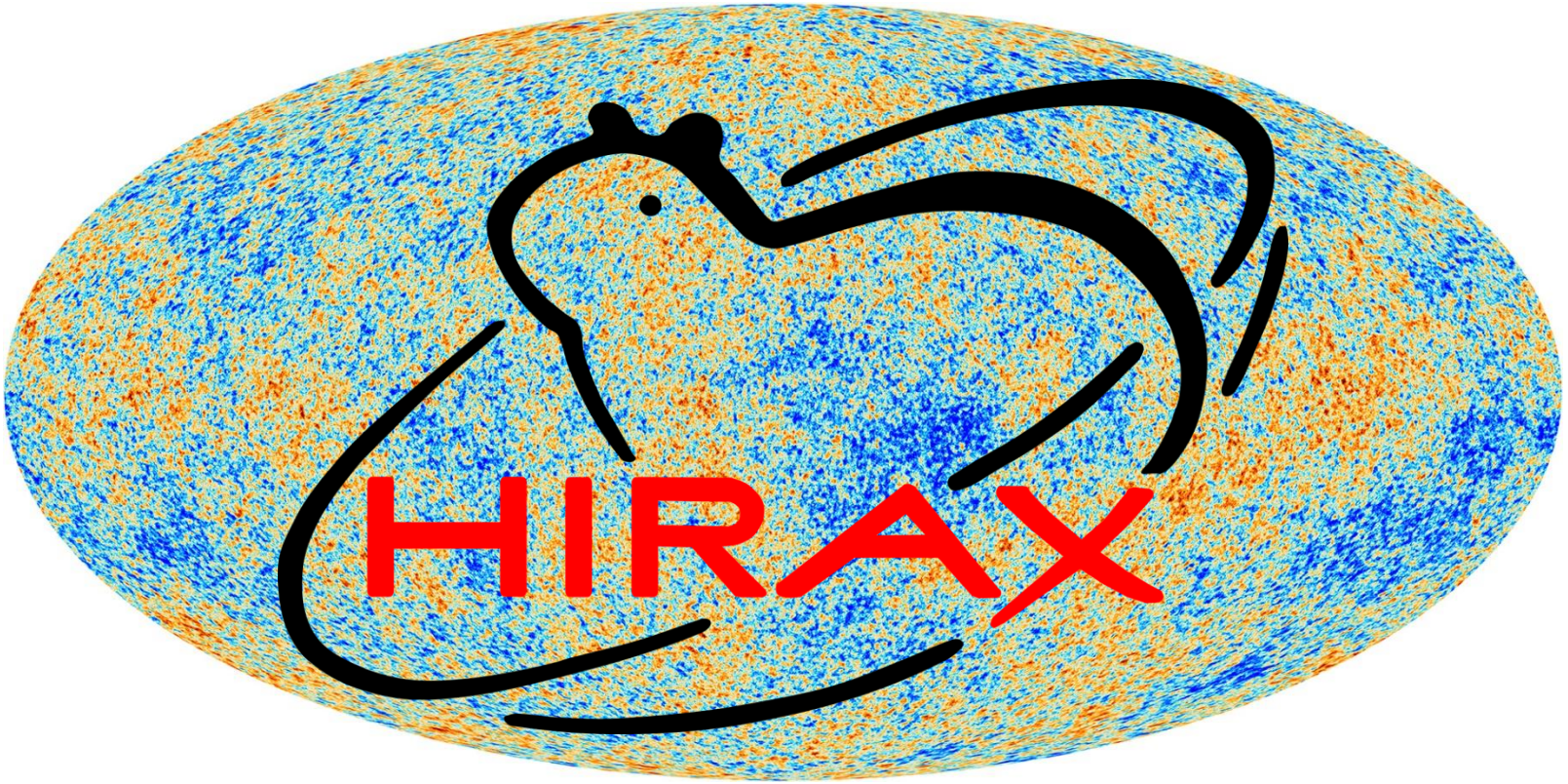
BAO-CMB Cross-Correlation with the HIRAX Array

