21-cm signal from cosmic dawn

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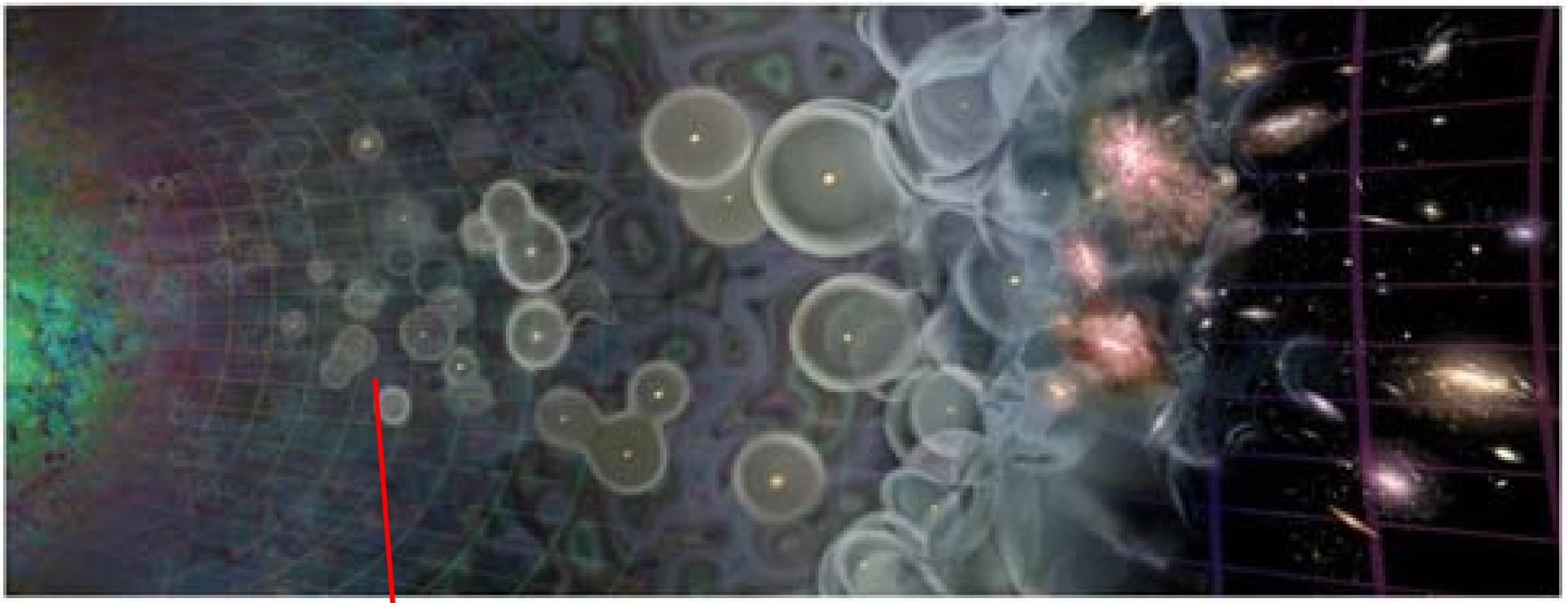
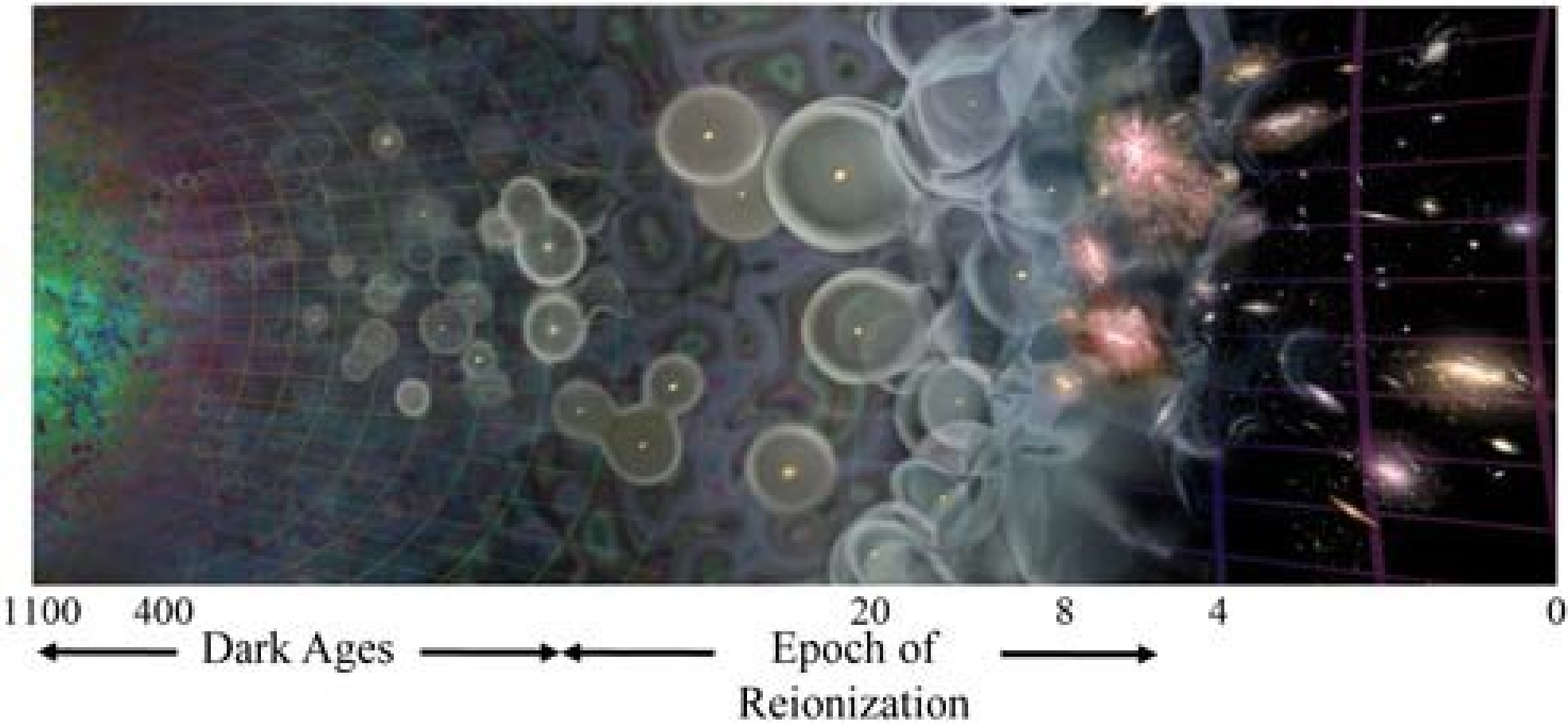
Cosmic dawn and Epoch of Reionization



