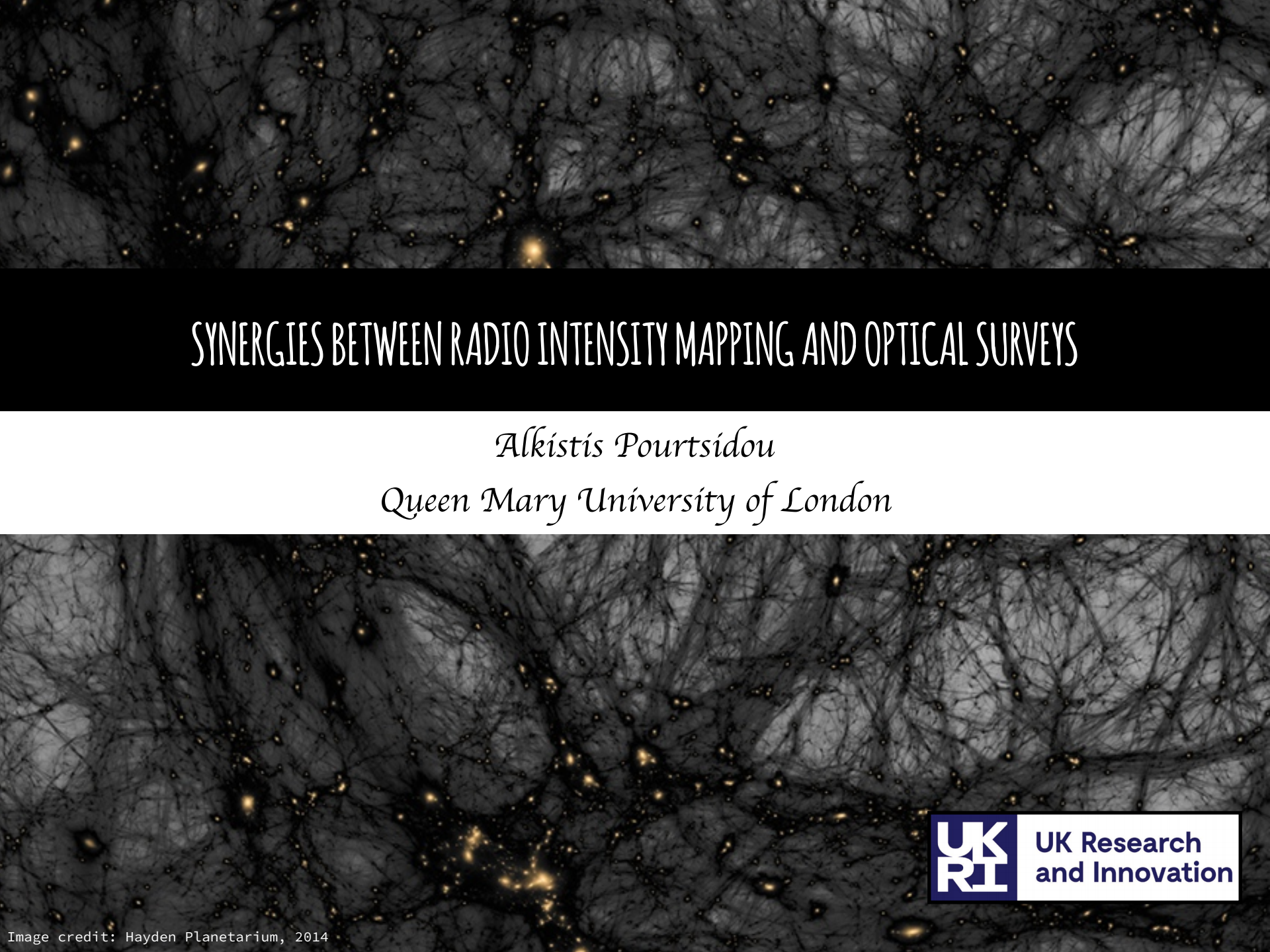


SYNERGIES BETWEEN RADIO INTENSITY MAPPING AND OPTICAL SURVEYS

Alkistis Pourtsidou

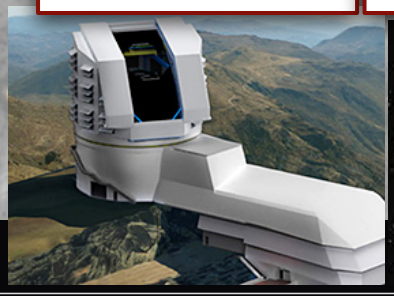
Queen Mary University of London

UK Research and Innovation

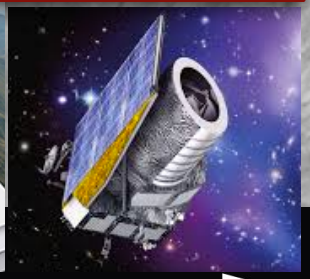
Image credit: Hayden Planetarium, 2014

Observing the universe with radio and optical galaxy surveys

LSST



Euclid satellite



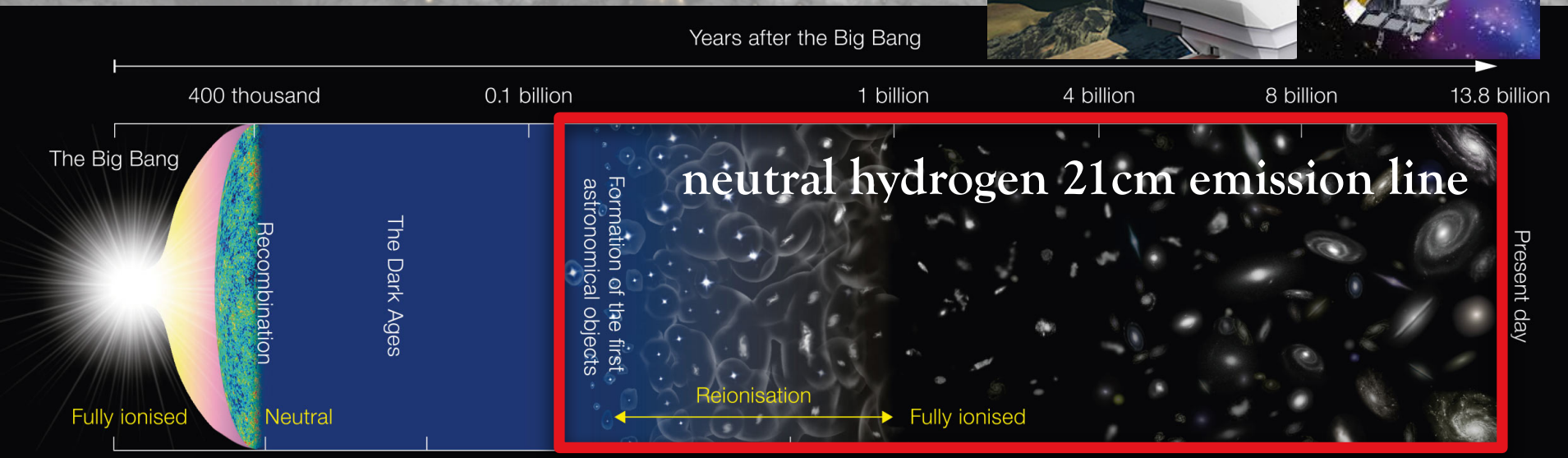
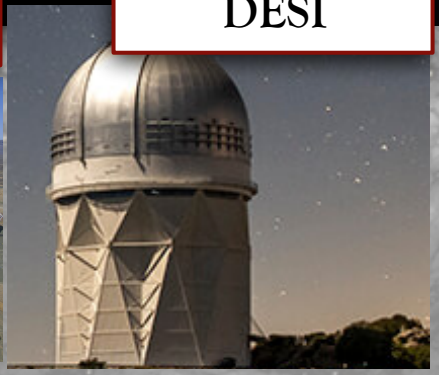


Image Credit: NAOJ

MeerKAT and the SKA

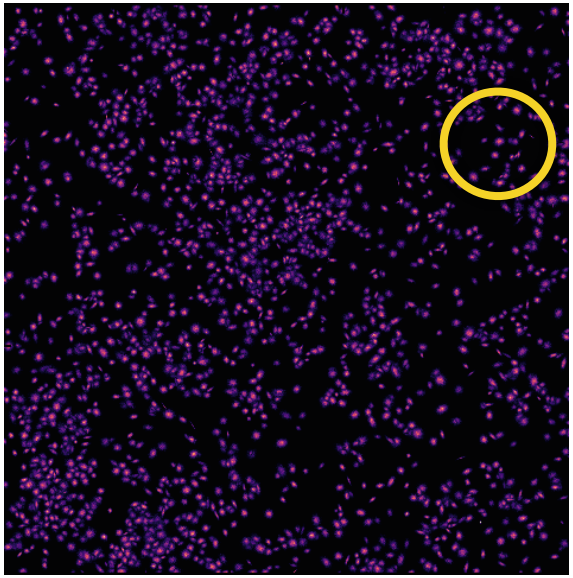
