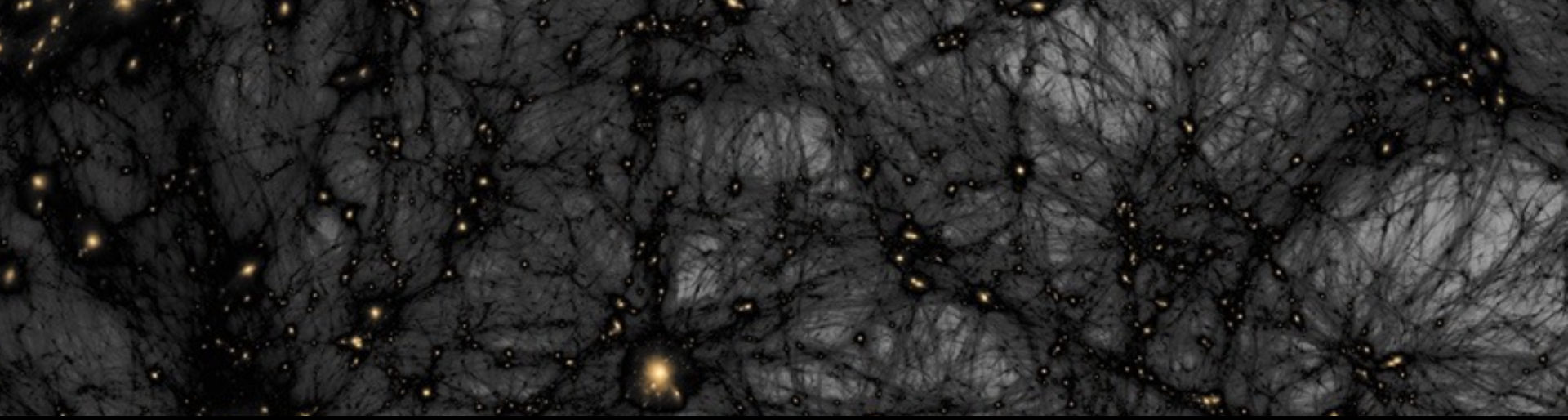
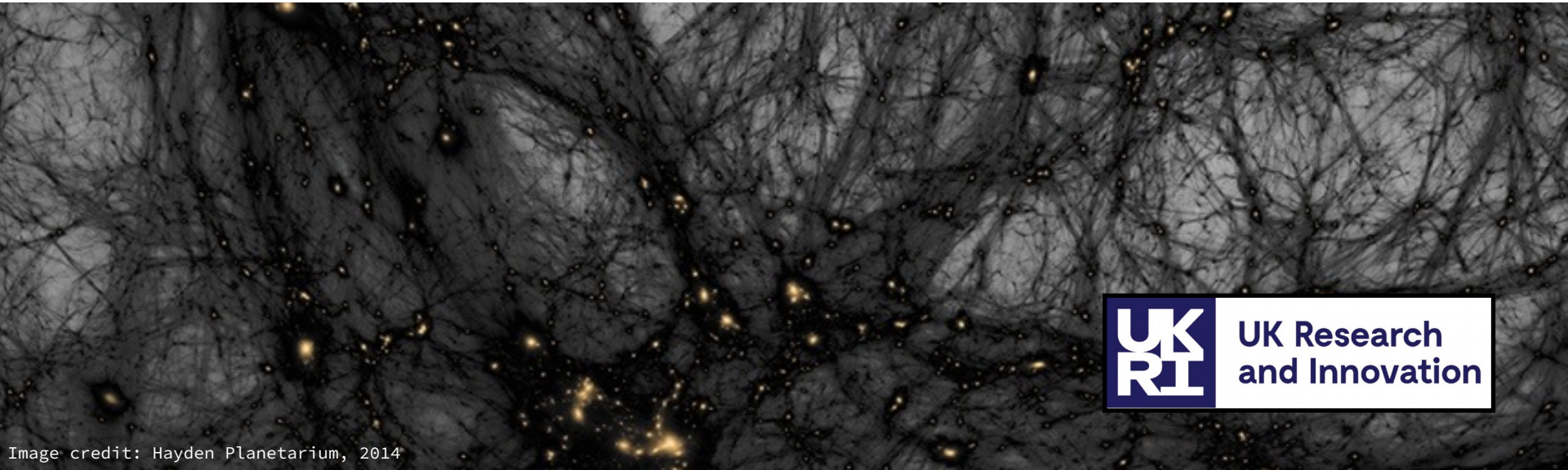


RaDio - optical synergies

Alkistis Pourtsidou
Royal Observatory & Higgs Centre, University of Edinburgh



UK Research and Innovation

Image credit: Hayden Planetarium, 2014

GBT & MEERKAT

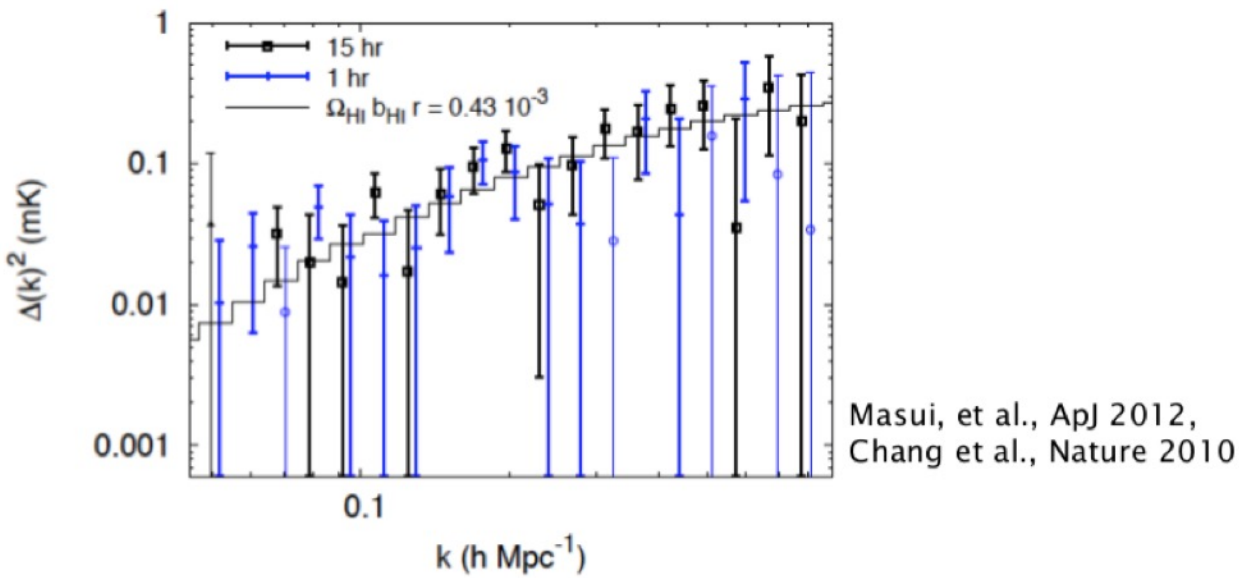
First detection in x-cross with optical

Survey at $0 < z < 1.4$

THE IMPORTANCE OF CROSS-CORRELATIONS

- Systematic effects are a big challenge for 21cm intensity mapping
- GBT x WiggleZ 2013 showed that cross-correlating with optical can mitigate this! **Systematics drop out in cross-correlation.**
- 2dF x Parkes 2018 detection, GBT x eBOSS detections a couple of years ago
- MeerKAT x WiggleZ last year!

