SYNERGIES BETWEEN HI INTENSITY MAPPING AND OPTICAL GALAXY SURVEYS

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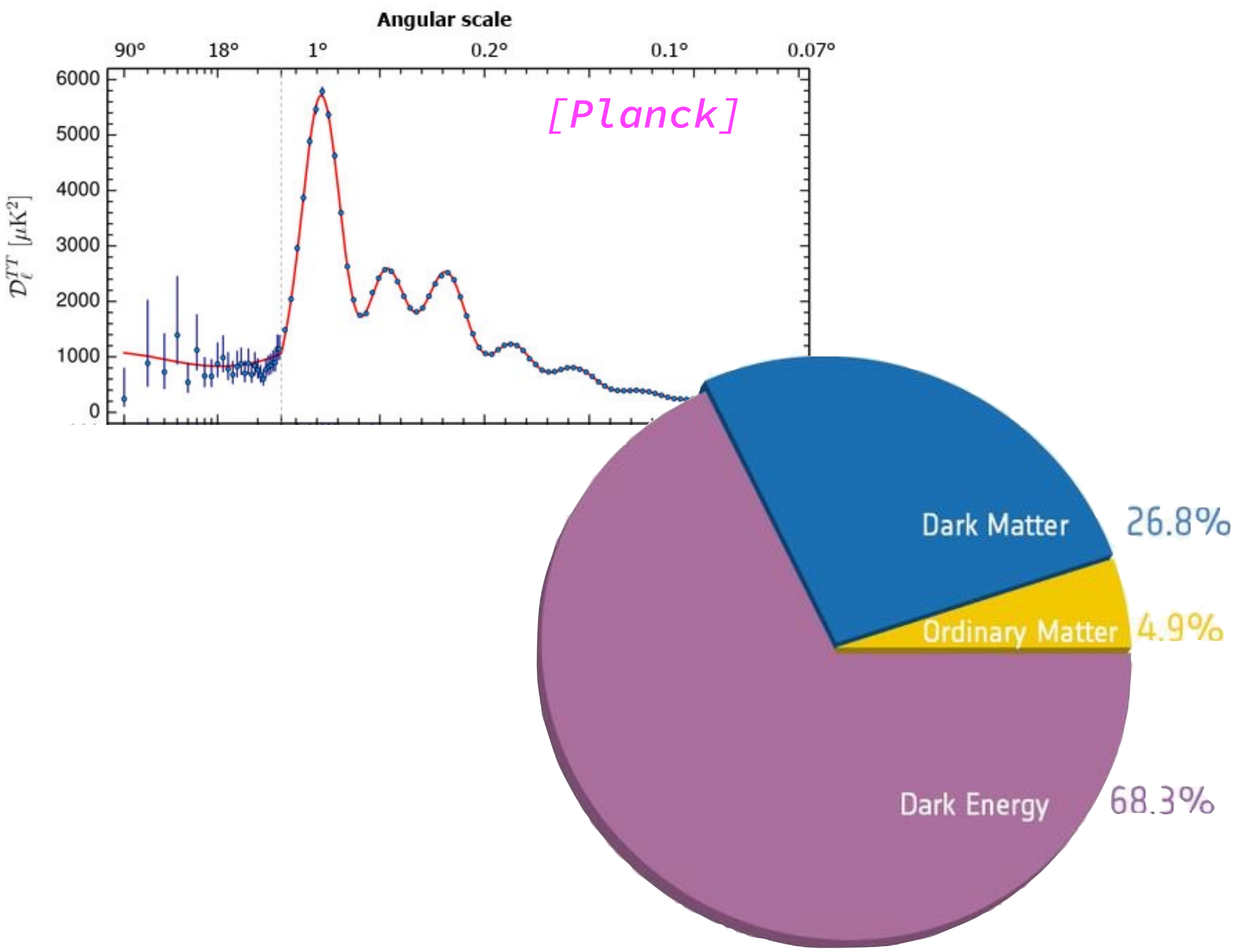
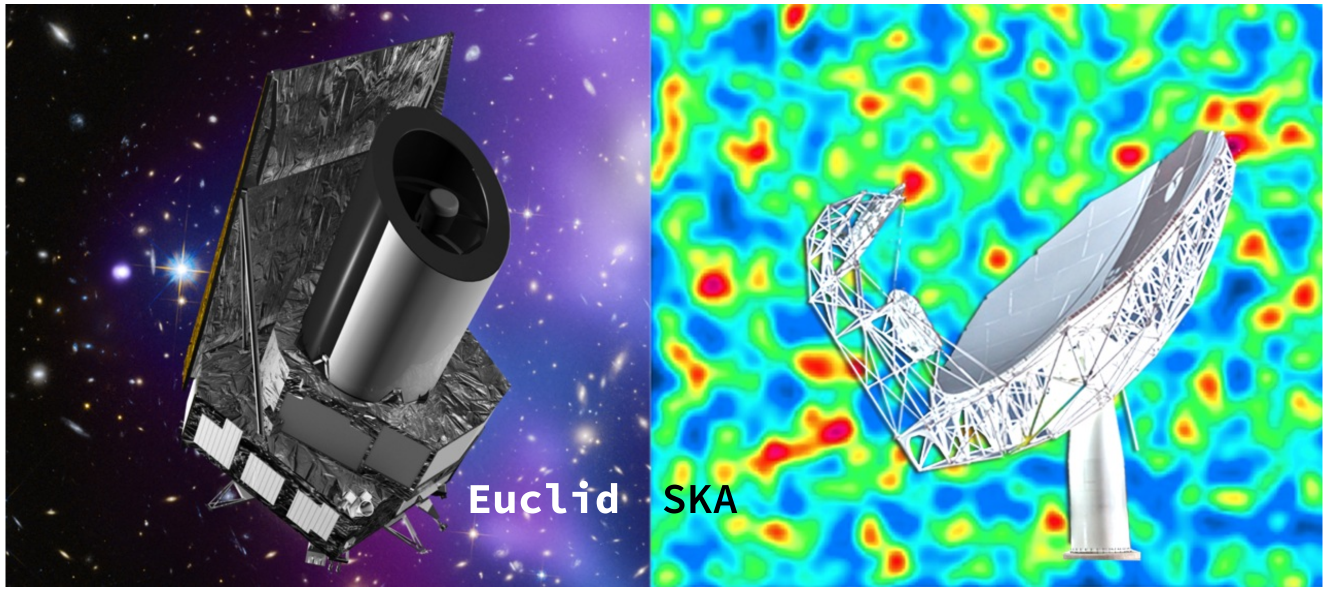
PASCOS 2019

Image credit: Hayden Planetarium, 2014

New Frontiers in Observational Cosmology



- 95% of our Universe is very strange - new physics!
- Use **large scale structure surveys**, multiple wavelengths, and multiple probes
- Exploit synergies and invest in pathfinders



21CM OBSERVABLE UNIVERSE

Huge unexplored volume can
be probed with 21cm!