DESI



RADIO PRECISION COSMOLOGY: THE INTENSITY MAPPING METHOD

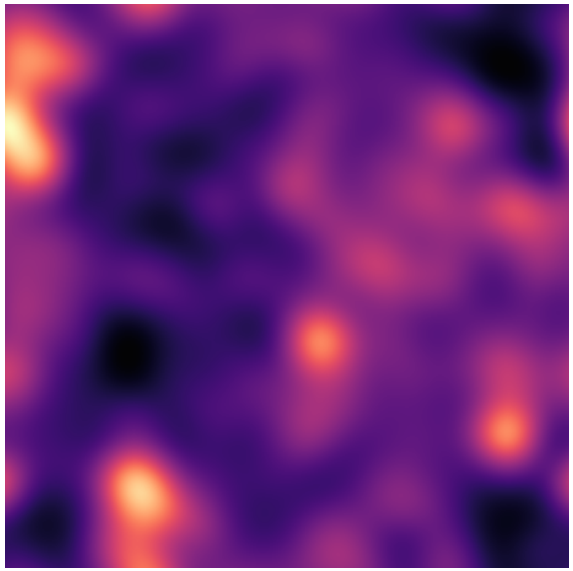
[Chang et al 2008, Peterson et al 2009, Seo et al 2010, …]

Galaxies



the telescope beam

Intensity map



[Simulated maps by S. Cunnington]

Need redshifts: very expensinve
In radio: 21cm line – SKA1 not sensitive enough to be competitive

- Intensity mapping is very fast → uses all the photons
- Provides high frequency/redshift resolution (in the radio…)
- Low resolution/large scales (which is fine for cosmology)