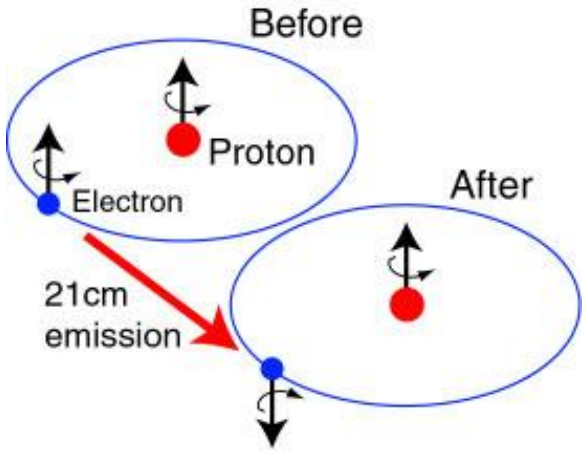


NORDITA, July 21th, 2017

Ben Saliwanchik for the HIRAX Collaboration

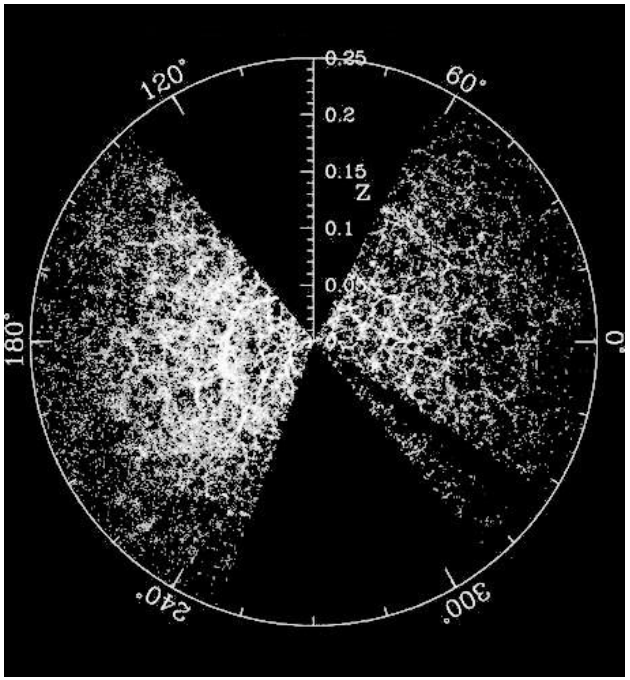
21 cm Line as Cosmological Probe

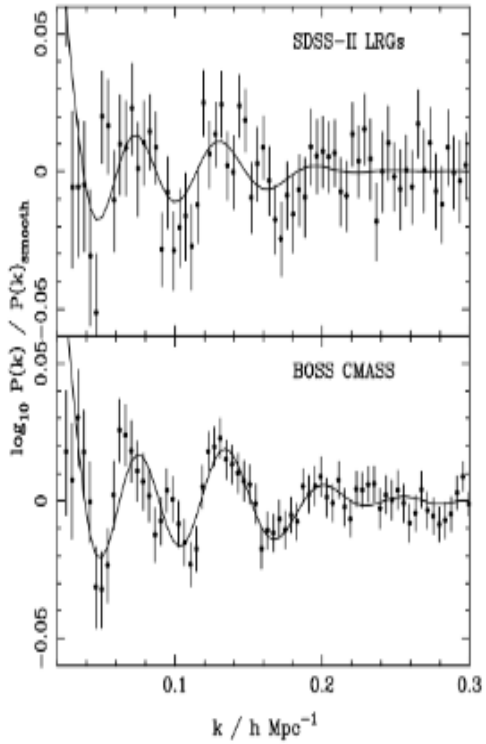
- 21 cm (1.4GHz) line becoming powerful cosmology probe
- Hydrogen abundant, not much confusion from other lines
- This is a “forbidden” transition, ~10Myr lifetime of excited state => observed frequency gives good measurement of redshift of emission
- Can use 21 cm line to study history of matter and growth of structure in universe