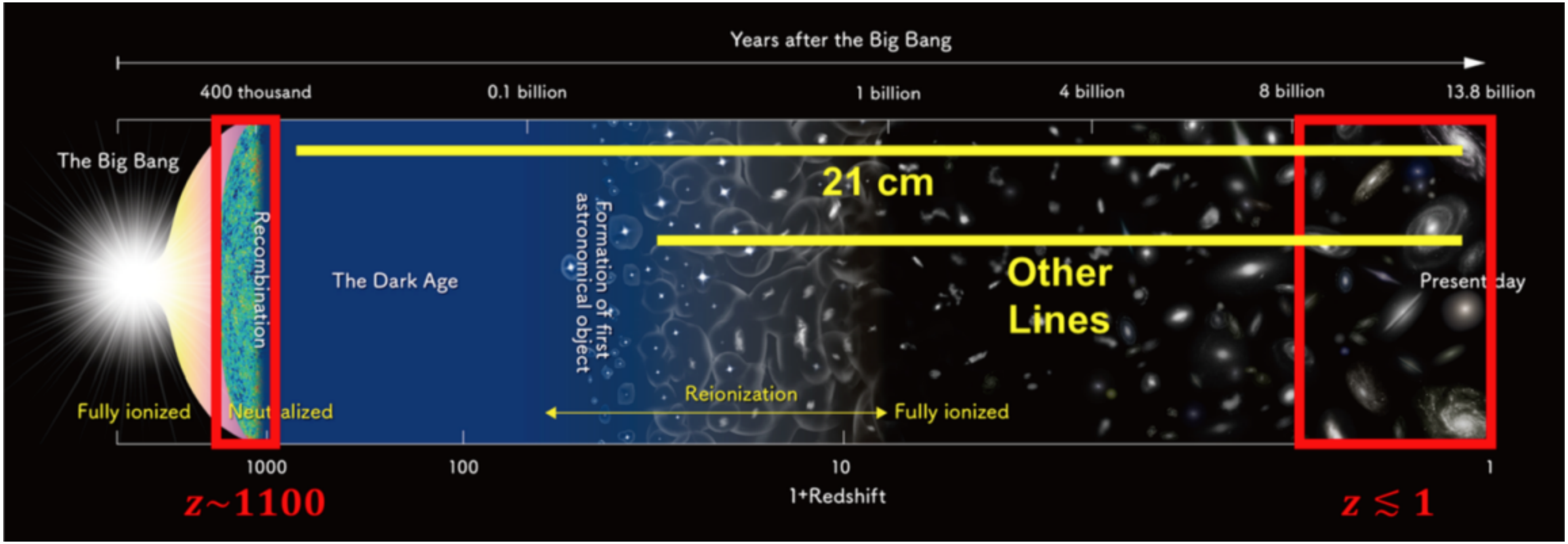


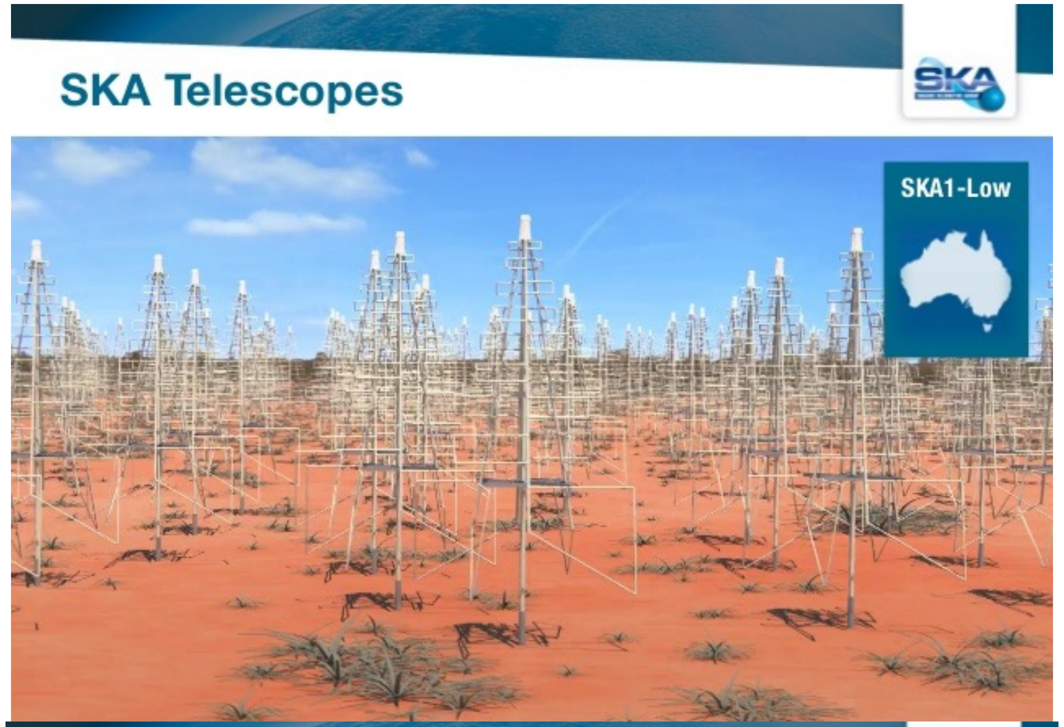
Image Credit: NAOJ [Kovetz et al. 2017 arXiv:1709.09066]

THE SQUARE KILOMETRE ARRAY (SKA)

- Series of radio telescopes, very sensitive to a wide range of frequencies (redshifts)
- **SKA-MID Phase 1**: 130 SKA-MID + 64 MeerKAT dishes, 2026+
- **MeerKAT-64** live now! The 64 dishes are up and running, about 20 more to be added

MeerKAT

MeerKAT/SKA-Mid will complement optical galaxy surveys (0<z<3)



SKA COSMOLOGY

SKA Office / A. Bonaldi

Publications of the Astronomical Society of Australia (PASA)
doi: 10.1017/pas.2018.xxx.

Cosmology with Phase 1 of the Square Kilometre Array

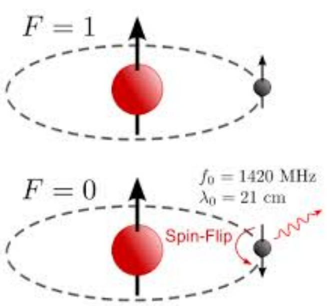
Red Book 2018: Technical specifications and performance forecasts

