21-cm signal from cosmic dawn:
Imprints of the light-cone effects

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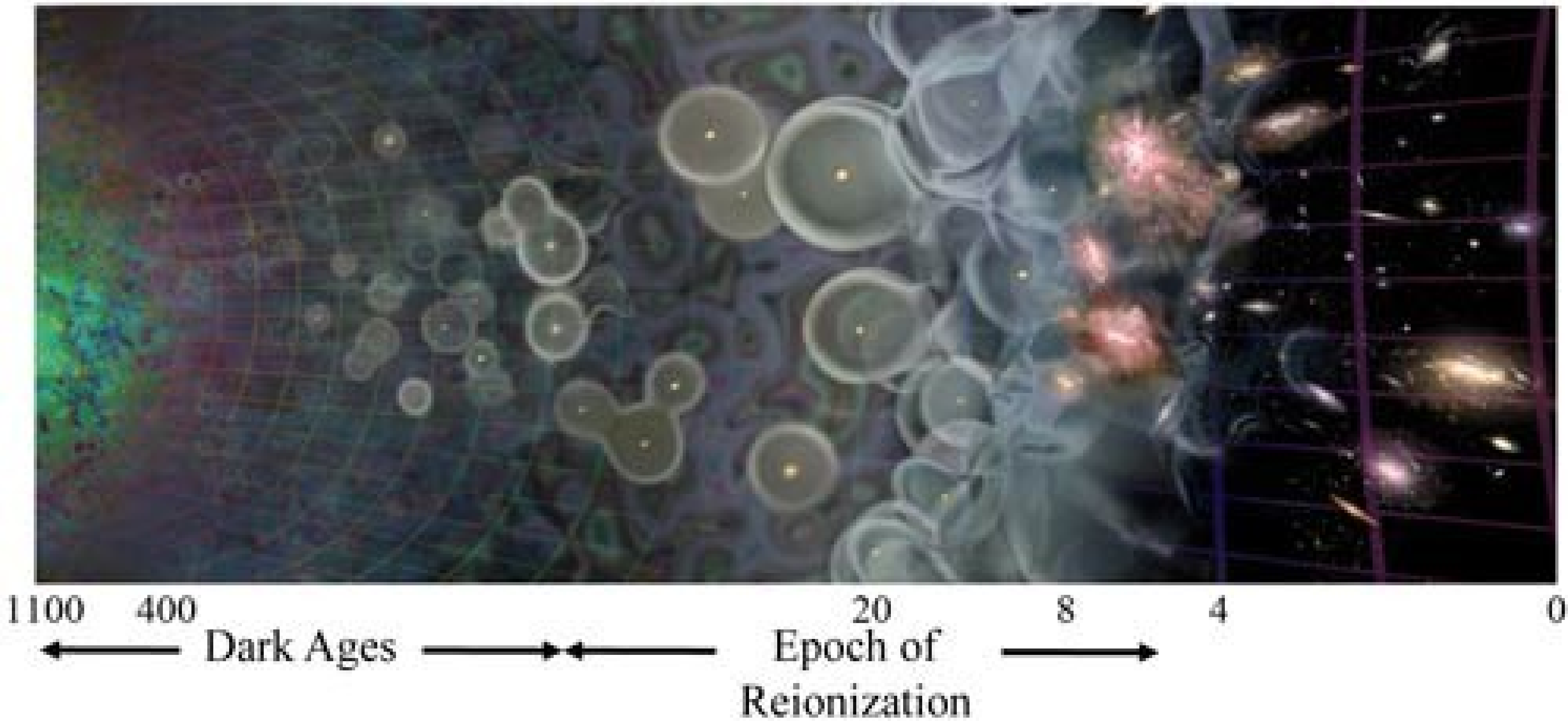
Key Questions



- When did the first sources form and reionization happen?
- What are the properties of the first sources?
- What is the nature of the IGM during these epochs?

How 21-cm signal answers such questions?

$$\delta T_b = 27\, x_{HI} (1+\delta_B) \left(\frac{H}{dv_r/dr + H}\right) \left(\frac{\Omega_B h^2}{0.023}\right) \left(\frac{0.15}{\Omega_m h^2} \frac{1+z}{10}\right)^{1/2} \left(\frac{T_S - T_\gamma}{T_S}\right) mK$$

Brightness temperature

Neutral fraction

Density contrast

Peculiar velocities

Spin temperature

Set by CMB, Collisional and Lyα coupling

Emission signal : Ts > Tγ   (δTb > 0)

Absorption signal : Ts < Tγ (δTb < 0)

