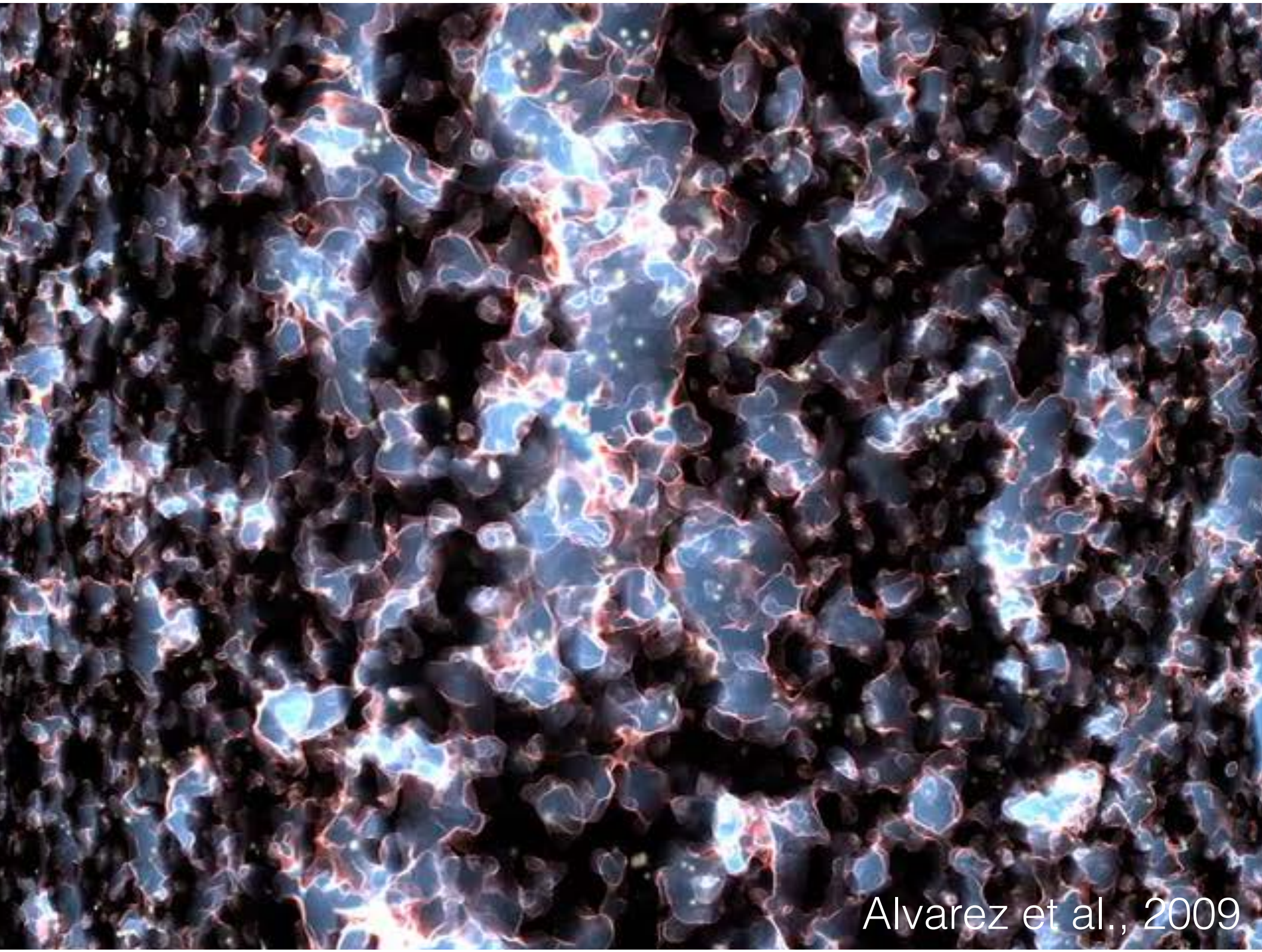
Imaging with EoR Instruments

Bryna Hazelton

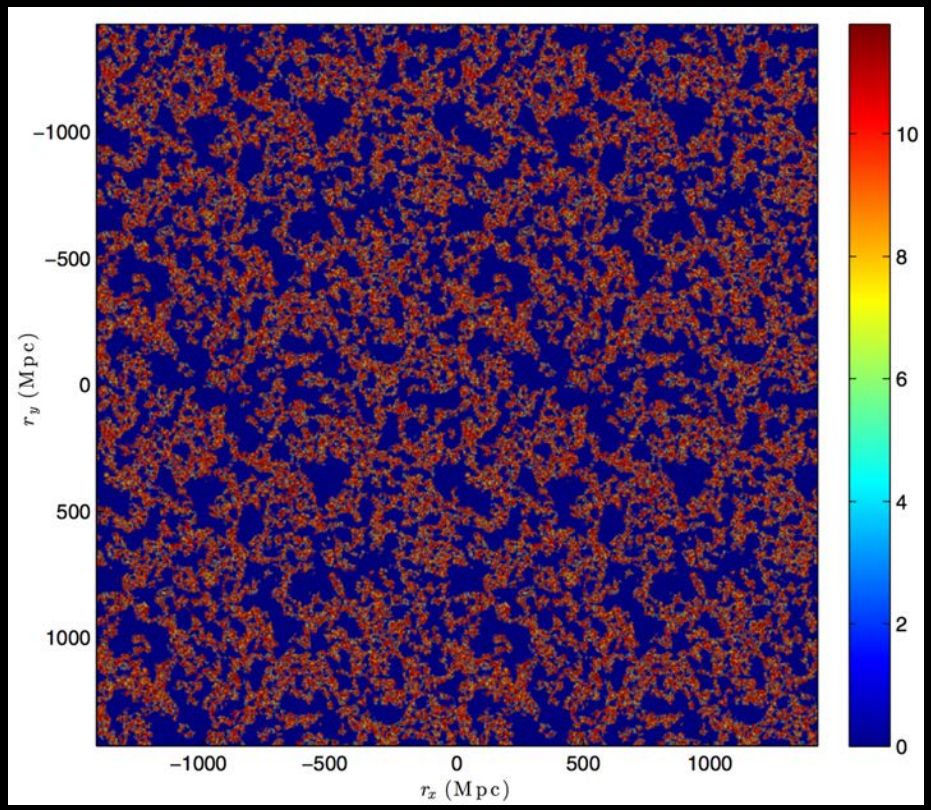
Radio Futures II, Baltimore, Aug 4 2016

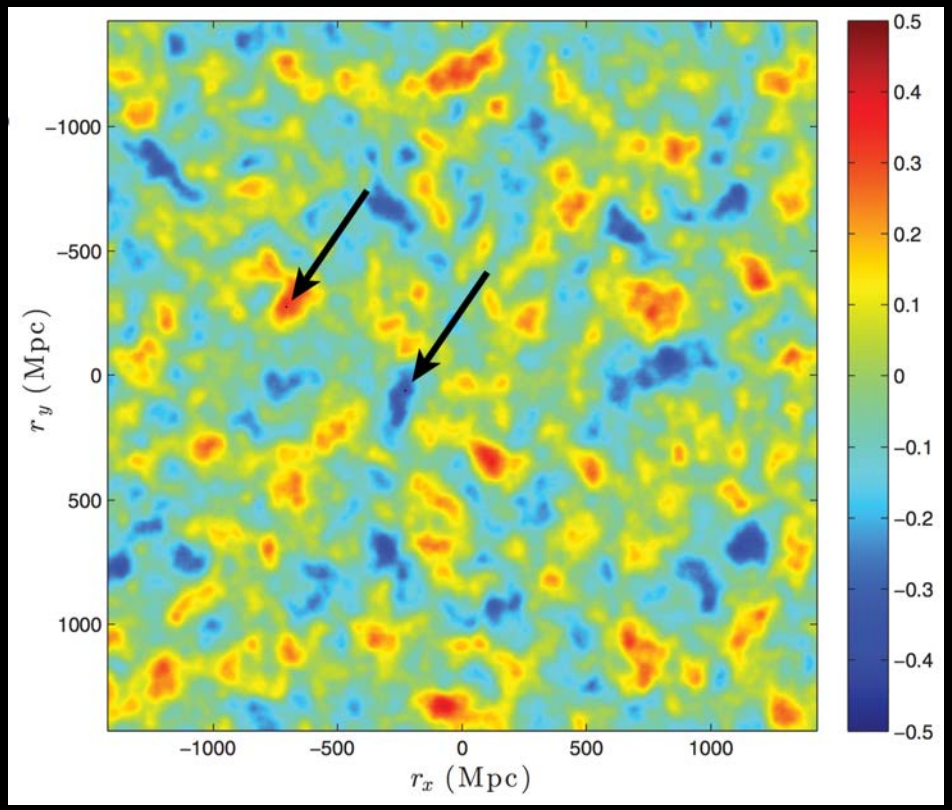

Alvarez et al., 2009

Why Imaging?