Square Kilometre Array Cosmology Science Working Group: David J. Bacon[1], Richard A. Battye[2,*], Philip Bull[3], Stefano Camera[4,5,6,2], Pedro G. Ferreira[7], Ian Harrison[2,7], David Parkinson[8], Alkistis Pourtsidou[3], Mário G. Santos[9,10,11], Laura Wolz[12,*], Filipe Abdalla[13,14], Yashar Akrami[15,16], David Alonso[7], Sambatra Andrianomena[9,10,17], Mario Ballardini[9,18], José Luis Bernal[19,20], Daniele Bertacca[21,36], Carlos A.P. Bengaly[9], Anna Bonaldi[22], Camille Bonvin[23], Michael L. Brown[2], Emma Chapman[24], Song Chen[9], Xuelei Chen[25], Steven Cunnington[1], Tamara M. Davis[27], Clive Dickinson[2], José Fonseca[9,36], Keith Grainge[2], Stuart Harper[2], Matt J. Jarvis[7,9], Roy Maartens[1,9], Natasha Maddox[28], Hamsa Padmanabhan[29], Jonathan R. Pritchard[24], Alvise Raccanelli[19], Marzia Rivi[13,18], Sambit Roychowdhury[2], Martin Sahlén[30], Dominik J. Schwarz[31], Thilo M. Siewert[31], Matteo Viel[32], Francisco Villaescusa-Navarro[33], Yidong Xu[25], Daisuke Yamauchi[34], Joe Zuntz[35]
Affiliations listed after references

Synergies with optical surveys (Euclid, LSST...) vital

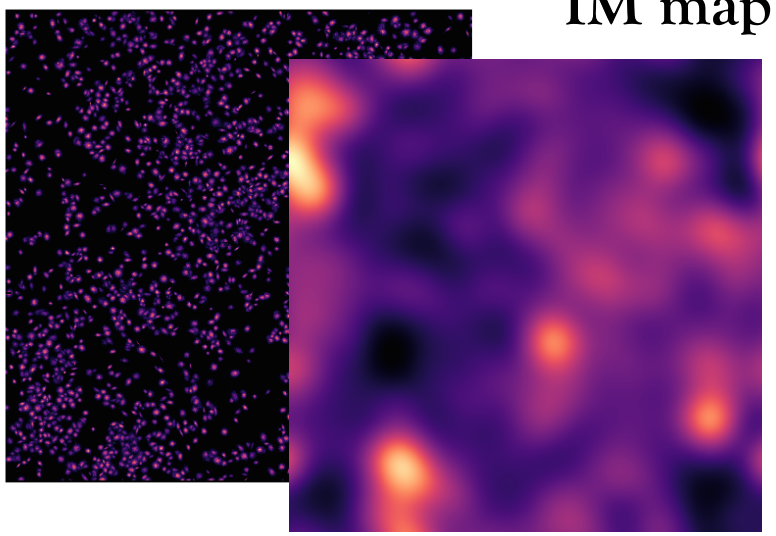
RADIO PRECISION COSMOLOGY: THE INTENSITY MAPPING METHOD

[Battye et al 2004, Chang et al 2008, Peterson et al 2009, Seo et al 2010, …]



galaxies

IM map



[Simulations by S. Cunnington]

- Detecting HI (neutral hydrogen) galaxies via their 21cm emission line is very expensive
- But cosmological information is on large scales
- Get intensity map of the HI 21cm emission line - like CMB but 3D!
- Excellent redshift resolution
- Signal of the order 0.1 mK – foregrounds much bigger
- Cross-correlations with optical help mitigate systematic effects

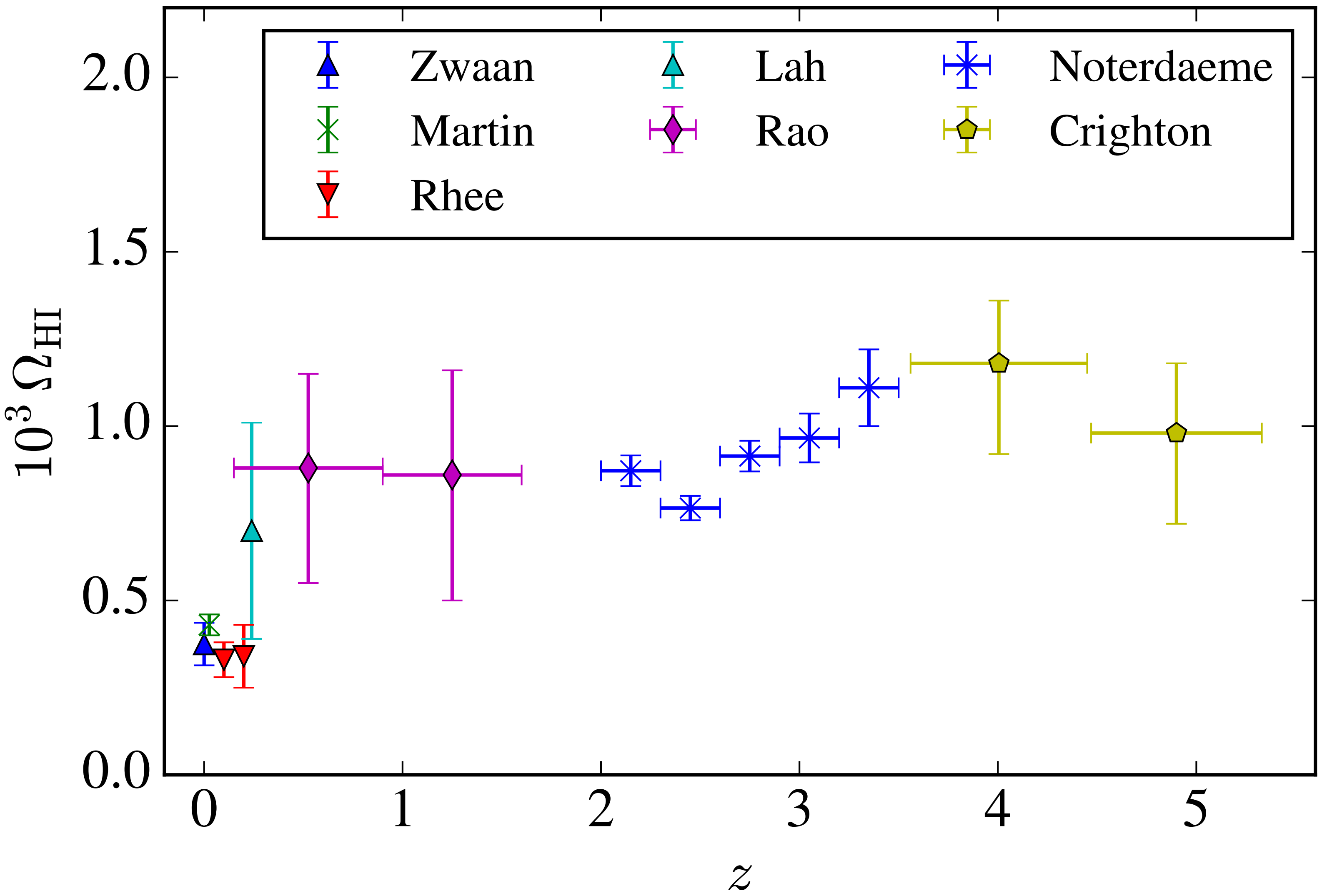
21cm IM surveys: GBT, BINGO, CHIME, HIRAX, MeerKAT, SKA!

