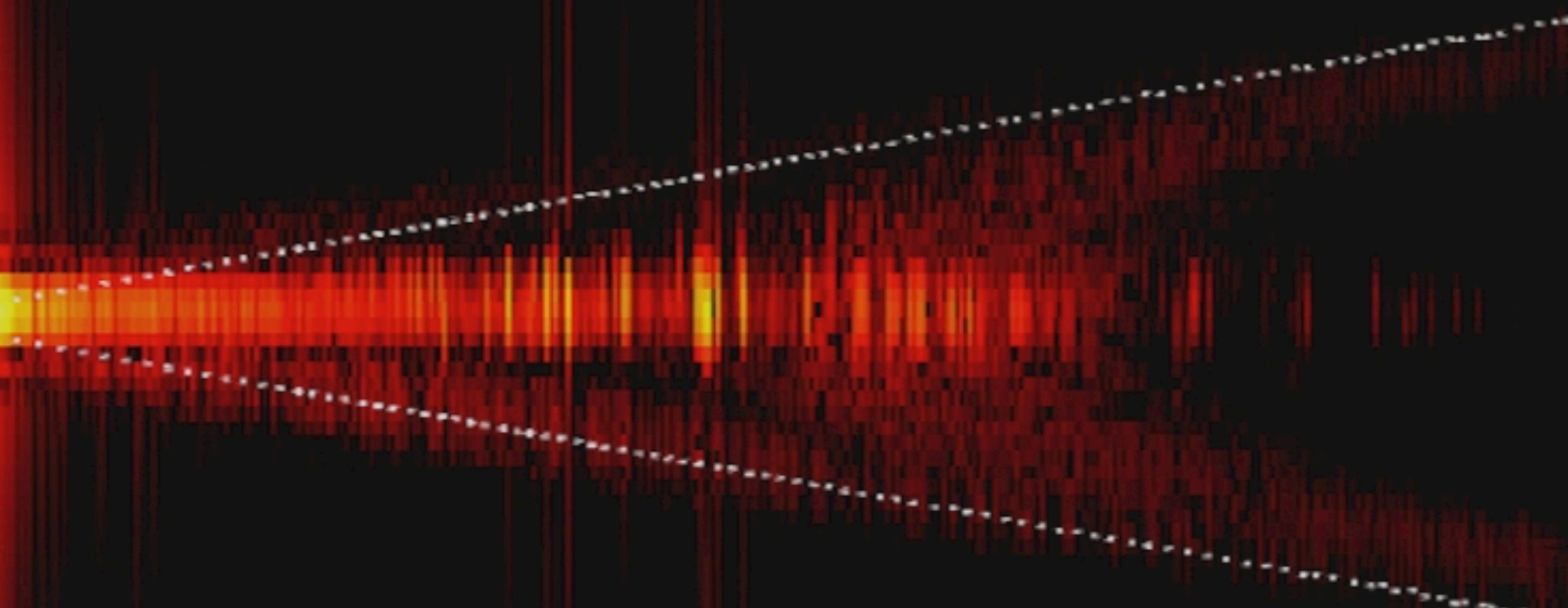
High precision wide-field instrument and foreground simulations for EoR experiments