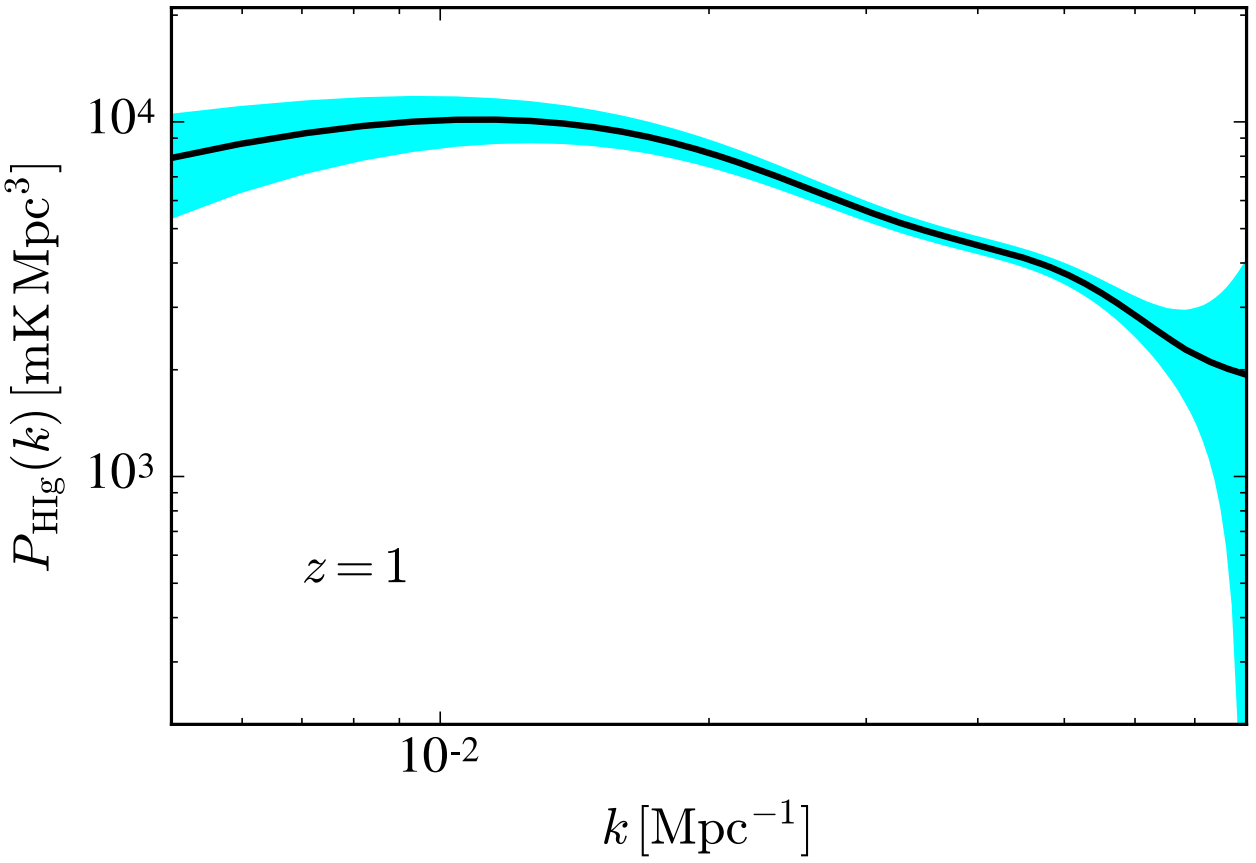
21cm IM surveys: GBT, CHIME, HIRAX, MeerKAT, SKA!

HI AUTO AND CROSS POWER SPECTRUM

- With intensity mapping we can constrain HI and cosmological parameters

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

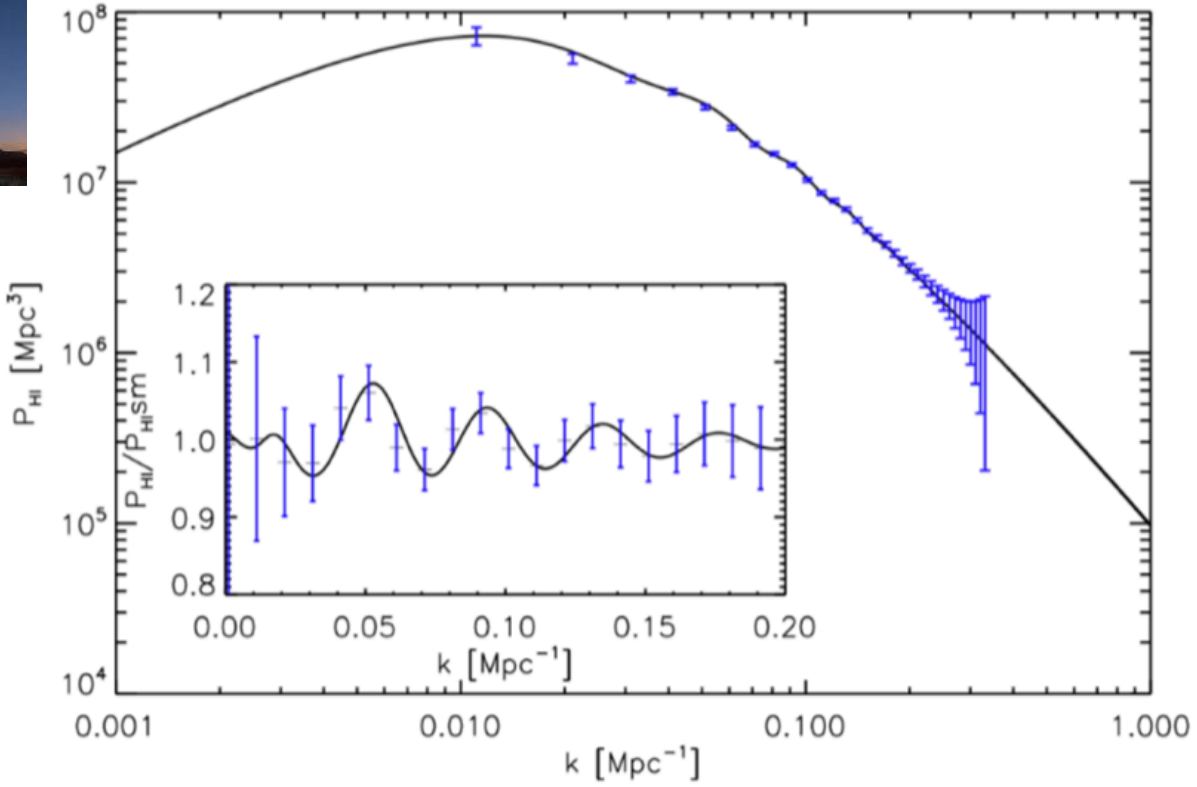
[e.g. SKA1-MID x Euclid]



Precision cosmology with 21cm intensity mapping

- A "single-dish" experiment can measure the power spectrum competitively to state-of-the art optical galaxy surveys

