21 cm EoR Power Spectrum Analyses of 3c196 Flanking field

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On behalf of the LOFAR collaboration

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Probing High redshift 21 cm

Single Element approach
Globally averaged temperature

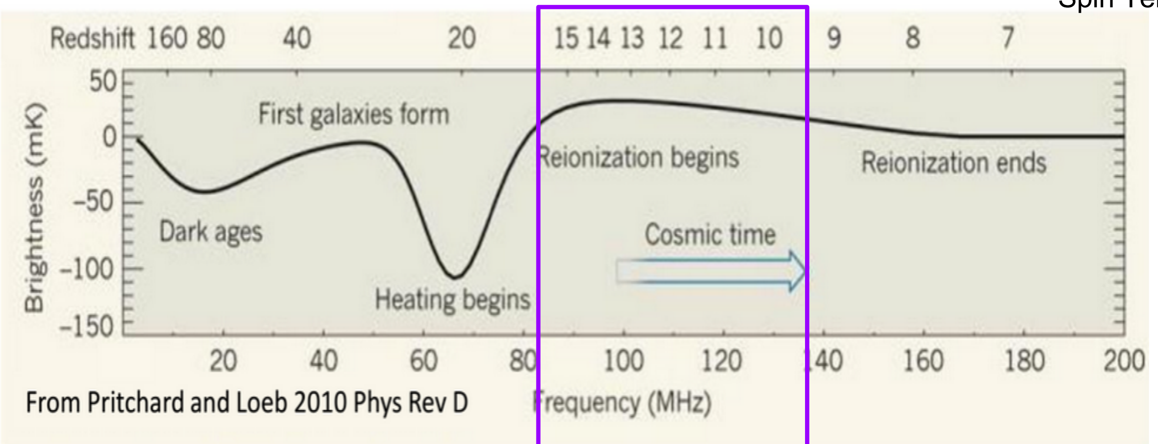
$$T_b \propto (T_S/T_{cmb} - 1)\, X_H$$

Brightness Temp

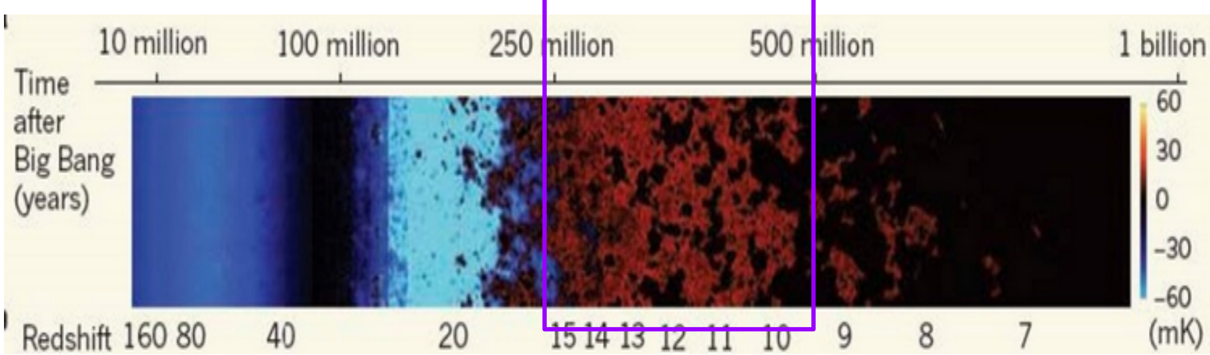
Spin Temp

Neutral Fraction

EDGES



Interferometric approach
Statistical detection - Power spectrum



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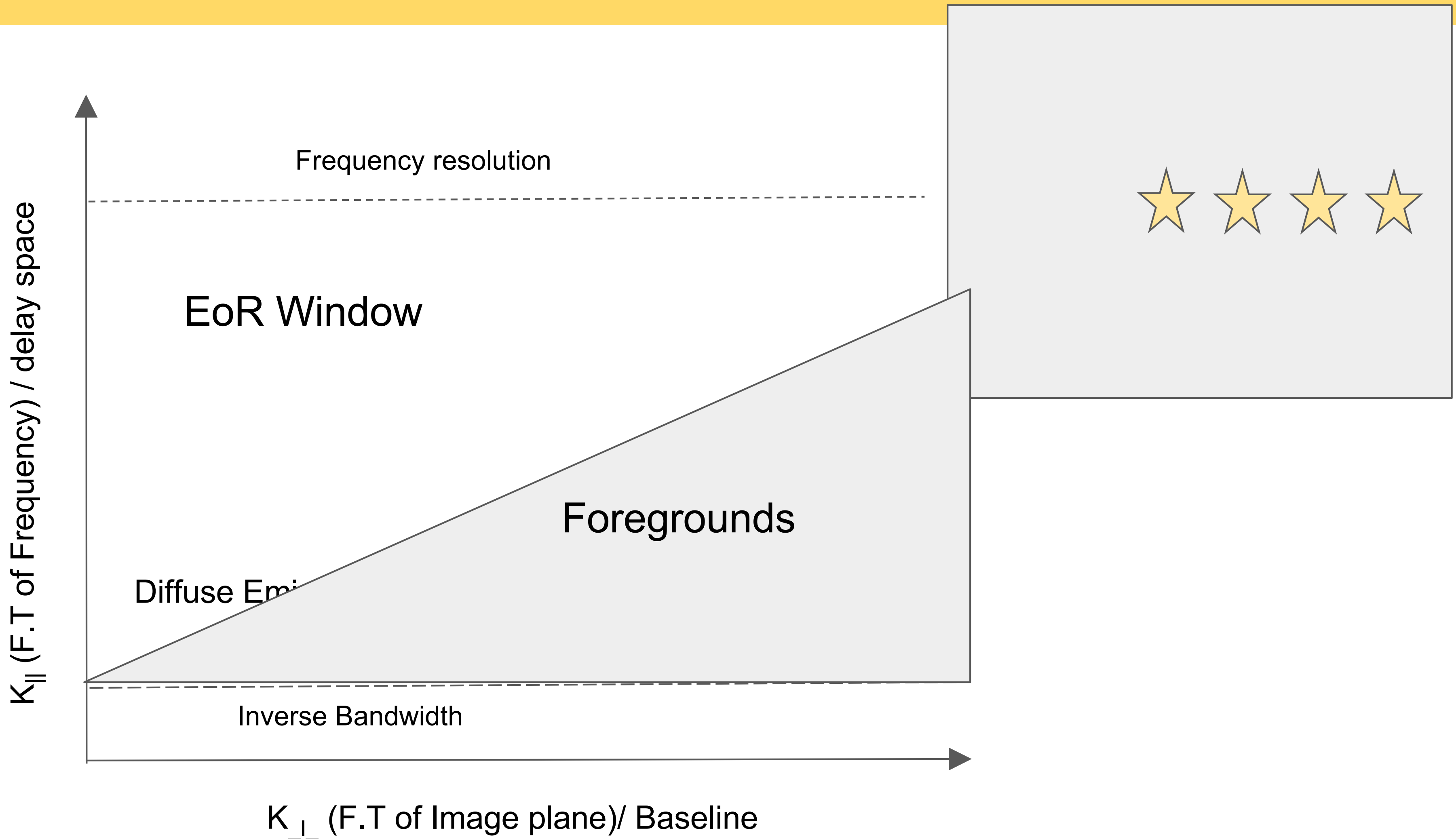
Understanding EoR window



Project Goals

1. Automated technique for effective foreground removal
2. Test the suitability of the flanking field for EoR Power spectrum.

APPROACH:

- ➢ Use the 3c196 Flanking field to:
  - ○ Make image of the sky
  - ○ Model the foregrounds
  - ○ Perform calibration & Imaging
- ➢ Make power spectra from the image cube
- ➢ Analyse the field using the power spectra

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3c196 Flanking field

- Actual 3c196 field was observed in the multi-beam mode with the HBA
- Adjacent field was chosen because of the center unresolved source ⇒ ease of calibration
- The available 96 MHz bandwidth was split between the main beam and the flanking field as 64 & 32 MHz.
- So this field has 32 MHz (114-145 MHz) ⇒ 2 redshift bins

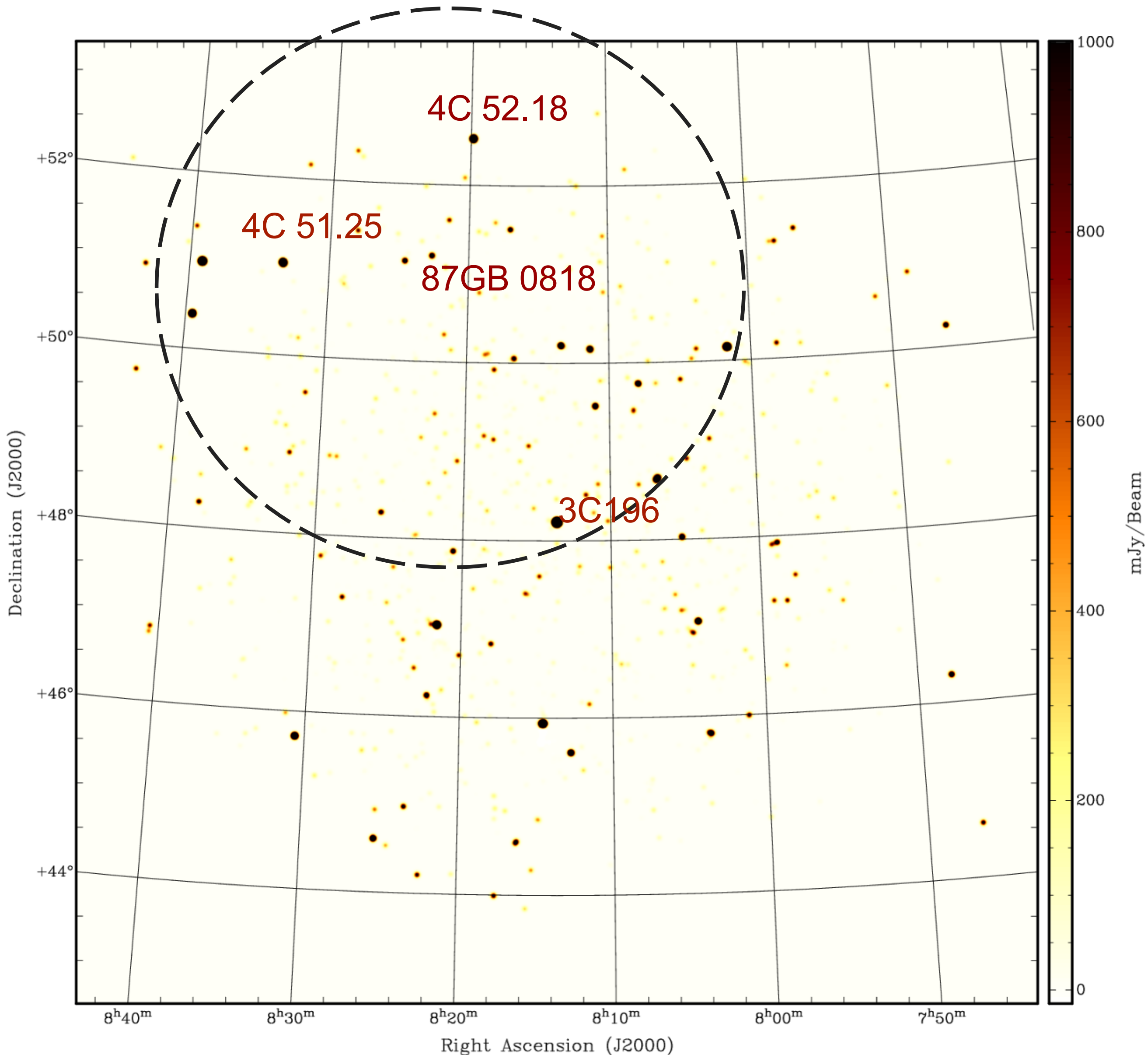
DATA Overview:

Each Suband -> 4 to 59 (Solving PFB aliasing)⇒ 56 channels /14 = 4 (Averaging)

Bandwidth -> 0.042 * 4 = 0.171 MHz

Time resolution -> 5393 * 4 ~ 6 hours

3c196 Flanking field



Calibration

Calibration was tested on one sub band first (127 MHz)

	4C 52.18 Flux (Jy)	**4C 52.18 flux (Jy)**	**87GB 0818 flux (Jy)**	**3C196 Flux (Jy)**	**J082433 Flux(Jy)**	**87GB 81317 Flux(Jy)**
Modelled using PyBDSM	11.50	12.42	1.59	95.97		
Modelled using FIRST	10.48	11.14	1.54	89.31		
Expected Flux	**9.18**	**9.26**	**1.28**	**88.40**	**1.534**	**1.361**
3c196 Flux *0.80	8.89	9.65	1.32	75.98		
Above model + more sources	8.91	9.39	1.31	76.87	1.462	1.347

Sky model Effectiveness

- The flux scale of the sources were close to the expected.
- RMS background noise ~ 13.14mJy for one sub-band
- The residue of the center source after subtraction = -52mJy

LOFAR NDPPP — Calibration — All Subbands 114-133 MHz

↓

wsclean — Imaging

- UV - 50l - 250l
- Pixel - 0.5'
- Size 1200 X 1200
- Trimming - 256 ⇒ 2 deg

↓

pstransform — Power Spectrum — Cylindrical power spectral, Spherical power spectra

