Can UV radiation of star forming galaxies reionize the universe?

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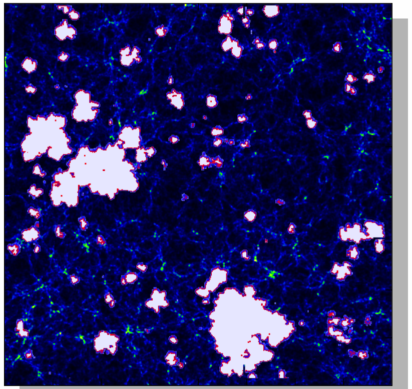
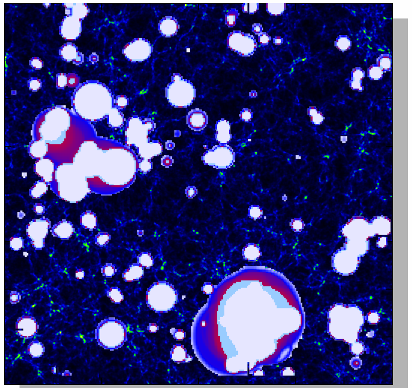
Introduction

- How does the SED of the first sources influence reionization?
- Can we put constraints on the escape fraction?
- How does reionization proceed regarding the large scale structure?



- Reionization simulation using pCRASH:
  - Source model
  - First results
- Approximate radiative transfer scheme

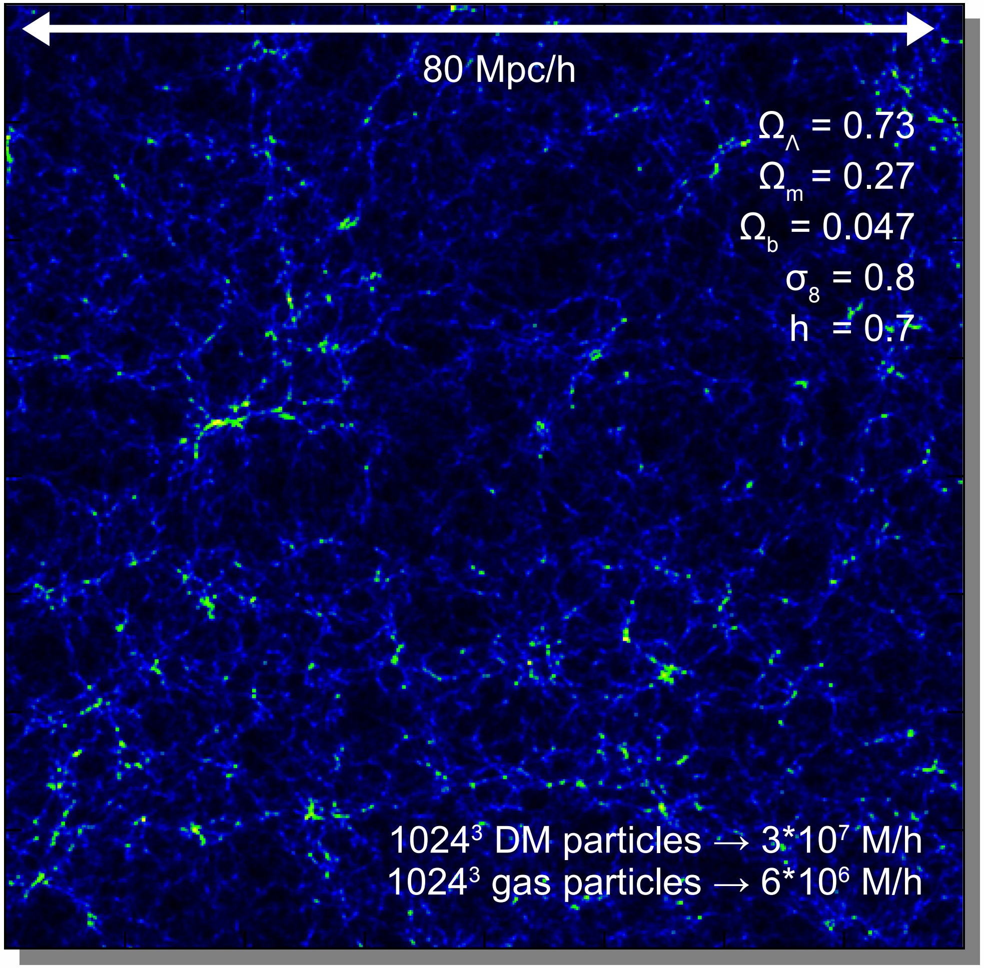


Hydrodynamical Simulation

Simulation with SPH code Gadget 2 [1]

including:

