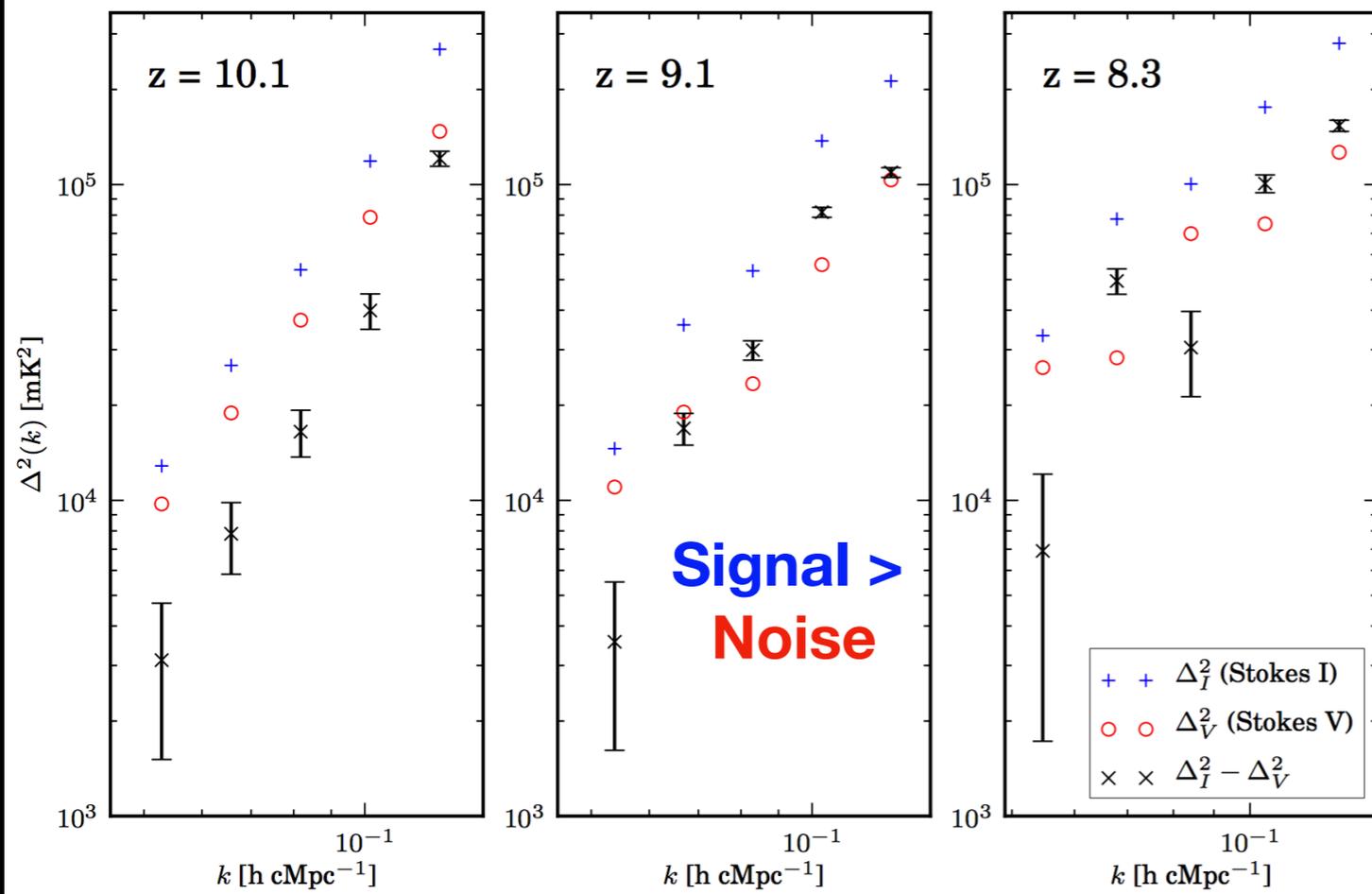
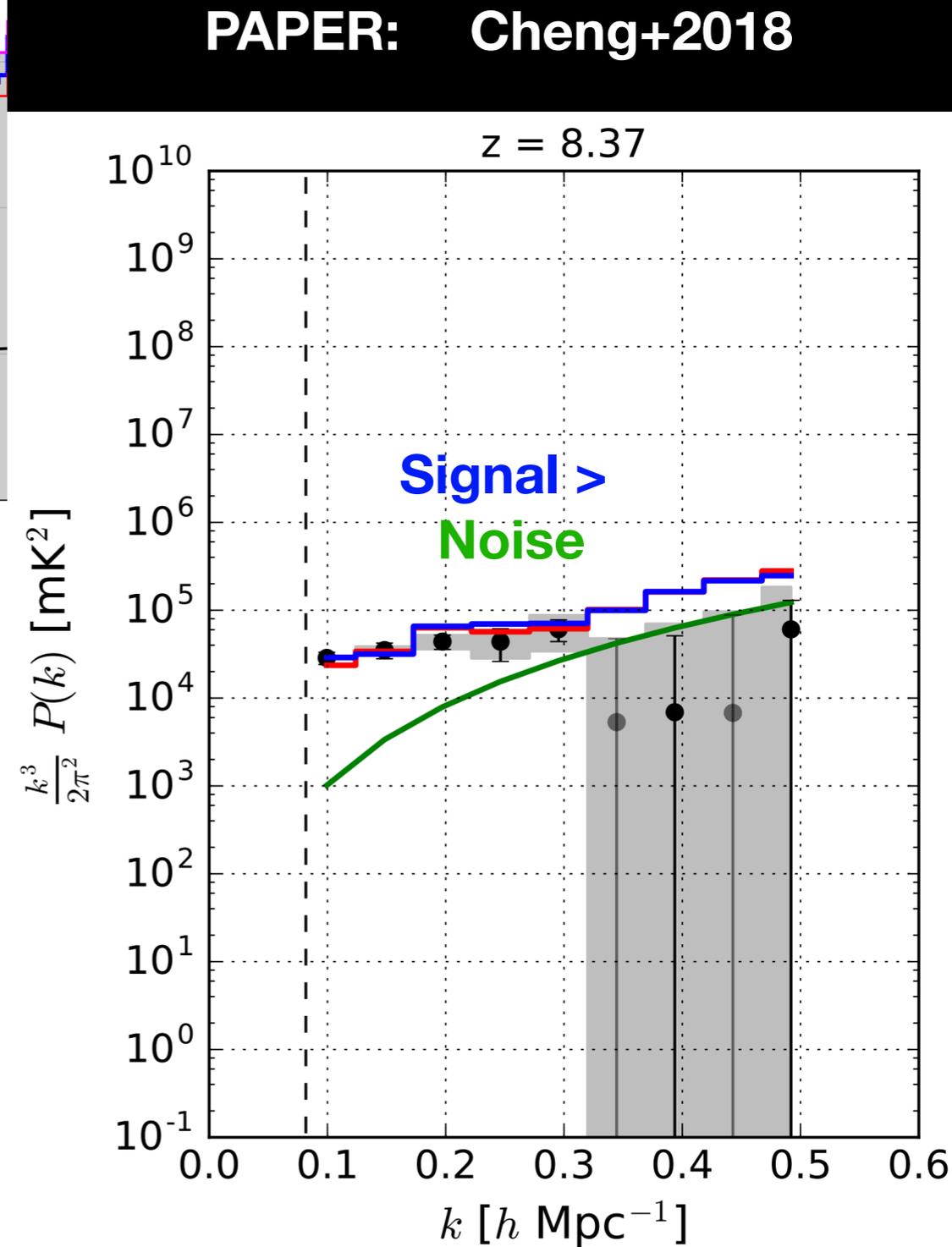
