Design Optimization for Interferometric Space-Based 21-cm Power Spectrum Measurements

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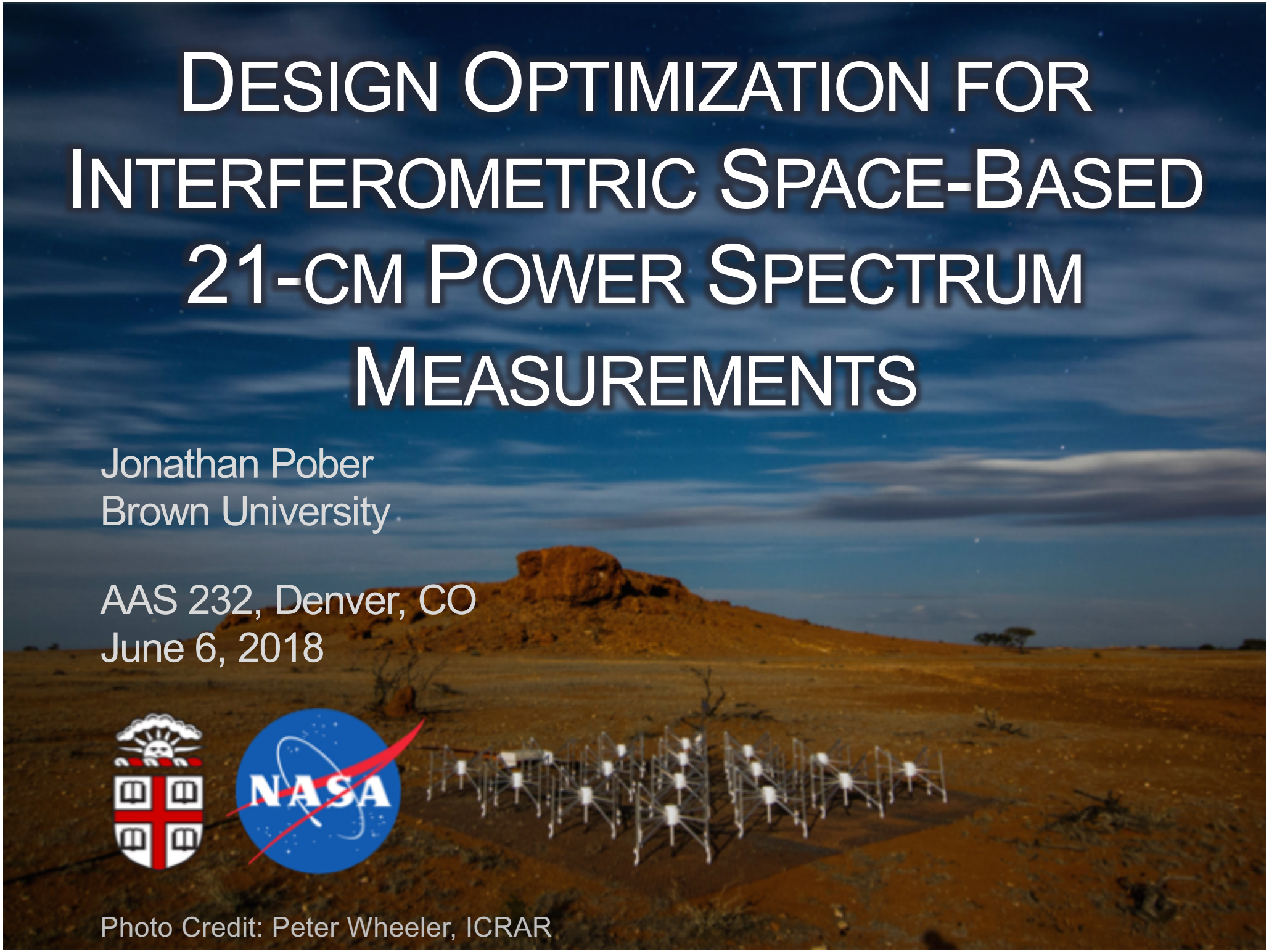
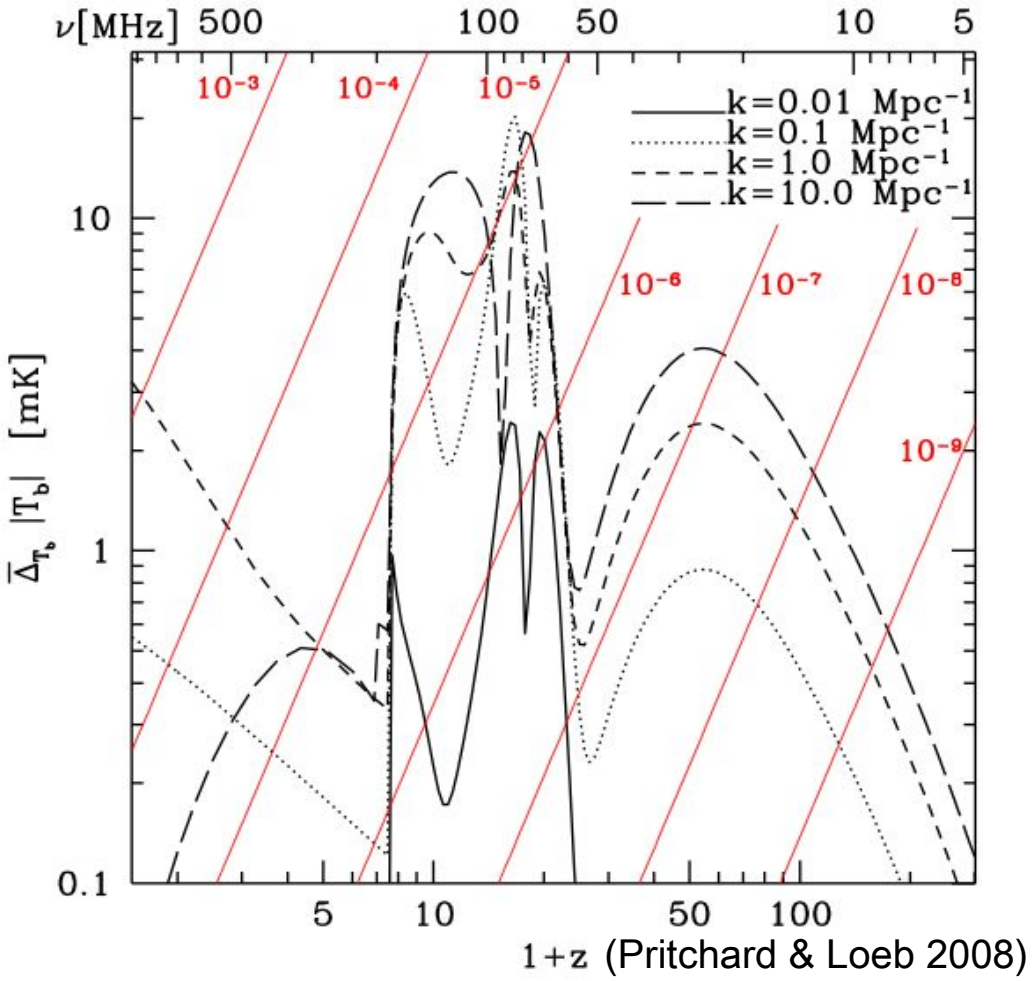


