

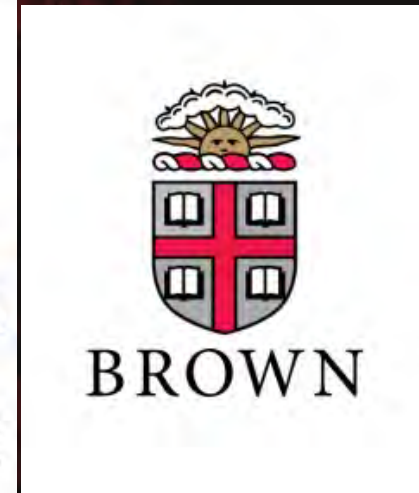
Enabling Detection Of the Epoch Of Reionization With Next-generation Radio Instruments

Nithyanandan Thyagarajan¹, Aaron R. Parsons²,
Judd D. Bowman¹, and the HERA Collaboration

¹ Arizona State University

² University of California, Berkeley

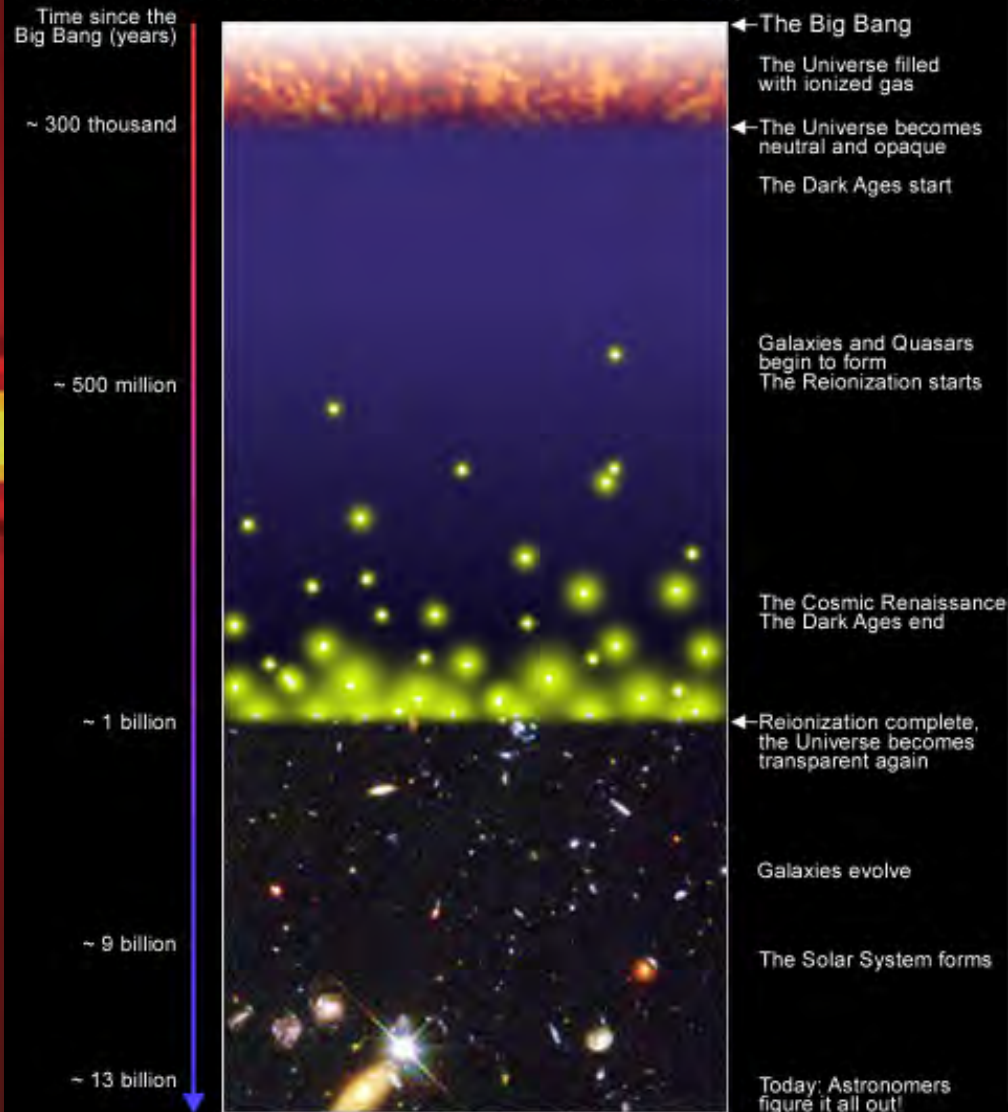
HERA Collaboration



Why study the Epoch of Reionization?

What is the Reionization Era?