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MWA+, HERA+

MWA Collaboration

CfA

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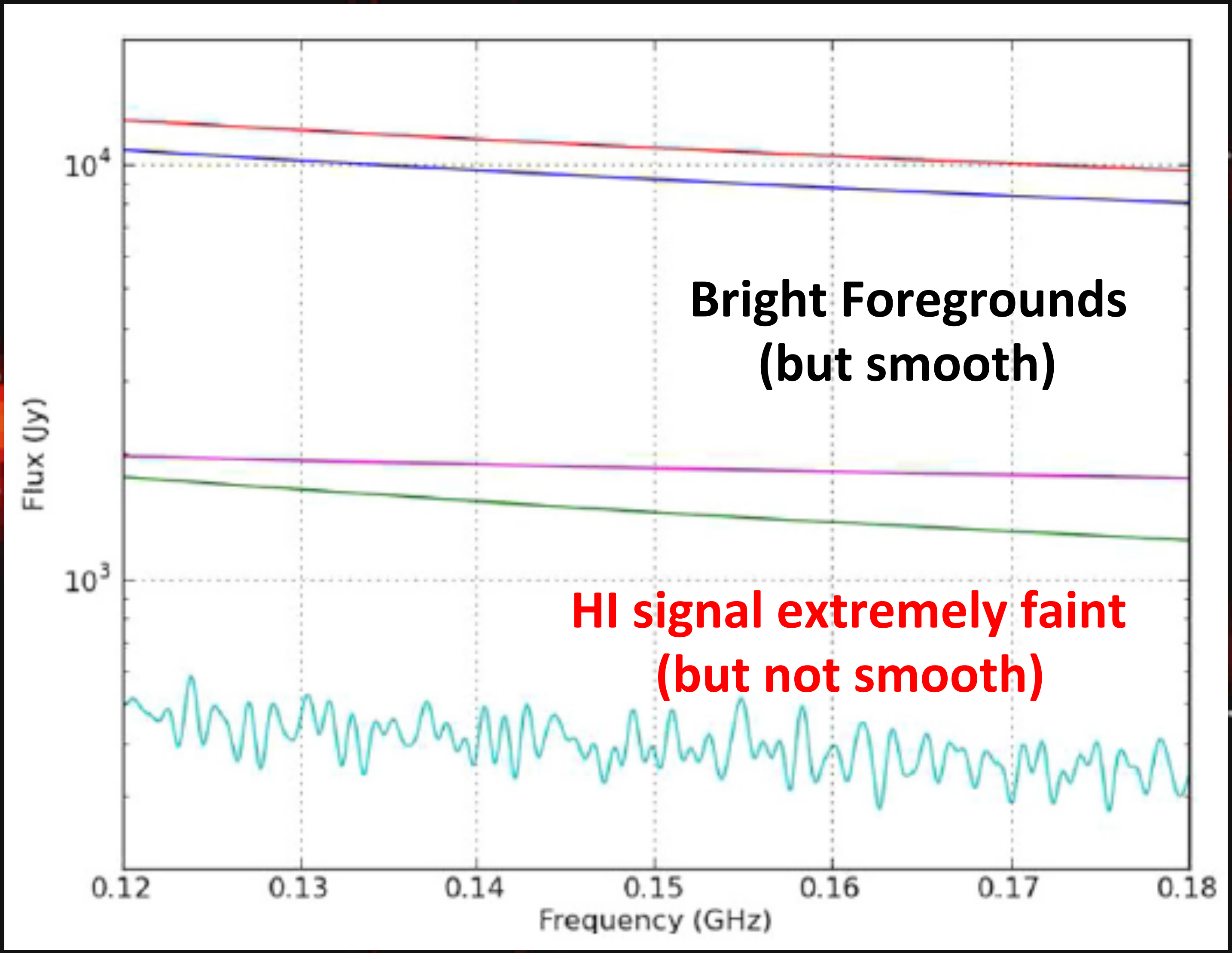
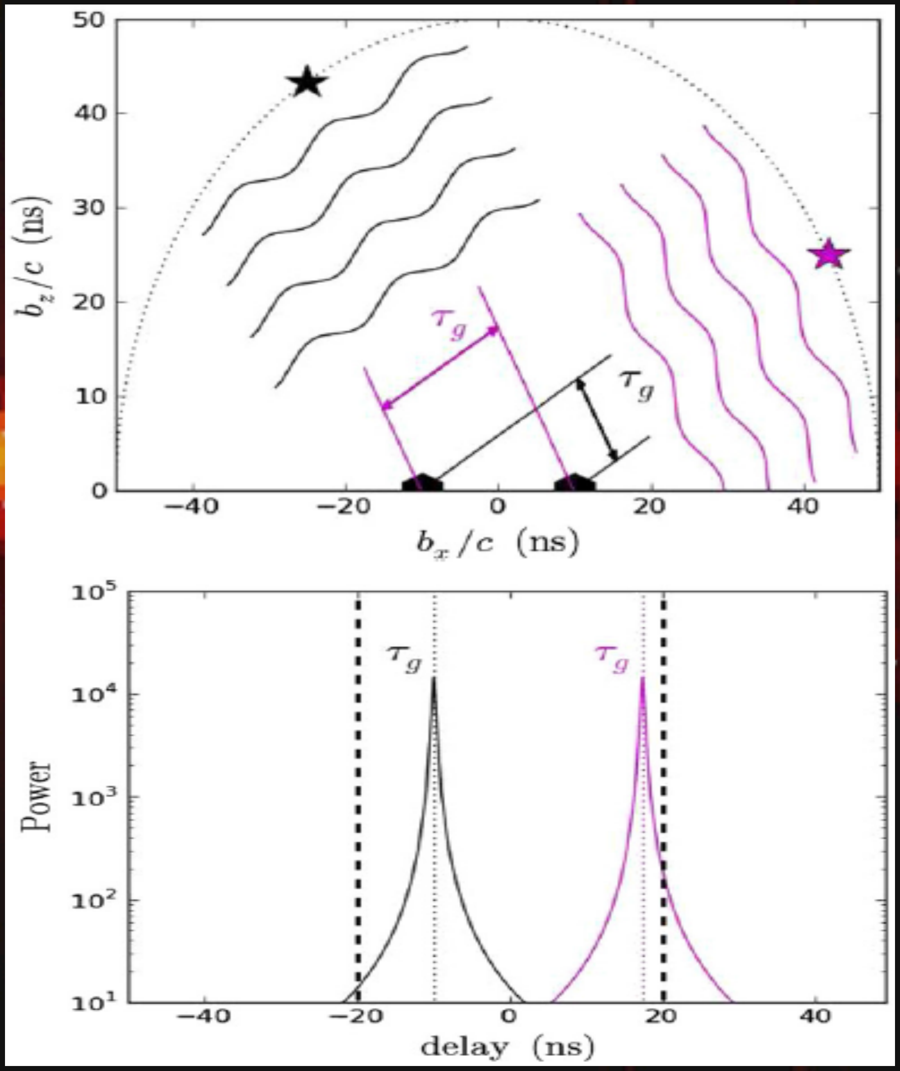
The Foreground Problem