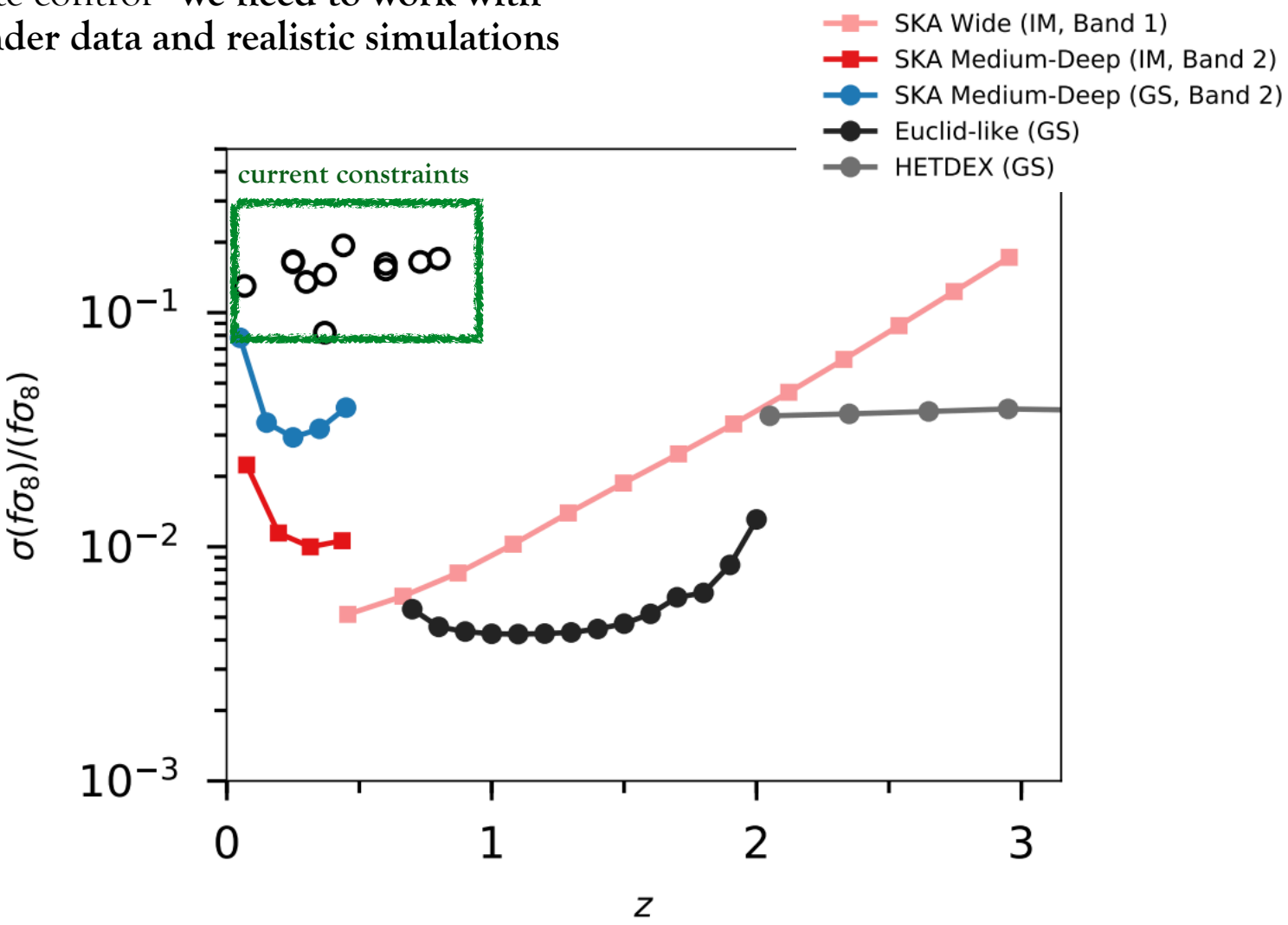
[Battye, AP et al. 2013]



[also see e.g. Chang et al 2008, Bull et al. 2015, Villaescusa-Navarro et al. 2016, ...]

MEASURING THE GROWTH OF STRUCTURE

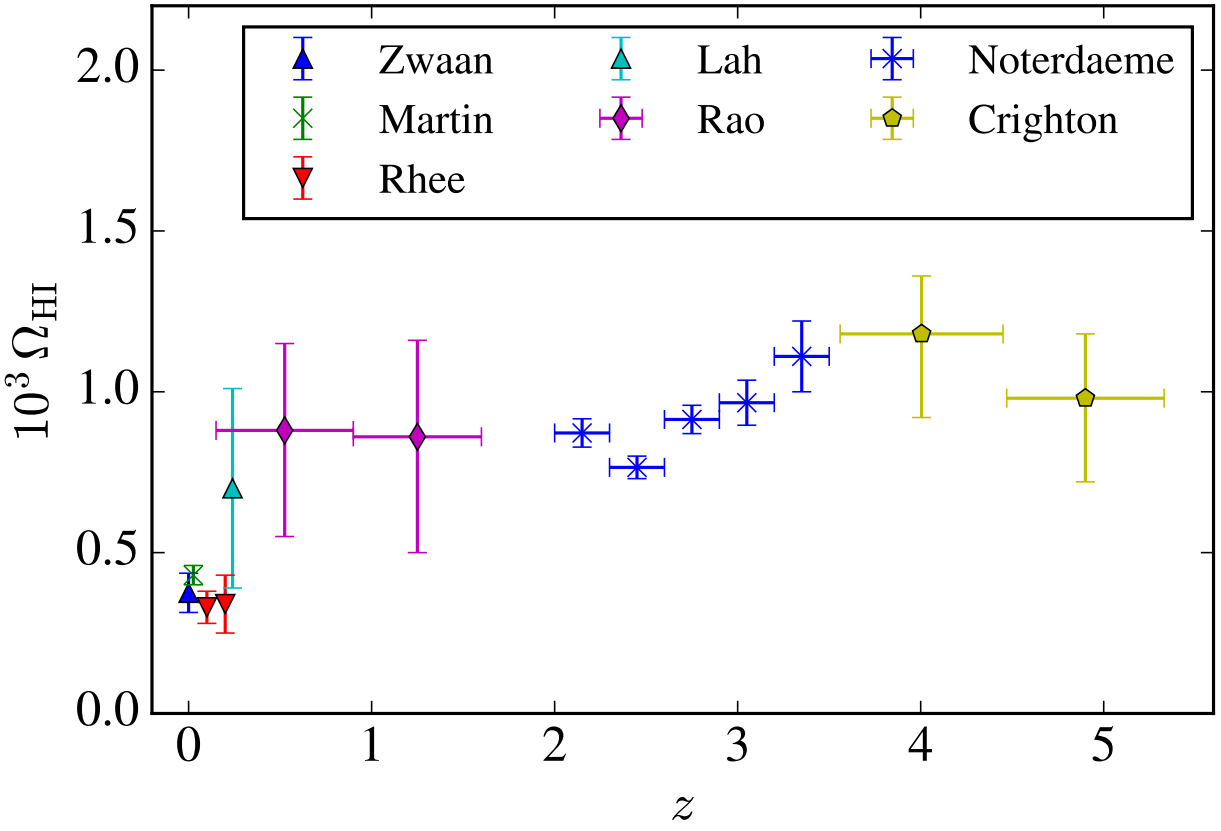
- Forecasts look great but assume foregrounds and systematics are under exquisite control - **we need to work with pathfinder data and realistic simulations**