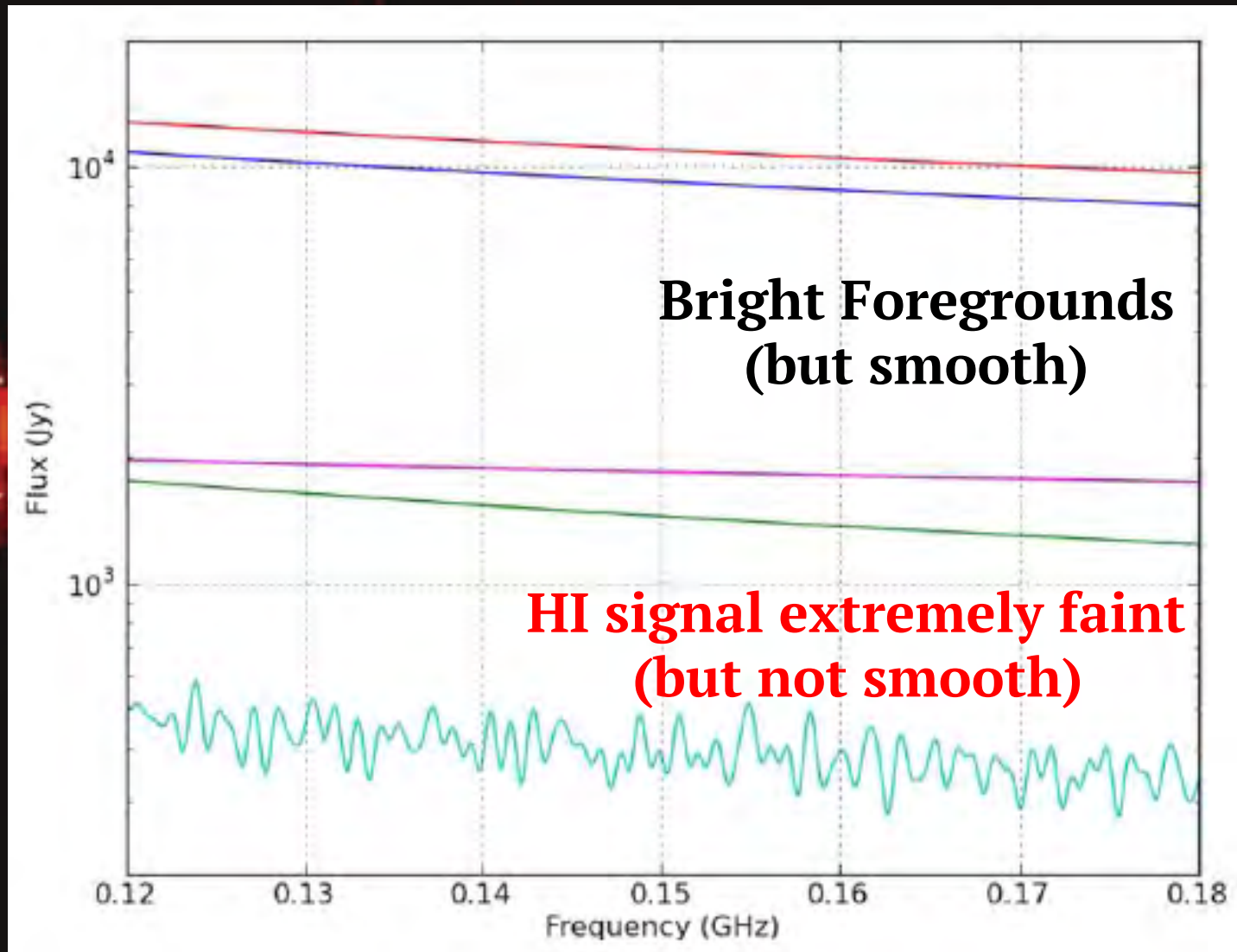
A Schematic Outline of the Cosmic History



S.G. Djorgovski et al. & Digital Media Center, Caltech

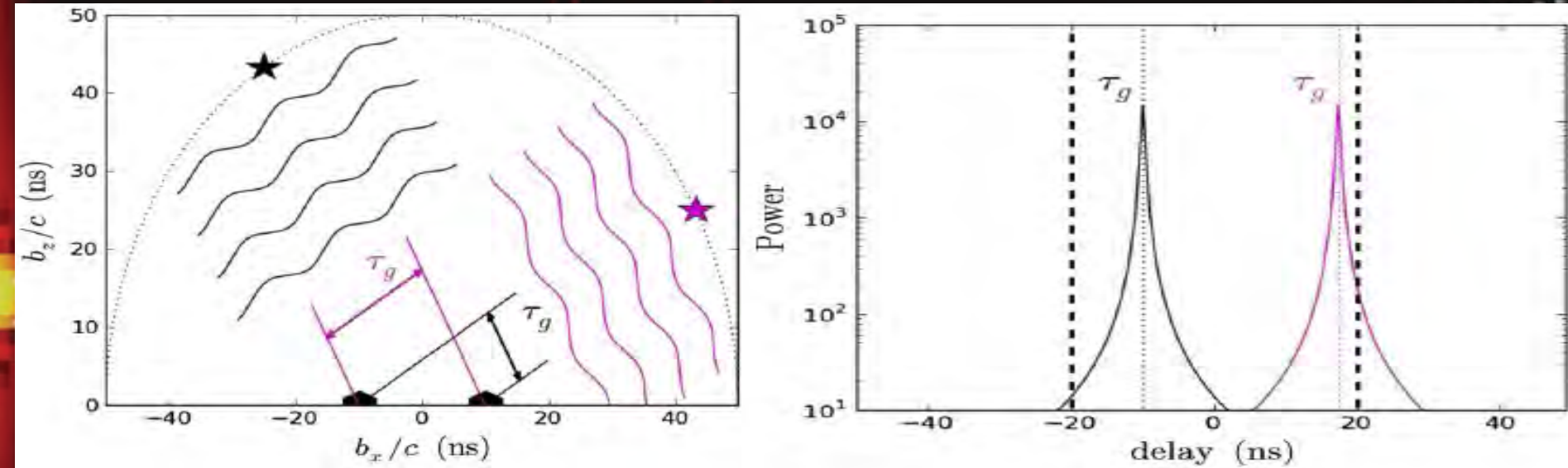
- Formation of large scale structures and evolution of astrophysical objects need to be probed
- Neutral Hydrogen is a direct probe of the Reionization epoch
- Current instruments have enough sensitivity for statistical detection of HI from the EoR