Analysing the image cube

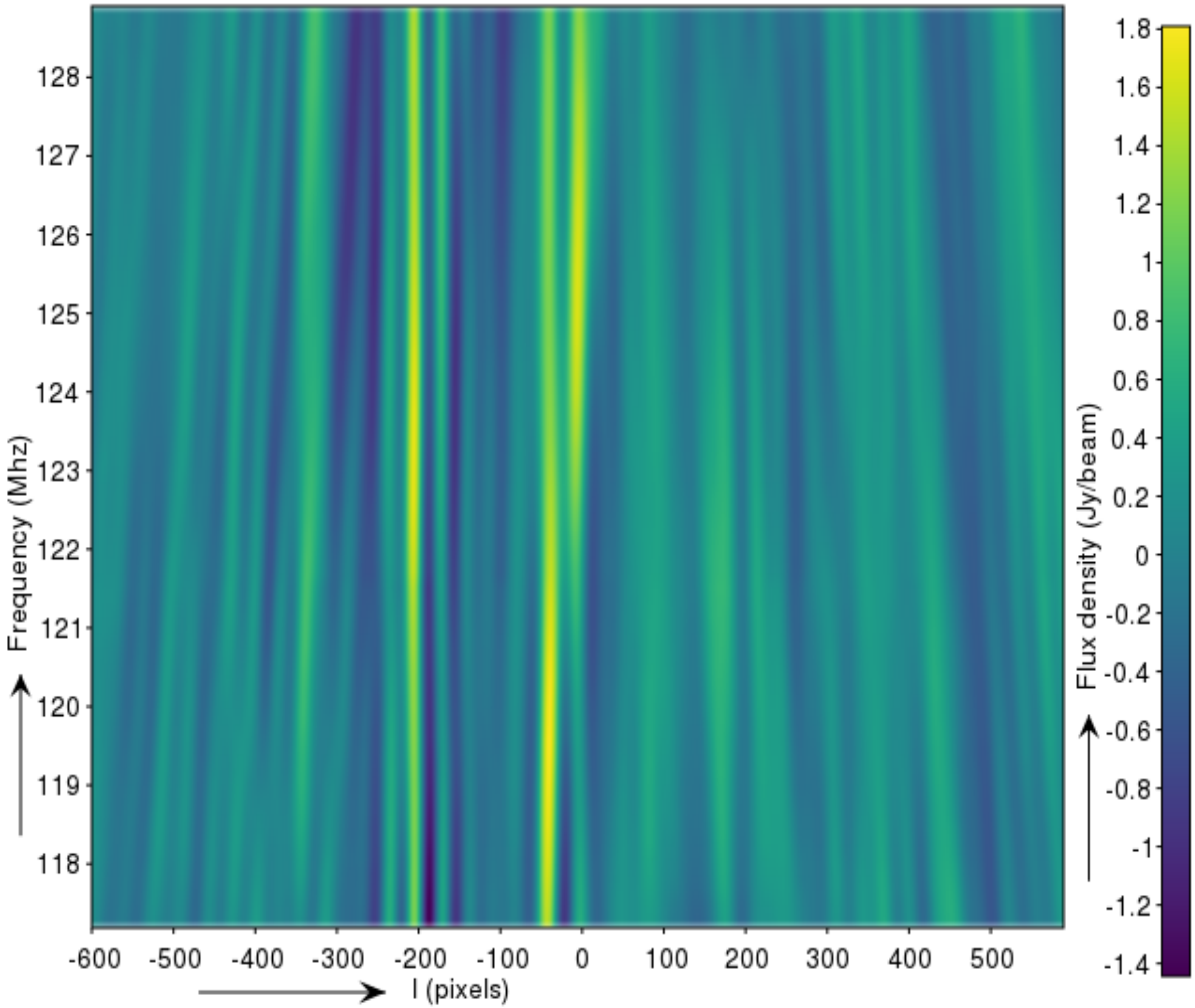


Image slice @ m=0 for stokes I

Image calibrated with the 6 source skymodel

No source removal

“Smooth Foregrounds”

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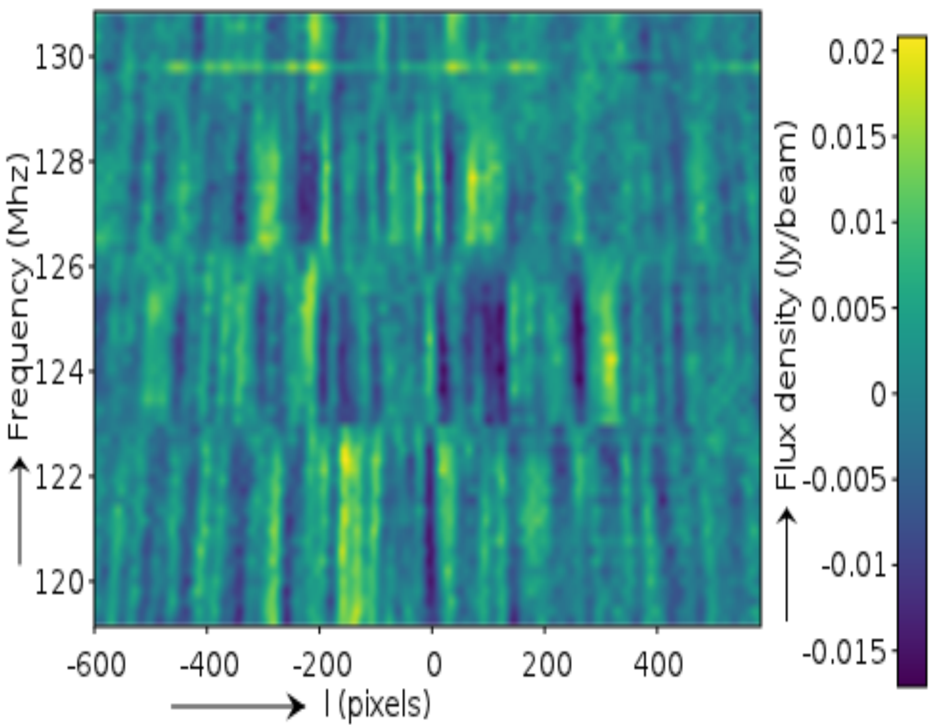
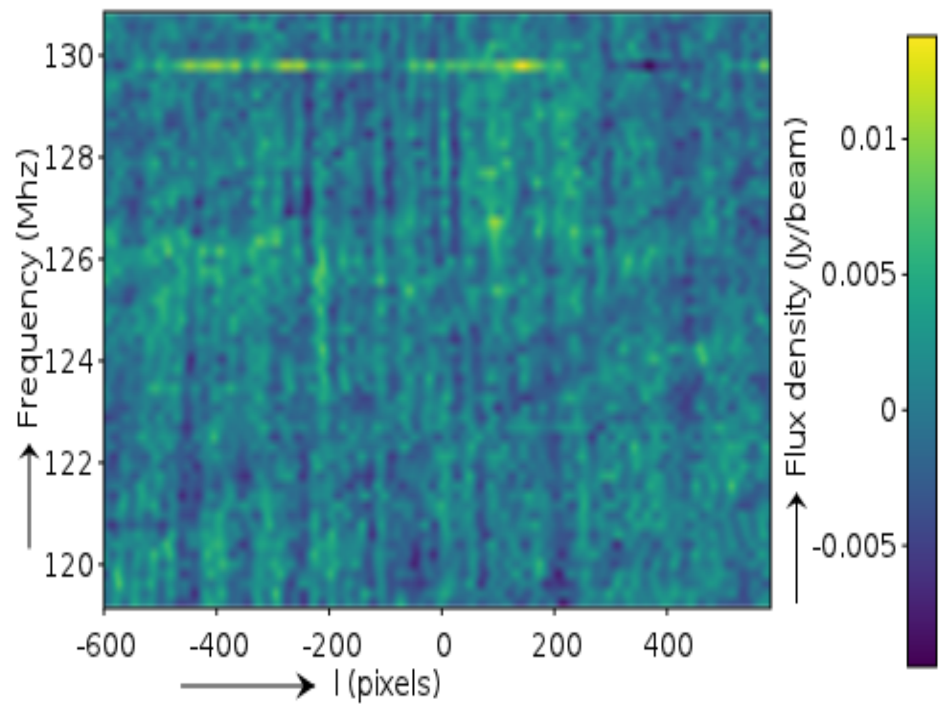
Analysing the image cube

Image slice @ m=0 for stokes V

Diagonal Calibration



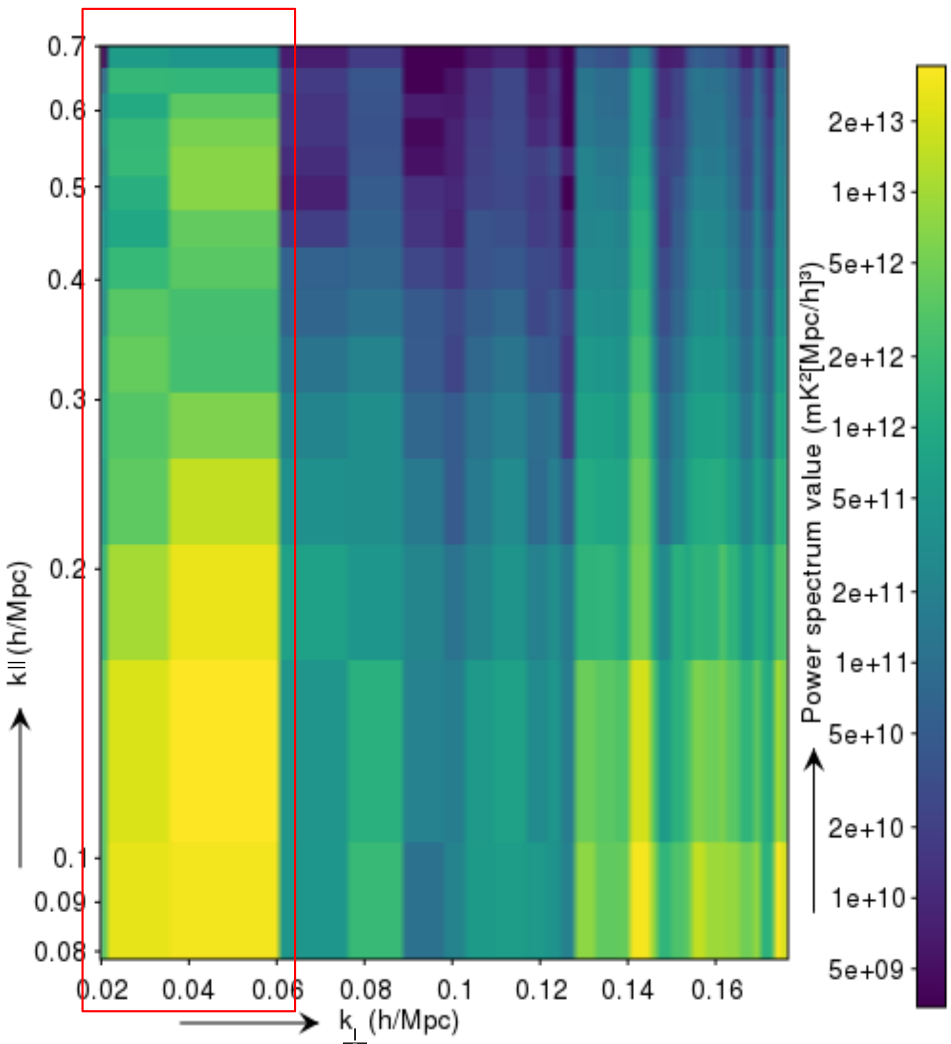
Full Jones Matrix calibration

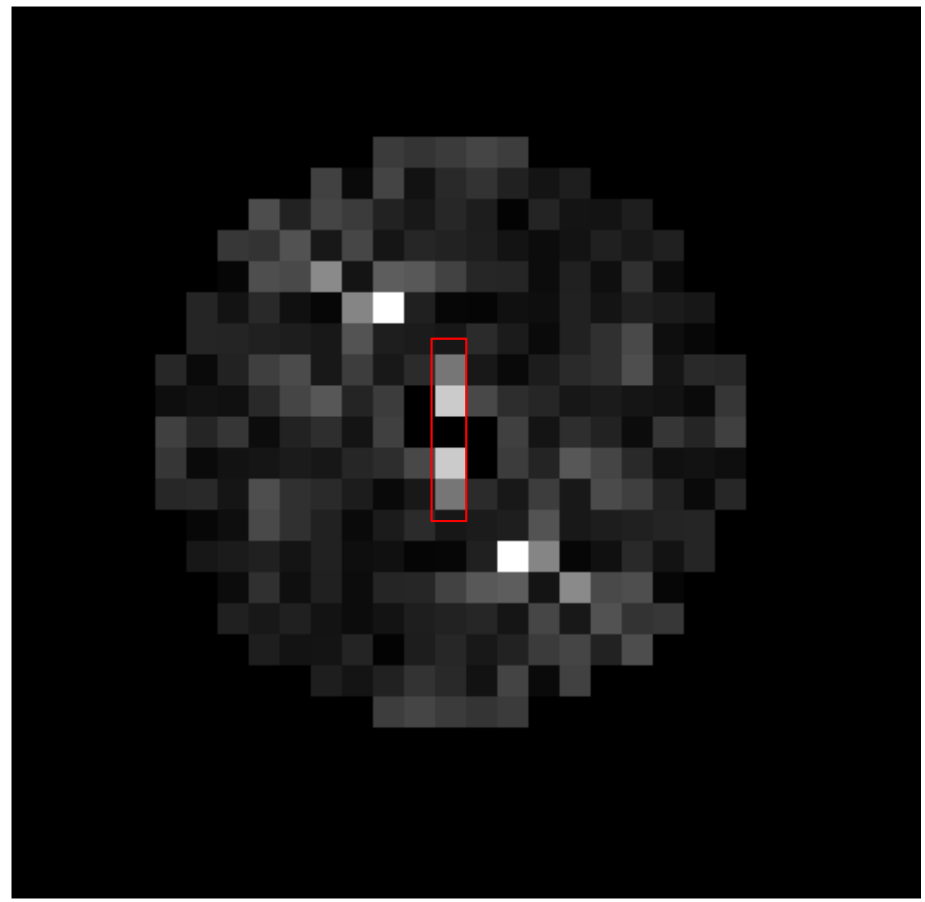


Diagonal Calibration in NDPP calibrates X & Y antennas independently ⇒ they are referenced to different phases

