Reionization on Large Scales: The 21 cm power spectrum and light cone effect

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Cosmology on the Beach
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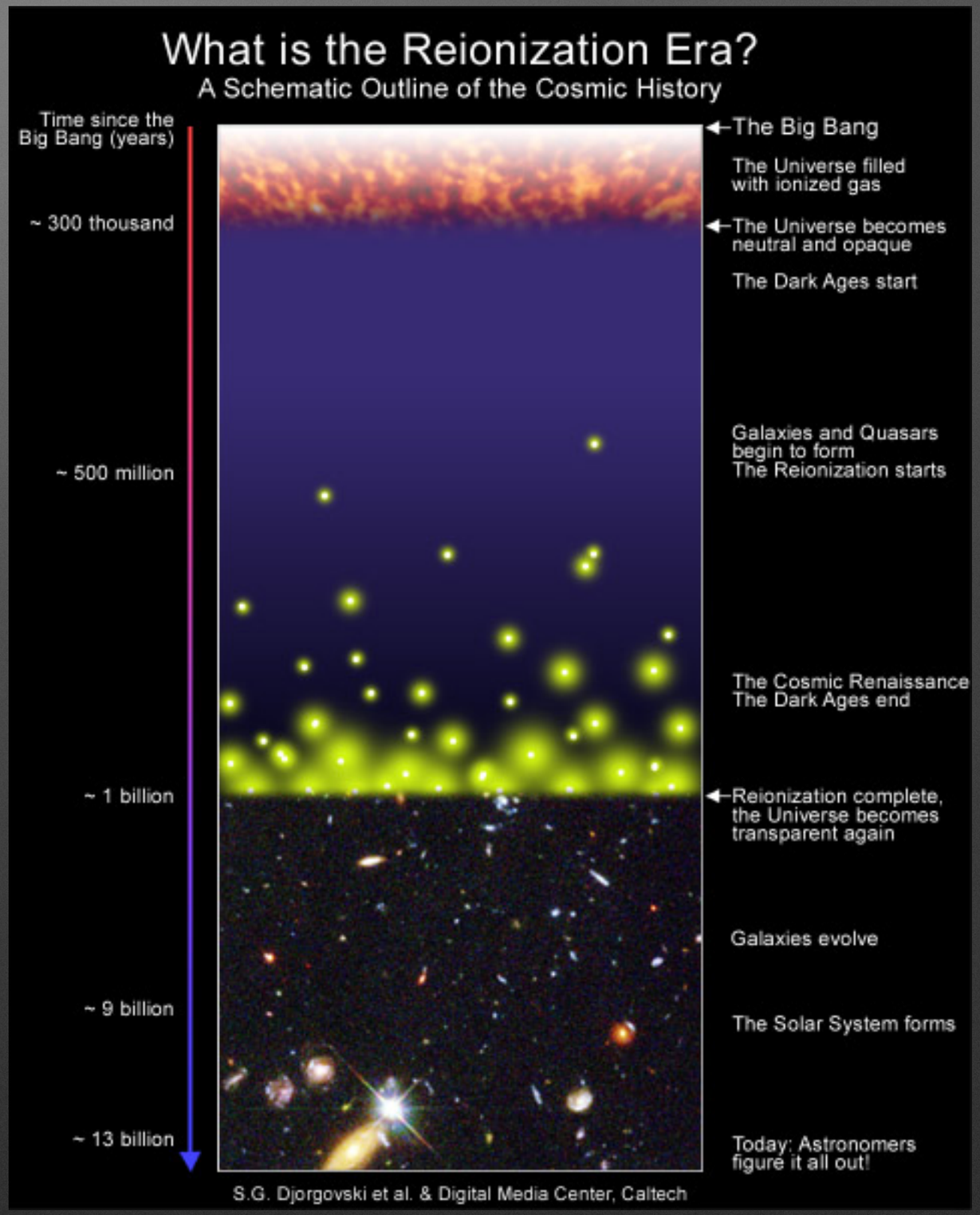
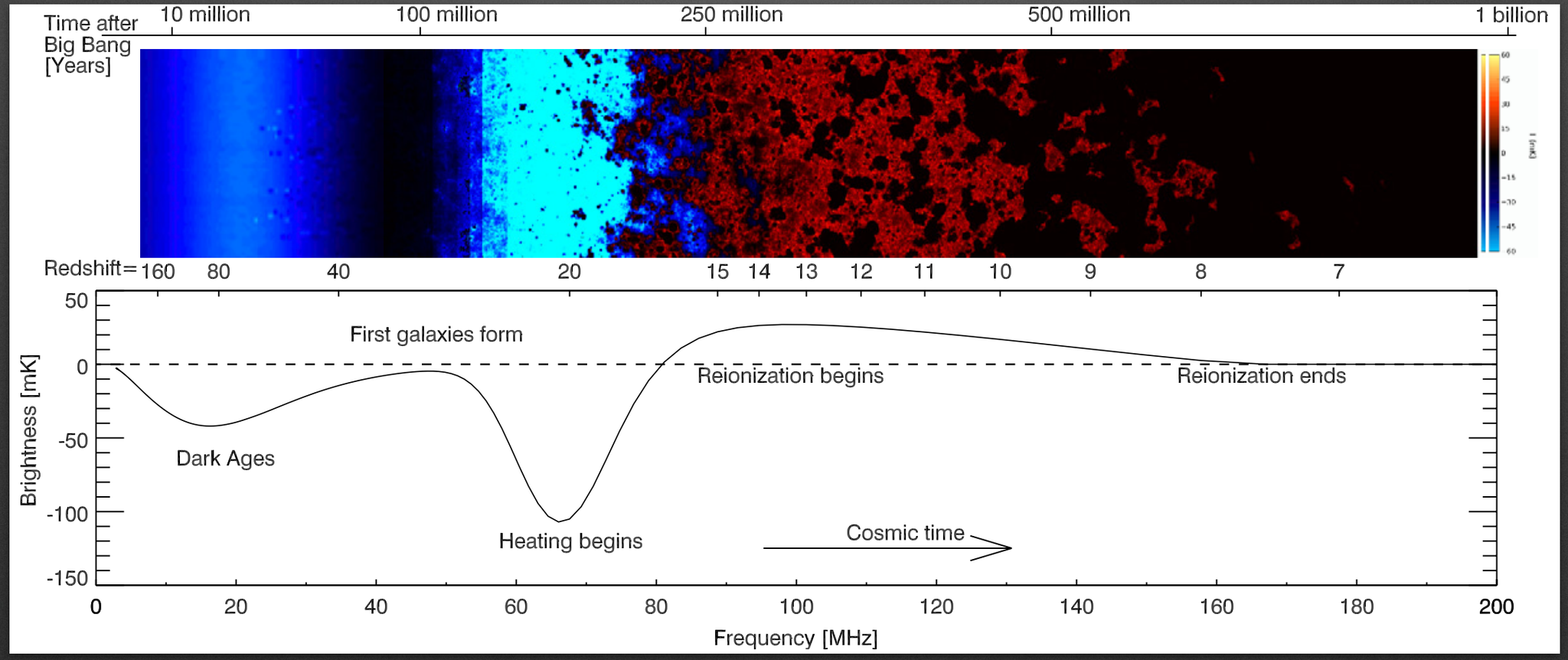
Reionization