(Cosmic Dawn)
Formation of
first sources of
light

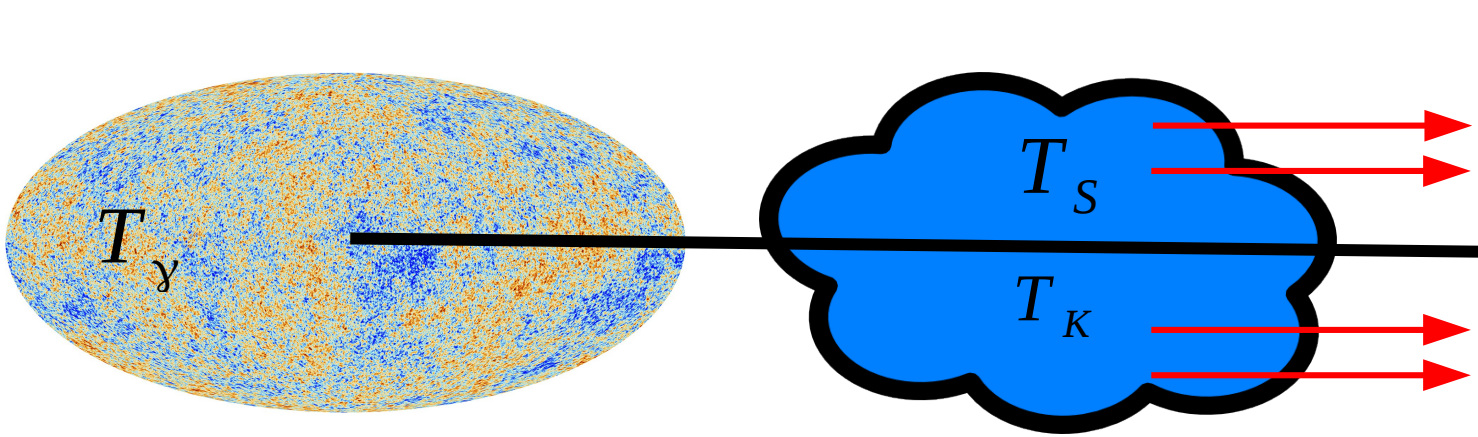
HI of the
universe got
ionized

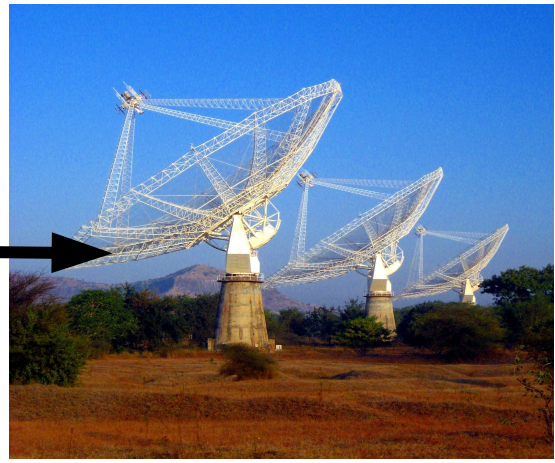
Questions to be asked



- When did first sources formed and reionization happened?
- What is the property of the first sources?
- What is the nature of the IGM during these epochs?

How 21 cm signal answers such questions?





CMBR

HI

$\nu = 1420\ MHz$

δT_b

Brightness temperature

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

Neutral fraction

Density contrast

Peculiar velocities

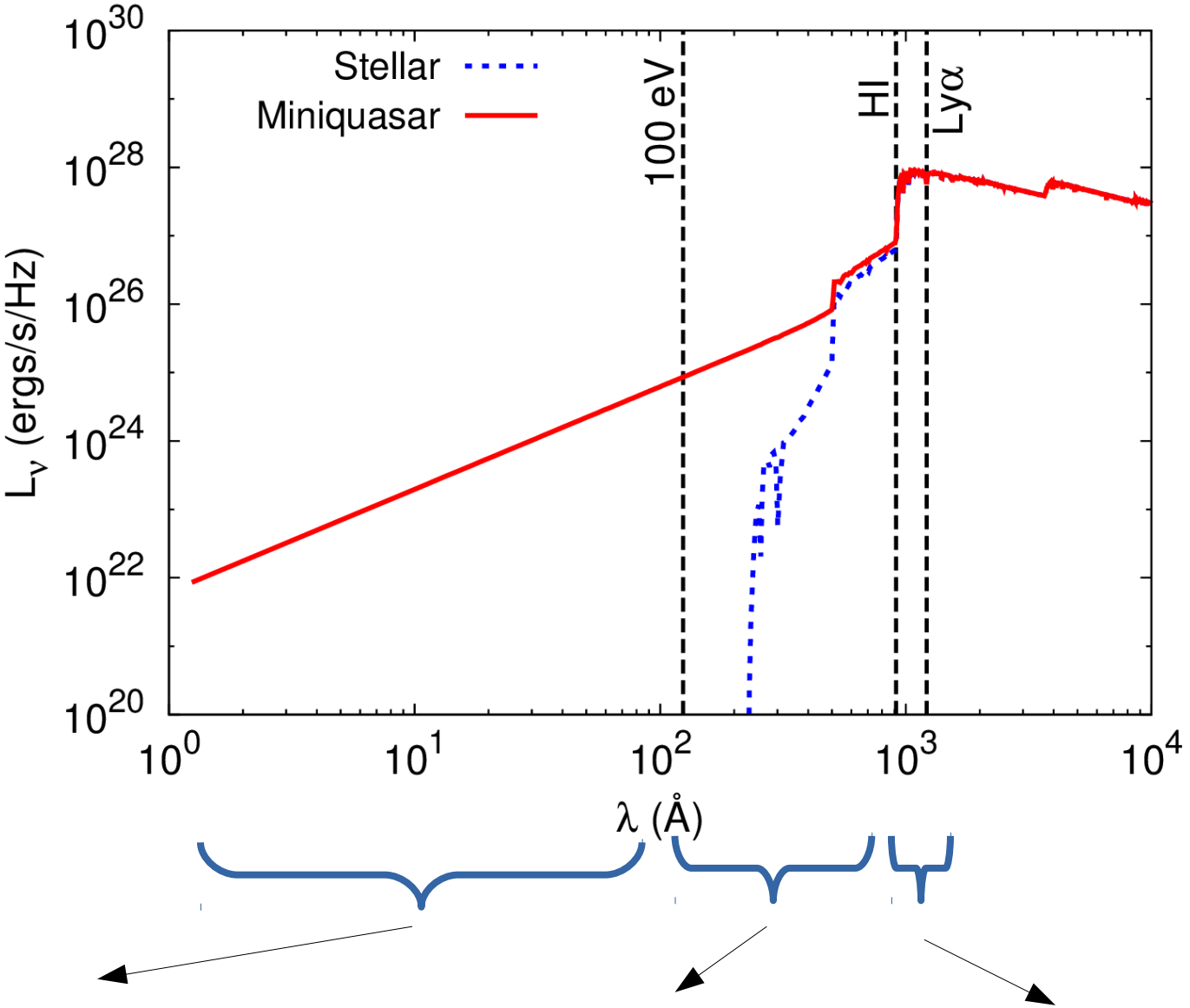
Spin temperature

Set by CMB, Collisional and Lyα coupling

Emission signal : Ts > Tγ (δTb > 0)

Absorption signal : Ts < Tγ (δTb < 0)

Astrophysical dependence



X-ray photon

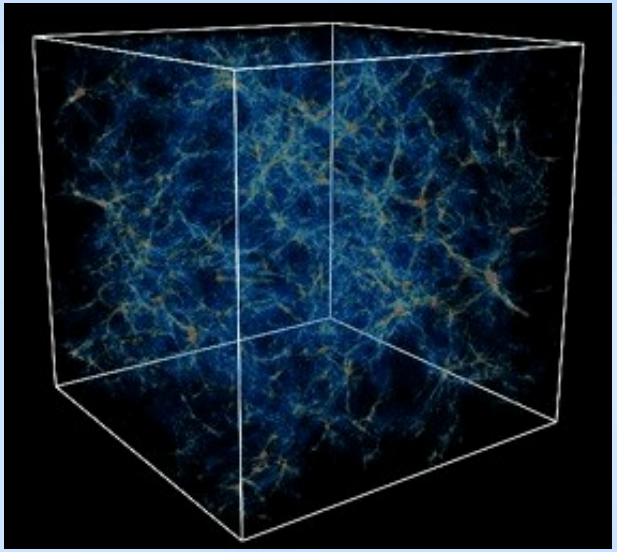
(Heating of the IGM)