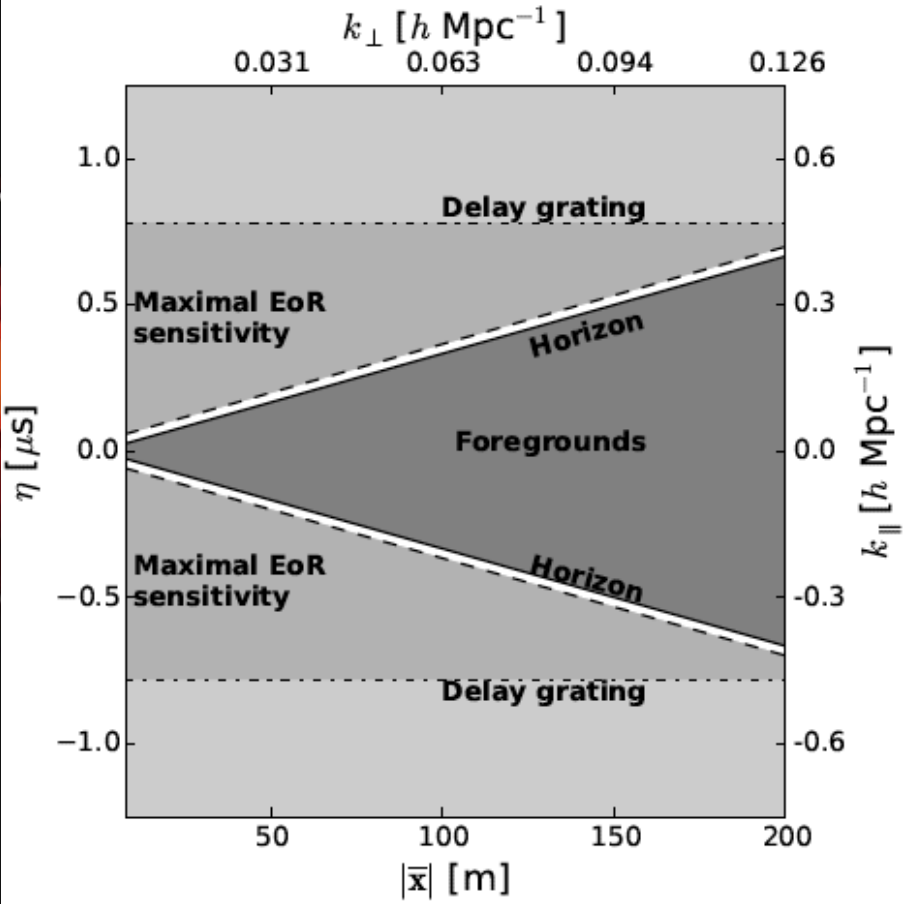


Parsons et al. (2012)

Fourier Space and Delay Spectrum

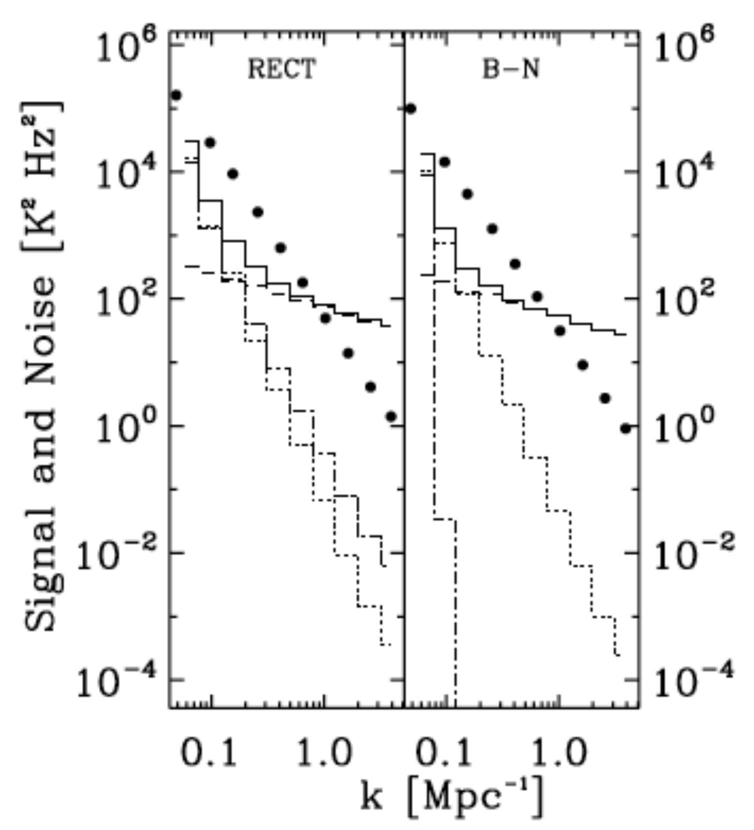


Parsons et al. (2012)