Analysing the pstransform plots

No Minuv clipping in Pstransform

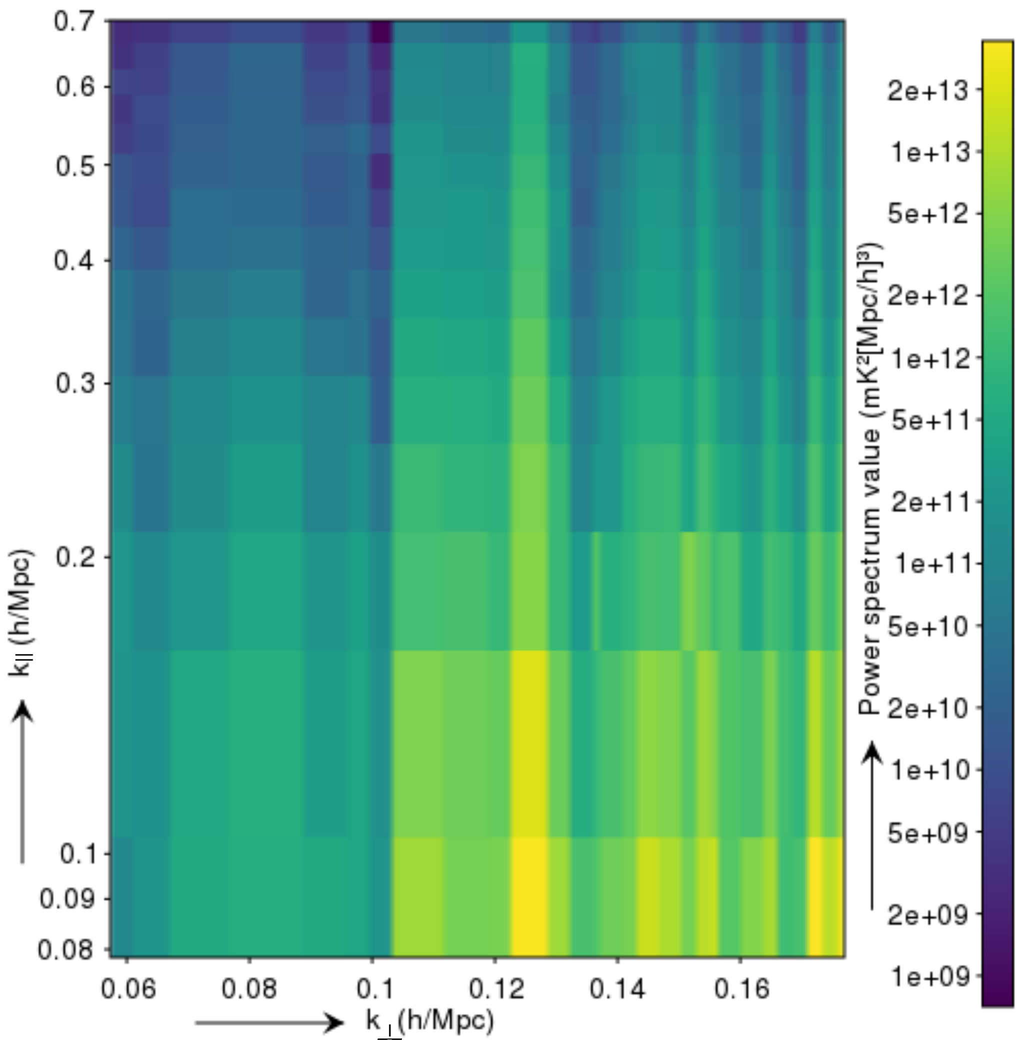


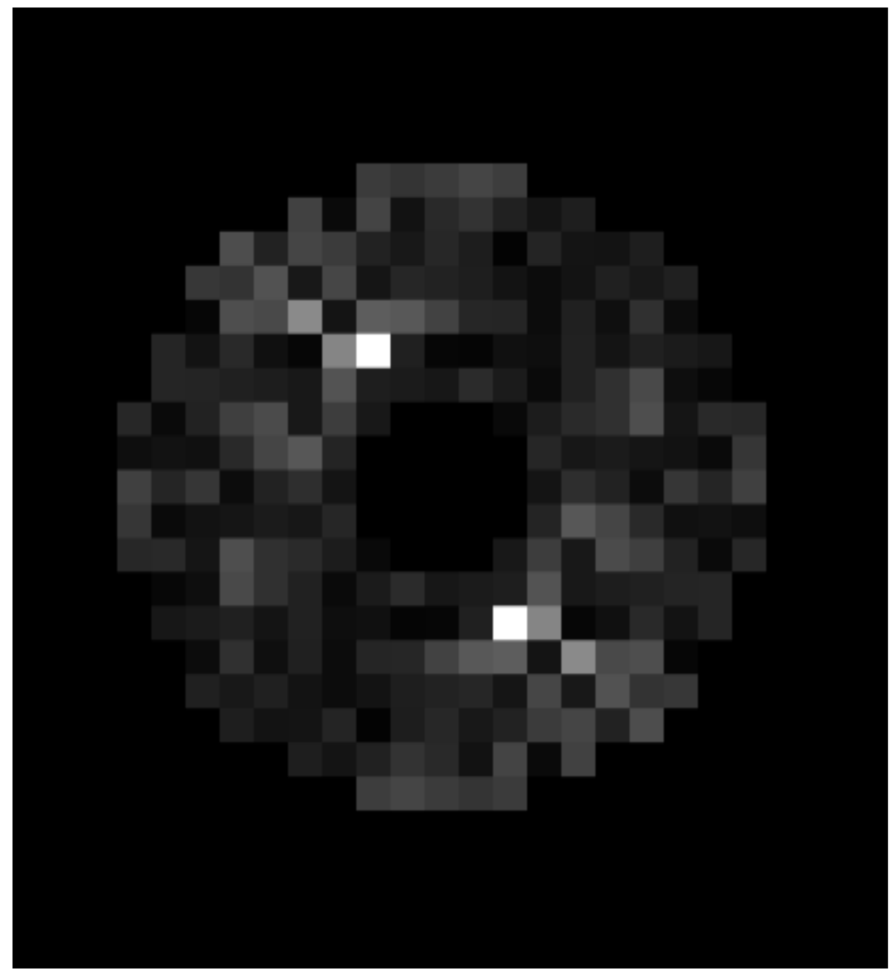


UV plane

Analysing the pstransform plots

Minuv clipped to 70 in Pstransform





UV plane

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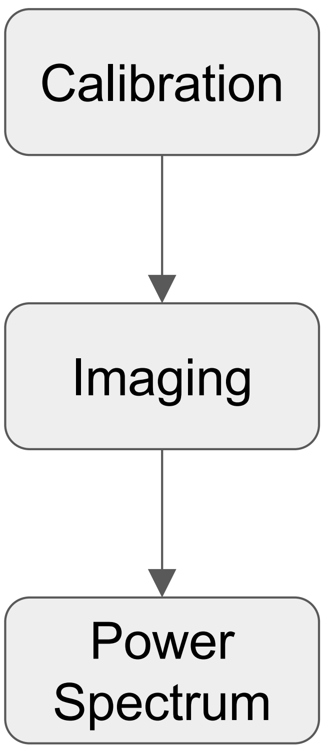
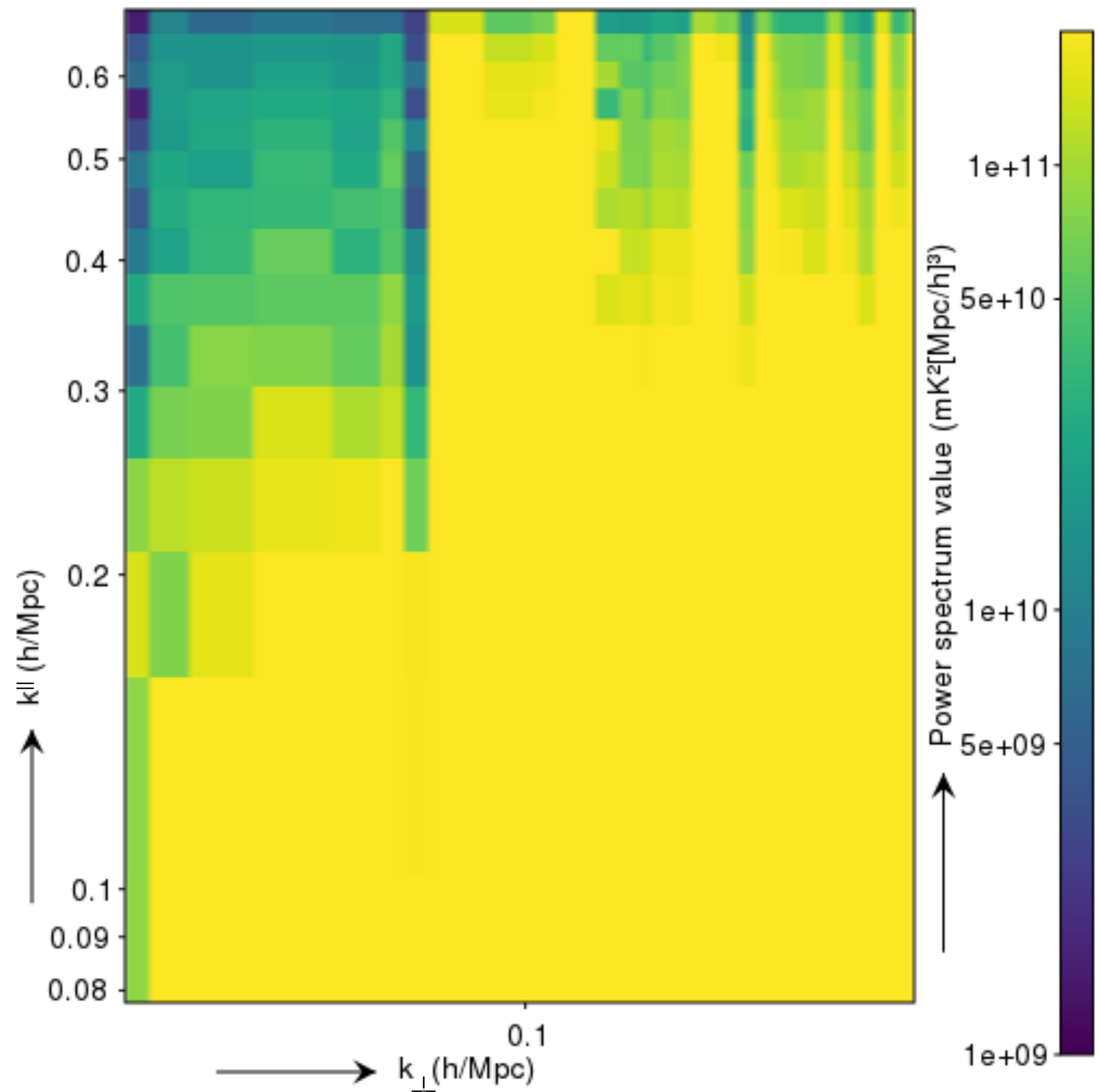
Cylindrical Power Spectrum