Photo Credit: Peter Wheeler, ICRAR

The Dark Ages Signal



(Pritchard & Loeb 2008)

- 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

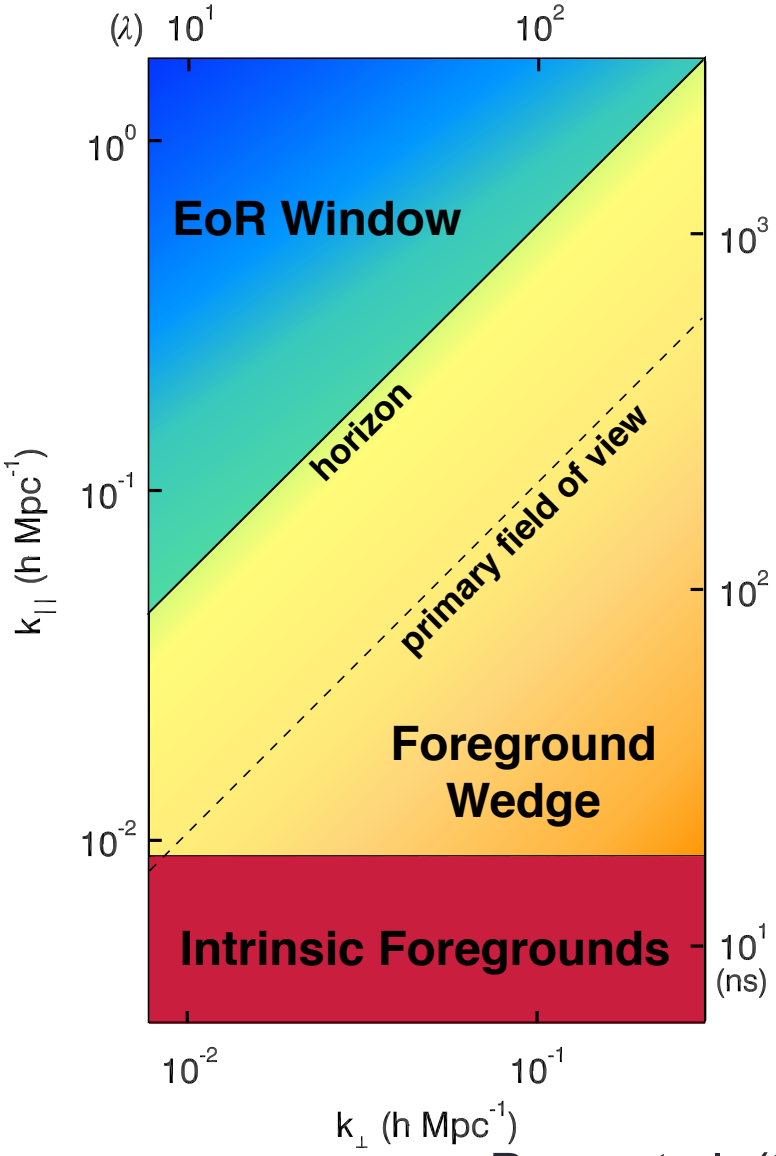






Lessons from the ground (1)

- 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*:

$$k_{\parallel,\mathrm{hor}} = \frac{2\pi}{Y}\frac{|\boldsymbol{b}|}{c} = \left(\frac{1}{\nu}\frac{X}{Y}\right) k_{\perp}$$

  - X converts from radians (primary beam) to Mpc
  - Y converts from Hz (bandwidth) to Mpc
  - Depend on on angular diameter distance, Hubble constant

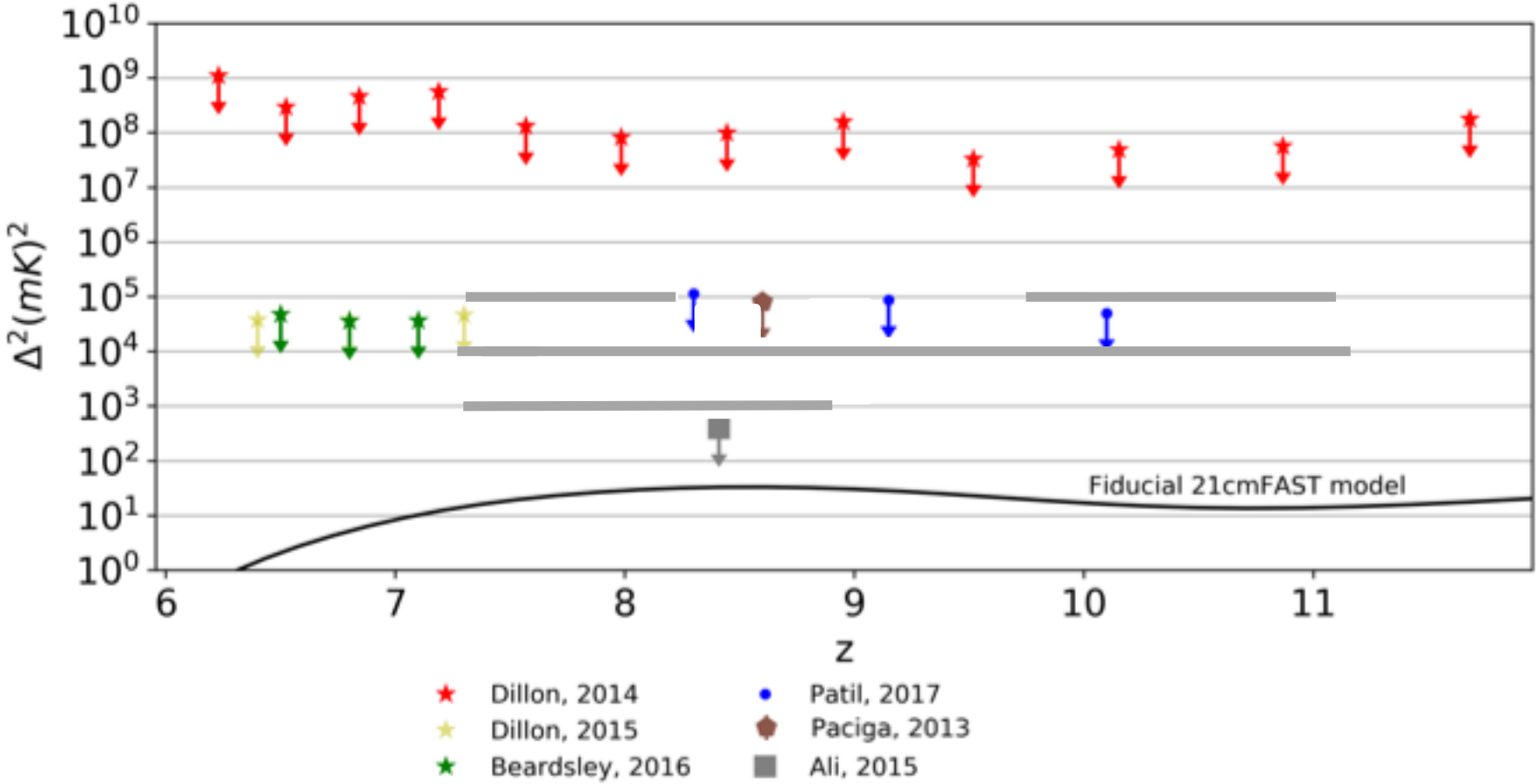
- Wedge slope is 3.9 at z = 9.5, but 11 at z = 50!