[SKA cosmology Red Book 2018]

INTENSITY MAPPING AND GALAXY EVOLUTION

- HI evolution is currently quite poorly constrained...
- Important for astrophysics and cosmology alike!



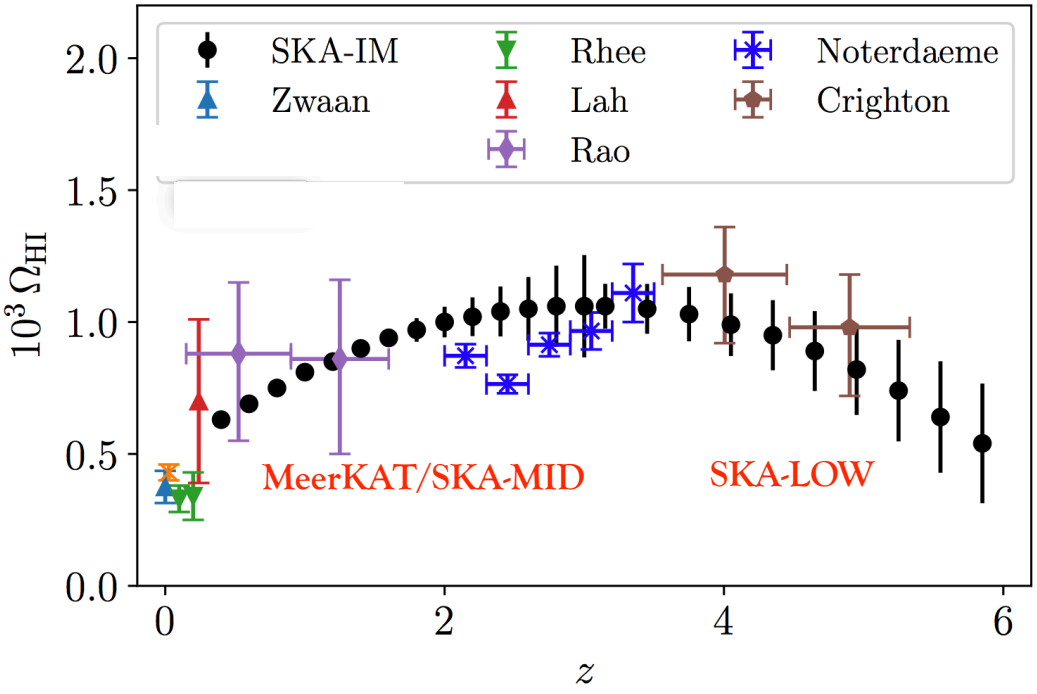
[c.f. Crighton et al 2015]

GALAXY EVOLUTION

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

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

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



[SKA cosmology Red Book 2018]

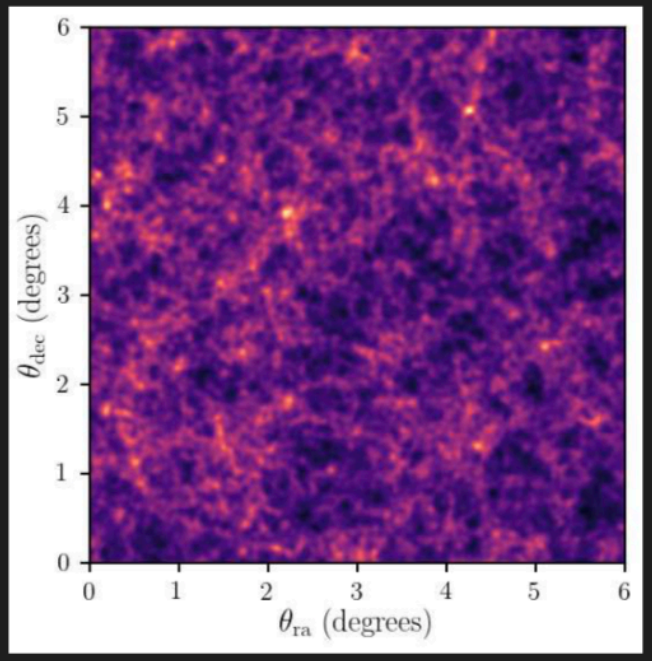
SIMULATING 21cm OBSERVATIONS

work with S. Cunnington (QMUL)

SIMULATIONS

N-body Sim → Halo Model → Galaxy Catalogue → HI galaxy properties → 21cm Intensity Map

$$\delta T_{\rm obs}(z) = \delta T_{\rm HI}(z) + \delta T_{\rm noise}(z) + \sum_i \delta T_i^{\rm FG}(z)$$



Intensity map using S³SAX-Sky

- We are also working on putting HI on Euclid's state-of-the-art Flagship simulation!