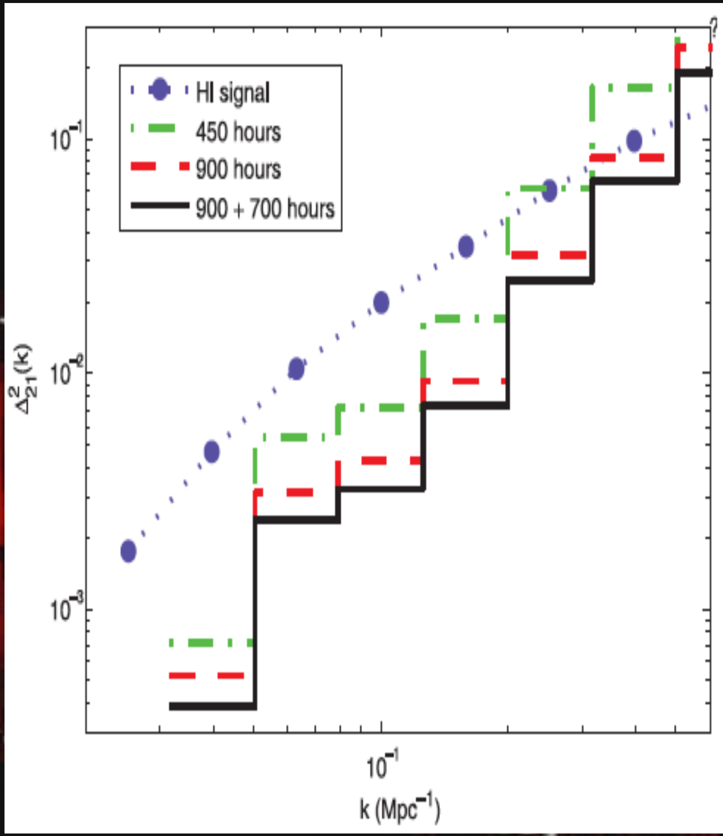


Thyagarajan et al. 2015a

Motivation for High Precision Modeling



Thyagarajan et al. (2013)



Beardsley et al. (2013)

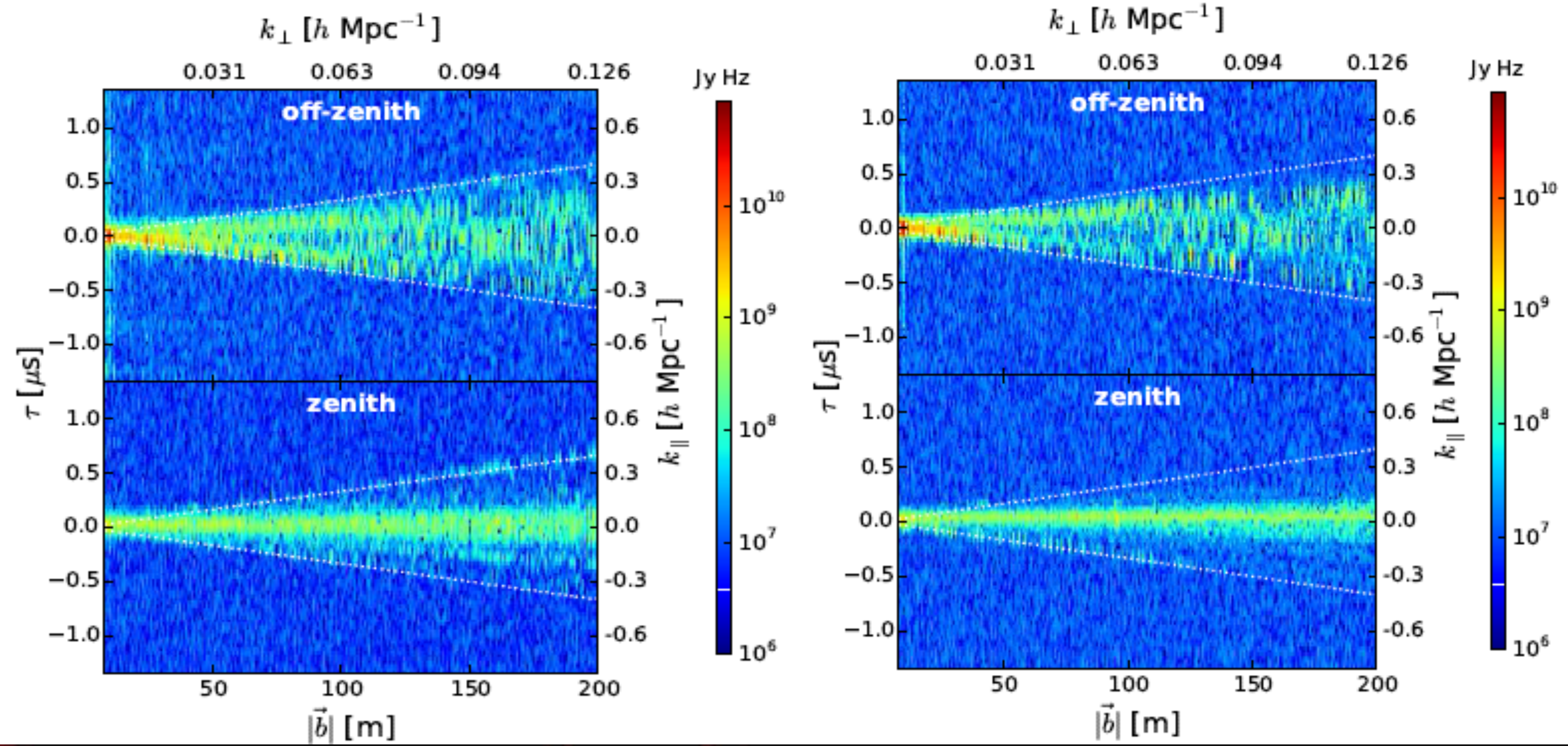
- >10-sigma statistical detection expected with ~1000 hours data
- Currently heavily limited by foregrounds and instrument systematics (e.g. PAPER64 - Ali et al. 2015, Pober et al. 2015; MWA – Dillon et al. 2013)

Precision Radio Interferometry Simulations (PRISim)