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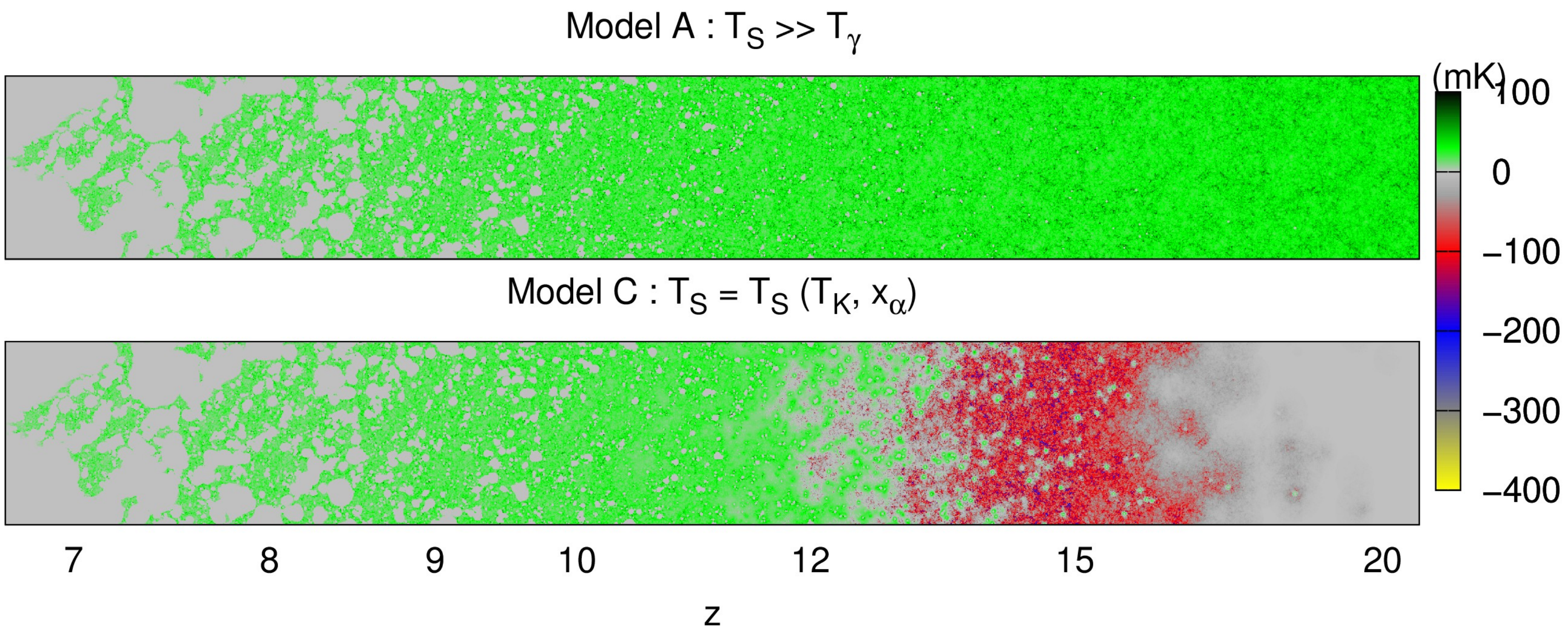
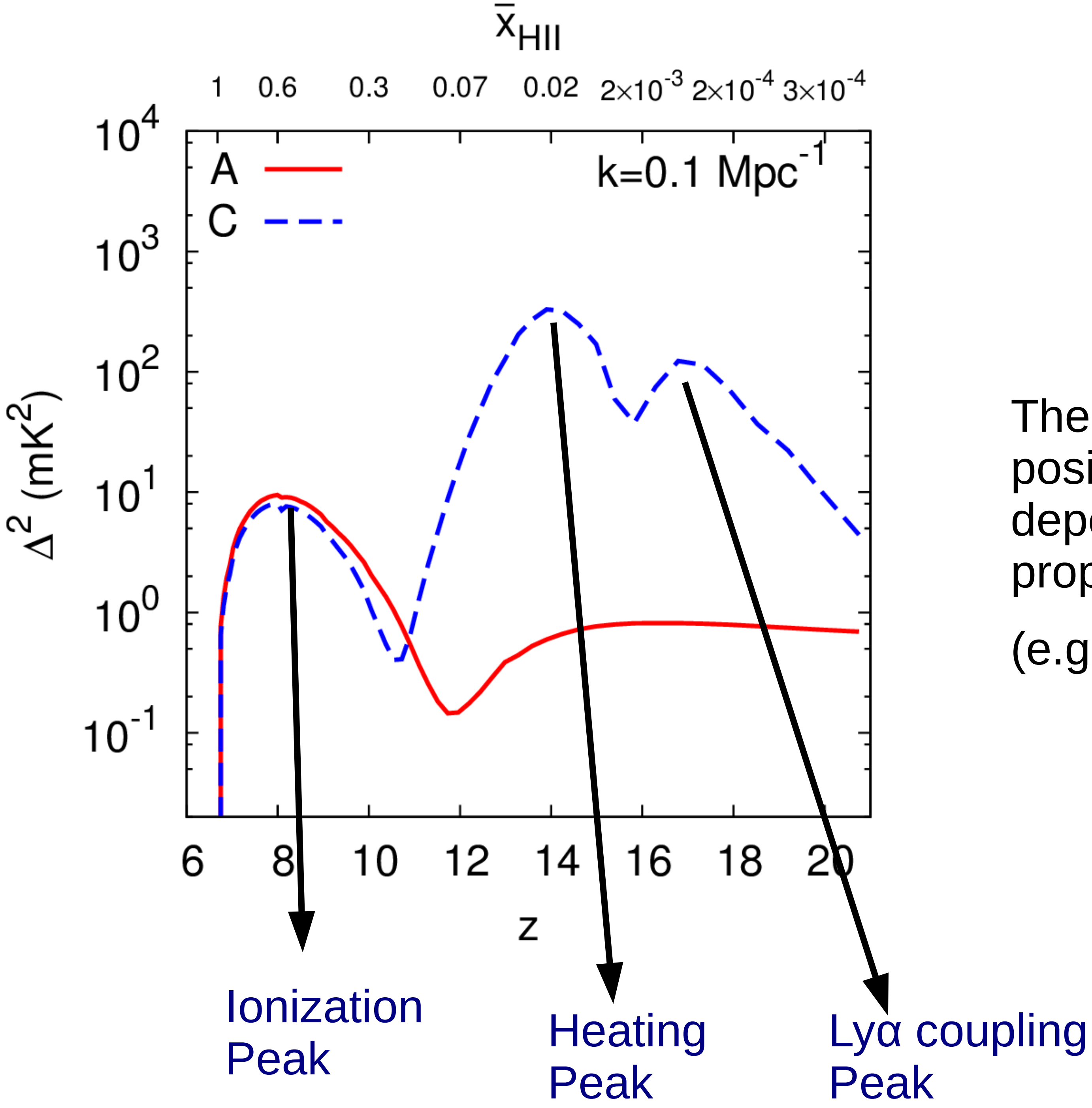


Power spectrum



Model A : Ts>>Tγ

Model C : Ts=Ts(Tk,Xα)

The amplitude and position of the peaks depend on the source properties.

(e.g, Mesinger et al. 2014)