- Foreground imaging: subtraction for EoR PS
- EoR Imaging: connect to other probes & wavelengths
  - Cross-correlation with CMB, large scale structure and galaxy surveys
  - Giving the ionization context for JWST and other observations of early galaxies
  - Does not require arcsecond resolution. ~½ degree resolution is sufficient

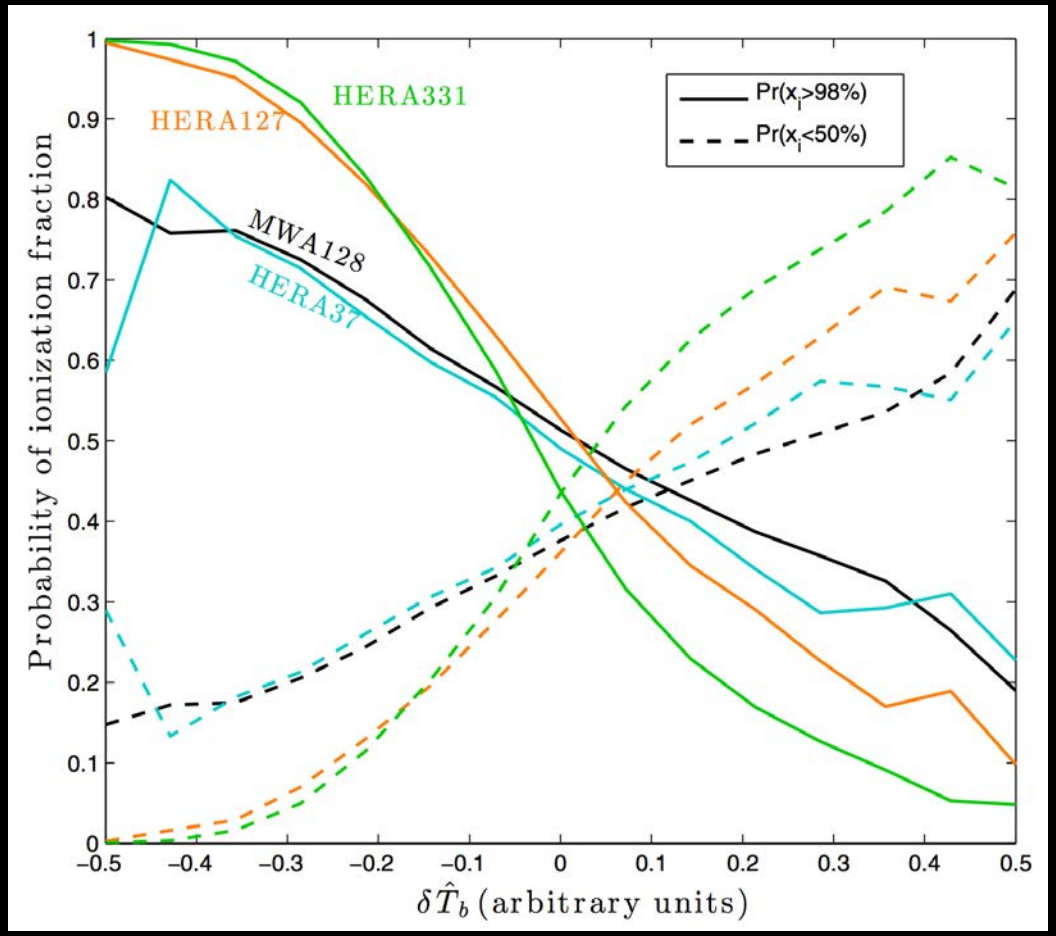
Imaging with foreground filtering





Beardsley et al. 2015

Imaging with foreground filtering

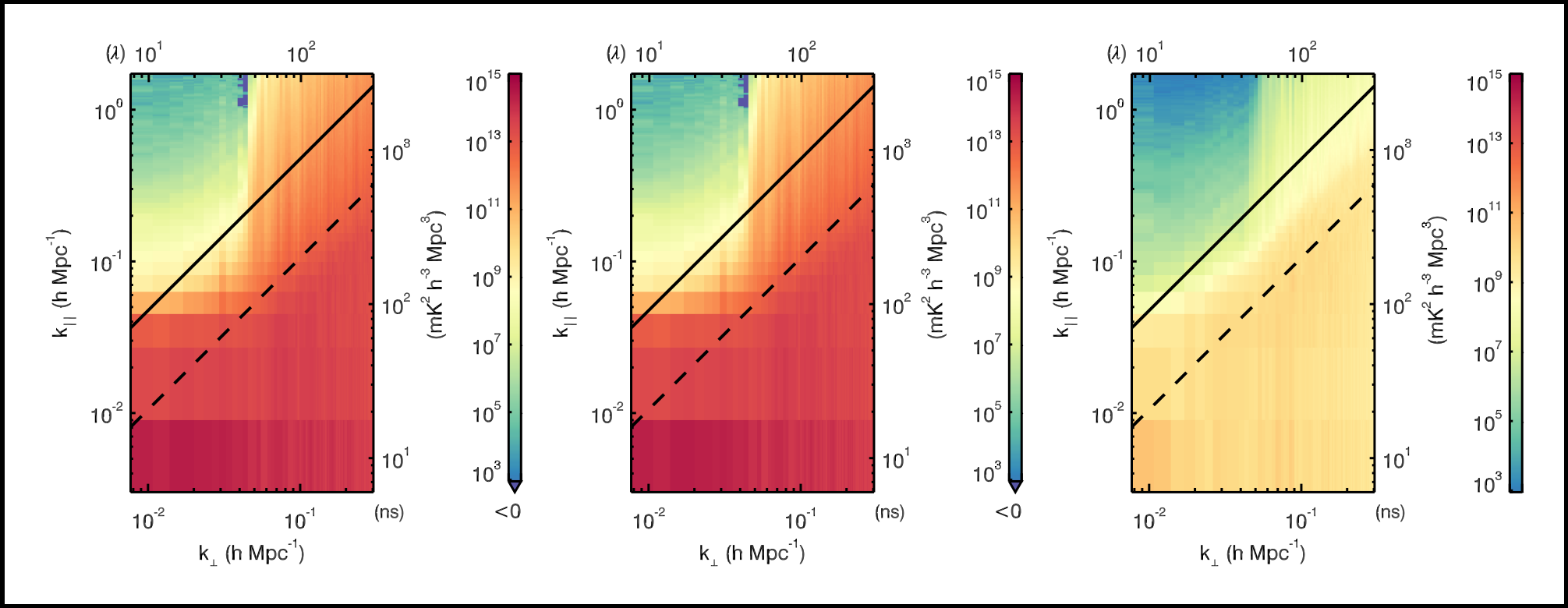


Beardsley et al. 2015

Primary Challenge: Calibration

- The sky is full at these frequencies
  - MWA and LOFAR calibration sky models have >1k sources, including in sidelobes
- Requires:
  - Excellent sky and instrument models
  - Good uv coverage
  - Very smooth instrumental bandpass

Calibration Simulations

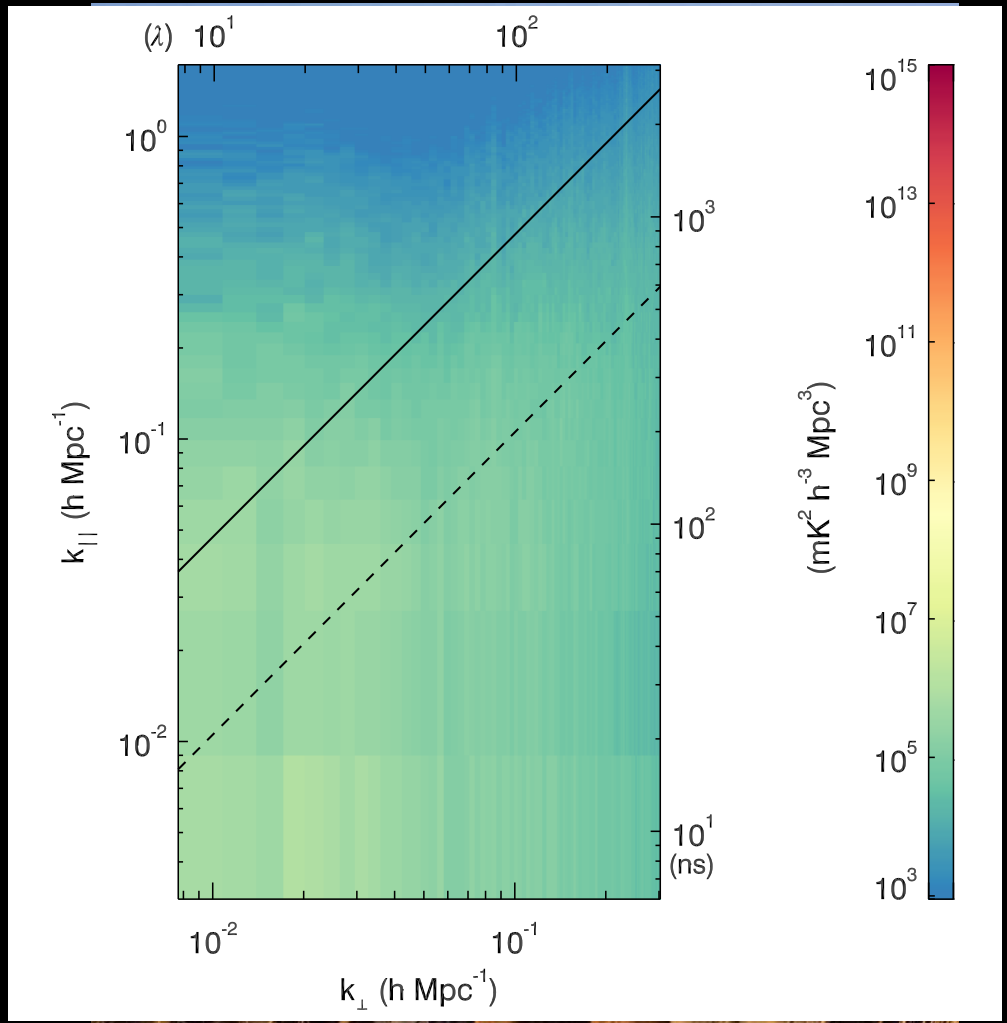


left: simulation with 6950 source
middle: simulation with brightest 4k sources
right: residual (2950 dim sources)