- Knowns:
  - Gunn-Peterson trough
  - Thomson optical depth τ
- Unknowns:
  - Midpoint?
  - Duration?
  - 3D information?



21 cm Imaging

- Hyperfine transition
- Maps neutral hydrogen
- Encapsulates evolution of reionization



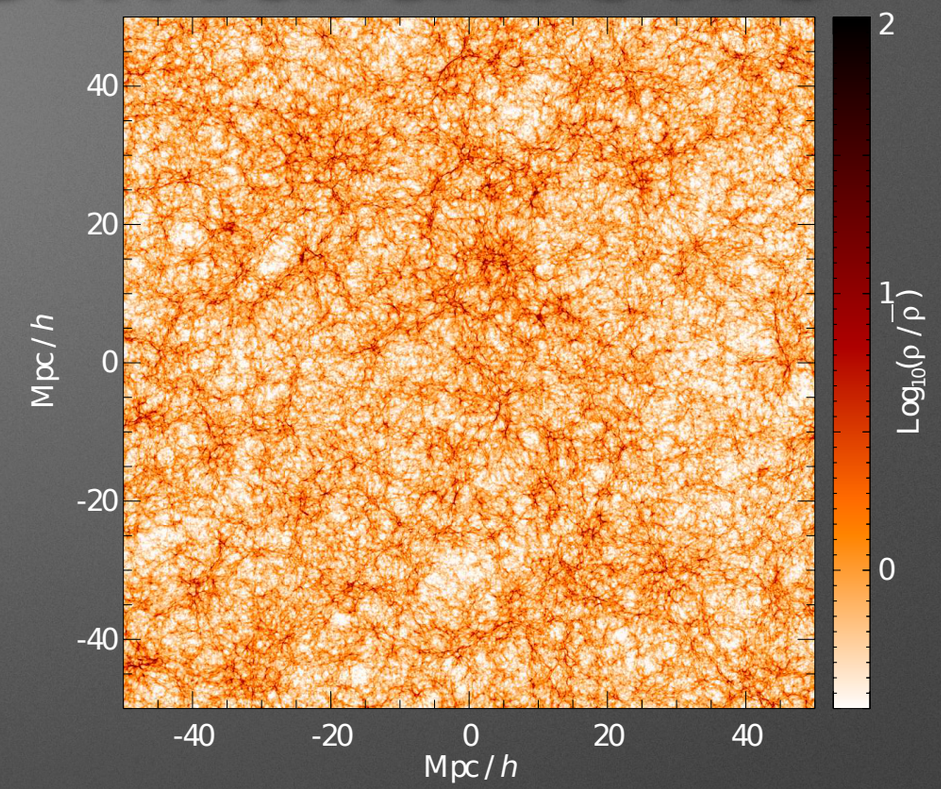
Pritchard & Loeb 2012

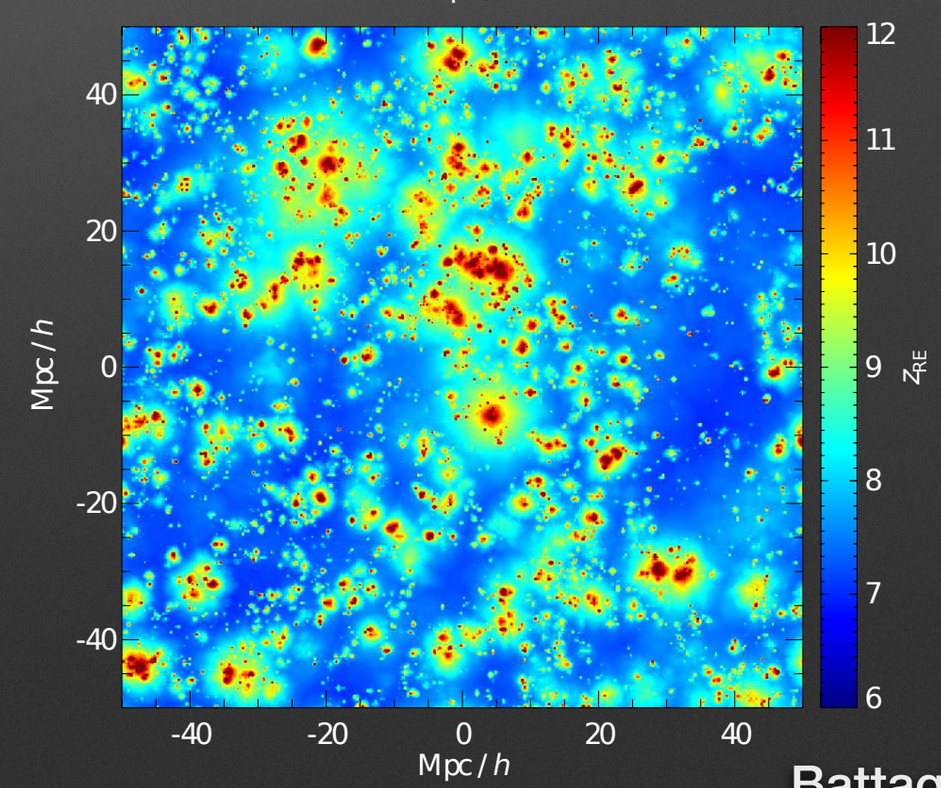
Reionization Simulations

- *N*-body + hydrodynamics + radiative transfer
- 100 Mpc/*h* volume
- Fit for matter/redshift of reionization bias:

$$\delta_z(\vec{\mathbf{k}}) = \frac{b_0}{(1+\frac{k}{k_0})^{\alpha}}\delta_m(\vec{\mathbf{k}})$$

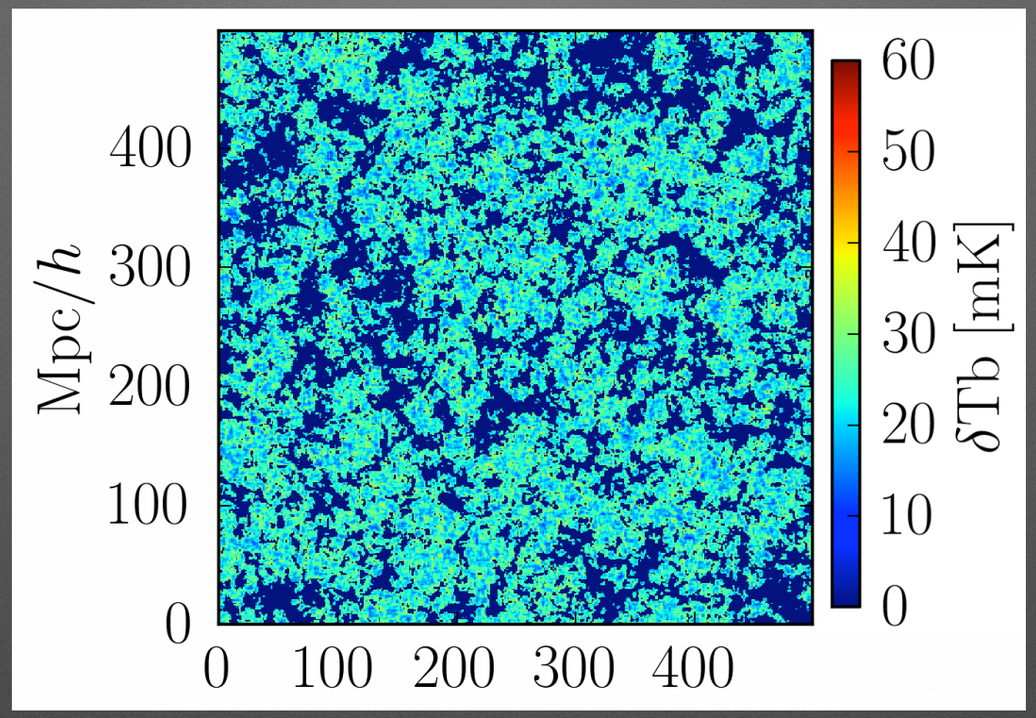
- Apply to large volume (2 Gpc/*h*)
- Create fiducial, long, and short reionization scenarios