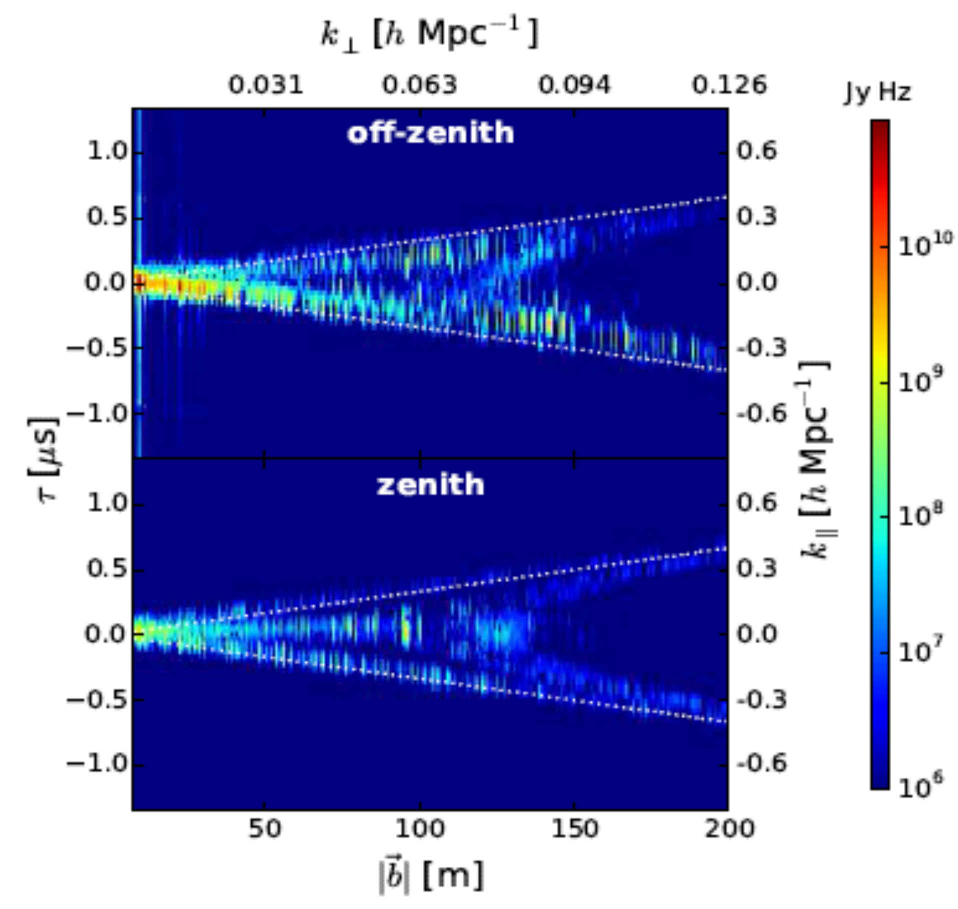
Objectives with PRISim:

- Comprehensive all-sky simulations (with good match to data)
- Role of Wide-field measurements
- Role of compact, diffuse foregrounds
- Role of instrument such as antenna aperture and its chromaticity
- Solutions to mitigate systematics