Barry et al., 2016

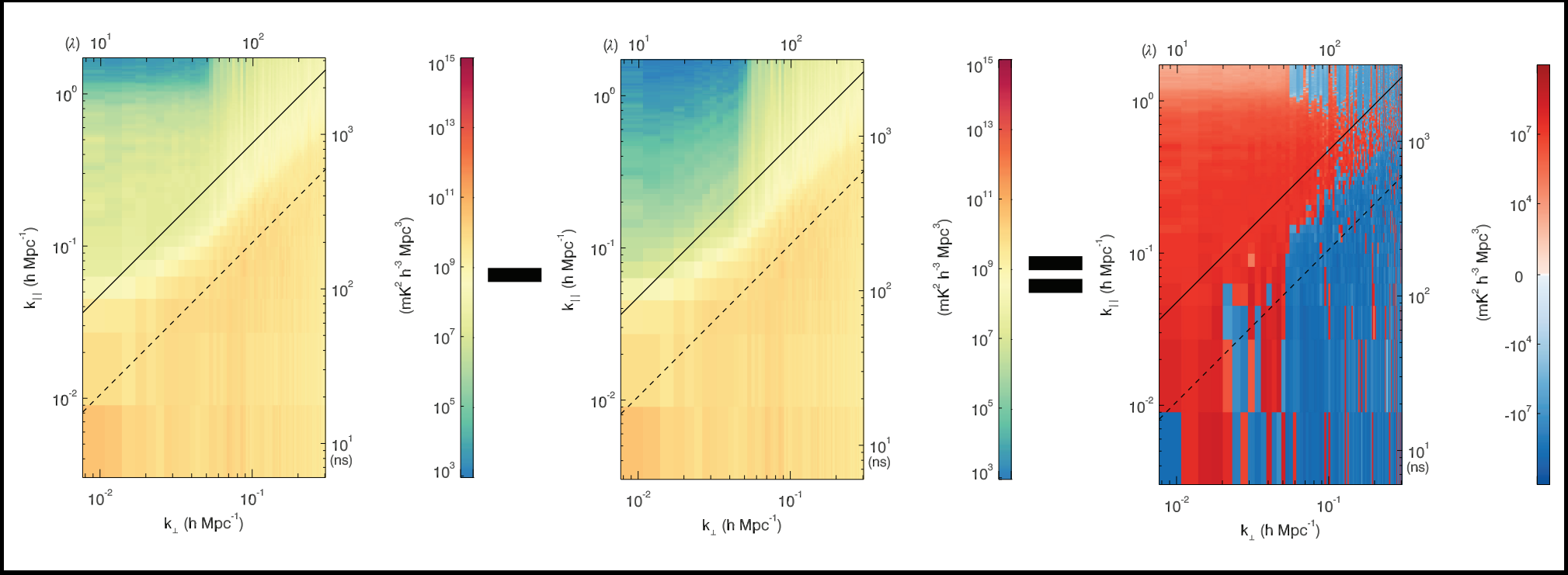
Calibration Simulations

- Model, calibrate and subtract all 6950 sources just leaves the EoR signal
- No signal loss



Barry et al., 2016

Calibration Simulations

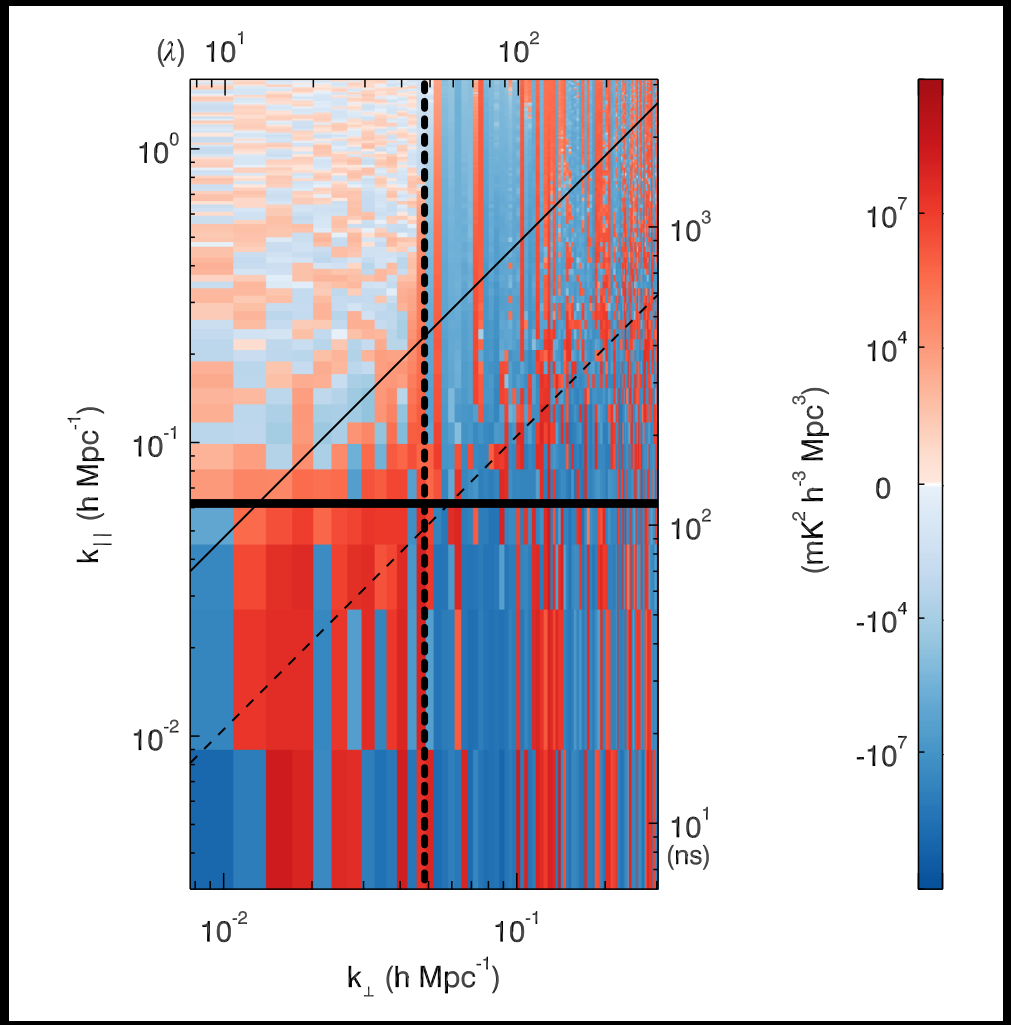


left: model, calibrate, subtract brightest 4k sources
middle: perfect calibration, subtract brightest 4k sources
right: power spectrum difference

Barry et al., 2016

Calibration Simulations

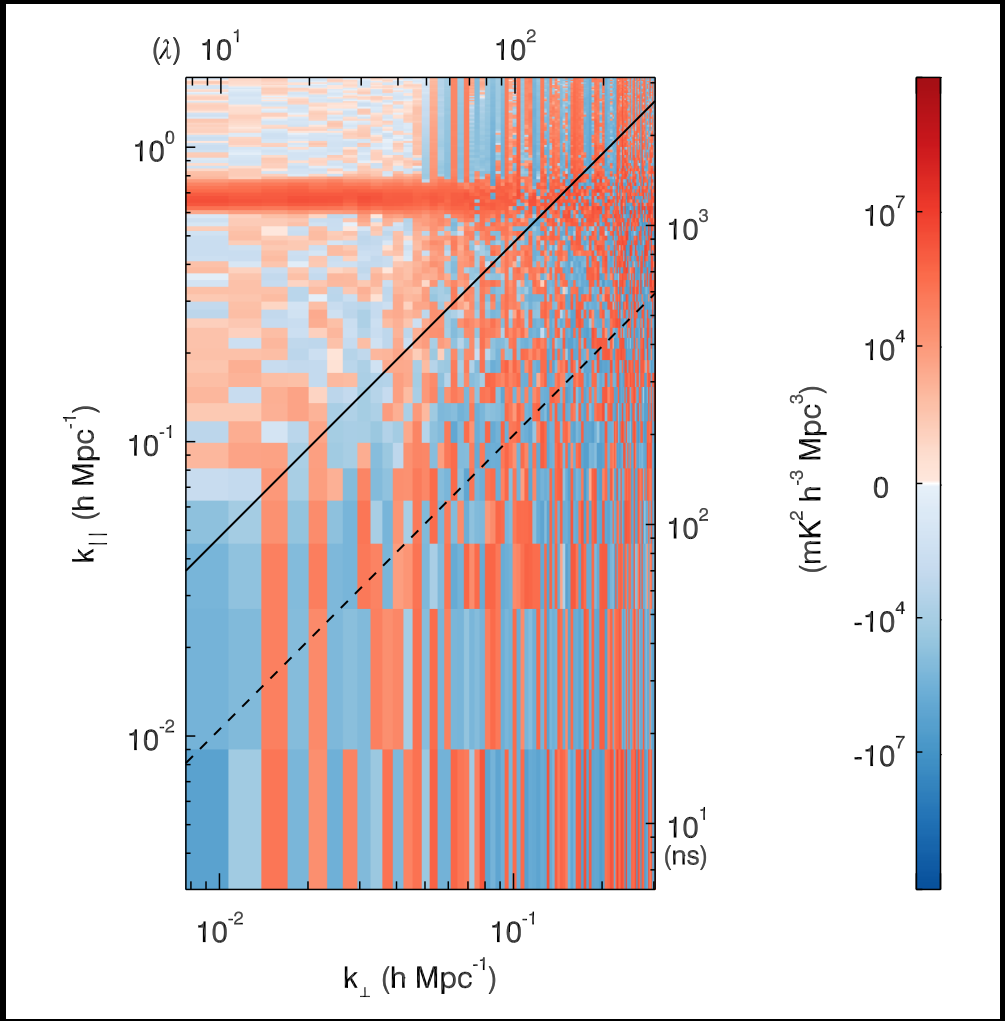
- Fit smooth functions to per-frequency, per-antenna solutions
- 2nd order polynomial in amplitude, linear in phase per antenna



