

21 cm Cosmology

Miguel F. Morales
Boulder, October 5th, 2010

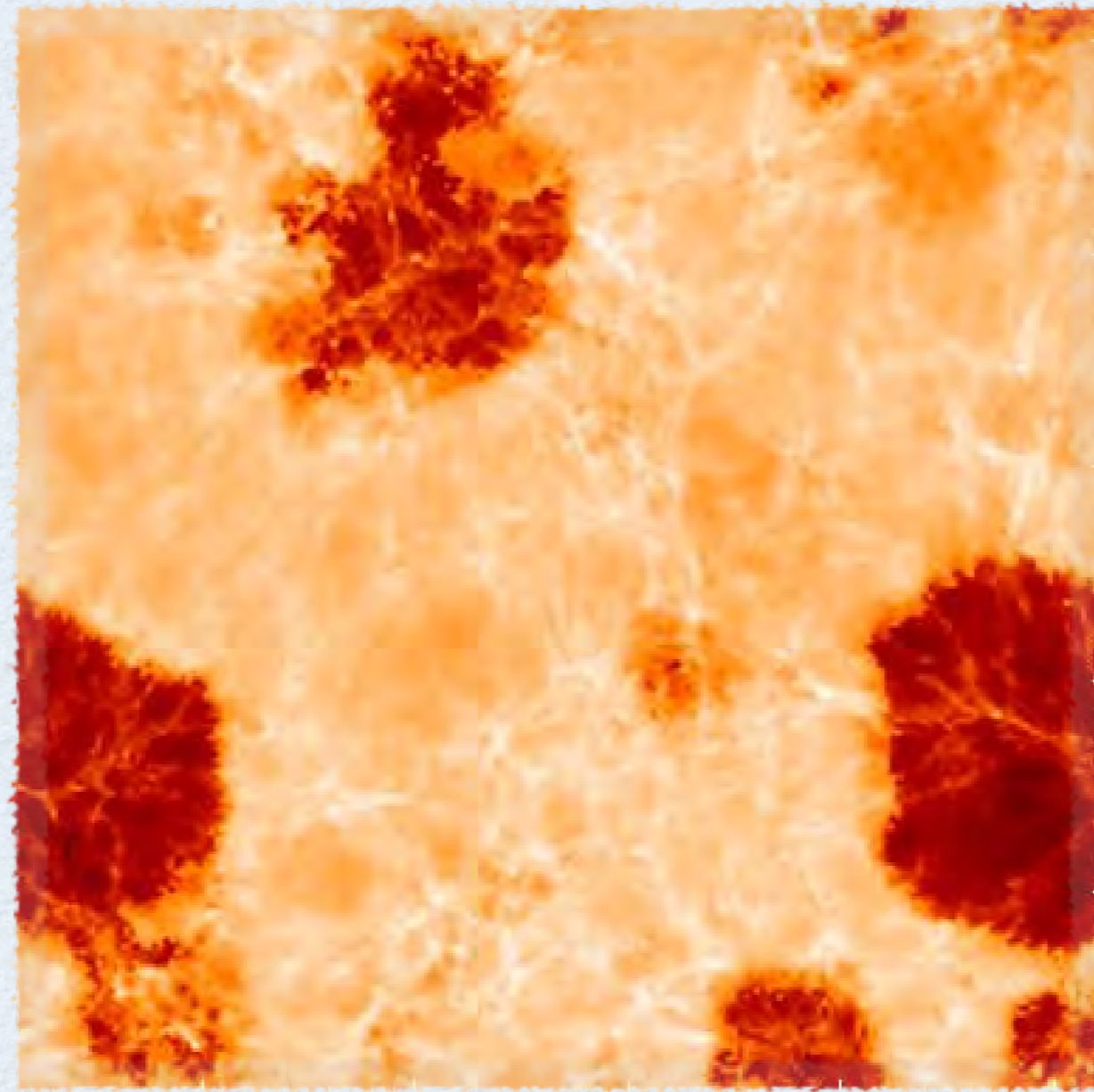
See invited ARAA review

Reionization and Cosmology with 21-cm Fluctuations

Miguel F. Morales¹ and J. Stuart B. Wyithe²

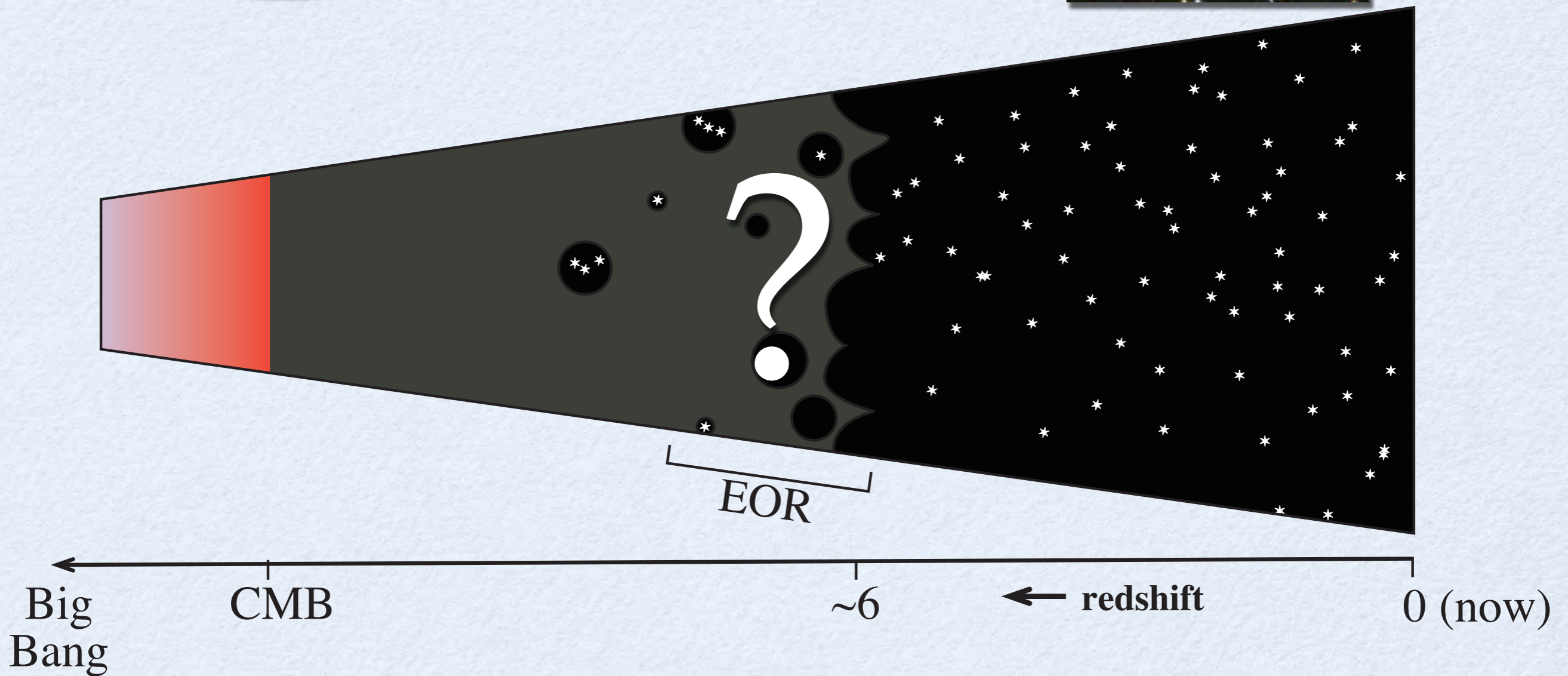
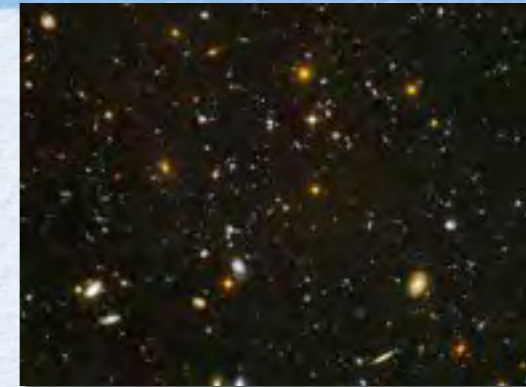
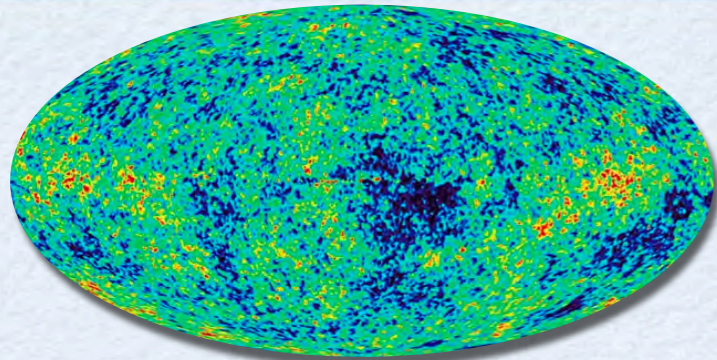
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The cosmological HI signal

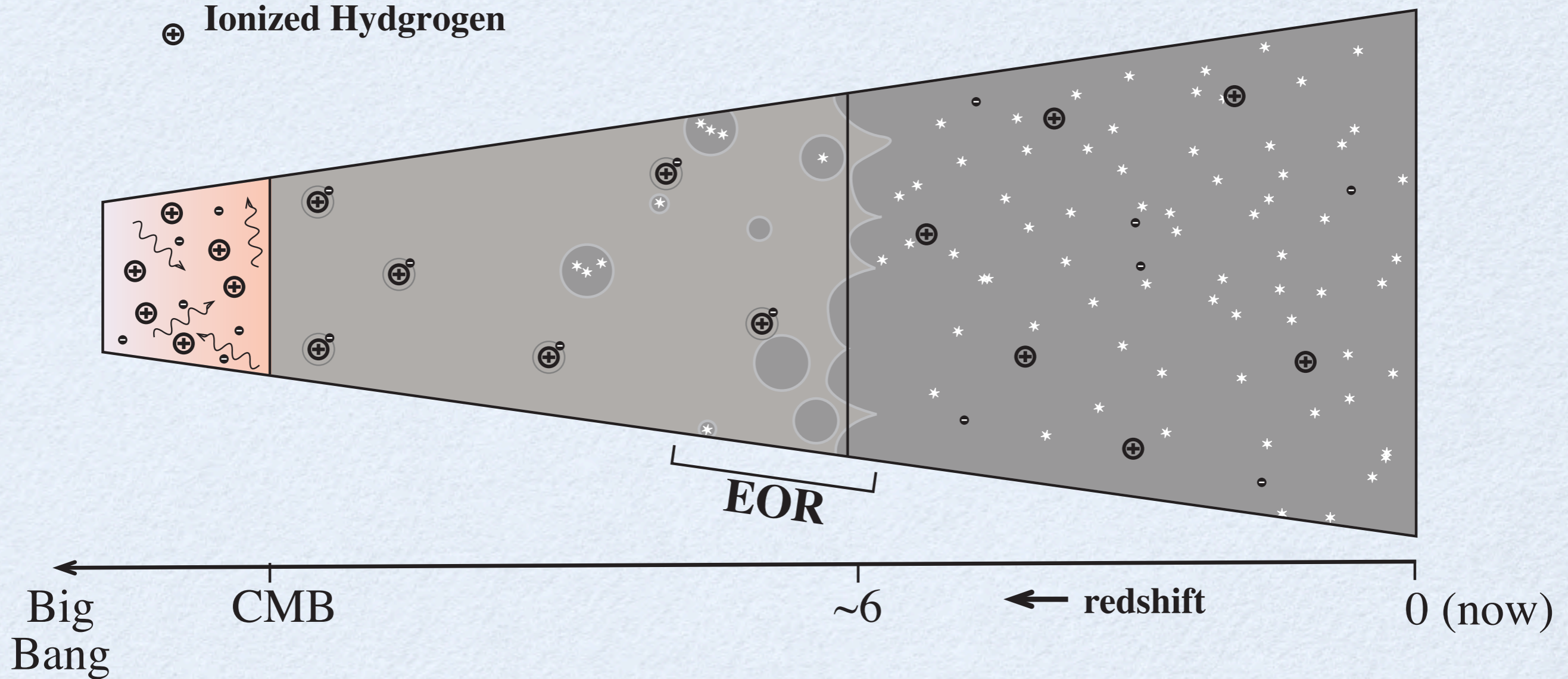
How did galaxies form?