$$\langle \delta T_{\rm HI} \delta_{\rm g} \rangle$$



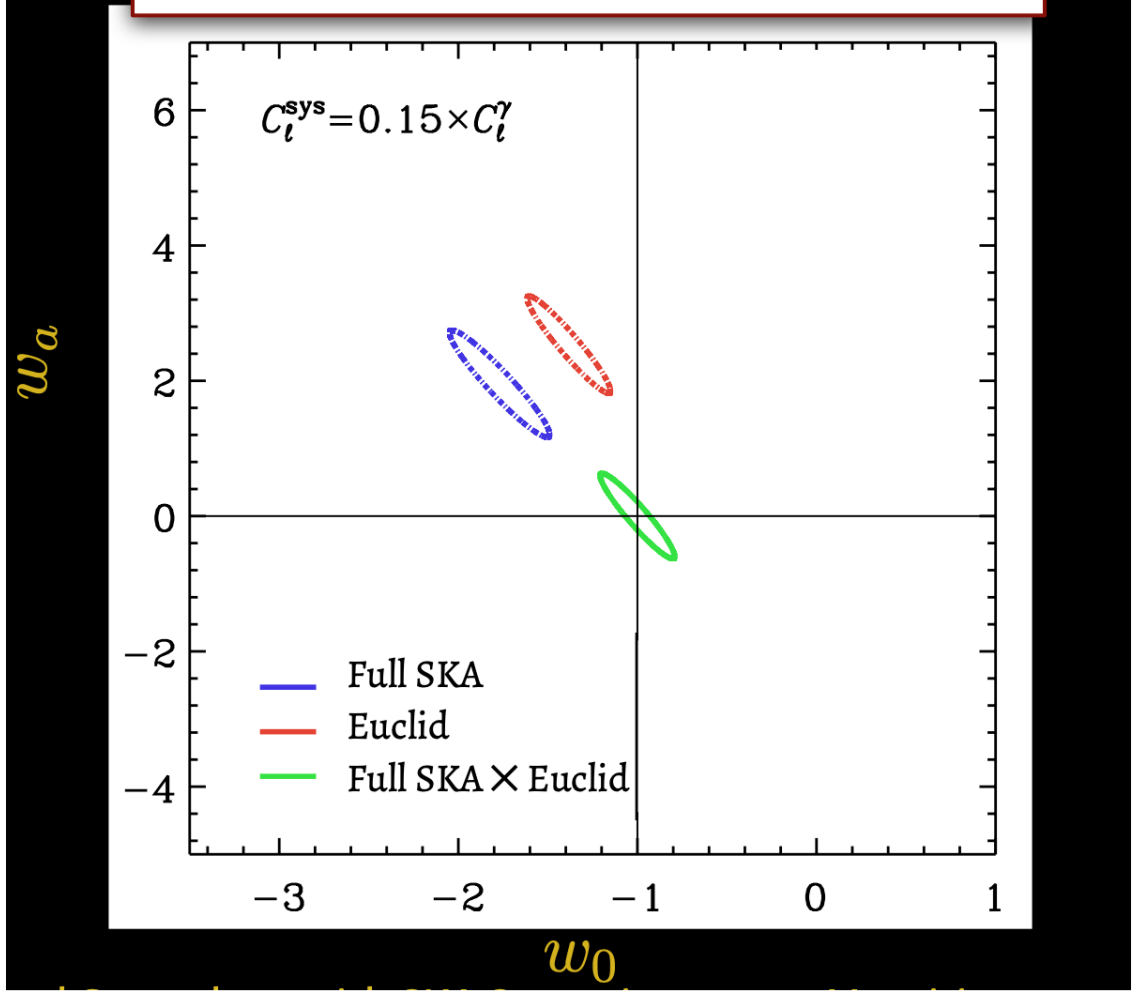
Masui, et al., ApJ 2012,
Chang et al., Nature 2010

$$\Omega_{\rm HI} b_{\rm HI} r = [0.43 \pm 0.07(stat.) \pm 0.04(sys.)] \times 10^{-3}$$

Less is more

Less systematics to worry about: the cosmic shear case

[Camera, Harrison, Bonaldi & Brown 2016]

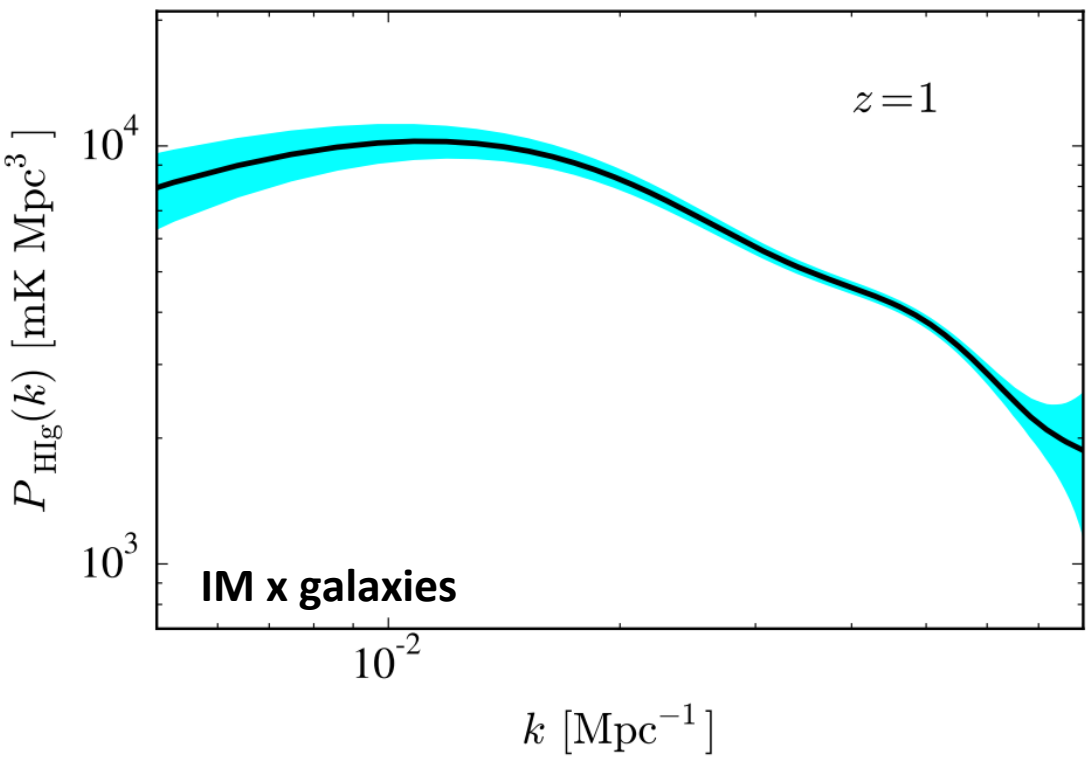


NEUTRAL HYDROGEN INTENSITY MAPPING POWER SPECTRUM

- With intensity mapping we can constrain HI and cosmological parameters

$$P_{\rm HI} \propto \Omega_{\rm HI}^2 b_{\rm HI}^2 P_{\rm m} \qquad P_{\rm HI,g} \propto \Omega_{\rm HI} b_{\rm HI} b_g r P_{\rm m}$$