The Foreground Problem



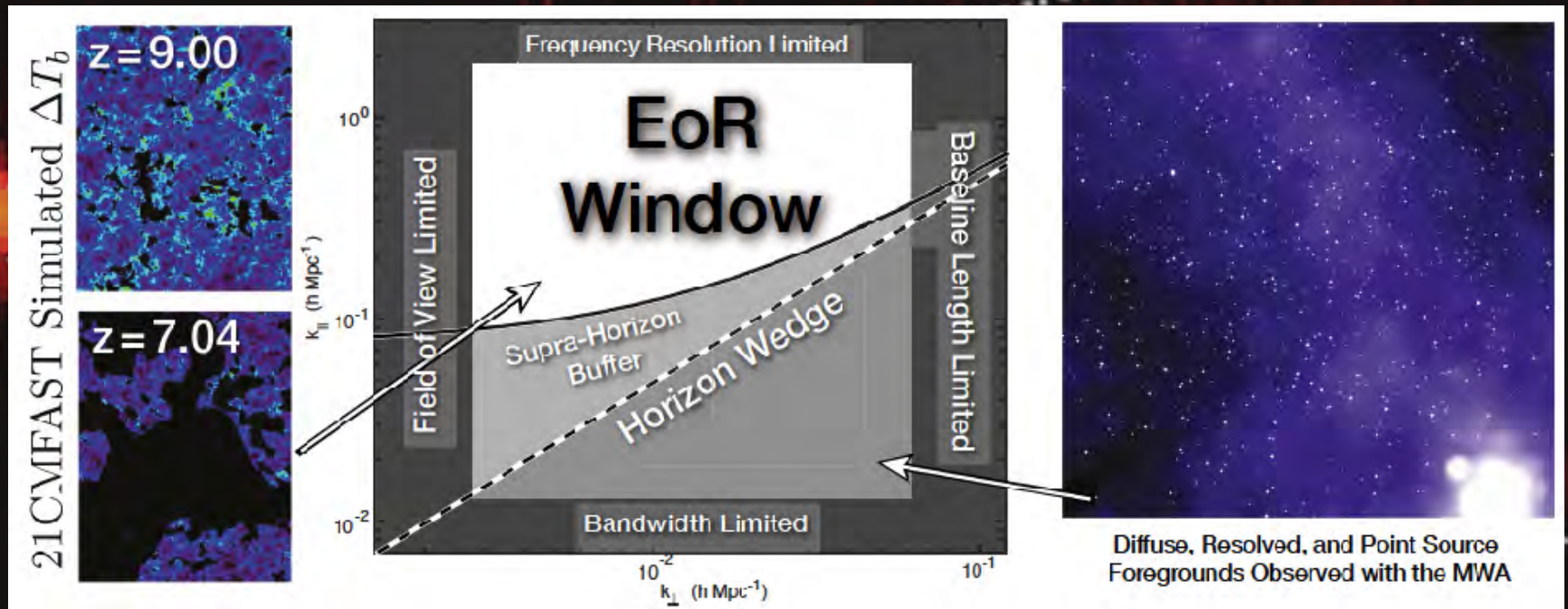
Parsons et al. (2012)

Fourier Space and Delay Spectrum

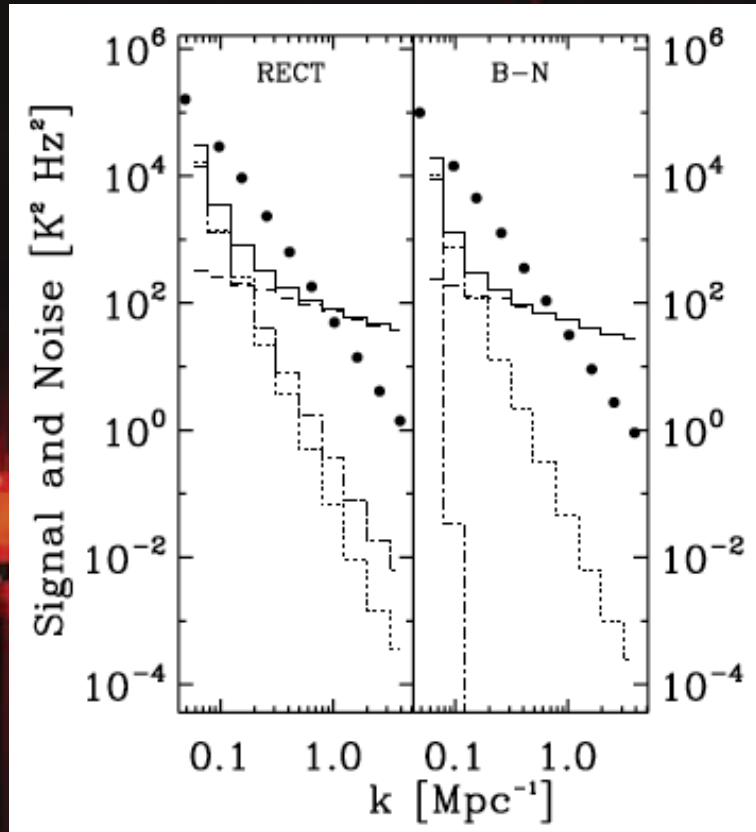


Parsons et al. (2012)

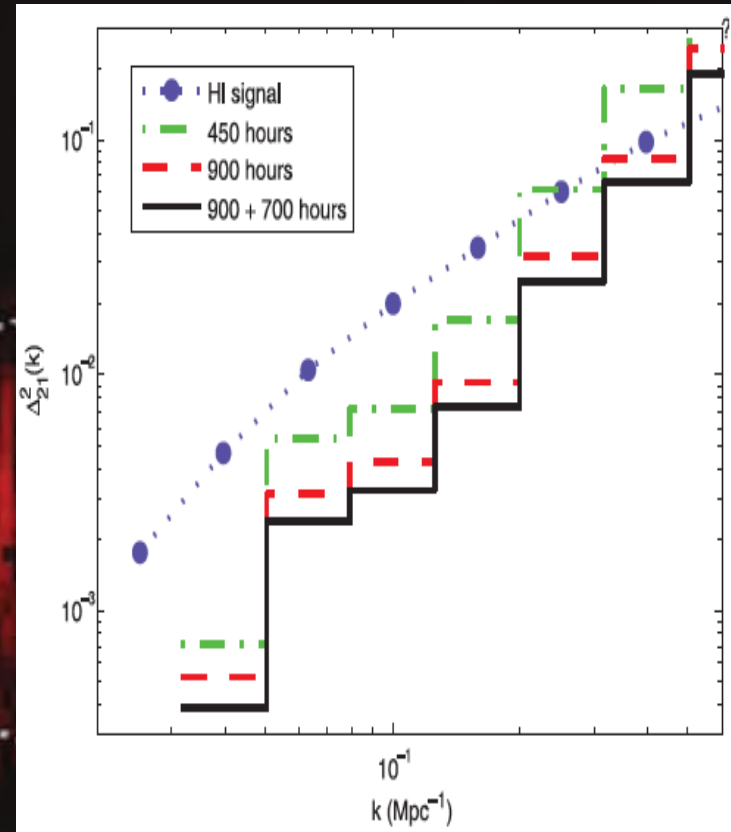
Foreground “Wedge” and EoR window



Motivation for High Precision Modeling



Thyagarajan et al. (2013)