Difficulties

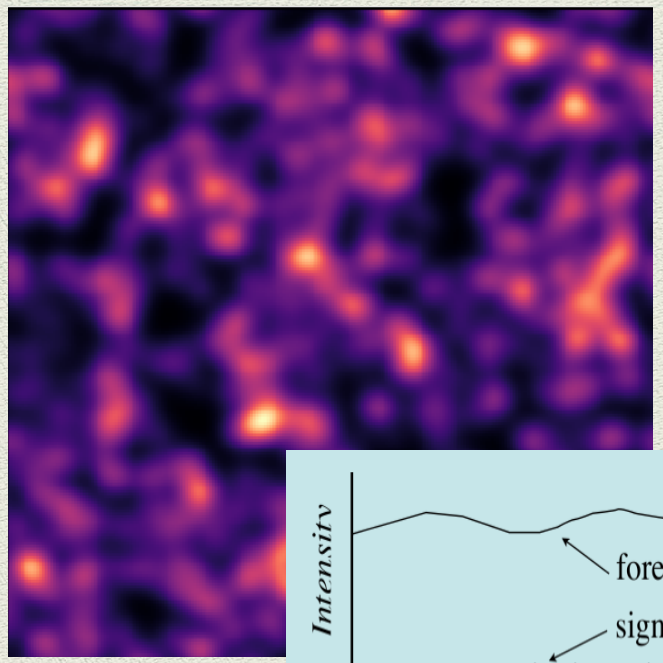
- 21cm signal is very weak
- Foregrounds are a big problem!

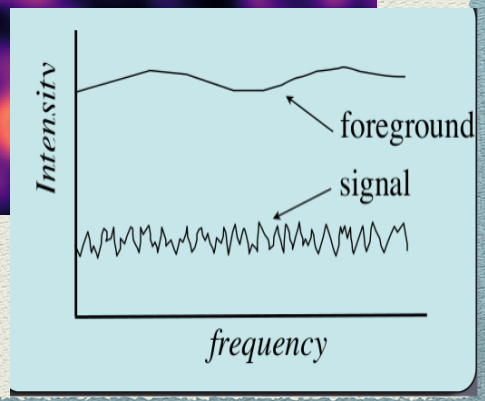
(i) Galactic synchrotron - relativistic cosmic ray electrons accelerated by the galactic magnetic field

(ii) Extra-galactic point sources - objects beyond our own galaxy emitting signals close to 21cm signal

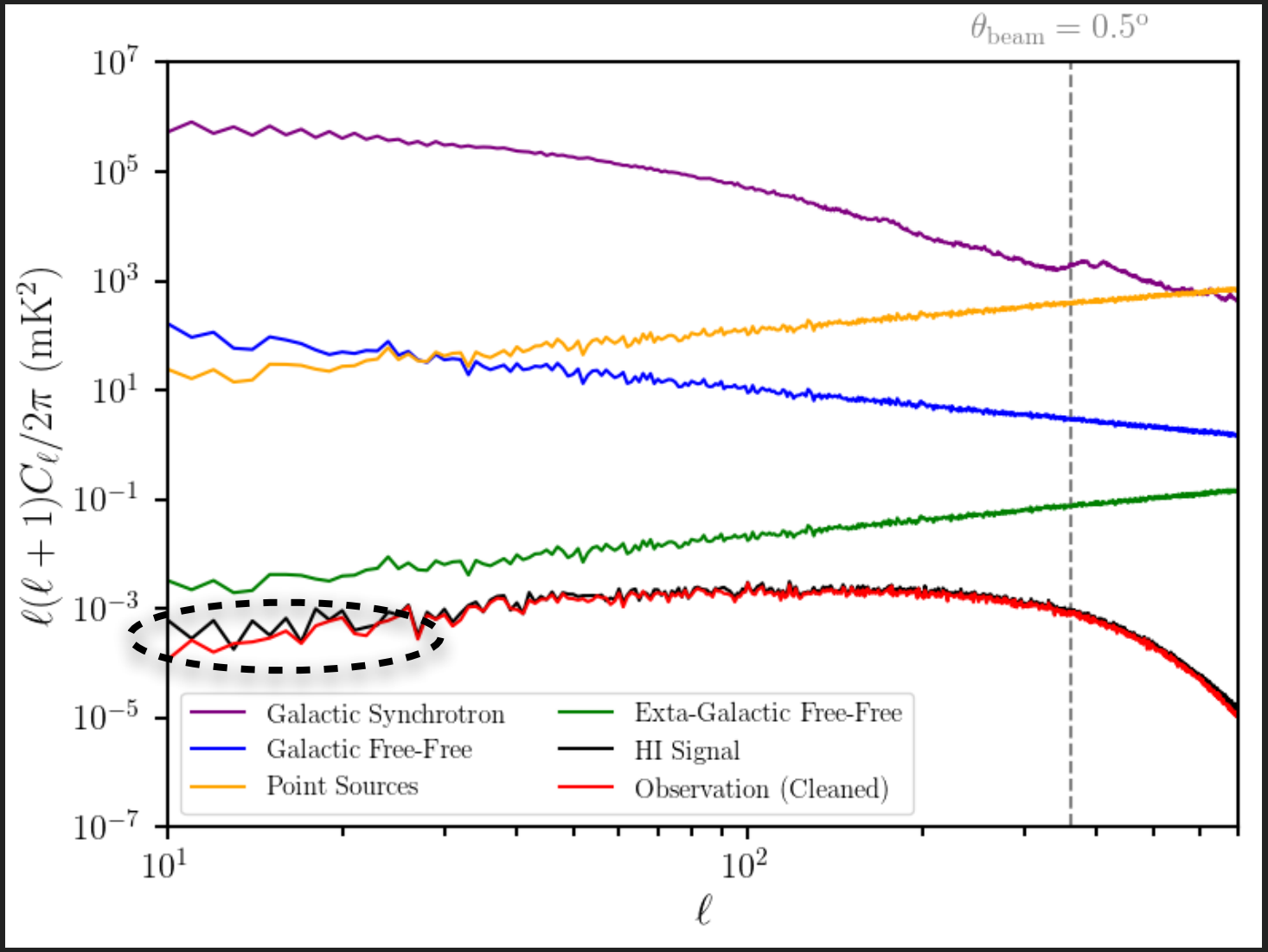
(iii) Extra-galactic free-free emission - free electrons scattering off ions without being captured and remaining free after the interaction