117 - 129 MHz (12MHz)

z bin: 10.02 - 11.12

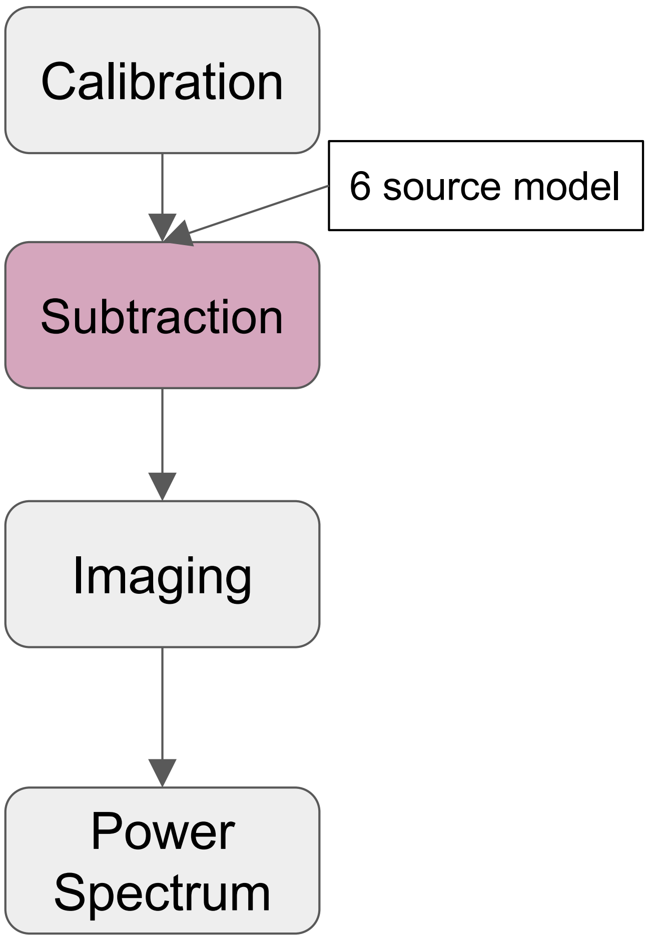


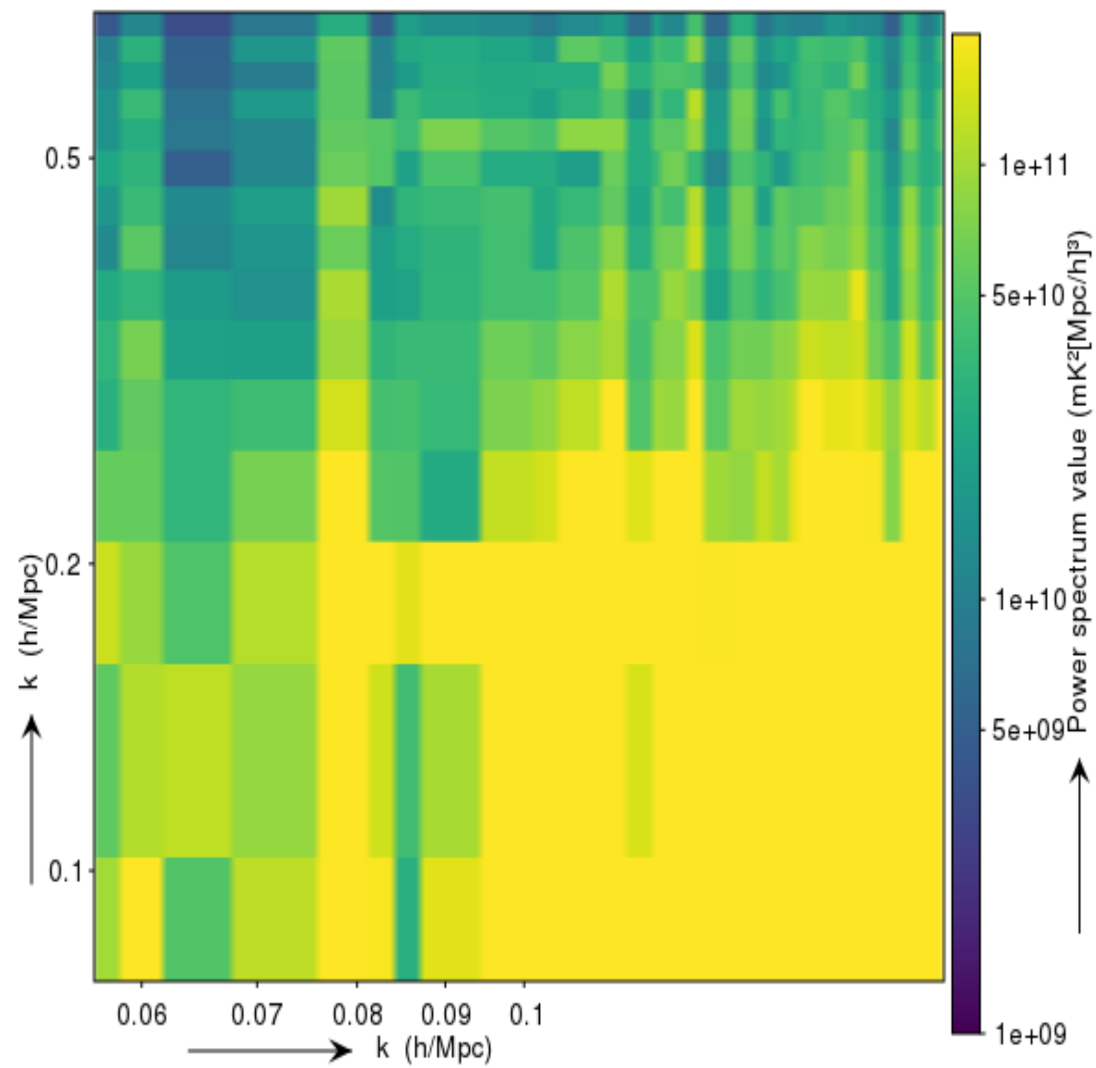
<u>No Source removal</u>



Cylindrical Power Spectrum

6 source removal





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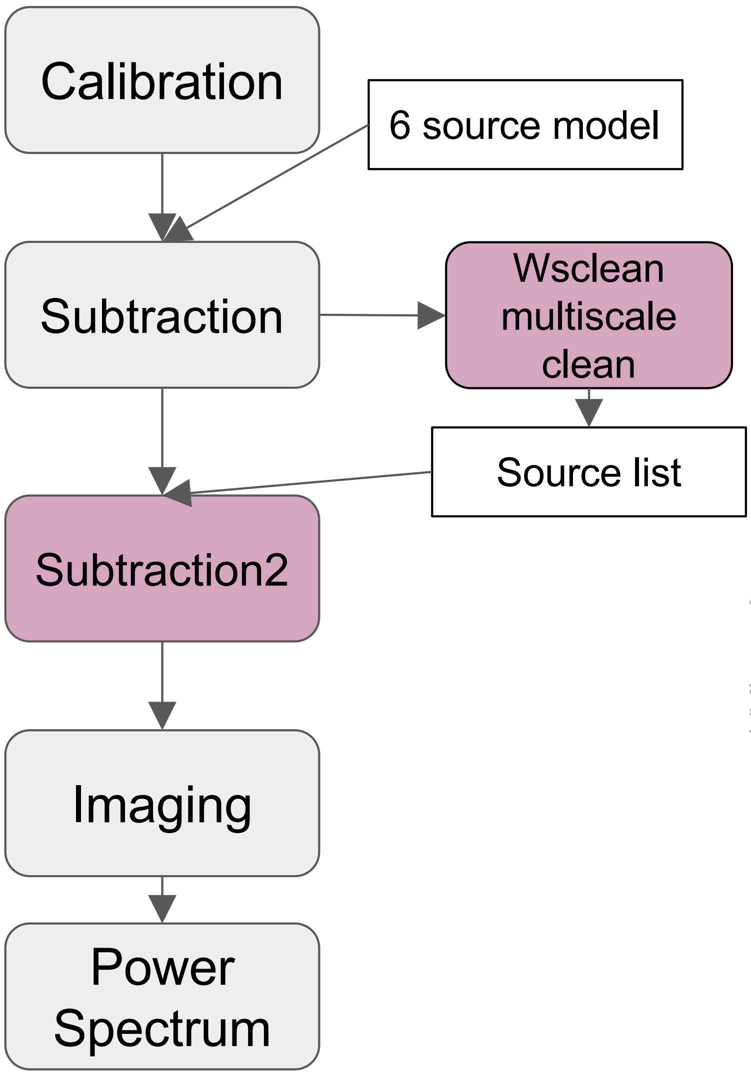
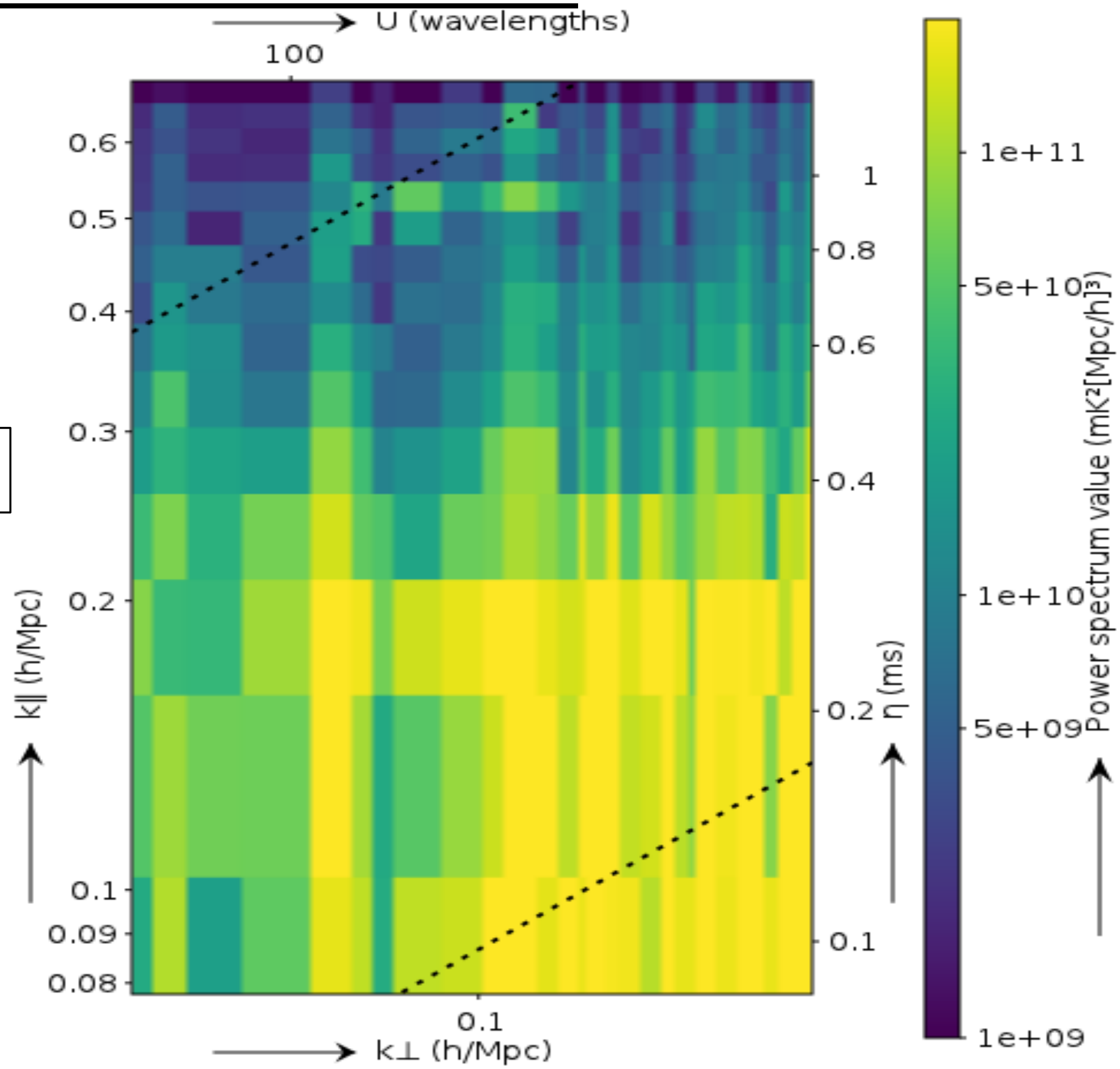
Cylindrical Power Spectrum