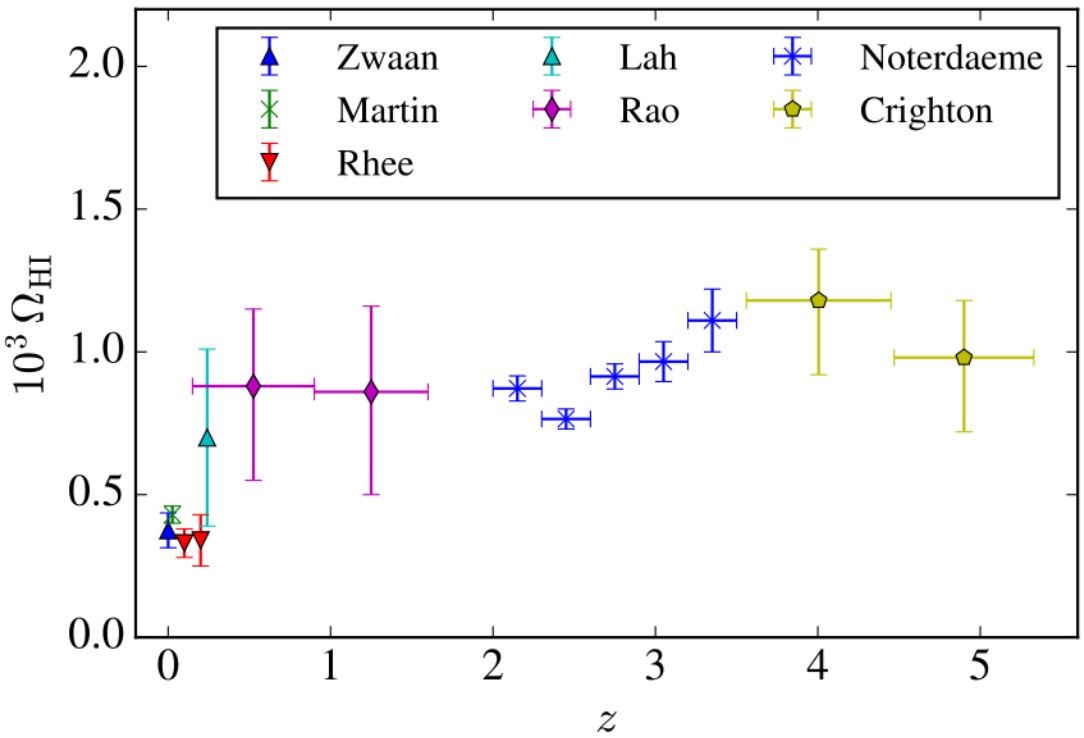
- The r coefficient tells us about the HI content of different galaxy samples, for example the different HI content of ELGs vs LRGs.



https://github.com/IntensityTools/IM-Fish

Optical and radio synergies

- Neutral hydrogen (HI) evolution is currently quite poorly constrained…
- Important for astrophysics and cosmology alike!



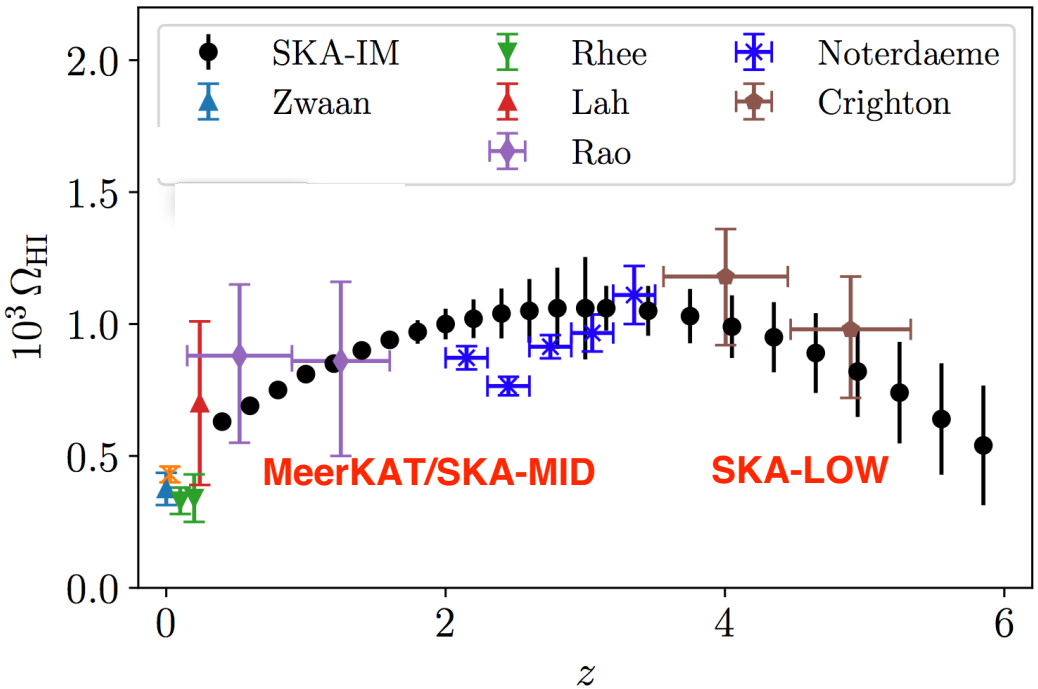
Crighton et al. 2015

GALAXY EVOLUTION

- Get HI constraints using intensity mapping surveys
- Cross-correlation with optical surveys helps with systematics and allows for studying the HI content of different galaxy samples

$$P_{\rm HI} \propto \Omega_{\rm HI}^2 b_{\rm HI}^2 P_{\rm m}$$

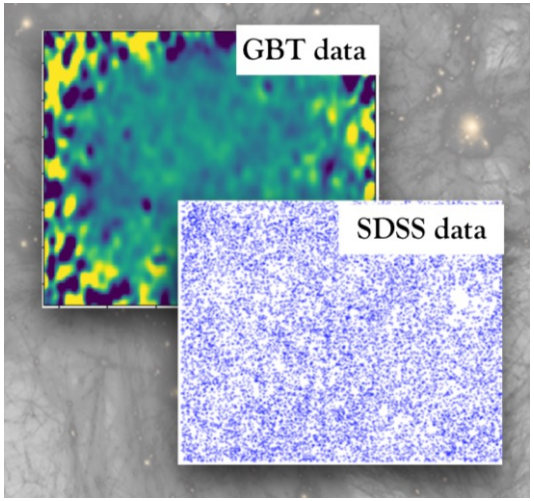
$$P_{\rm HI,g} \propto \Omega_{\rm HI} b_{\rm HI} b_g r P_{\rm m}$$

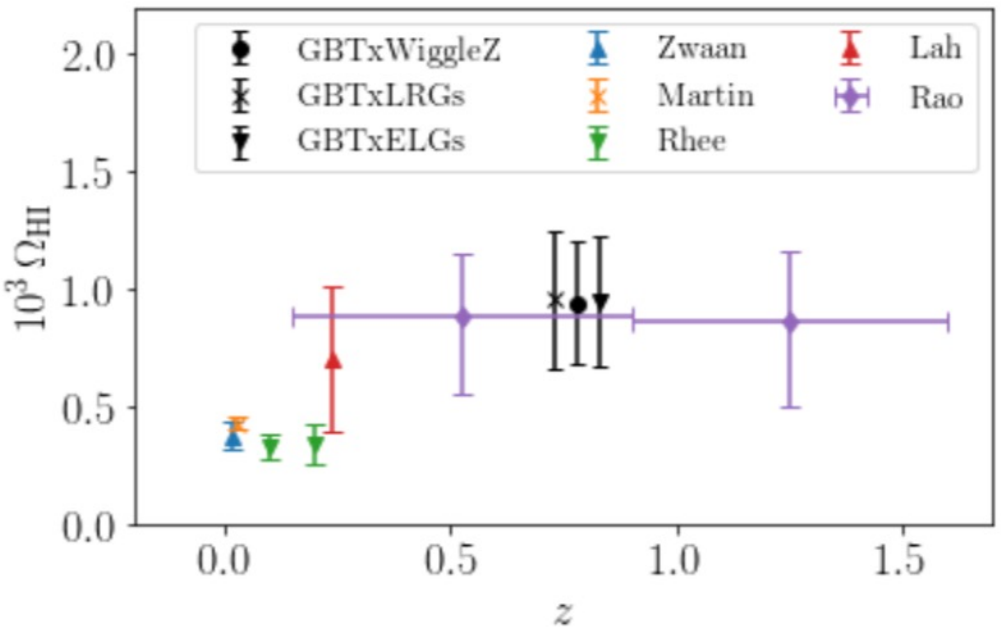


[Pourtsidou et al. 2017, SKA cosmology Red Book 2020]