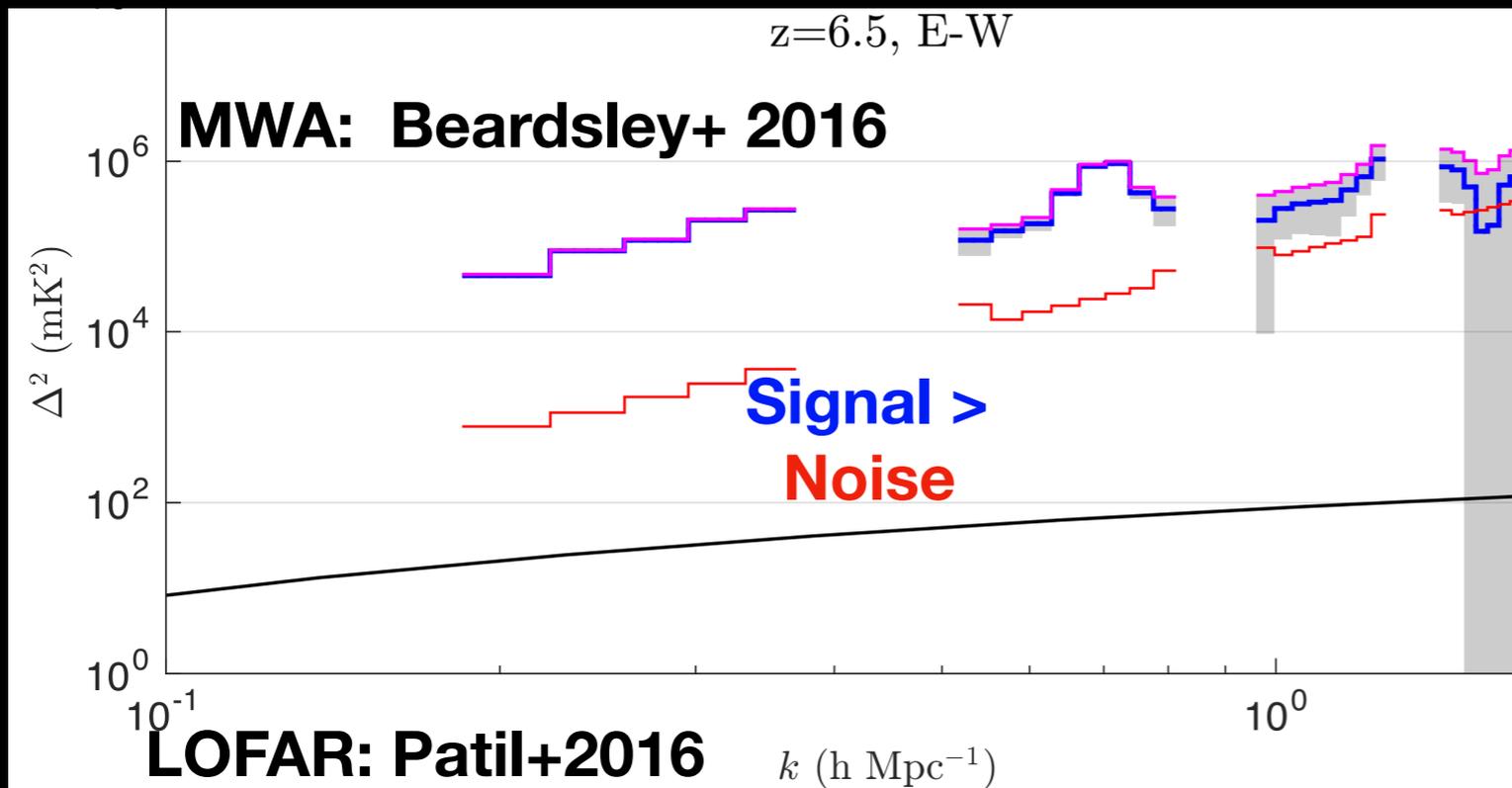