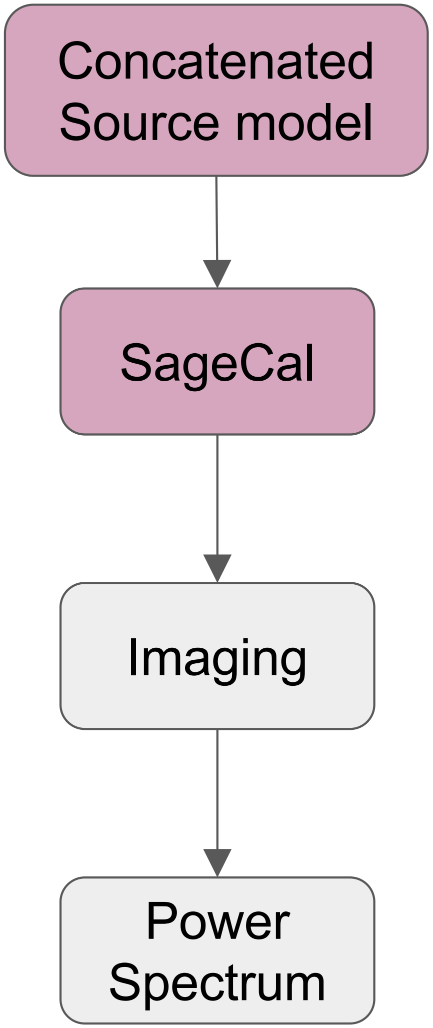
6 source & wsclean source removal

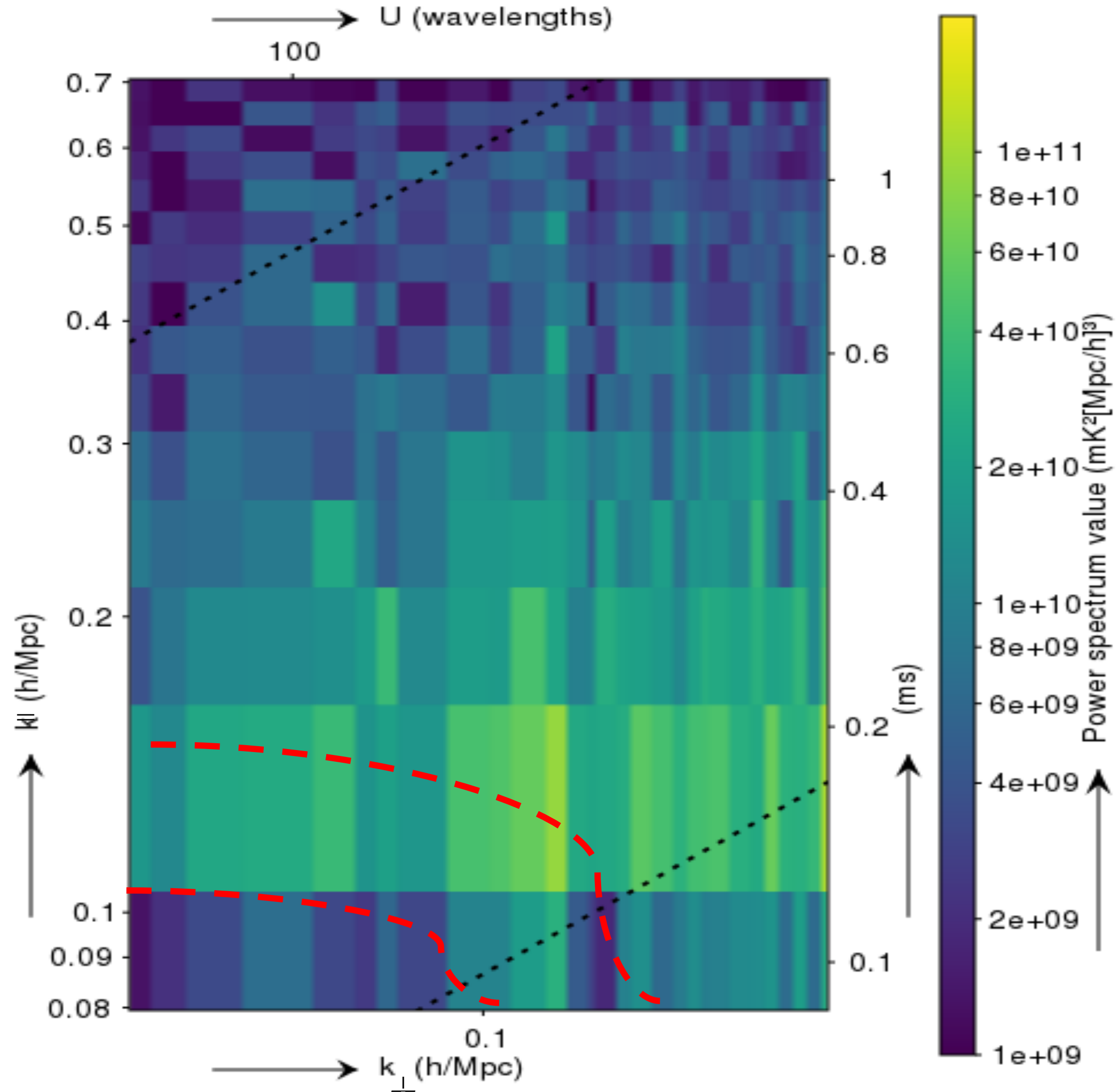




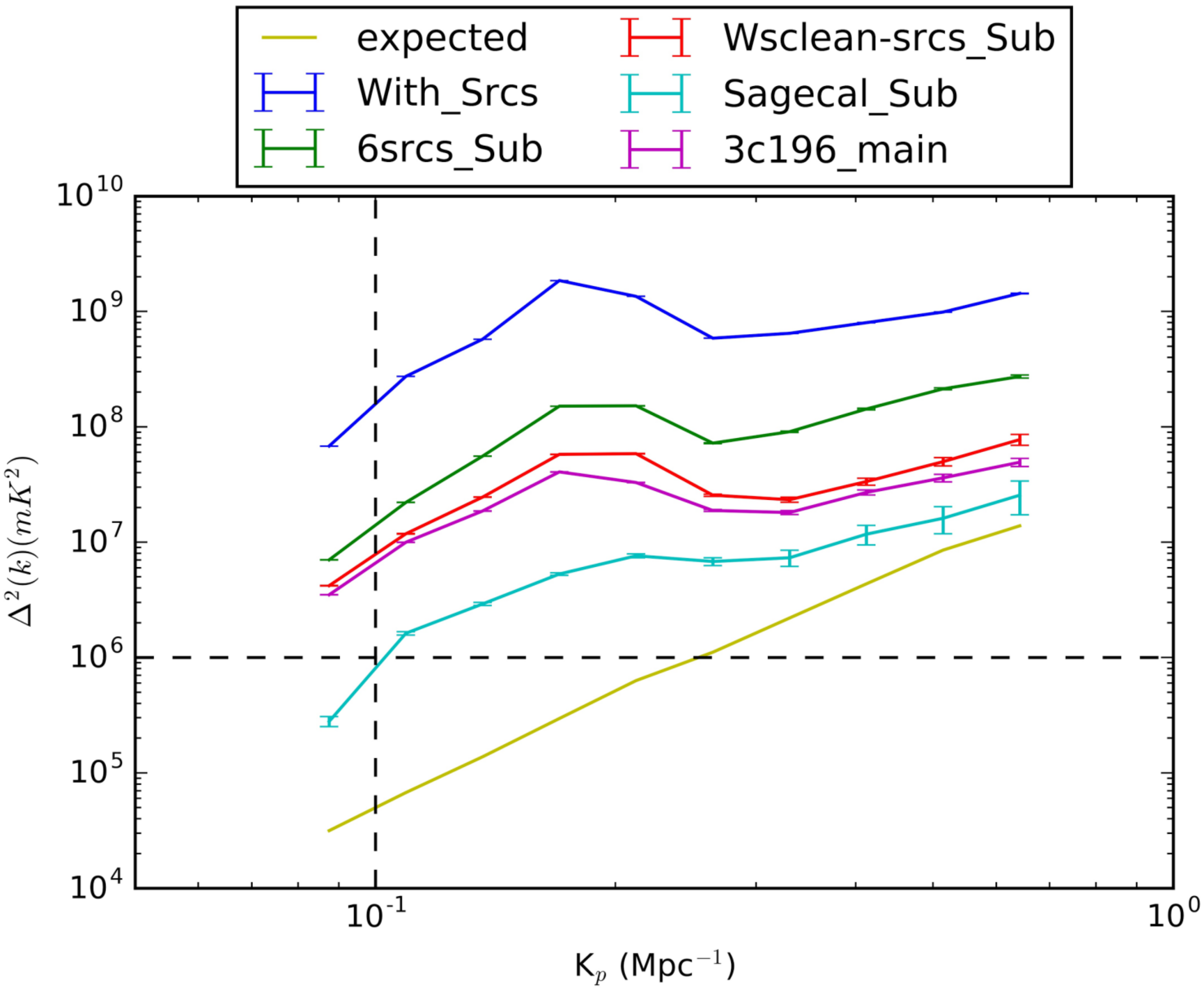
Cylindrical Power Spectrum

6 source & wsclean source ⟶ Sagecal





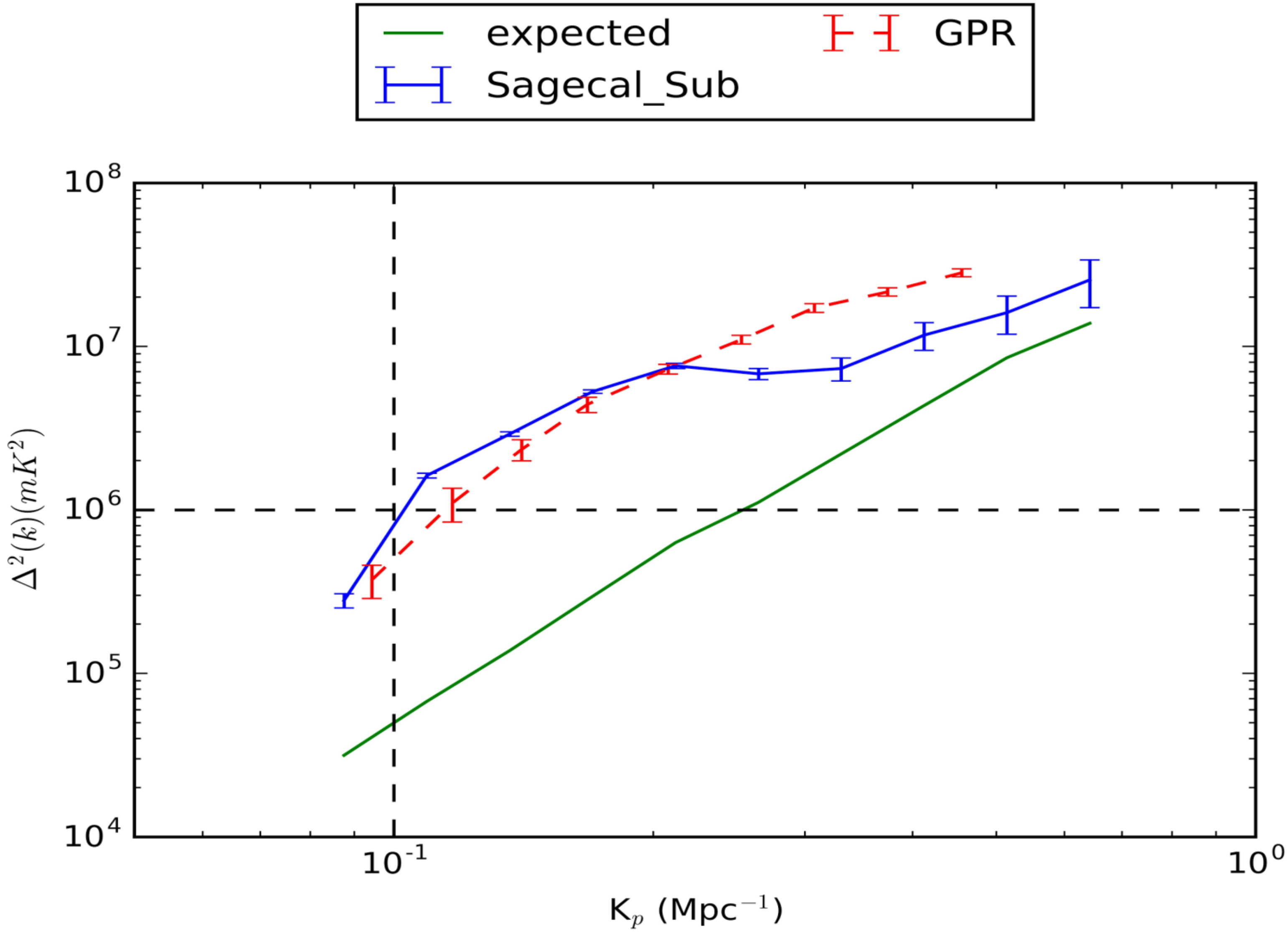
Spherical Power spectrum



The 6 bright sources gave the first big improvement in power reduction

Sagecal with the concatenated skymodel did well which was previously not seen with the main 3c196 field.

Trying Gaussian Process Regression



SUMMARY

- ★ The new hybrid approach of extracting sources - manual modelling + wsclean extraction worked quite well.
- ★ The 3c196 flanking field does look promising with:
  - Power reduction using sage cal
  - Some foreground removal with GPR.

<u>Work in Progress:</u>

- ➢ Calibration with more sources
- ➢ Improve the foreground models
- ➢ Run sagecal with more sources
- ➢ Investigate the power spectra with GPR foreground removal.

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Thank You!