Foreground avoidance is a losing battle at high z. Sensitivity will depend on how well foreground subtraction works!

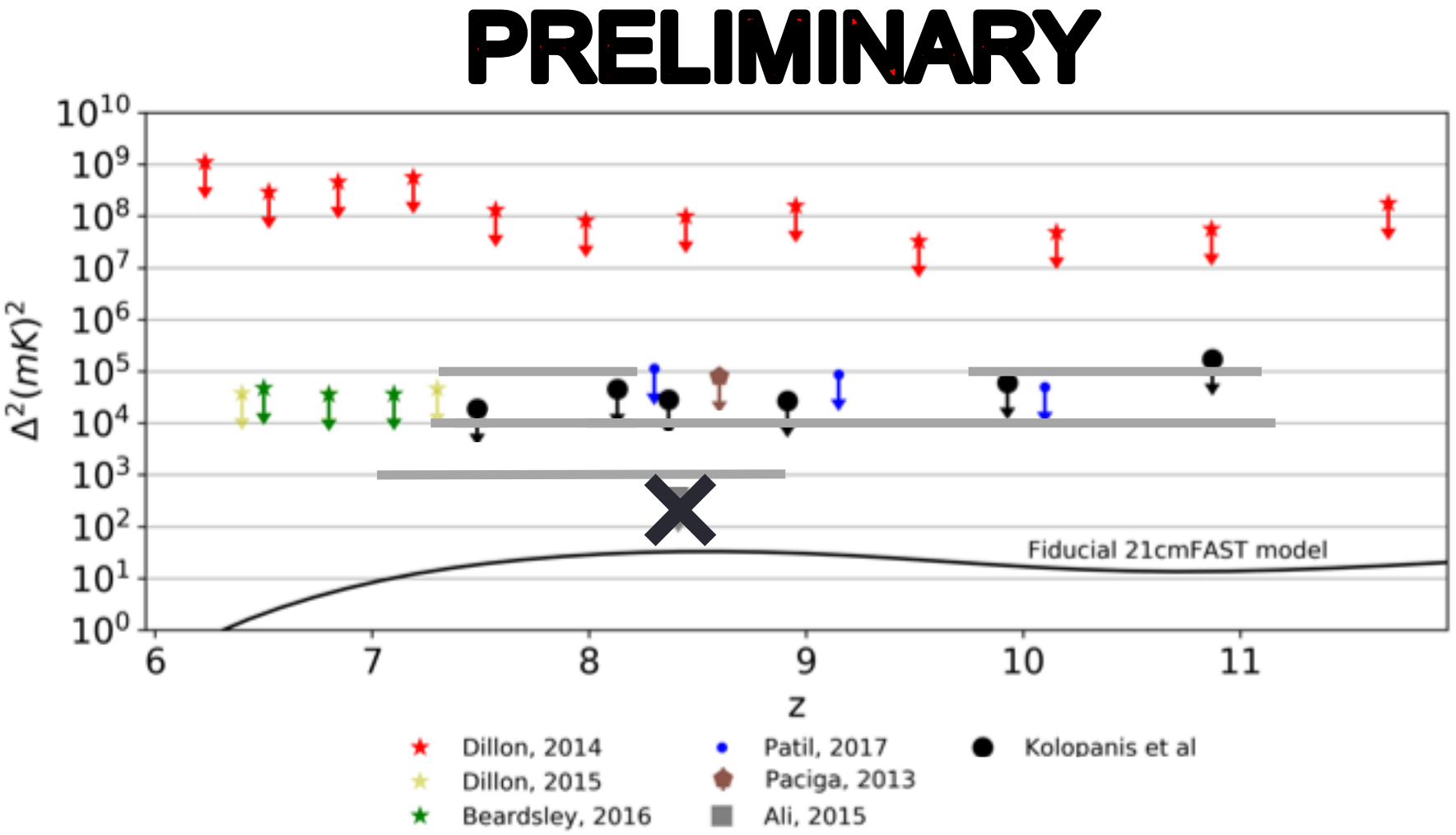
Lessons from the ground (2)