Barry et al., 2016

Calibration Simulations

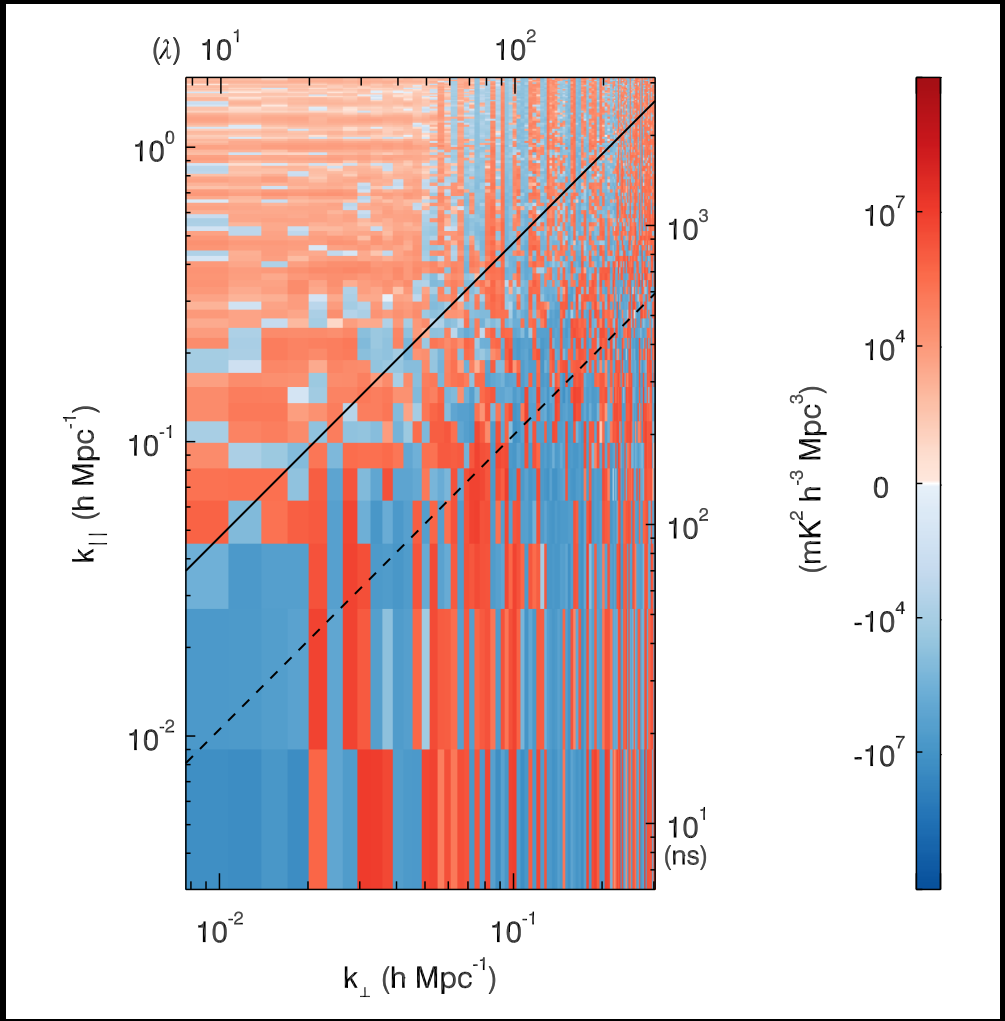
- Fitting for actual antenna frequency structure
- Fit 150 m cable mode on affected tiles
- Affected mode is unavailable for EoR



Barry et al., 2016

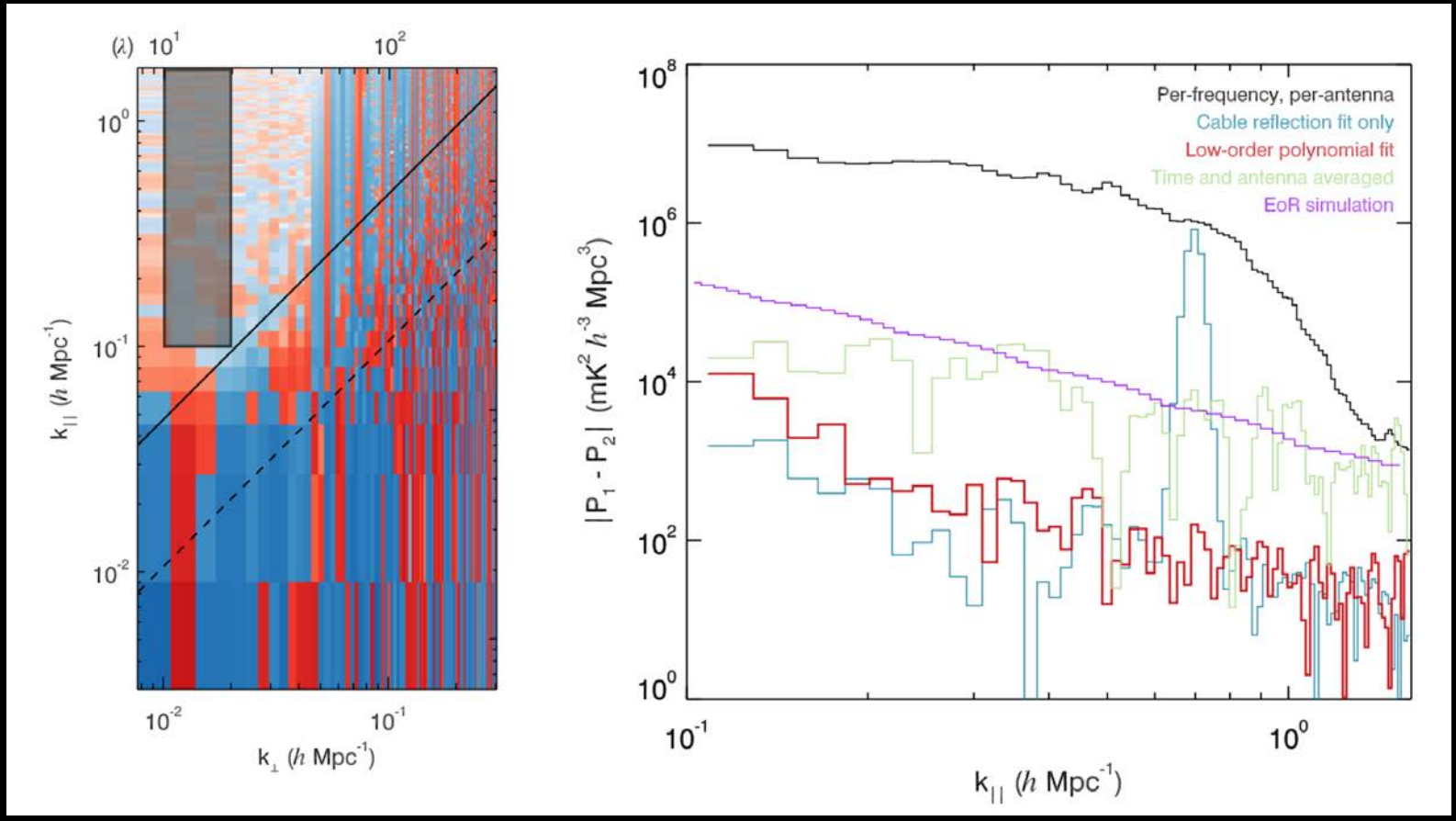
Calibration Simulations

- Maximal averaging of calibration solutions
- averaged over all 128 tiles, 30 minutes (excluding 2σ outliers)
- Residual is at EoR level



Barry et al., 2016

Calibration Simulations



recommendation: No frequency structure > 10^{-5} on scales smaller than 8 MHz (125 ns)