GOALS: Probe HI evolution, dark energy, gravity, inflation, …

EUCLID AND SKA SYNERGIES: GALAXY EVOLUTION

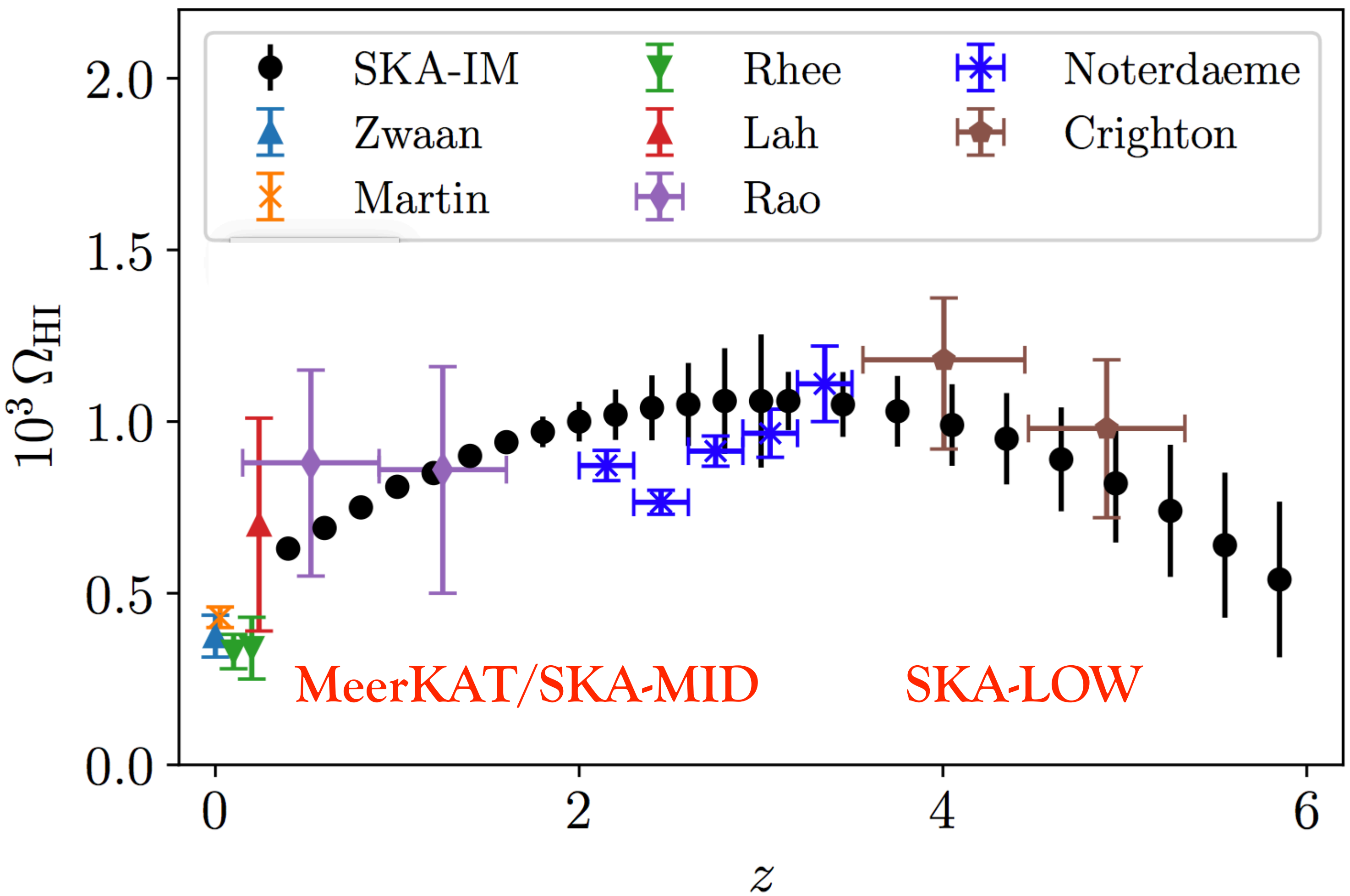
- HI evolution is currently quite poorly constrained…

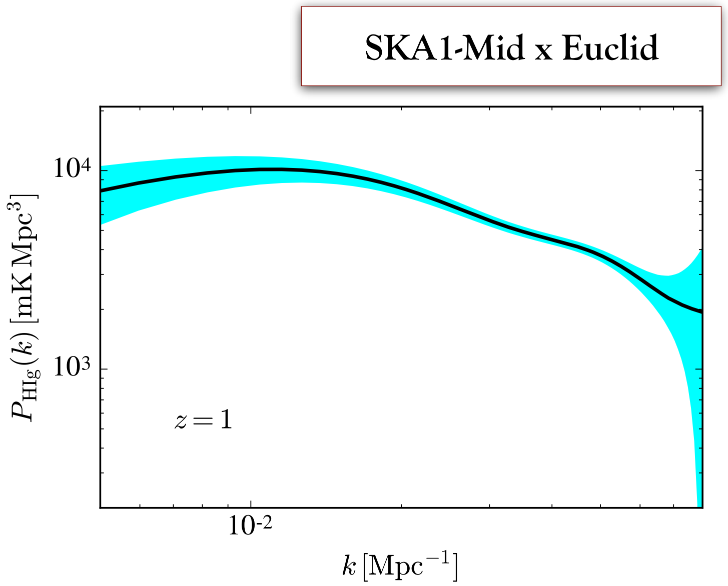
[c.f. Crighton et al 2015]



EUCLID AND SKA SYNERGIES: GALAXY EVOLUTION

- Can massively improve this diagram using HI intensity mapping data
- Cross-correlation helps with systematics and allows for studying the HI content of different galaxy samples