Simulation

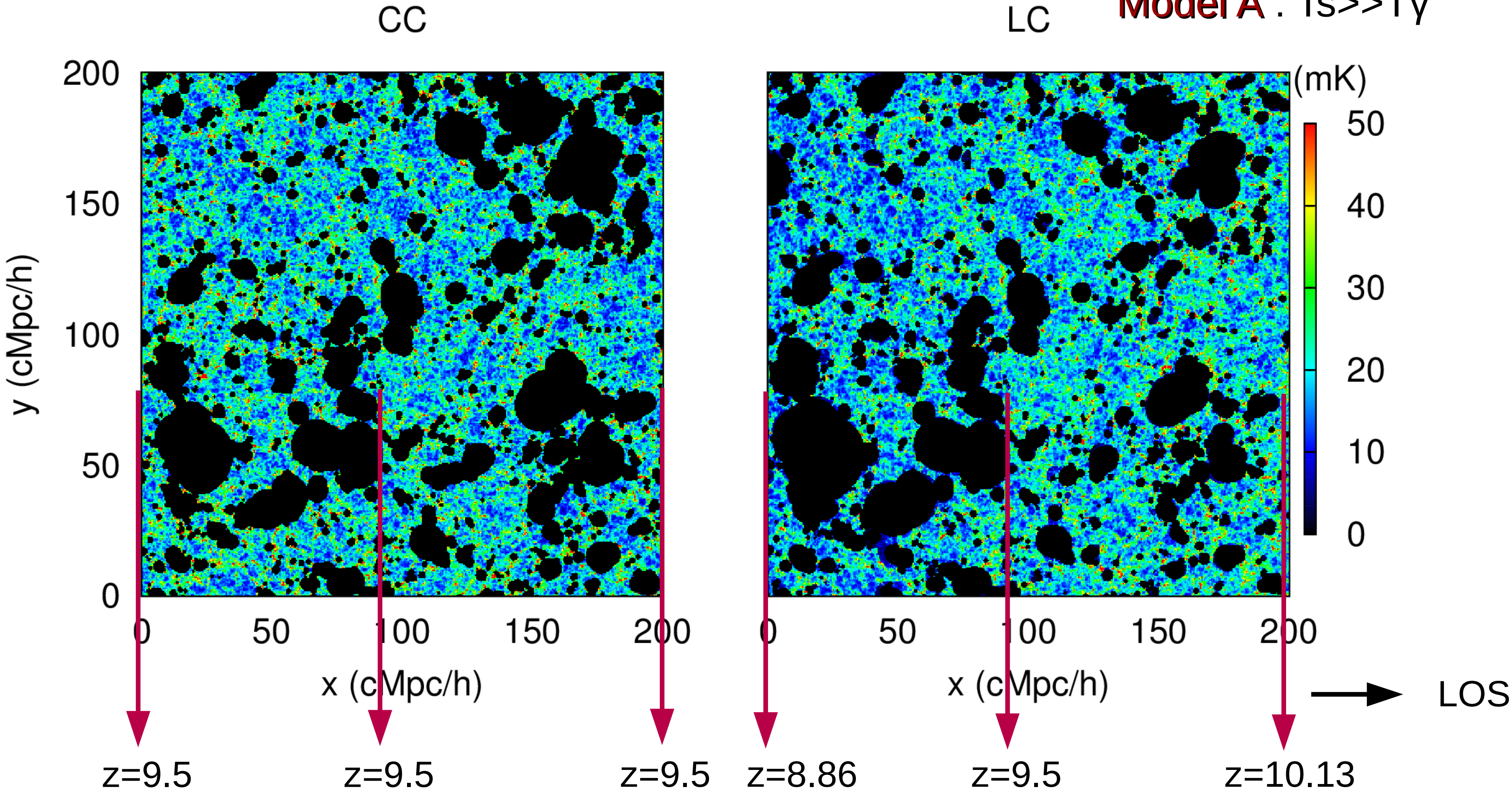
- Dark matter N-body simulation using CUBEP3M
  - Box size : 200 cMpc/h.
  - Particle number :(1728)^3
  - Particle Mass: 2 x 10^8 $M_\odot$

- Identify Dark matter halos.
  - Minimum halo mass using spherical overdensity method is ~ 2 x 10^9 $M_\odot$
  - Small mass halos down to 10^8 $M_\odot$ is included using a sub-grid model.

- These halos are hosting reionization sources.
  - Stellar + mini-quasar type source (Power law SED).
  - 1D radiative transfer.

Light-cone effect

Model A : Ts>>Tγ

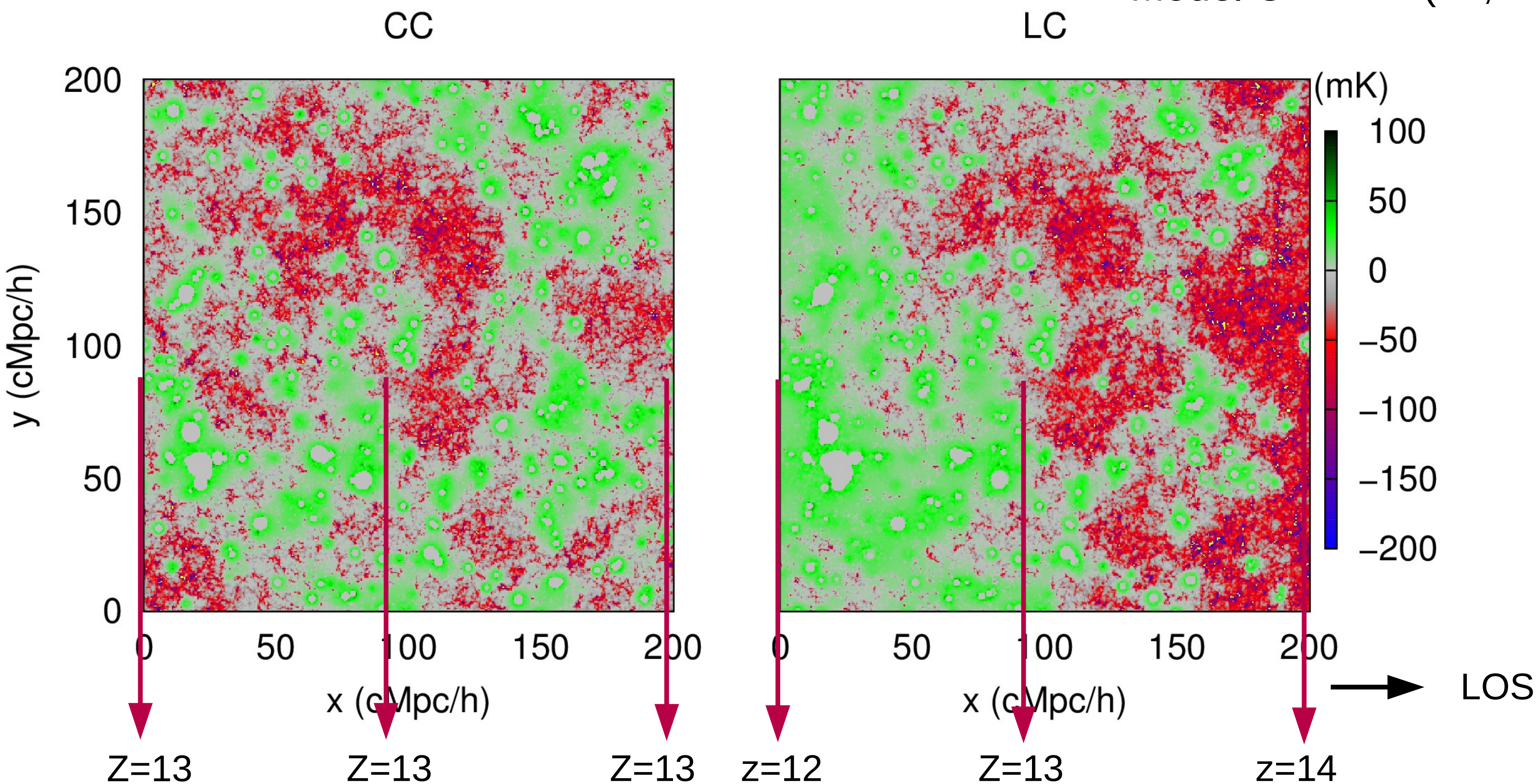


coeval cube : assumed that every part of the simulation box have the same redshift.

Light-cone cube : incorporate the redshift evolution of the signal.

Light-cone effect

Model C : Ts=Ts(Tk,Xα)



coeval cube : assumed that every part of the simulation box have the same redshift.