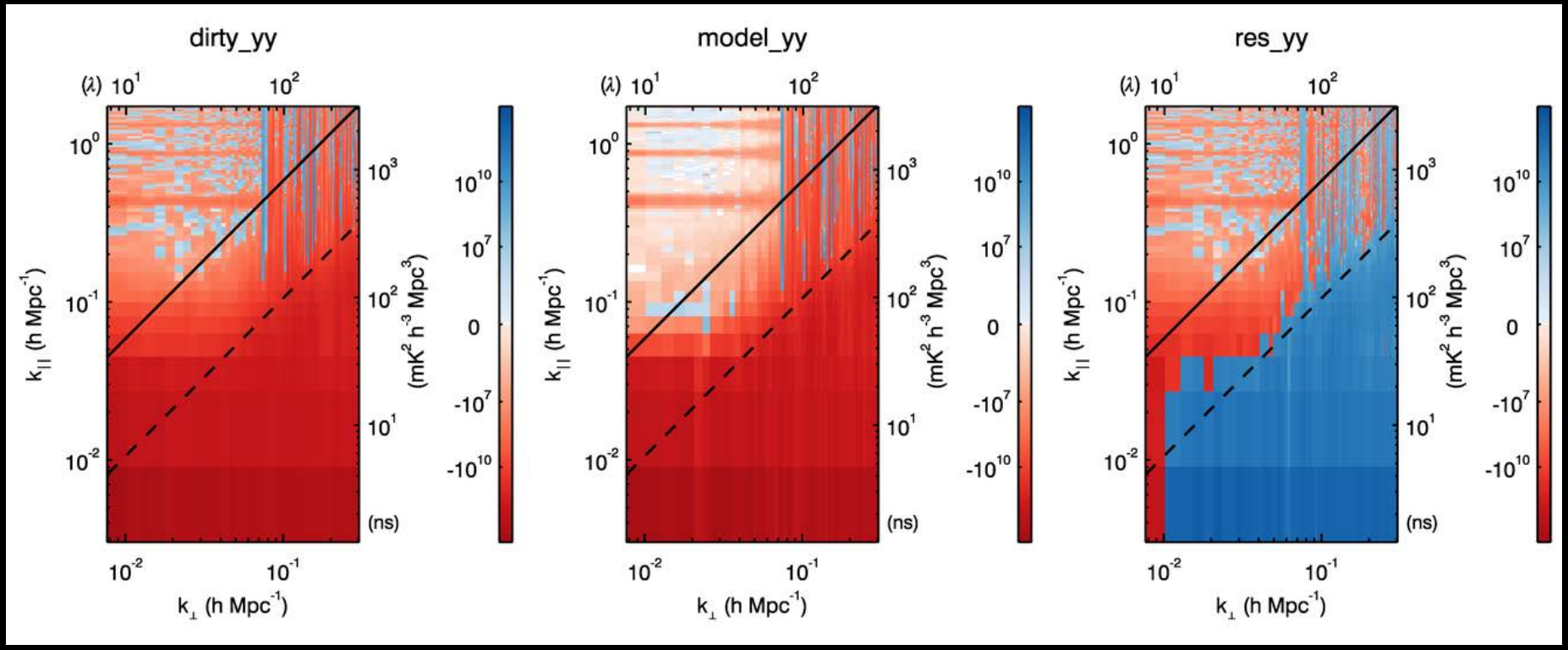
Barry et al., 2016

Excellent Sky Models: KATALOGSS

- Operates on FHD deconvolution components from a single night of observing (74 2-minute observations)
- Clustering & Machine Learning algorithms to identify reliable sources, verification through matching to existing surveys
- Complete to ~80 mJy within FWHM of beam
- High fidelity catalog designed for 21cm cosmology
- 1” astrometry on 2.3’ beam
- 17 new radio sources

Carroll et al., 2016

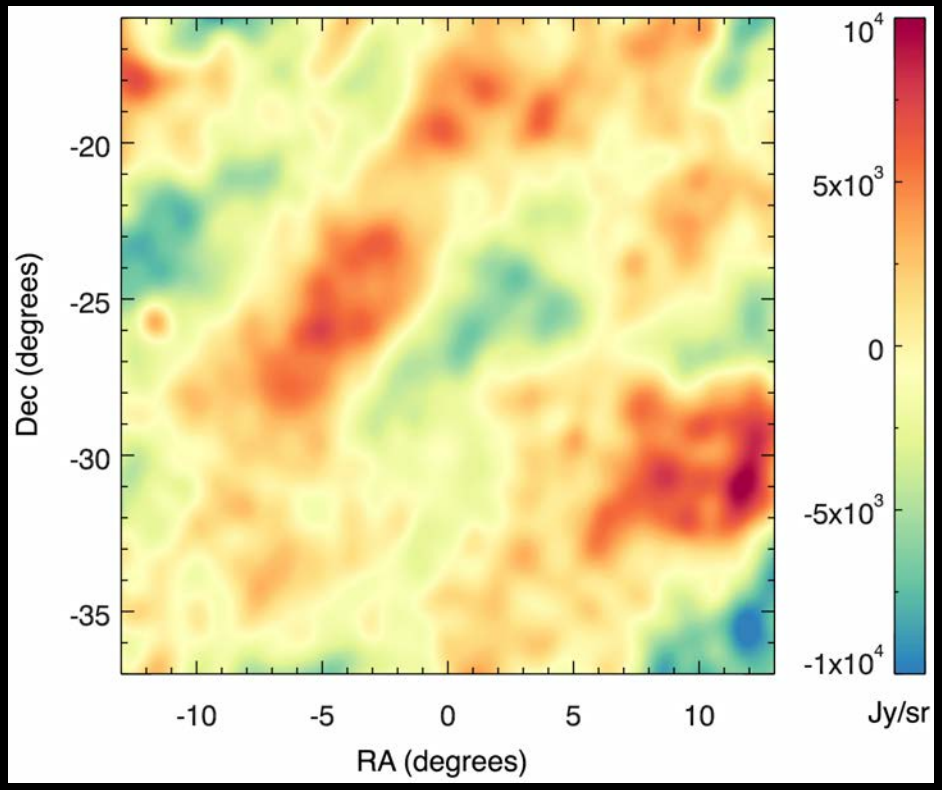
KATALOGSS

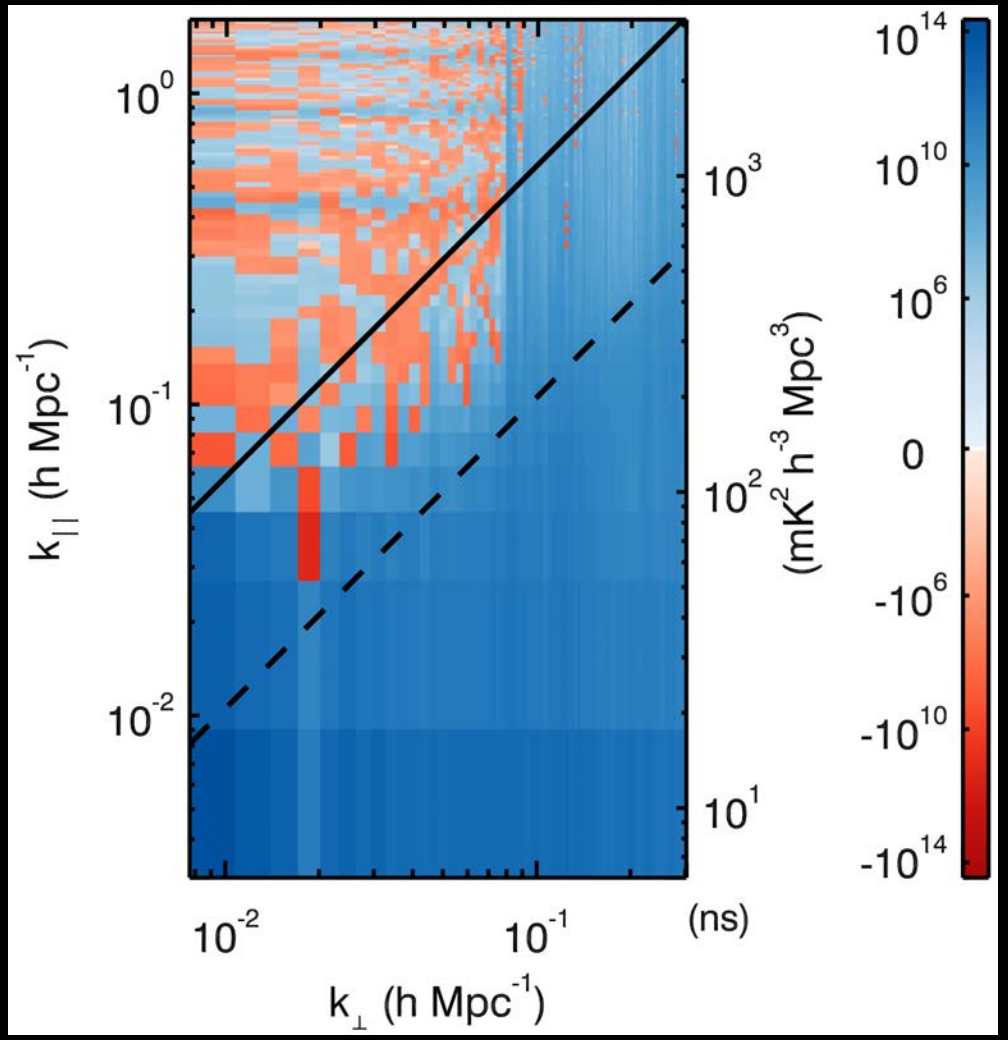


Power Spectrum difference using MWACS and KATALOGSS

Carroll et al., 2016

Excellent Sky Models: Diffuse Models





Beardsley et al., in review

Imaging Frontier

- Help improve EoR PS measurements
- Open the door to new science
  - cross-correlation studies
  - providing HI ionization context for early galaxies