Baryon Acoustic Oscillations (BAO)

- Sound horizon at recombination produces characteristic length scale in density perturbations (~150 Mpc)
- Structures preferentially form in peaks of density field
- Should see rings of correlation in galaxy positions

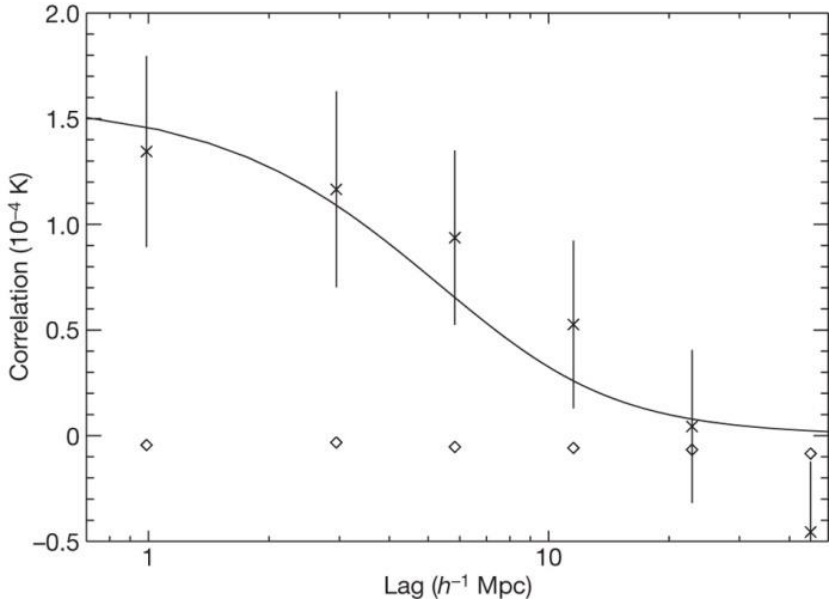




SDSS galaxy power spectrum (Image from SDSS).

Intensity Mapping

- Have ~10^5 L_* galaxies/BAO volume - individual galaxies not that important. Use aggregate signal from many galaxies with low resolution survey.
- Signal is O(0.1 mK), while galactic foreground is O(10^5 K)
- Sample variance limits => map sensitivity of 1-2μJy necessary



- First HI intensity mapping detection, DEEP2 density field x GBT HI brightness temperature cross correlation at z=0.8

T-C Chang *et al. Nature* **466**, 463-465 (2010) doi:10.1038/nature09187

HIRAX: Who are we? Where are we?

HIRAX Design and Goals

Instrument:

- 1024 close-packed 6-m stationary dishes, operating in drift scan
- Operating frequency: 400 – 800 MHz, $0.8 < z < 2.5$
- Survey area of 15,000 deg^2
- Daily sensitivity of ~12μJy
- Manually repoint every 150 days, 4 years for full survey (~1μJy)

Science goals:

- Measure BAO to characterize dark energy
- Radio transient + pulsar searches
- Neutral hydrogen absorbers
- Diffuse polarization of the Galaxy