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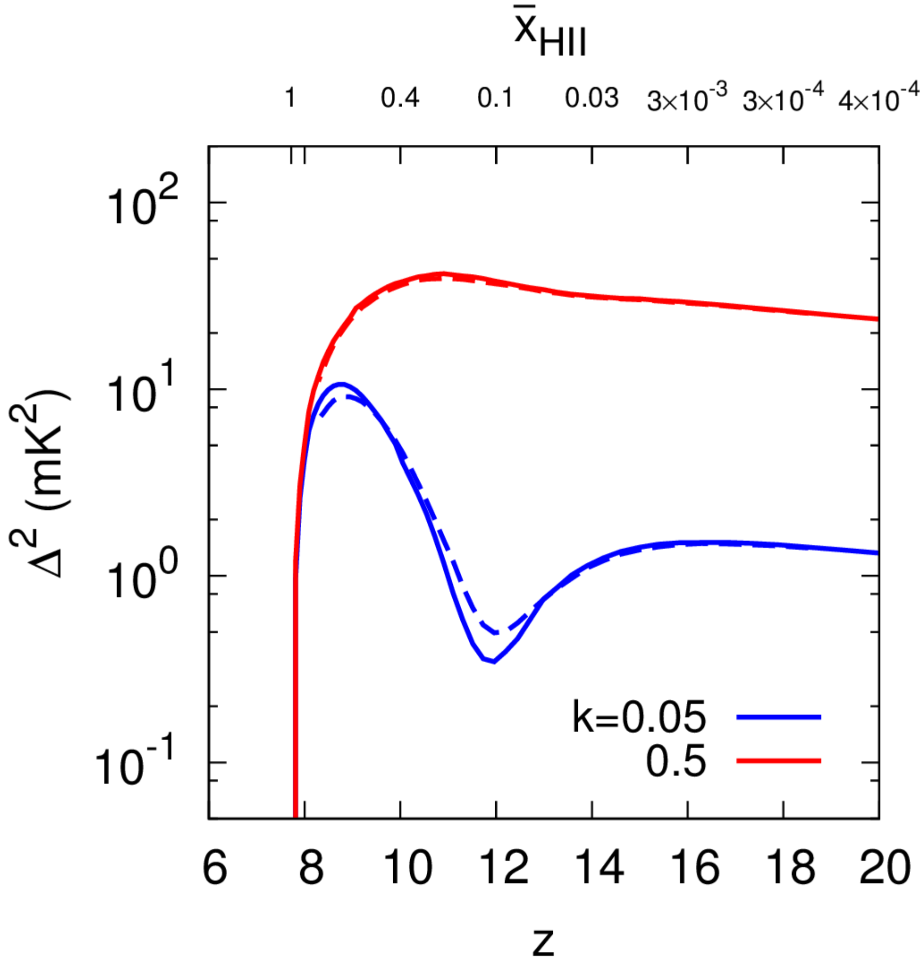
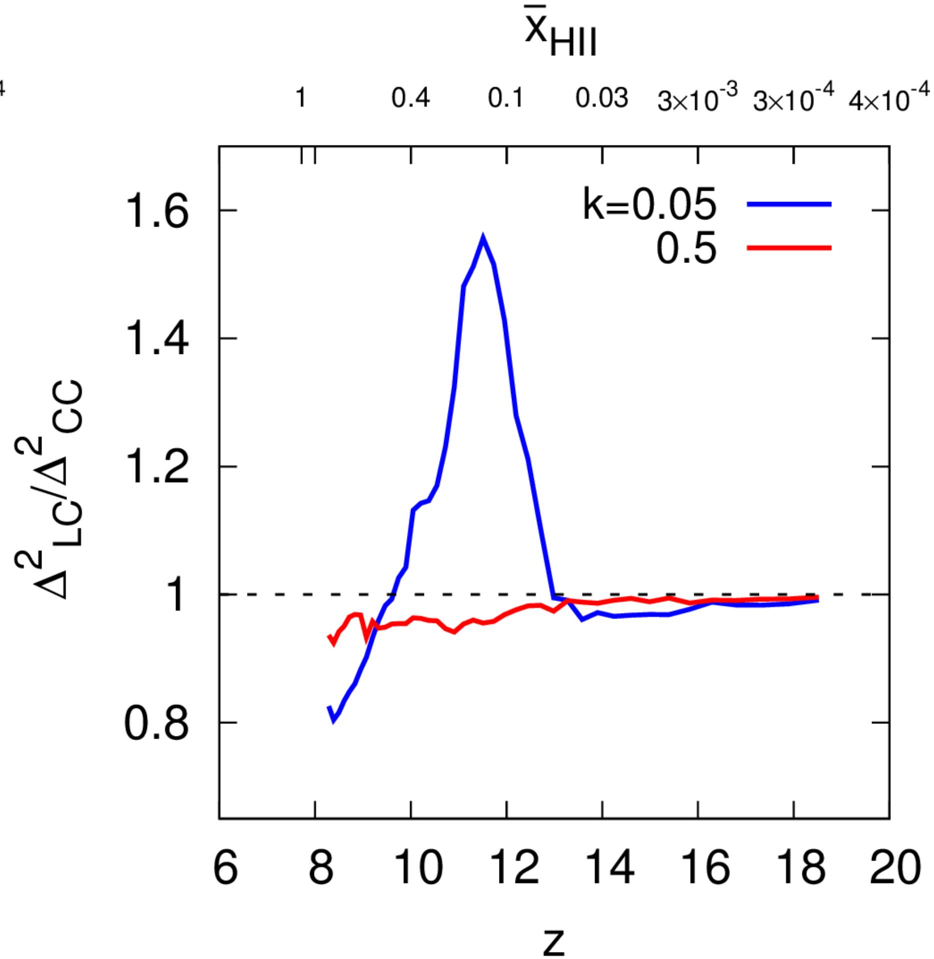
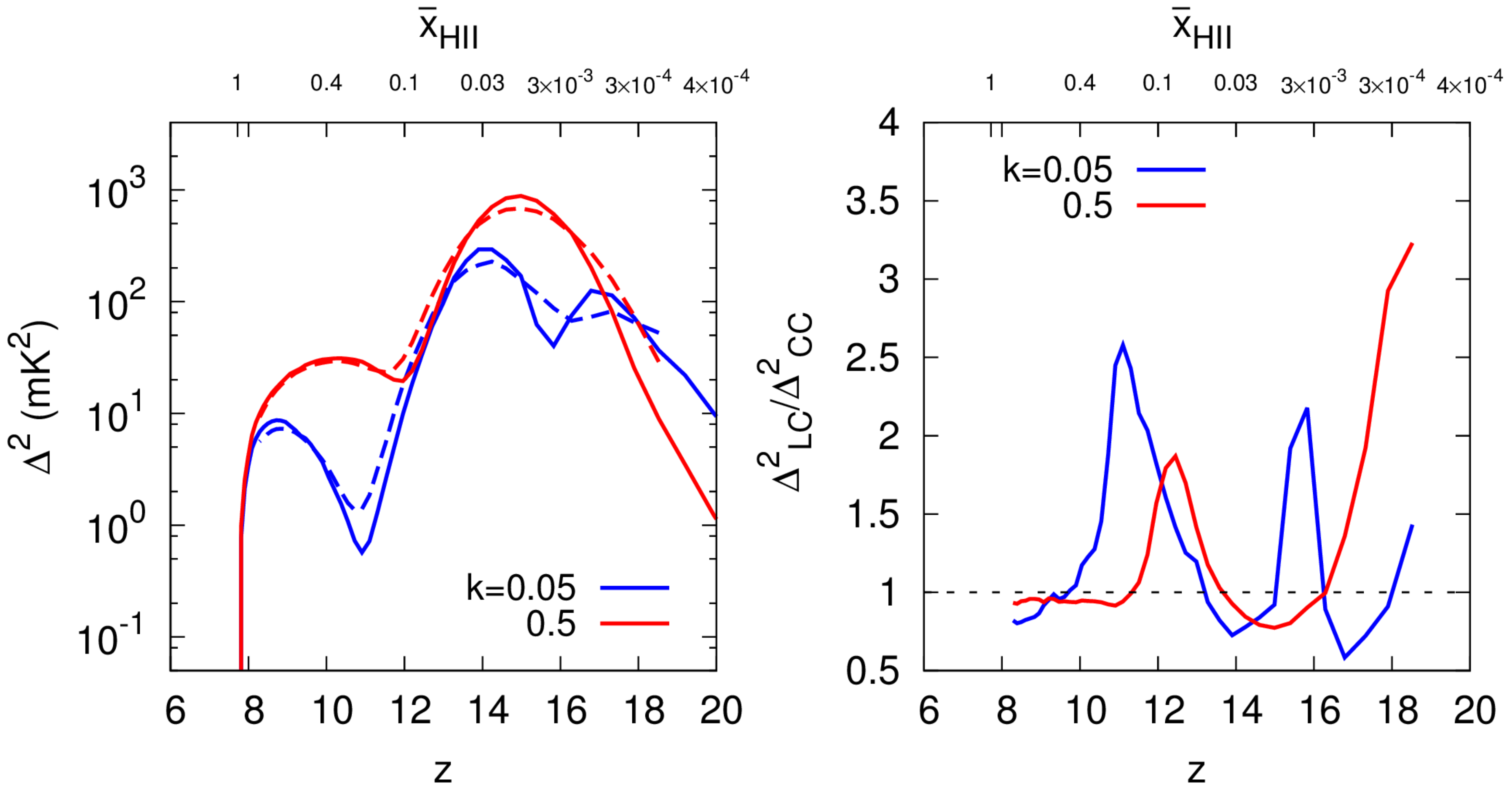
Light-cone effect for model A (Ts>>Tγ)