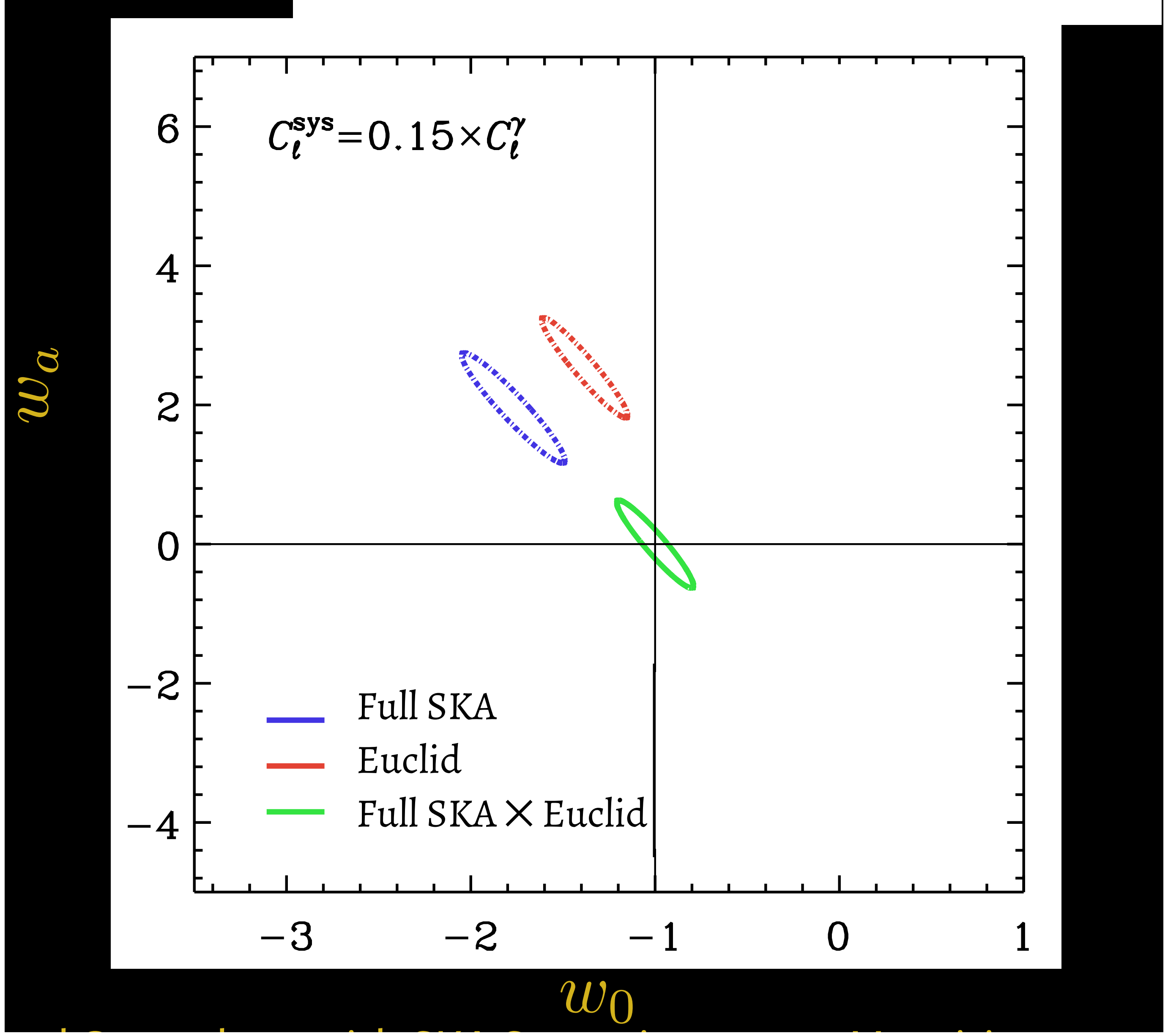


- **Also precision cosmology:** BAO, RSDs, primordial non-gaussianity, and more…[SKA Cosmo Red Book 2018]

SYSTEMATICS MITIGATION

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

[Camera, Harrison, Bonaldi & Brown 2016]