UV photon

(ionization of HI)

Lyα photon (Lyα coupling or Wouthysen-Field effect)

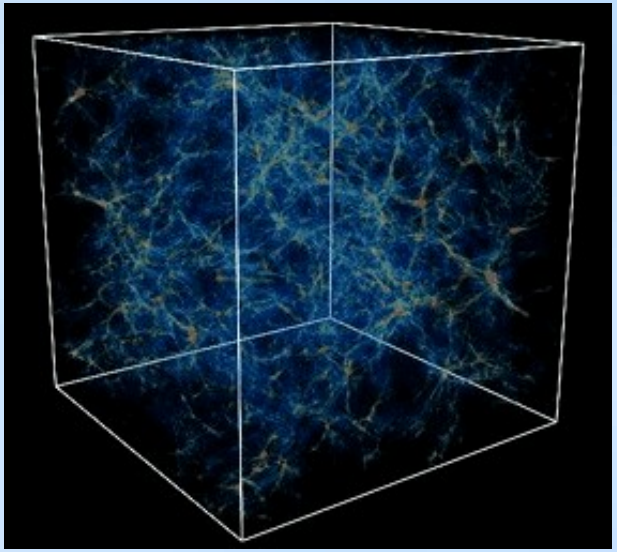
Why modelling of 21-cm signal is important?



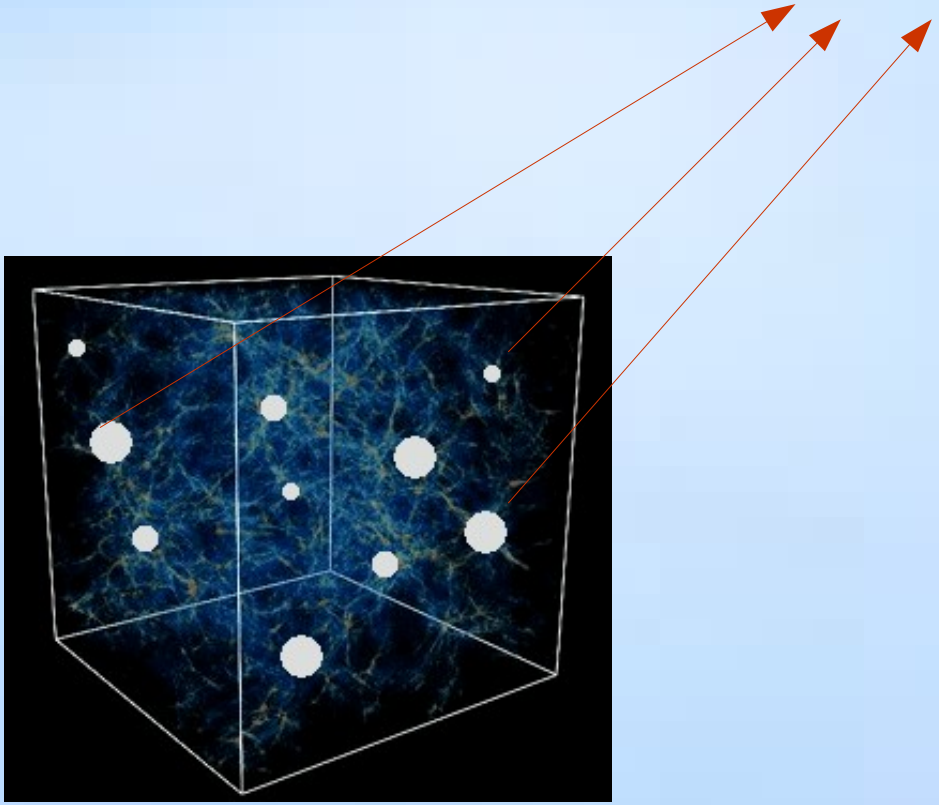
- Dark matter N-body code : CUBEP3M
- Box size : 200 cMpc/h.
- Particle number : (1728)^3
- Particle Mass:

  2 x 10^8 $M_{\odot}$

Why modelling of 21 cm signal is important?



- Identify Dark matter halos.



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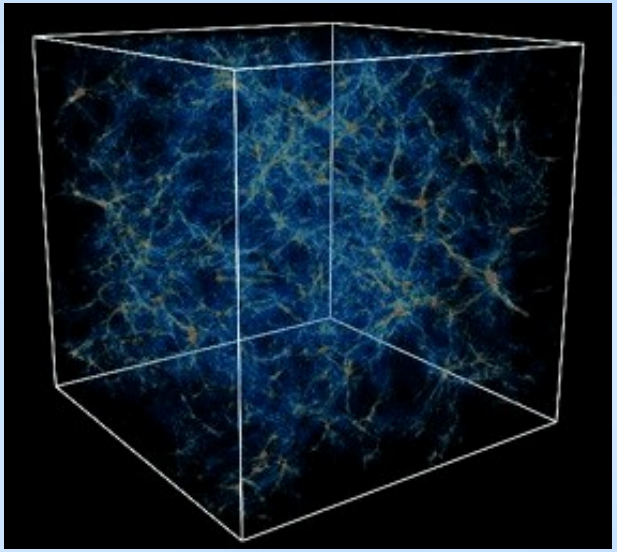
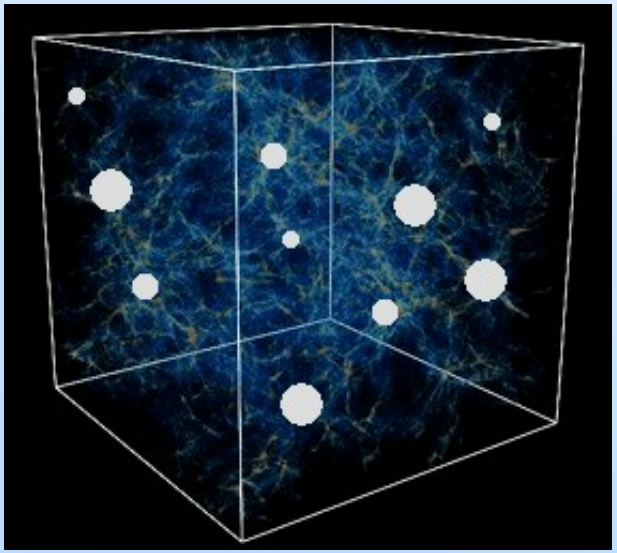
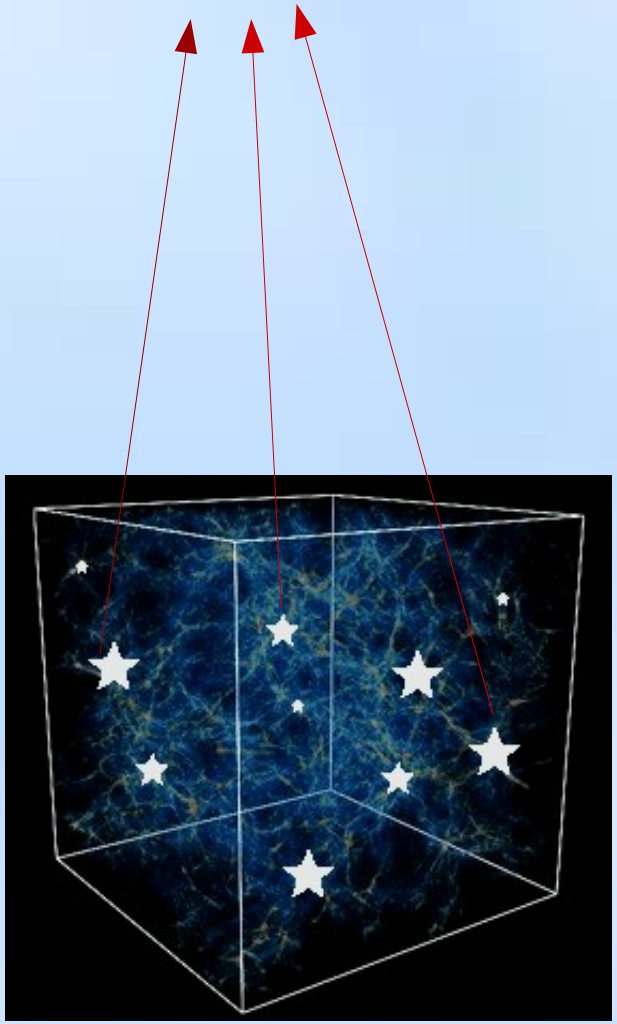


