Neutral hydrogen intensity mapping on Mpc scales with MeerKAT interferometer

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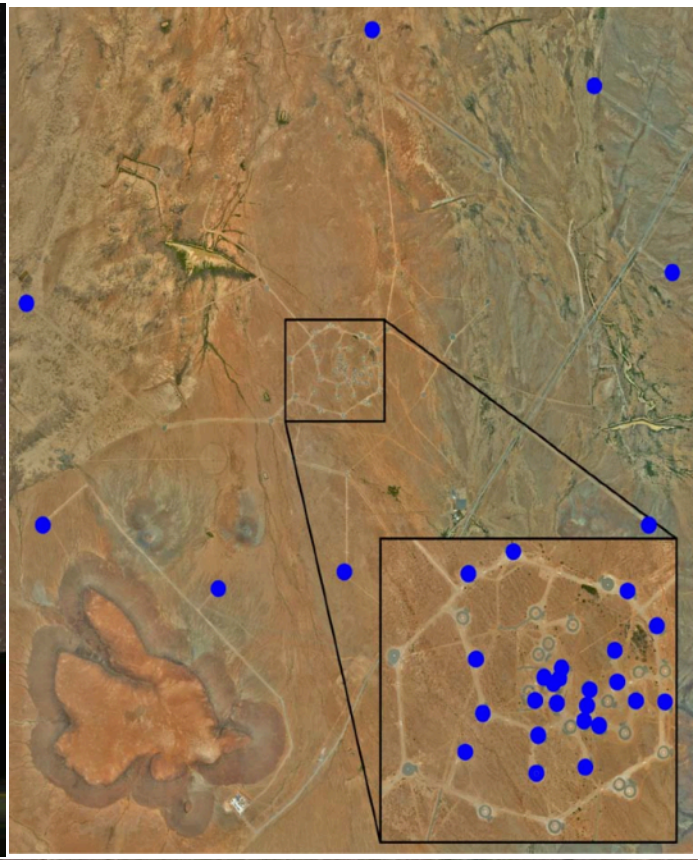
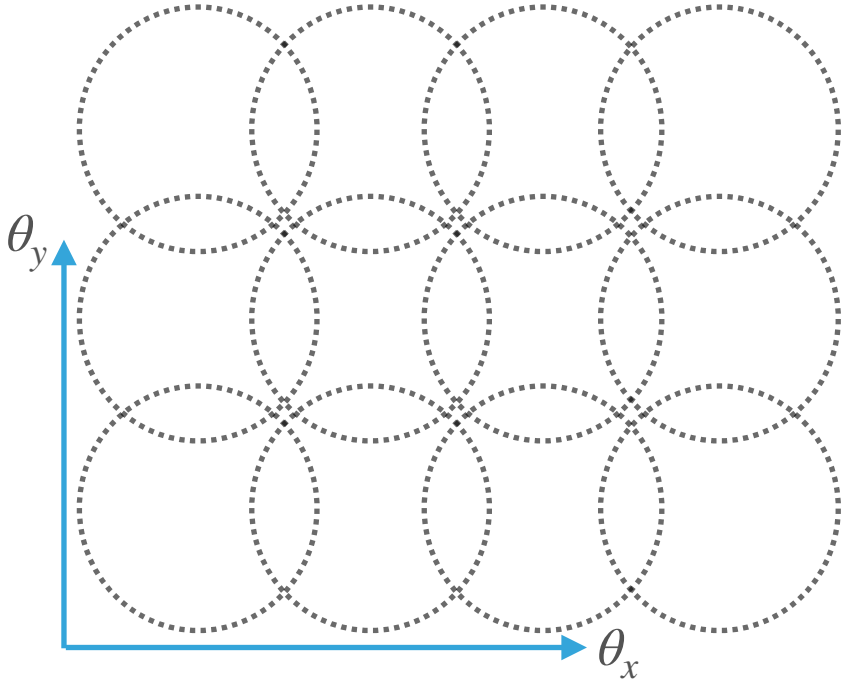
MeerKAT Radio telescope



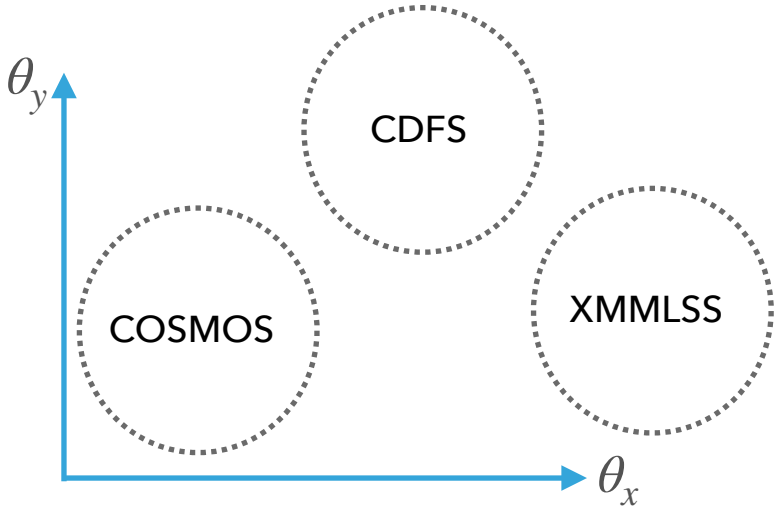
- MeerKAT, precursor to SKA, managed by SARAO. Located in the Karoo region, South Africa.
- 64 dish antennas of 13.5 meter diameter.
- Central core region of 1km houses 48 antennas, other 16 antennas are distributed upto a radius of 4km from the center.
- Dense core facilitates higher sensitivity at low $k_\perp$ modes.
- L-band range: 856 ~ 1712 MHz.
- UHF-band range: 544 ~ 1087 MHz.

(https://www.sarao.ac.za/gallery/meerkat/)

Single Dish & Interferometric IM (MeerKAT)