- Radiative & Compton cooling
- UV background [3]
- Star formation [2]
- Thermal feedback of supernova [2]
- Effects of stellar winds [2]



[1] Springel 2005

[2] Springel & Hernquist 2003

[3] Haardt & Madau 1996

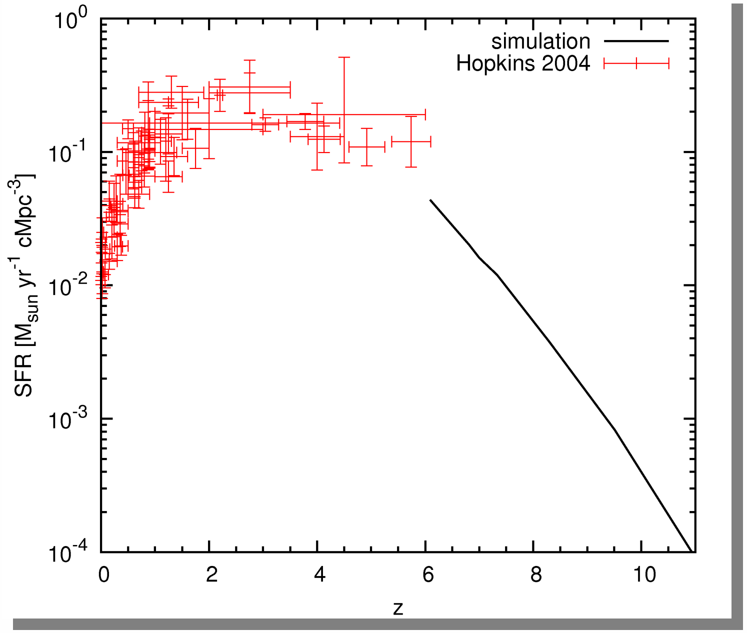
Source model

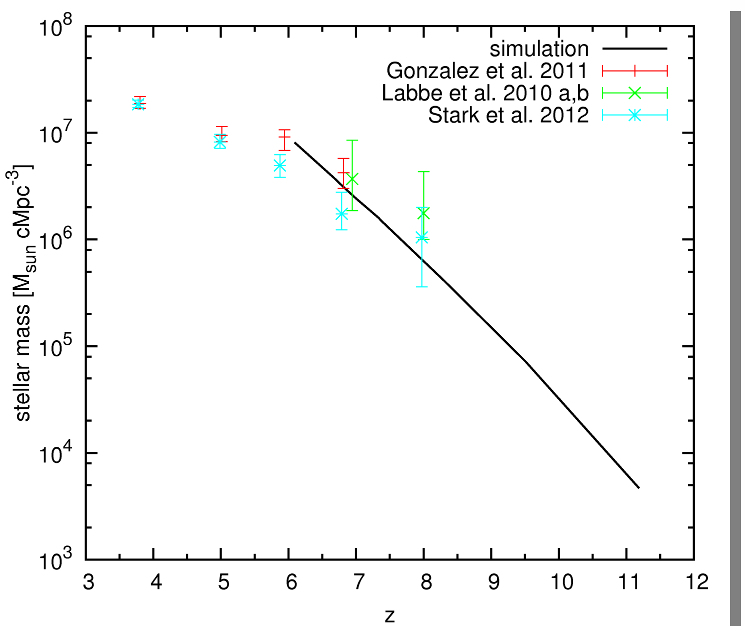
- Model sources with starburst spectra [4] using star particle information from Gadget: mass, age & metallicity
- Model spectra of halos by summing up spectra of each star particle
- Assume escape fraction = 0.2 [5,6]