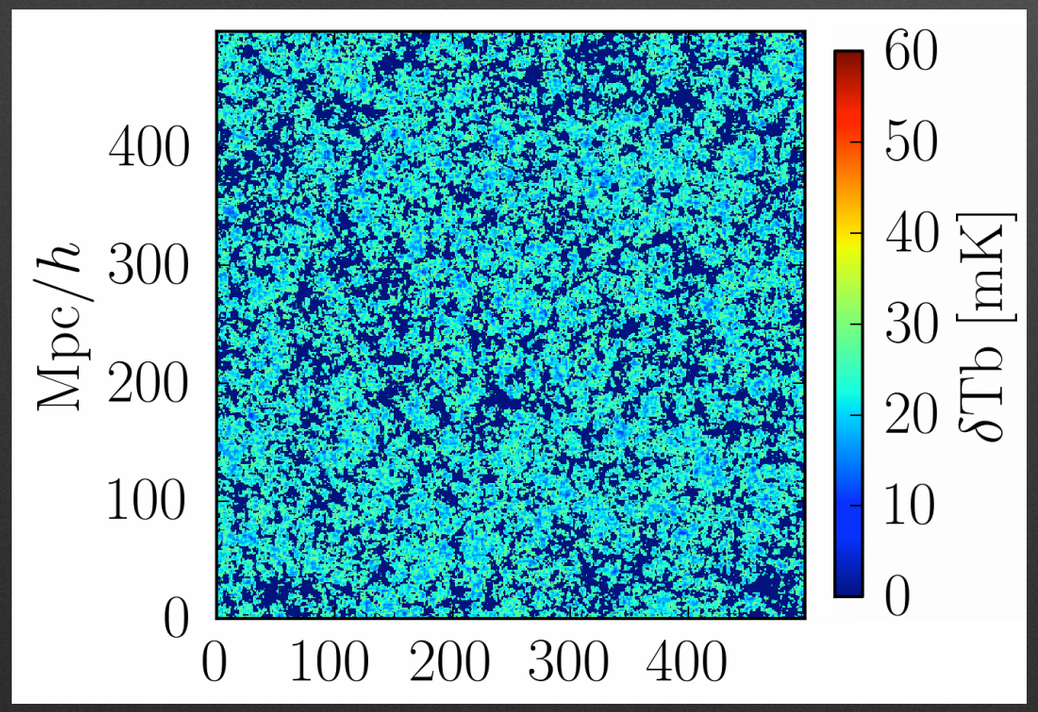


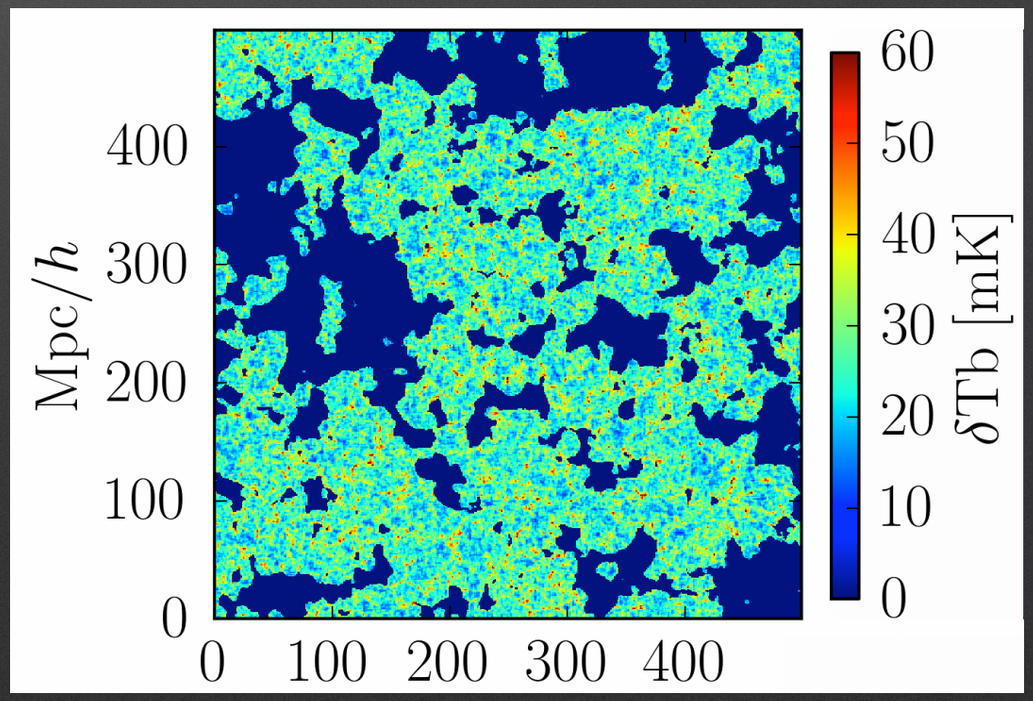


Battaglia+ 2013

Reionization Simulations

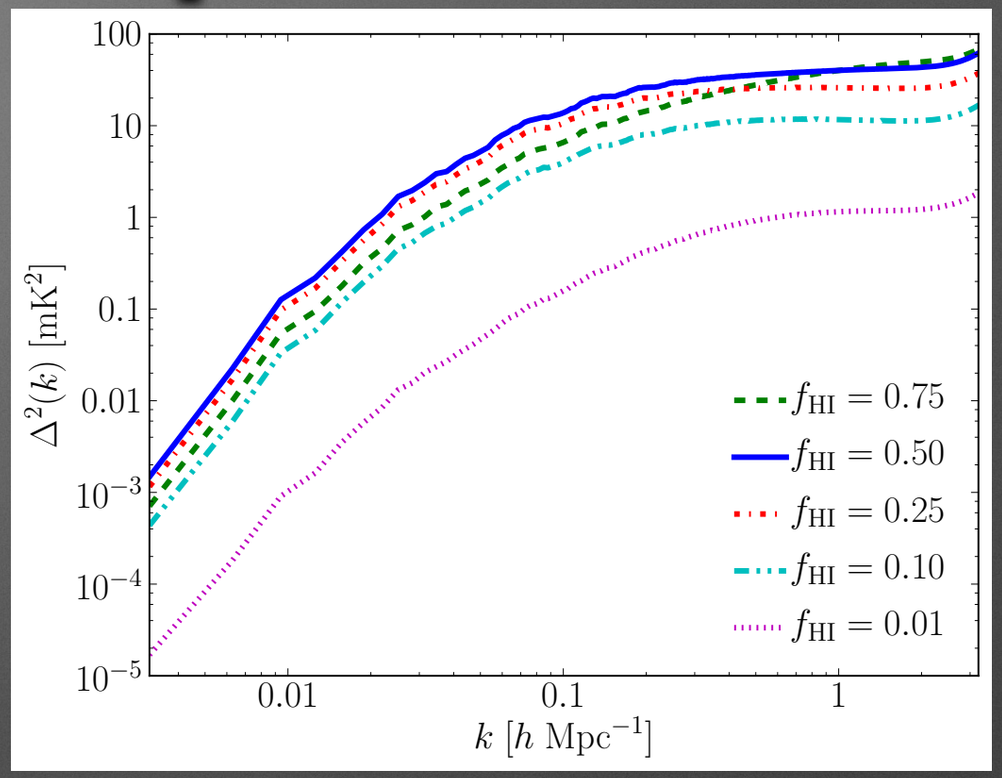


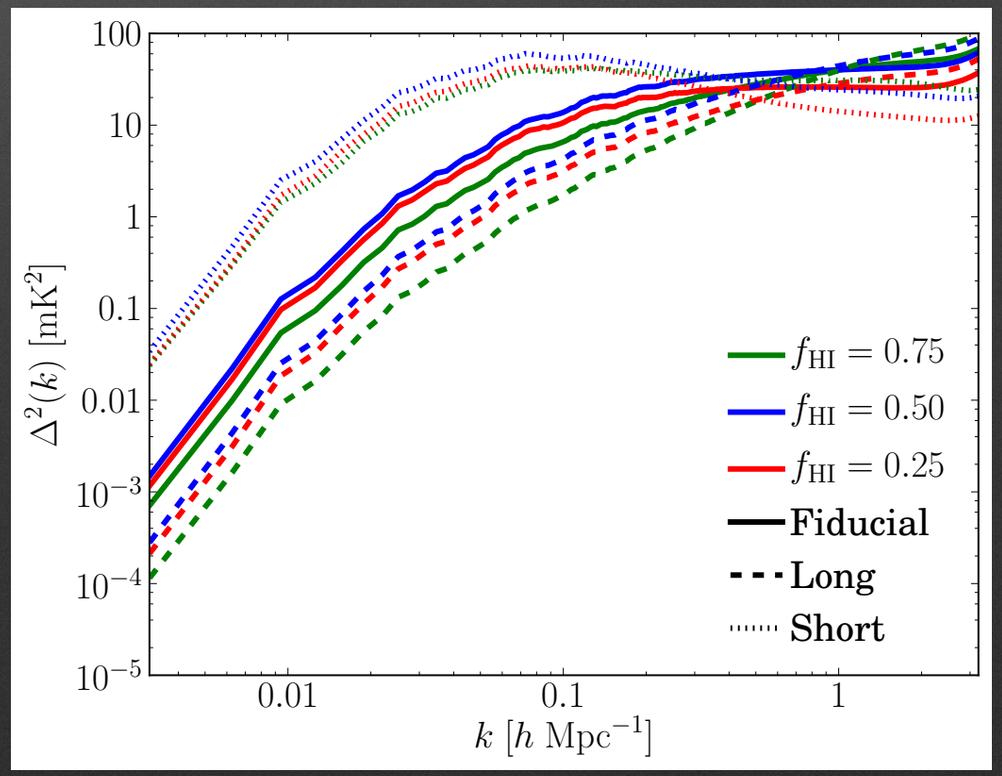




21 cm Power Spectrum

- Compute power spectrum as function of neutral fraction
- Change in amplitude + change in shape
- Large-scale power peaks at ~50% ionization
- Shorter scenarios have more (less) large scale (small scale) power