(iv) Galactic free-free emission - as above but within our own galaxy





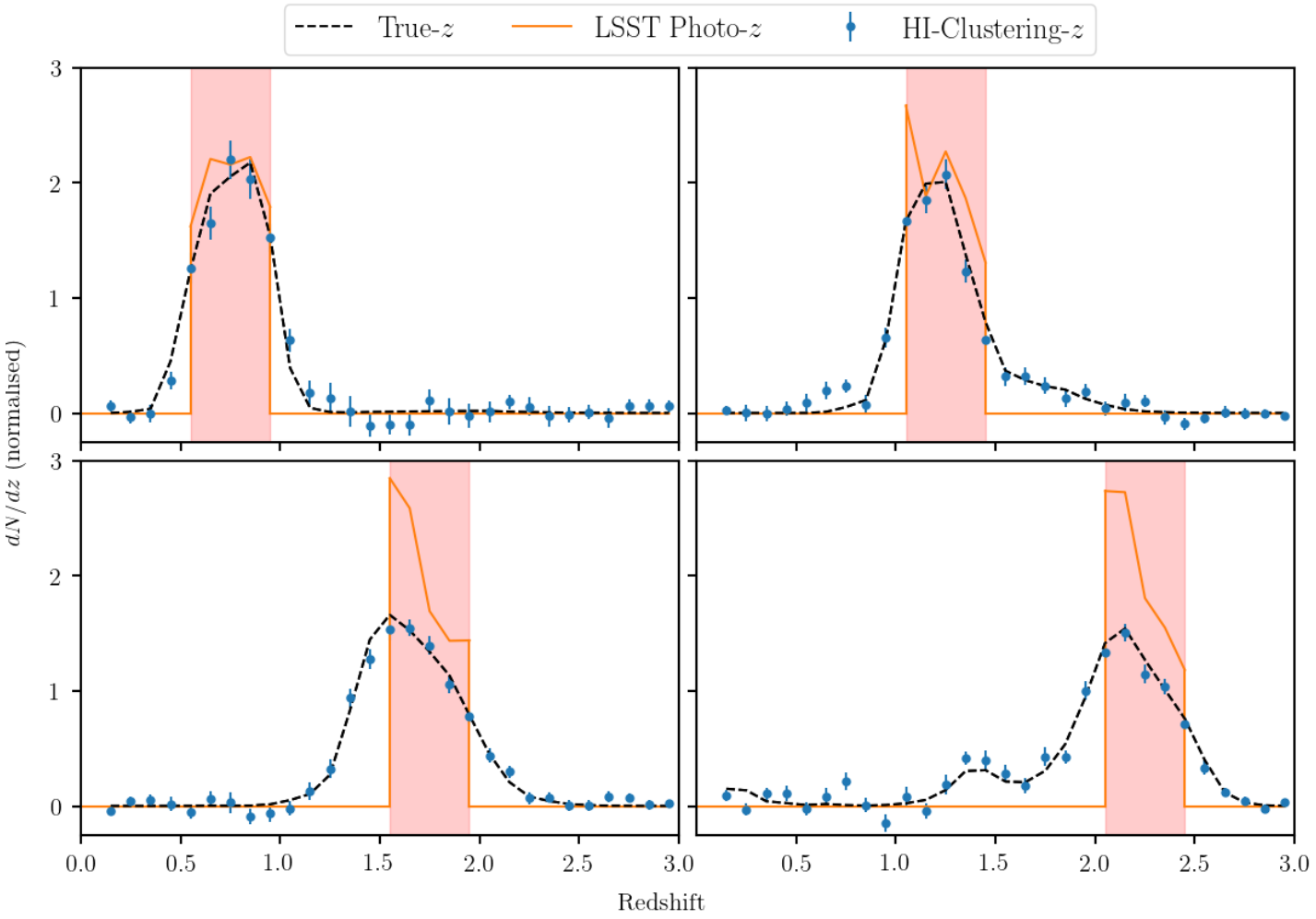
Cunnington, AP, Harrison, Wolz, Bacon 2018 & 2019



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

RADIO-OPTICAL SYNERGIES: PHOTOMETRIC REDSHIFT CALIBRATION

- Using our simulations we showed that 21cm intensity maps can be used for photo-z calibration. This could be very useful for LSST and Euclid. **[more in Steve's talk later]**



Cunnington et al. (2018 and 2019)

INTENSITY MAPPING: CURRENTLY OPERATING TELESCOPES

First detection in x-cross with optical

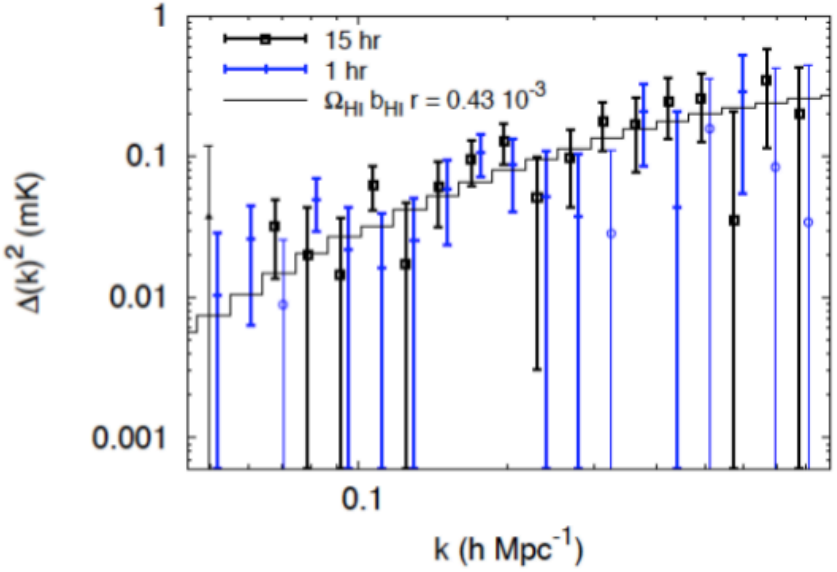
North, whole sky, 0.8<z<2.5

Survey at 0<z<0.6

PATHFINDER DATA ANALYSIS

- Systematic effects are a big challenge for 21cm intensity mapping
- **GBT x WiggleZ 2013** showed that cross-correlating with optical can mitigate this!
- **2dF x Parkes** detection last year.