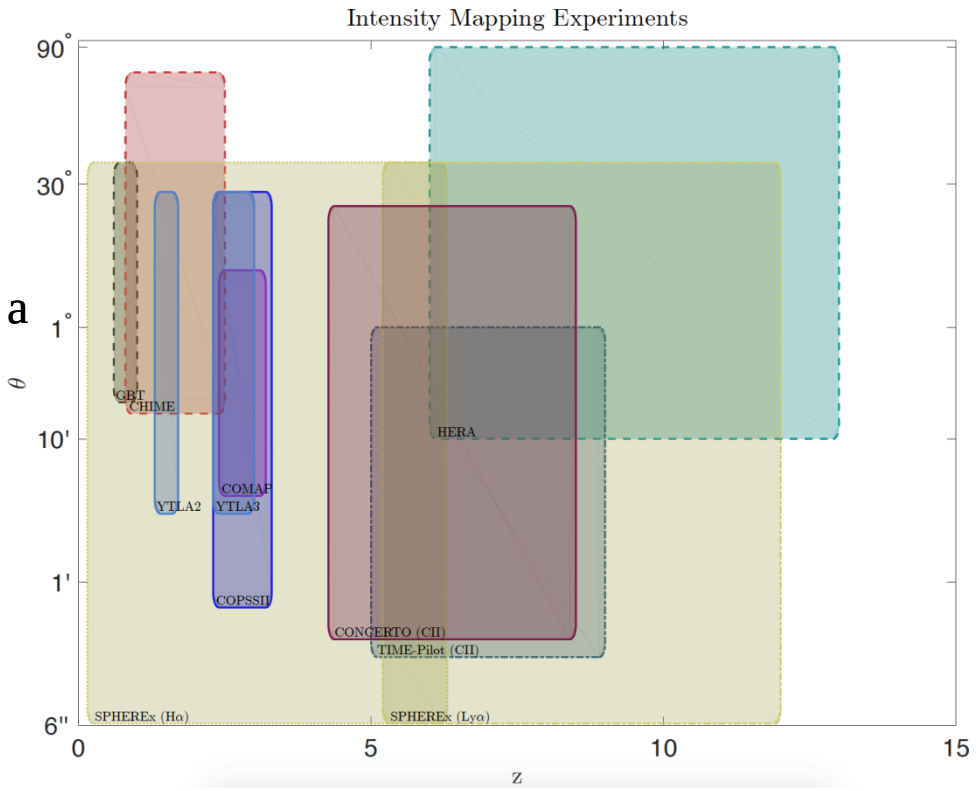
Complementarity with CHIME

	CHIME	**HIRAX**
Site	DRAO, Canada	South Africa (lower RFI, no snow)
Telescope	Cylinder array	Dish array (easier to baffle)
Field of view	100° NS, 1°– 2° EW	5° – 10° deg
Beam size	0.23° – 0.53°	0.1° – 0.2°
Collecting area	8000 m^2	28,000 m^2
Sky coverage	North	South

- Optical surveys in the south, esp. LSST: cross-correlate for foreground mitigation and other science. More pulsars in the south.

κ-δT_{21} Cross-correlations

- Cross-correlating IM surveys with CMB provides interesting cosmological and astrophysical constraints, including bias of IM tracer relative to dark matter.
- Many possible IM tracers: HI, CO, CII, Ly-α, H-α
- Upcoming 21cm IM surveys: HIRAX, CHIME, MeerKAT, BINGO, SKA
- For HIRAX, cross-correlate 21cm intensity fluctuations (δT_{21}), with CMB lensing (κ)