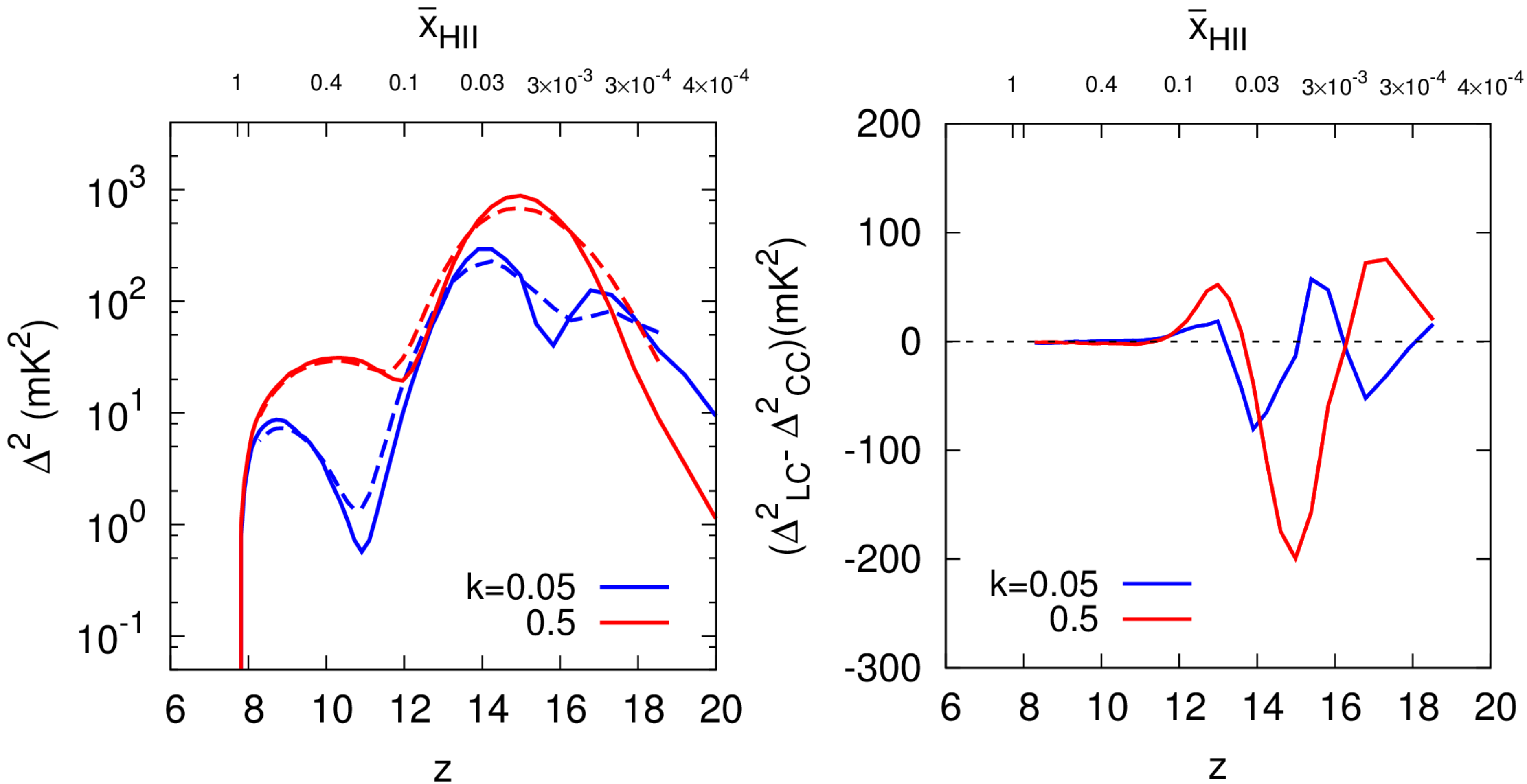
- LC effect is most significant when ionization fraction is ~ 0.15 and 0.8 for model A.
- LC effect can increase/ decrease the power spectrum at large scales by a factor of ~1.5 and 0.8 for this model.
- Effect is minimum when ionization fraction is ~ 0.5
- LC effect at small scale is small. Consistent with Datta et al. 2014.