Beardsley et al. (2013)

- >10 -sigma statistical detection expected with ~ 1000 hours data
- Currently limited by foregrounds and instrument systematics (e.g. PAPER64 - Ali et al. 2015, Pober et al. 2015; MWA - Dillon et al. 2013, Beardsley et al. 2016)

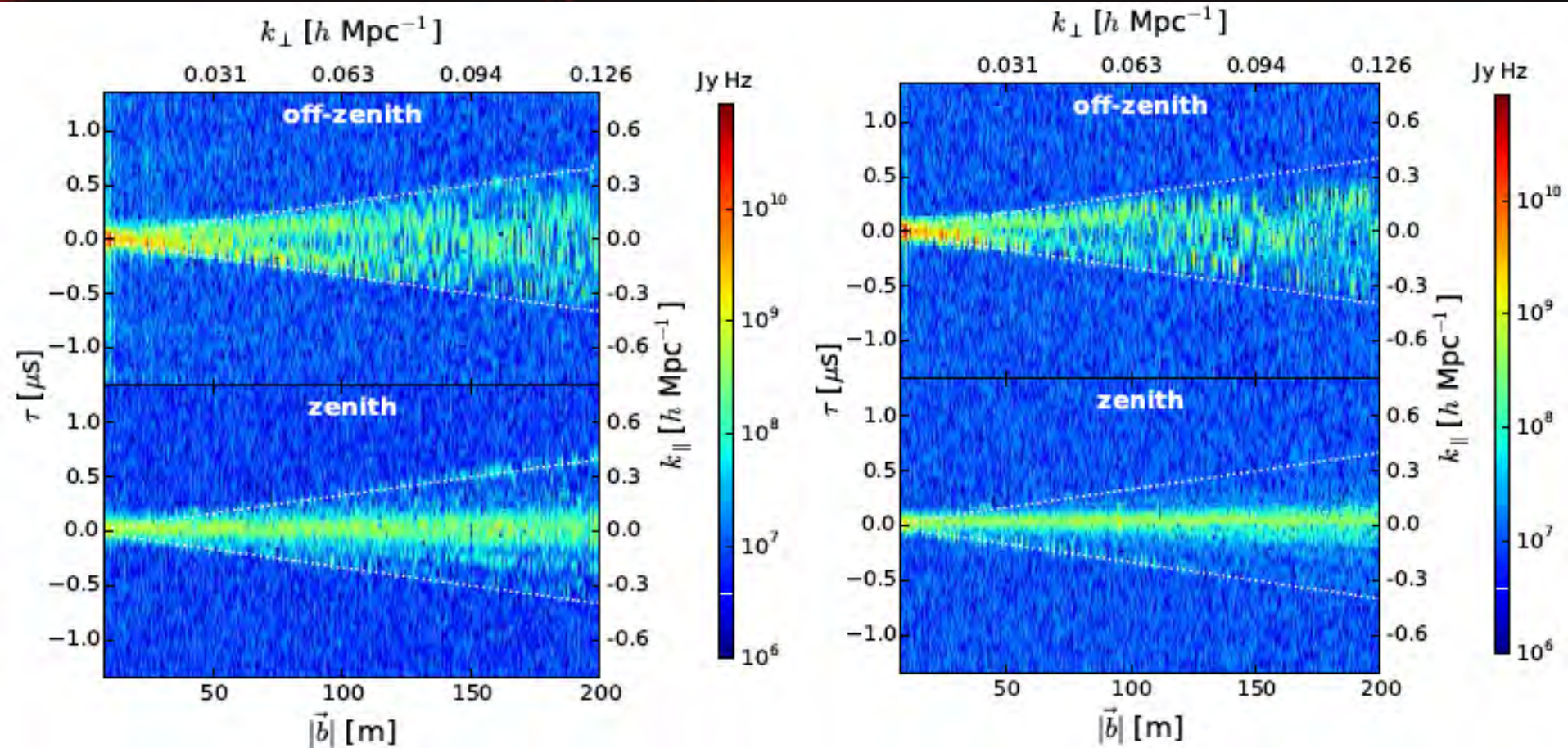
Precision Radio Interferometry Simulations (PRISim)

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 - antenna aperture, chromaticity
- Antenna Position Errors
- Post-processing solutions to mitigate systematics