CROSS-CORRELATION DATA ANALYSIS

- Green Bank Telescope intensity mapping data at 0.6<z<1
- eBOSS ELGs and LRGs samples (and the WiggleZ sample)
- Area overlap: 100 square degrees
- Foreground removal with Principal Component Analysis

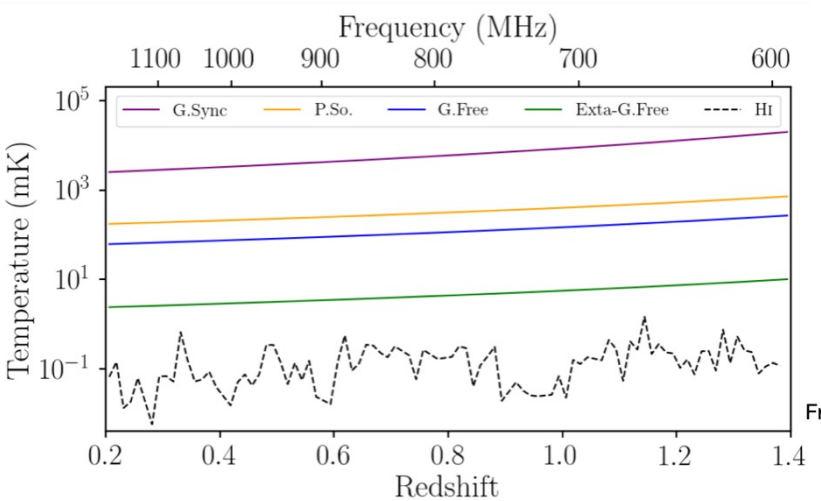


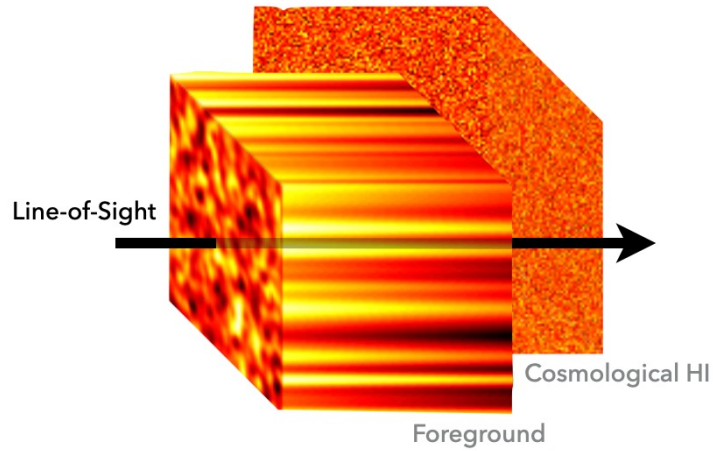


[Wolz, Pourtsidou et al. 2021]

Foregrounds are spectrally smooth

Idealised simulation demo:



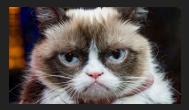


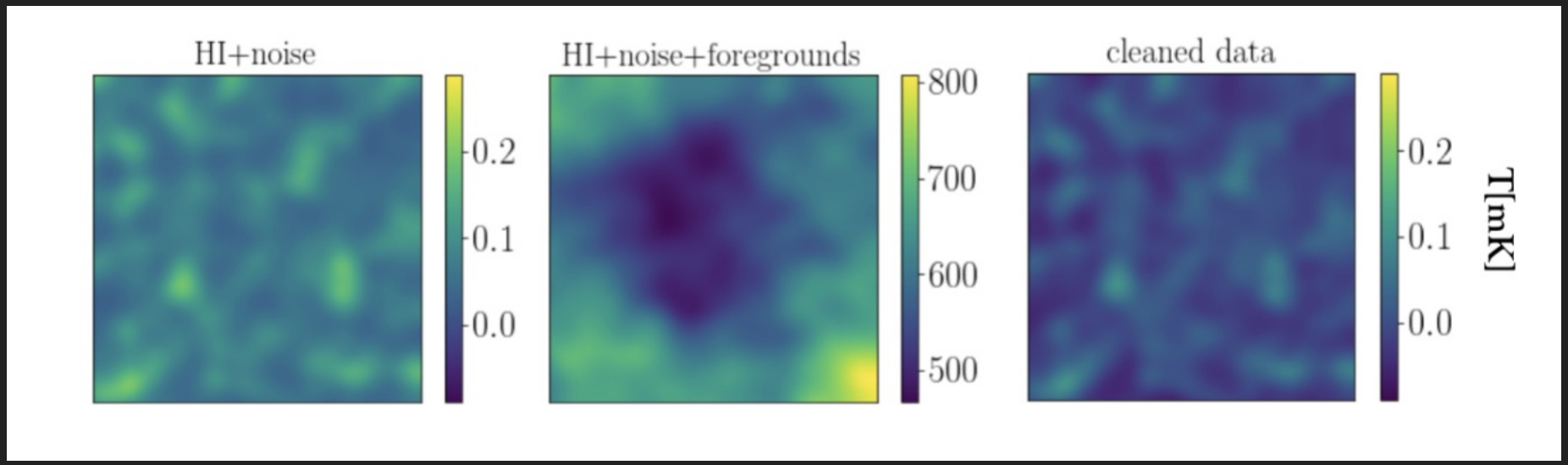
From S.Cunnington+19 [arXiv:1904.01479]

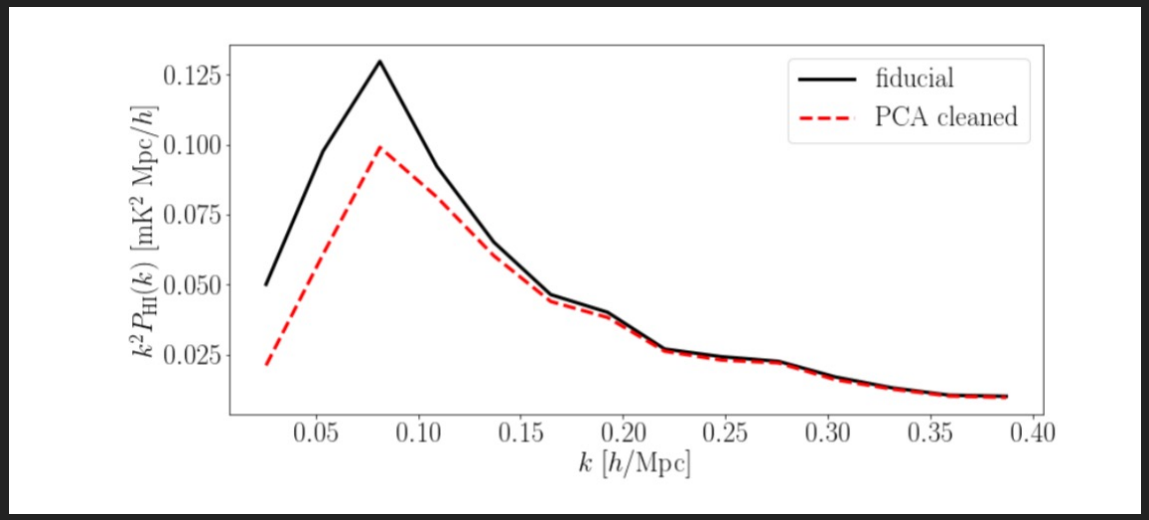
- We utilise smooth foreground spectra to distinguish them from cosmological signal

https://github.com/IntensityTools/gpr4im [Soares et al. 2020 for GPR technique]

21CM FOREGROUNDS CLEANING: SIGNAL LOSS EFFECT







Soares, Cunnington, AP, Blake 2020

Also see work by Alonso et al., Chapman et al., Shaw et al., Wolz et al.