- Identify Dark matter halos.
- These halos are embedded with source of radiation.





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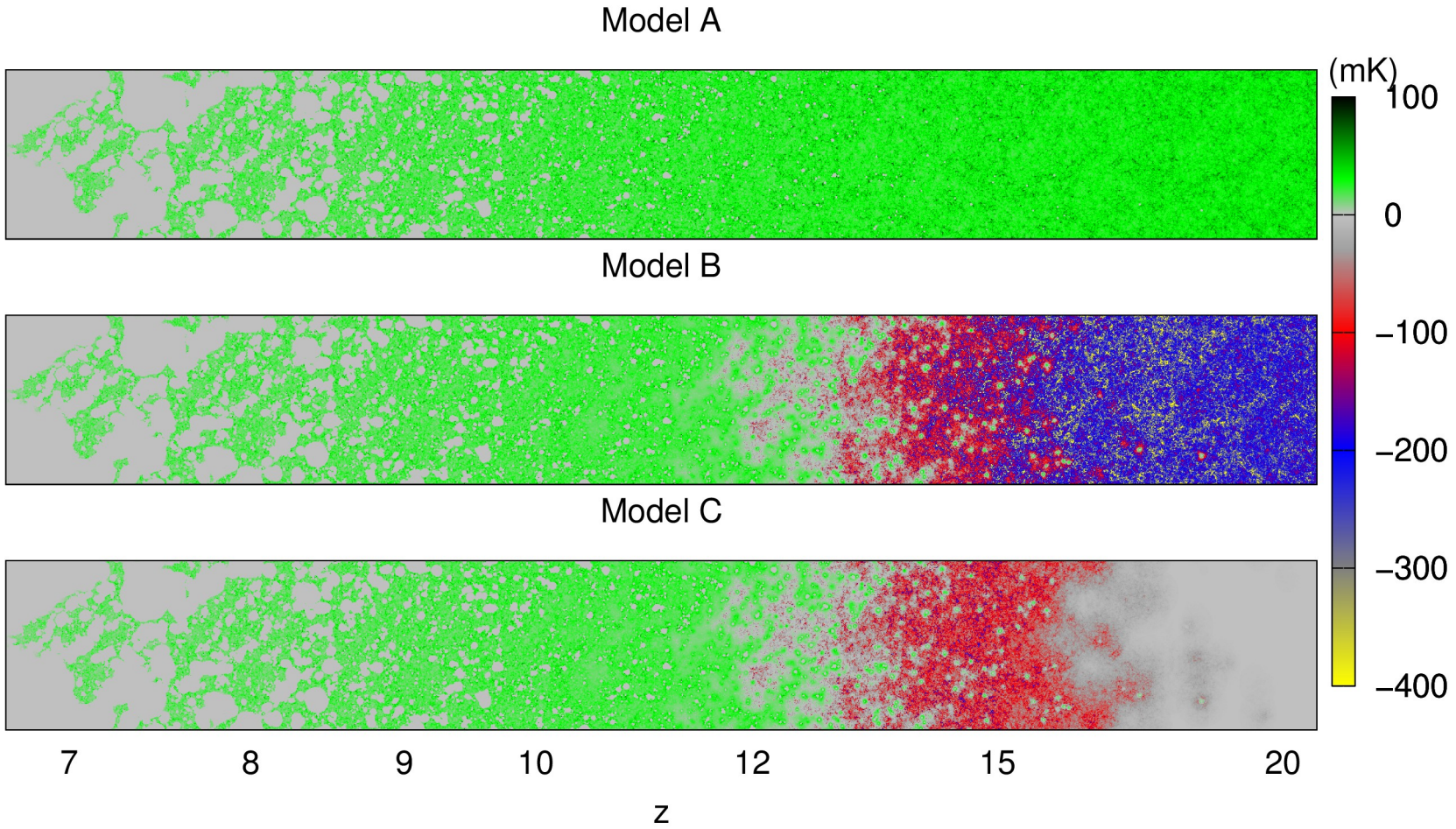
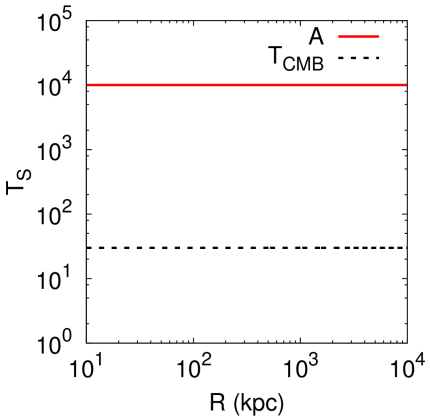
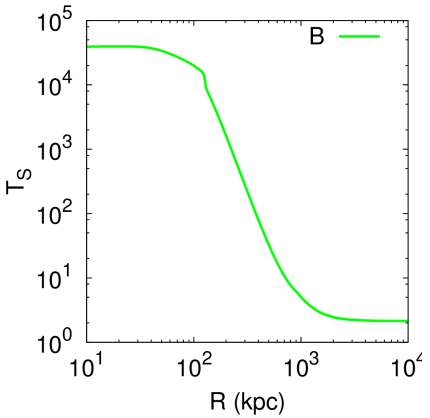
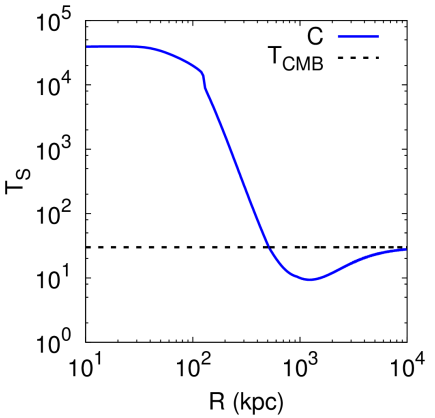
Effect of heating and Lyα coupling on 21-cm signal