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

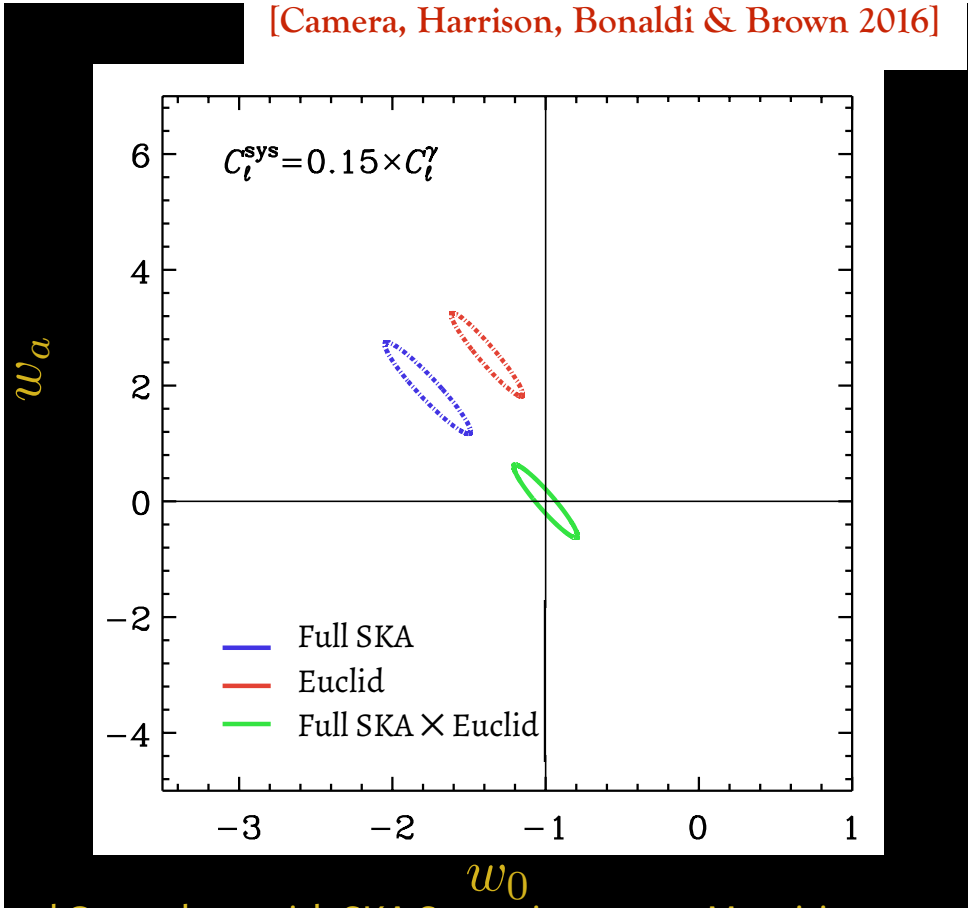


Masui, et al., ApJ 2012,
Chang et al., Nature 2010

SYSTEMATICS MITIGATION

- Survey specific systematics should drop out in cross correlation
- Example: **the cosmic shear case**

[Camera, Harrison, Bonaldi & Brown 2016]

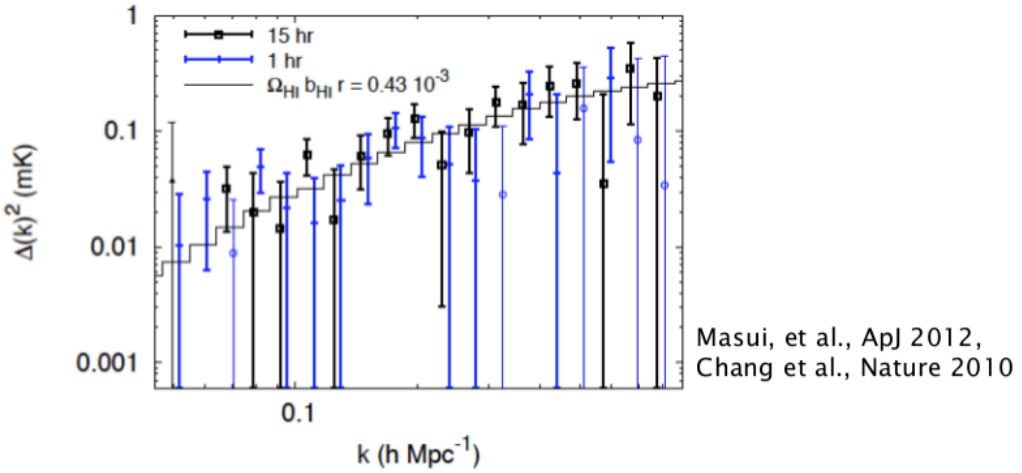


GBT X EBOSS DATA ANALYSIS (SDSS-IV PROJECT)

In progress with Wolz, Bautista, Chang, Masui, Avila, Berger, Cunnington, Mueller, et al.

- GBT updated intensity mapping data at 0.6<z<1
- eBOSS ELGs and LRGs samples (and WiggleZ)
- Area overlap: **100 square degrees**

The project builds upon the first pioneering detection:
GBT x WiggleZ
[Masui et al. 2013]



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

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

GBT X EBOSS DATA ANALYSIS (SDSS-IV PROJECT)

- **GBT updated intensity mapping data at 0.6<z<1**
- **eBOSS ELGs and LRGs samples (and WiggleZ)**
- Area overlap: **100 square degrees**

- **Goal:** estimate the HI content of eBOSS ELGs and LRGs via cross-correlation with GBT HI intensity maps
- **Goal:** constrain HI density and HI bias at z=0.8
- **Goal:** compare different foreground removal methods
- **Goal:** understand the systematics better