Light-cone effect for model C : Ts=Ts(Tk,Xα)



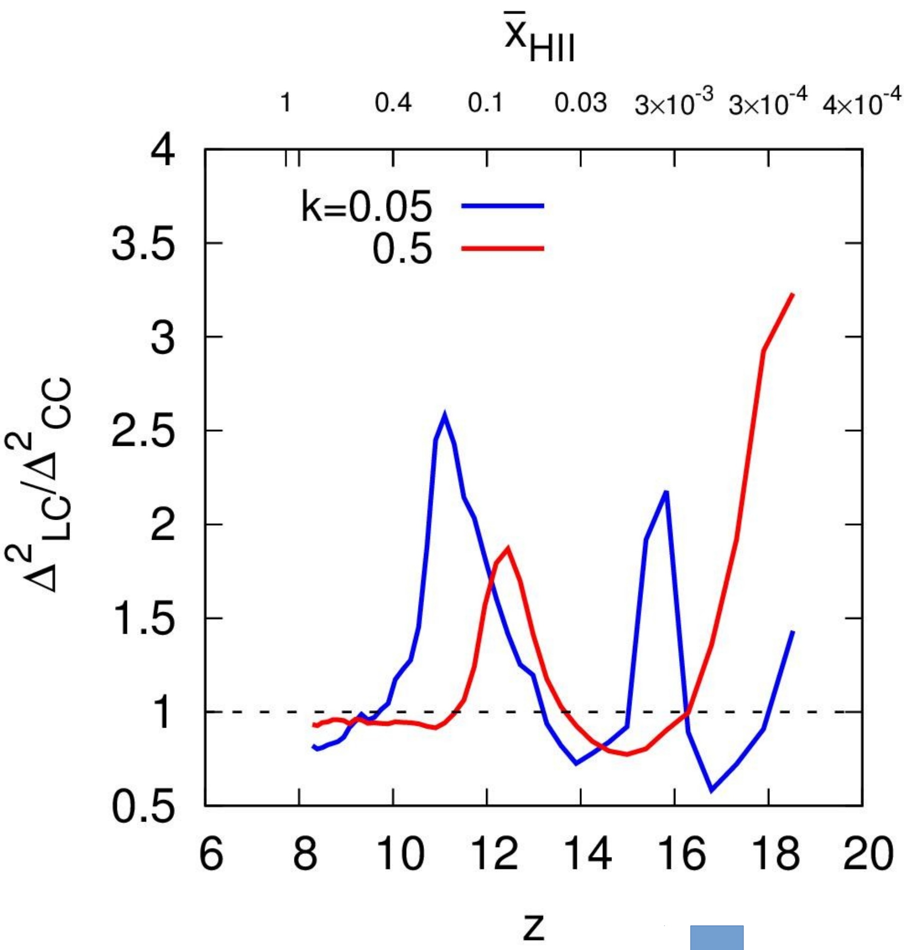
- LC effect has significant impacts in various stages of reionization.
- LC can increase/decrease the power spectrum by a factor of 2-3/0.6-0.8 at the dips/peaks.
- LC effect is also important at small scales.
- LC effect is smoothing the three peak nature of the evolution plot of the power spectrum.

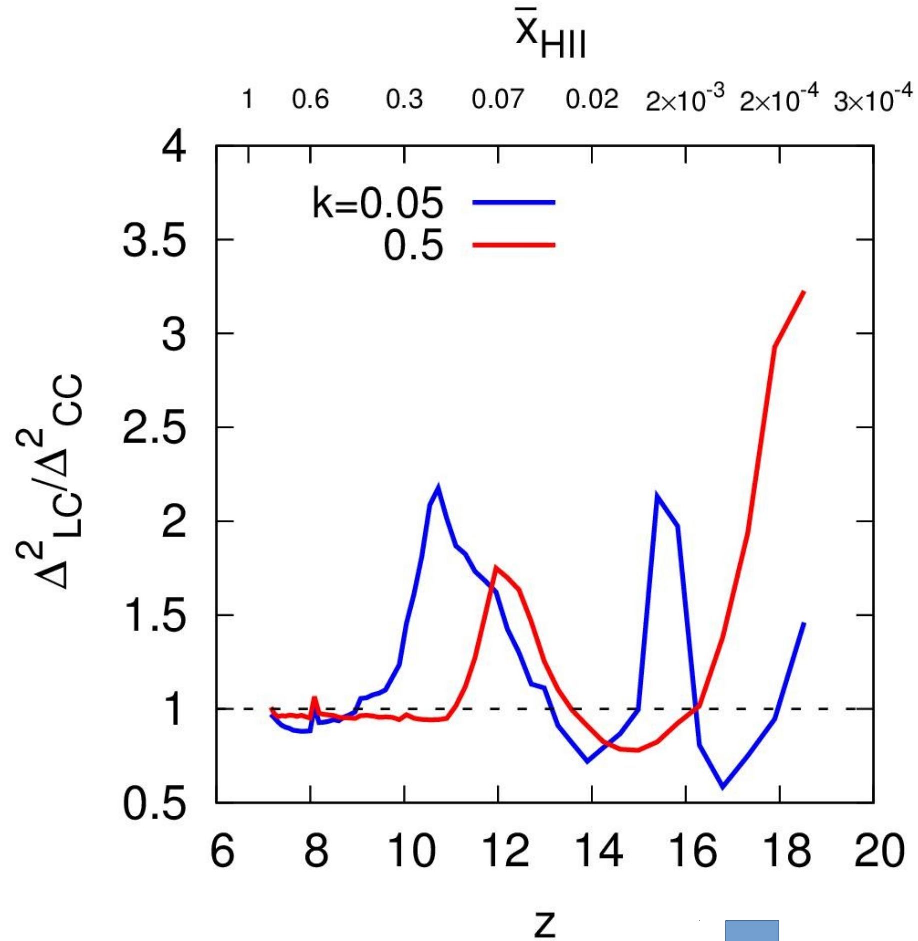
Light-cone effect for model C



- The difference between the power spectra, with and without light-cone effect, lie in the range ∼ −100 to 100 mK^2 for scales k ∼ 0.05 / Mpc for model C.
- The absolute difference increases at small scales (k ~0.5 / Mpc) to the range ∼ −250 to 100 mK^2 .
- Should easily be detected by future experiments like the SKA.