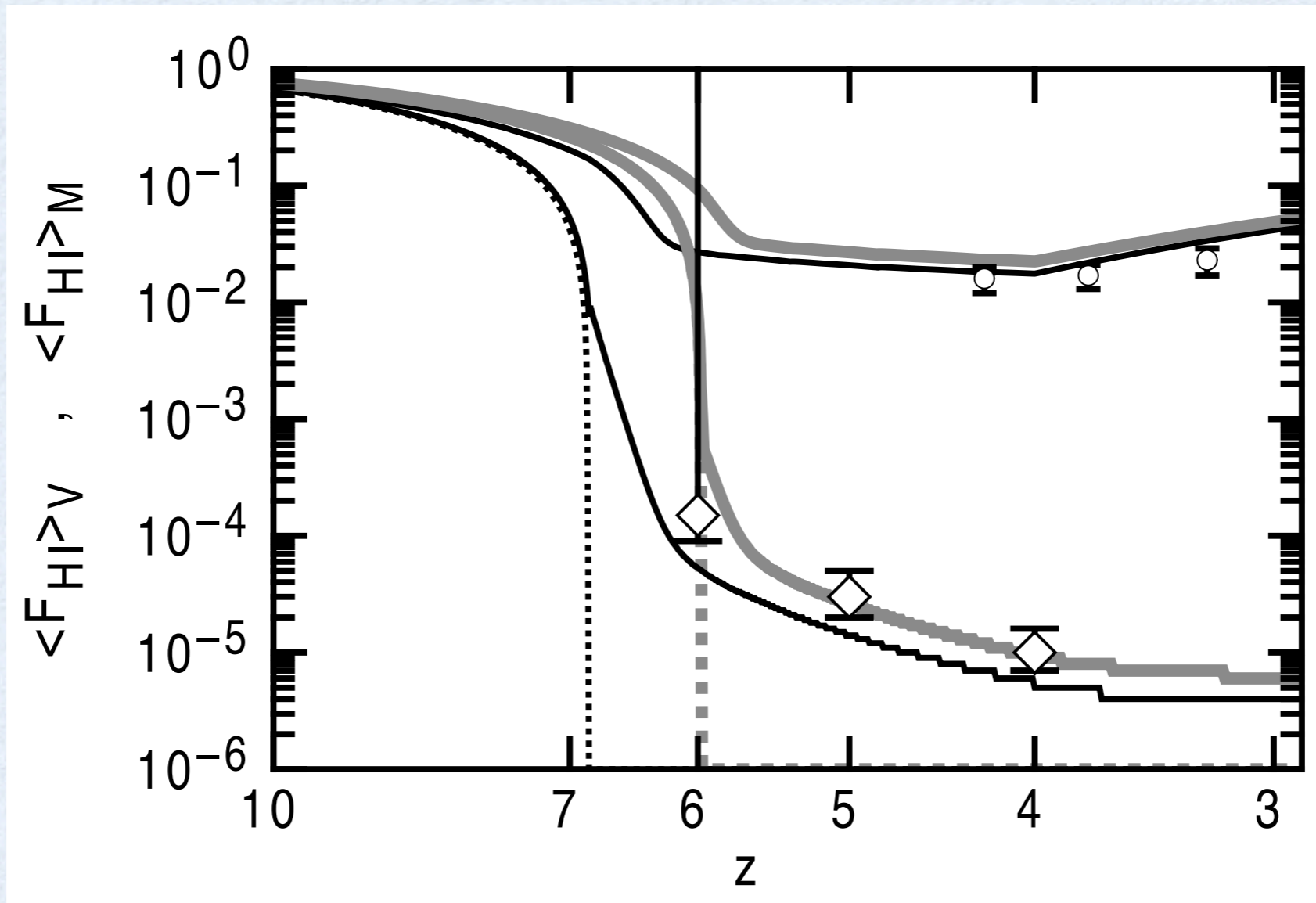
Short history of hydrogen

⊕ Neutral Hydrogen

⊕⁺ Ionized Hydrogen

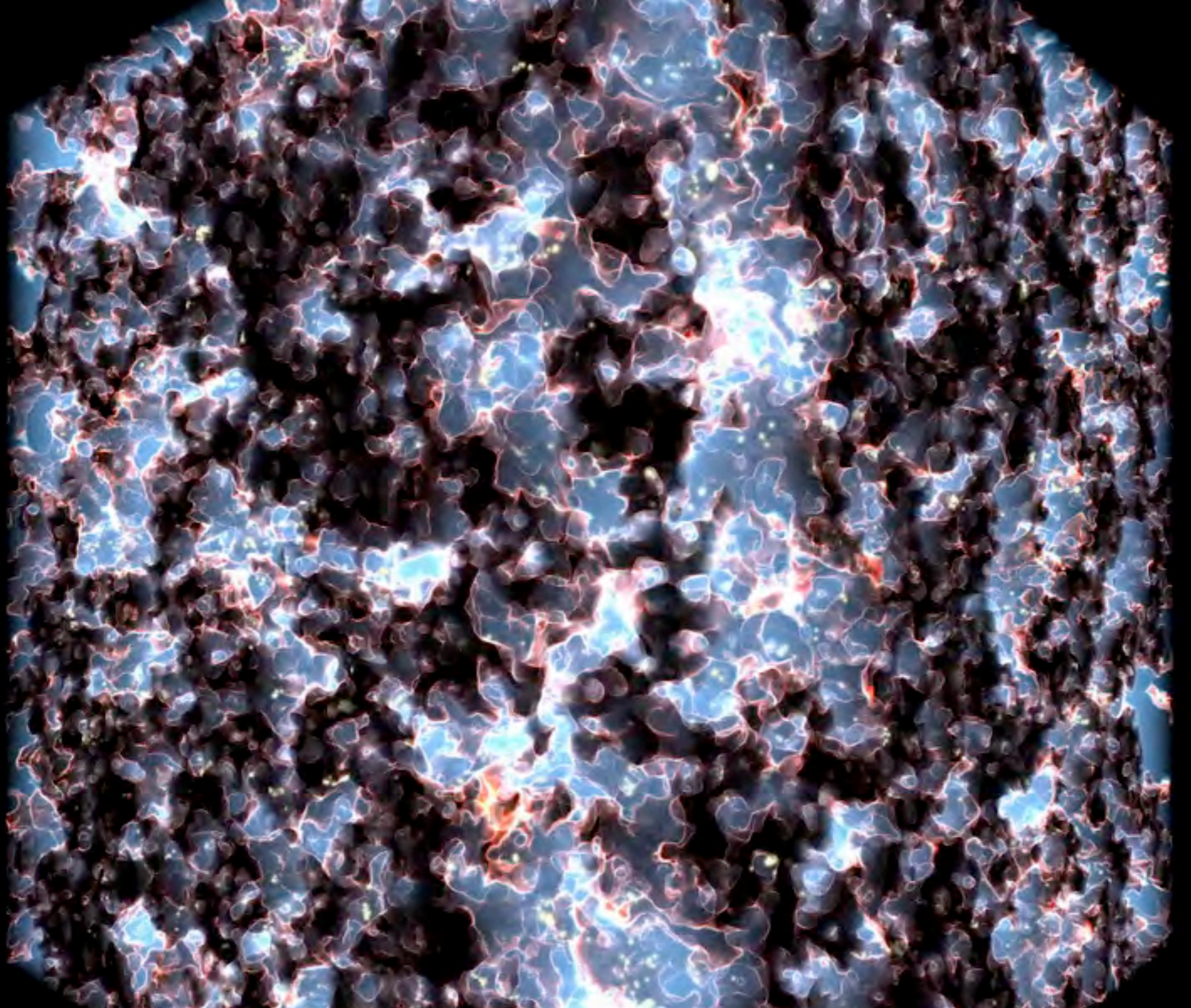


Dark energy with HI

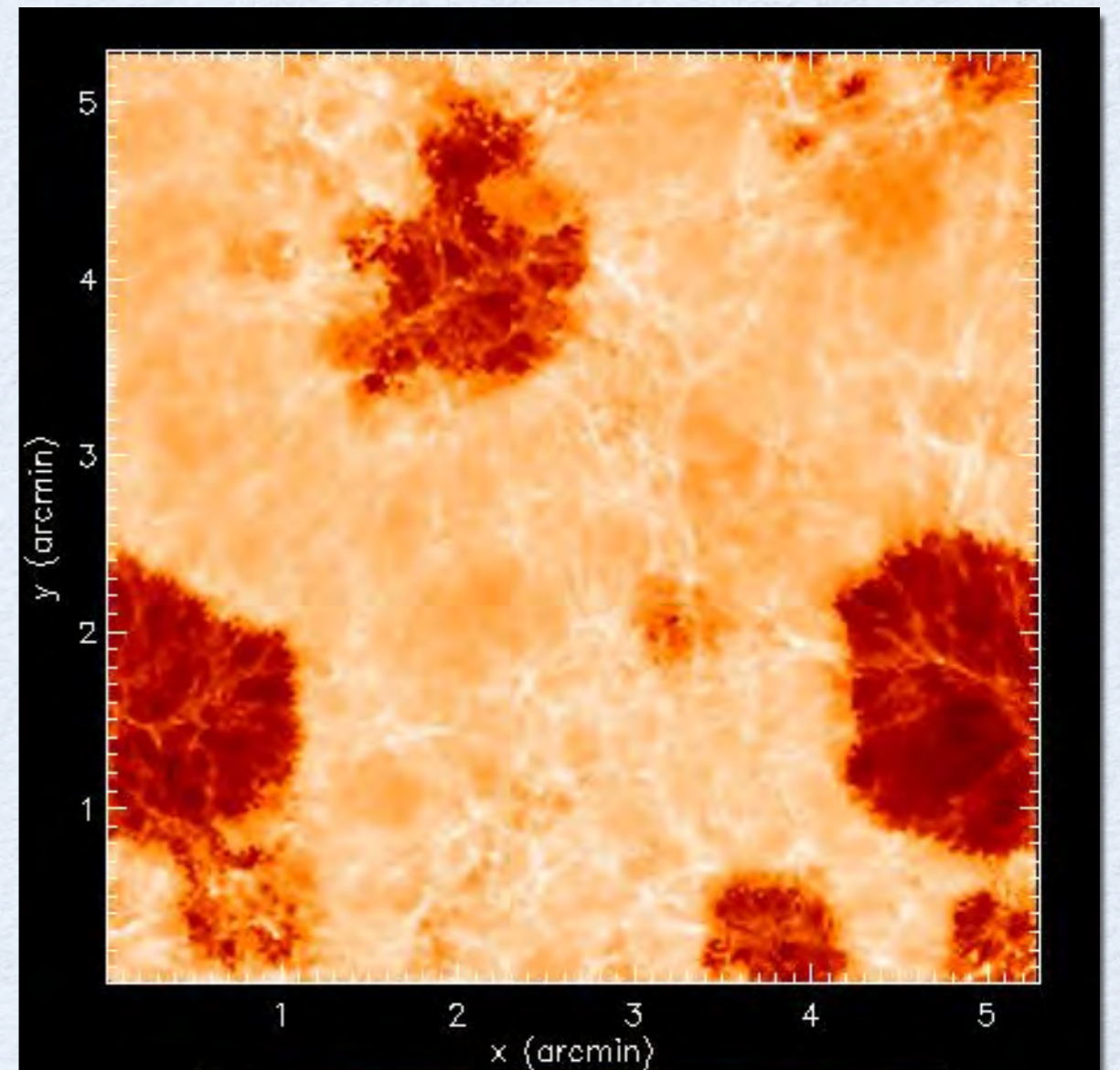
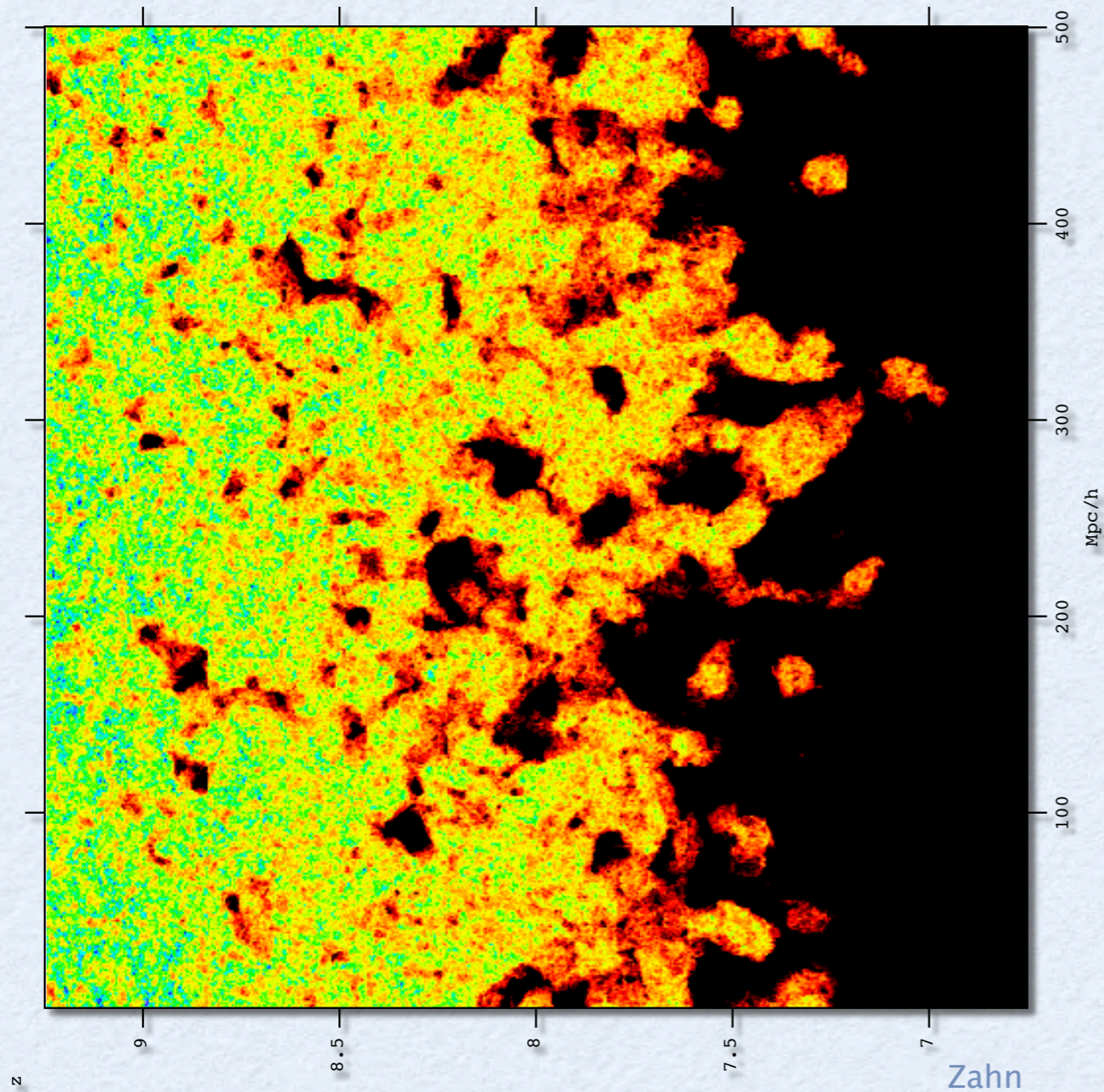