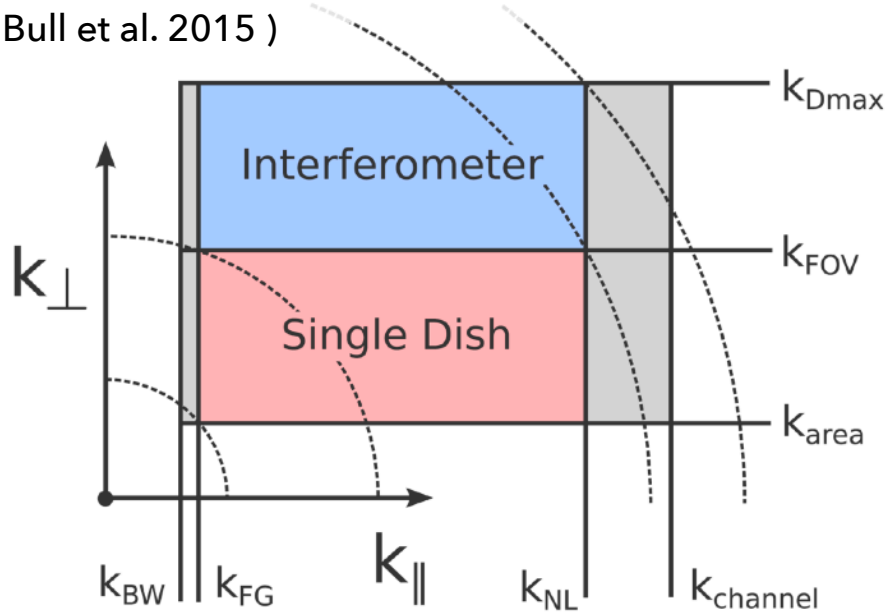


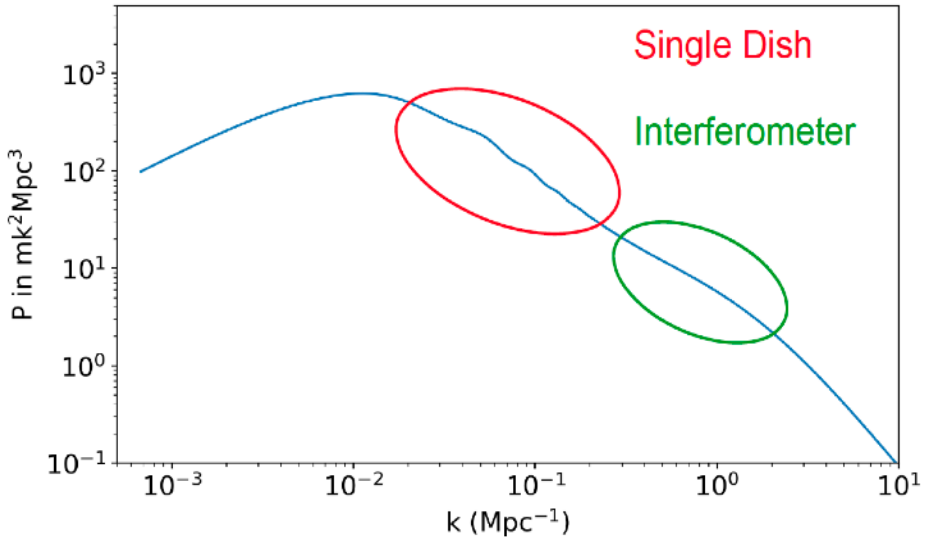
Single Dish



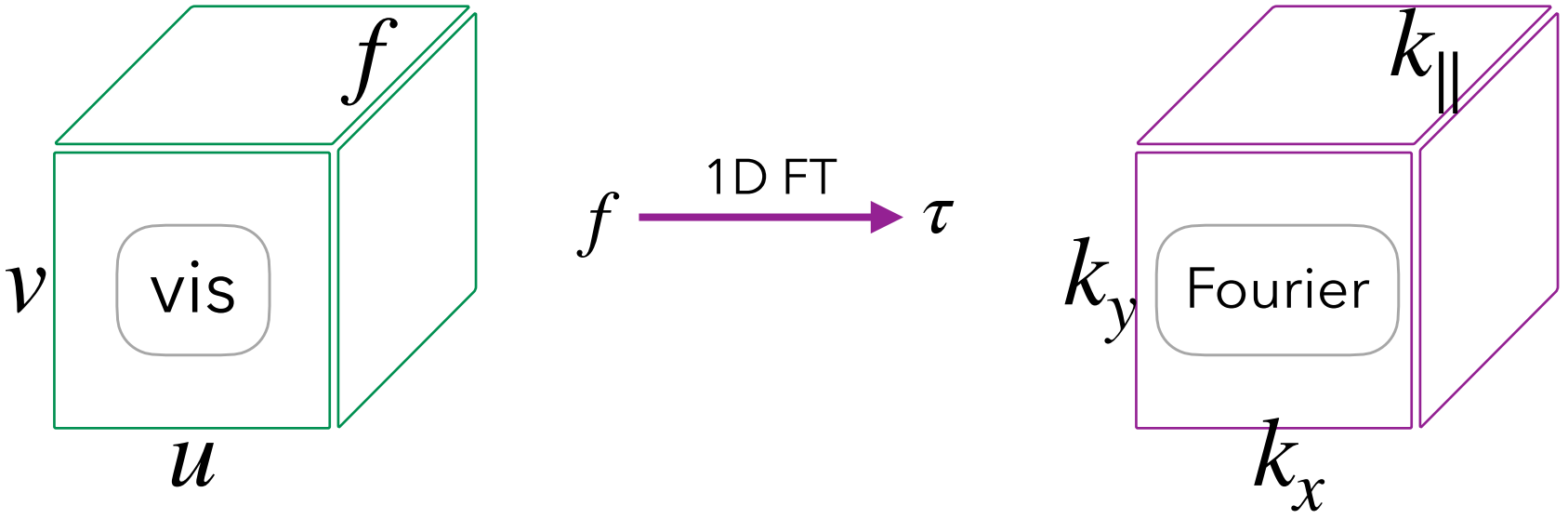
Interferometer

(Bull et al. 2015)





Power Spectrum from visibility data

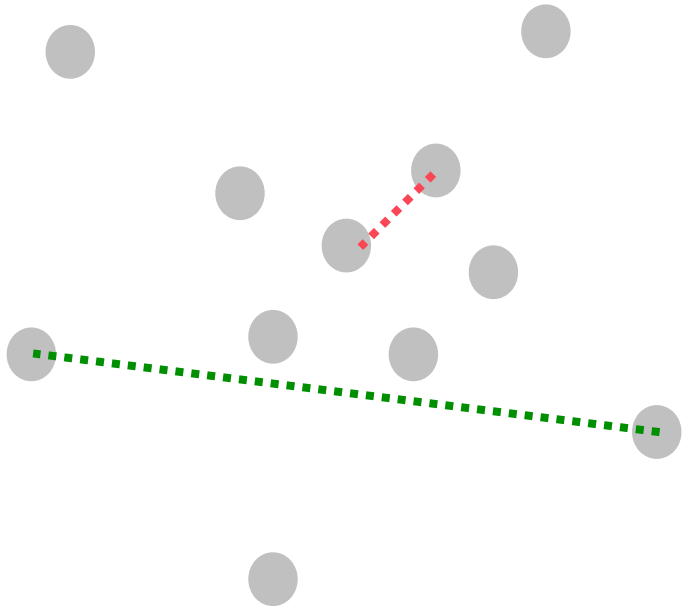


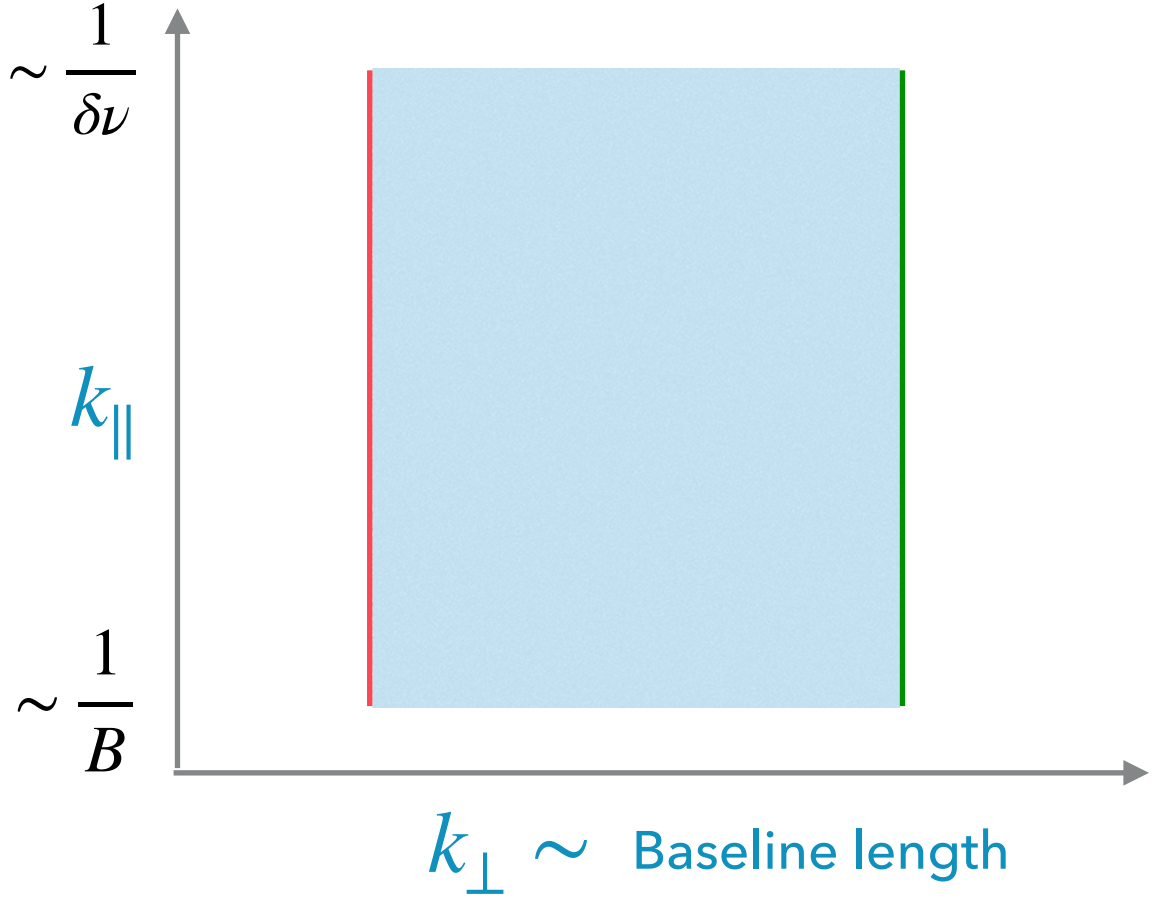
$$k_x = \frac{2\pi}{R} u \; ; \qquad k_y = \frac{2\pi}{R} v \; ; \qquad k_{\parallel} = \frac{2\pi \nu_{21} H_0 E(z)}{c(1+z)^2} \tau$$