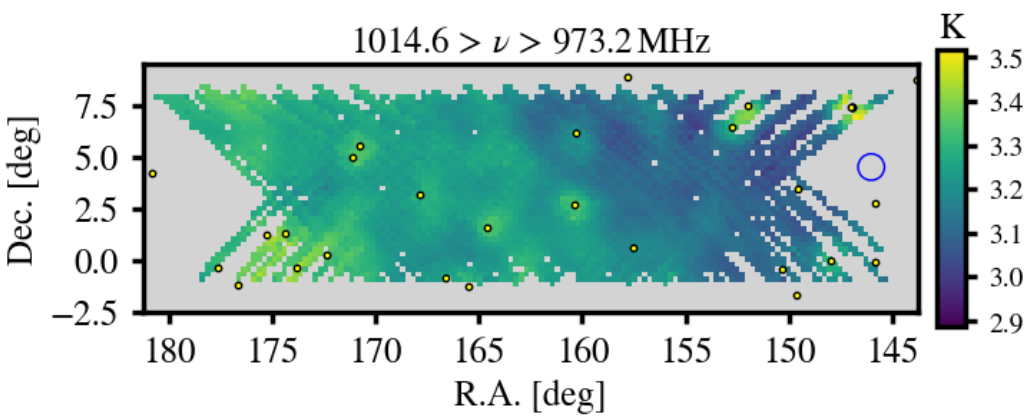
MEERKAT (SKA'S PATHFINDER) – TAKING DATA!

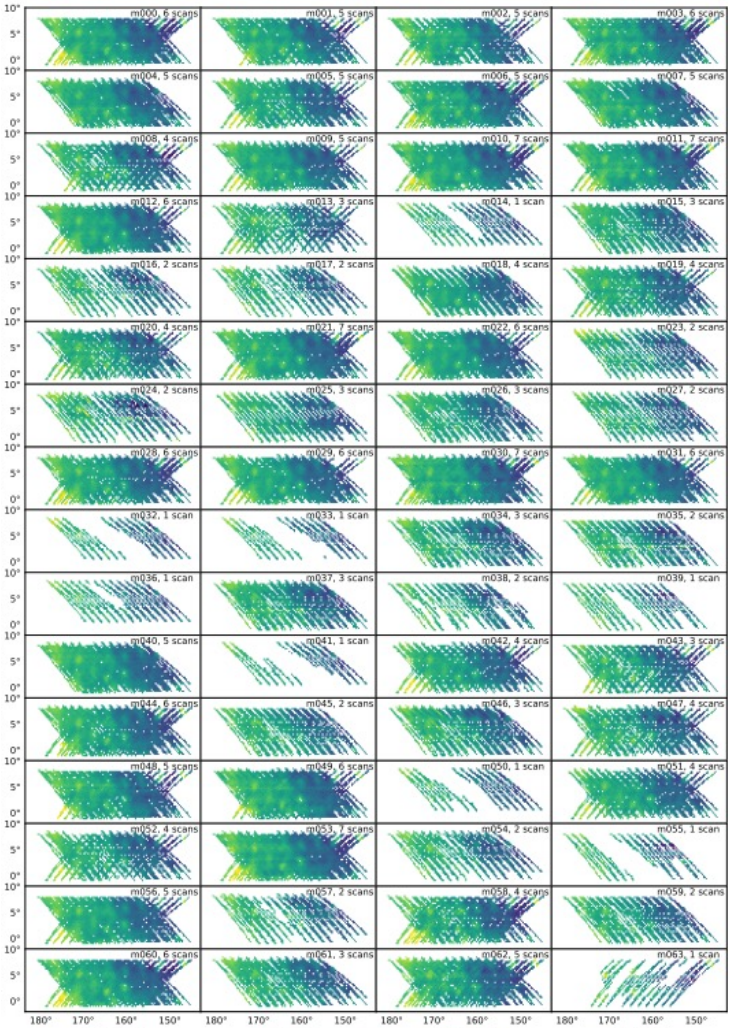
- 64 dishes in Karoo, South Africa
- Will become part of the SKA Observatory (SKA-MID)

MeerKAT data analysis

Pilot survey data:

- 10.5 hours of data from six nights of observations
- Overlapping with the WiggleZ11hr field (~200 deg^2)
- We use data in range 973-1015 MHz ($0.40 < z < 0.46$)



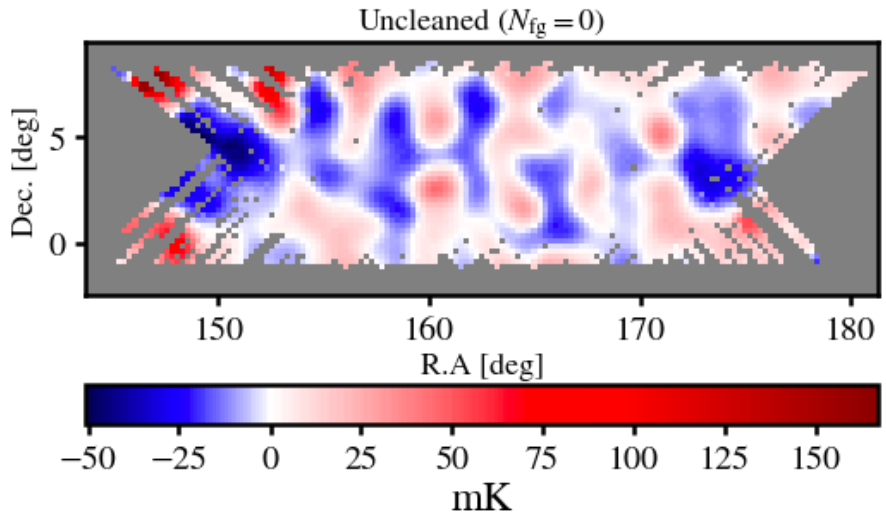


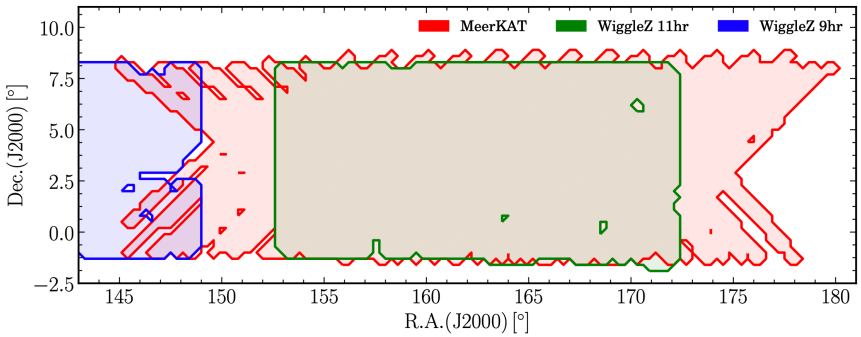
Huge problem: we lose a lot of data due to RFI

J.Wang et al. 2021 [arXiv:2011.13789]