Wyithe & Loeb (2007)

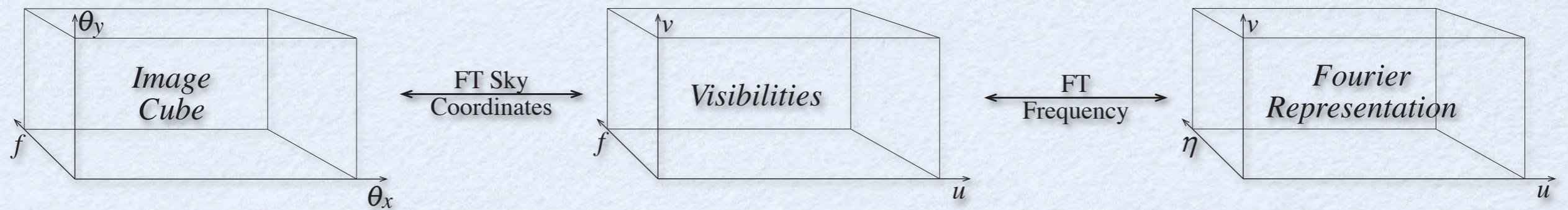
- $\langle F_{\text{HI}} \rangle_V$ related to Lyman- α absorption, $\sim 10^{-4}$
- $\langle F_{\text{HI}} \rangle_M$ related to HI emission, $\sim 10^{-2}$



HI during EoR

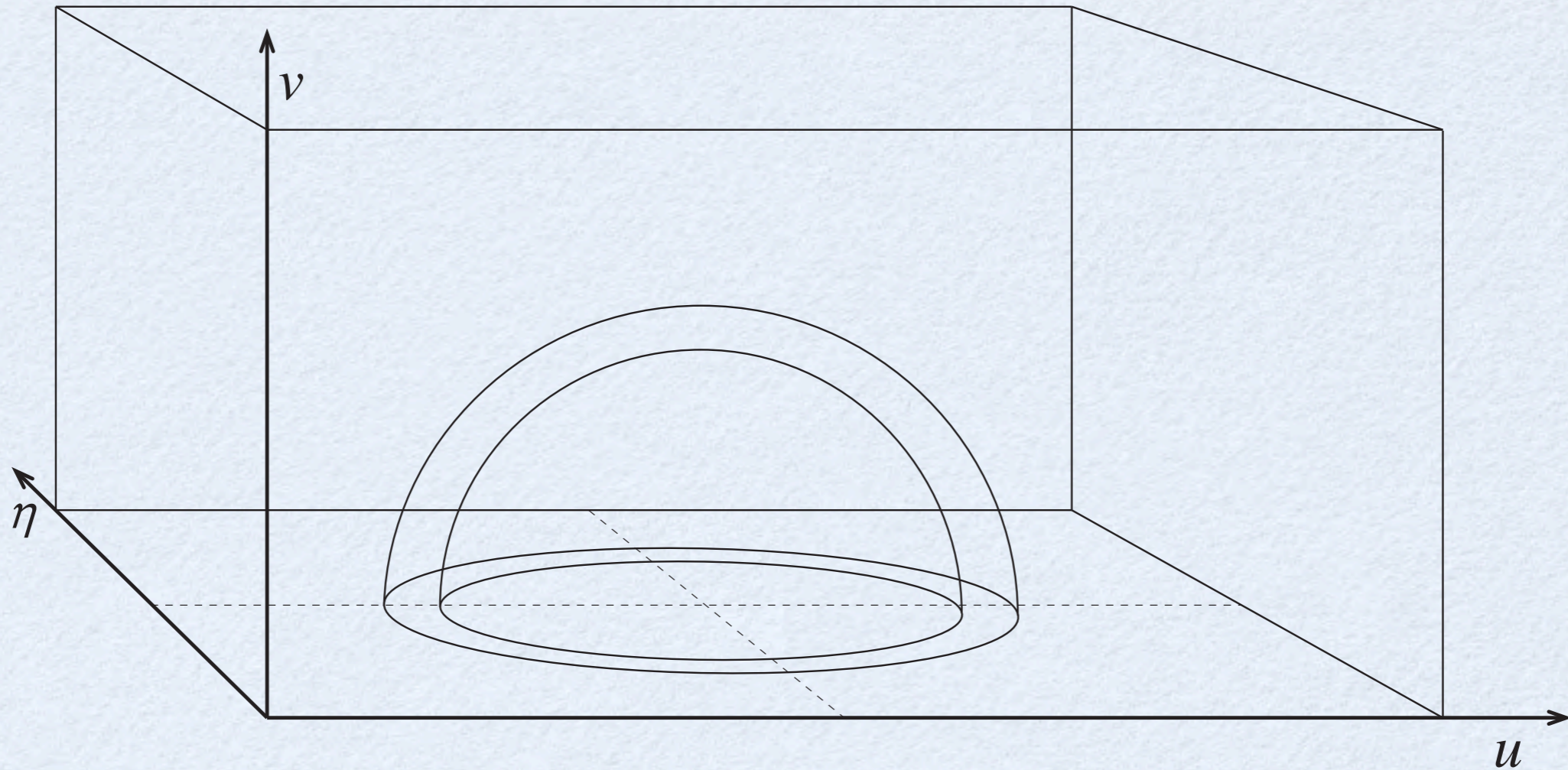


Statistical EoR detection



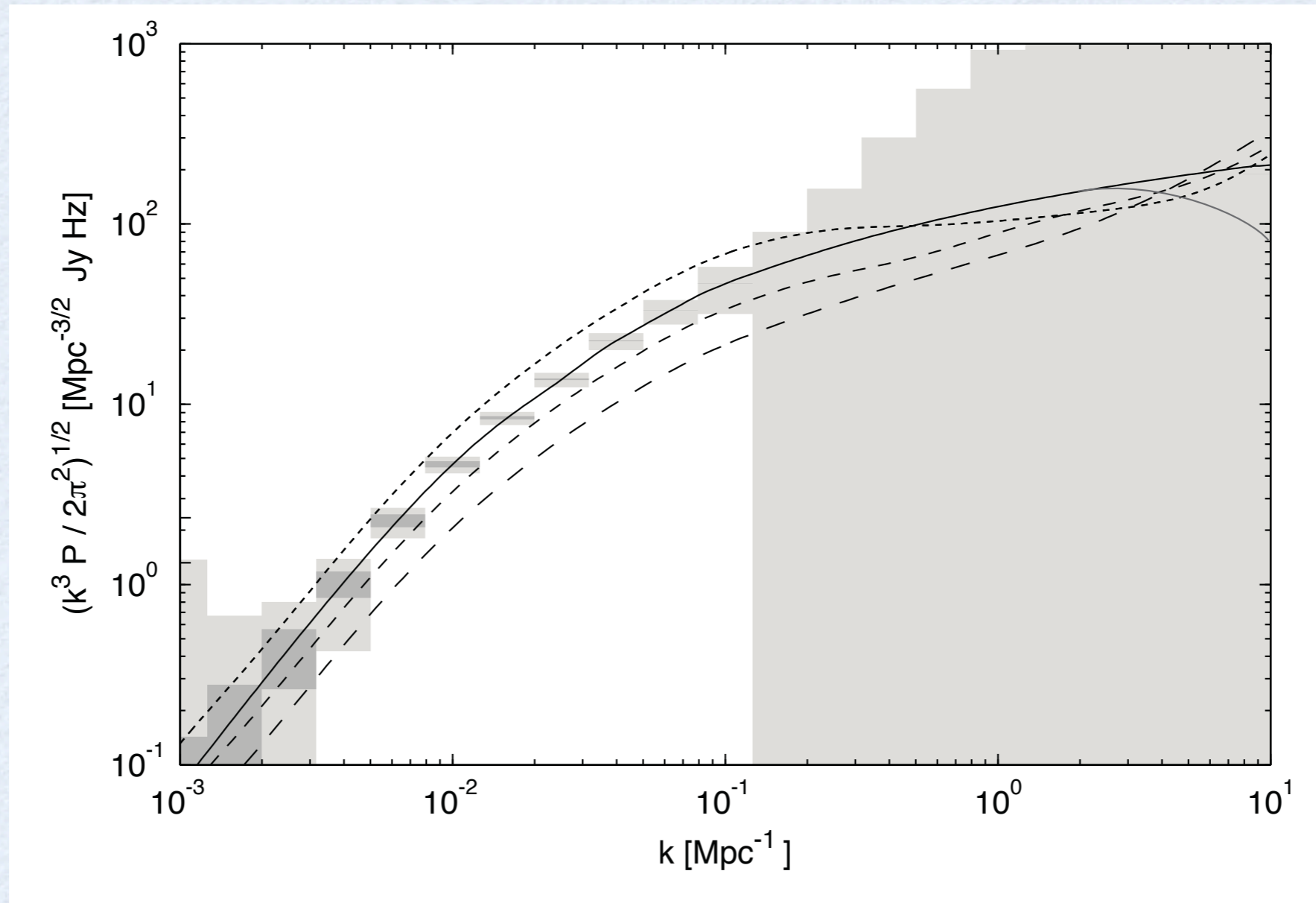
Morales & Hewitt (2004)

Spherical symmetry



Morales & Hewitt (2004)