Delay PS

$$P\left(k_{\perp}, k_{\parallel}\right) \equiv \frac{A_e}{\lambda^2 B} \frac{R^2 \Delta R}{B} \left| V(u, v, \tau) \right|^2 \left(\frac{\lambda^2}{2 k_B} \right)^2$$

Power Spectrum from visibility data

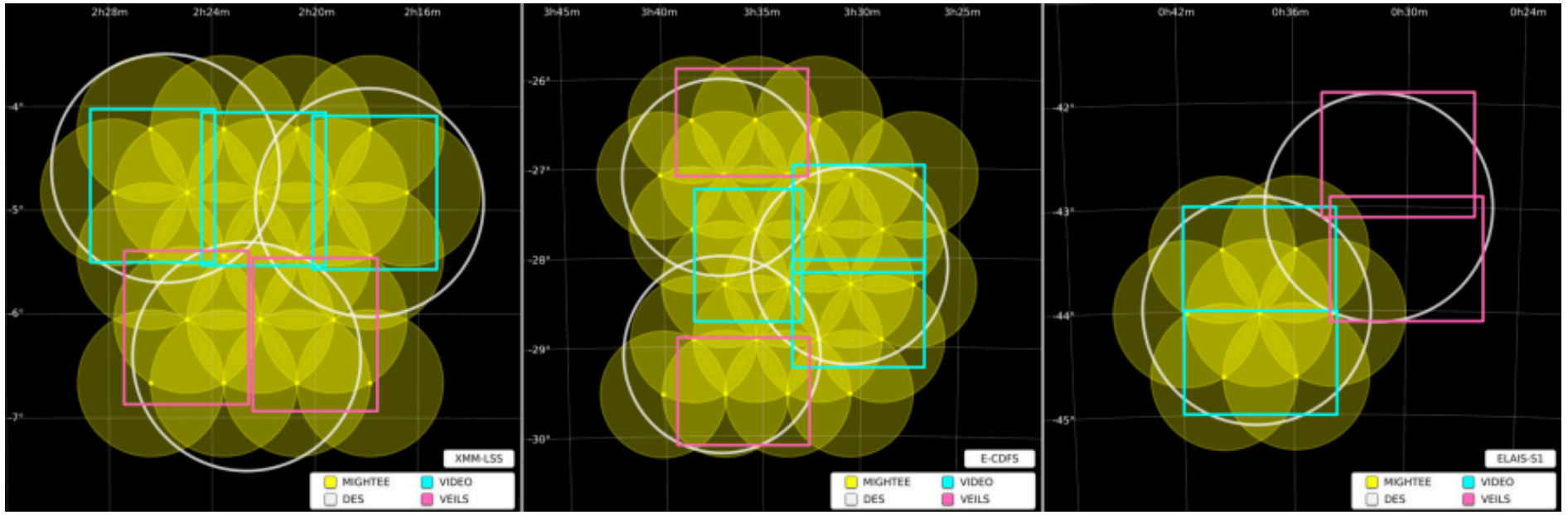




MIGHTEE

(MeerKAT International GHz Tiered Extragalactic Exploration)

- 20 square deg sky area, L and UHF bands
- COSMOS, CDFS, XMMLSS, ELAIS-S1, ~ few thousand hours



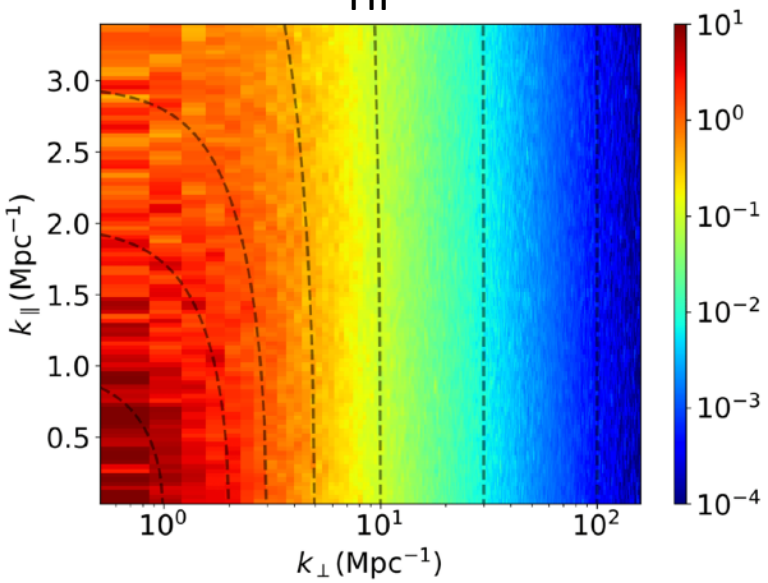
XMMLSS CDFS ELAIS-S1

https://www.mighteesurvey.org/

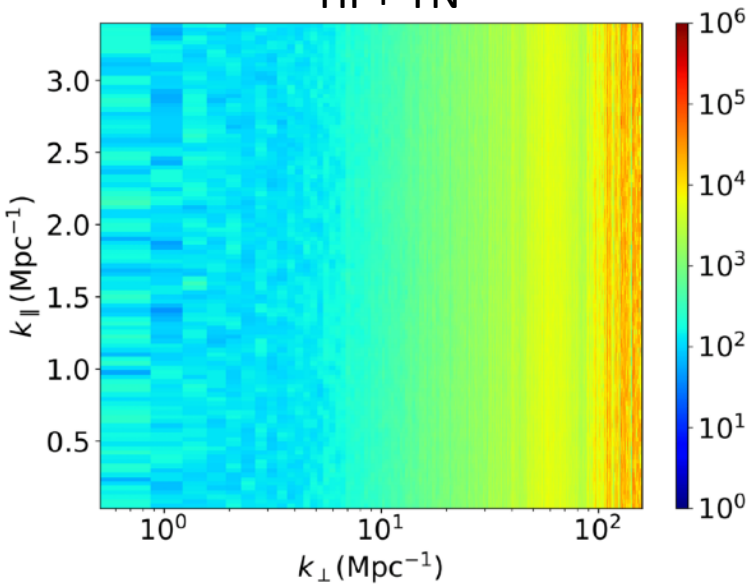
IM with MeerKAT interferometer

2d Power spectrum, 11.2 hours: $P(k_\perp, k_\parallel)$ [mk²Mpc³]