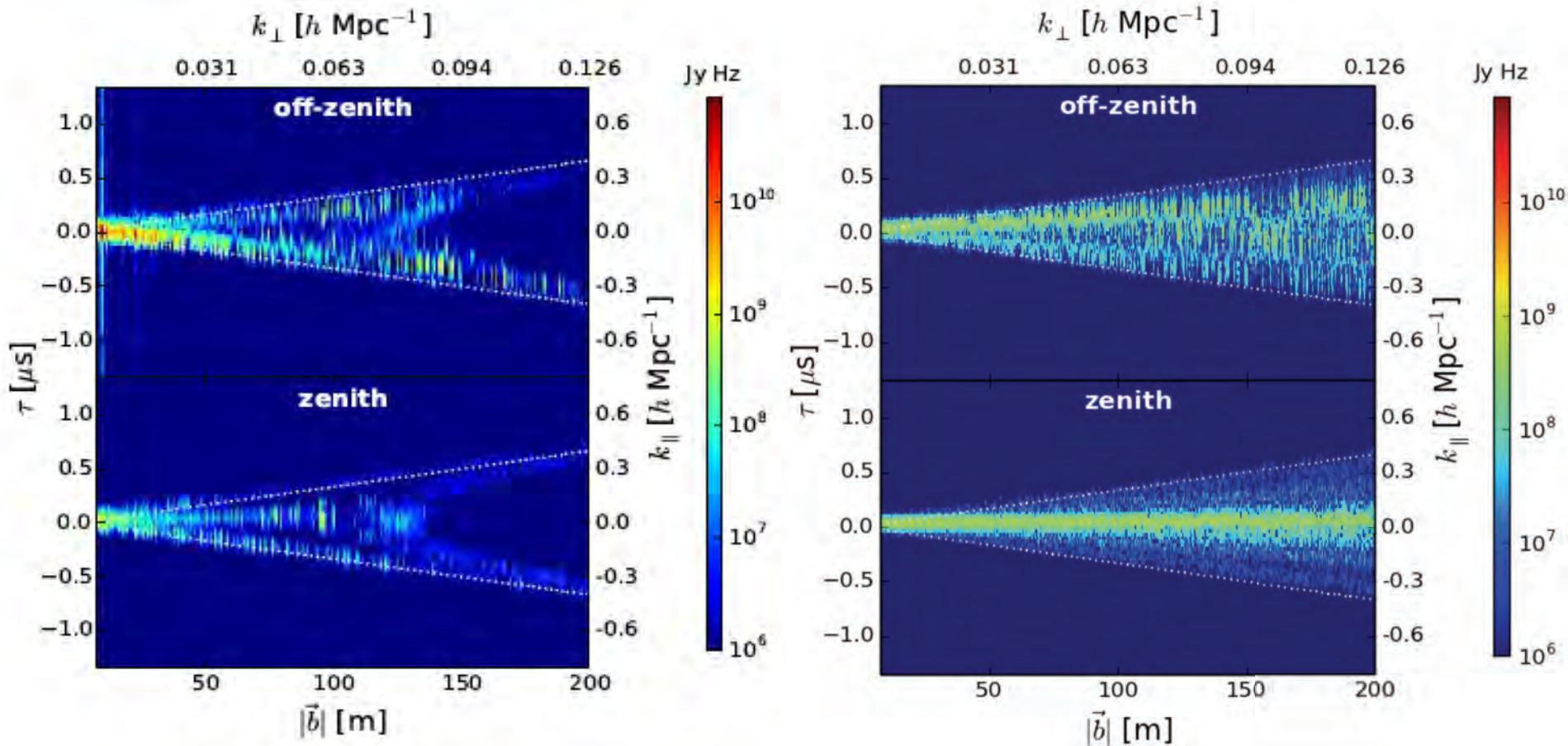
On Github => <https://github.com/nithyanandan/PRISim>

Model-Data Agree well



Thyagarajan et al. 2015b

Impact of Wide-Field Foregrounds – “Pitchfork” effect

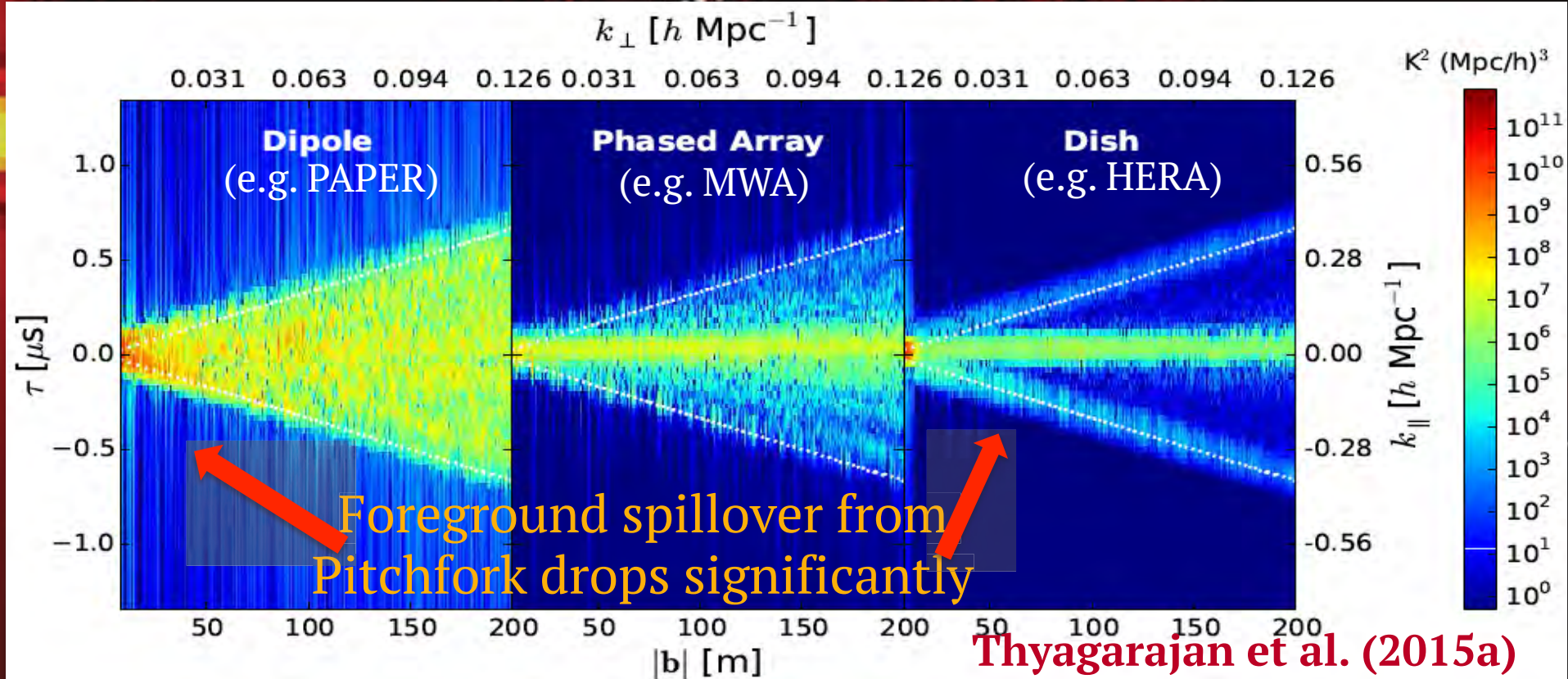
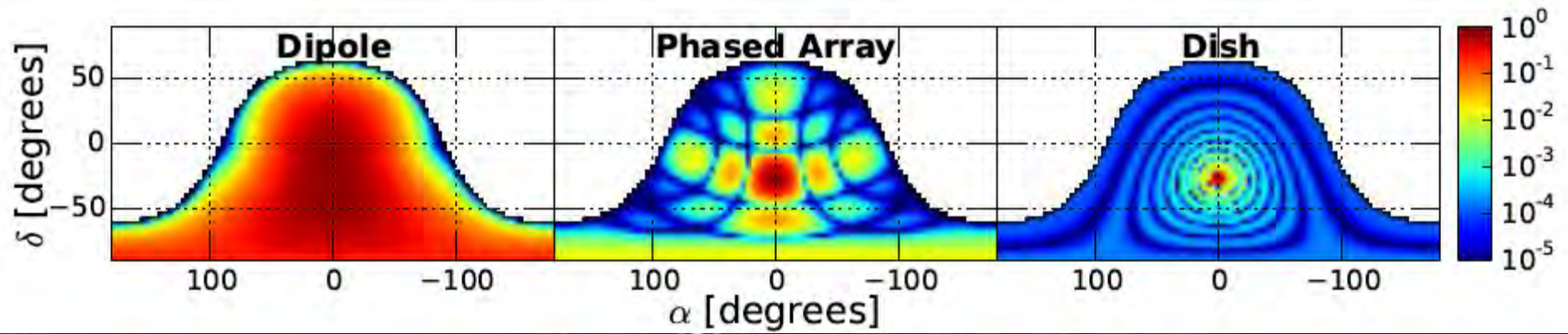