EoR power spectrum



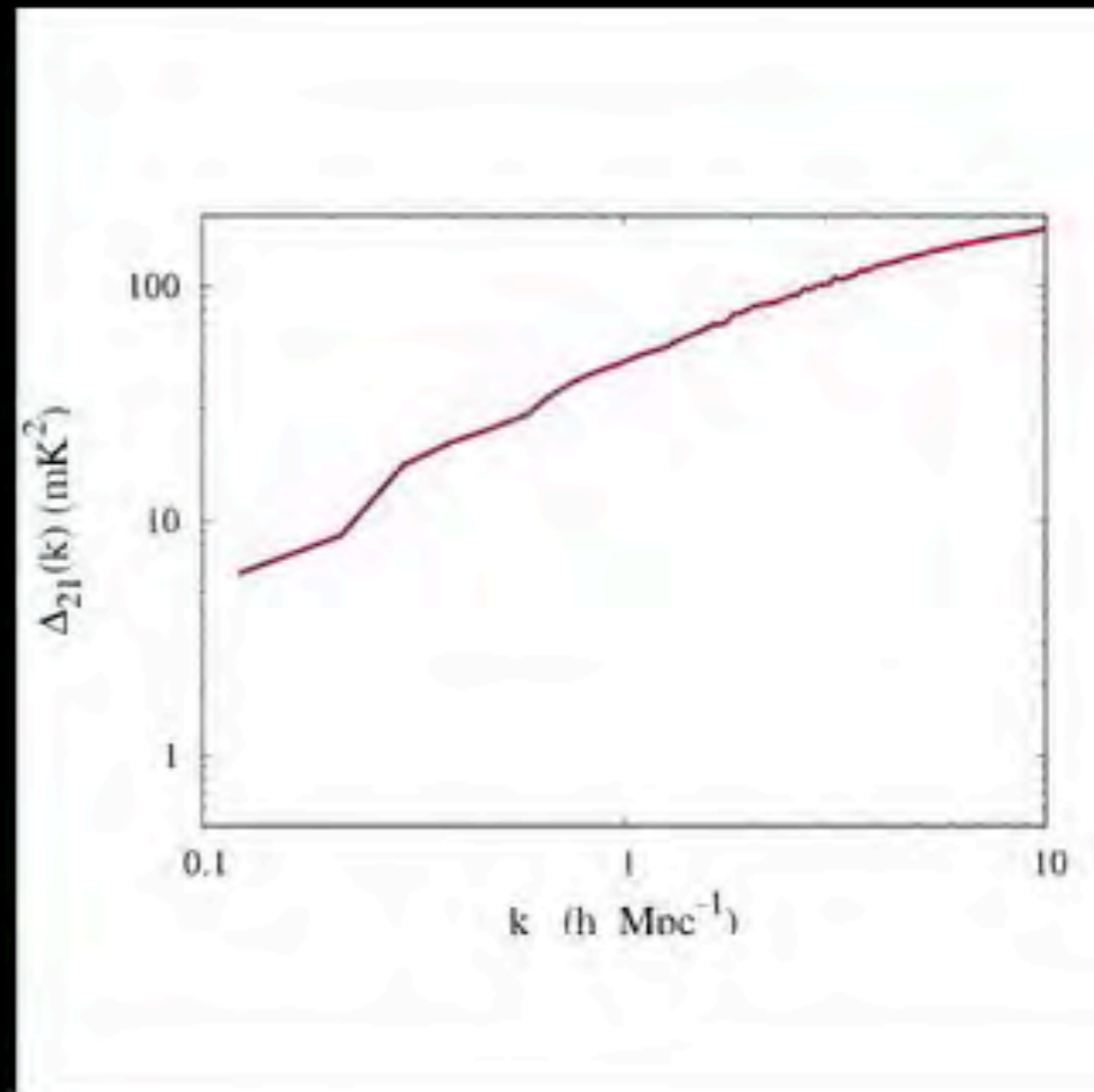
$z = 8$, 360 hours of integration

Furlanetto, Zaldarriaga, Hernquist (2004a,b)
Bowman, Morales & Hewitt (2005)

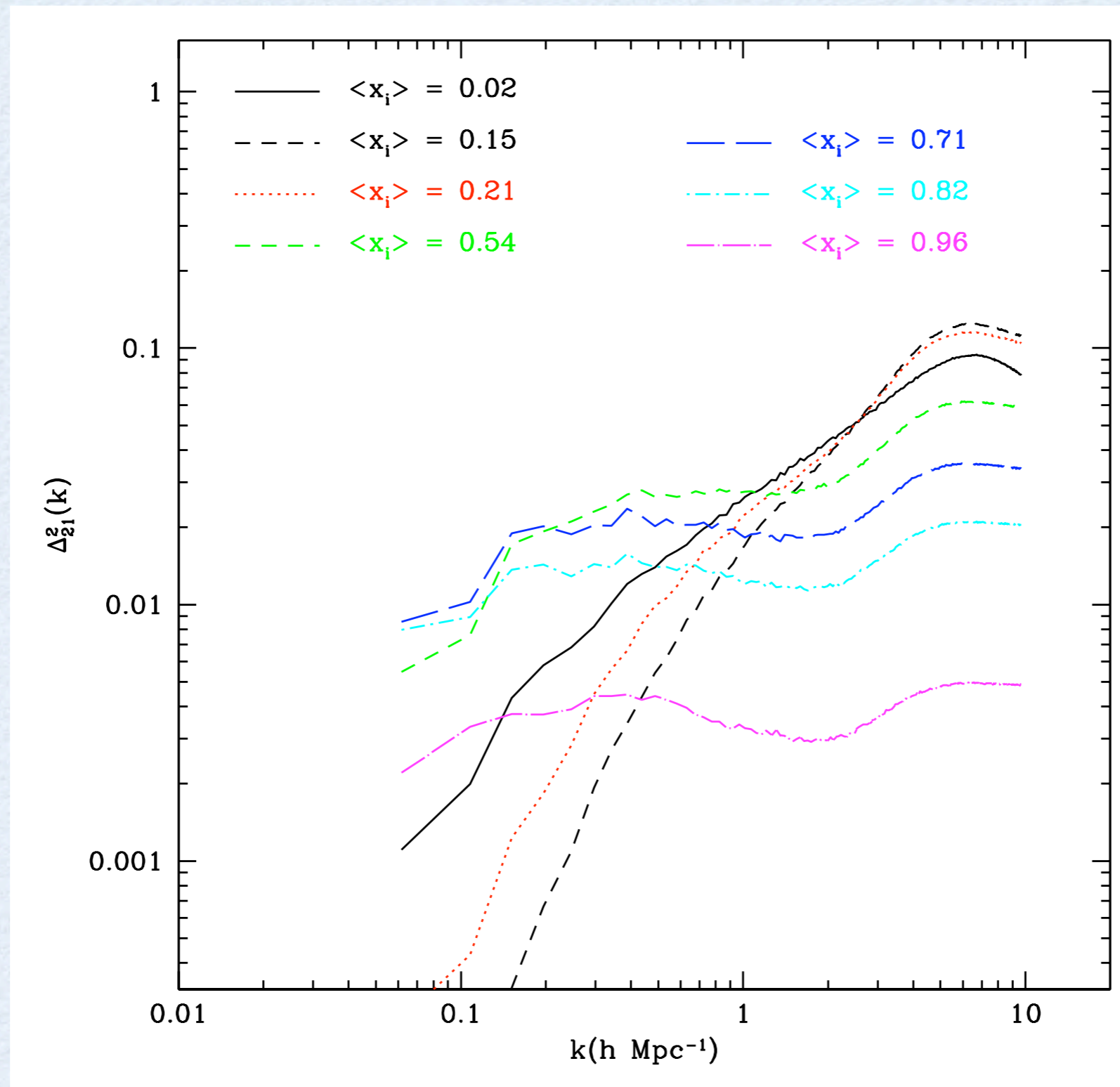
Kaplinghat (2005)

