DESIGN OPTIMIZATION FOR INTERFEROMETRIC SPACE-BASED 21-cm POWER SPECTRUM MEASUREMENTS

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Photo Credit: Peter Wheeler, ICRAR
The Dark Ages Signal

- Low frequencies require space-based observatory

- Compared with EoR/CD redshifts:
  - Signal is ~ 10 times fainter (in mK) than EoR/CD
  - Foregrounds ~3 orders of magnitude brighter
  - Noise ~3 orders of magnitude higher
Ground Based Experiments

- Numerous experiments have pursued a detection of the EoR and (more recently) post-EoR 21 cm signal for nearly a decade

- Need to compare performance with prediction, translate lessons to space-based trade studies
Lessons from the ground (1)

- Foregrounds are not uniformly distributed across the power spectrum domain
- Potential for “foreground avoidance” – just use modes unaffected by instrumental contamination

Barry et al. (2016)
The Wedge Paradigm at Other Redshifts

- Wedge slope is a function of redshift:
  \[ k_{\parallel,\text{hor}} = \frac{2\pi |b|}{Y \frac{c}{\nu}} = \left( \frac{1}{\nu} \frac{X}{Y} \right) k_{\perp} \]
  - \( X \) converts from radians (primary beam) to Mpc
  - \( Y \) converts from Hz (bandwidth) to Mpc
  - Depend on on angular diameter distance, Hubble constant

- Wedge slope is 3.9 at \( z = 9.5 \), but 11 at \( z = 50 \)!

Foreground avoidance is a losing battle at high \( z \). Sensitivity will depend on how well foreground subtraction works!
Lessons from the ground (2)

- Potential gains from “non-traditional” interferometry
  - Delay/delay rate filters (Parsons and Backer 2009)
  - Redundant arrays (Parsons et al. 2012a)
  - Fringe-rate filtering (Parsons et al. 2016)
PAPER-64 Revisions
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PRELIMINARY

\[ \Delta^2 (\text{mK})^2 \]

- Dillon, 2014
- Dillon, 2015
- Patil, 2017
- Paciga, 2013
- Beardsley, 2016
- Ali, 2015
- Kolopanis et al

Fiducial 21cmFAST model
What happened…?

Empirical Covariance Matrices

- Frequency-frequency covariance matrix calculated from time average of data
- Need lots of time samples for empirical covariance to converge to true covariance

Fringe Rate Filter

- Sinc-like time average of data, characteristic width of ~ 1 hour
- Reduces the number of independent time samples to increase sensitivity

Cheng et al. (in prep.)
• Open source, massively parallelized visibility simulator
• All-sky “brute force” evaluation of the interferometer measurement equation
• Use for end-to-end testing of full analysis pipelines
  • Power spectrum is our metric for trade studies!
pyuvsim

- Will support non-terrestrial observers
  - No assumptions about horizons, sidereal rates, etc.

- Use to explore:
  - Observing strategies
  - Antenna placement and construction tolerances
  - Sensitivity gains from advanced analysis techniques
pyuvsim Team

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Thanks!