Diffuse Emission

Thyagarajan et al. (2015a)

Point sources

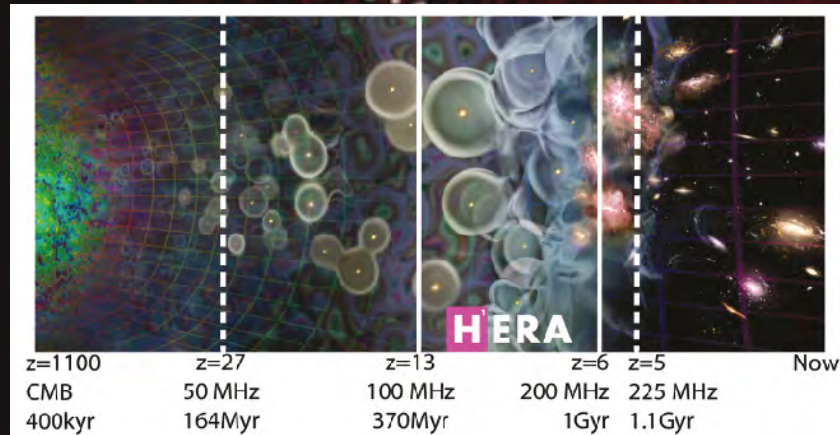
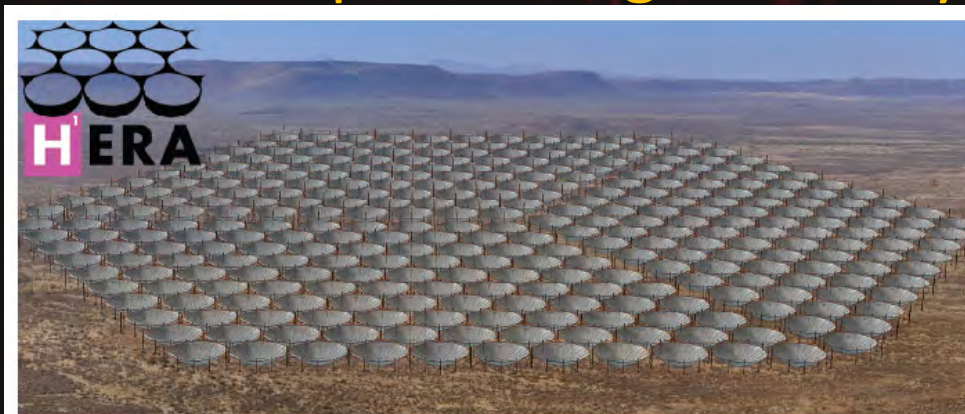
Mitigation of systematics via Antenna Geometry