Power spectrum dynamics

$z=11.1$



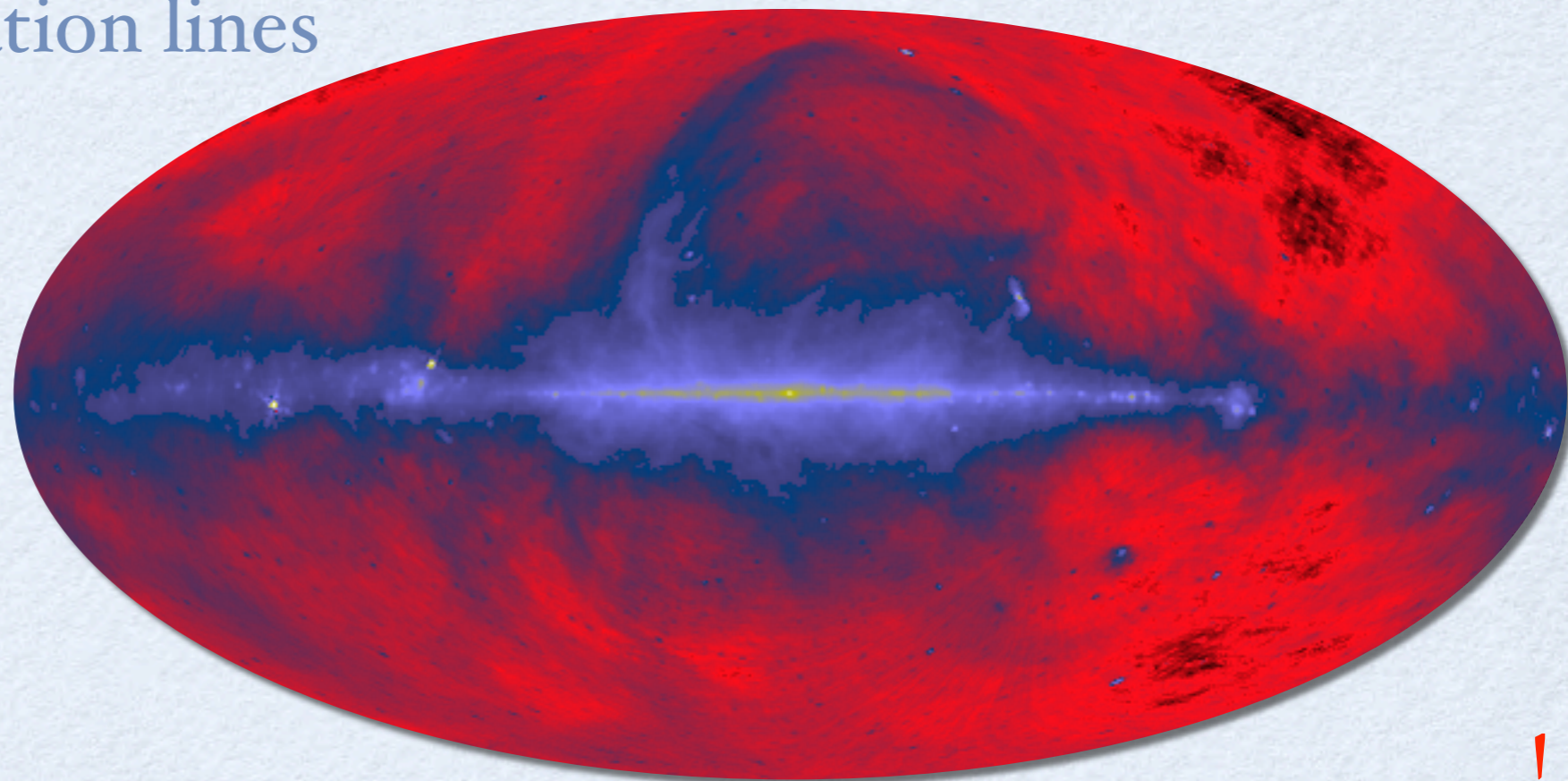
HI power spectra evolution



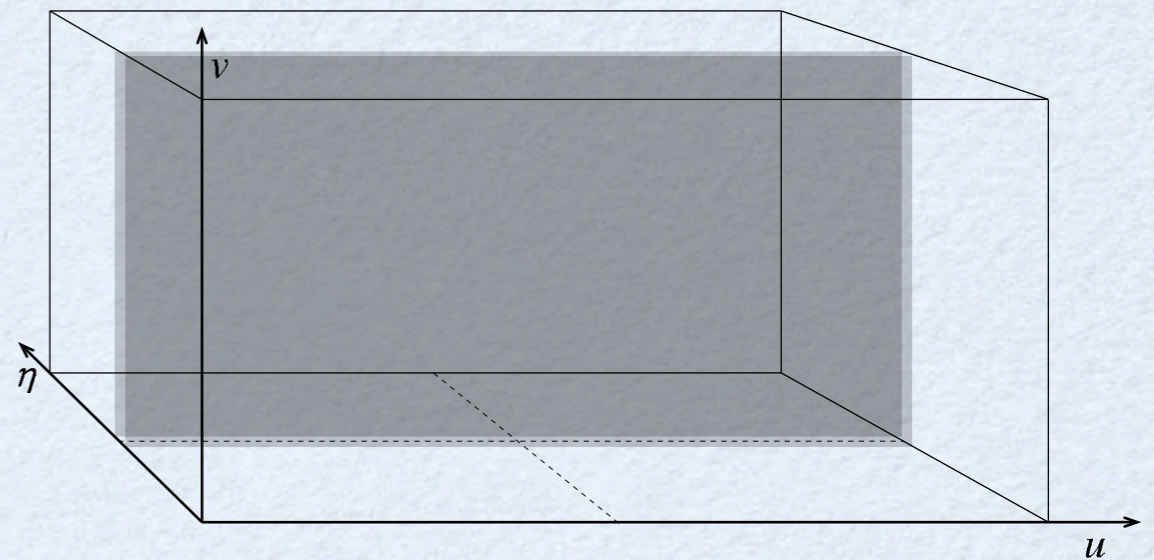
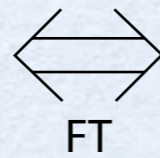
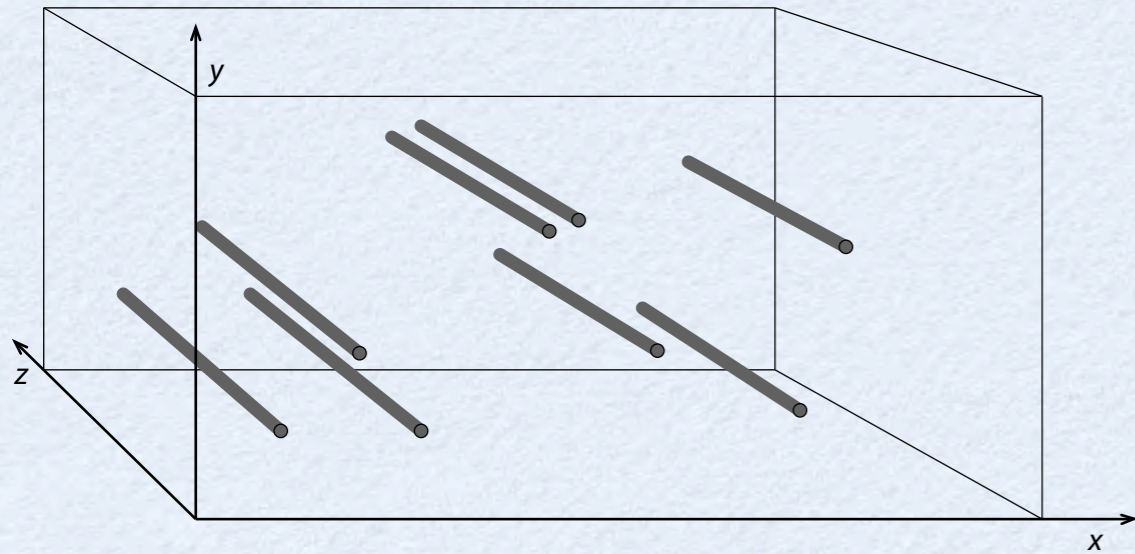
Lidz

Why is this hard? Foregrounds

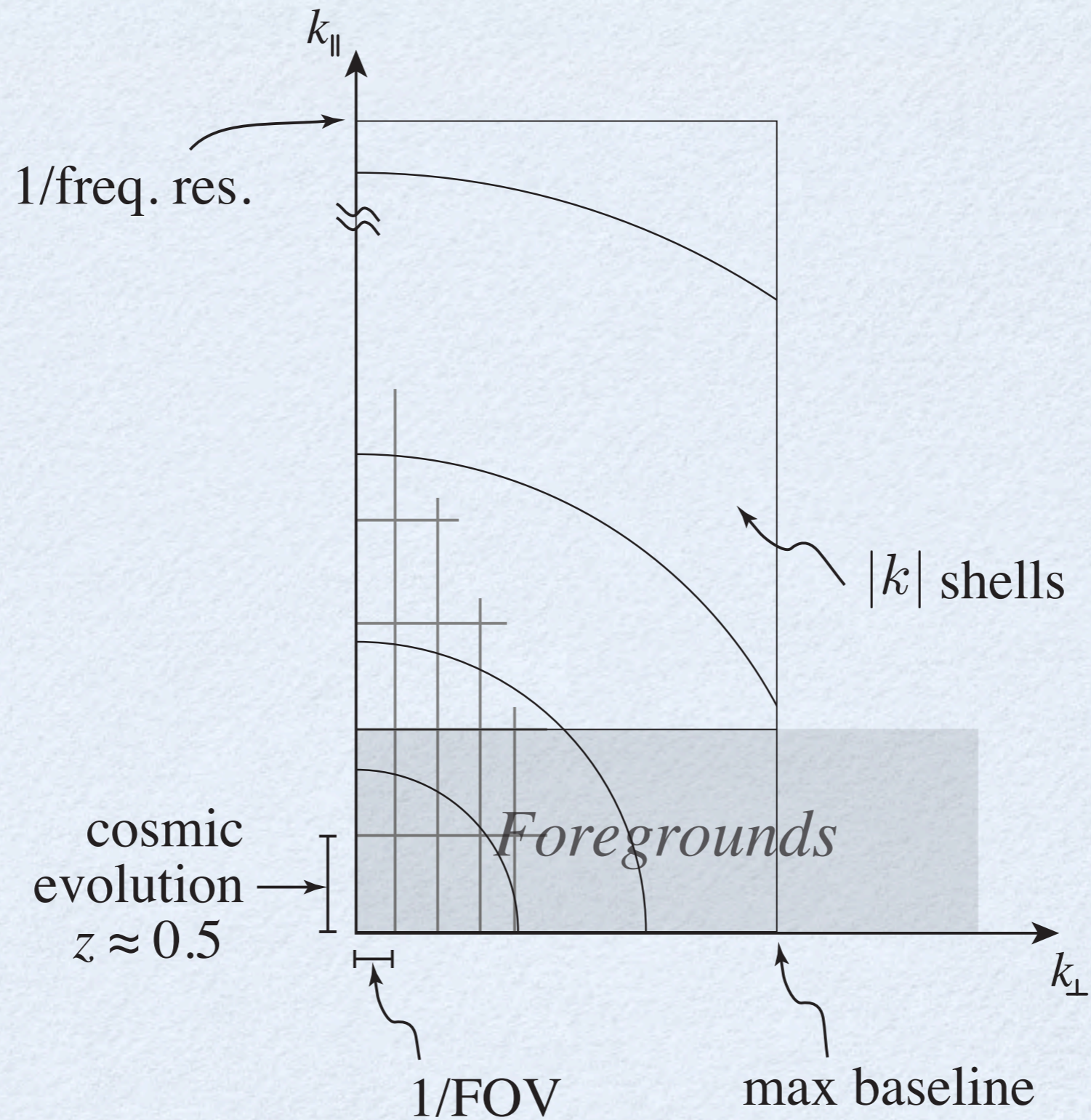
- Galactic emission (polarized and Faraday rotated)
- Bright point sources
- Faint point sources
- Instrumental contamination
- Radio recombination lines
- RFI
- Mode mixing
- ...