[4] Leitherer et al. 1999

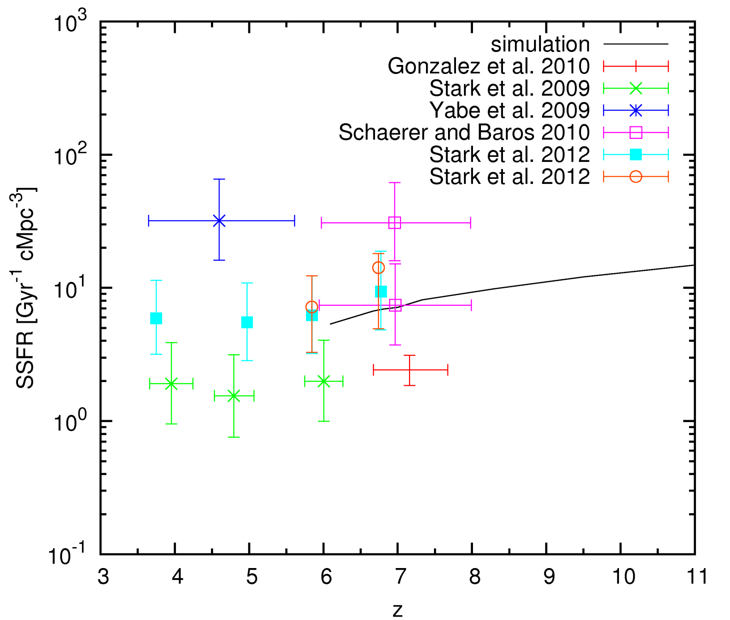
[5] Mitra et al. 2012

[6] Yajima et al. 2012





Considering only halos with $|M_{UV}| > 18$



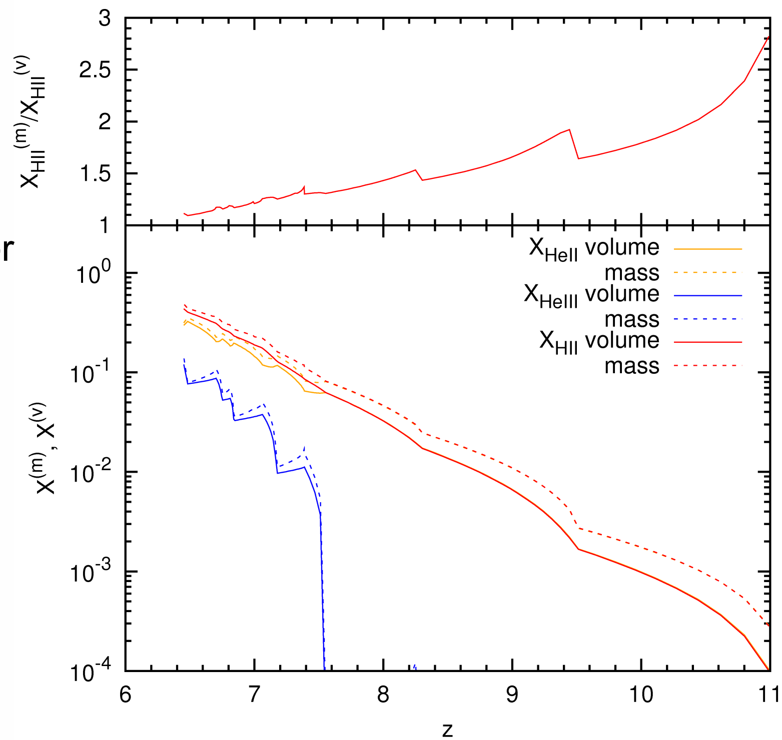
Radiative Transfer with pCRASH

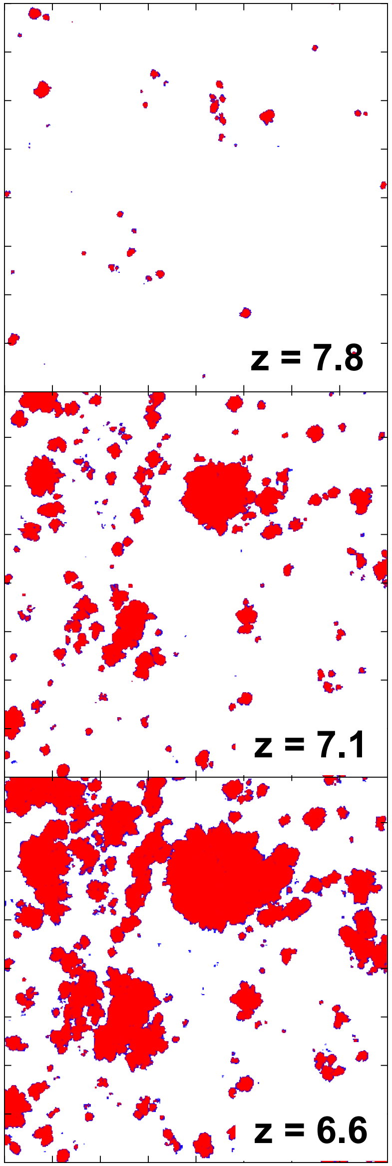
Post-processing snapshots of hydrodynamical simulation using:

- density, temperature
- clumping factor [7]
- halos with at least 5 star particles & circular velocity > 60km/s [8]

→ pCRASH[9] (3D ray-tracing radiative transfer scheme based on Monte Carlo technique)

+ spatially dependent clumping factor
+ reading different spectra





Ionization fractions for H & He

resolution: $512^3 \leftrightarrow$ 156 kpc/h

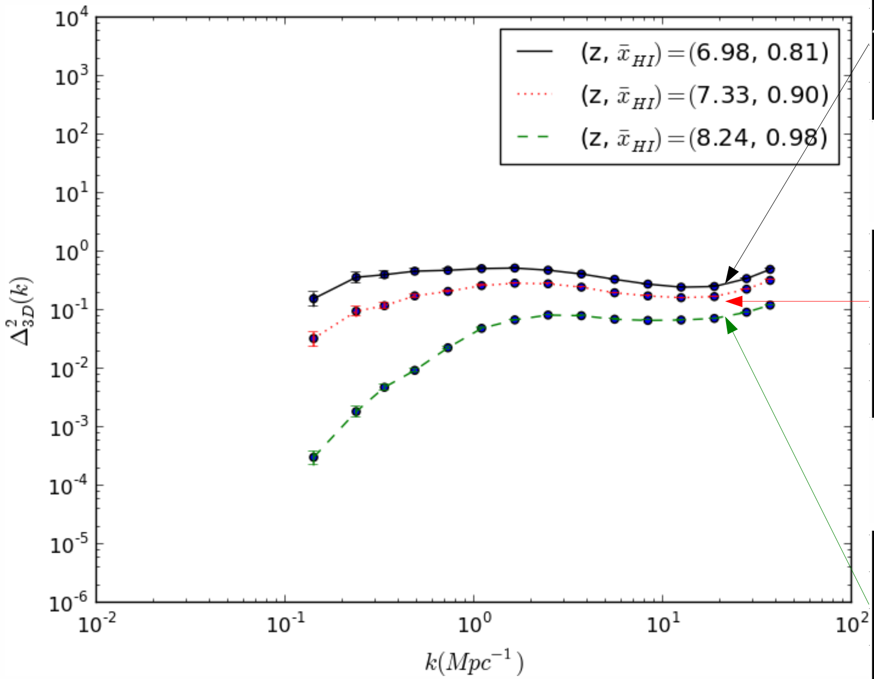
[7] Raičević & Theuns 2011