signal

f (MHz)

k_{\parallel} ($h\text{Mpc}^{-1}$)

Existing Limits are set by Systematics



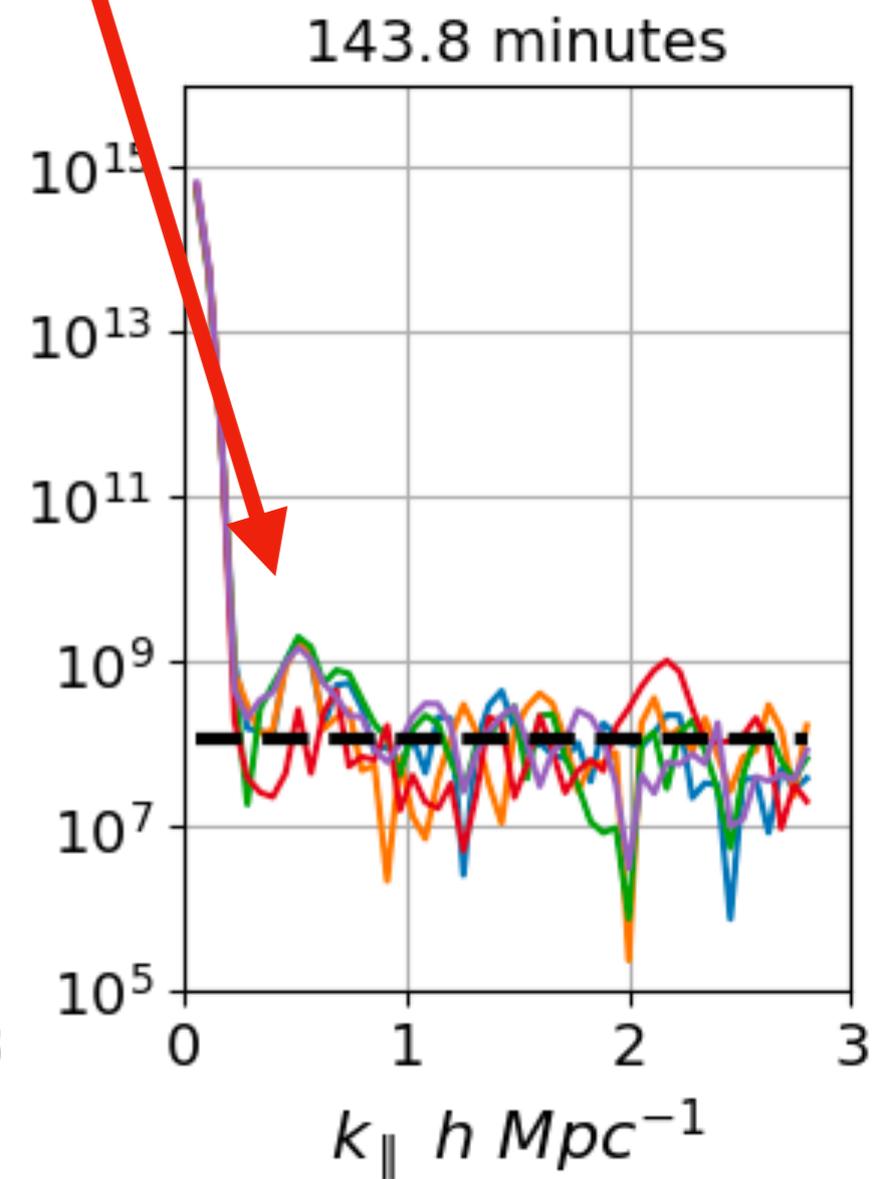