Foreground symmetry



k -space measurement

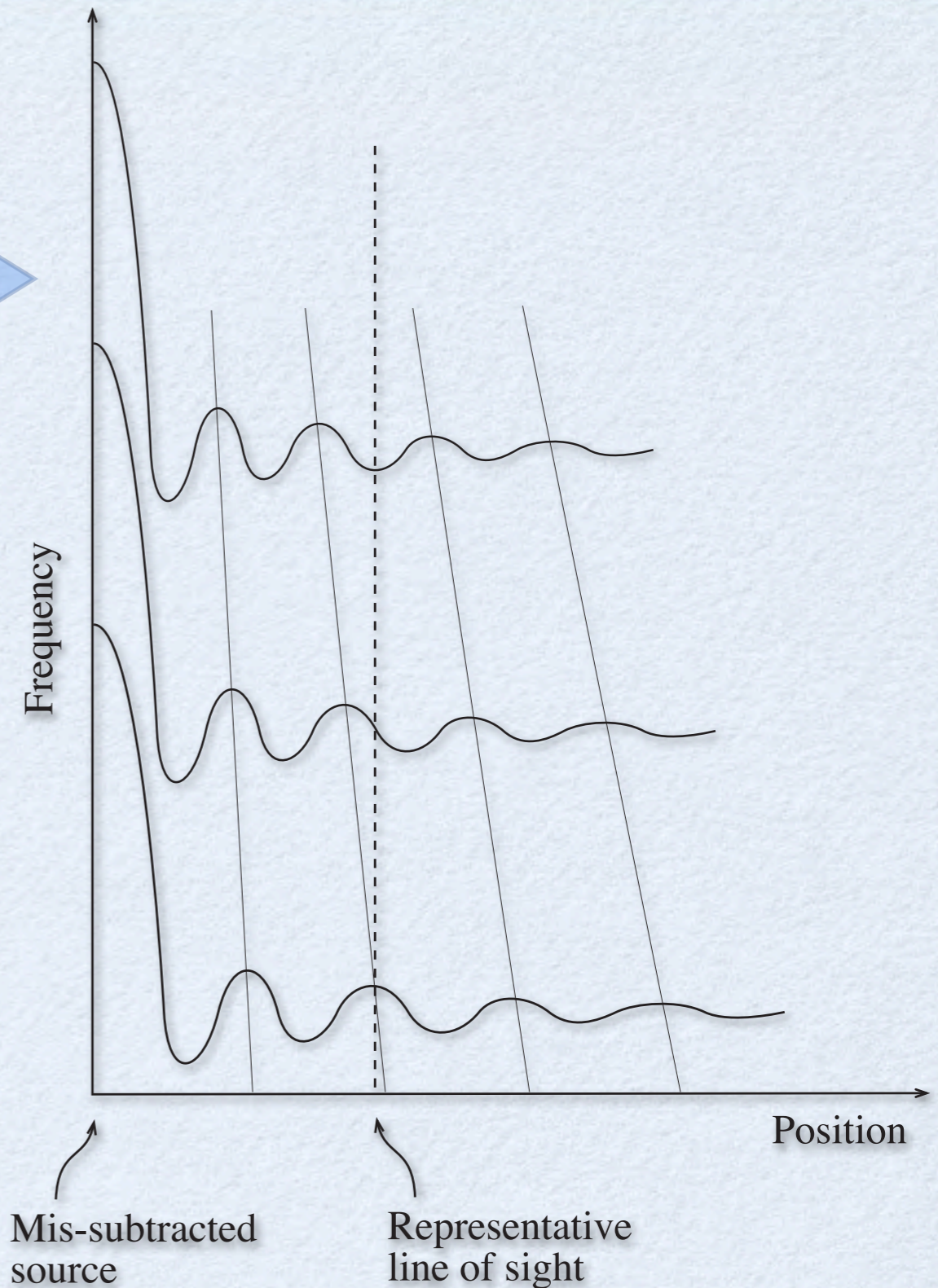


Mode mixing

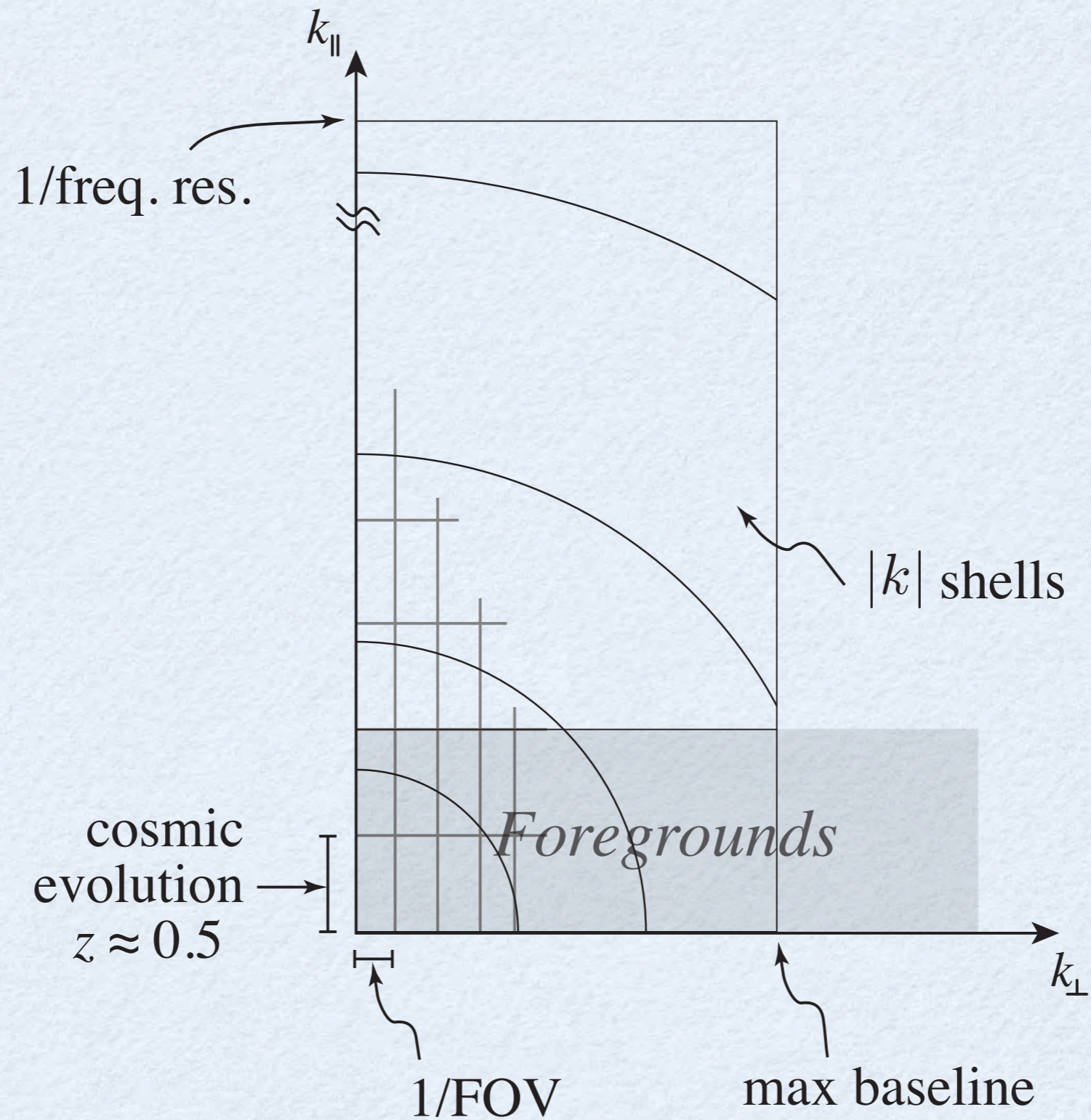
- Frontier of foreground subtraction is interactions between calibration and foregrounds
- Need measurement fidelity of 10^{-4} – 10^{-6}
- Effectively a product of the calibration errors and foreground uncertainty

Examples

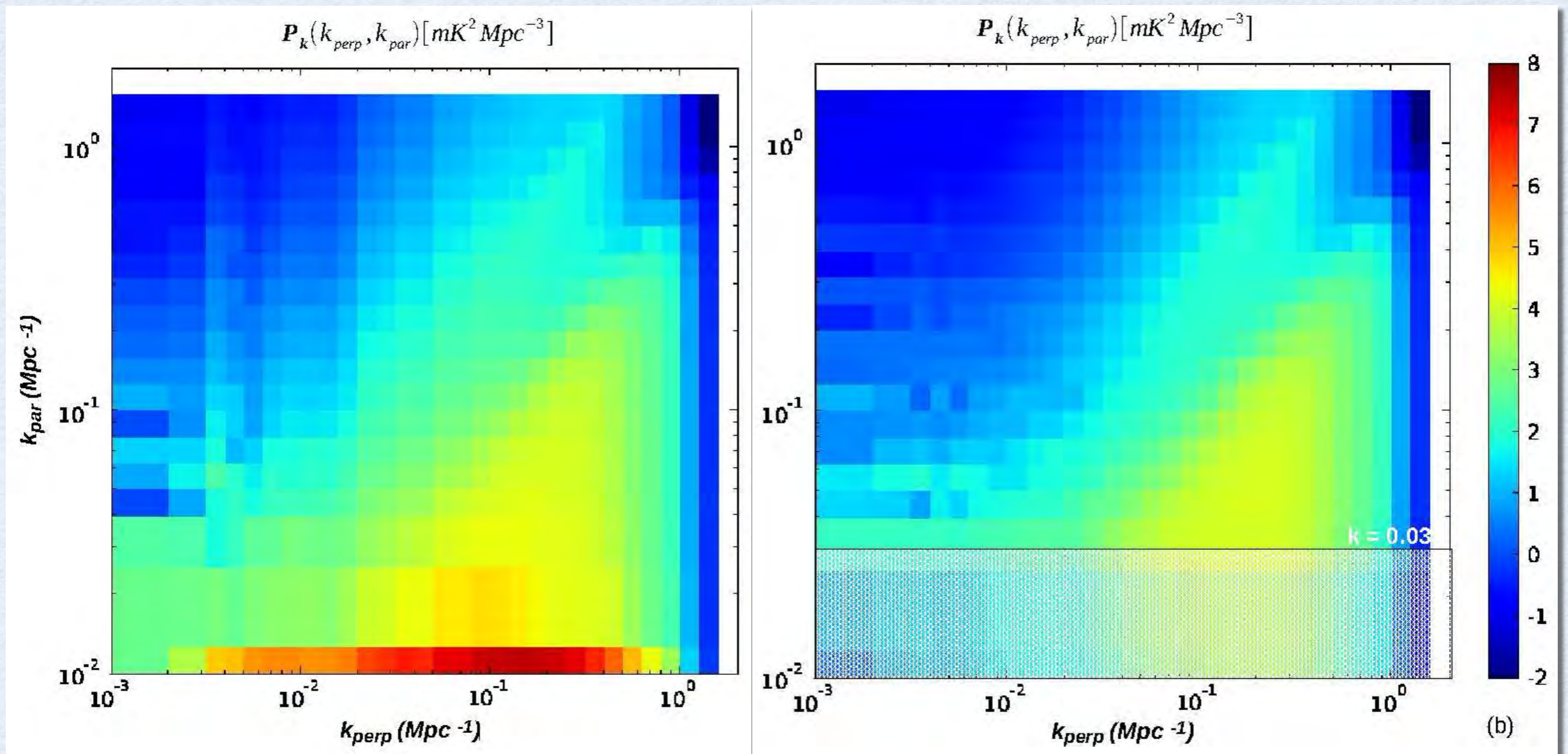
- Chromatic array beam (PSF) & residual source flux, residual frequency ripple
- Polarized foreground & polarization mis-calibration, flux leakage from Q & U \rightarrow I
- Antenna beam dependence & point sources, decorrelation of visibilities at different frequencies