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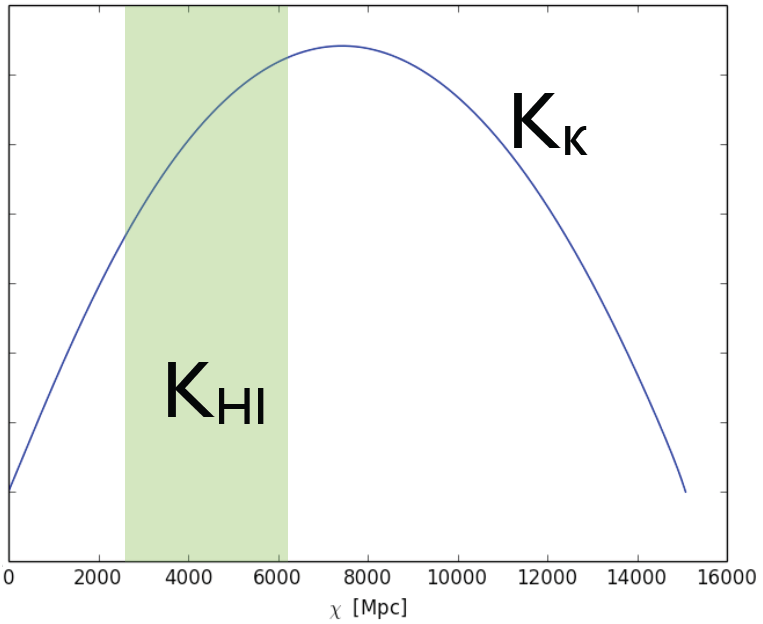
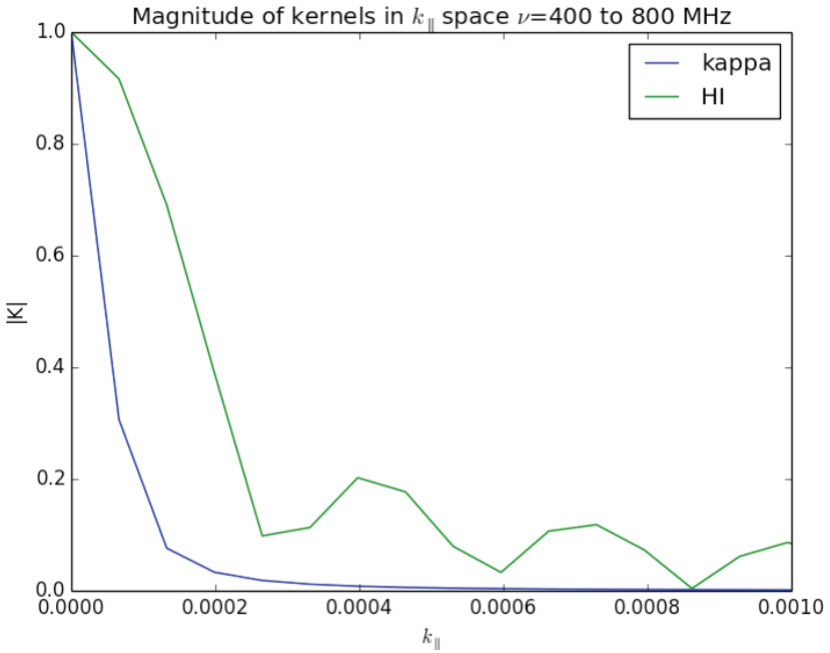
JHU Intensity Mapping Meeting, 2017

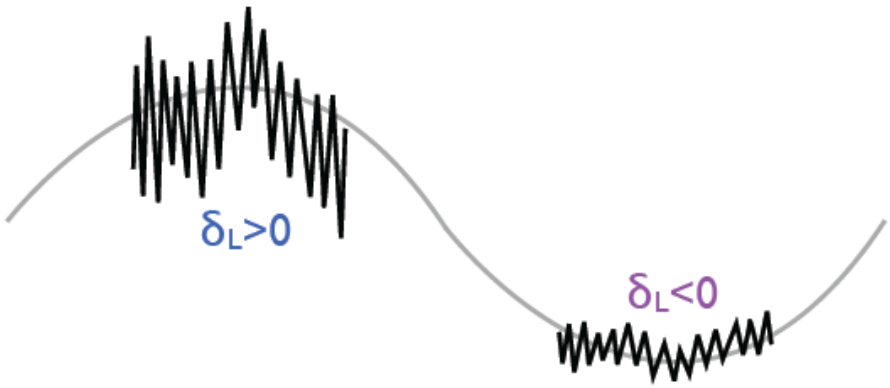
κ-δT_{21} Cross-correlations





- Work done by Kavi Moodley, Heather Prince, and Aurélie Pénin
- Good redshift overlap between κ and 21cm IM, similar physical scales
- However, 21cm foreground filtering removes $k_{||}$ modes below ~0.01Mpc^{-1}
- Results in negligible 2-point κ-δT_{21} correlation