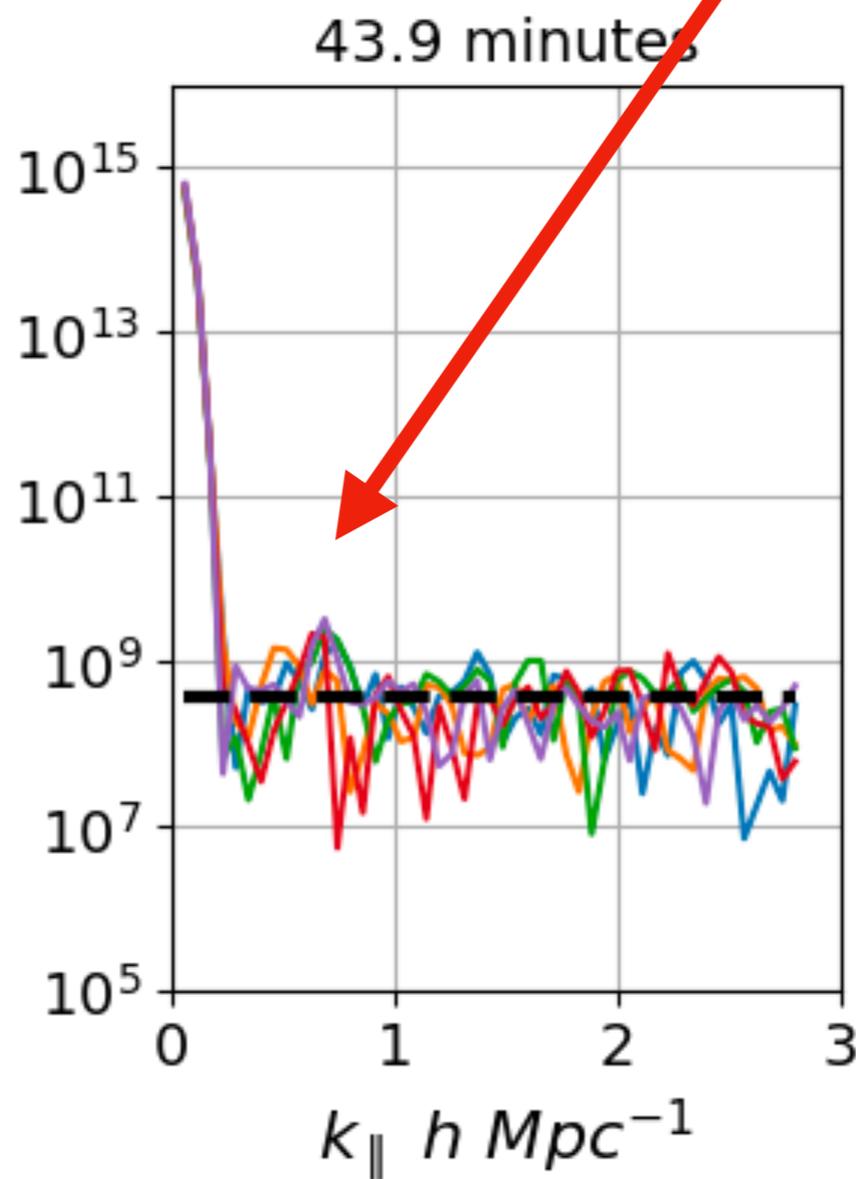
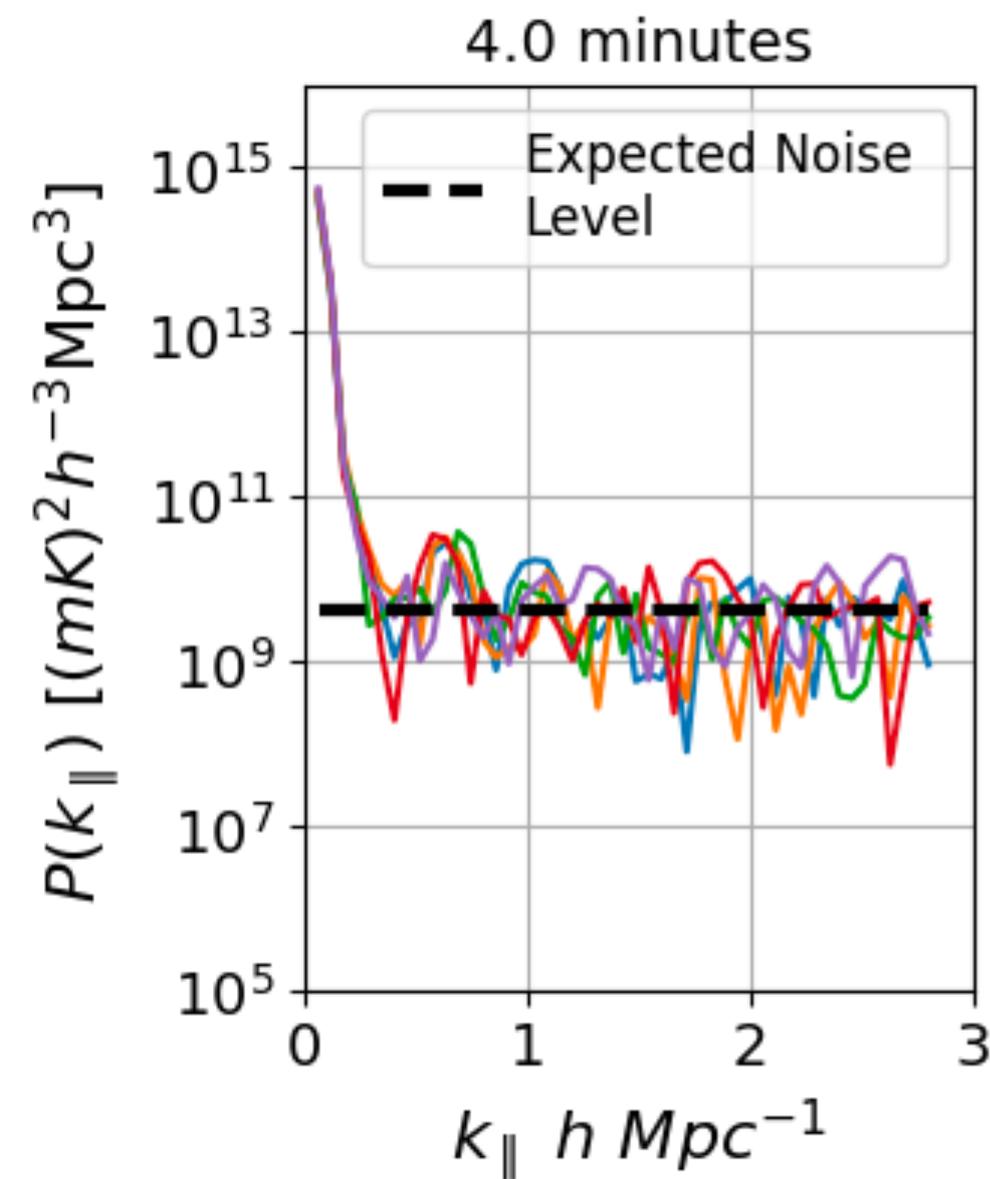
See Talks by Nichole, Carina, and Matt