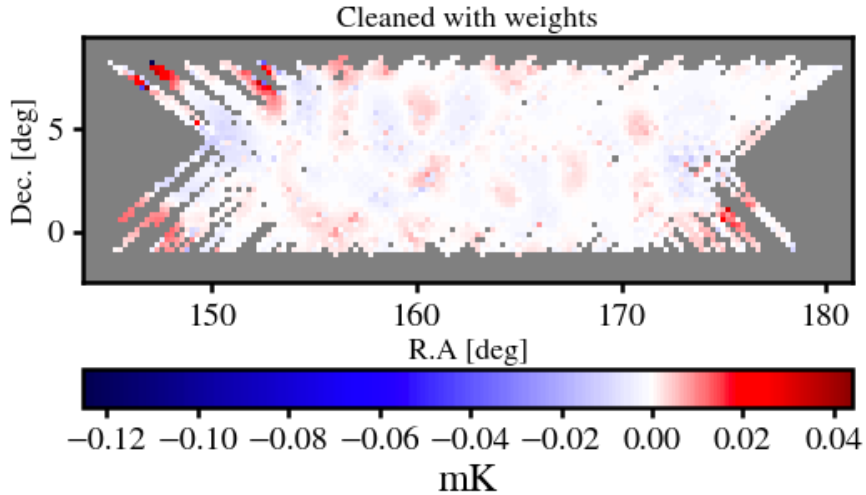
MEERKAT X WIGGLEZ DATA ANALYSIS

MeerKAT pilot observations on WiggleZ 11hr field

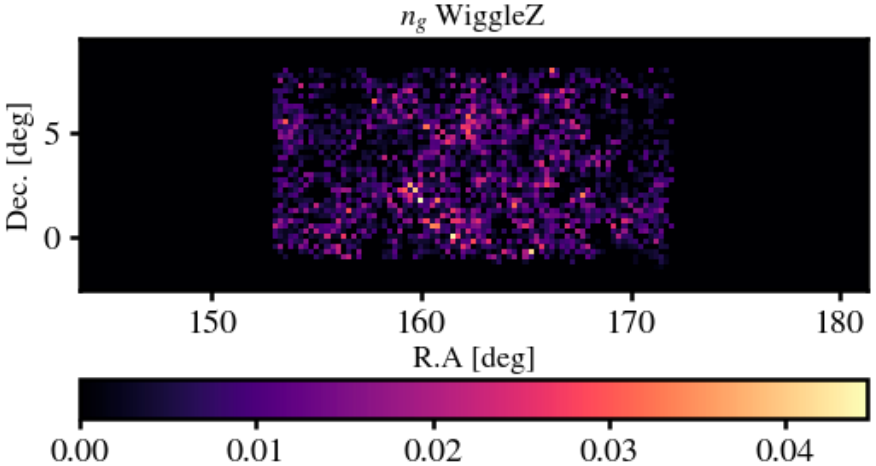




Final foreground cleaned MeerKAT HI intensity map



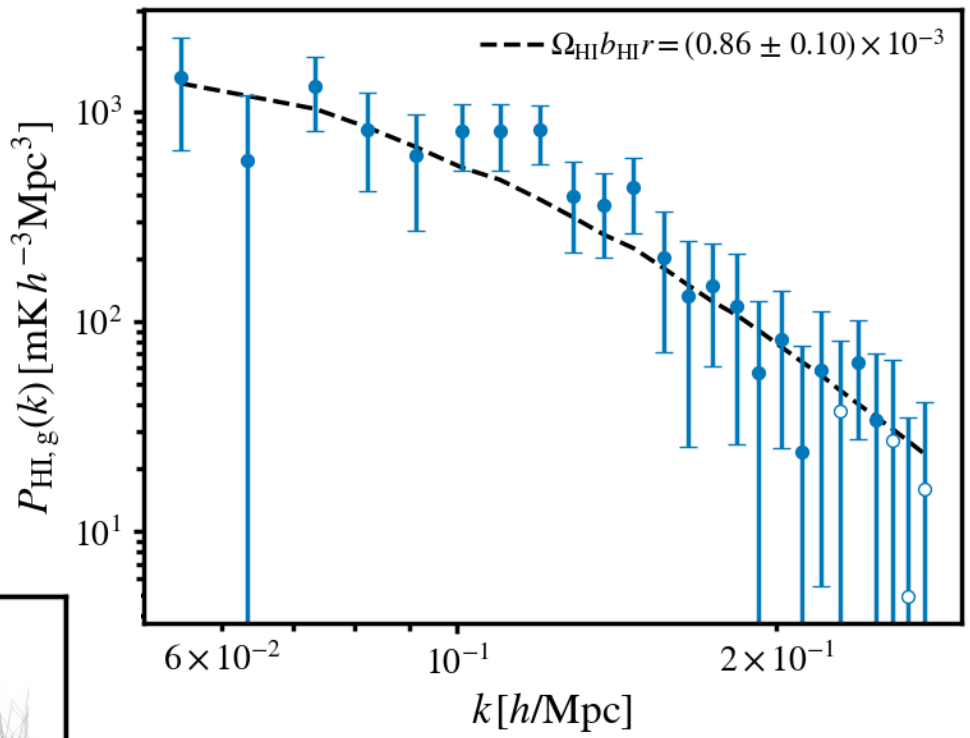
WiggleZ Dark Energy Survey galaxies

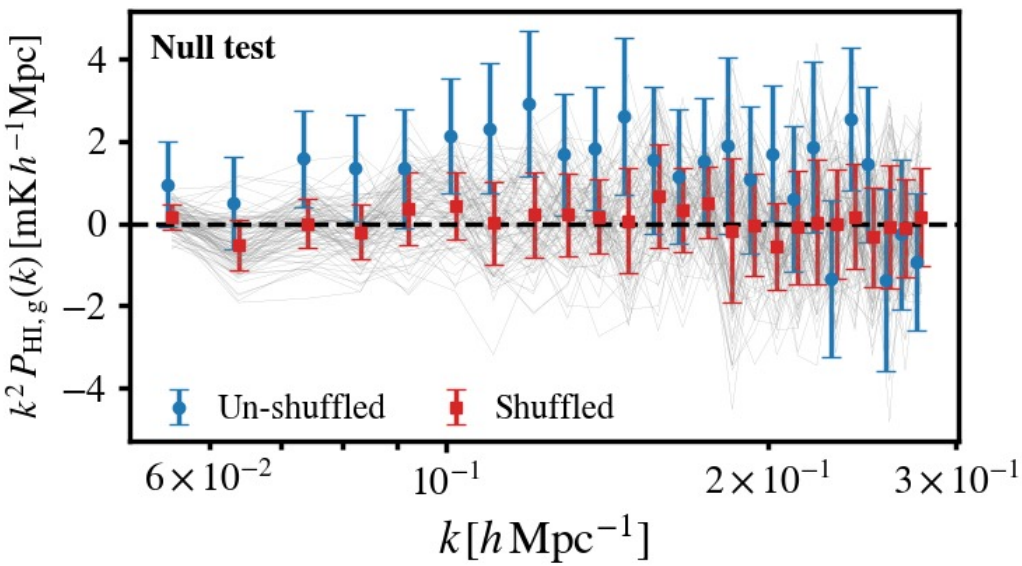


Slide from Steven Cunnington

MEERKAT X WIGGLEZ DATA ANALYSIS

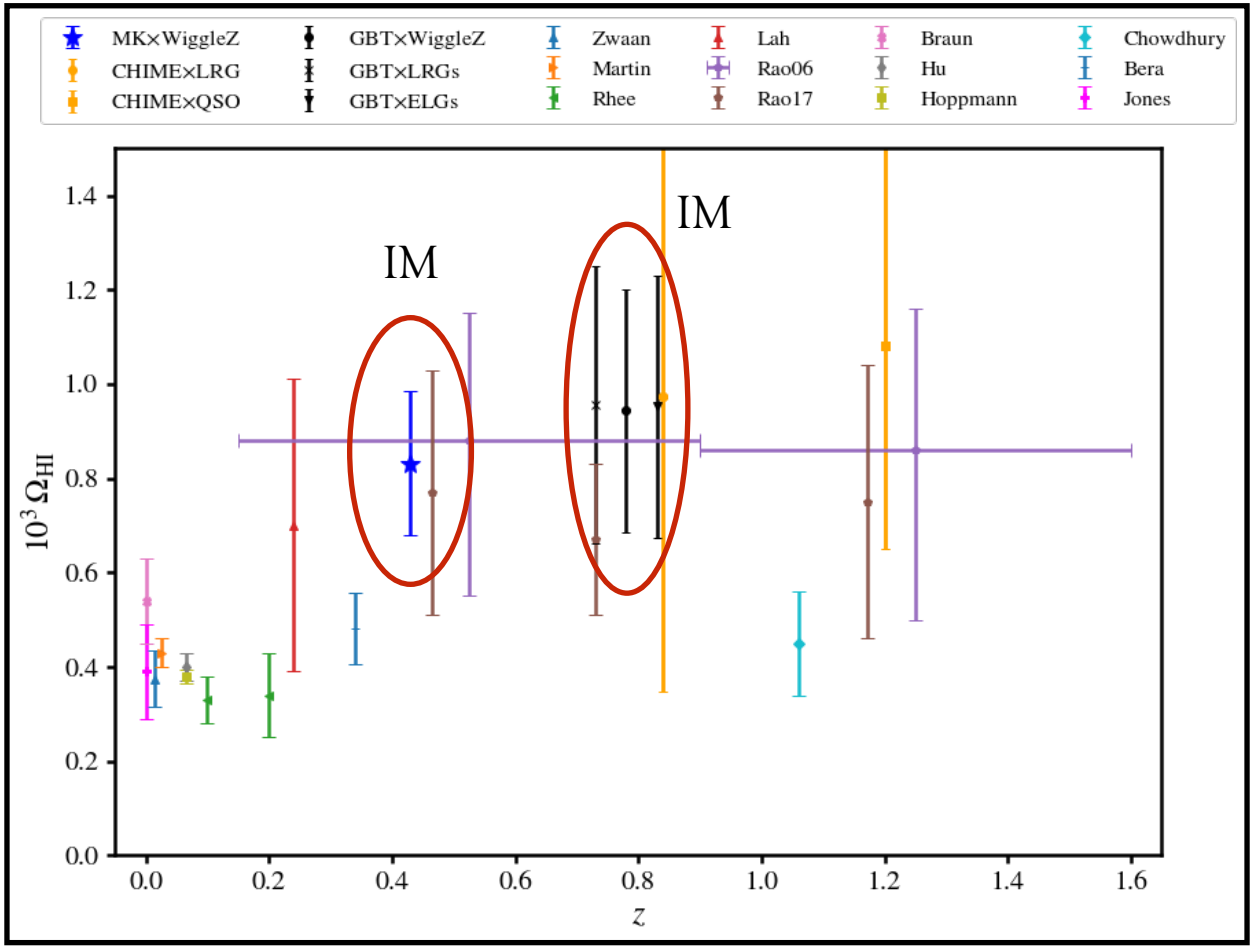
- Positive correlation (7.7σ) between galaxy survey and array of dishes in single-dish mode
- The first detection of its kind
- Important milestone for Cosmology with SKA intensity mapping