Backup Slides

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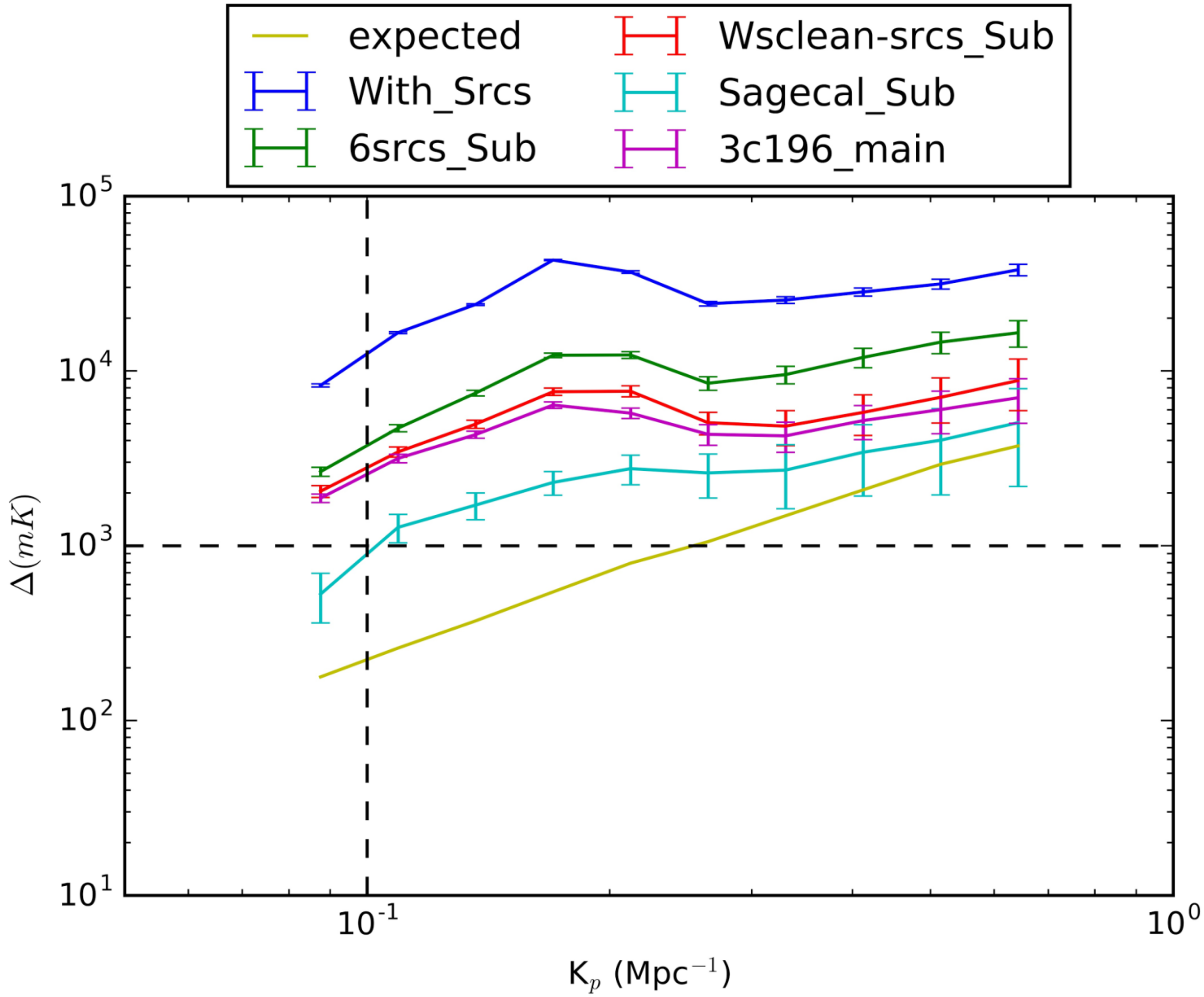
Spherical Power spectrum



The 6 bright sources gave the first big improvement in power reduction

Sagecal with the concatenated skymodel did well which was previously not seen with the main 3c196 field.

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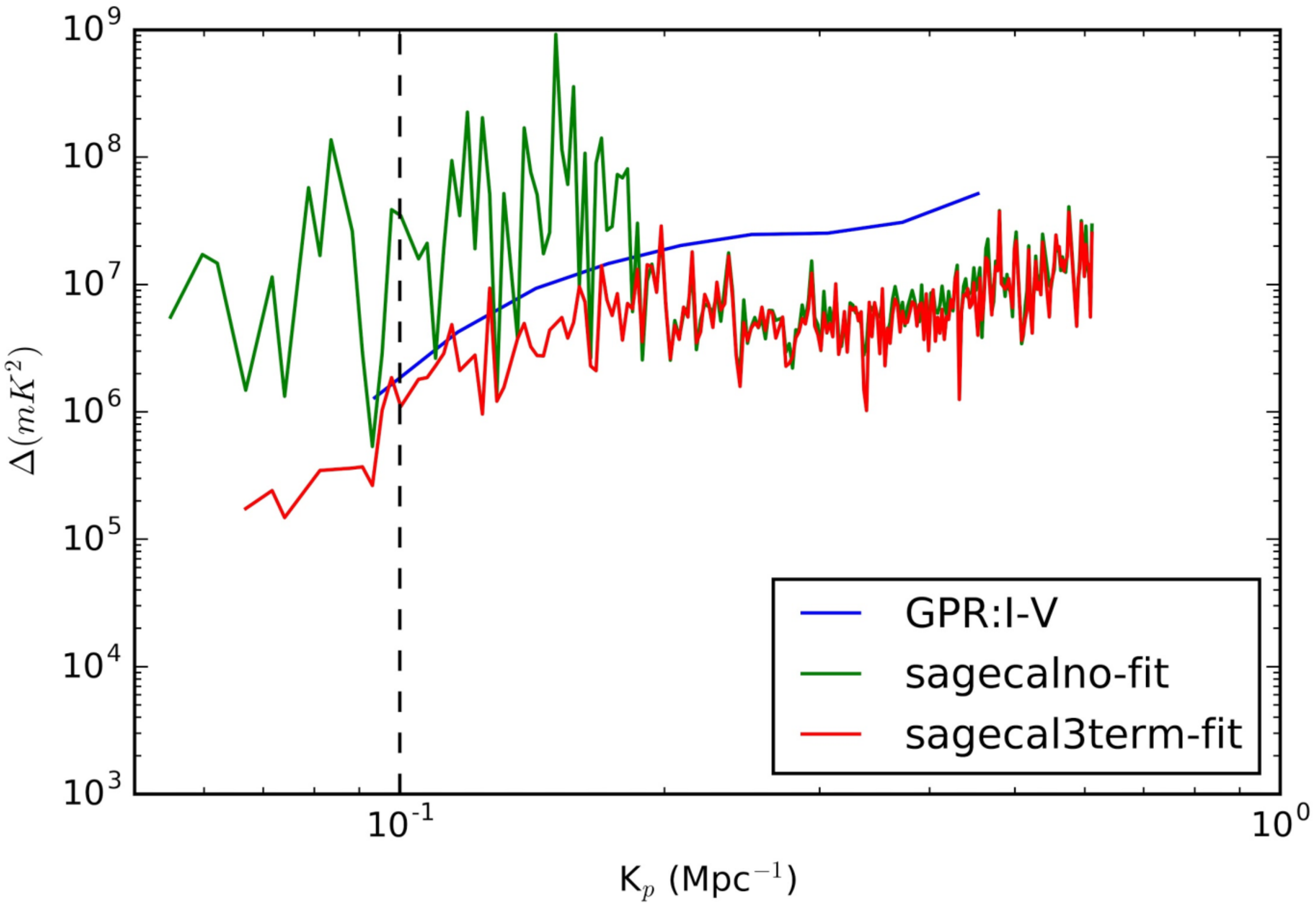
Comparing GPR & Pstransform



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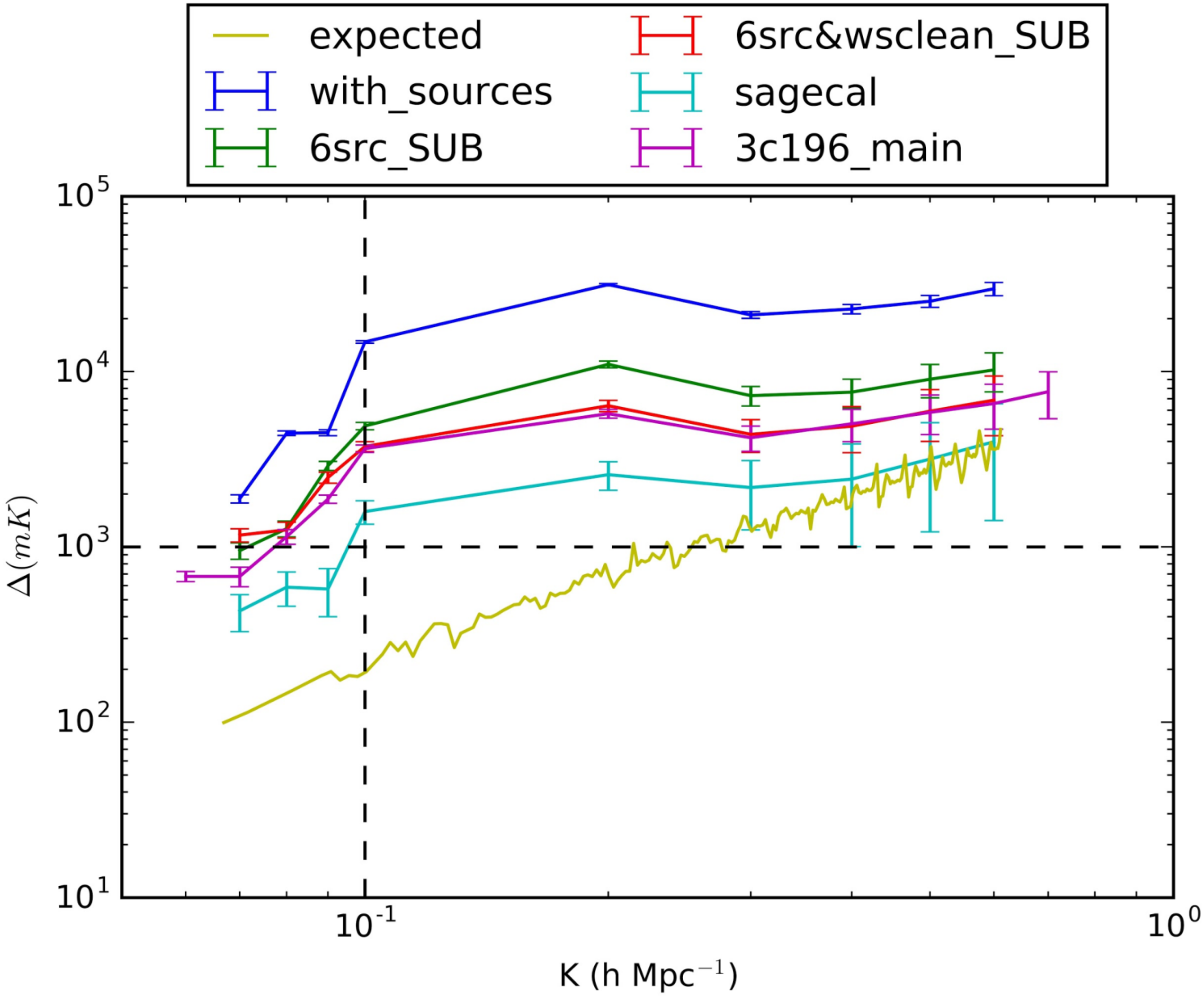
Spherical Power spectrum

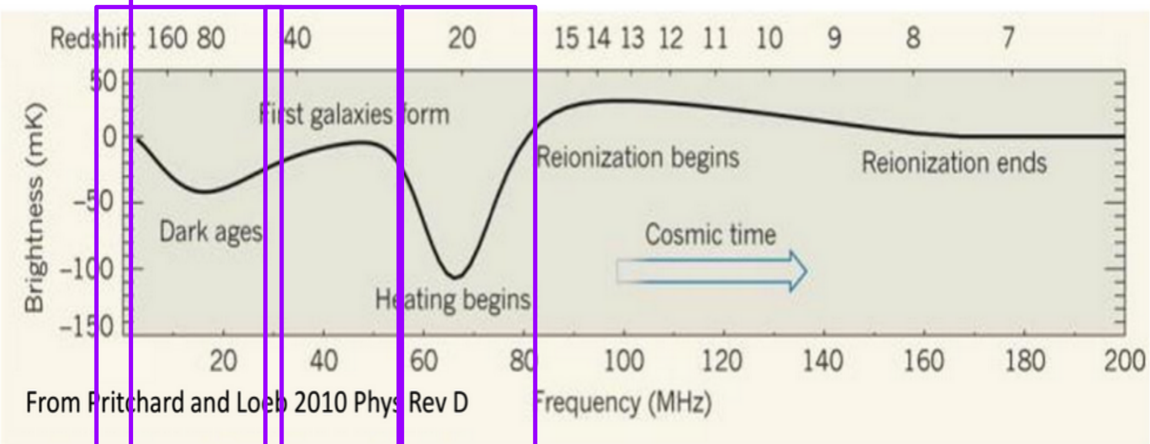


Just the Wsclean model did as well as the concatenated model

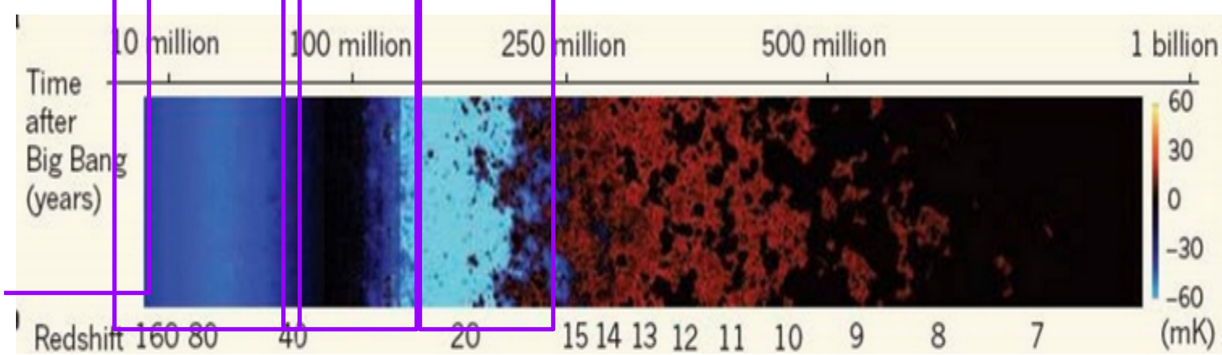
Probing High redshift 21 cm

Signal Element approach
Globally averaged temperature

$$T_b \propto (T_S/T_{cmb} - 1)\, X_H$$



Interferometric approach
Statistical detection - Power spectrum



Overview of the Program

Lec

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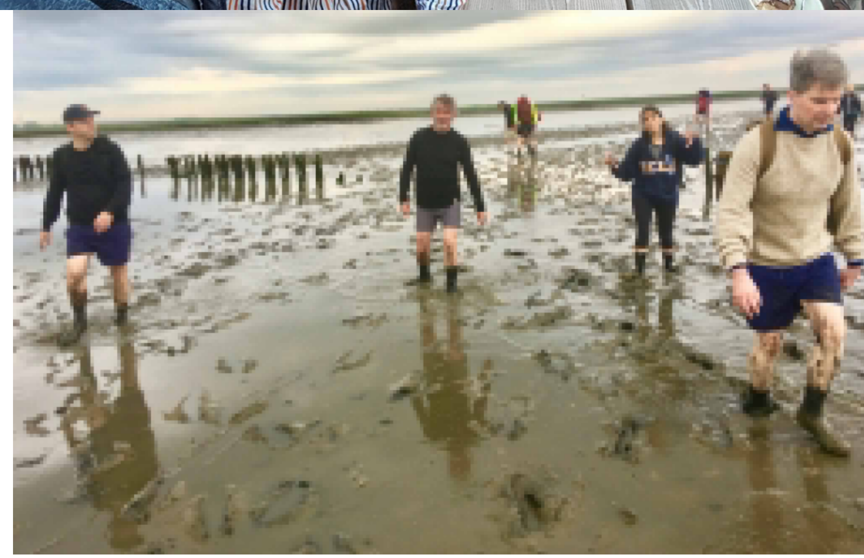
6.