k -space measurement

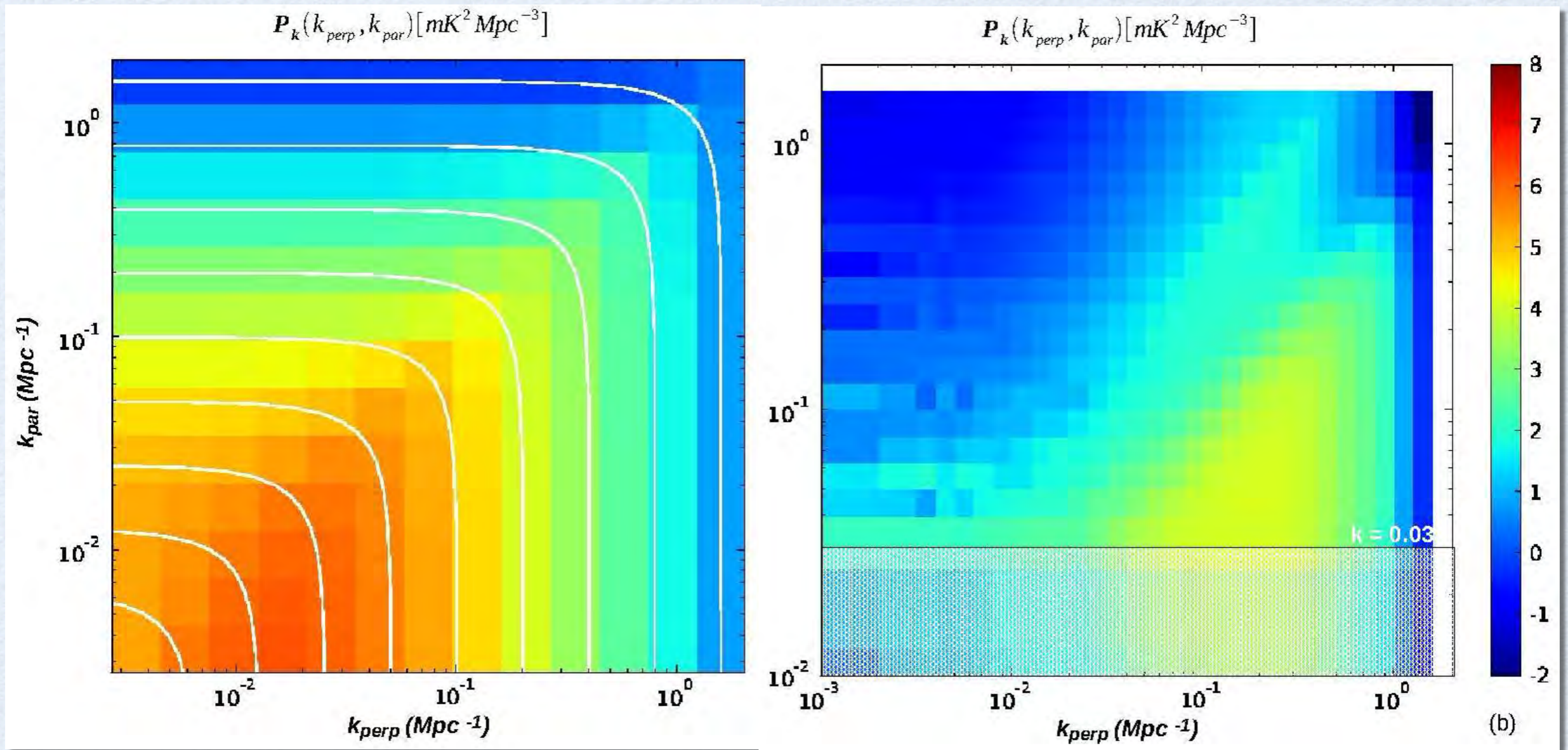


Bright source location error



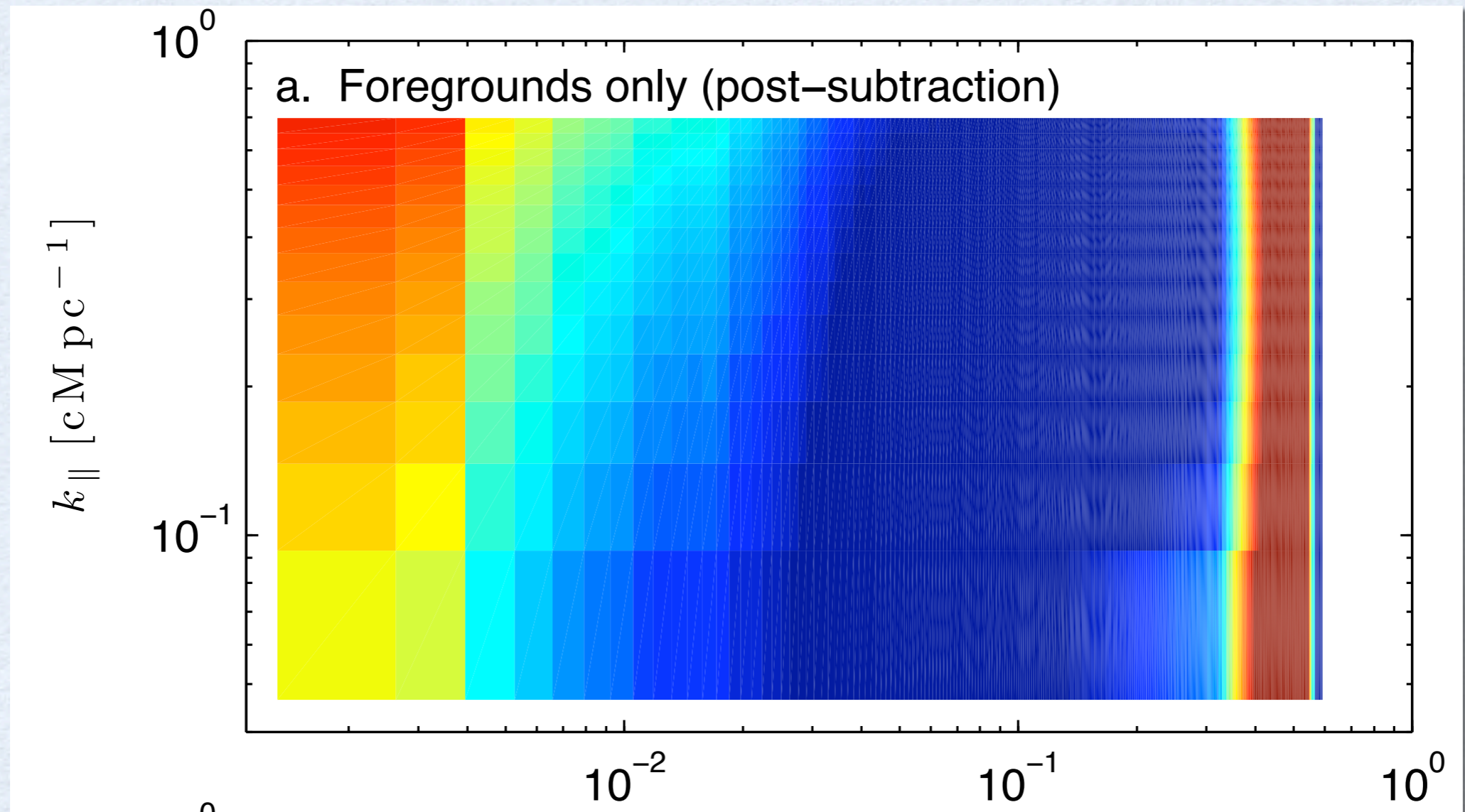
Datta et al. (2010)

Foreground subtraction



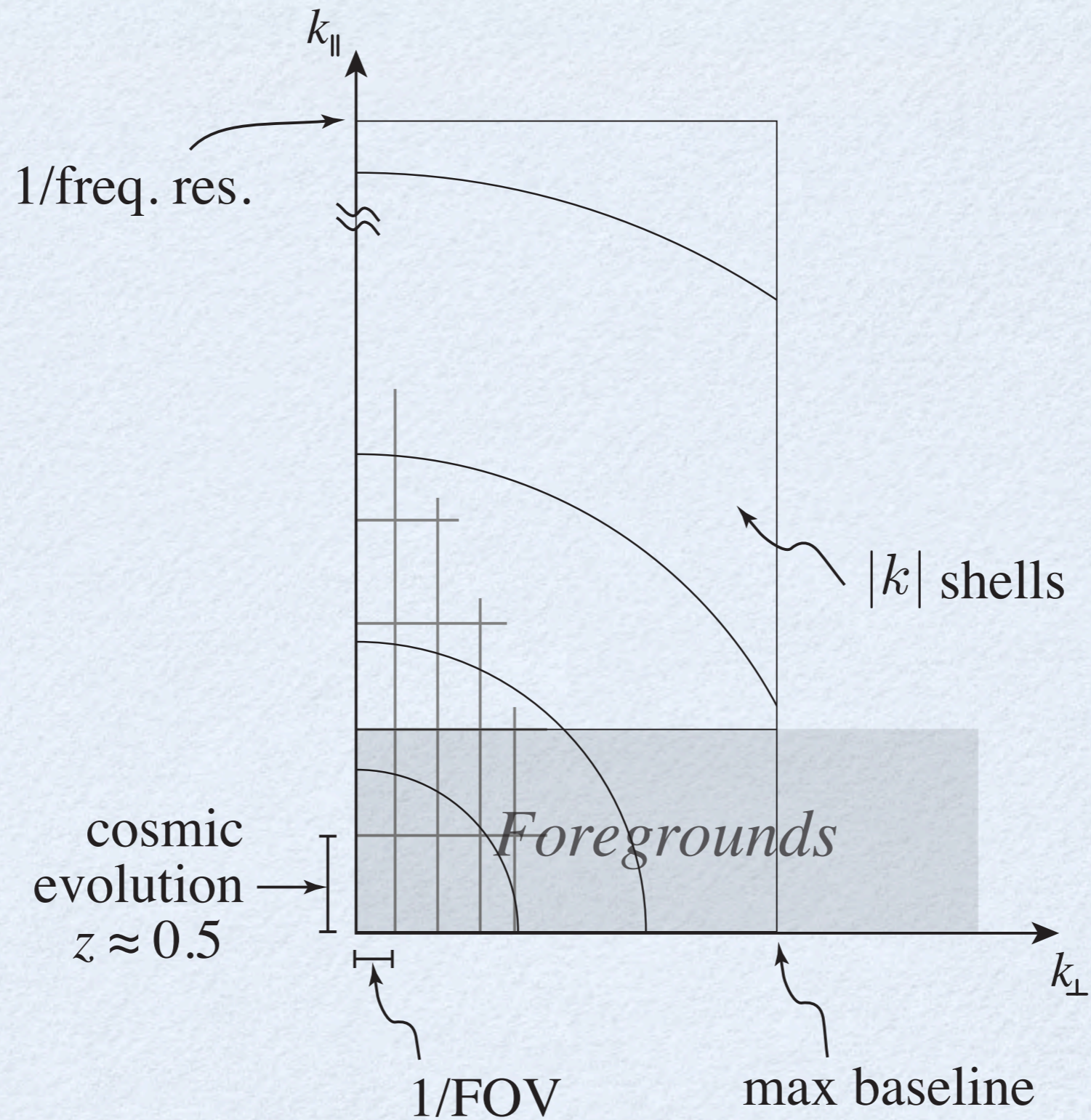
Datta et al. (2010)

Confusion level sources

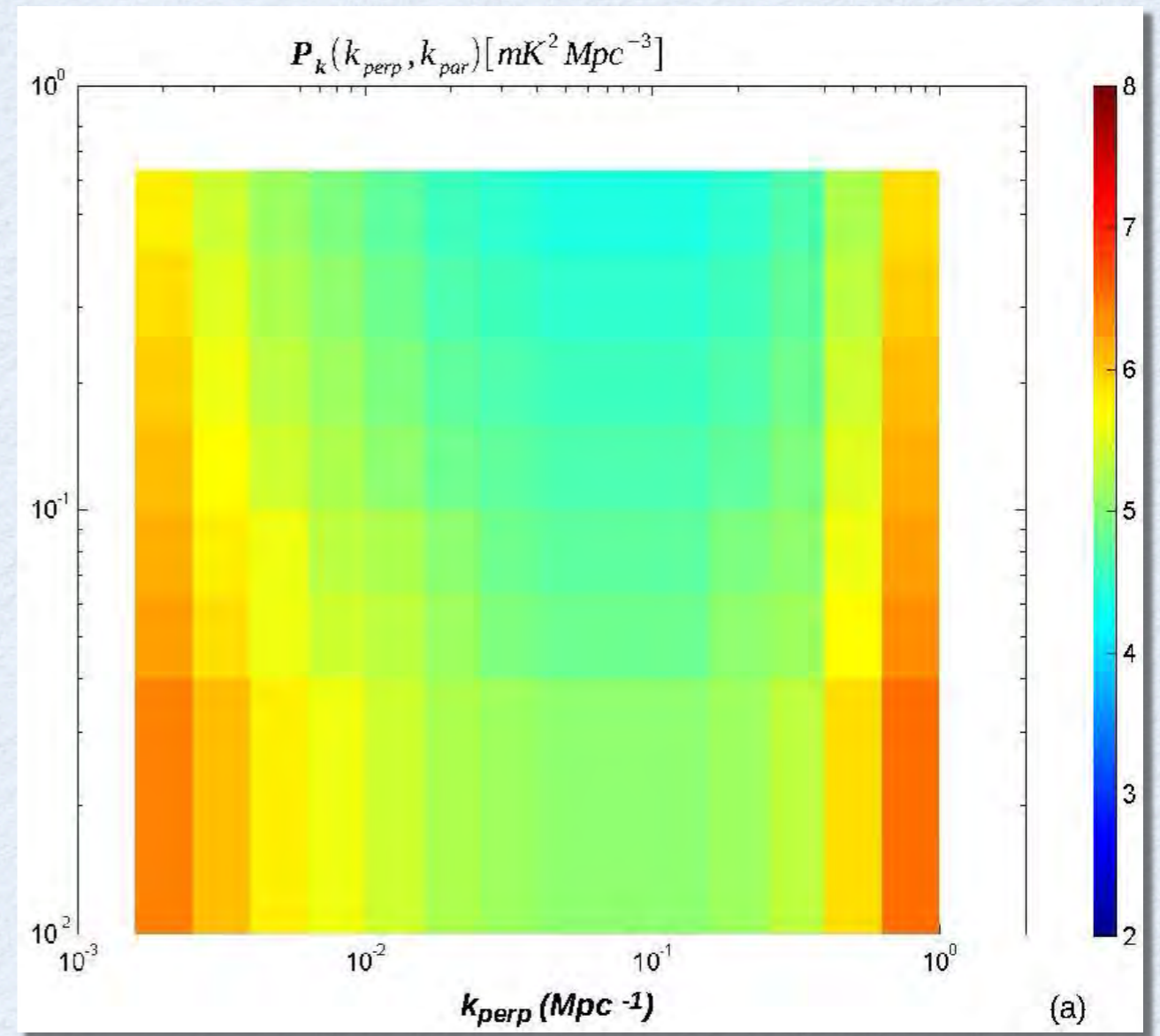
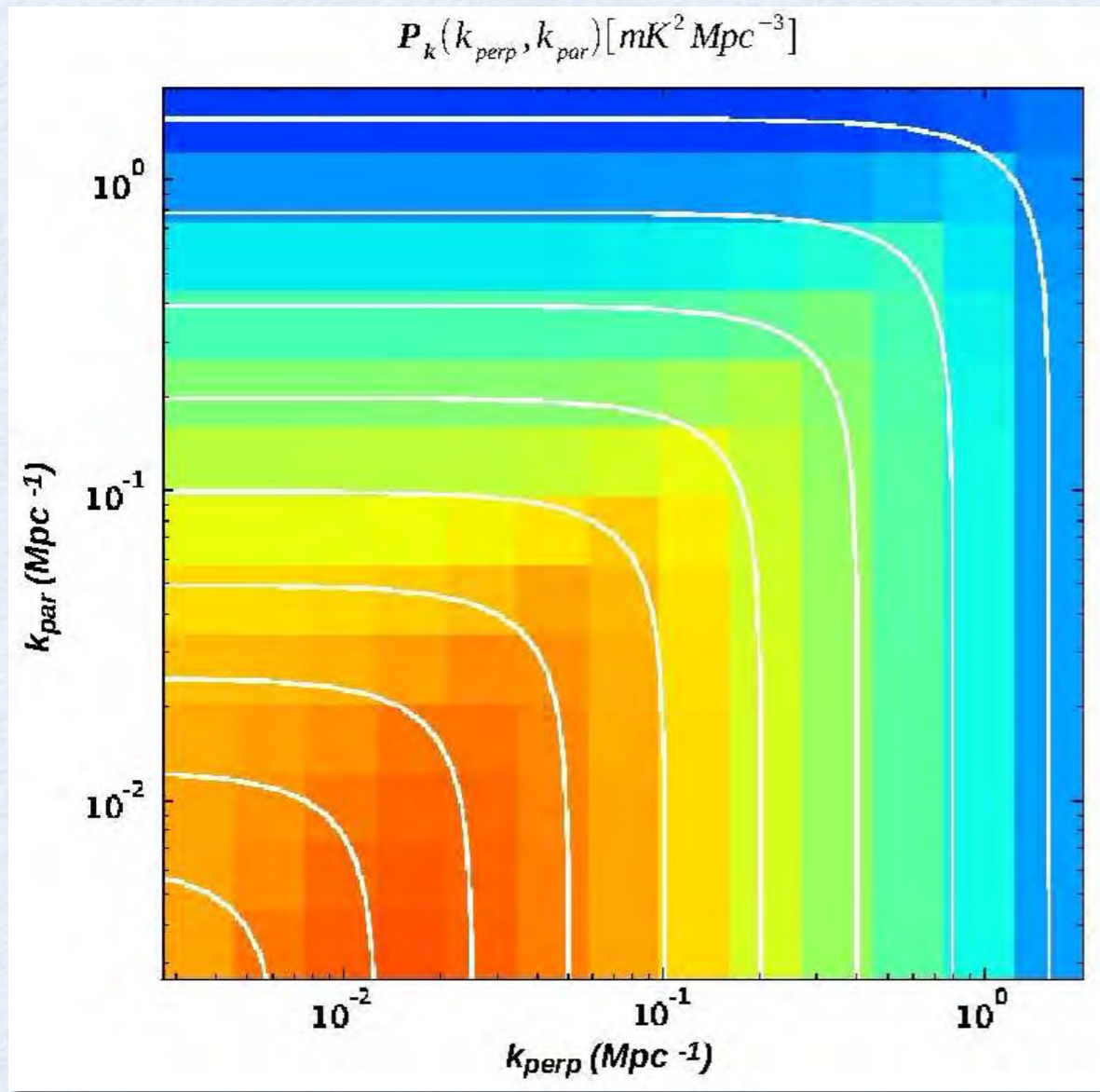