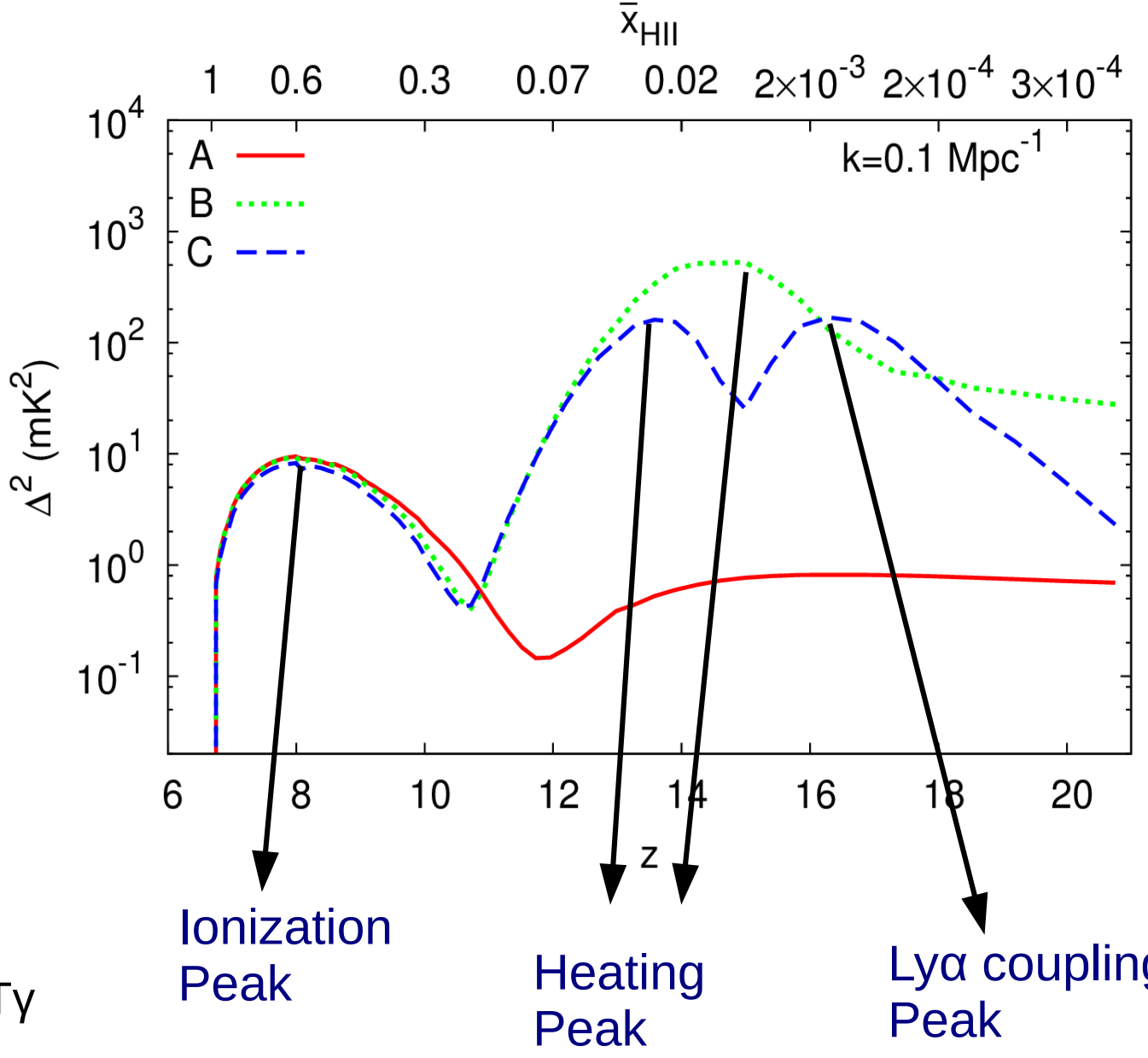


Model A : Ts>>Tγ

Model B: Ts=Tk

Model C : Ts=Ts(Tk,Xα)

Power spectrum



Model A : Ts>>Ty

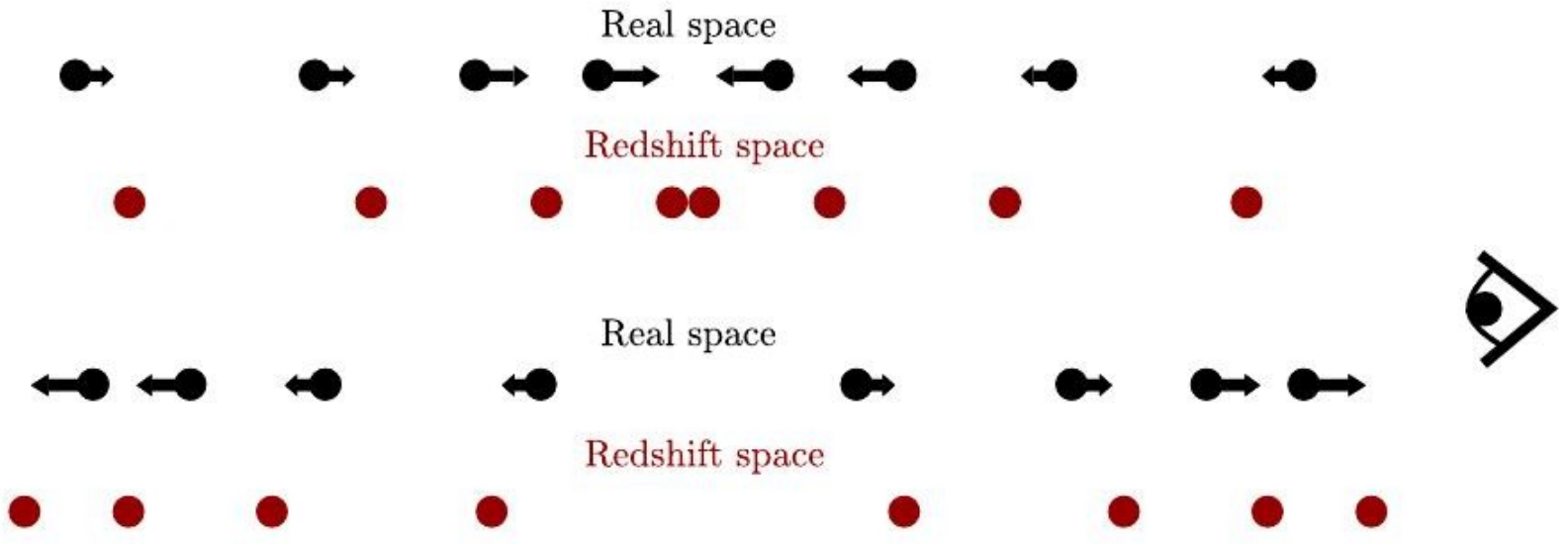
Model B: Ts=Tk

Model C : Ts=Ts(Tk,Xα)