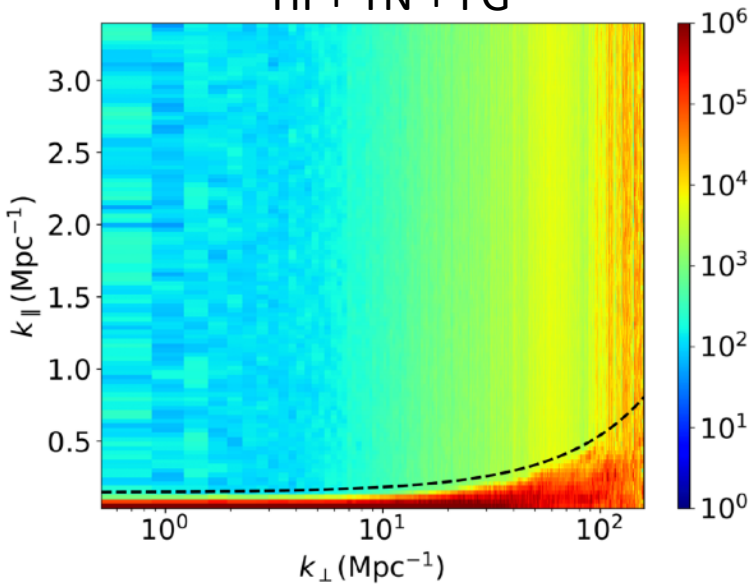
HI

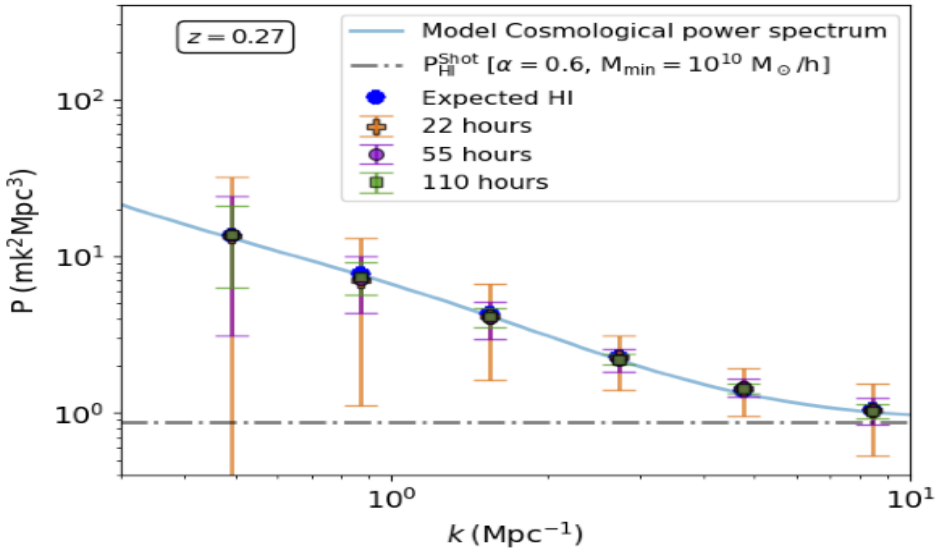


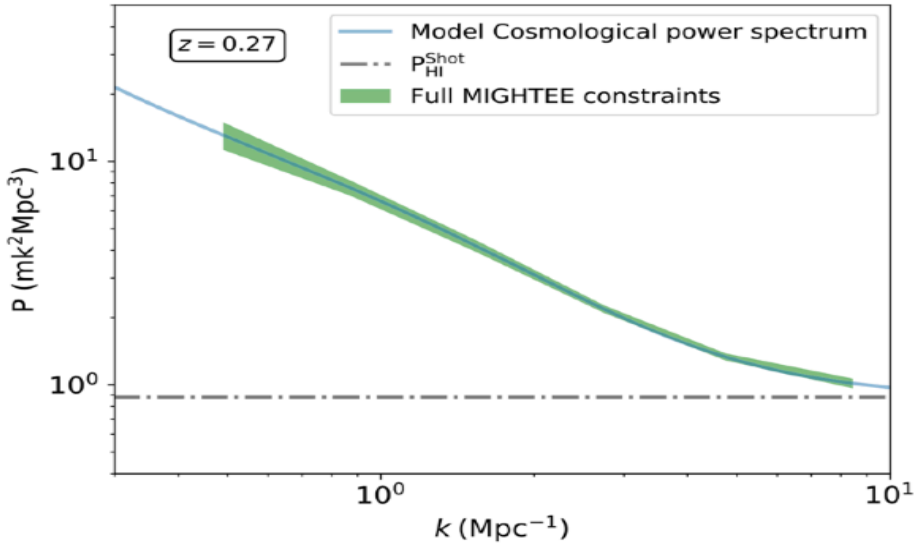
HI + TN



HI + TN + FG







Full MIGHTEE (COSMOS, CDFS, XMMLSS, ELAIS-S1) 20 square degrees, ~ 1000 hrs observation time

HI intensity mapping with the MIGHTEE survey: power spectrum estimates
Paul, Santos et al., 2021, MNRAS, 505, 2, 2039

Long integration time, avoid bright foreground sources

Data used ~ 96 hrs (9 observing sessions, > 58 antennas)