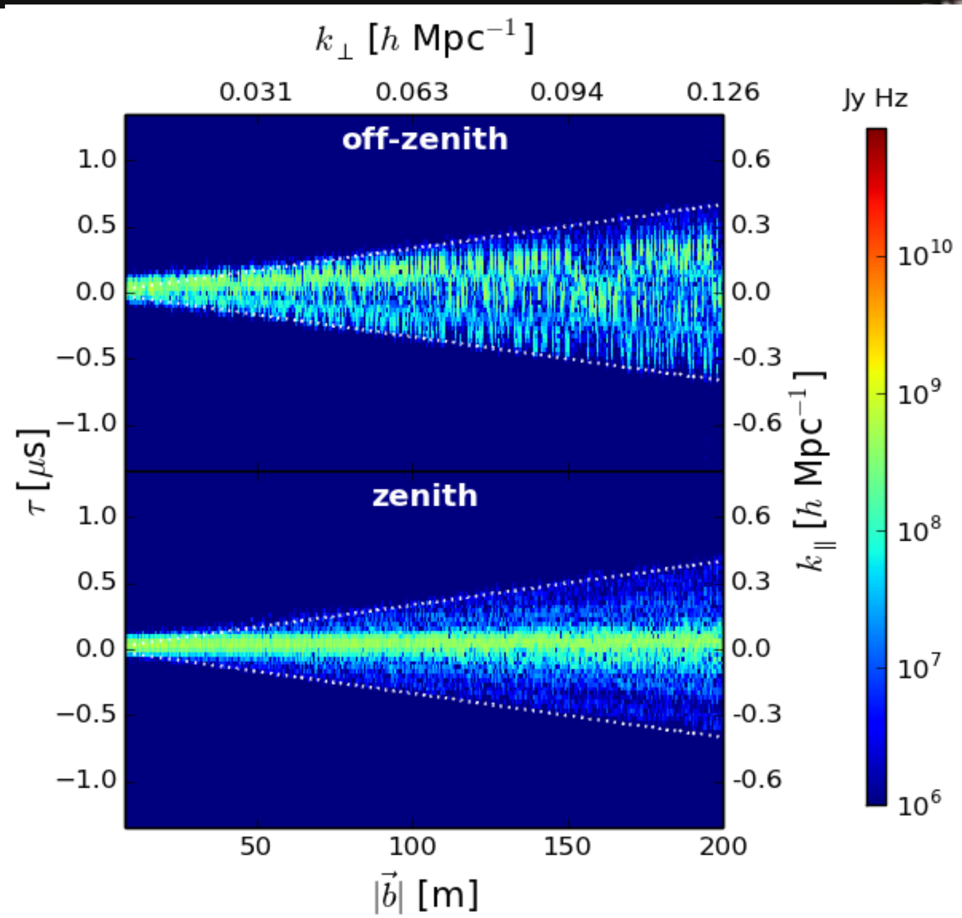
Model-Data Agree well



Impact of diffuse, compact emission with LST

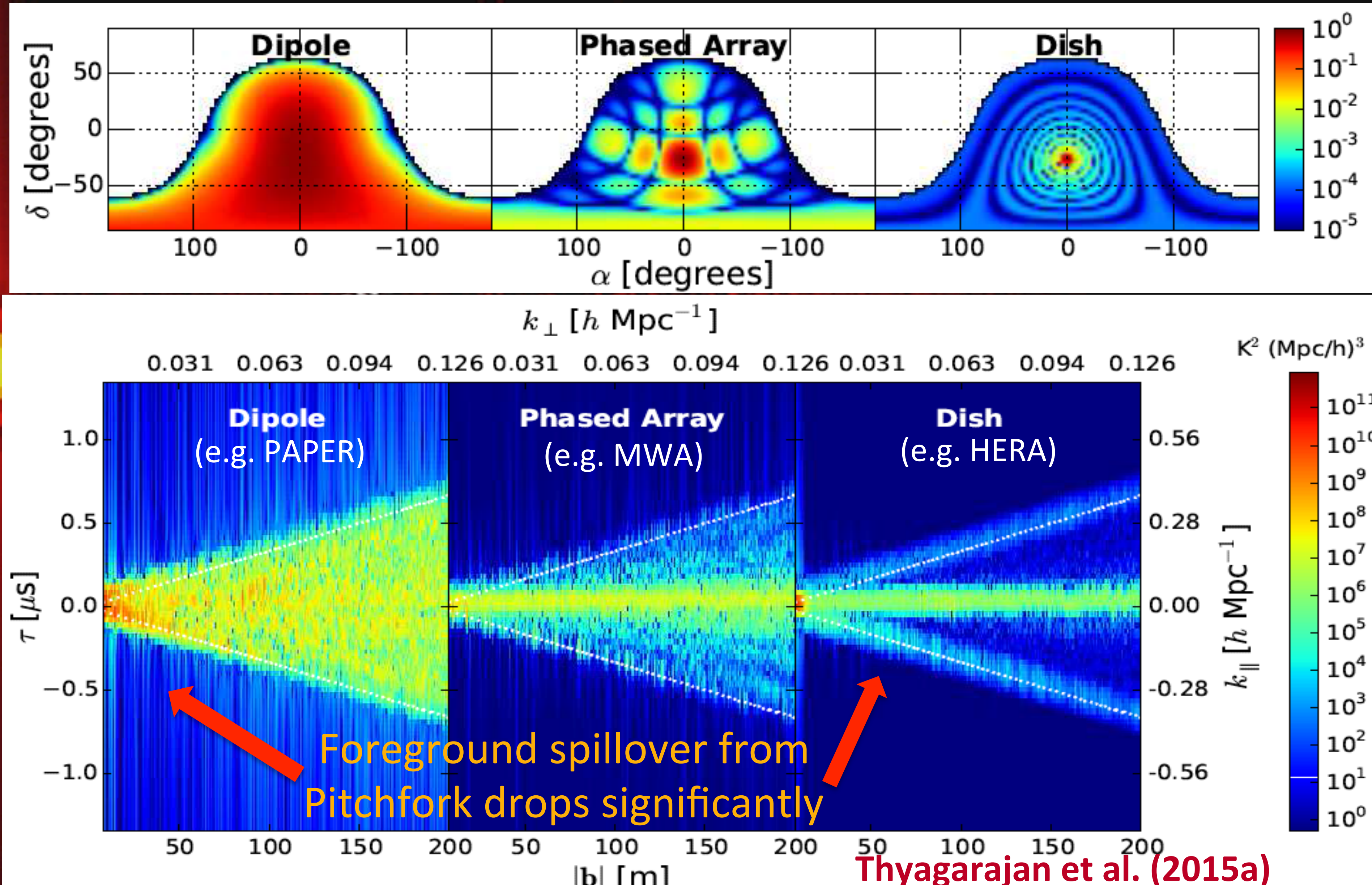


Diffuse Emission