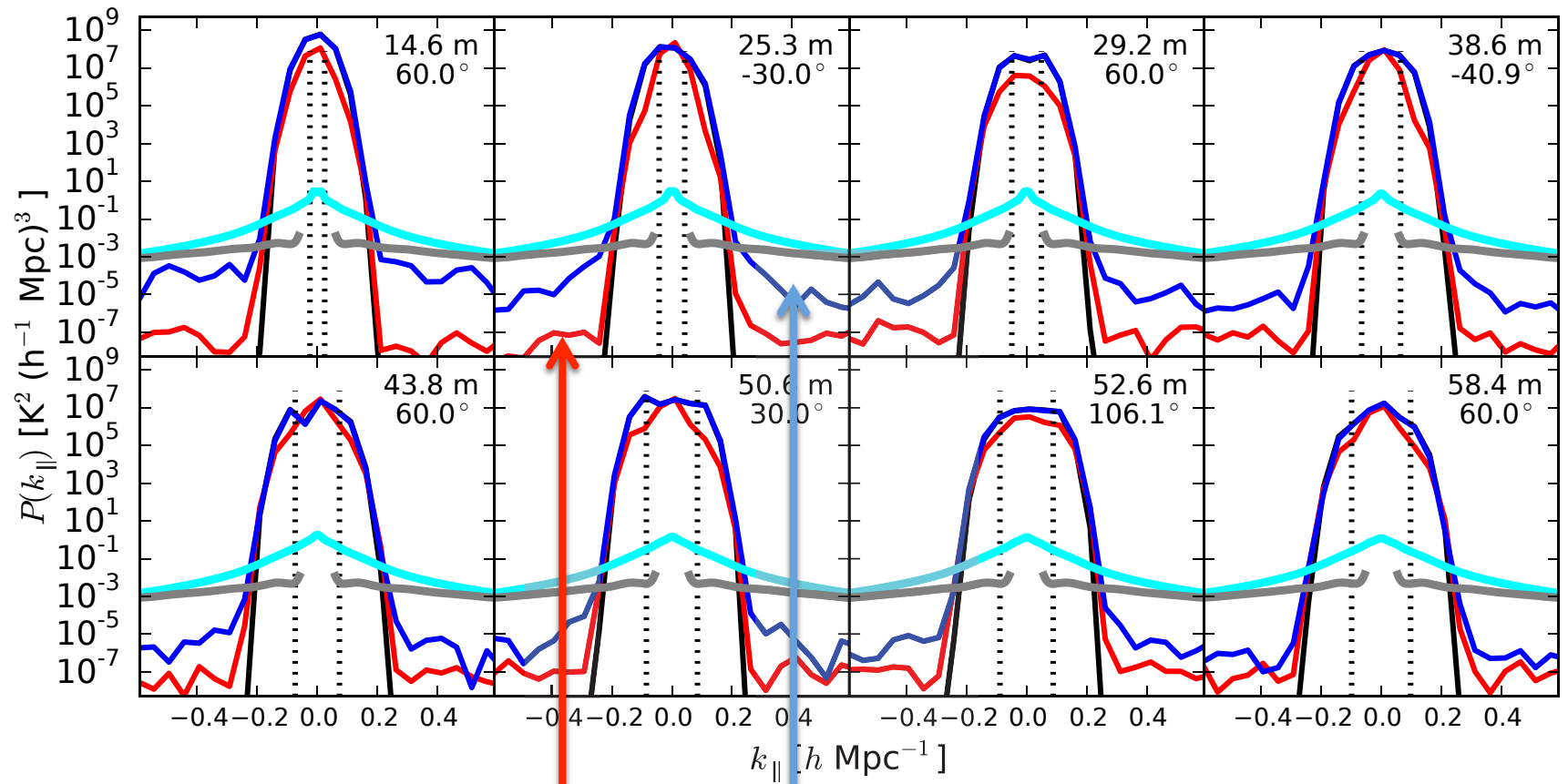
Thyagarajan et al. (2015a)

HERA Example

- HERA (Hydrogen Epoch of Reionization Array)
 - $B = 100\text{MHz}$
 - 1024 channels
 - $\sim 100\text{ kHz}$ channels
 - 14m dishes
 - FoV $\sim 10\text{ deg.}$ at 150 MHz
 - Compact hexagonal array



Effects of Beam Chromaticity



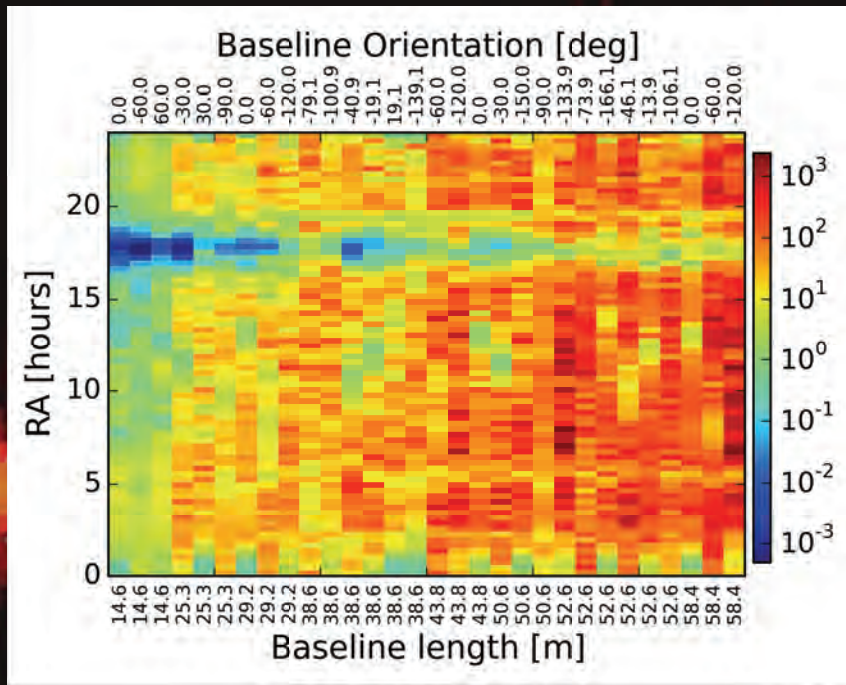
Thyagarajan et al. (2016)