J2000 $\alpha = 04^{h}13^{m}26.4^{s},\ \delta = -80°0'0''$

Time resolution: 8s

Frequency resolution: 0.209MHz

Calibration: processMeerKAT + selfcals

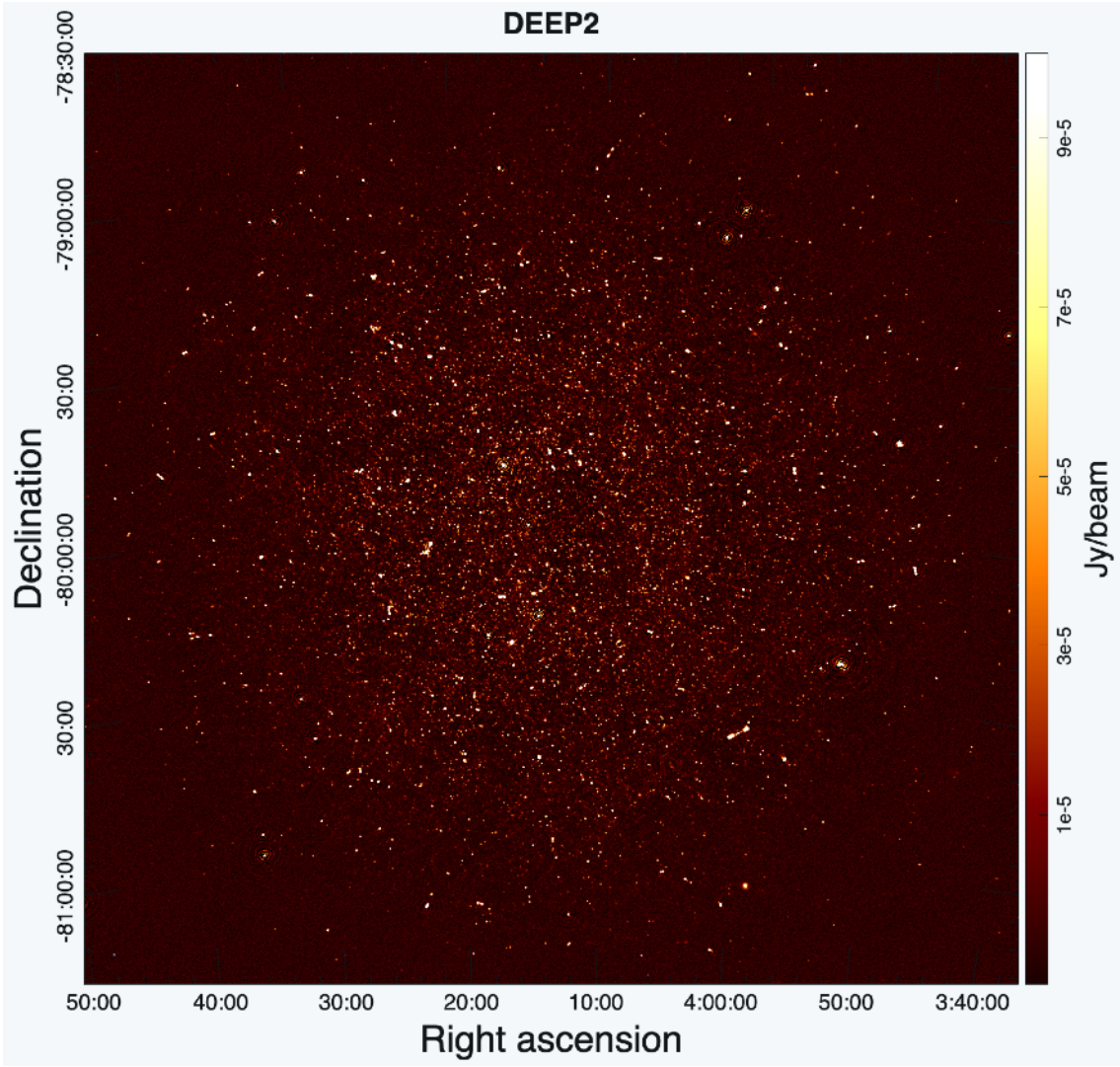
Bandwidth: 950 ~ 1170 MHz

RMS: 3 μJy/beam

Target scan duration: 15 mins

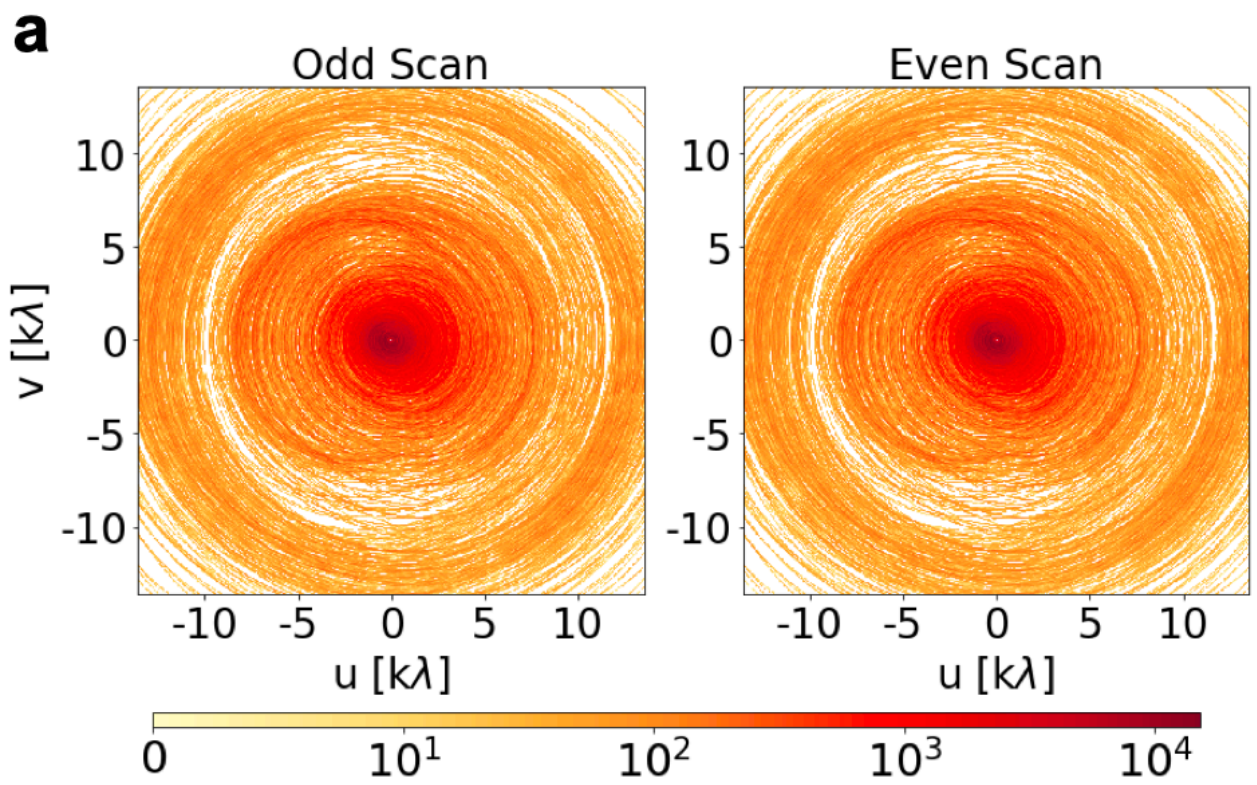
Two sub-bands: 1078 MHz (z ~ 0.32)