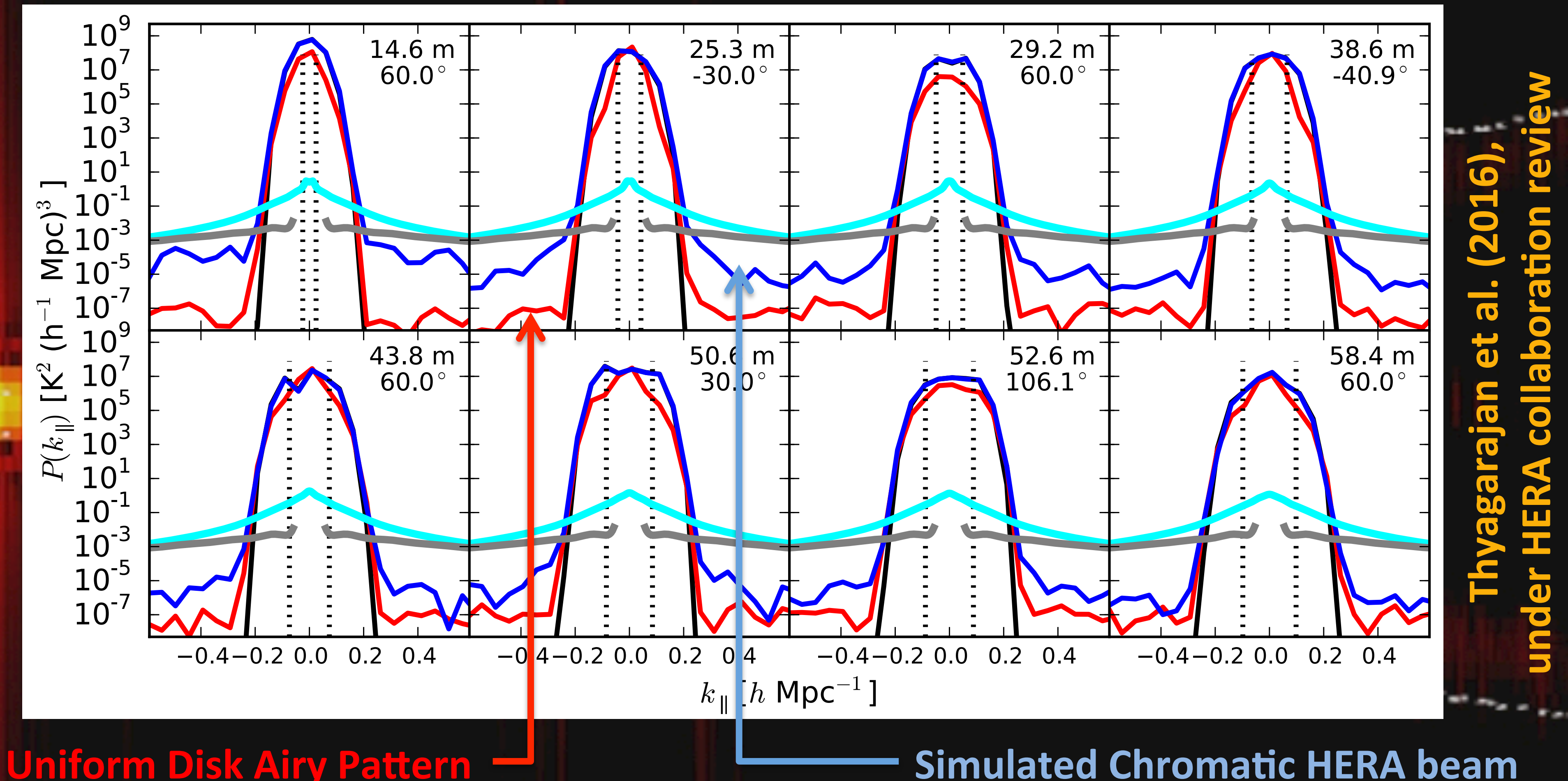
Point sources

Mitigation of systematics via Antenna Geometry



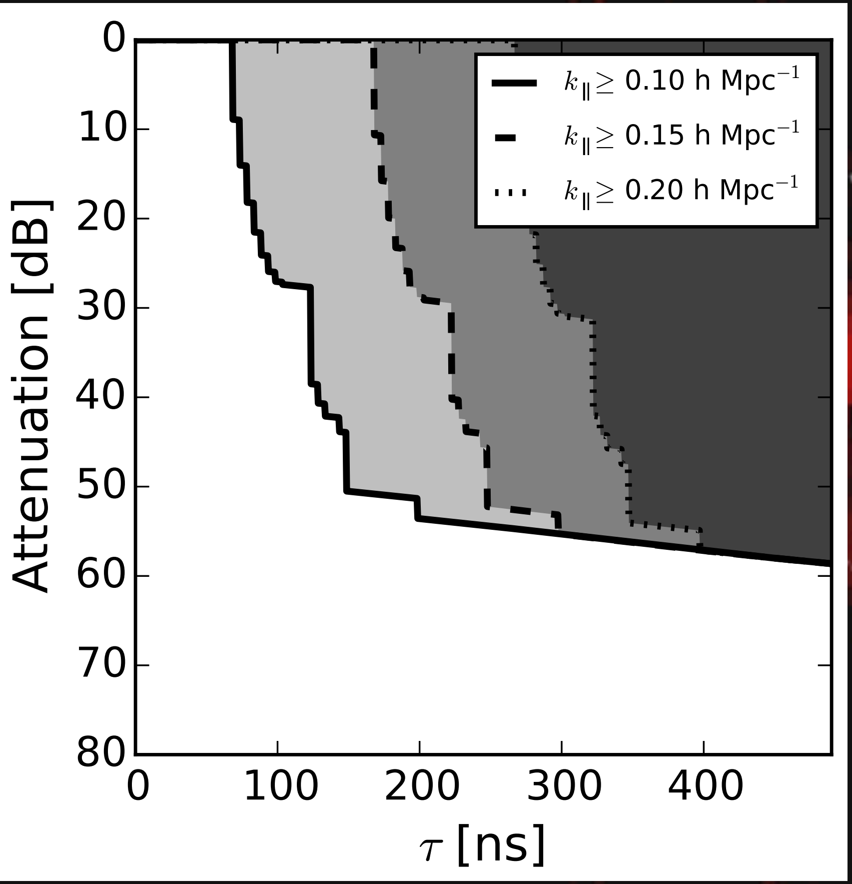
Thyagarajan et al. (2015a)