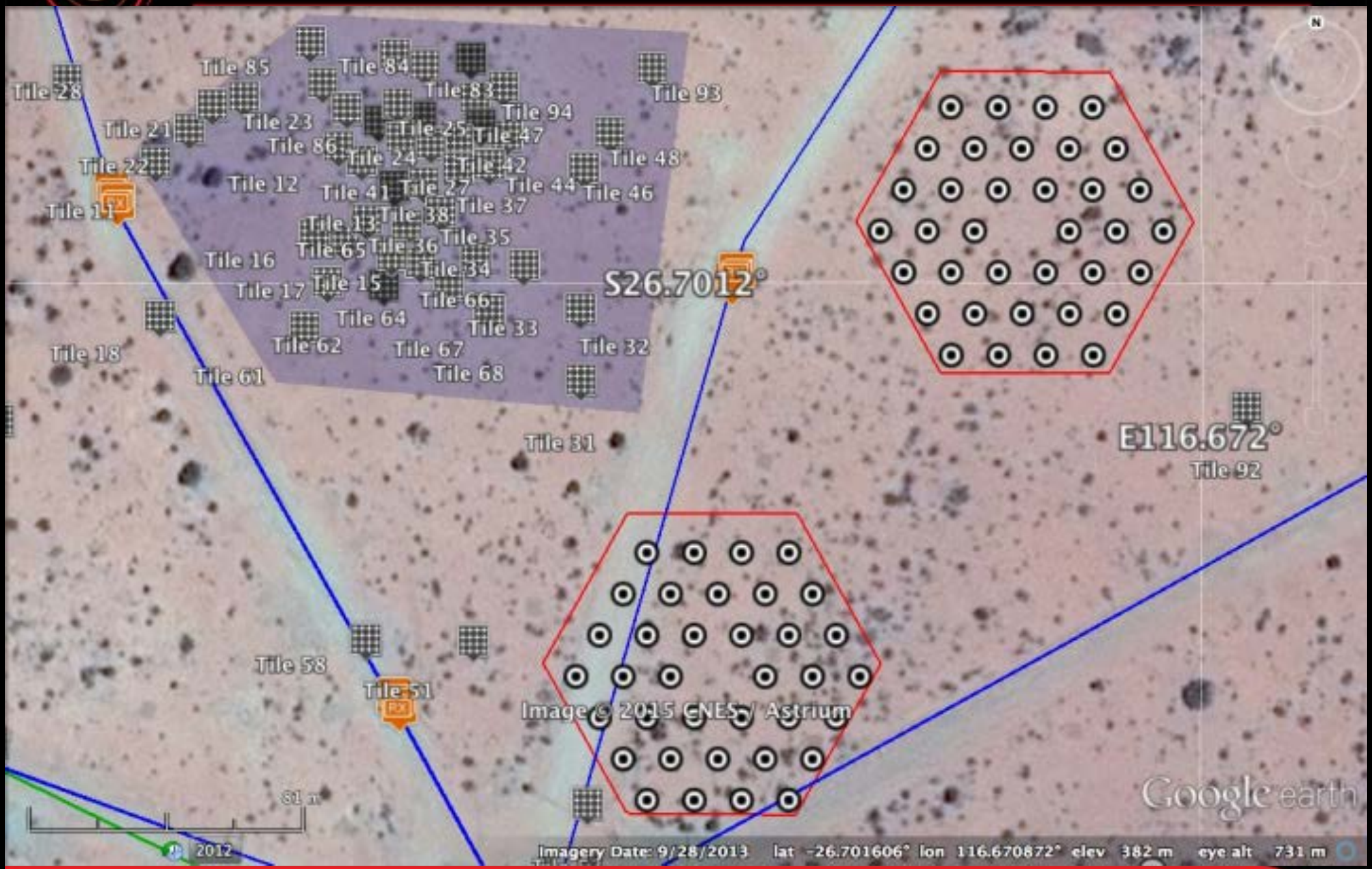
Imaging Frontier

- Several current and future telescopes are planning for imaging
  - MWA phase II & III
    - 128 new antennas, 72 in a redundant array
    - new digital system, smooth bandpass
  - Imaging capabilities for HERA not currently funded but desired
  - LOFAR
  - SKA Low

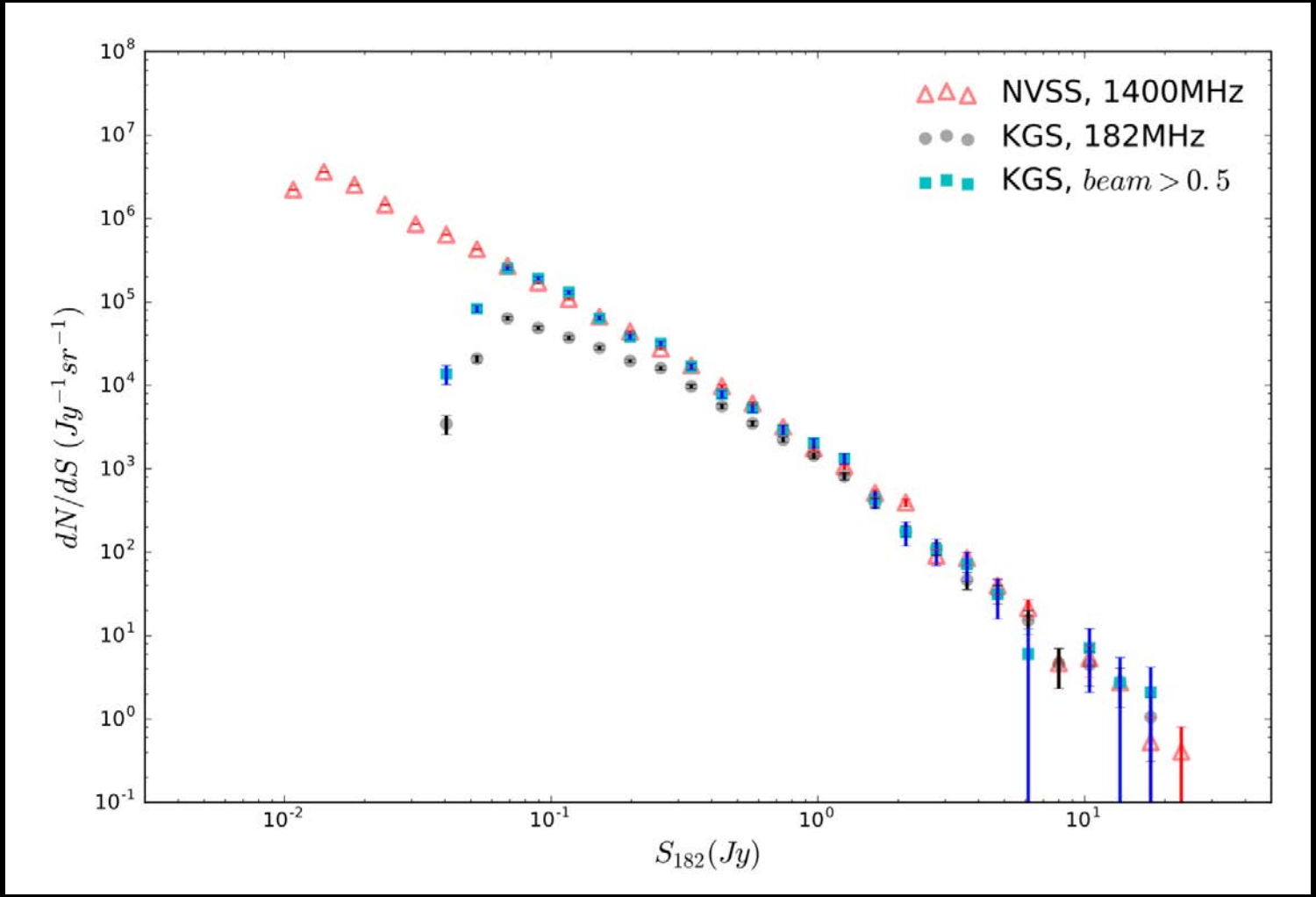
Imaging Frontier

- Tools and techniques for calibrating, imaging and building sky models for these experiments are being developed
- Instrumental requirements:
  - good uv coverage
  - smooth bandpass