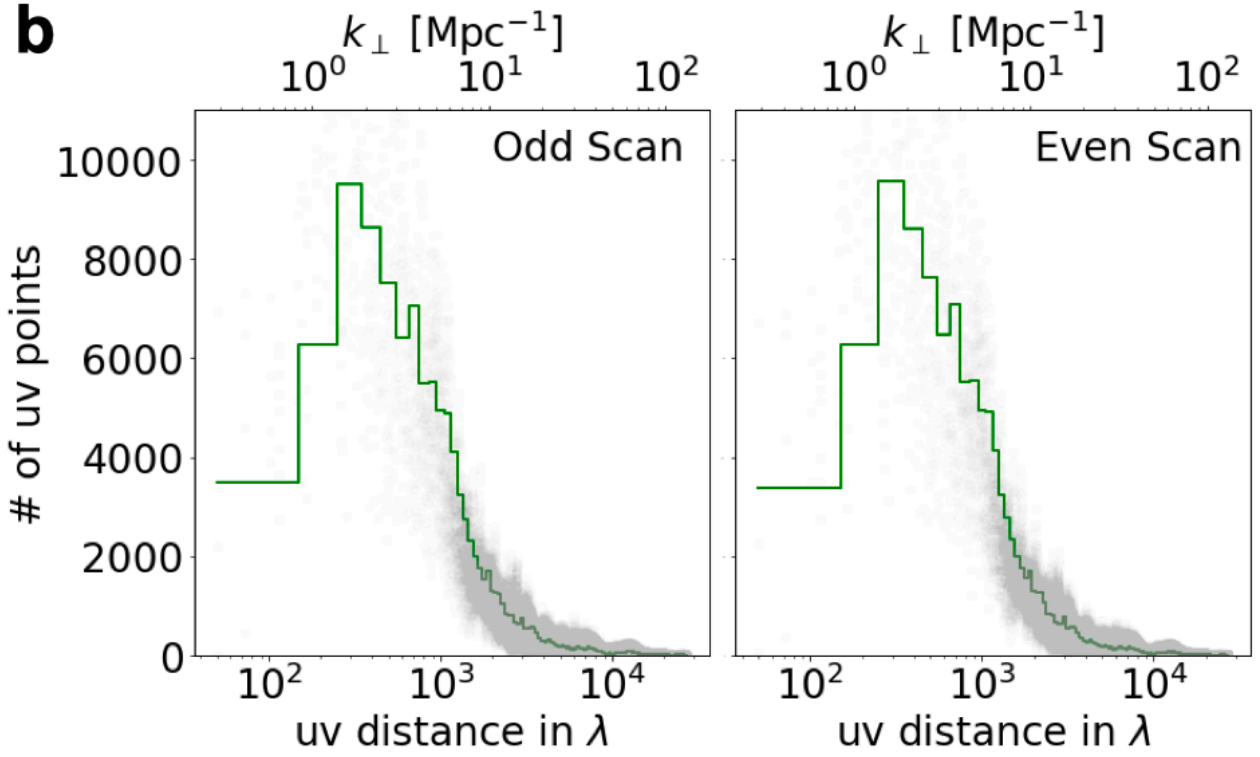
(46 MHz) 986 MHz (z ~ 0.44)



A first detection of neutral hydrogen intensity mapping on Mpc scales at z ~ 0.32 and z ~ 0.44
arXiv:2301.11943

Power spectrum (odd scans vis x even scans vis)





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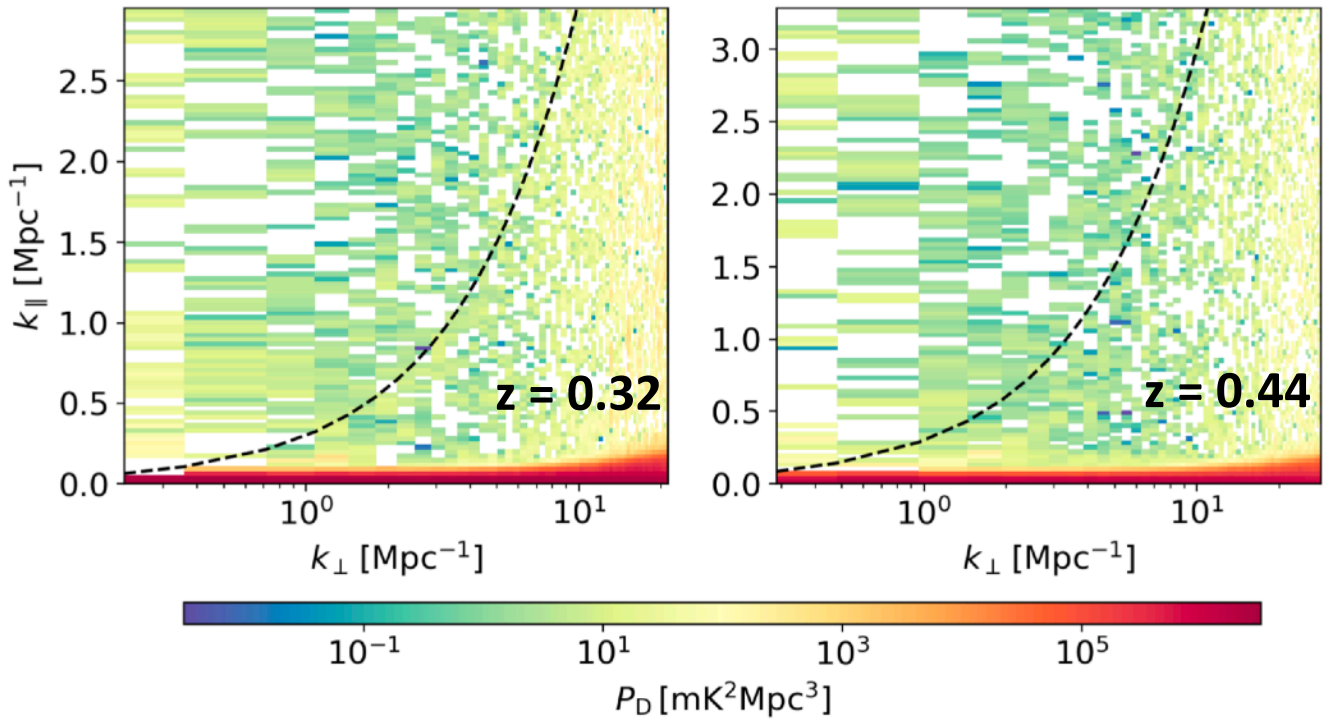
First detection of auto power spectrum