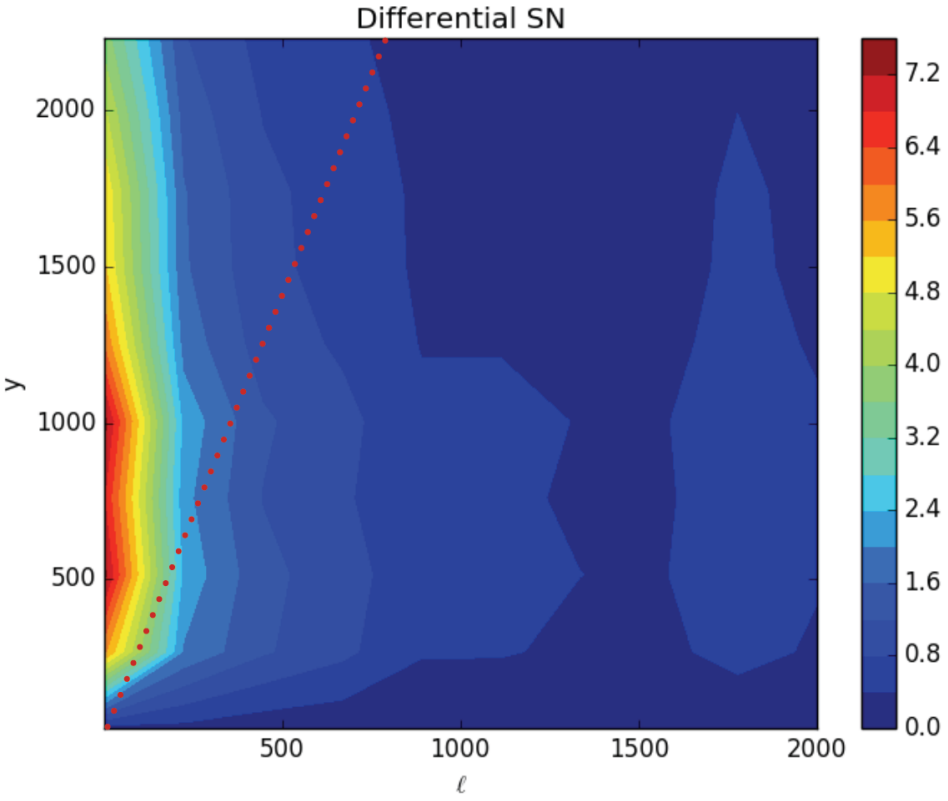
κ-δT_{21} Cross-correlations

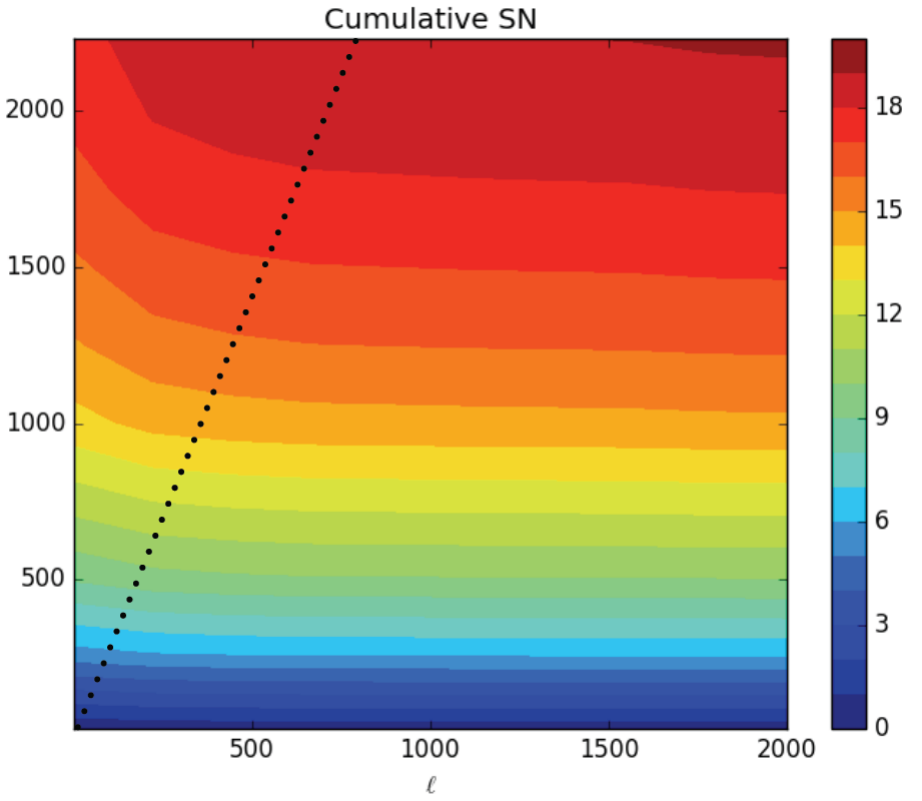


- Construct a bispectrum estimator that uses two copies of 21cm IM field, and one copy of CMB lensing field. Estimator relies on modulation of small-scale 21cm modes by large scale (super-sample) modes.
- Two small-scale 21cm modes are coupled by a long-wavelength matter mode. This allows us to recover the line-of-sight matter modes on large scales that are required for correlation with CMB lensing.
- Similar techniques also used in CMB lensing reconstruction (Lewis & Challinor 2006, Bucher et al. 2012)