HERA HI/FG Sensitivity vs. Beam Chromaticity



- Differences seen only due to spectral differences in Antenna beam
- Beam chromaticity worsens foreground contamination
- HERA is sensitive to EoR nevertheless

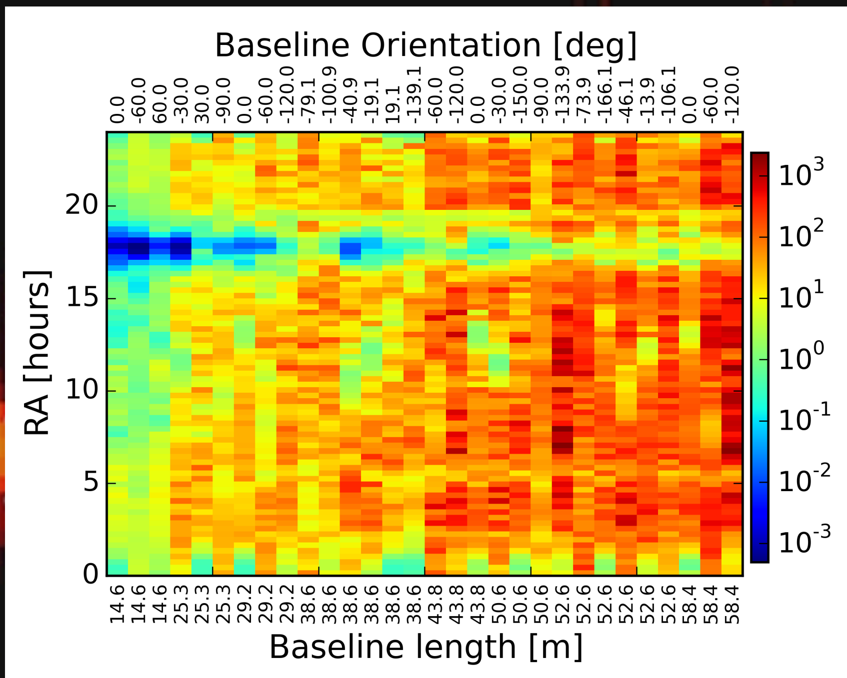
Design Specs on Reflections in Instrument



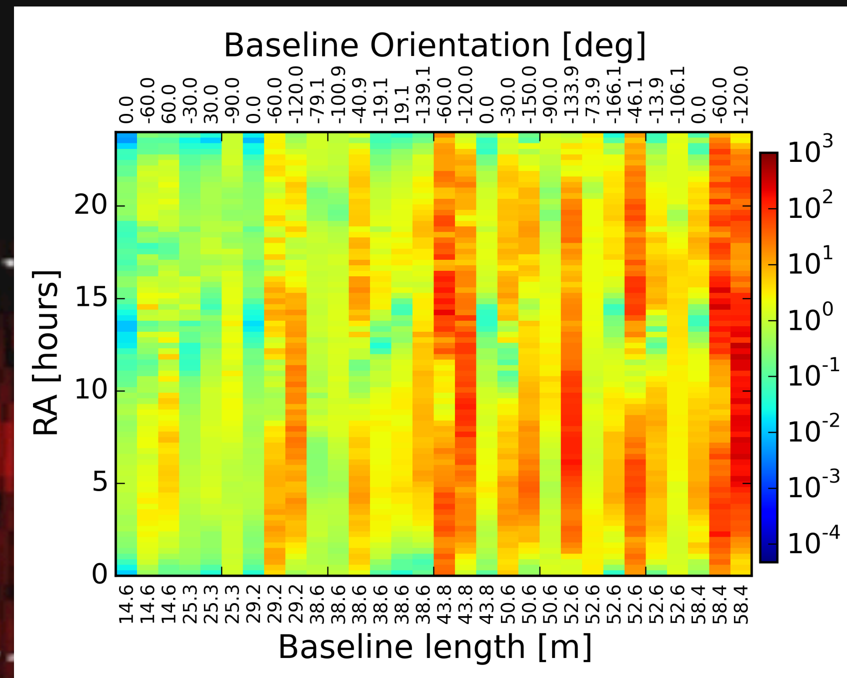
Thyagarajan et al. (2016), under HERA collaboration review

- Reflections are inevitable in electrical systems
- Reflections extend foregrounds and contamination in delay spectrum
- Require reflected foregrounds to be below HI signal levels
- HERA will beat these specs comfortably

EoR Observing Window Efficiency



150 MHz subband (z=8.47)



170 MHz subband (z=7.36)

- All HERA baselines sensitive to EoR for most of observing window
- Robust to different models and redshifts
- HERA has extreme control over instrumental systematics and foreground contamination

Summary

- PRISim – high precision simulations for wide-field radio interferometry – publicly available (https://github.com/nithyanandan/PRISim)
- Discovery of new instrument + foreground physics:
  - Foregrounds through the instrument are not smooth
  - Wide-field effects lead to pitchfork effect - diffuse emission near horizon even on long baselines
  - Contamination significant from far away from primary field of view due to small but non-zero beam response
  - Antenna beam chromaticity and reflections worsen contamination
- Solutions to tackle systematics and the way forward for HERA and SKA-low:
  - Critical to explore antenna apertures and spectral features in future designs
  - Baseline weighting technique prospective for power spectrum estimation methods
  - HERA design robust to systematics - offers great promise for EoR detection