Bowman et al. (2008)

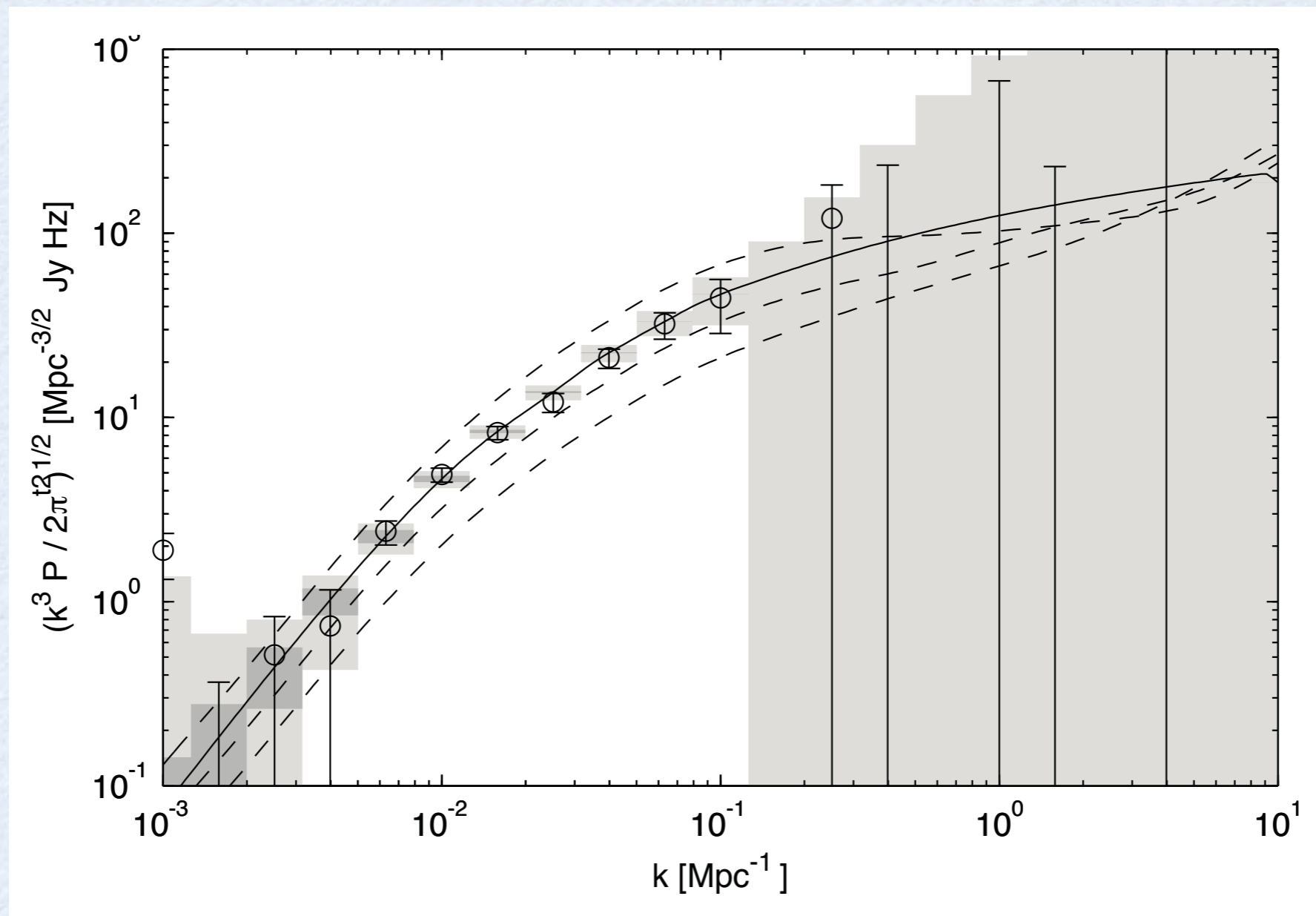
k -space measurement



MWA sensitivity



MWA power spectrum sensitivity

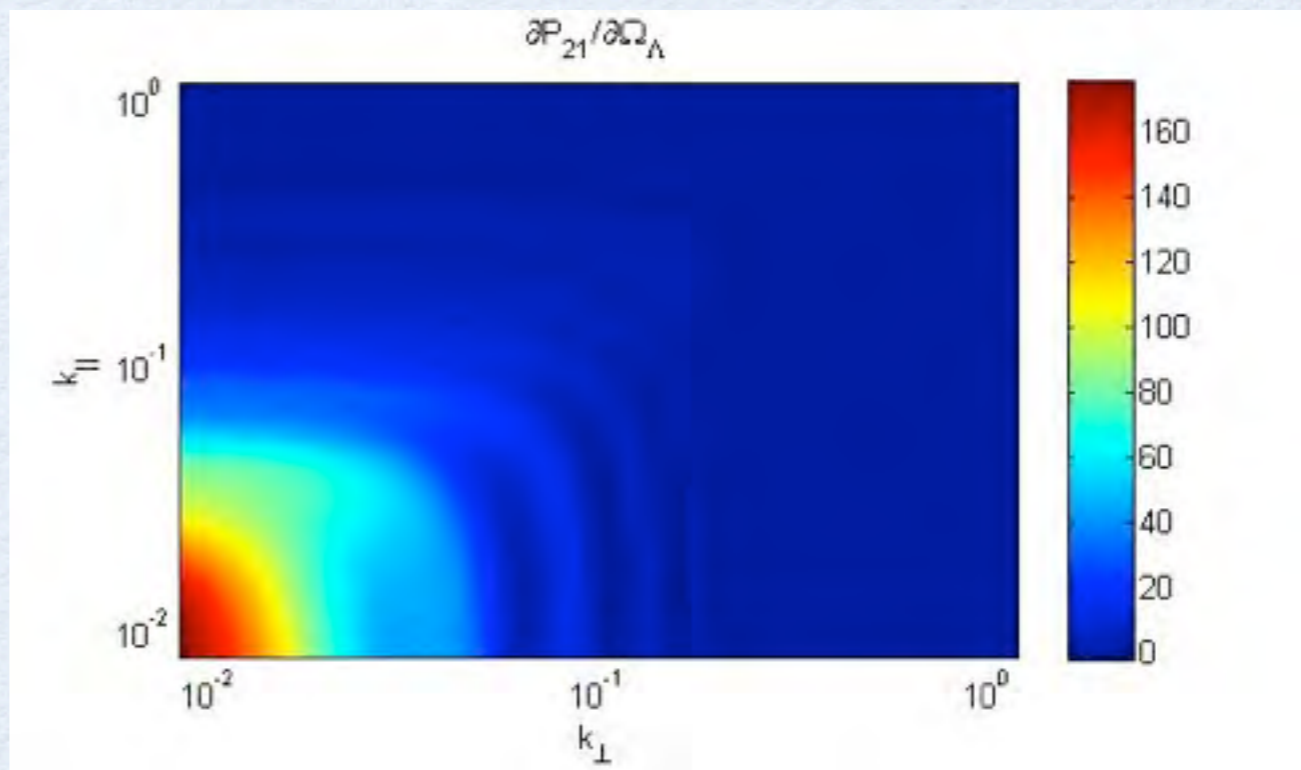
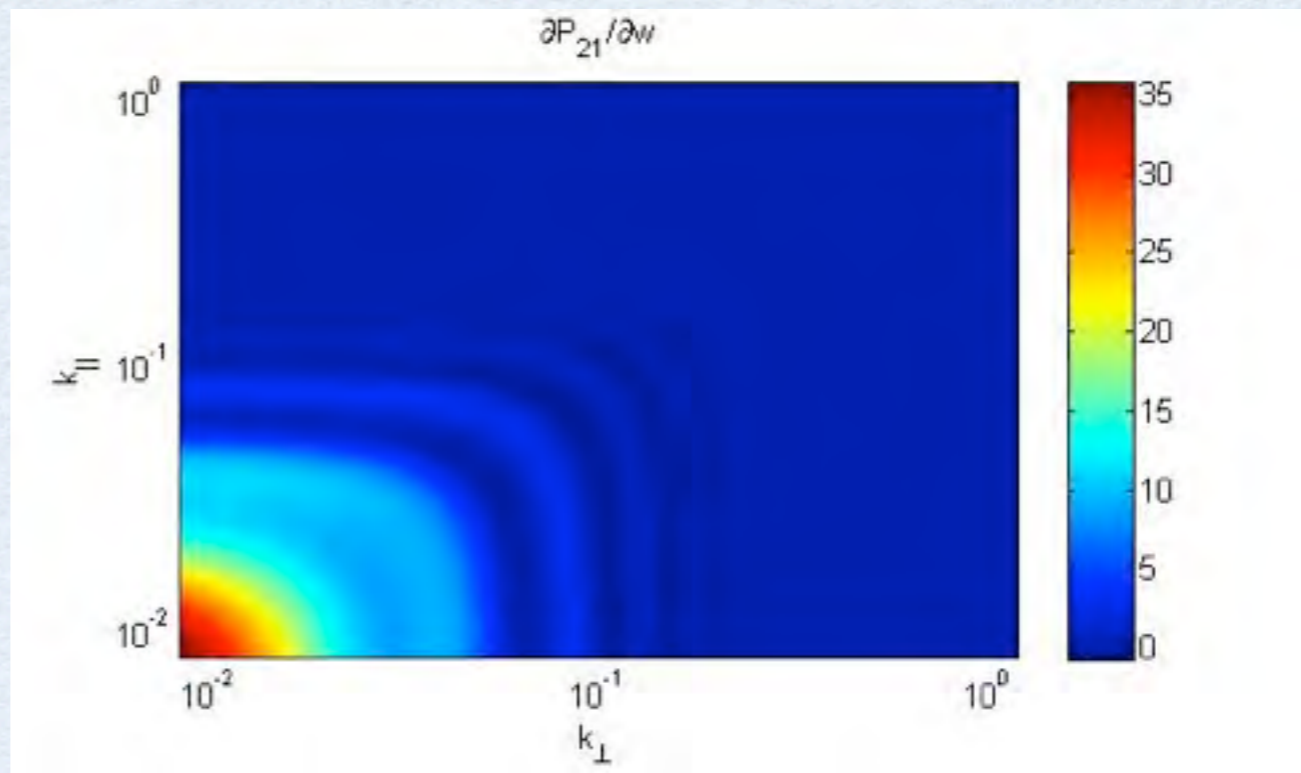


$z = 8$, 360 hours of

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Kaplinghat (2005)

k -space Fisher matrixes

Tuning parameter
sensitivity



Visbal, in prep.

Opportunities for lunar 21 cm

- Low RFI
- No ionosphere
- Slow rotation rate
- Dark ages (redshift > 40)
 - Very large arrays, novel hardware (e.g. MOFF?)
- Challenge of very fast ground-based development

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