Cosmological Dependence

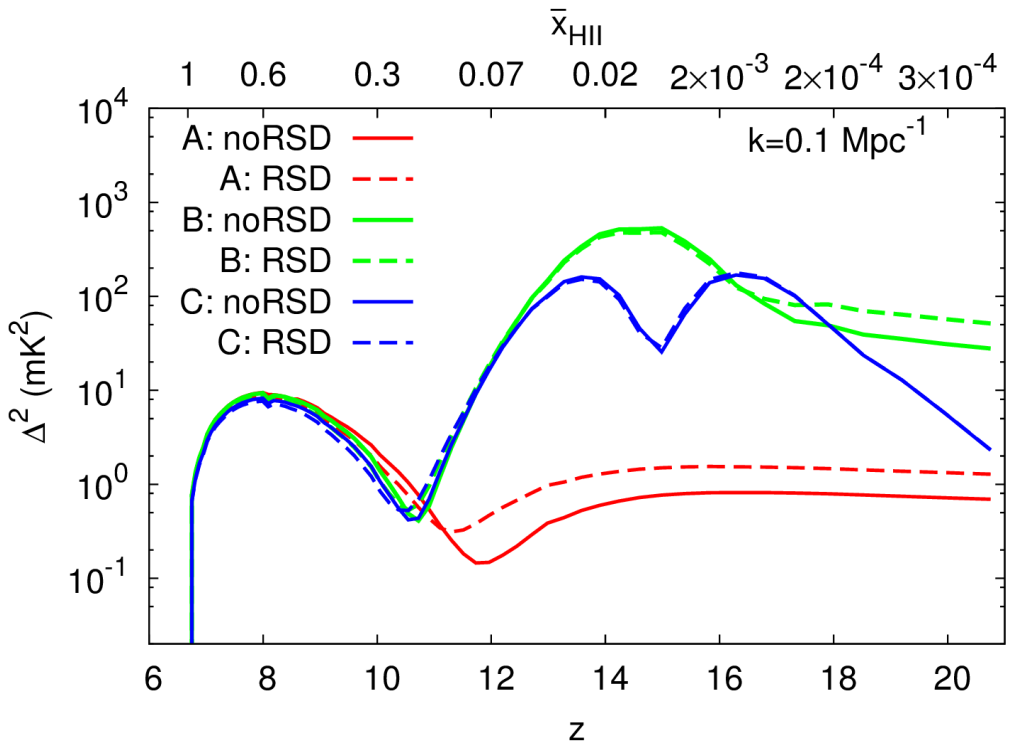
$$\delta T_b = 27\, x_{HI}\,(1+\delta_B)\left(\frac{H}{dv_r/dr + H}\right)\left(\frac{\Omega_B h^2}{0.023}\right)\left(\frac{0.15}{\Omega_m h^2}\,\frac{1+z}{10}\right)^{1/2}\left(\frac{T_S - T_\gamma}{T_S}\right) mK$$

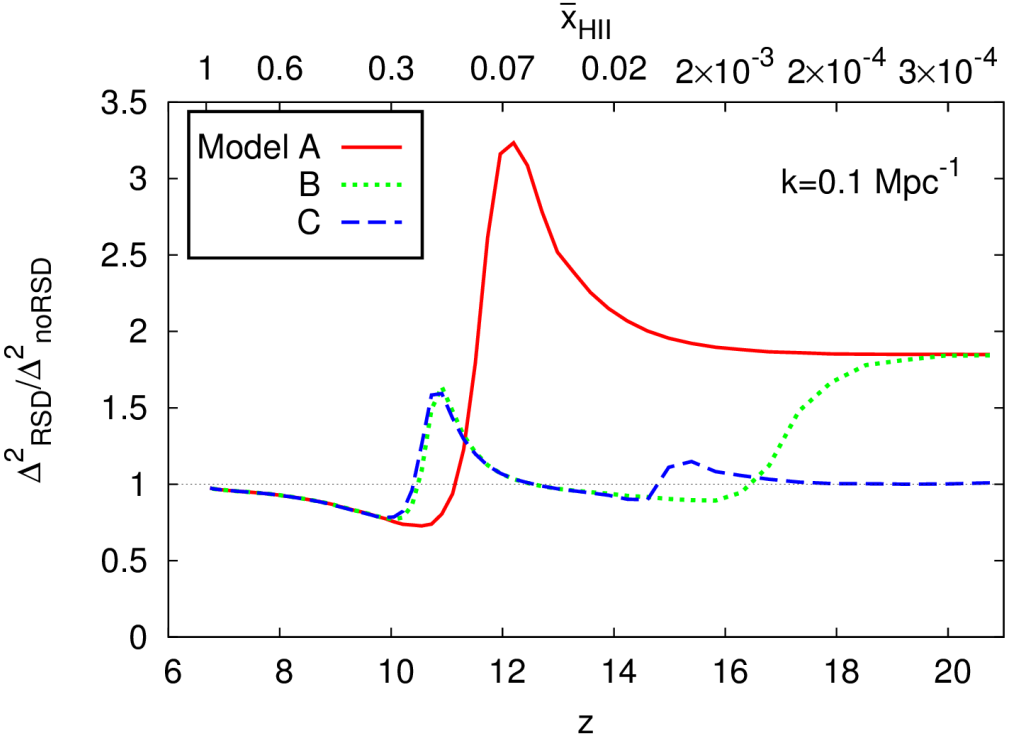
Peculiar velocities



Over/under dense regions will appear more over/under dense at large scales.