Uniform Disk Airy Pattern

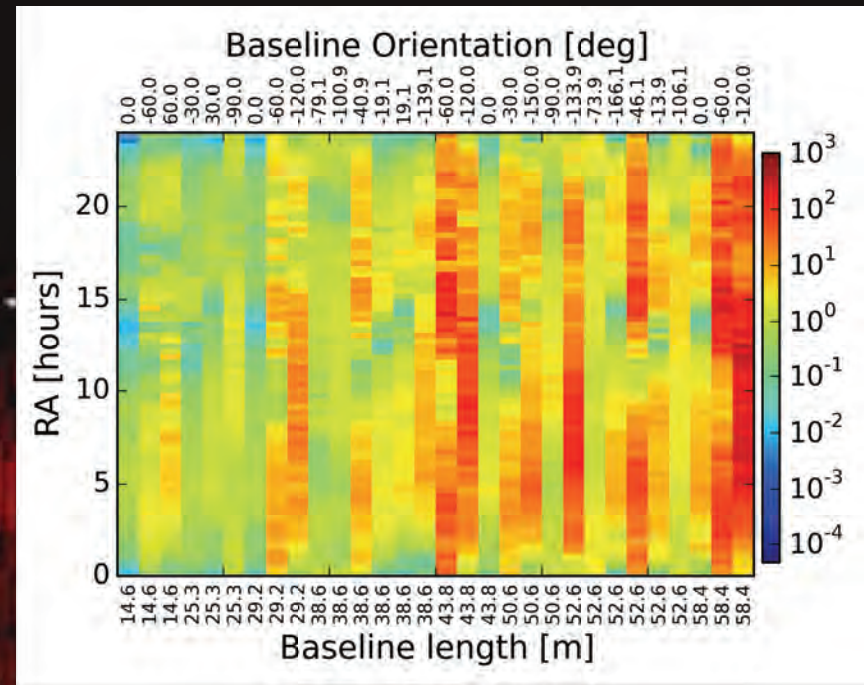
Simulated Chromatic HERA beam

- Differences seen only due to spectral differences in Antenna beam
- Beam chromaticity worsens foreground contamination
- HERA aiming for such a robust element design

EoR Observing Window Efficiency



150 MHz subband ($z=8.47$)

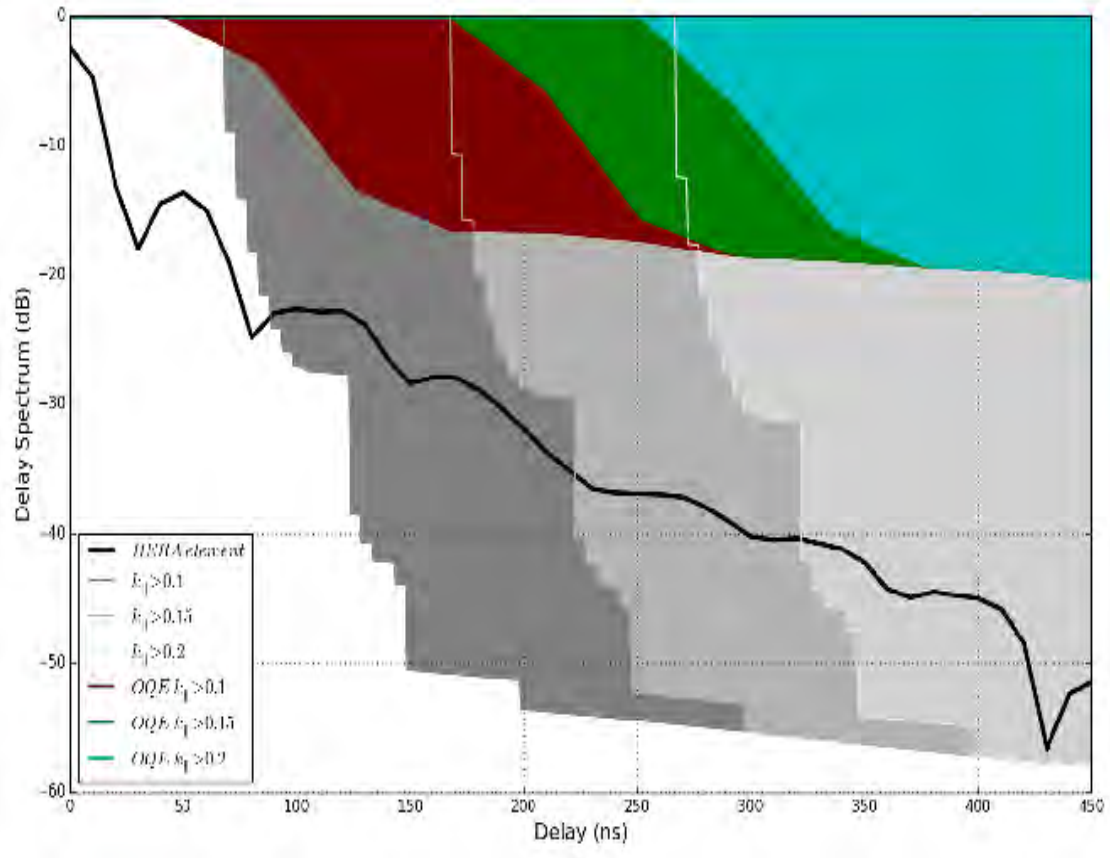


170 MHz subband ($z=7.36$)

- All HERA baselines sensitive to EoR for most of observing window
- Robust to different models and redshifts
- HERA will have good control over instrumental systematics and foreground contamination
- Working on SKA point of view

Design Specs on Reflections in Instrument

Dish-Feed Reflections Antenna-to-Antenna Reflections



Thyagarajan et al. (2016)
Ewall-Wice et al. (2016)
Neben et al. (2016)
Patra et al. (2016)
DeBeor et al. (2016)

- Reflections inevitable in electrical systems
- Reflections extend foregrounds and contamination in delay spectrum
- Require reflected foregrounds to be below HI signal levels
- HERA will aim for these specs
- Similar study is ongoing for SKA (with de Lera Acedo et al., Cambridge)

Summary

- Systematics are the biggest challenge to EoR and low frequency experiments - HERA, SKA, MWA, PAPER, LOFAR
- Best solutions are via robust instrument design
- PRISim – high precision simulations for wide-field radio interferometry – publicly available: <https://github.com/nithyanandan/PRISim>
- Discovery of new instrument + foreground physics:
 - Foregrounds + wide-field instruments leads to “pitchfork” contamination
 - Antenna beam chromaticity, reflections worsen contamination (thus requires careful design motivated cosmologically)
 - Control antenna position errors to preserve redundancy
 - HERA design based on these principles- offers great promise for EoR detection
 - SKA design also under study