HERA-47: PAPER feed and analog chain.

Similar Structures appear in initial HERA deployment

150 meter Cable Reflection + Possible Cross-Talk



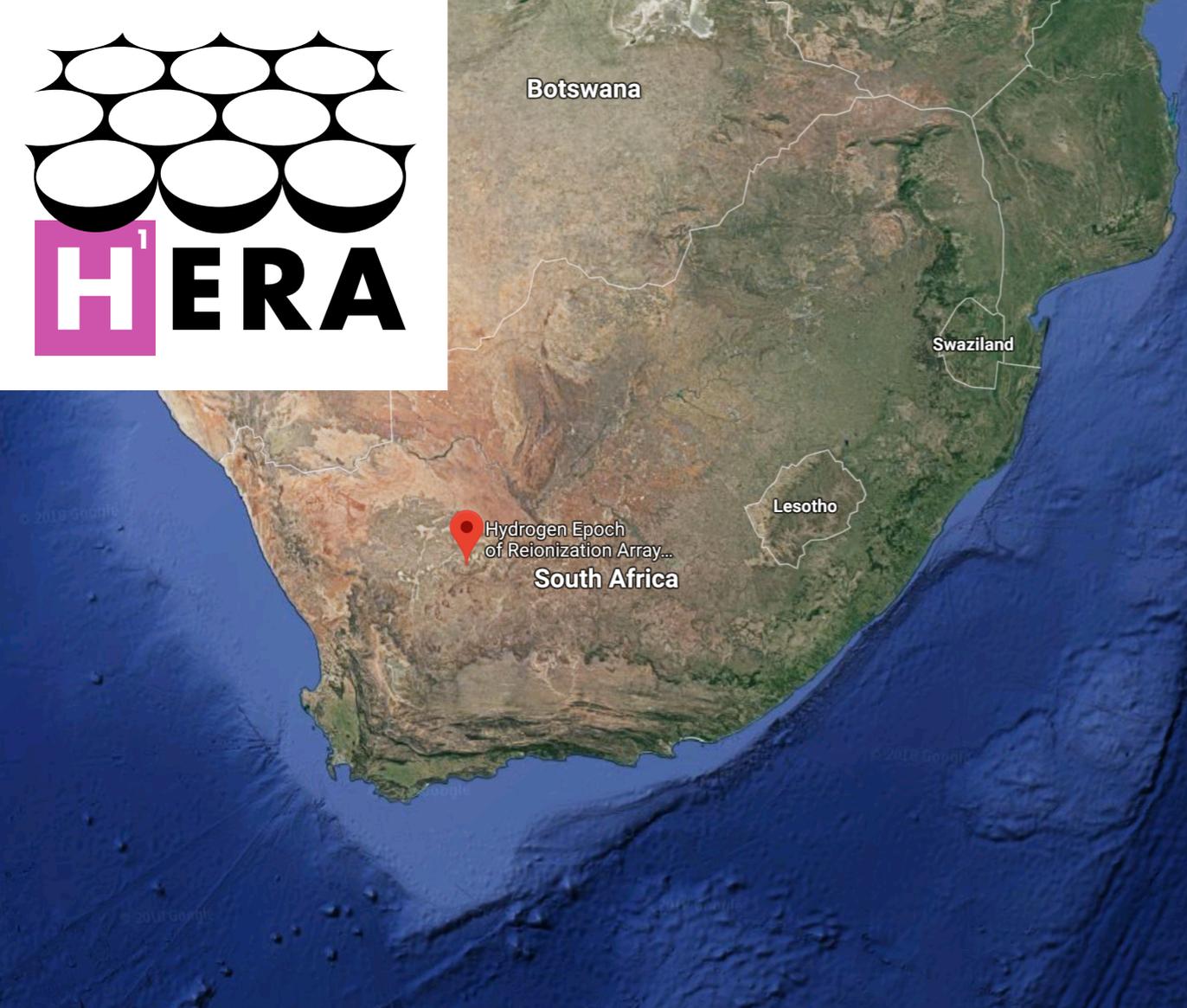
Kern + In Prep

Spectrally Smooth*

“All you need is [^]paperclips and a supercomputer”

-Don Backer

*up to one part in $\sim 10^{-5}$



2017-2018 initial deployment of 61, 100-200 MHz PAPER RF chains.