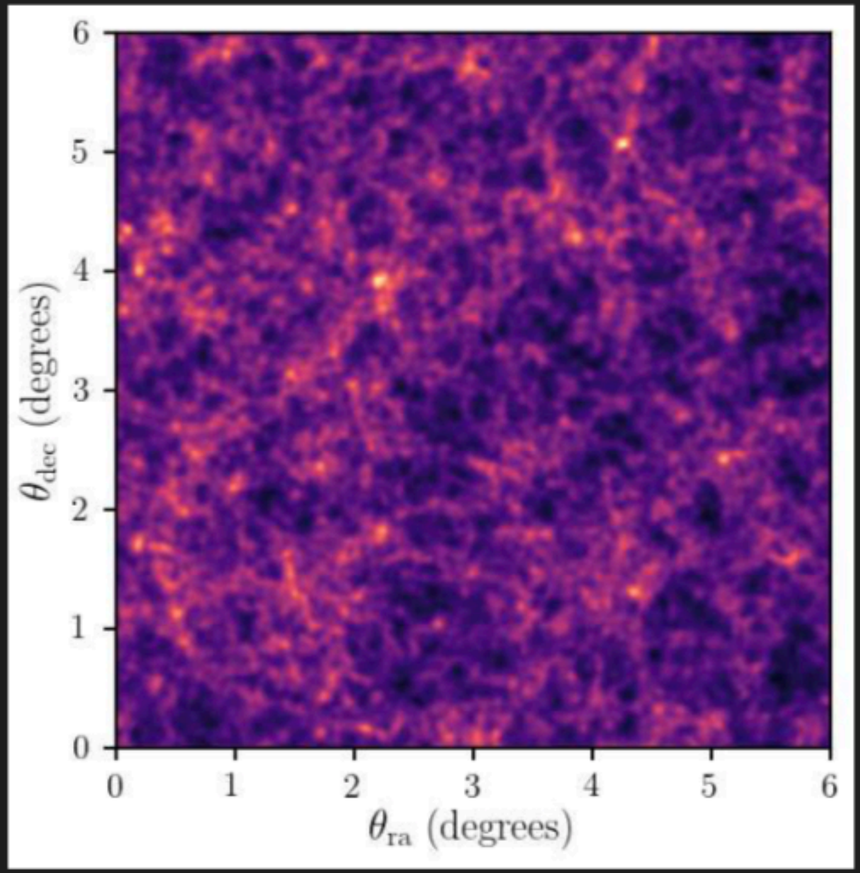
RADIO-OPTICAL SIMULATION SYNERGIES

Work with S. Cunnington, L. Wolz, and D. Bacon

SIMULATIONS

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

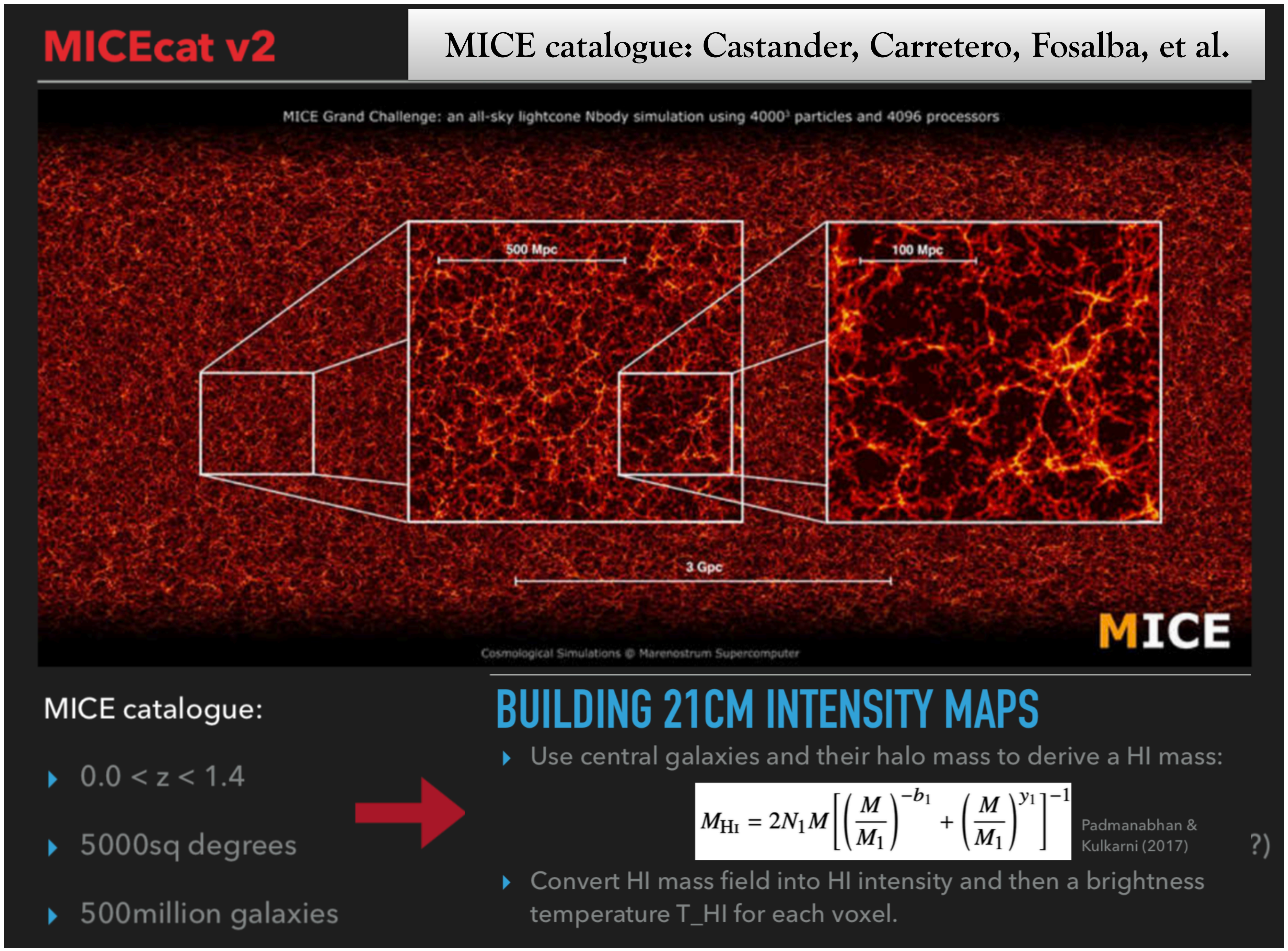
$$\delta T_{\rm obs}(z) = \delta T_{\rm HI}(z) + \delta T_{\rm noise}(z) + \sum_i \delta T_i^{\rm FG}(z)$$



Intensity map using S³SAX-Sky

SIMULATION SYNERGIES

- Preparing Euclid's cross-correlations with radio data
- Work within Euclid's **Additional GC Probes WP**

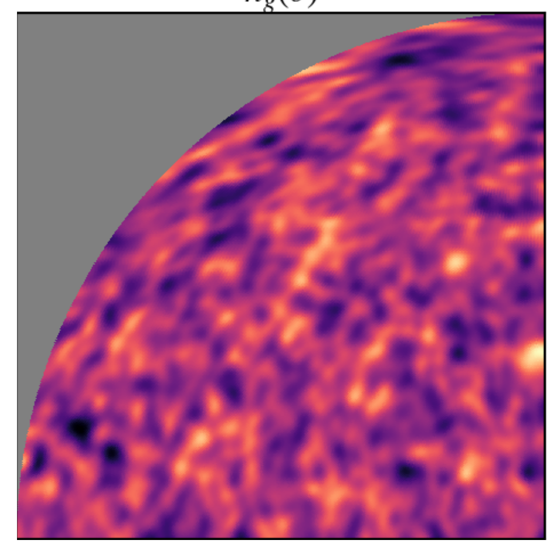


Cunnington et al. (2018 and 2019)