Cunnington,Li+22

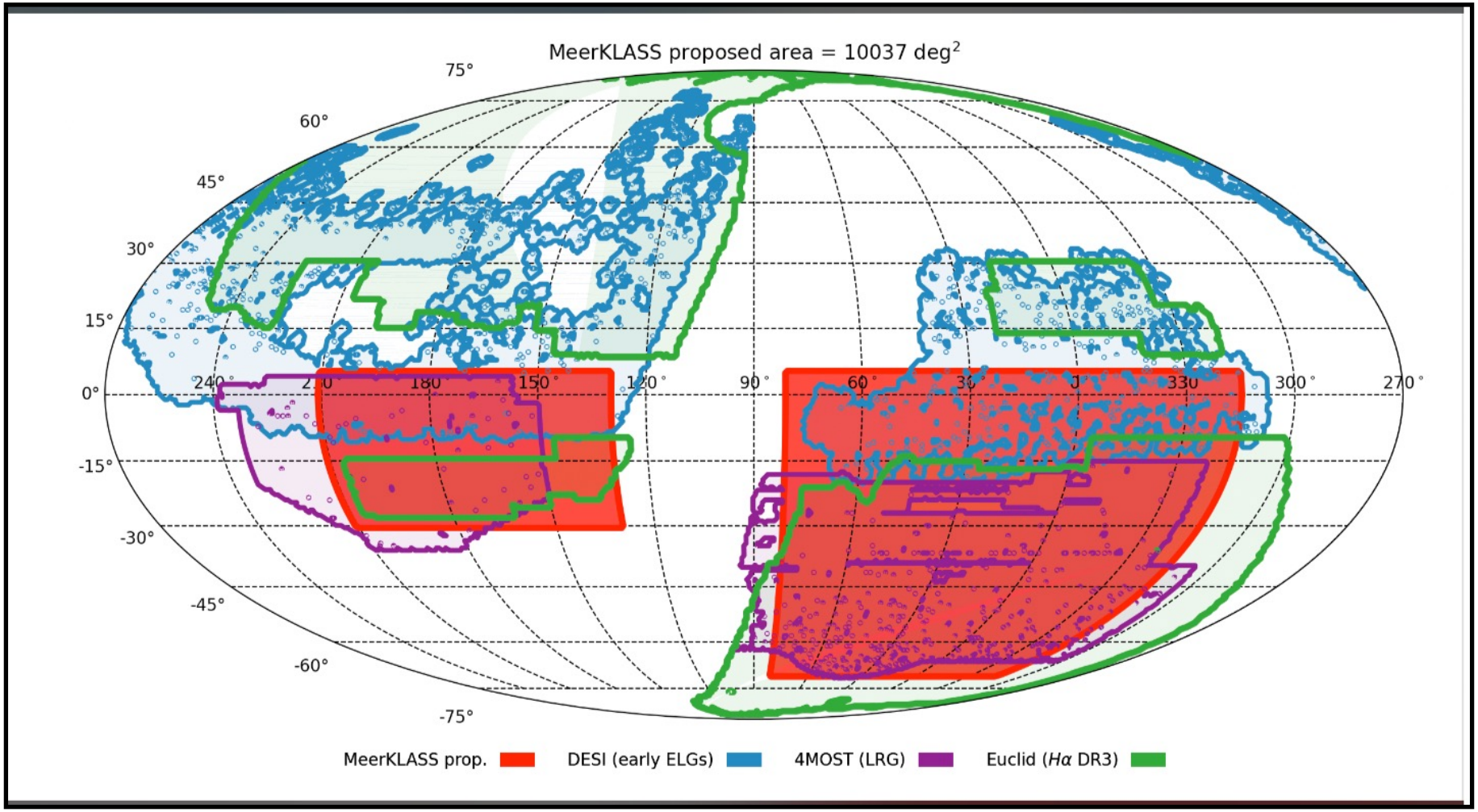
MEERKAT X WIGGLEZ DATA ANALYSIS



Cunnington,Li+22

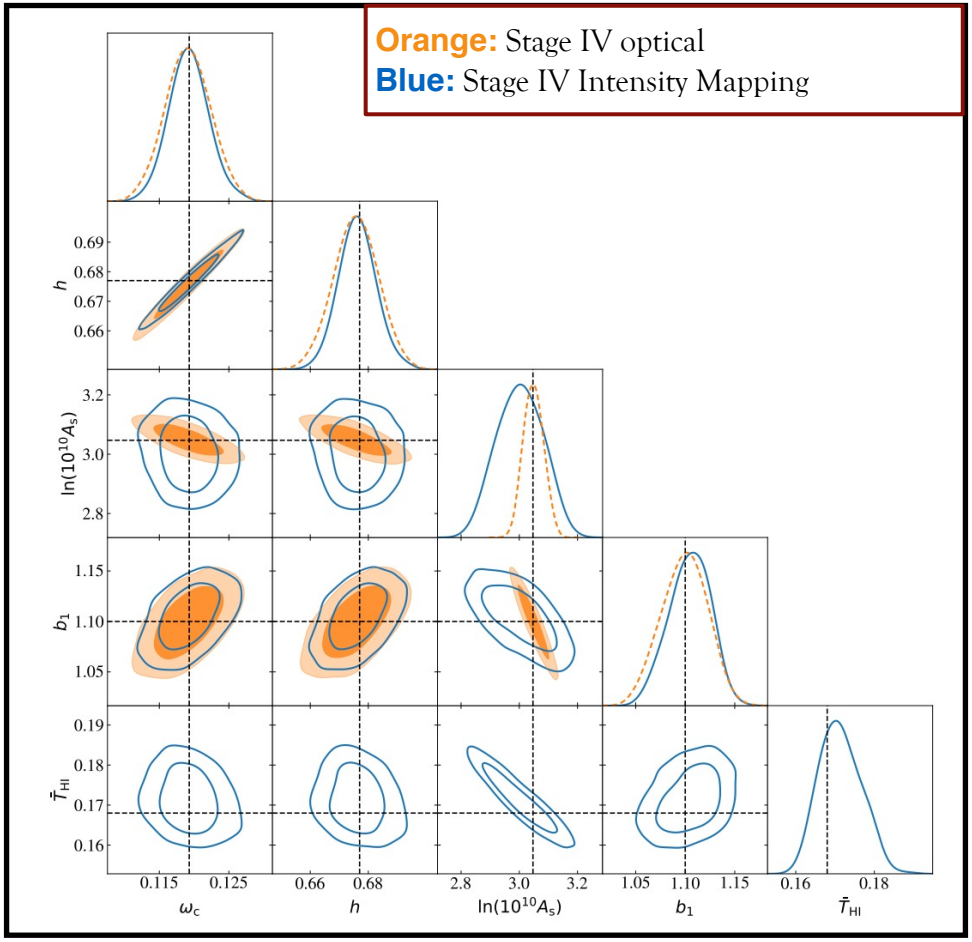
The (near) future

A large sky survey with MeerKAT



HI INTENSITY MAPPING FORECASTS

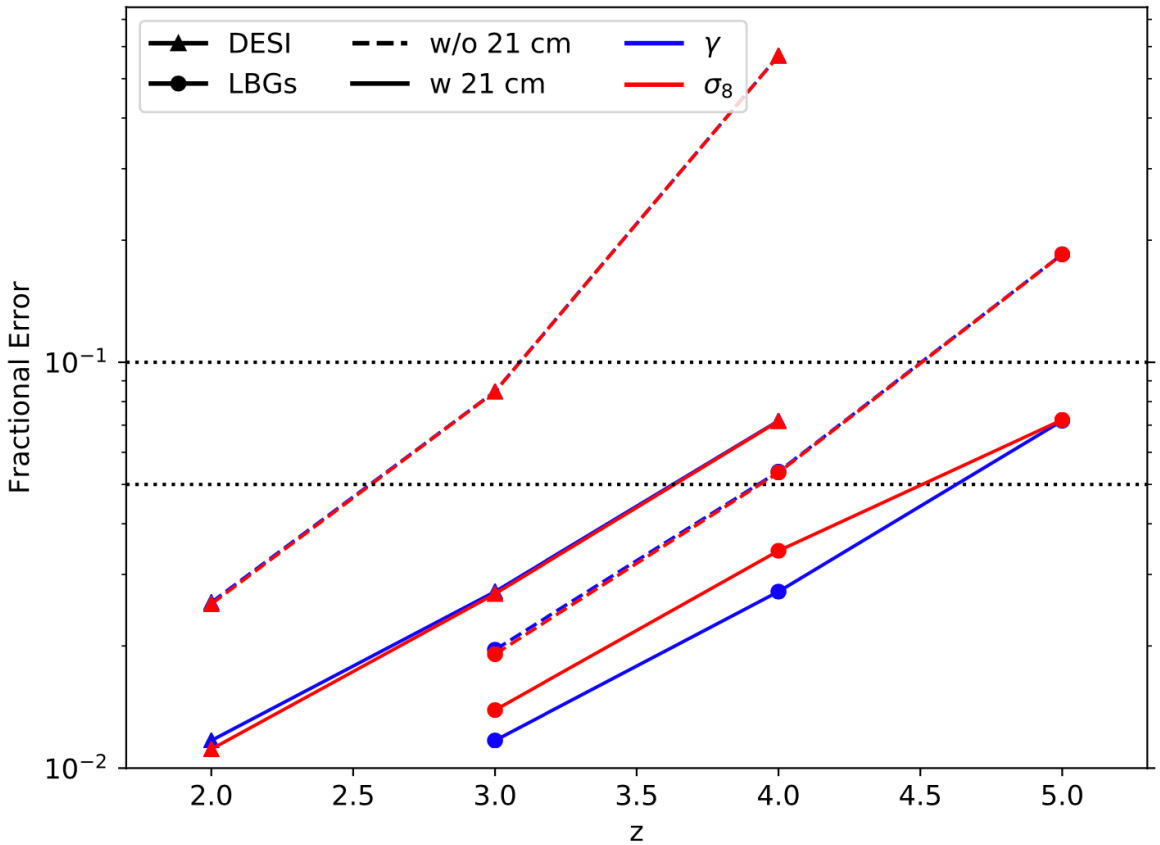
- Interferometers like PUMA and CHORD competitive with Stage-IV optical galaxy surveys like Euclid and DESI [with caveats]
- Can get to high redshifts



Pourtsidou 2023

STAGE-IV CROSS-CORRELATIONS

- Cosmological constraints using a combination of LSST - CMB lensing cross correlations, 21cm intensity mapping and spectroscopic data from DESI