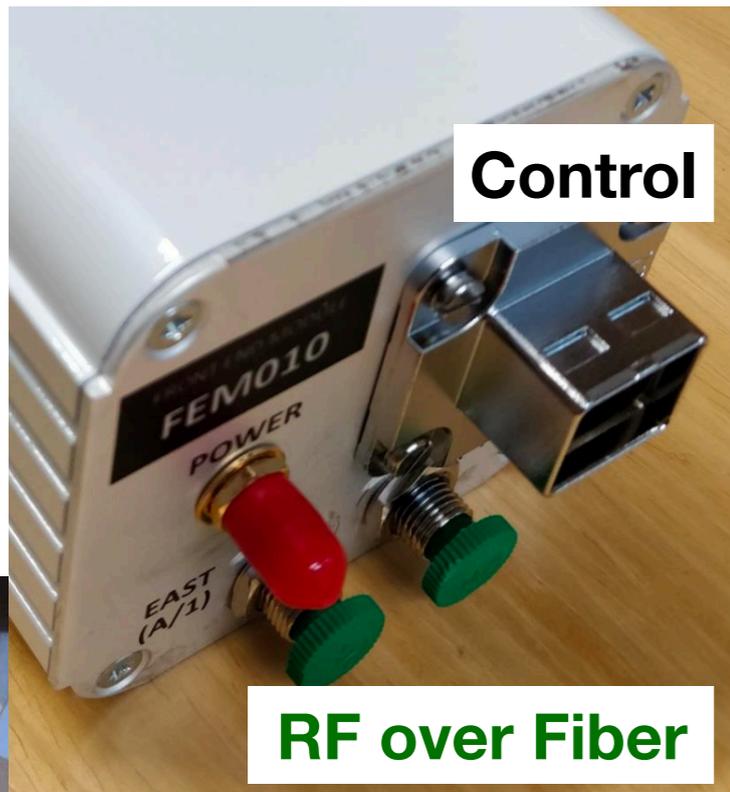
139 Dishes (~61 signal chains)
Currently deployed at SKA-MID Site

Currently being replaced with 350, 50-250 MHz RF chains

Funded to build and analyze 350 dishes/signal chains.