Overview of the Program



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Why Reionization?

Thermal history of the universe requires it:
– Expansion and adiabatic cooling implies recombination of the IGM at z ~ 1100.

97% of the IGM now is ionized
– Transmission of UV light from nearby quasars requires a largely ionized IGM at z ~ 0 (indeed, up to z ~ 6)

Probes of EoR

- Lyman α Forest in High redshift Quasars (Gunn-Peterson Effect)
- CMB Polarization
- 21cm Hydrogen spin flip

Physics of EoR

Probing the re-ionized regions using the 21cm signal from the neutral hydrogen

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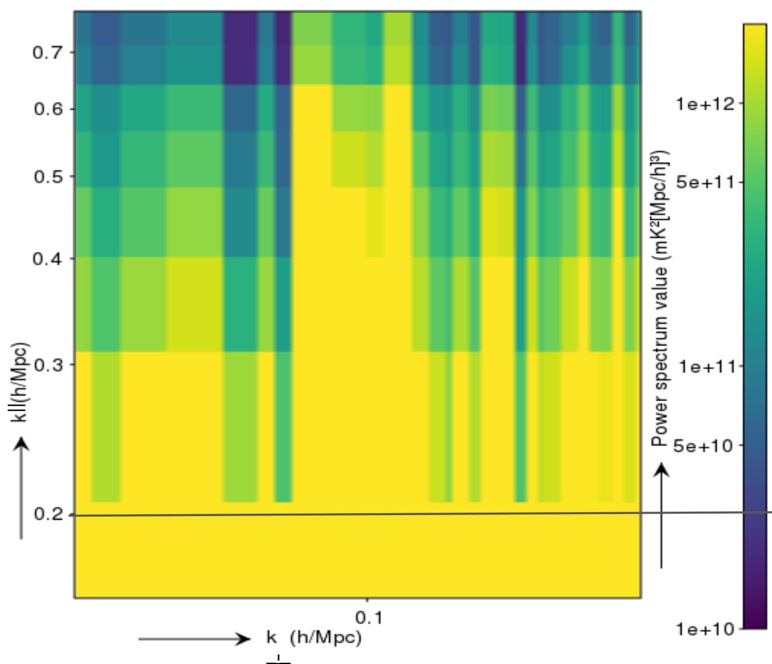
Comparing Frequency Ranges

117 - 123 MHz (6MHz)

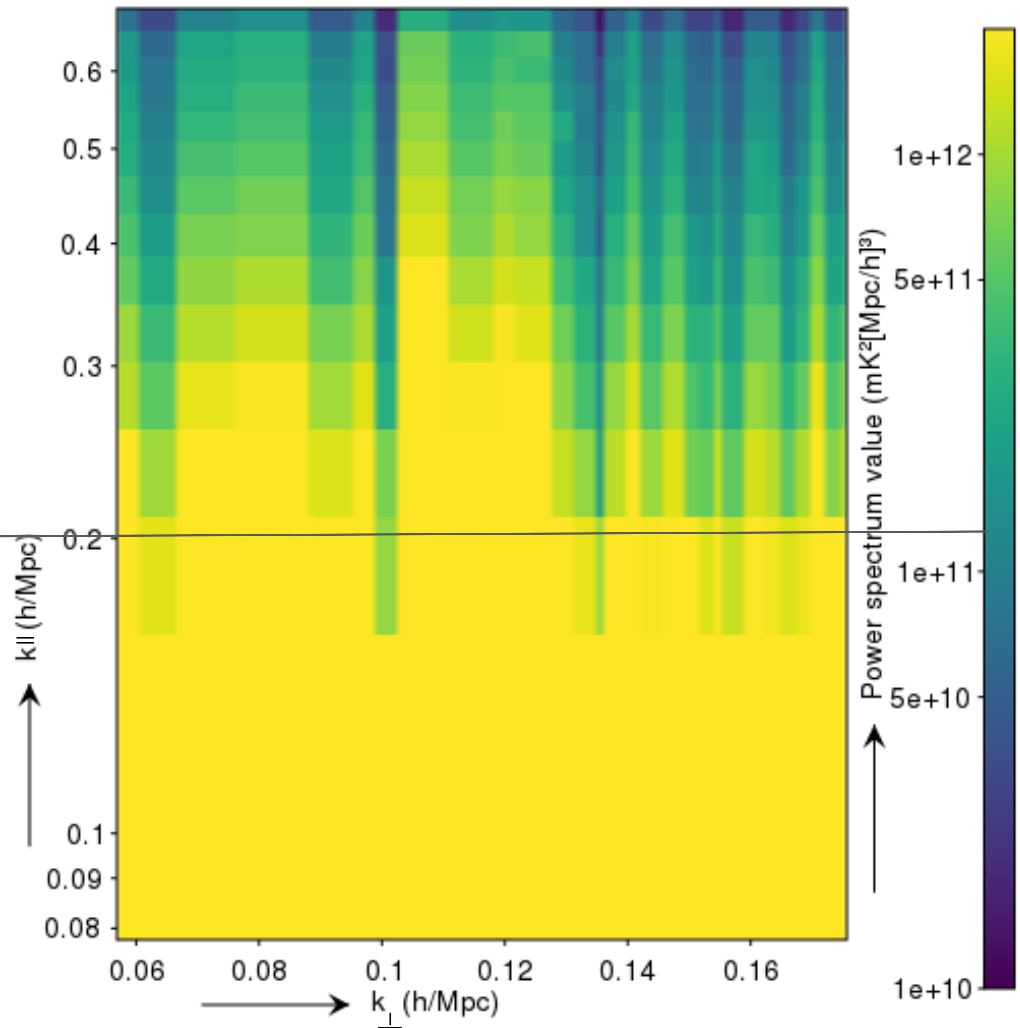
z bin: 10.56 - 11.12



Increased bandwidth ⇒ more lower $K_{||}$ power

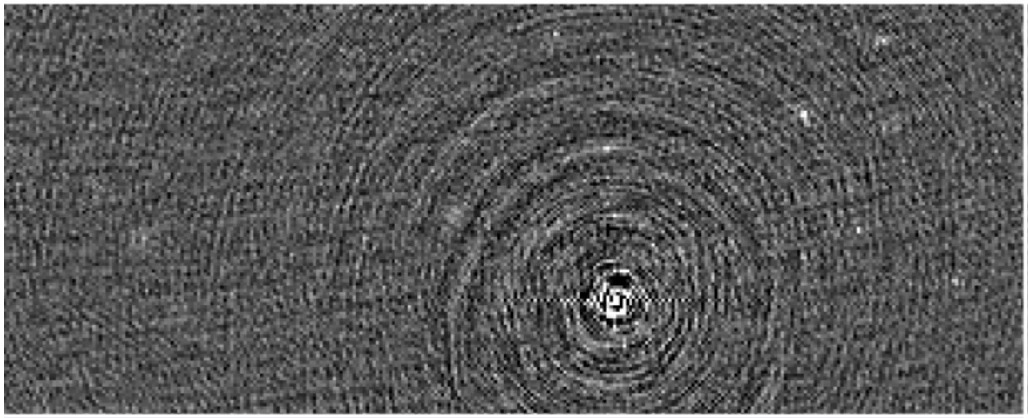
117 - 129 MHz (12MHz)

z bin: 10.02 - 11.12

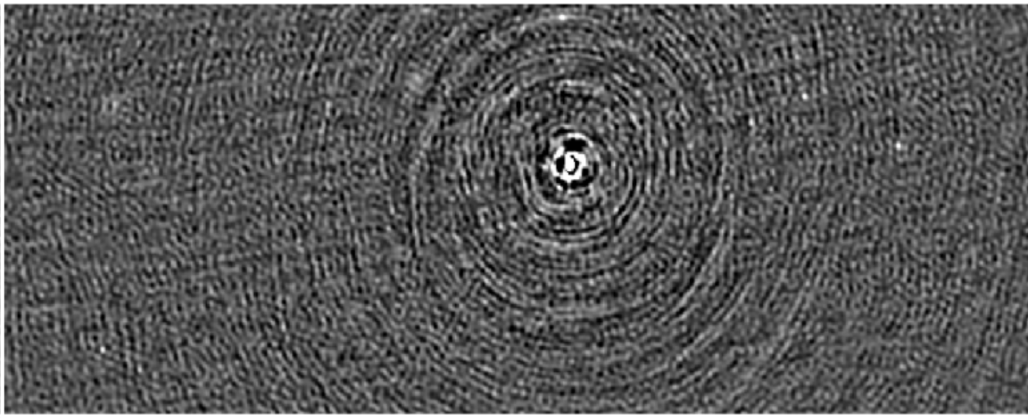


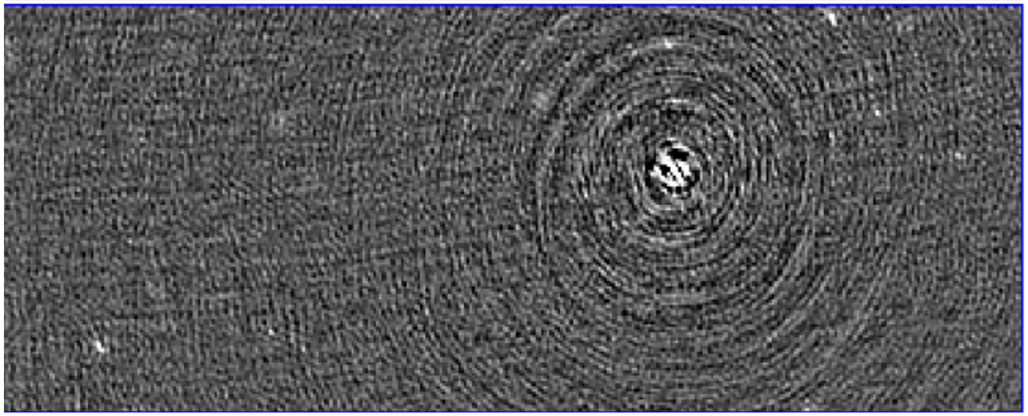
Pixel resolution Vs beam resolution

Beam size = 28” pixel = 20”



Beam size = 39.46” pixel = 10”





Beam size = 39.16” pixel = 20”

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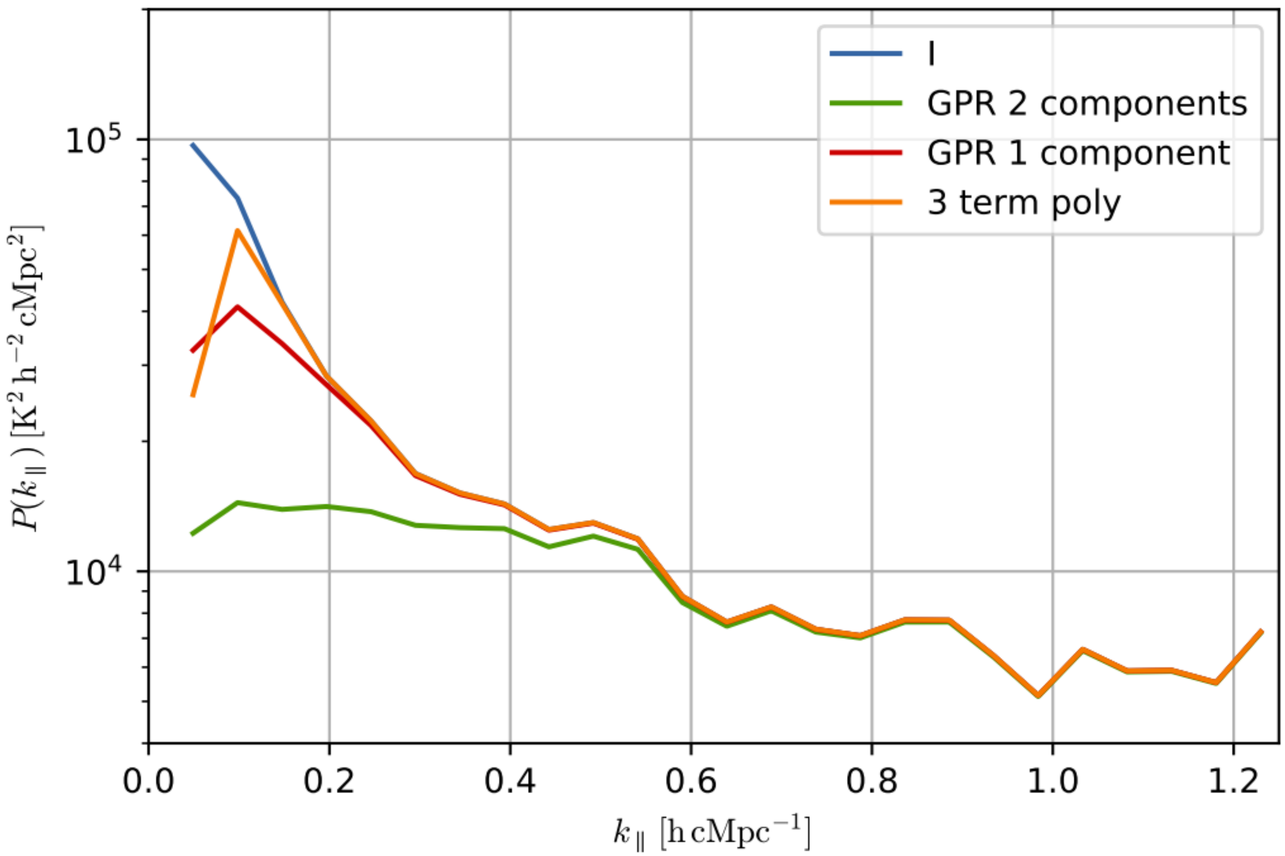
Current Interferometer Experiments

Comparing Gaussian Process Regression & Polynomial fit



Vertical cut along the cylindrical averaged Power spectra.