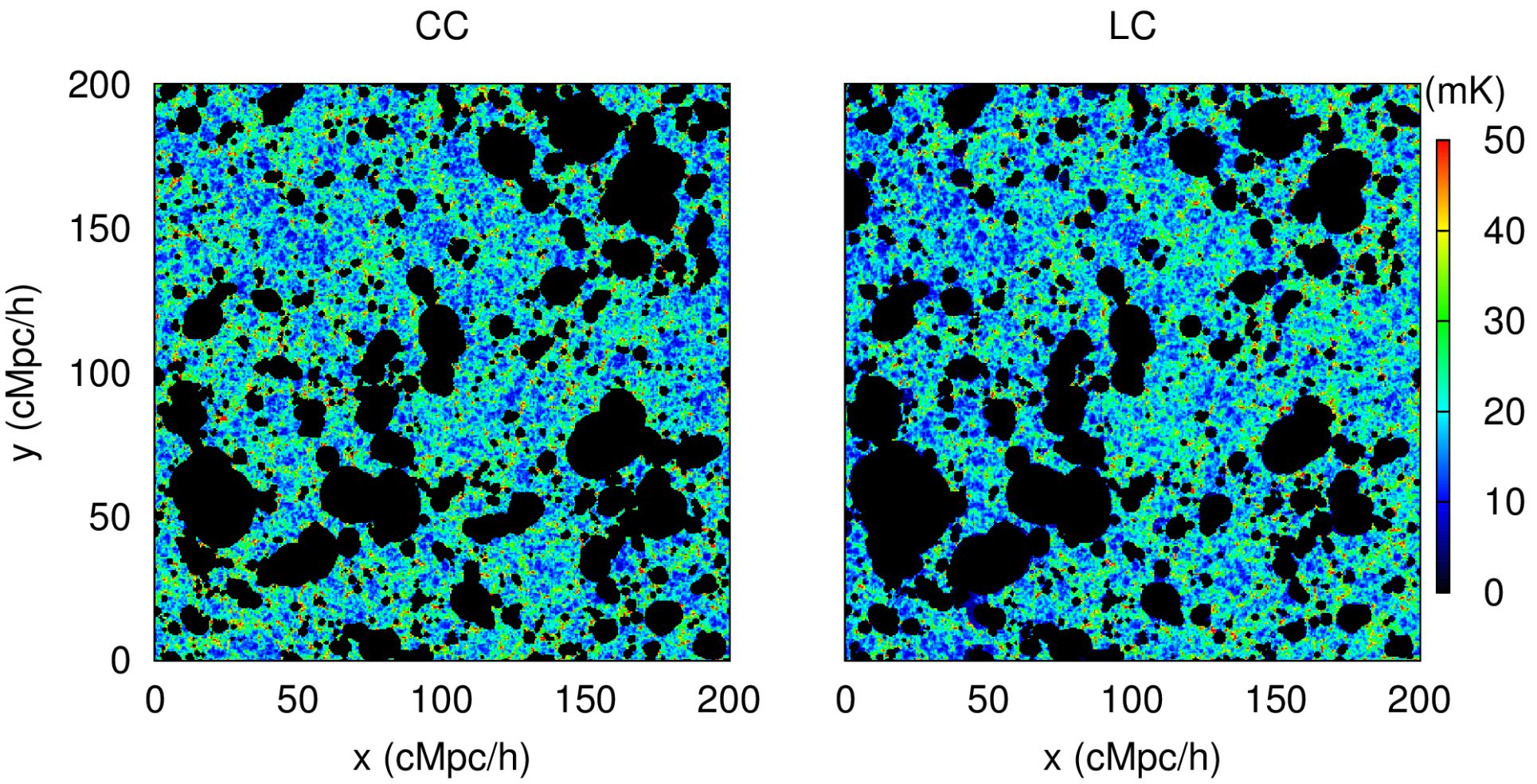
Redshift space distortion





- Model A : Effect of RSD is very strong before the universe got 20% ionized by mass.
- Model C : No significant effect of RSD.

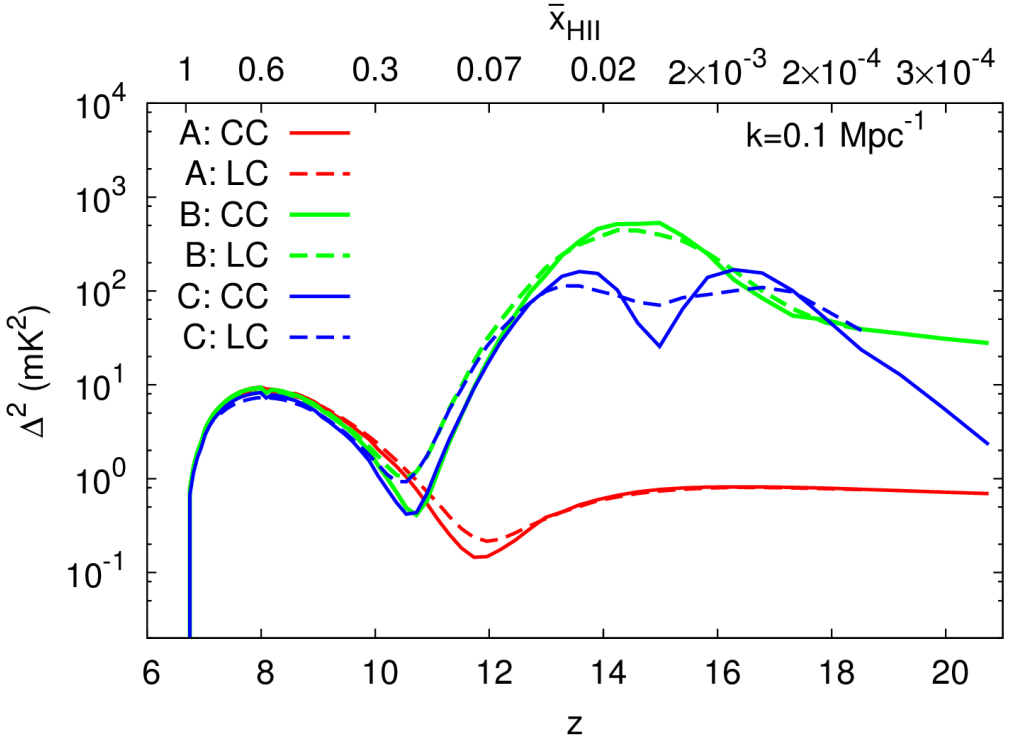
Light cone effect

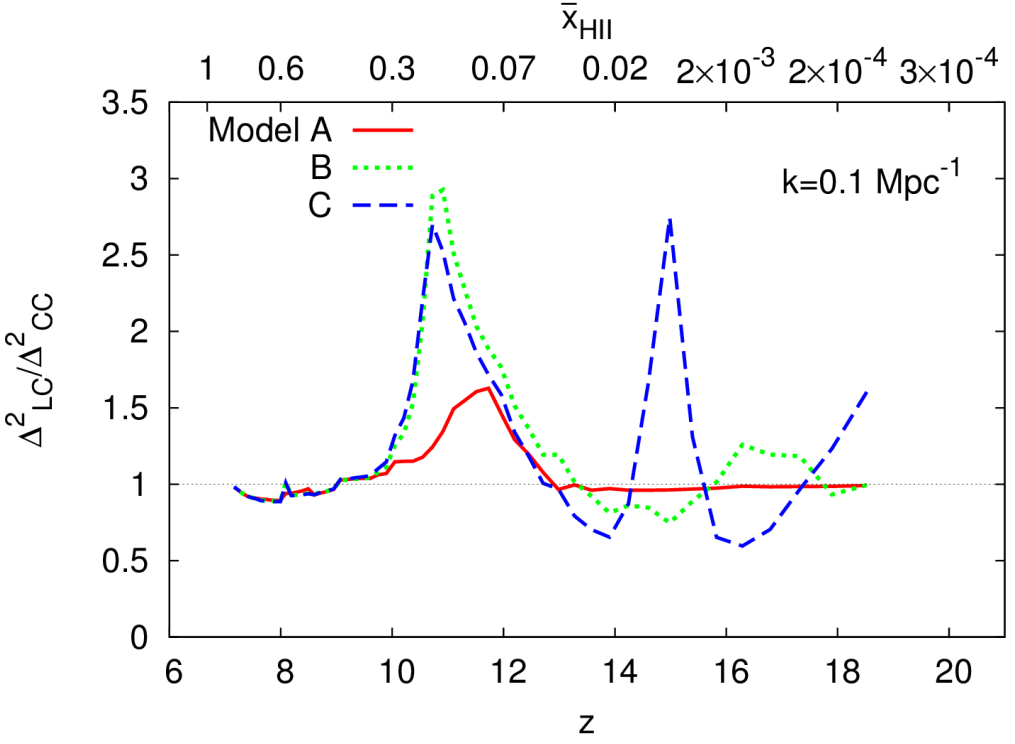


Coeval cube (CC) at redshift 9.5 (with mass averaged ionization fraction 0.5)

Light conel cube (LC) of the same CC.