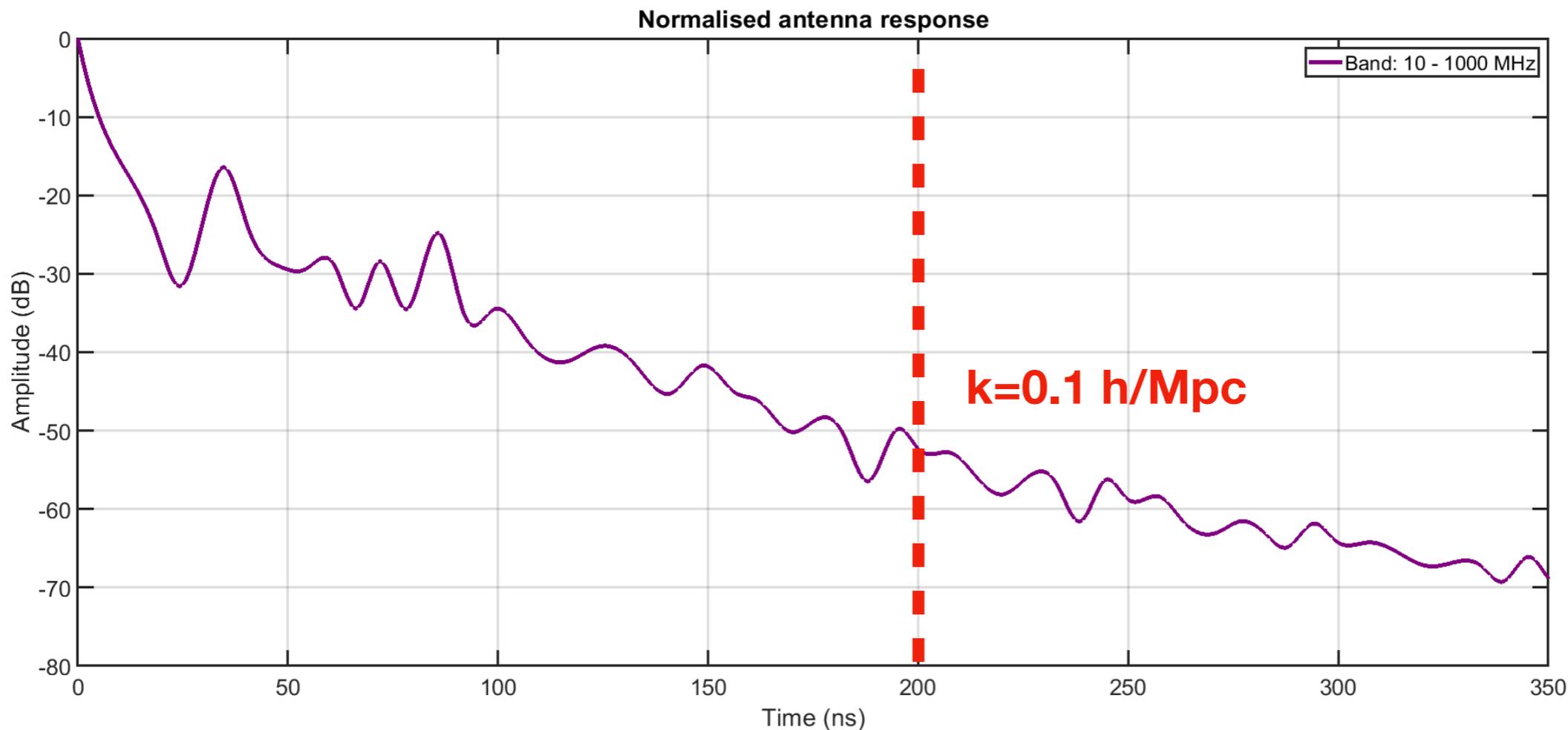
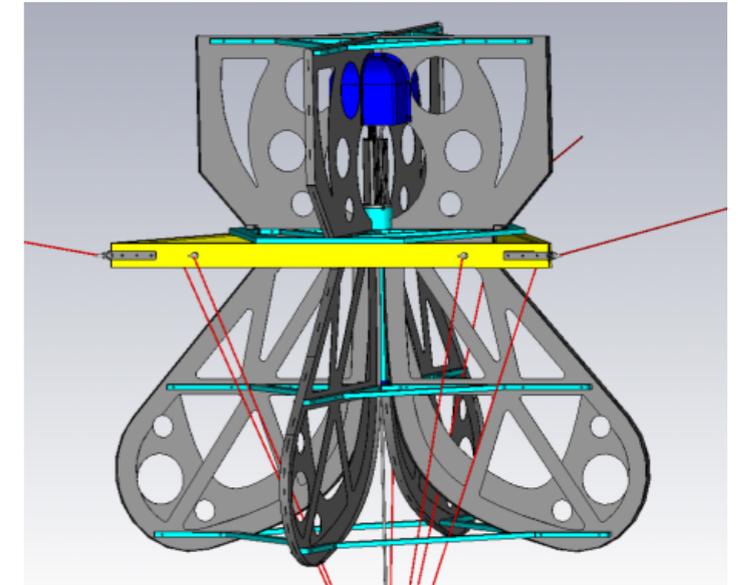
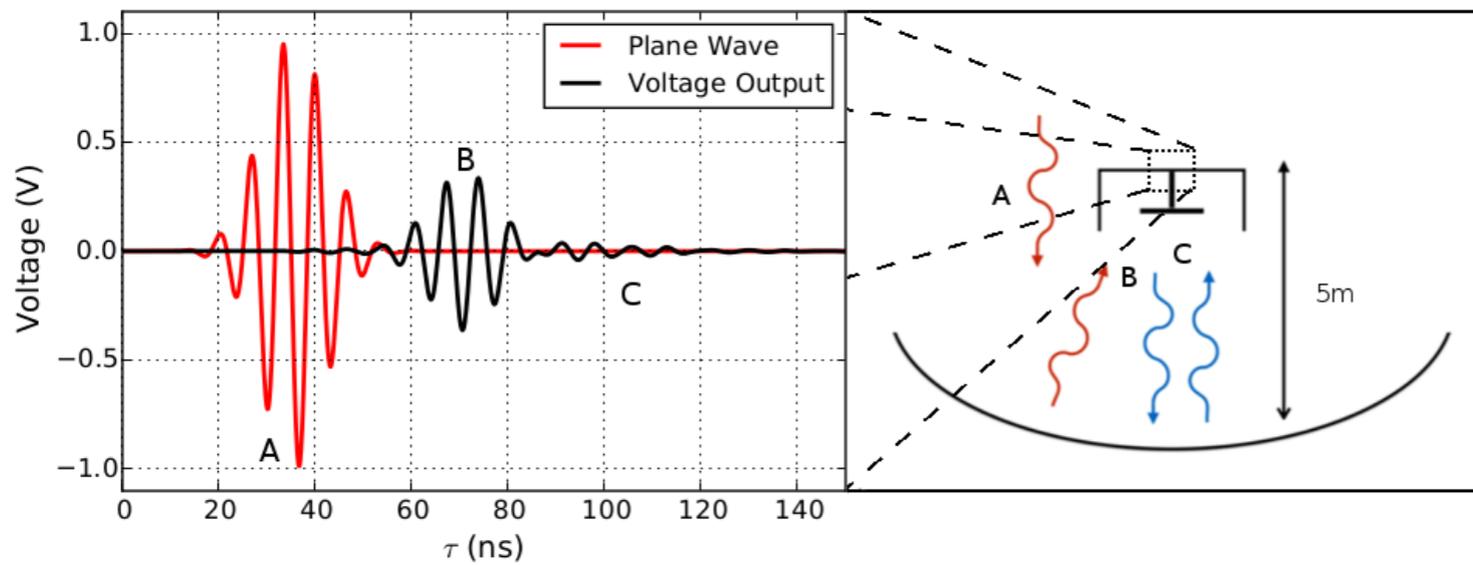
Spectral Smoothness is the
main criteria for HERA's design

To mitigate reflections, the signal chain uses RF over Fiber.