- Great improvement from 21cm at high z

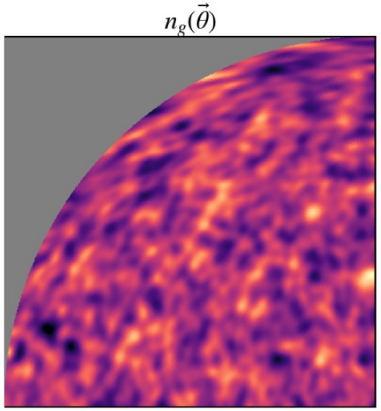


[Chen, Castorina, White, Slosar 2020]

Cunnington et al. (2018 and 2019)

CLUSTERING-BASED REDSHIFT ESTIMATION WITH HI INTENSITY MAPPING

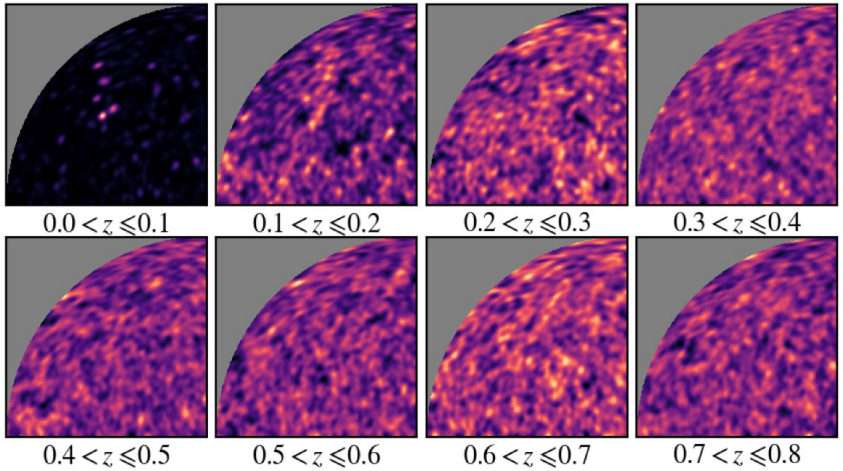
- *Reference sample doesn't need to be catalogue of resolved sources*
- *So can use HI intensity maps:*



$0.0 < z < 0.8$

- *Can make intensity maps for each redshift slice then cross-correlate these with the unknown sample*

$$\frac{dN}{dz}(z) \propto \langle \delta_g \delta_{HI}(z) \rangle$$



RADIO-OPTICAL SYNERGIES: PHOTOMETRIC REDSHIFT CALIBRATION

Cunnington et al. (2018 and 2019)