21 cm Cosmology

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Reionization and Cosmology with 21-cm Fluctuations

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The cosmological HI signal
How did galaxies form?
Short history of hydrogen

- Neutral Hydrogen
- Ionized Hydrogen

Big Bang  CMB  ~6  redshift  0 (now)

EOR
Dark energy with HI

- \(<F_{H\alpha}>_V\) related to Lyman-\(\alpha\) absorption, \(\sim 10^{-4}\)
- \(<F_{H\alpha}>_M\) related to H\(\alpha\) emission, \(\sim 10^{-2}\)
HI during EoR

Zahn

Statistical EoR detection

Image Cube $\theta_y$ $\theta_x$

Visibility

FT Sky Coordinates

FT Frequency

Fourier Representation

Spherical symmetry

EoR power spectrum

$$(k^3 P / 2\pi^2)^{1/2} \text{[Mpc}^{-3/2} \text{Jy Hz]}$$

$z = 8, 360 \text{ hours of integration}$

Furlanetto, Zaldarriaga, Hernquist (2004a,b)
Bowman, Morales & Hewitt (2005)
Kaplinghat (2005)
Power spectrum dynamics
HI power spectra evolution

In Figure 1, we show the spherically-averaged 21 cm power spectrum from our fiducial model for a range of redshift at fixed ionization fraction than the ionization power spectrum. If the sources are rare but very powerful, the large-scale 21 cm power spectrum falls below the den-

...
Why is this hard? Foregrounds

- Galactic emission (polarized and Faraday rotated)
- Bright point sources
- Faint point sources
- Instrumental contamination
- Radio recombination lines
- RFI
- Mode mixing
- ...

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Foreground symmetry
$k$-space measurement
Mode mixing

- Frontier of foreground subtraction is interactions between calibration and foregrounds
- Need measurement fidelity of $10^{-4} - 10^{-6}$
- Effectively a product of the calibration errors and foreground uncertainty
Examples

- Chromatic array beam (PSF) & residual source flux, residual frequency ripple
- Polarized foreground & polarization mis-calibration, flux leakage from Q & U → I
- Antenna beam dependence & point sources, decorrelation of visibilities at different frequencies
$k$-space measurement

- $k_{\parallel}$
- $k_{\perp}$
- 1/freq. res.
- $|k|$ shells
- Cosmic evolution $z \approx 0.5$
- Foregrounds
- 1/FOV
- Max baseline

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Bright source location error

Datta et al. (2010)
Foreground subtraction

Datta et al. (2010)
Confusion level sources

a. Foregrounds only (post-subtraction)

$k_{\parallel} [\text{cM pc}^{-1}]$

Bowman et al. (2008)
$k$-space measurement

Diagram showing:
- $k_{\parallel}$ and $k_{\perp}$
- 1/freq. res.
- $|k|$ shells
- Cosmic evolution $z \approx 0.5$
- Foregrounds
- 1/FOV
- Max baseline

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MWA sensitivity

$P_k(k_{\text{perp}}, k_{\text{par}}) [\text{mK}^2 \text{Mpc}^{-3}]$

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MWA power spectrum sensitivity

$z = 8$, 360 hours of

Furlanetto, Zaldarriaga, Hernquist (2004a,b)
Bowman, Morales & Hewitt (2005)
Kaplinghat (2005)
$k$-space Fisher matrixes

Tuning parameter sensitivity

Visbal, in prep.
Opportunities for lunar 21 cm

- Low RFI
- No ionosphere
- Slow rotation rate
- Dark ages (redshift > 40)
  - Very large arrays, novel hardware (e.g. MOFF?)
- Challenge of very fast ground-based development
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