- 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



PAPER-64 Revisions



What happened…?

Empirical Covariance Matrices

Fourier-Transforms along frequency

Inverse Covariance

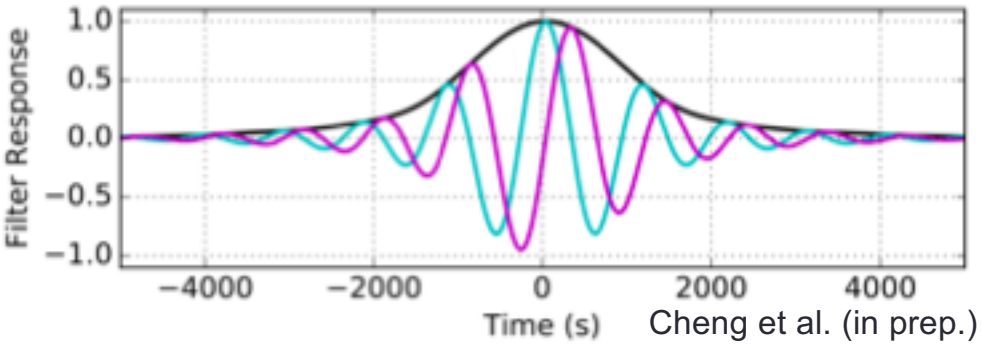
$$\hat{p}_\alpha \propto \mathbf{x}^\dagger \mathbf{C}^{-1} \mathbf{Q}_\alpha \mathbf{C}^{-1} \mathbf{x}$$