Phase 2 Core Region

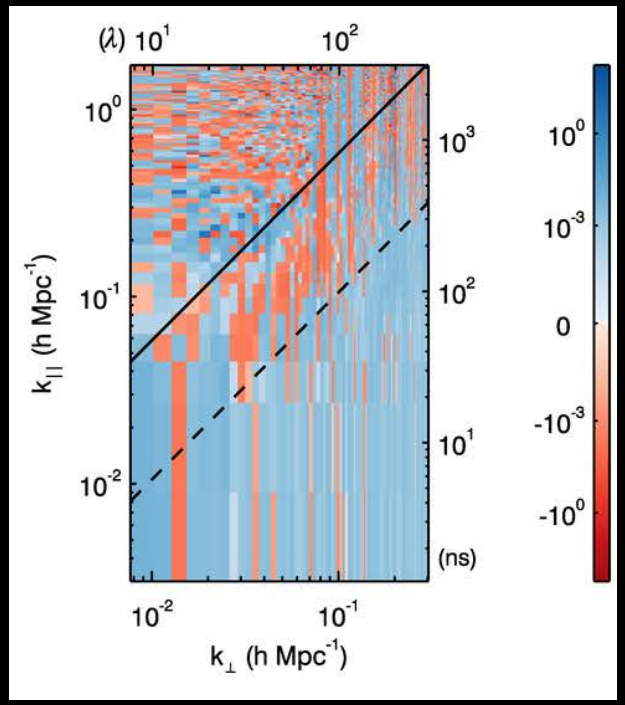


KATALOGSS



Carroll et al., 2016

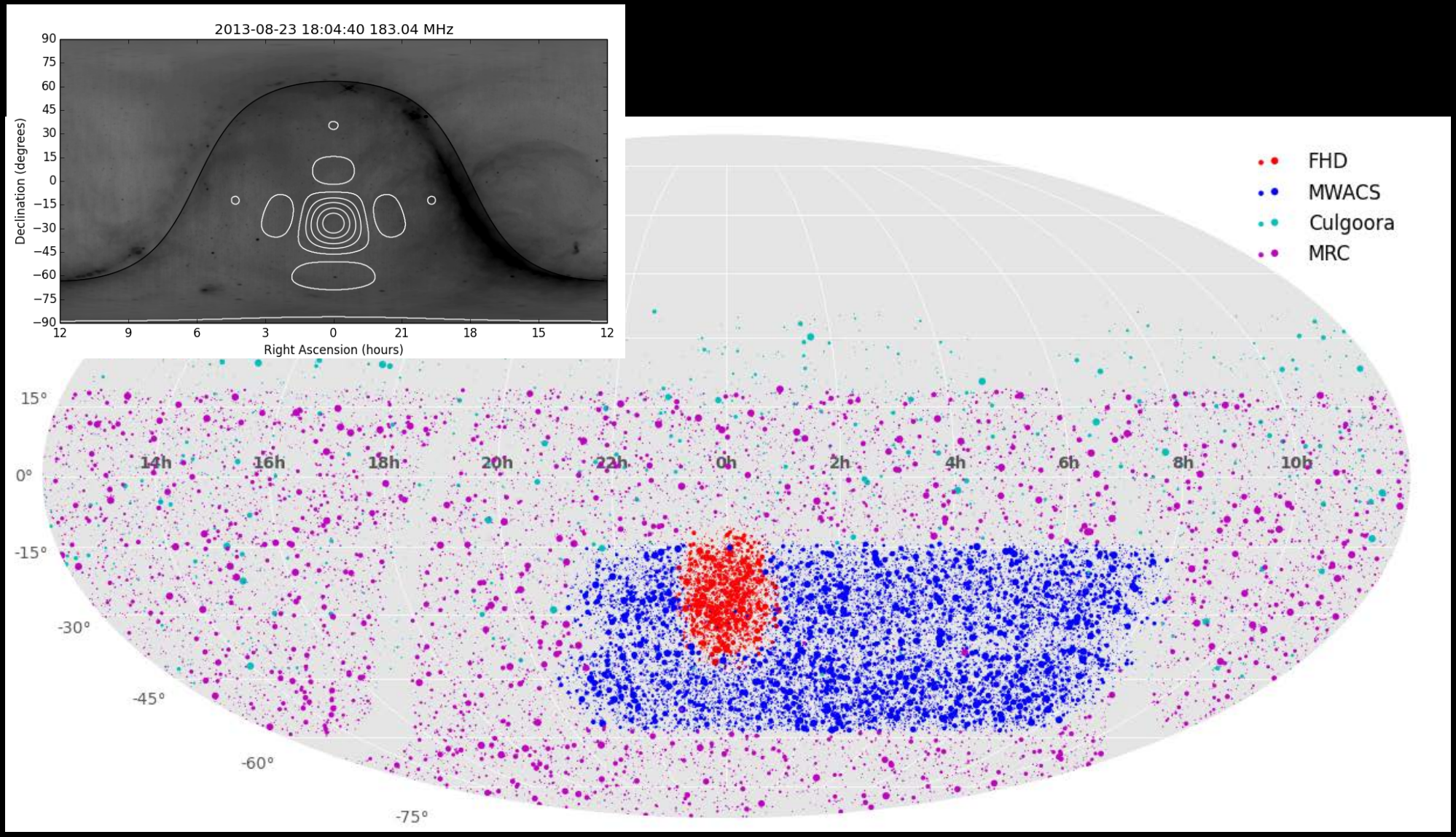
KATALOGSS



$$\text{ratio difference} = \frac{\text{residual}_1}{\text{dirty}_1} - \frac{\text{residual}_2}{\text{dirty}_2}$$

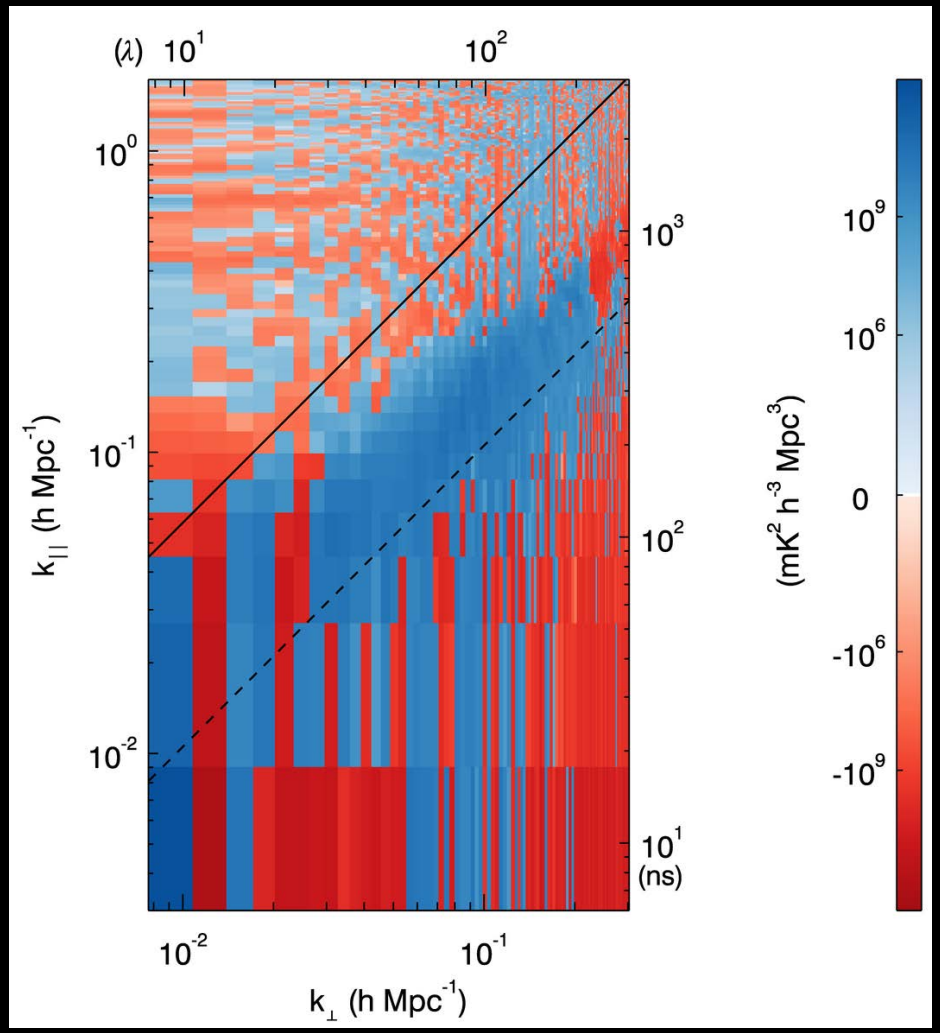
Carroll et al., 2016

Master Catalog



Sidelobe sources matter

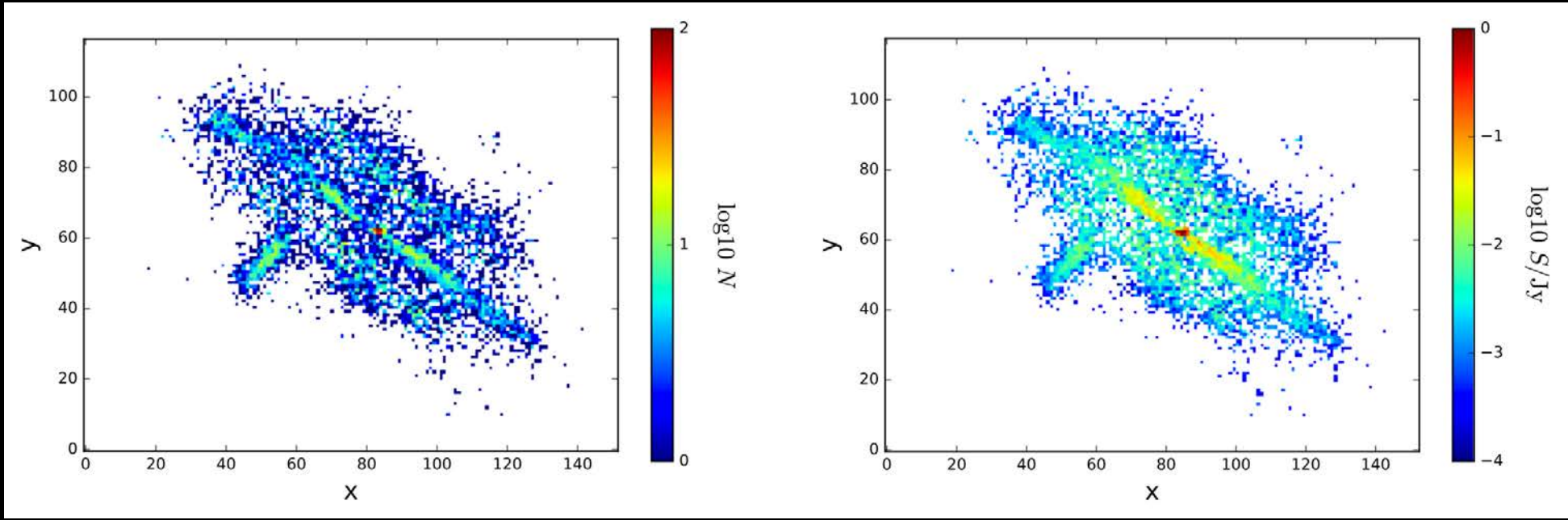
- Power spectrum difference of residuals with and without sidelobe sources in the model



Pober et al., 2016

Models for Extended Sources

NGC 253 (starburst galaxy)



left: number density of deconvolution components
(9416 from 74 2-minute observations)
right: flux density of deconvolution components