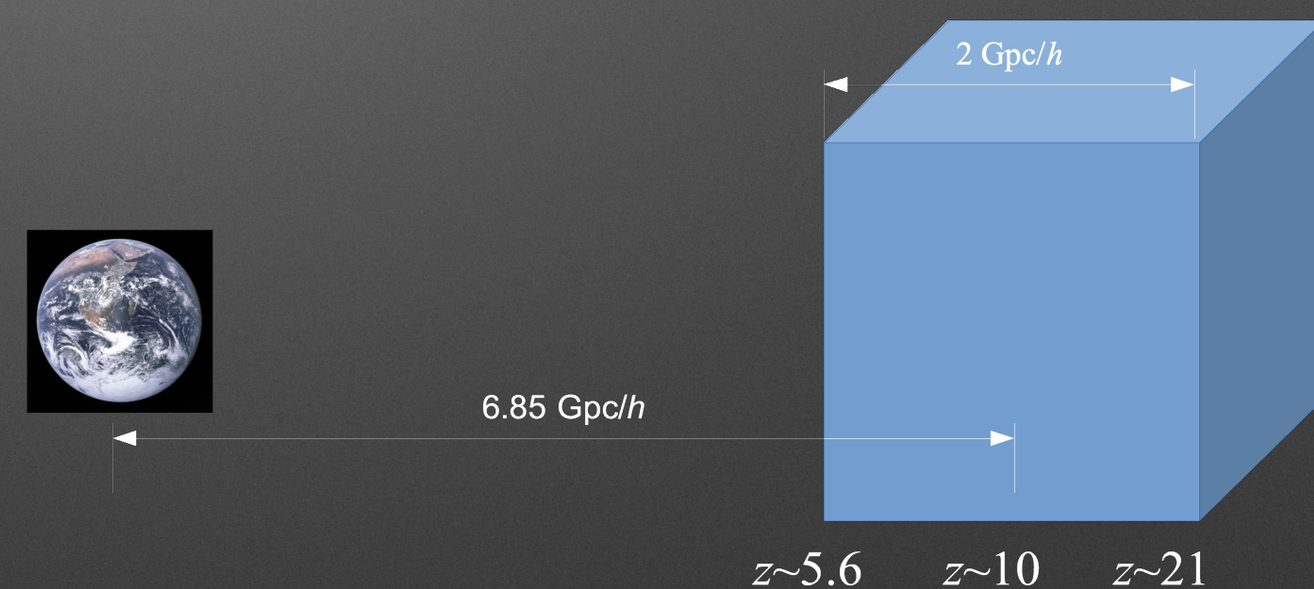


Light Cone Effect

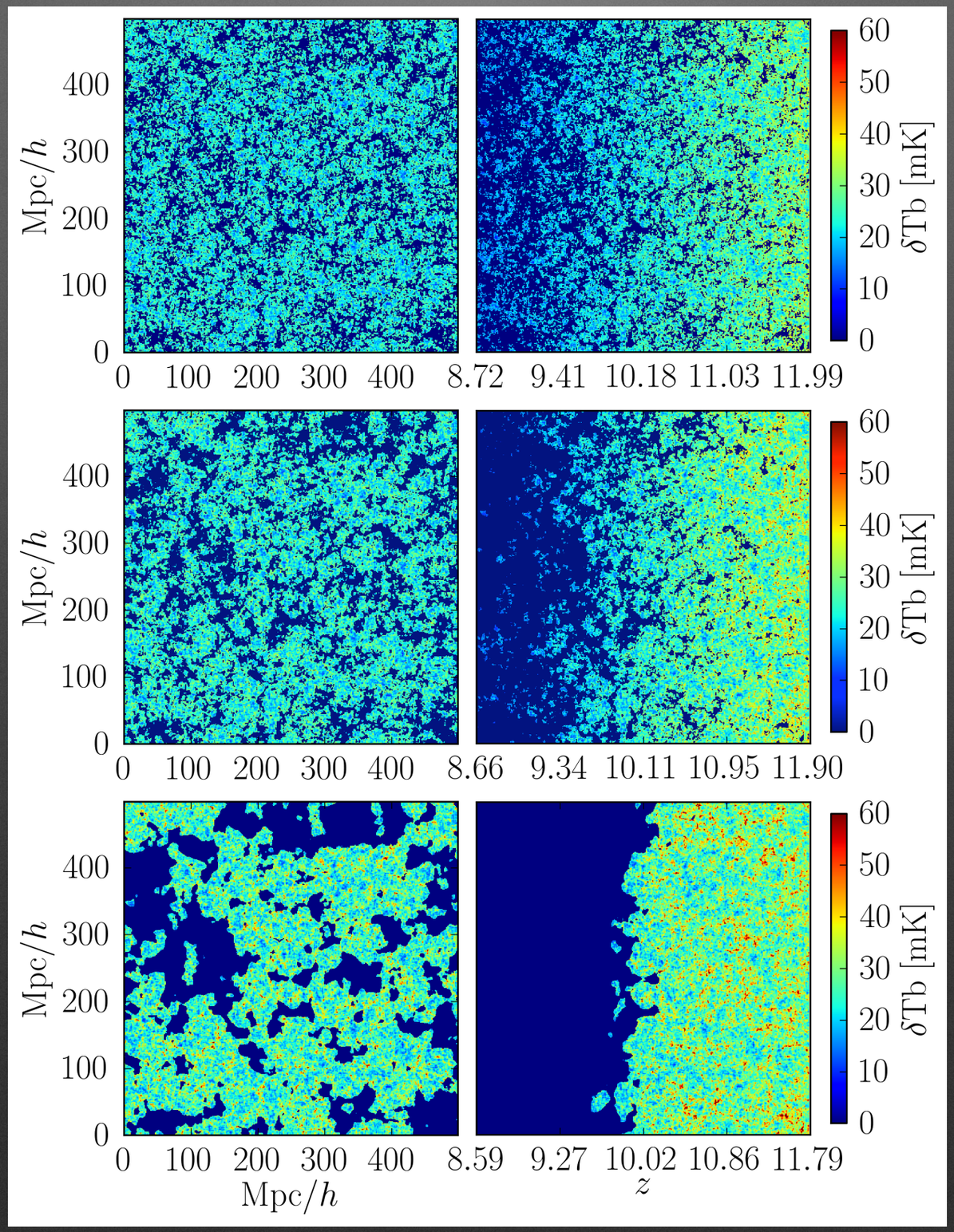
- Large distance = long propagation time
- Compute distance vs. redshift:

$$r(z) = \int_0^z \frac{c}{H(z')} \, \mathrm{d}z'$$

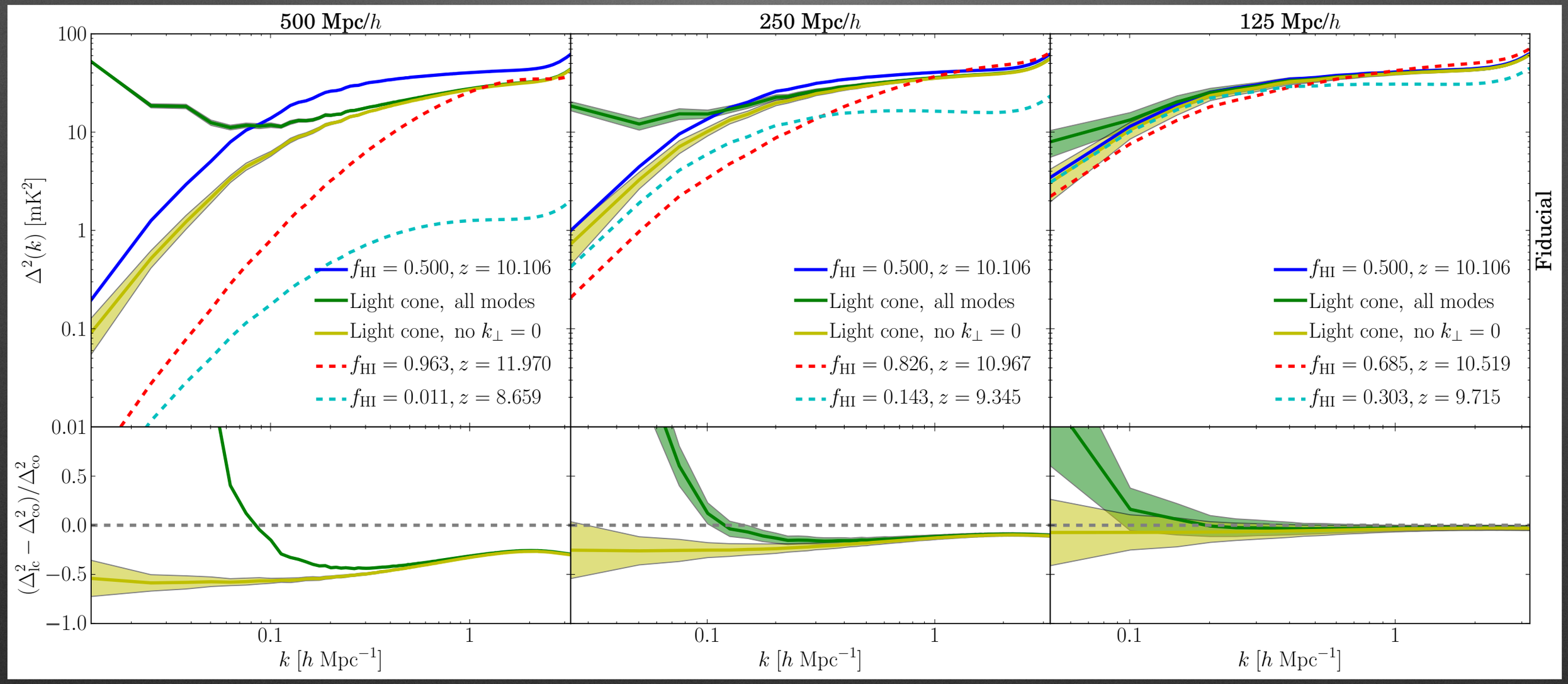
- Far side is neutral, near side ionized
- Can't measure coeval cube!