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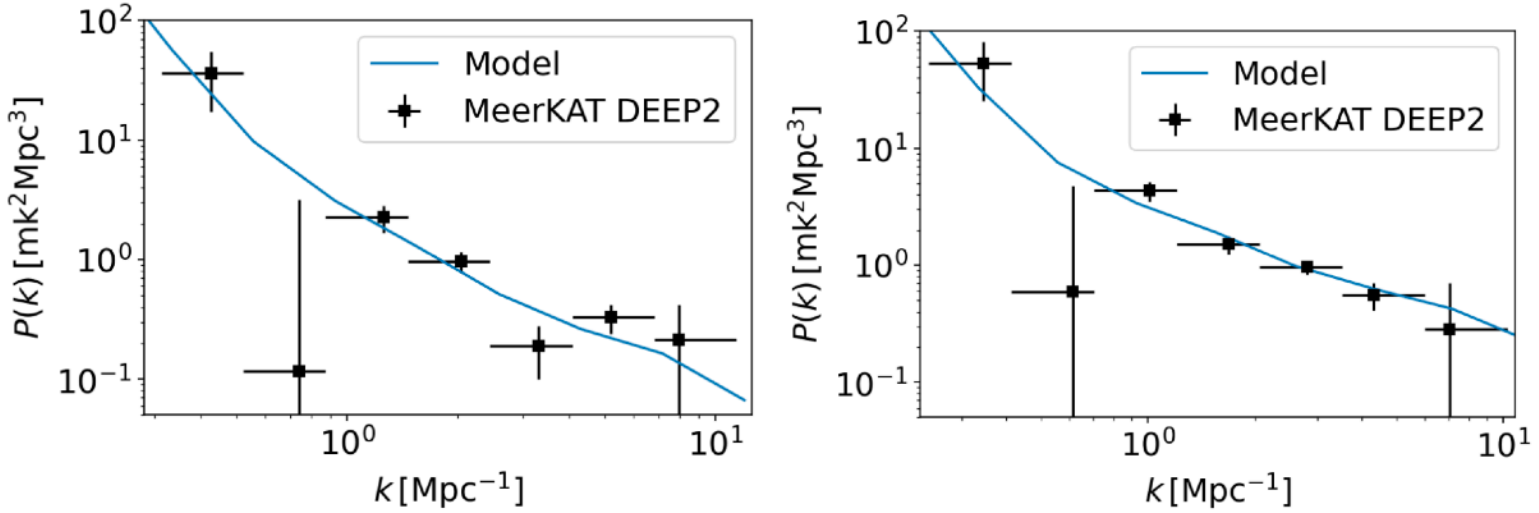
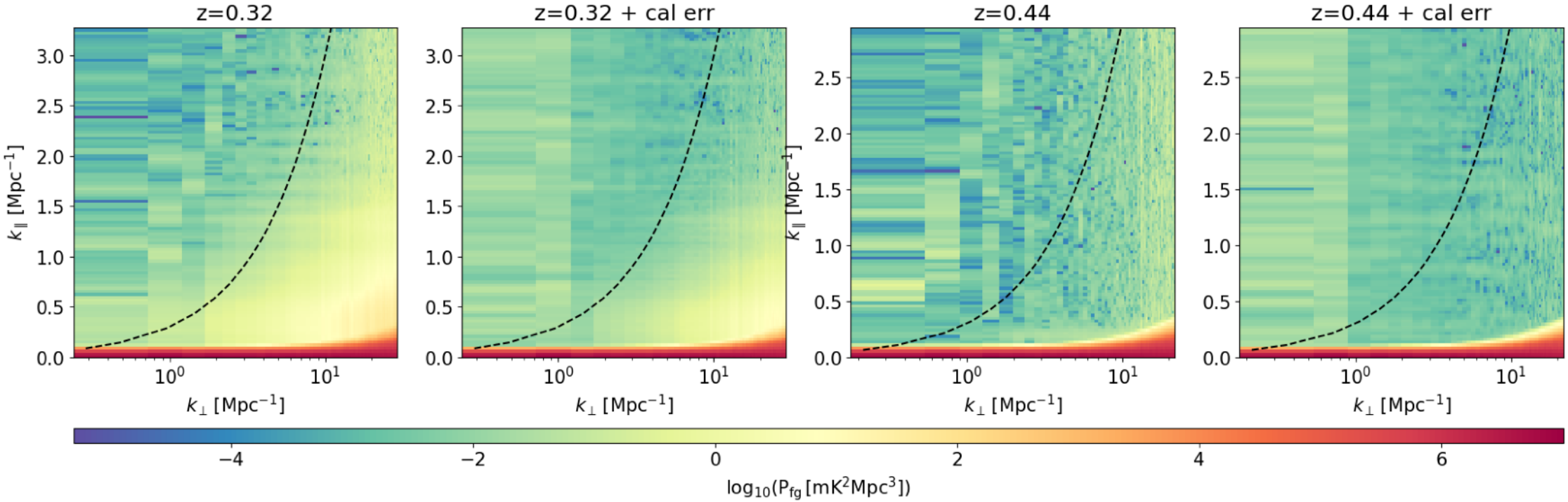
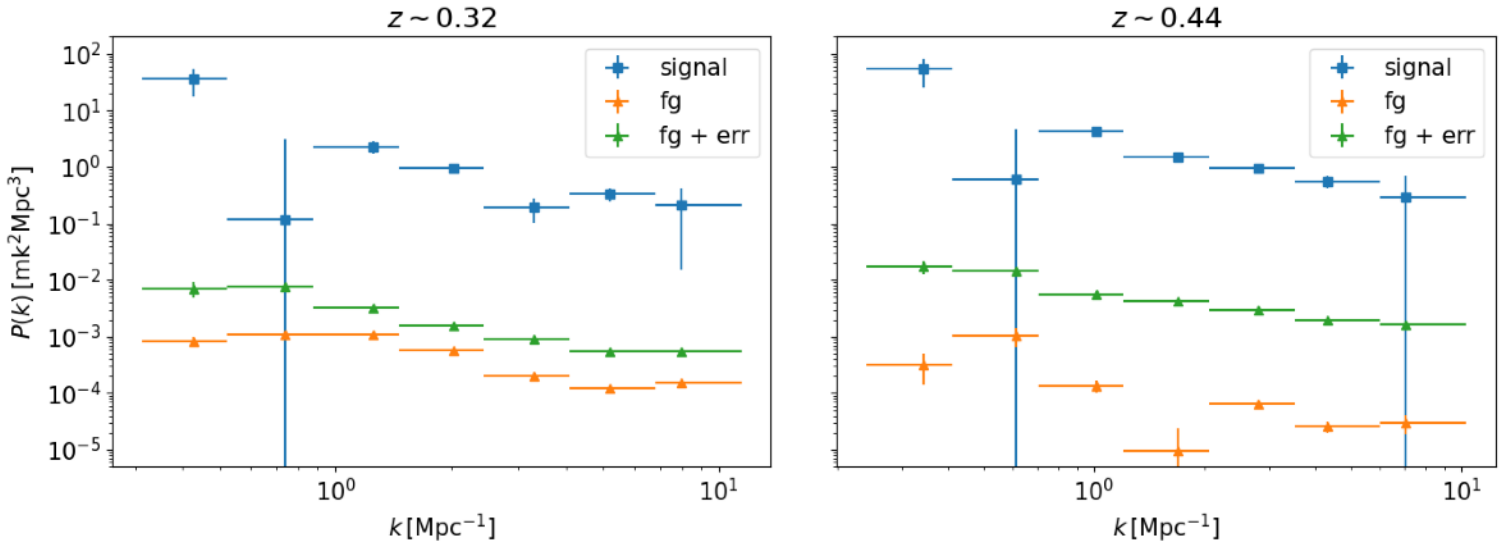
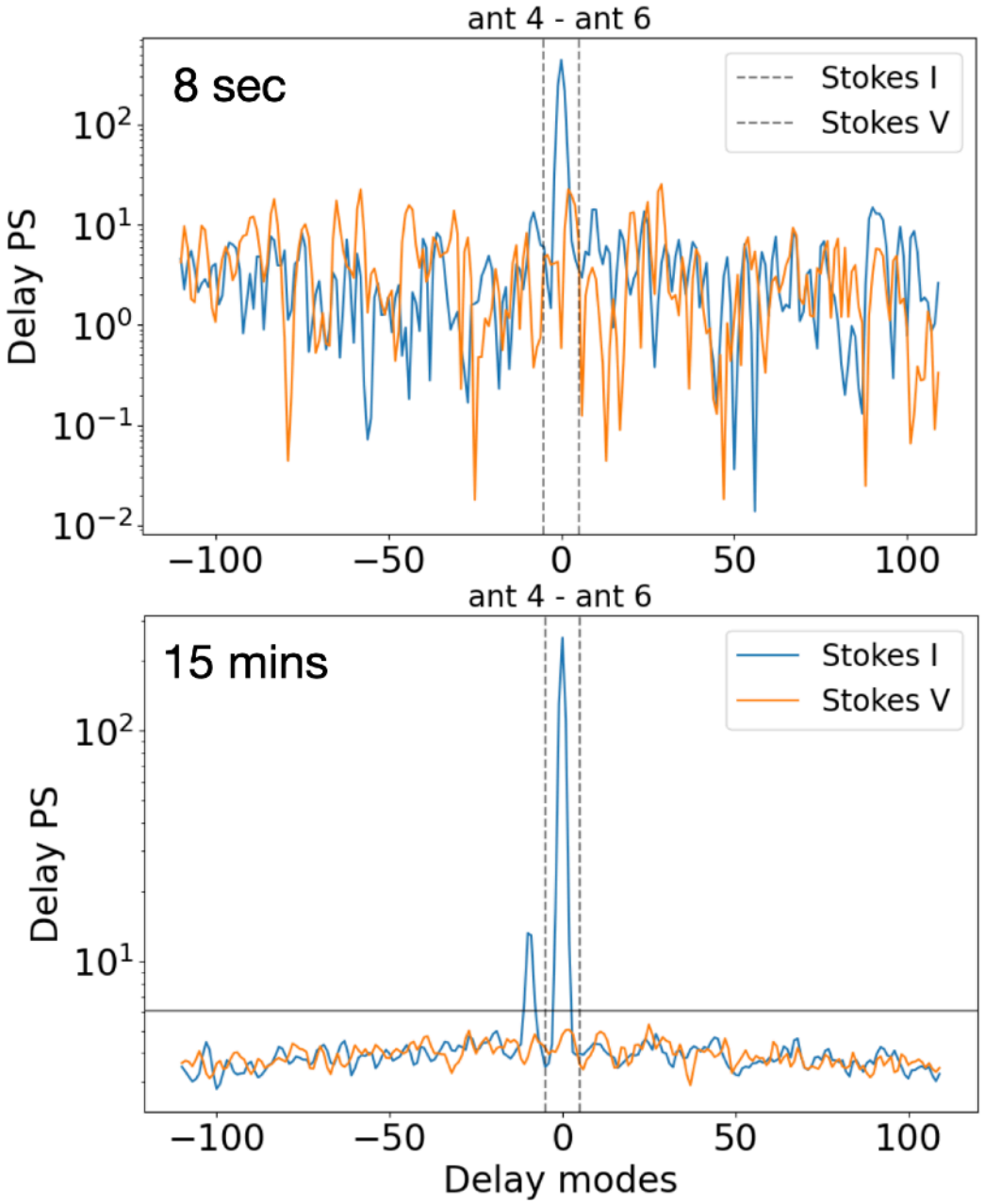