For rapid reionization model



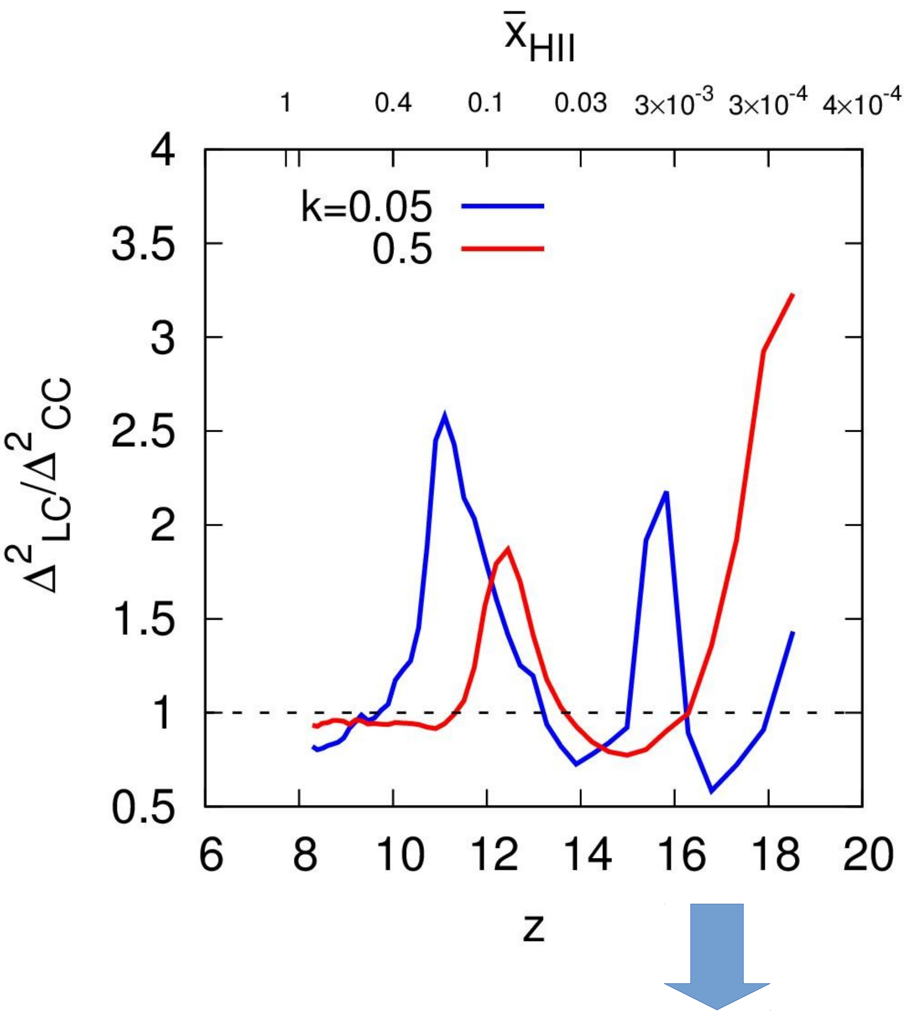


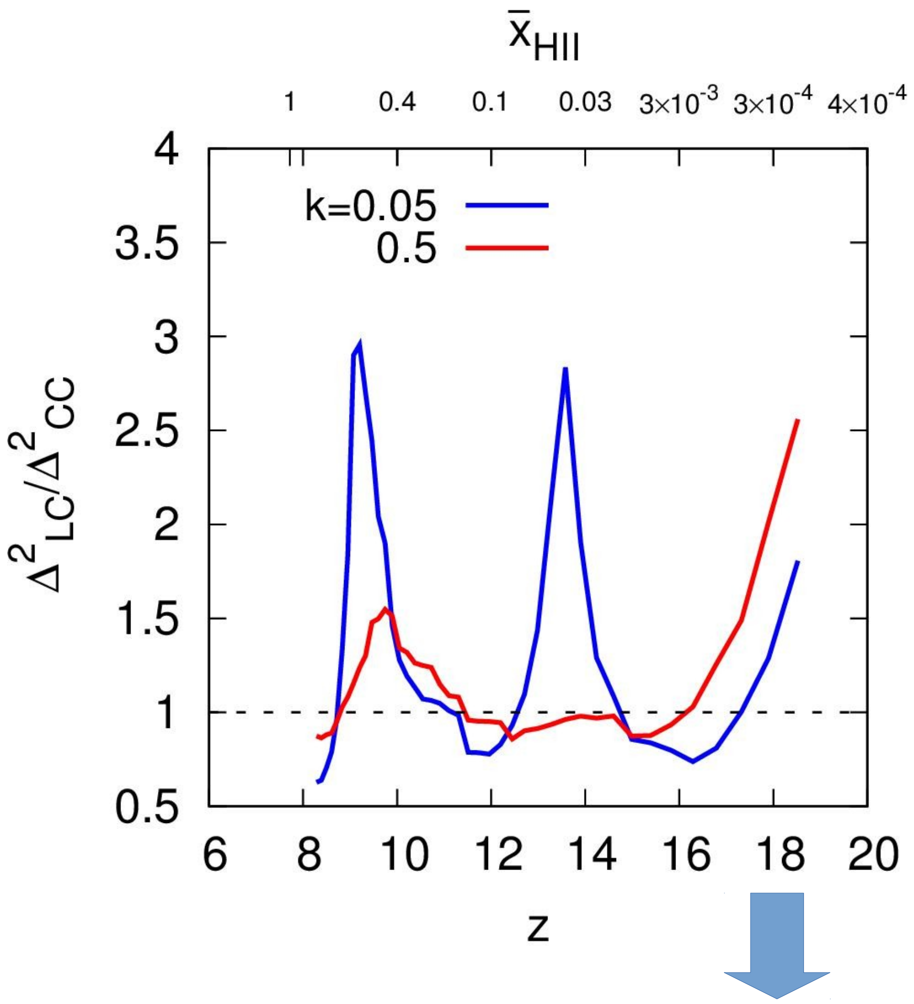
Rapid reionization model (z_end ~ 8)

Smoother reionization model (z_end ~ 6.5)