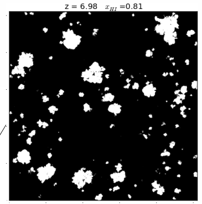
[8] Chiu, Gnedin, Ostriker 2001

[9] Partl et al. 2011

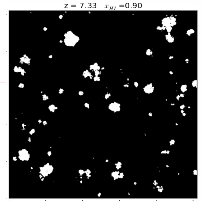
Statistics

21cm power spectrum

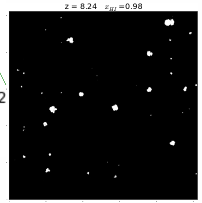




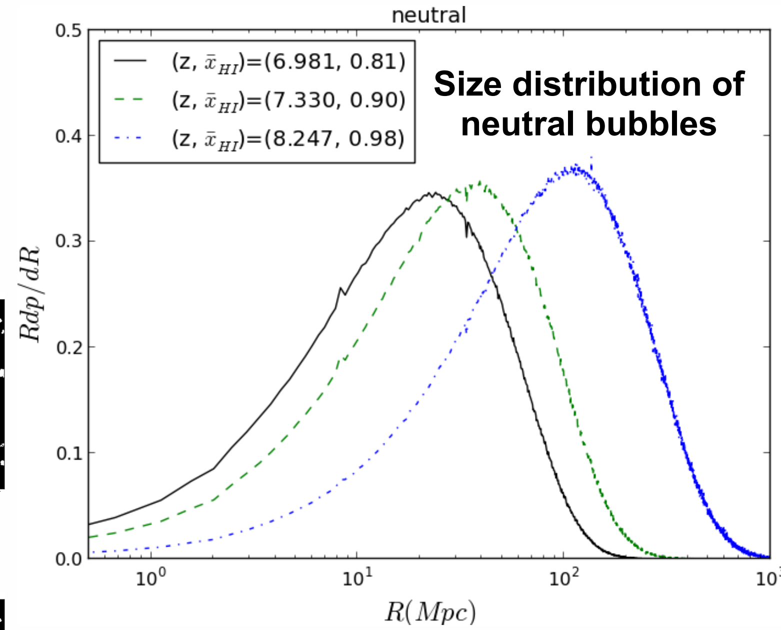
z = 6.98

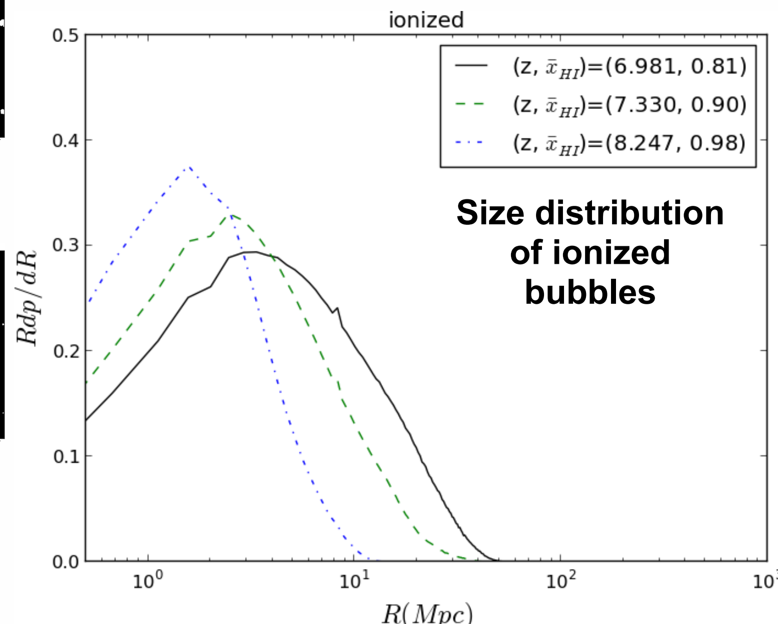


z = 7.33



z = 8.24





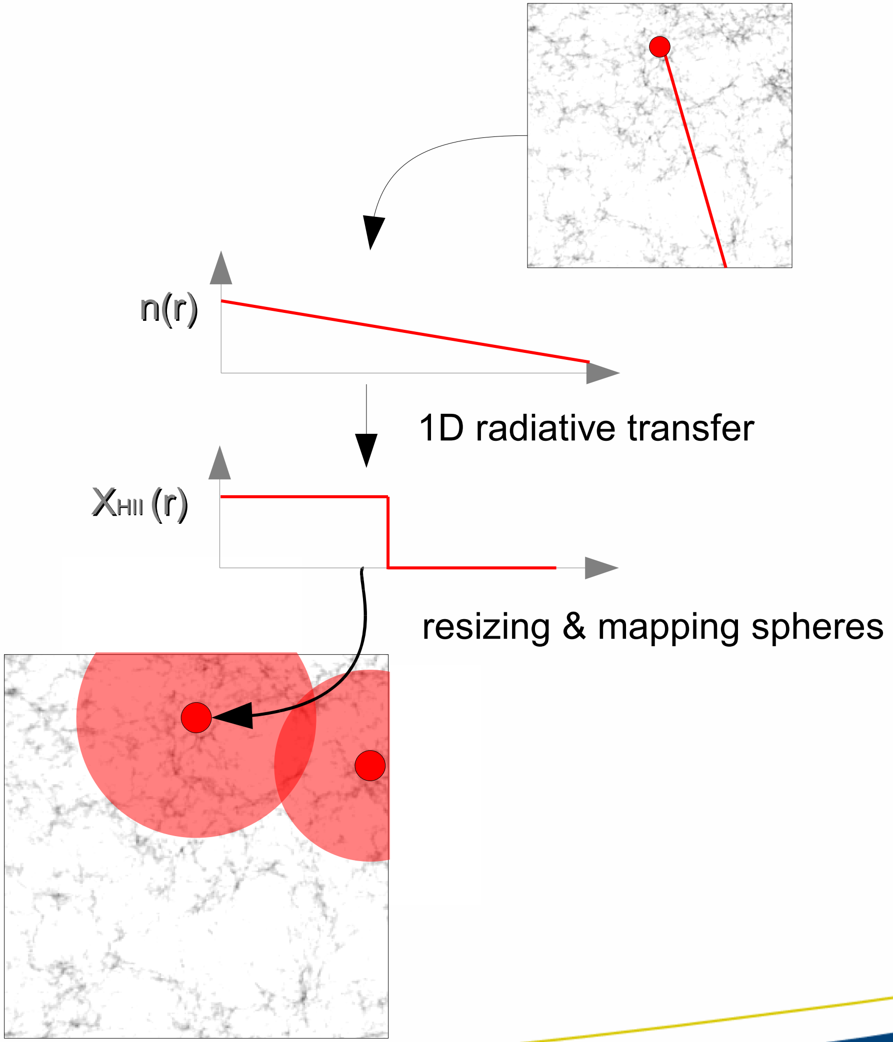
Fast approach to (3D) radiative transfer:
1D radiative transfer & mapping scheme