$K_{||}$ Vs power.

GPR does a good job of removing power at low $K_{||}$ where the foreground is dominant

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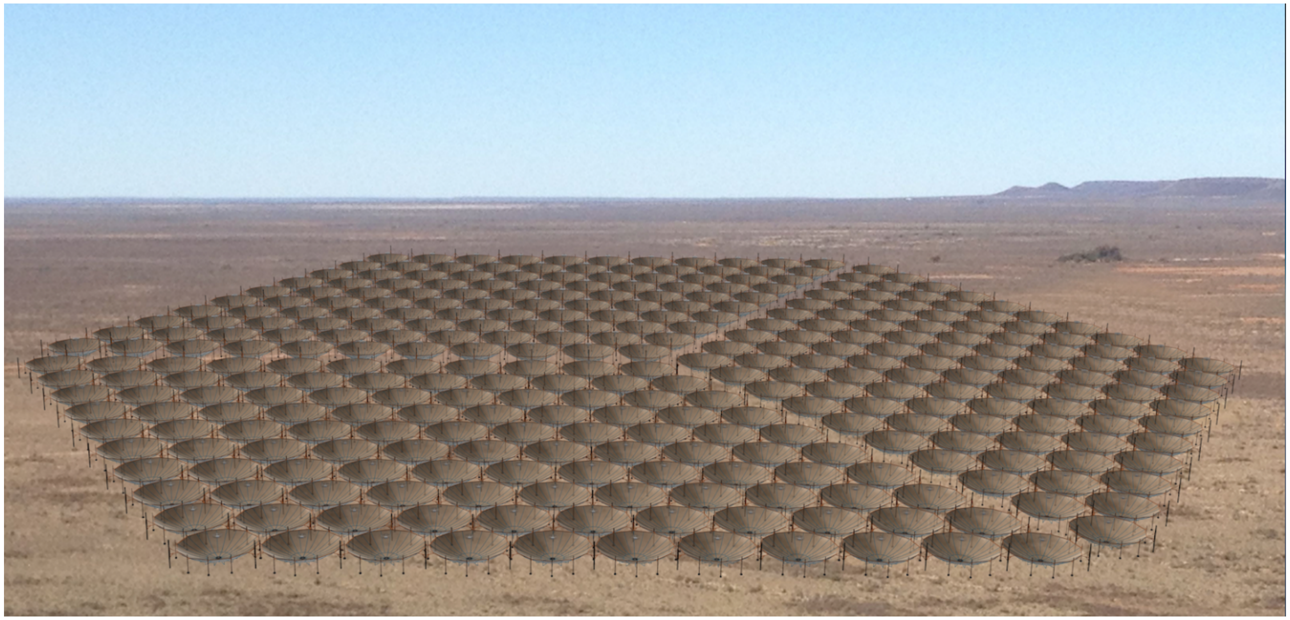
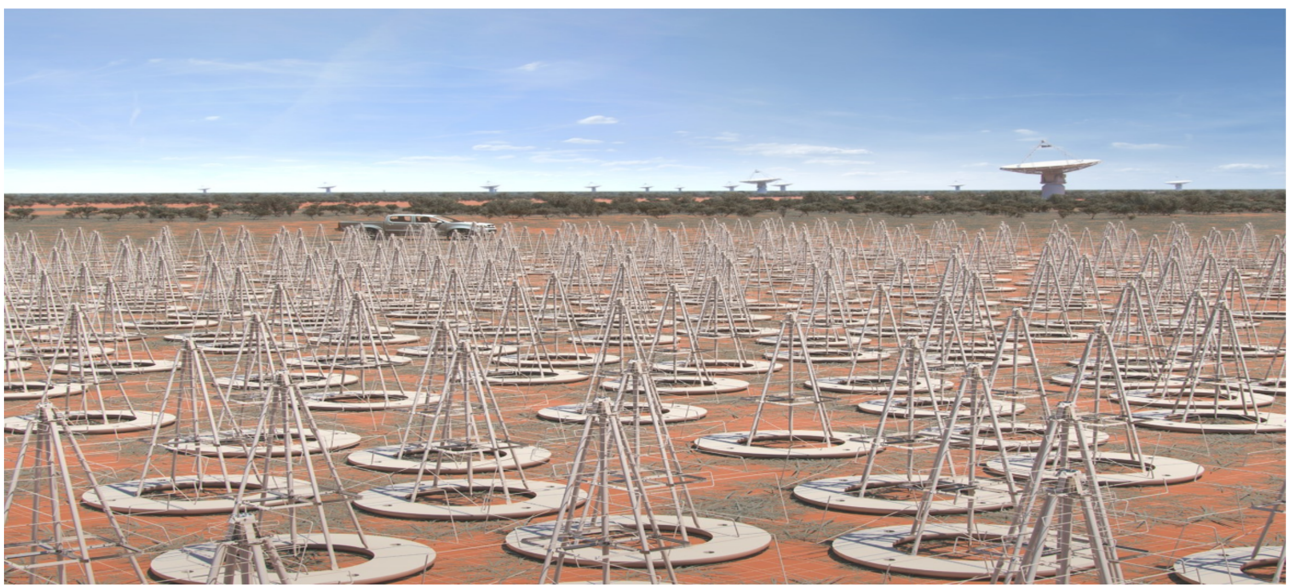
Future Interferometer Experiments

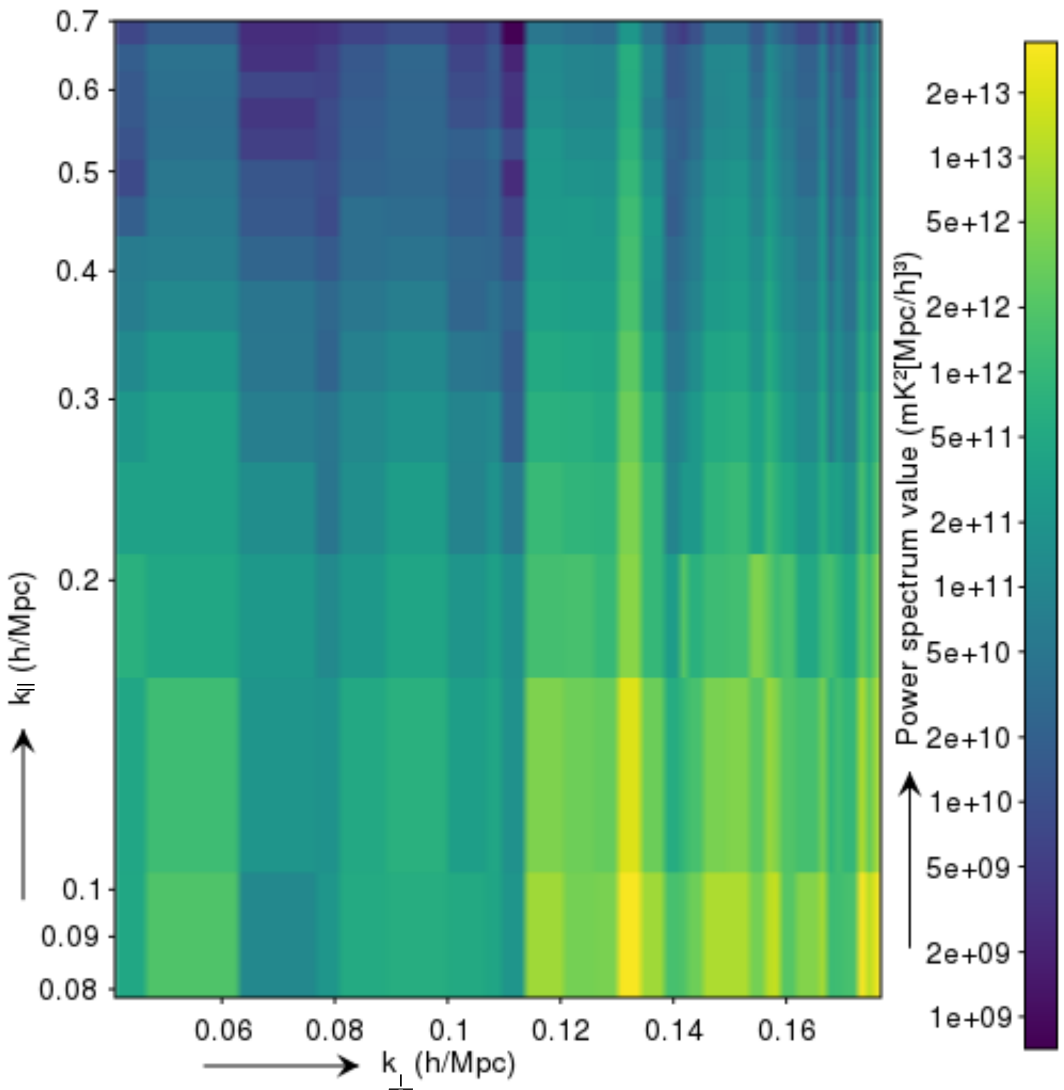


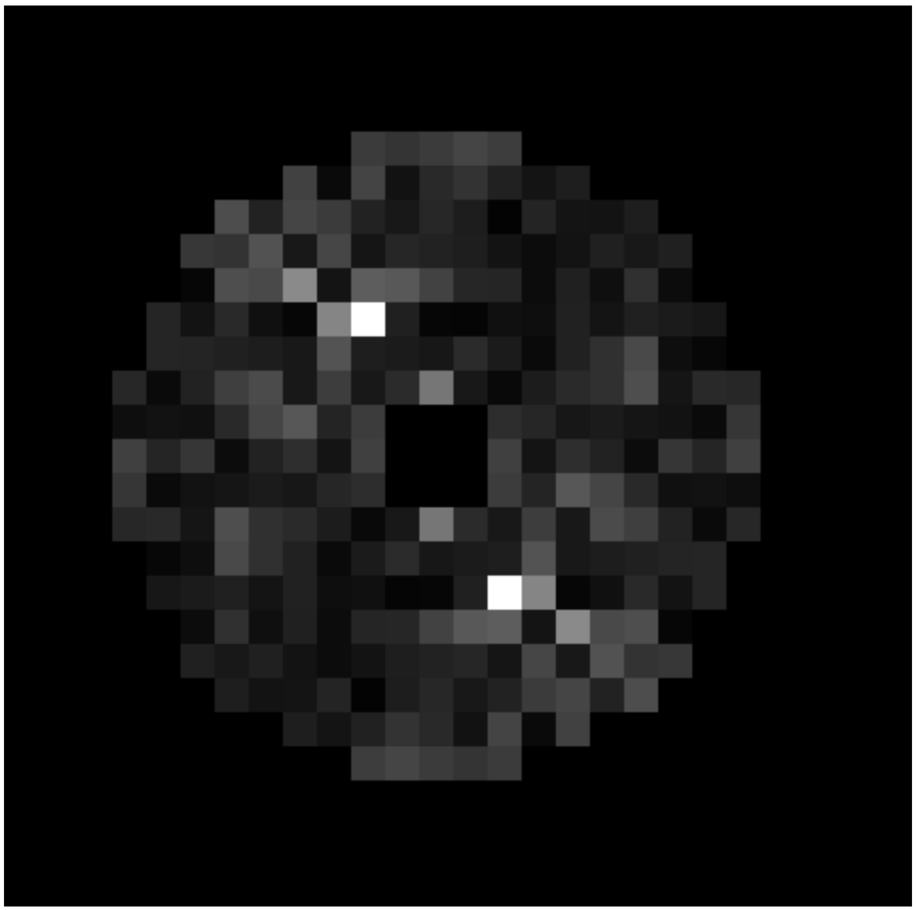


- ➢ Direct imaging instead of Statistical detection
- ➢ Compact core ⇒ increased sensitivity
- ➢ Lower frequency ⇒ Larger redshifts

Analysing the pstransform plots

Minuv clipped to 50 in Pstransform





UV plane