- LC effect is less for a smoother ionization model

With small mass haloes



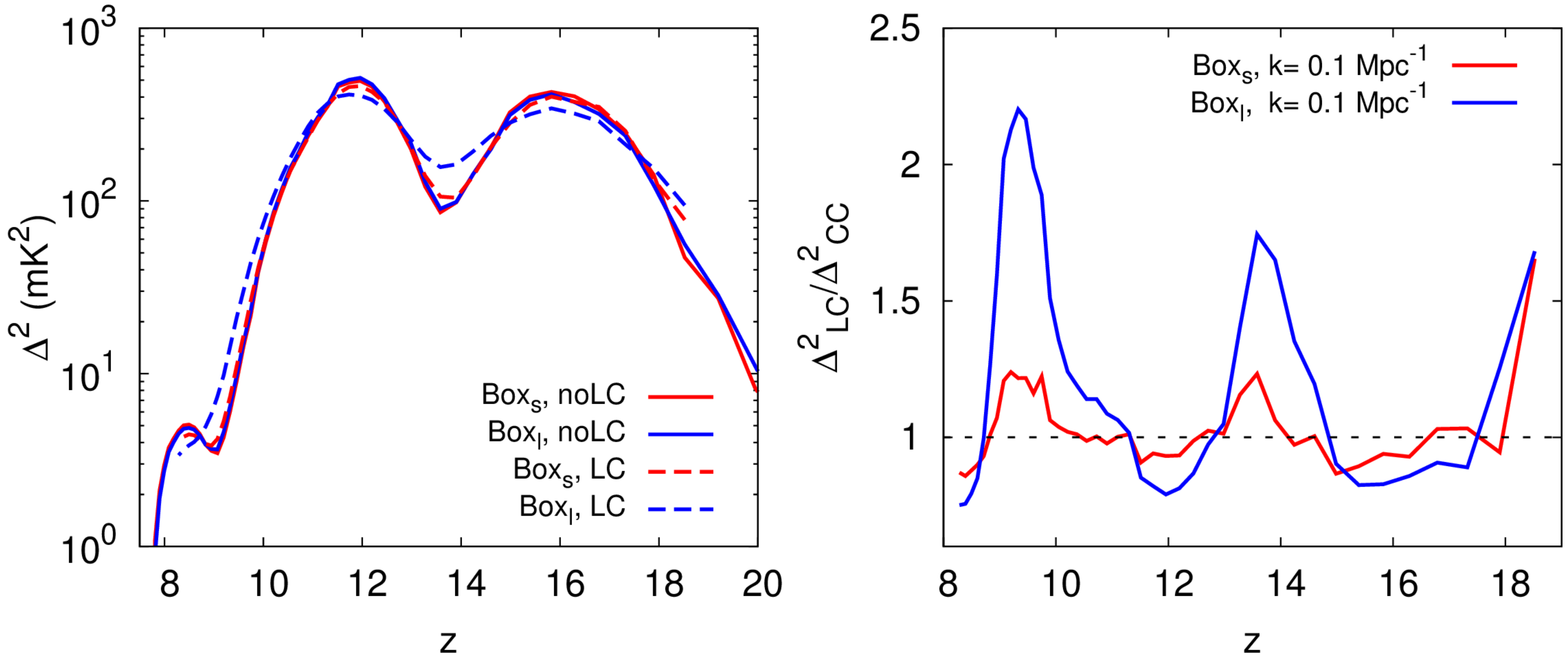


Minimum halo mass
~ 2 x 10^9 solar mass.

Minimum halo mass
~ 10^8 solar mass.

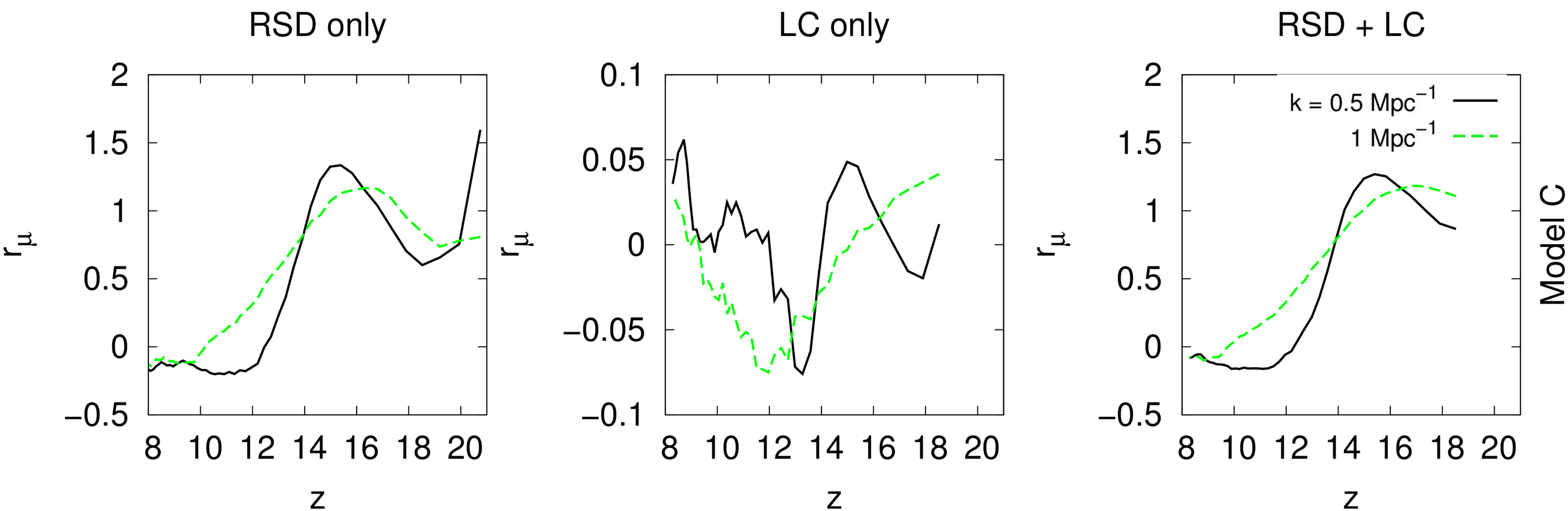
- Light-cone effect is larger if small mass halos are incorporated.

Box size impact



- Box_s = 100/h Mpc, Box_l = 200/h Mpc
- The smoothing is larger for large simulation box.
- The three peak nature of the plot can be completely smoothed out for large enough box ~ 600 Mpc (Mesinger et al. 2014, Datta et al. 2014).
- This will constrain us to choose smaller frequency band width during 21-cm observations to avoid strong light-cone effect

Anisotropy



- Anisotropy ratio $$r_\mu(k,z) = \frac{\left\langle \Delta^2(\mathbf{k},z)_{|\mu_k|>0.5} \right\rangle}{\left\langle \Delta^2(\mathbf{k},z)_{|\mu_k|<0.5} \right\rangle} - 1$$

μ = cos θ, with θ be the angle between the line of sight and the Fourier mode k.

- Redshift space distortion can cause significant anisotropy for all the models.
- LC anisotropy is not very significant for scales k ~ 0.5 / Mpc

Conclusions

- We find that the light-cone effect is much stronger and dramatic in presence of inhomogeneous heating and Lyα coupling compared to the case where these processes are not accounted for.
- One finds increase (decrease) in the coeval spherically averaged power spectrum up to a factor of 3 (0.6) at large scales (k ~ 0.05 / Mpc), though these numbers are highly dependent on the source model.
- Consequently, the peak and trough-like features seen in the evolution of the large-scale power spectrum can be smoothed out to a large extent if the width of the frequency bands used in the experiment is large.
- We argue that it is important to account for the light-cone effect for any 21-cm signal prediction during cosmic dawn.