BAO-CMB Cross-Correlation with the HIRAX Array

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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 $\sim 10^5$ L$_\odot$ galaxies/BAO volume - individual galaxies not that important. Use aggregate signal from many galaxies with low resolution survey.
- Signal is $\mathcal{O}(0.1 \text{ mK})$, while galactic foreground is $\mathcal{O}(10^5 \text{ K})$
- 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 $z=0.8$

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 deg²
- 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**

- Site: DRAO, Canada
- Telescope: Cylinder array
- Field of view: 100° NS, 1° – 2° EW
- Beam size: 0.23° – 0.53°
- Collecting area: 8000 m²
- Sky coverage: North

**HIRAX**

- Site: South Africa (lower RFI, no snow)
- Telescope: Dish array (easier to baffle)
- Field of view: 5° – 10° deg
- Beam size: 0.1° – 0.2°
- Collecting area: 28,000 m²
- Sky coverage: South

- Optical surveys in the south, esp. LSST: cross-correlate for foreground mitigation and other science. More pulsars in the south.
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-$\alpha$, H-$\alpha$
- Upcoming 21cm IM surveys: HIRAX, CHIME, MeerKAT, BINGO, SKA
- For HIRAX, cross-correlate 21cm intensity fluctuations ($\delta T_{21}$), with CMB lensing ($\kappa$)
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
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
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

- $\kappa\delta T_{21}$ 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
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.