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:*

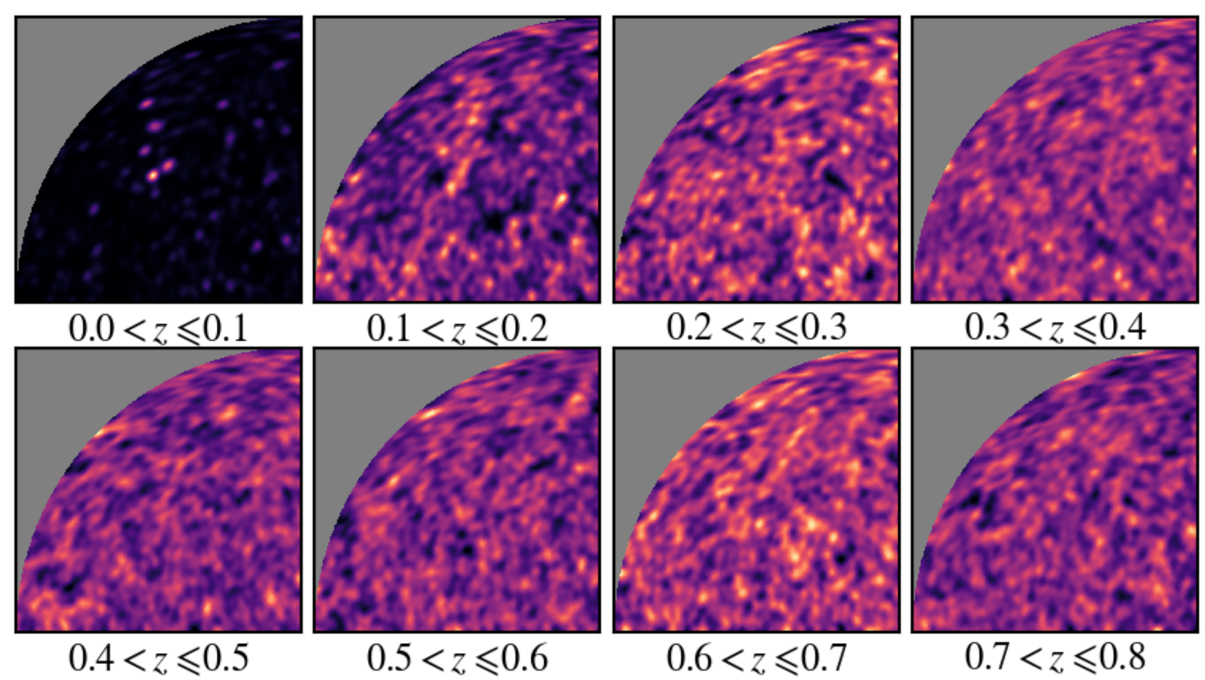
$n_g(\vec{\theta})$



$0.0 < z < 0.8$

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

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



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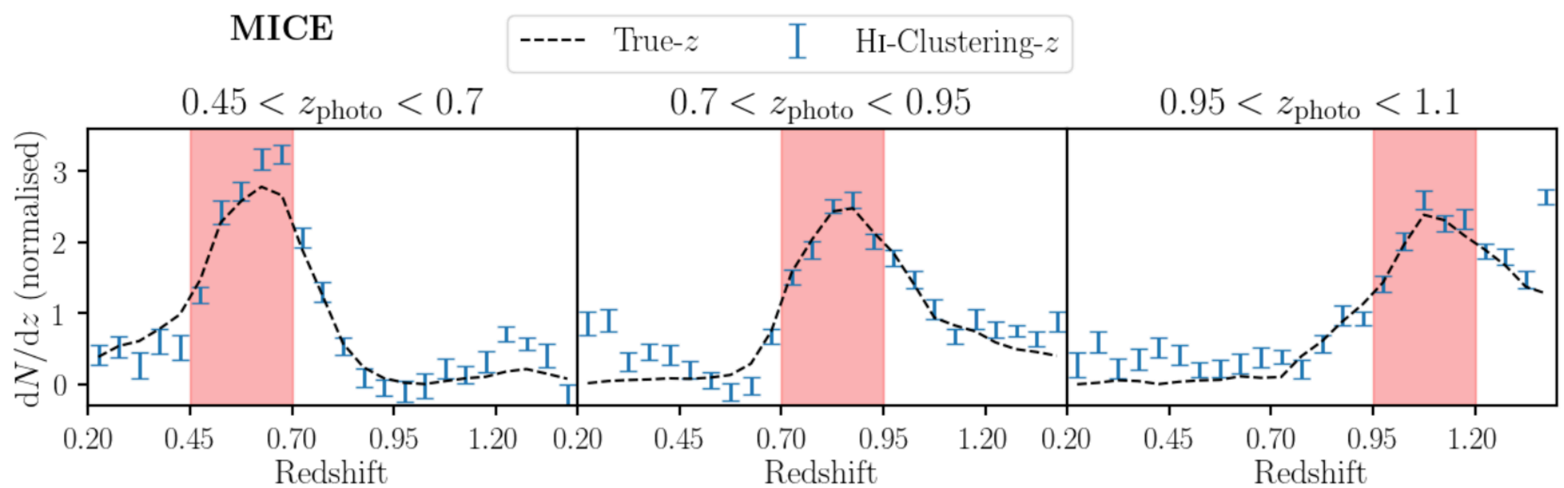
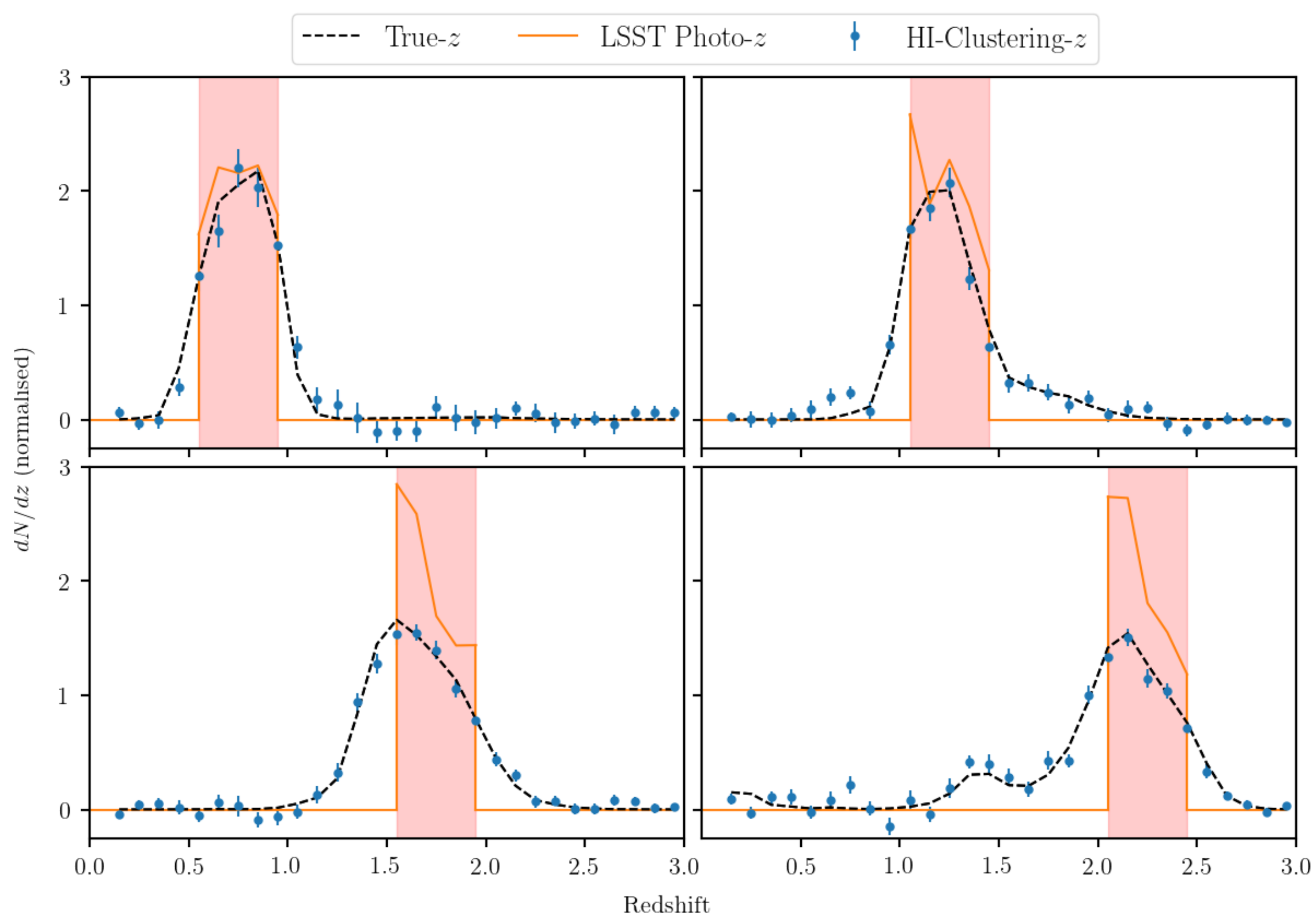
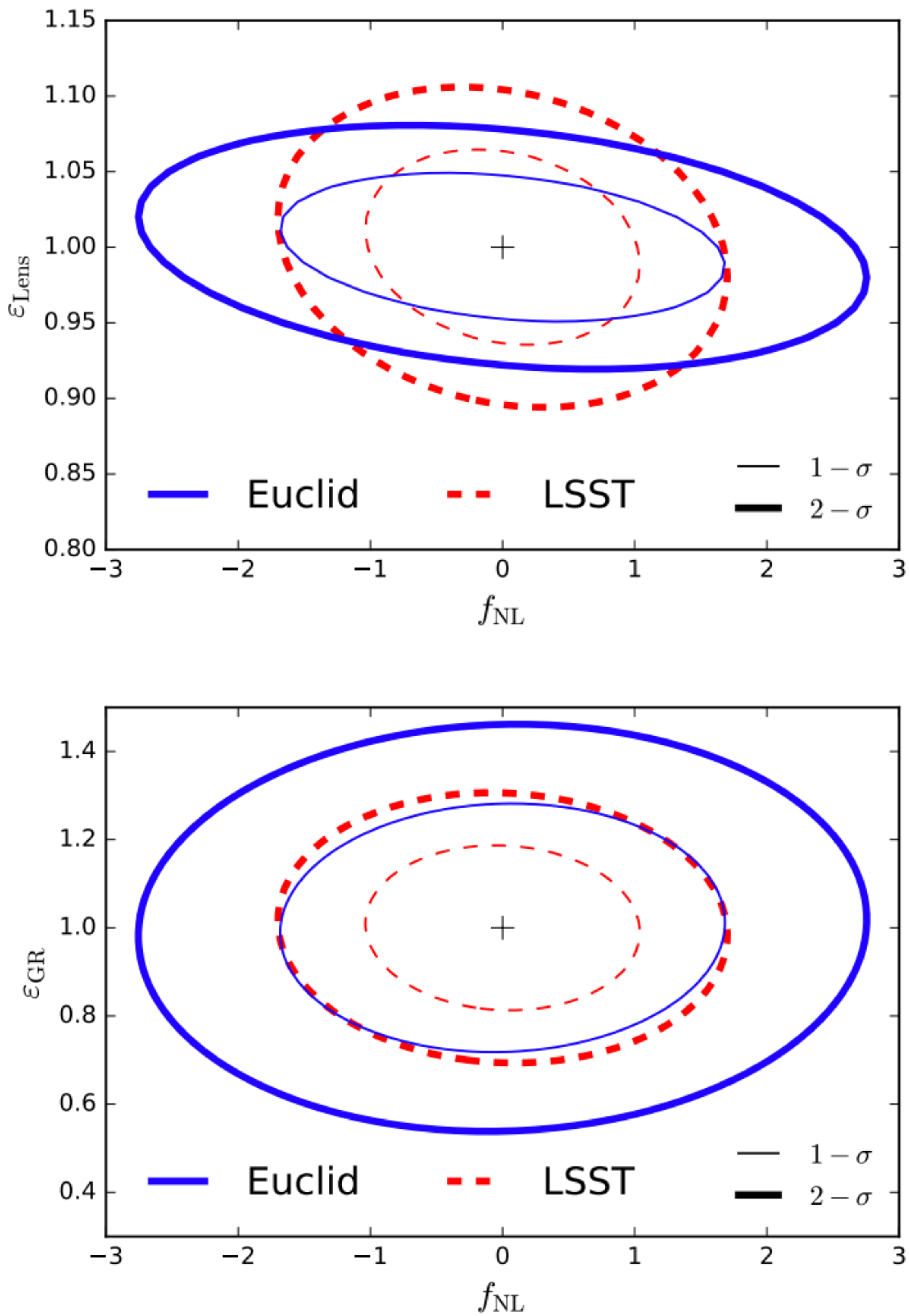