Site trip deploying first RFoF chains and new feeds

We use Electromagnetic Simulations to optimize feed and RF front-end together



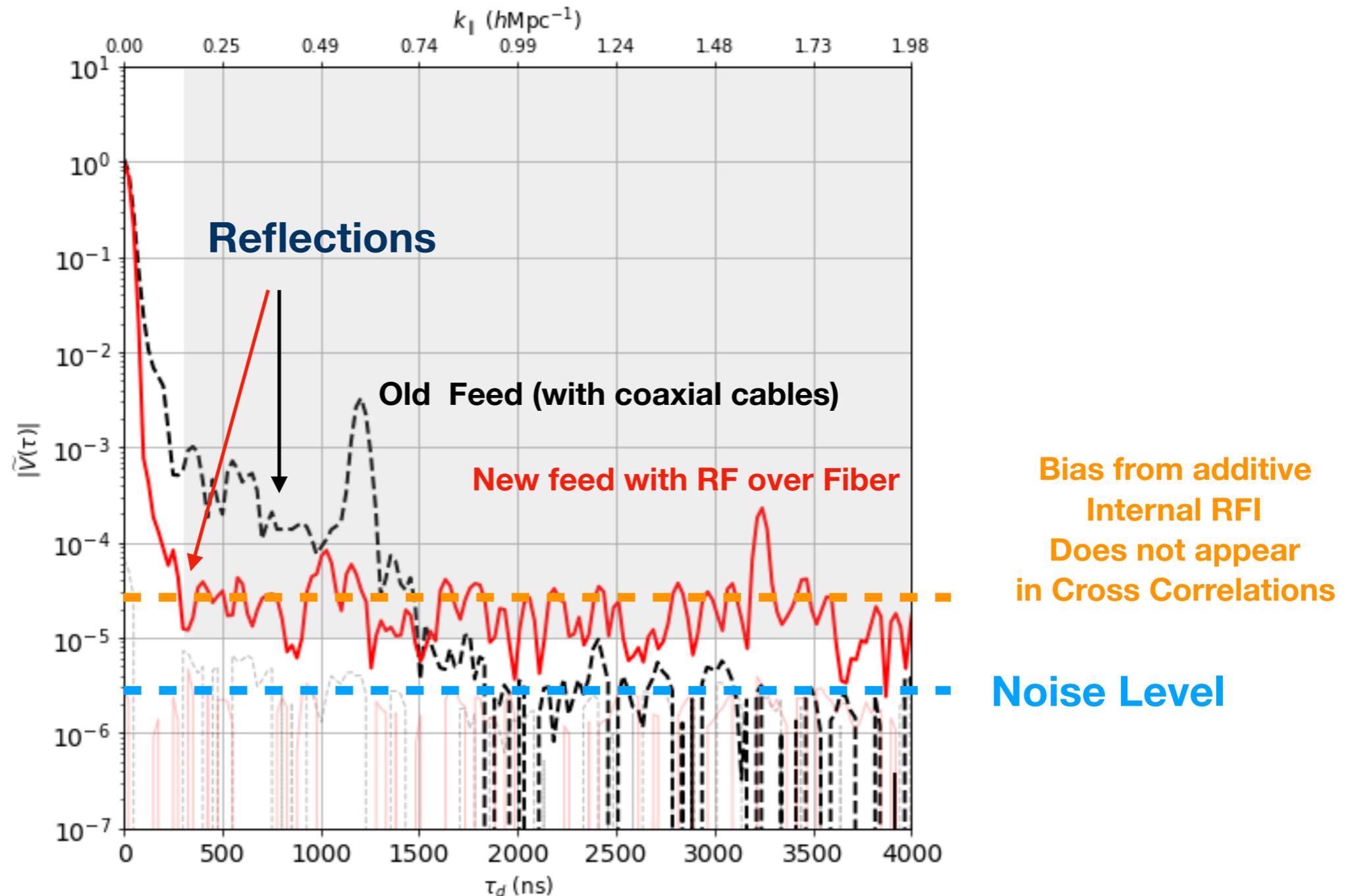
Fagnoni+
in prep.

How do we verify that our signal chain is spectrally smooth?

Problem: Cross Correlations Between antennas have low signal to noise

Validating the absence of features in cross correlations requires the full instrument.

Solution: Look at Autocorrelations!



When subtracting internal RFI bias, spectral leakage falls fast enough to allow 21cm Detection. Necessary but not sufficient

Take-Aways

- Observations of fluctuations in in the brightness temperature of 21cm emission from HI will allow us to map out the era of the first stars.
- Foregrounds are 10000 times brighter, but spectrally smooth! Allows them to be distinguished from 21cm signal.
- This only works if the gain of the radio telescope is spectrally smooth **Minimize Reflections!**
- We are validating the spectral performance of the Hydrogen Epoch of Reionization Array by inspecting high signal to noise autocorrelations.