Foreground scatter



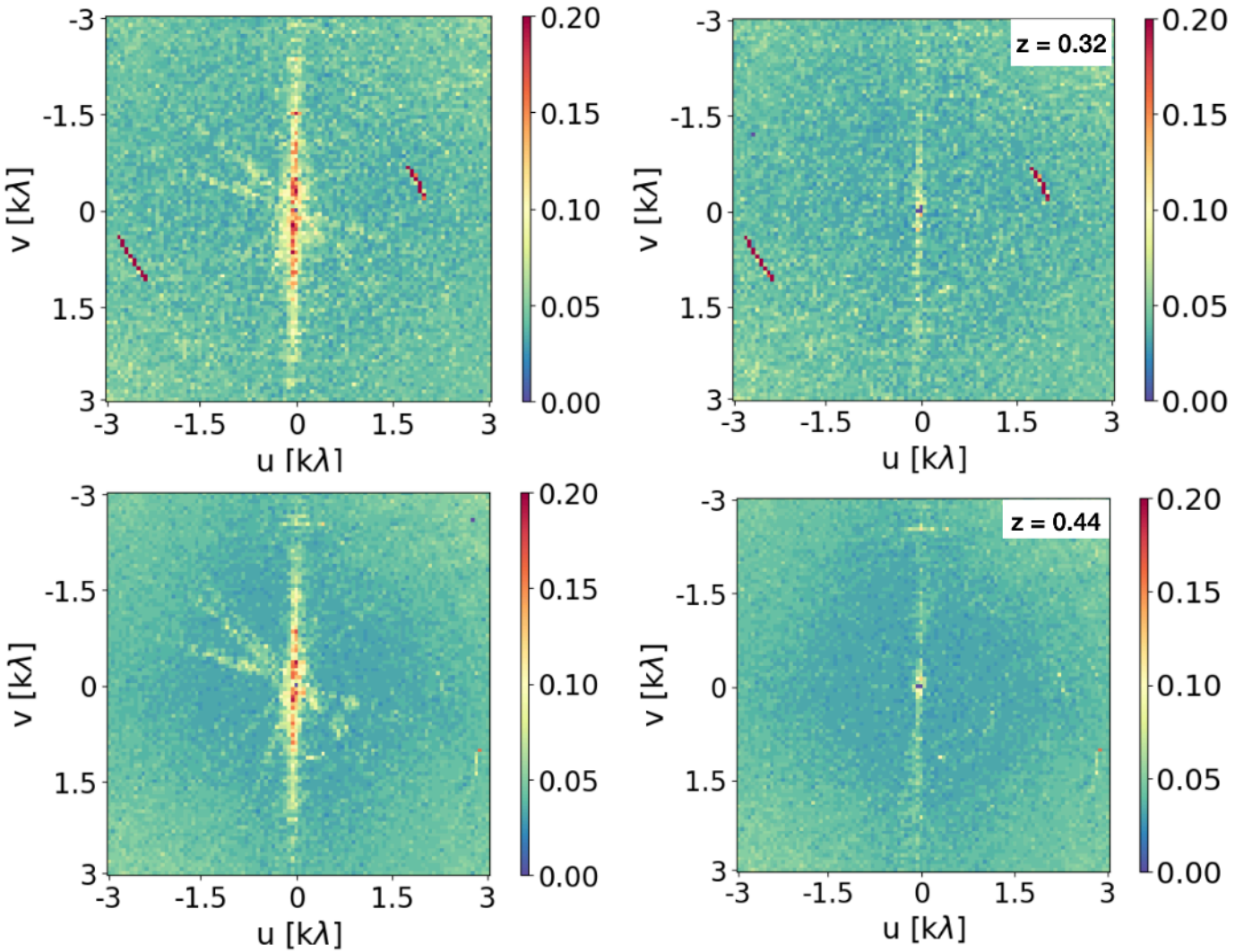


Low-level broadband RFI Flagging

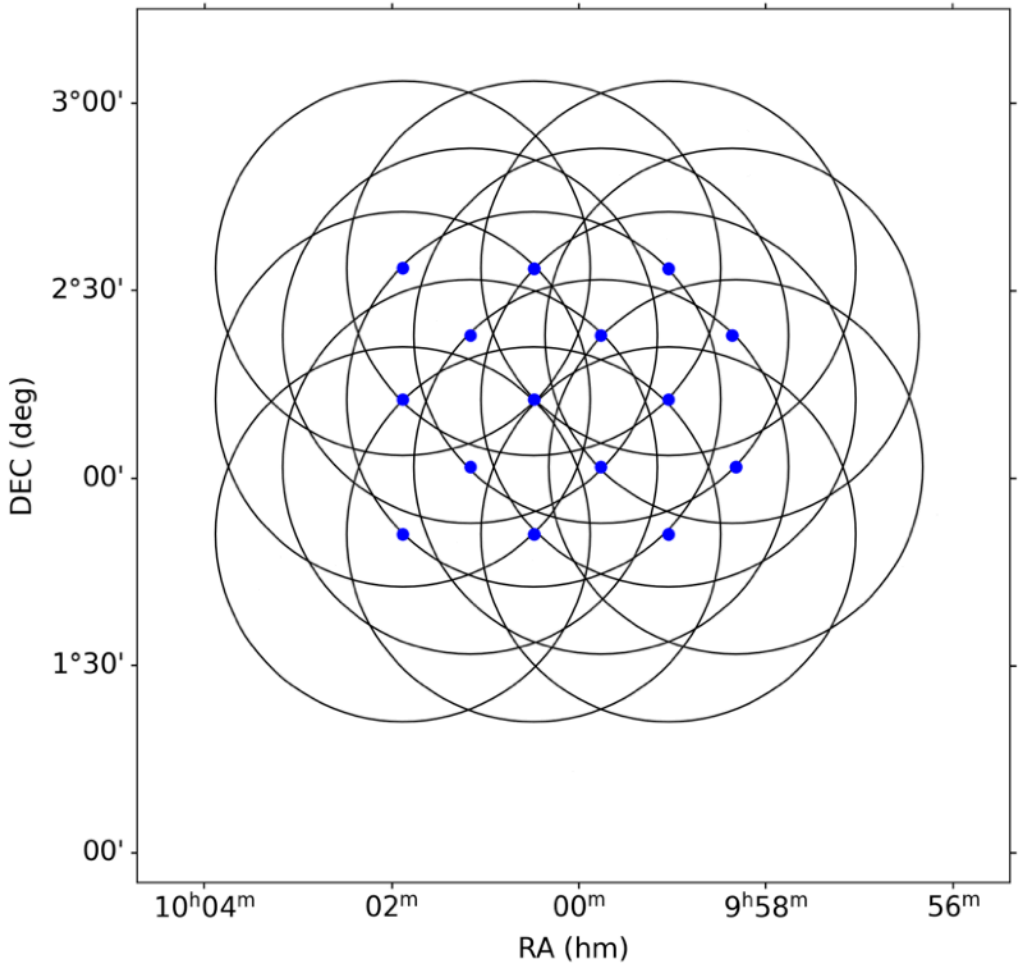


Before

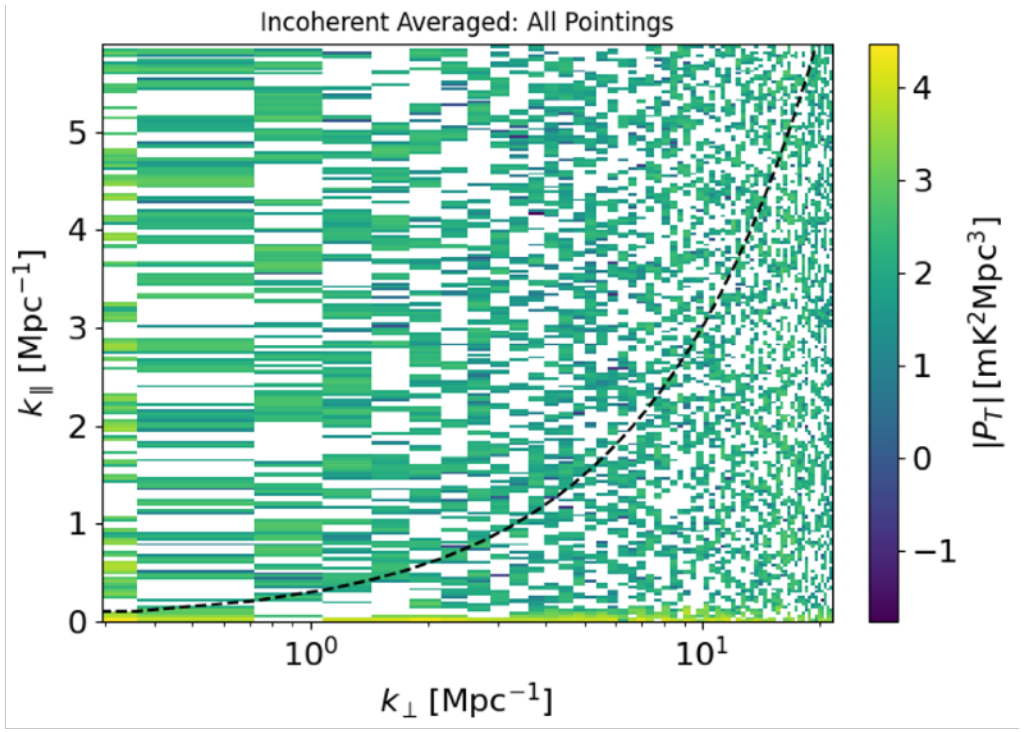
After

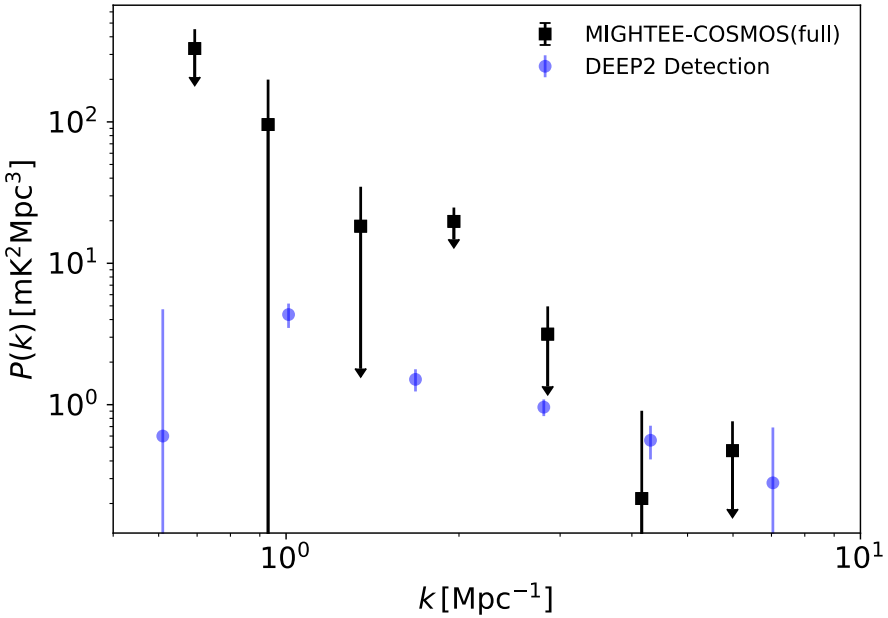


Intensity mapping with MIGHTEE survey



COSMOS pointings





Mazumder et al. (submitted)

Summary

- 21cm Intensity mapping research is at the forefront of cosmology, with the potential to provide new insights into the large-scale structure of the Universe.
- MeerKAT offers a distinctive approach to Intensity Mapping by leveraging both single-dish and interferometric capabilities.
- First detection in auto-correlation with MeerKAT interferometer—significant step towards precision cosmology with intensity mapping with new generation of radio telescopes and upcoming SKA.
- Many challenges are yet to overcome, detection are still limited to small scales.