- **Current work:** applying our estimator and pipeline to Euclid's Flagship simulation



EUCLID-SKA SYNERGIES: MULTIPLE TRACERS TECHNIQUE



- **Multiple tracers technique to beat cosmic variance**
- Hard to achieve using only one survey and splitting in two (I think)
- Primordial non-gaussianity constraints can in principle reach $\sigma(f_{NL}) = 1$

SKA Red Book 2018, based on Fonseca et al. 2018

WORKING WITH REAL DATA TO PREPARE FOR THIS SCIENCE

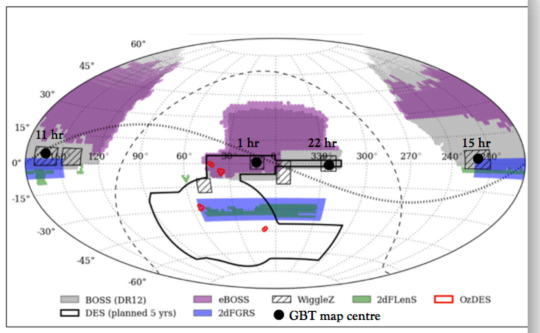
GBT X EBOSS DATA ANALYSIS (SDSS-IV PROJECT)

Wolz, Bautista, Cunnington, AP, Avila, Chang, Masui, Mueller, Percival, Bacon, et al

- GBT updated intensity mapping data in 0.6<z<1
- **eBOSS ELGs:** 0.7<z<1.1; **LRGs:** 0.6<z<0.9
- Area overlap: **100 square degrees**

- **Goal:** estimate the HI content of eBOSS ELGs and LRGs via cross-correlation with GBT HI intensity maps
- **Goal:** measure the cross-correlation power spectrum
- **Goal:** constrain HI density and HI bias at z=0.8

Figure adapted from Anderson et al 2015

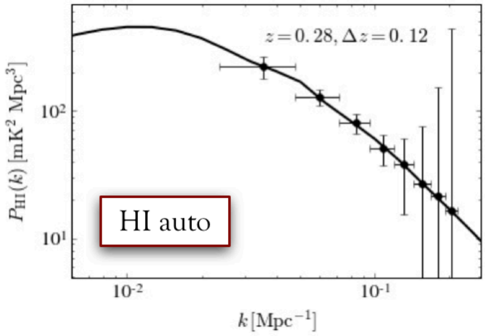


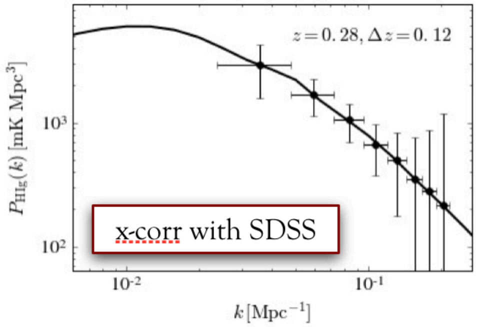
AN INTENSITY MAPPING SURVEY USING MEERKAT

[White papers: Santos et al, 2017; AP, 2017]

[Fonseca, AP, Santos]

- MeerKAT: 64 13.5 m dishes
- **MeerKLASS survey:** 4000 sq. deg. overlapping with DES, and 5 months observation time
- We are working on calibration and foreground removal with test data
- **Science Verification data (200 sq. deg.) overlapping with WiggleZ**





COSMIC MAGNIFICATION MEASUREMENTS

Witzemann, Pourtsidou, Santos 2019

$$\langle \delta_g^L(\theta_f, z_f)\delta_g^L(\theta_b, z_b)\rangle = \langle (5s_g^b - 2)\kappa_b \delta_g(\theta_f, z_f)\rangle + \langle (5s_g^f - 2)(5s_g^b - 2)\kappa_f\kappa_b\rangle$$

8sigma detection using SDSS galaxies x quasars (Scranton et al 2005)

$$\langle \delta_{HI}^L(\theta_f, z_f)\delta_g^L(\theta_b, z_b)\rangle = \langle (5s_g^b - 2)\kappa_b b_{HI} \delta(\theta_f, z_f)\rangle$$

HI intensity maps x galaxies