Light cone effect

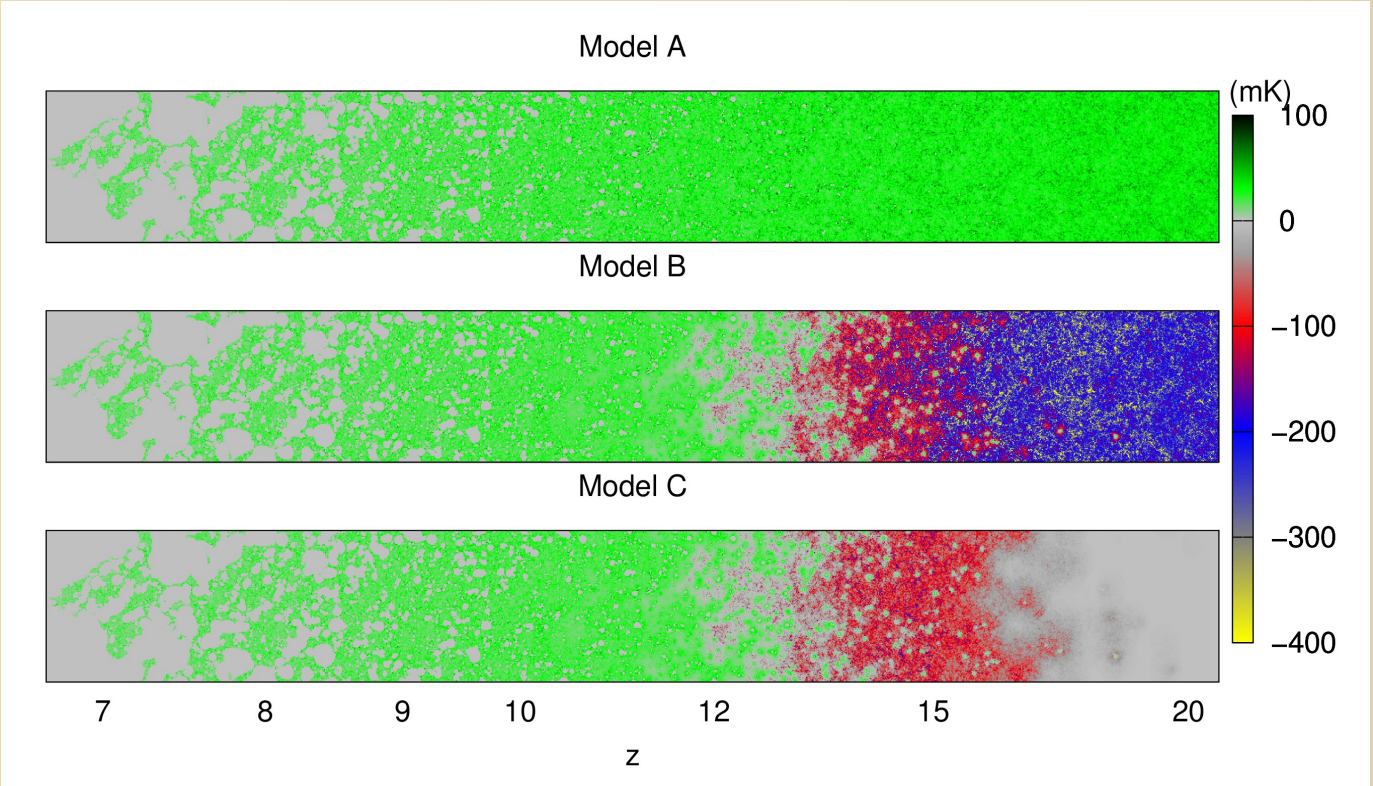




- Model A : Light-cone effect has the largest impact when reionization is ~20 % and ~80% completed.
- Model C : Light-cone effect has significant impacts in various stages of reionization.

Conclusions

- Effect of inhomogeneous Lyα coupling and X-ray heating is very important to study during first phase of reionization (cosmic dawn). These provide distinct peaks in the evolution of 21 cm power spectrum.



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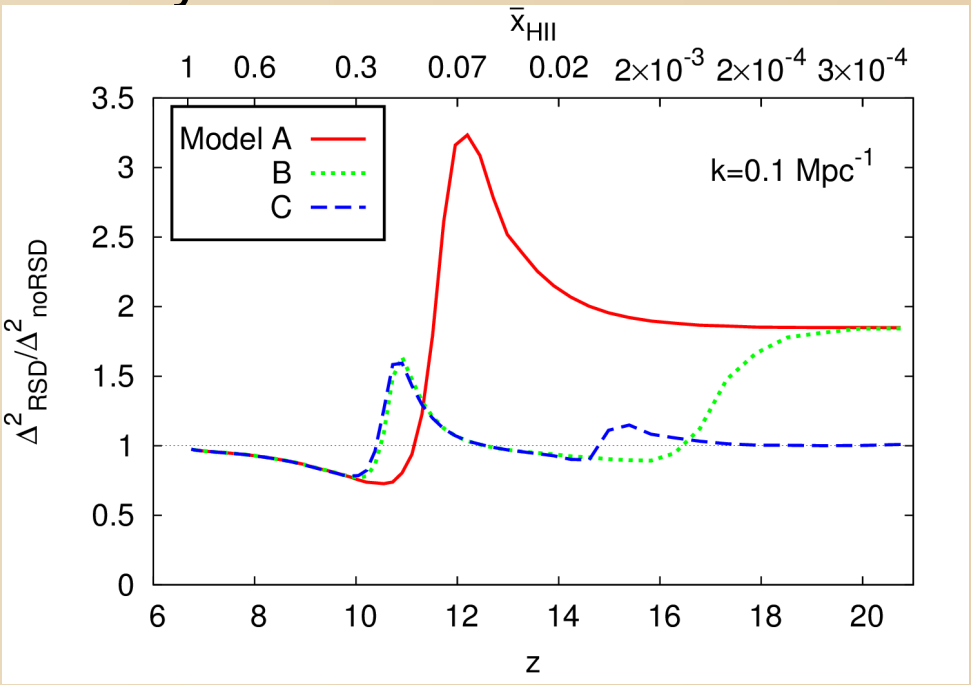

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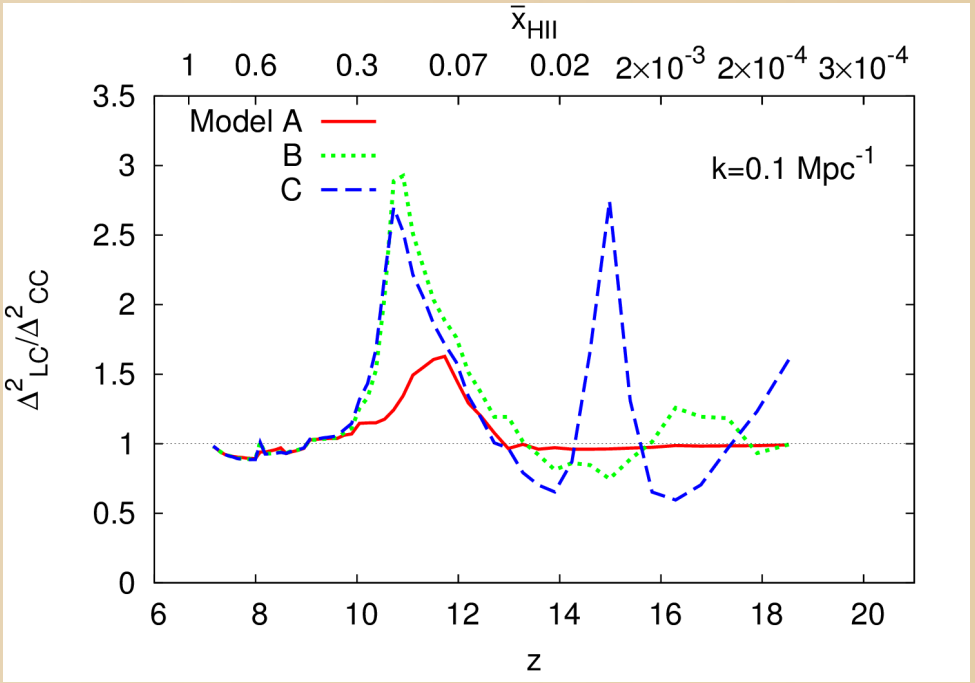

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Thank you