Data

$$\hat{\mathbf{C}} \equiv \langle \mathbf{x}\mathbf{x}^\dagger \rangle_t$$

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

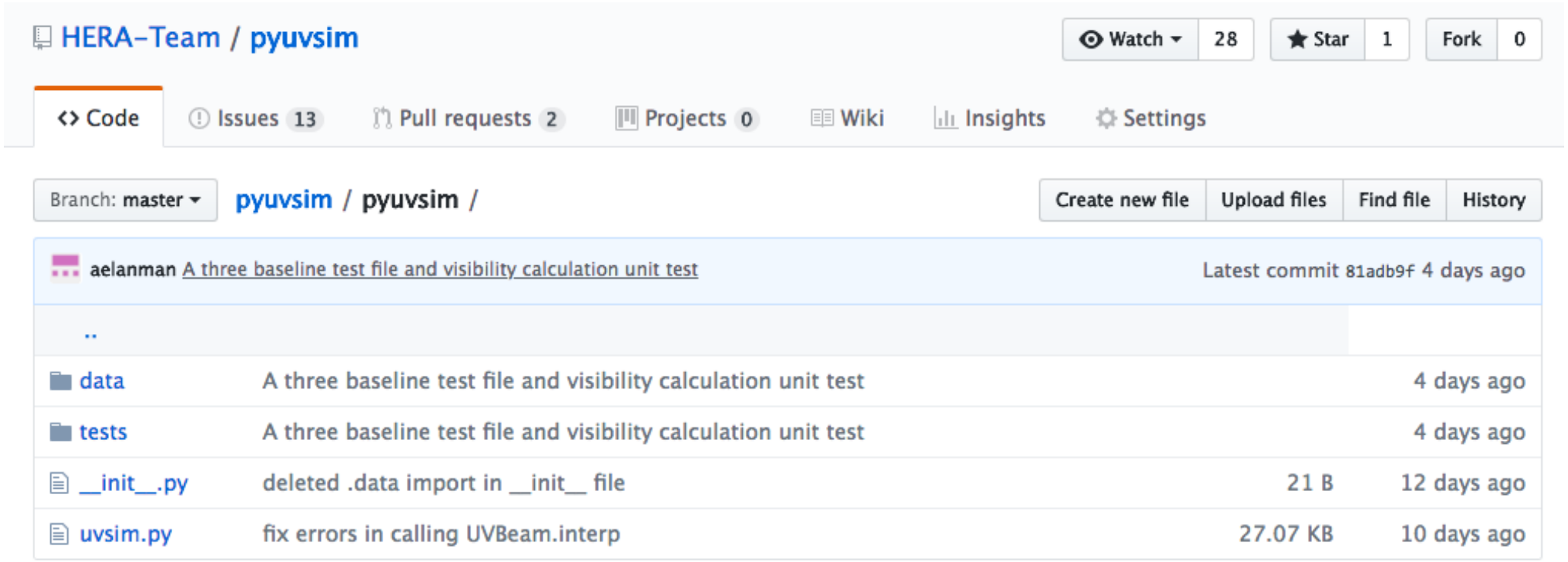
Fringe Rate Filter



Cheng et al. (in prep.)

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

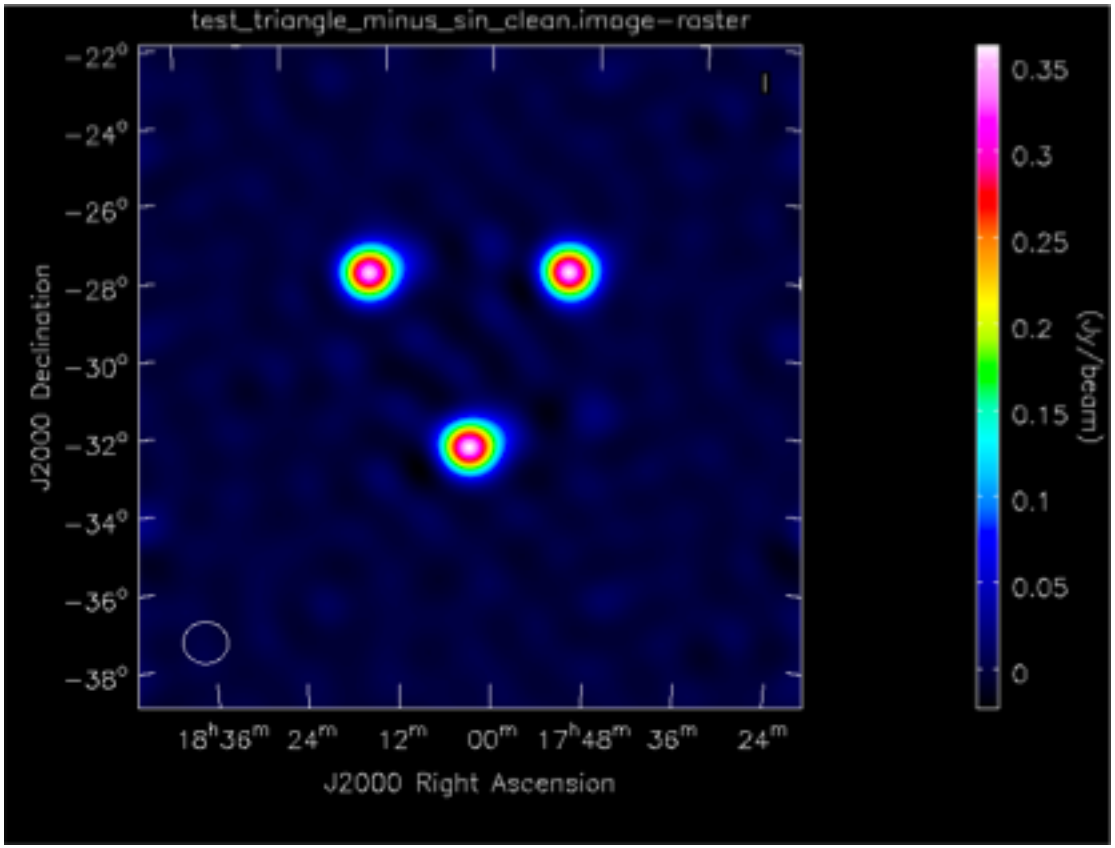
pyuvsim



- 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



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Thanks!