- Requires high spectral resolution (>1000 channels)

κ-δT_{21} Cross-correlations

- Forecast of HIRAX-ACTpol bispectrum detectability
- HIRAX survey: ~15,000 deg^2, 1μJy survey depth, redshift $0.8 < z < 2.5$
- el ~10-2000, $k_{\parallel} \sim [10^{-3},1]$ Mpc^{-1}, y ~10-2000





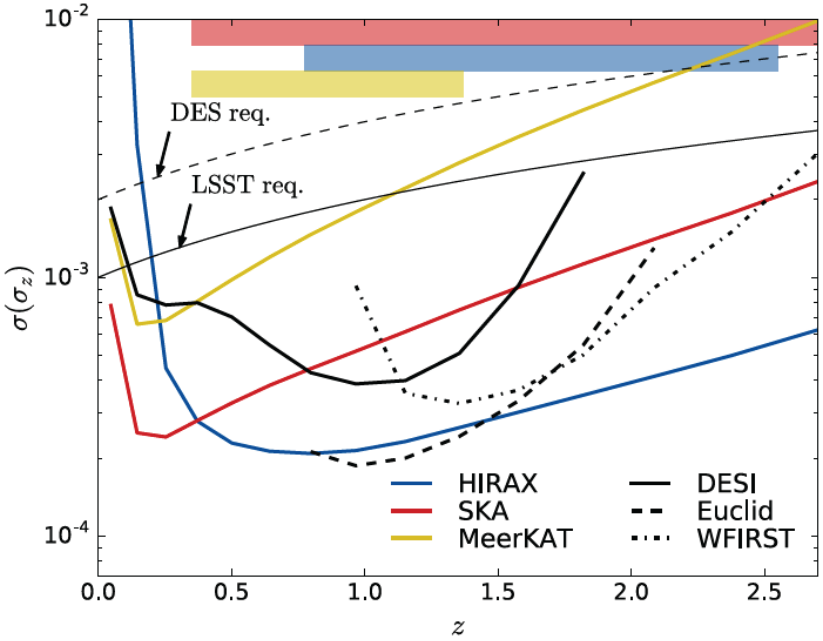
Status and Summary

- HIRAX approved by NRF, funded through 128-elements
- 8-element prototype/outrigger array commissioning in progress
- Next stage: Build out to 128-elements in Karoo beginning in 2018