Light Cone Effect

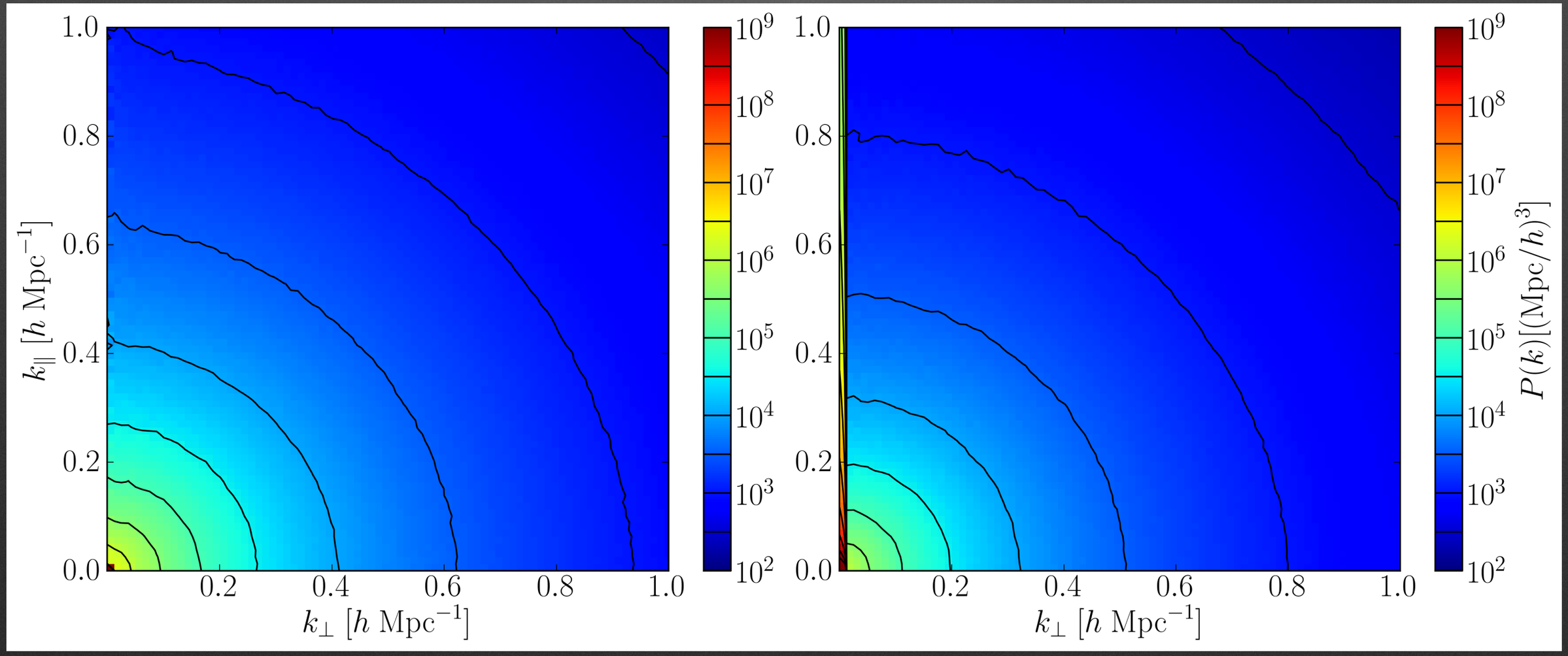


Light Cone Effect

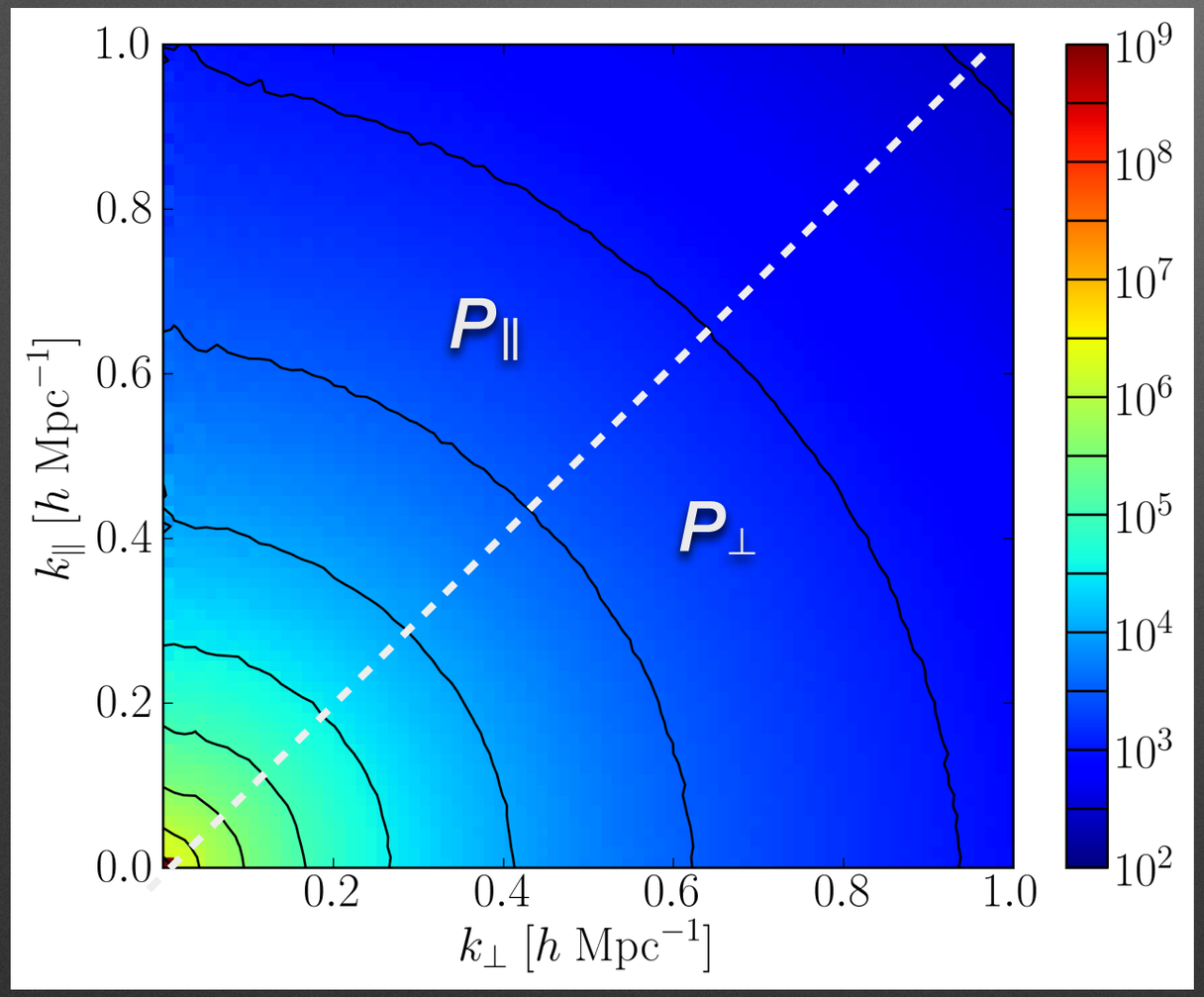


Anisotropic Power Spectrum

- Light cone introduces anisotropy along line of sight
- Decompose into $k_{\parallel}$ and $k_{\perp}$
- Most power when $k_{\perp} = 0$, more power when $k_{\parallel} \sim k_{\perp}$ than near axes



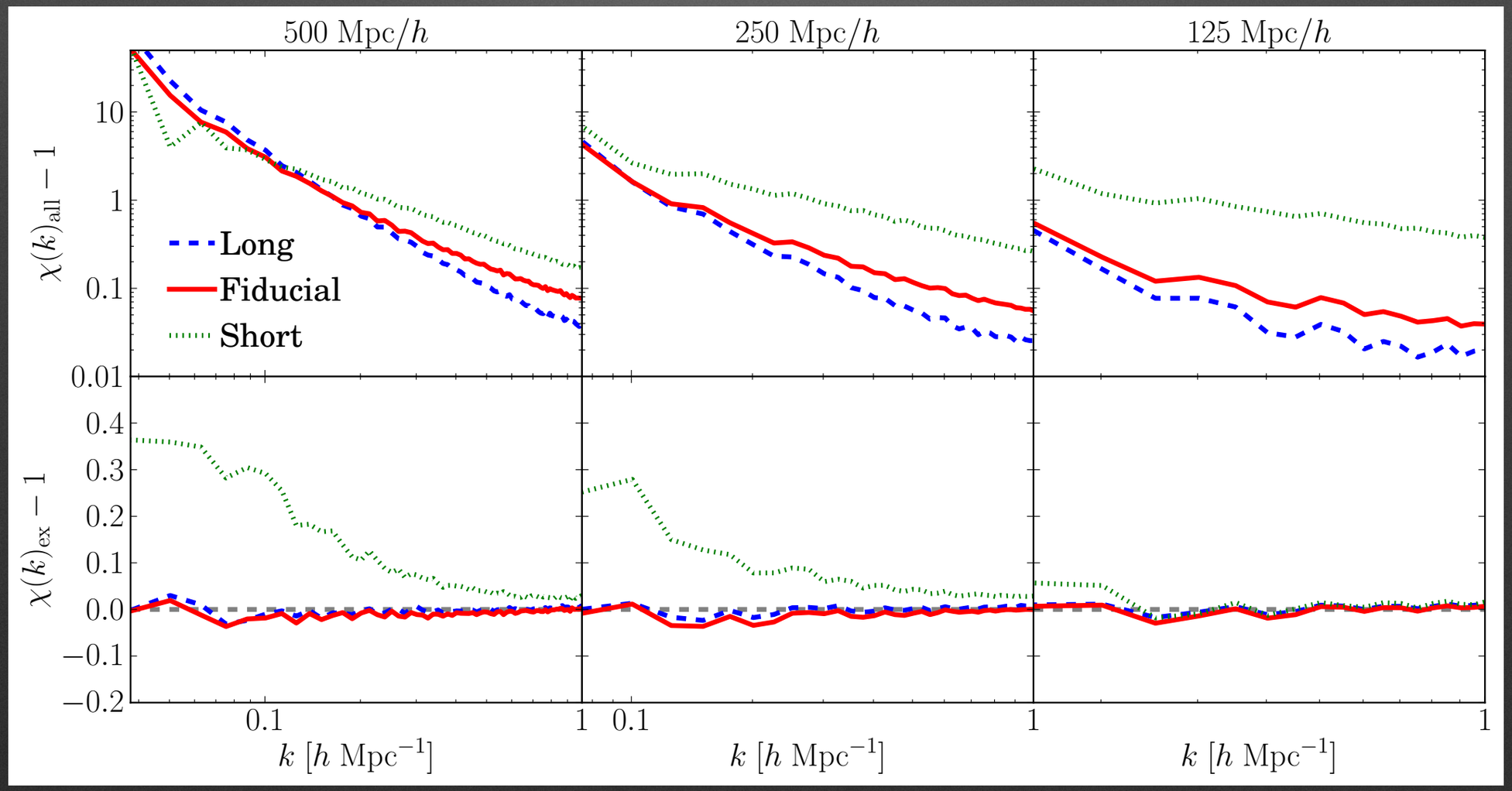
Power Wedges



$$\chi(k) \equiv \frac{\langle P_\parallel(k) \rangle}{\langle P_\perp(k) \rangle}$$

Power Wedges

- All modes: large anisotropy in all cases
- No $k_\perp = 0$: anisotropy only for short history
- Important quantity: Δz_{reion} vs. $\Delta z_{\text{light cone}}$



Conclusions

- Light cone effect important for 3D measurements, spec. 21 cm power spectrum
- Introduces large anisotropy into measurement
- In flat sky, can remove $k_\perp = 0$ to mitigate most anisotropy
- Large changes in ionization fraction exhibit large deviations from isotropy