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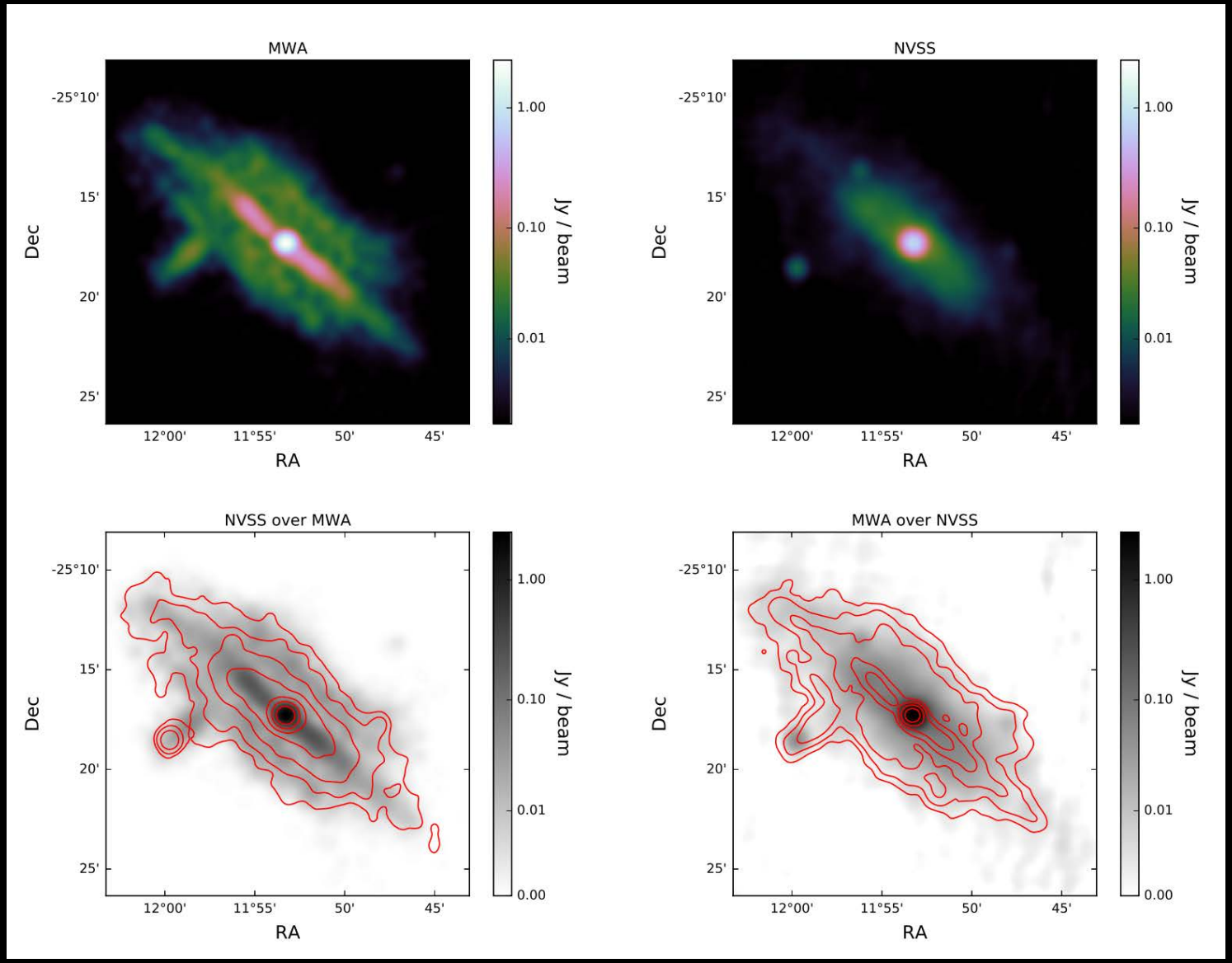
Models for Extended Sources

NGC 253 (starburst galaxy)



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Models for Extended Sources

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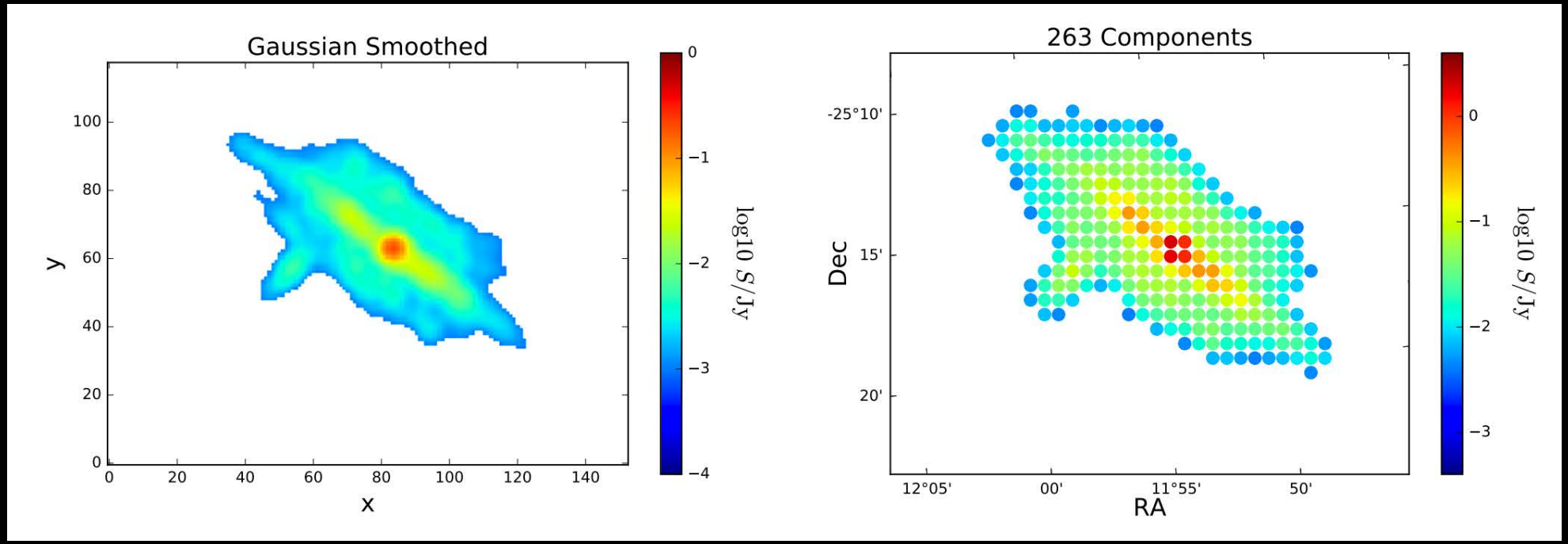

left: Gaussian smoothed deconvolution components
right: down sampled by a factor of 4 & flux normalized

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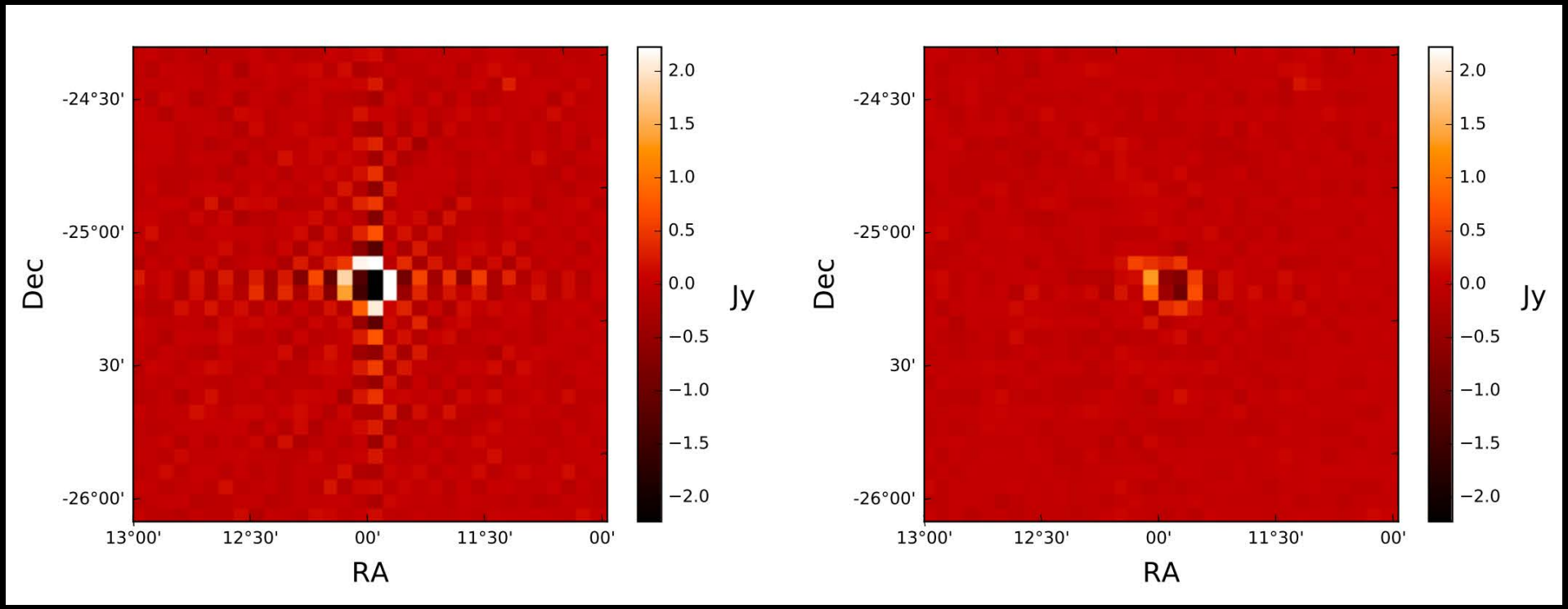
Models for Extended Sources

NGC 253 (starburst galaxy)



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