- κ-δT_{21} power spectrum vanishes because large 21cm modes are lost in foreground removal
- Can use bispectrum to recover large modes
- Decent S/N (~18) expected in cross correlation with current generation CMB experiments

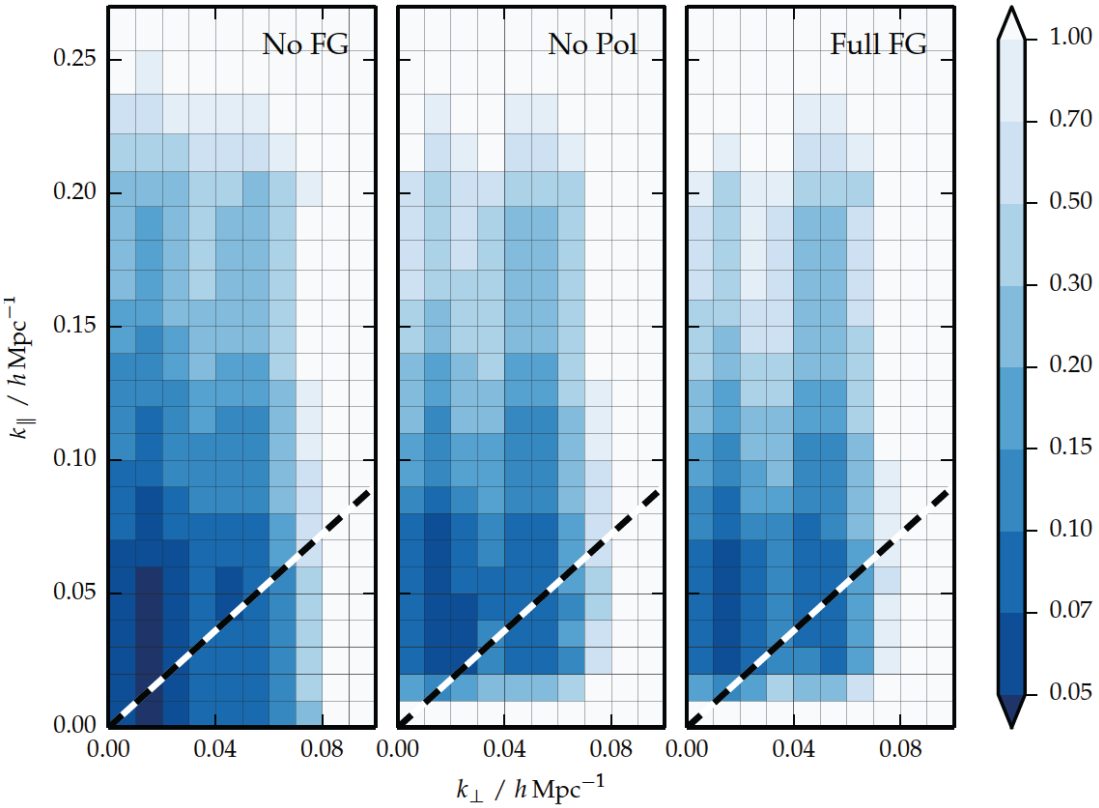
Backup slide: Other BAO Cross-correlations

- Cross-correlation of 21cm IM surveys with galaxy surveys illuminates HI distribution in galaxies (small scales), and correlation b/w HI in ICM and tracer galaxies (large scales).
- Cross-correlation with photometric surveys can provide photo-z calibration.



Alonso et al., 2017

Backup slide: The Wedge



- Foreground removal relies on fact that smooth spectrum foregrounds are limited to region below k-space “wedge”, while line emissions have power that extends beyond wedge.
- Wedge determined by maximum delay possible for a smooth spectrum source as a function of baseline.