1D radiative transfer

- solves ionization fractions of H & He and temperature
- underlying density and temperature fields can be chosen
- time and spatial dependent

Mapping scheme

- Calculate averaged underlying radial density and temperature profiles
- Calculate ionization fractions, flux and temperature profiles of sources (1D radiative transfer)
- Correct for overlapping
- Map profiles to grid



Accounting for overlapping spheres

Scheme:

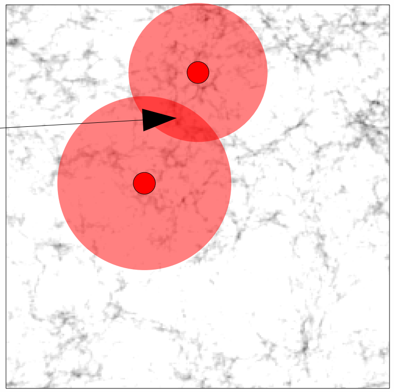
(1) Compute overlapping volume

(2) Resize spheres according to their luminosities and overlapping ionized volume

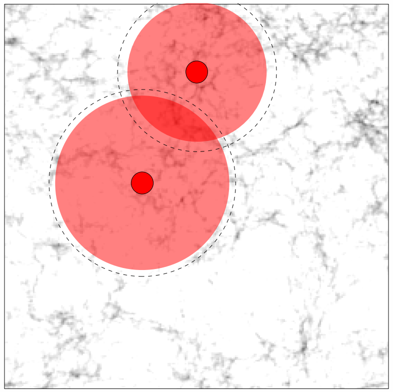
(3) Map and sum up photoionization rates of the overlapping spheres

(4) Compute the equilibrium state for X_{HII}, X_{heII} and X_{HeIII} from photoionization rates Γ_{HI} , Γ_{HeI} , Γ_{HeII} for each cell

(1)



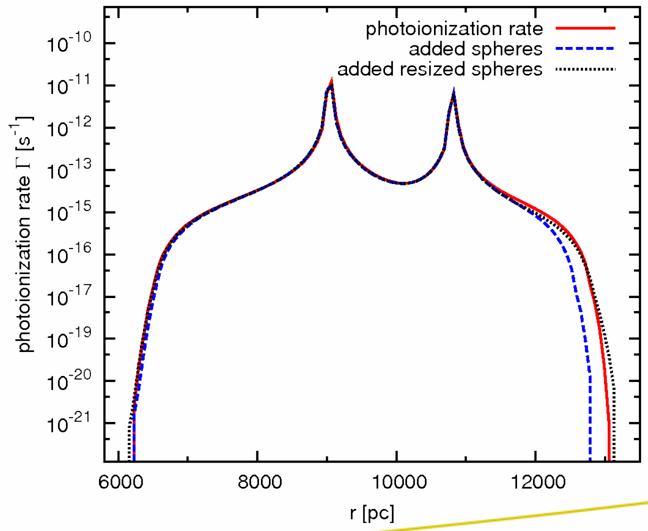
(2)



$$0=\frac{dn_{HII}}{dt}=\gamma_{HI}n_{HI}+\beta_{HI}n_e n_{HI}-\alpha_{HII}n_e n_{HII} \qquad \textbf{(4)}$$

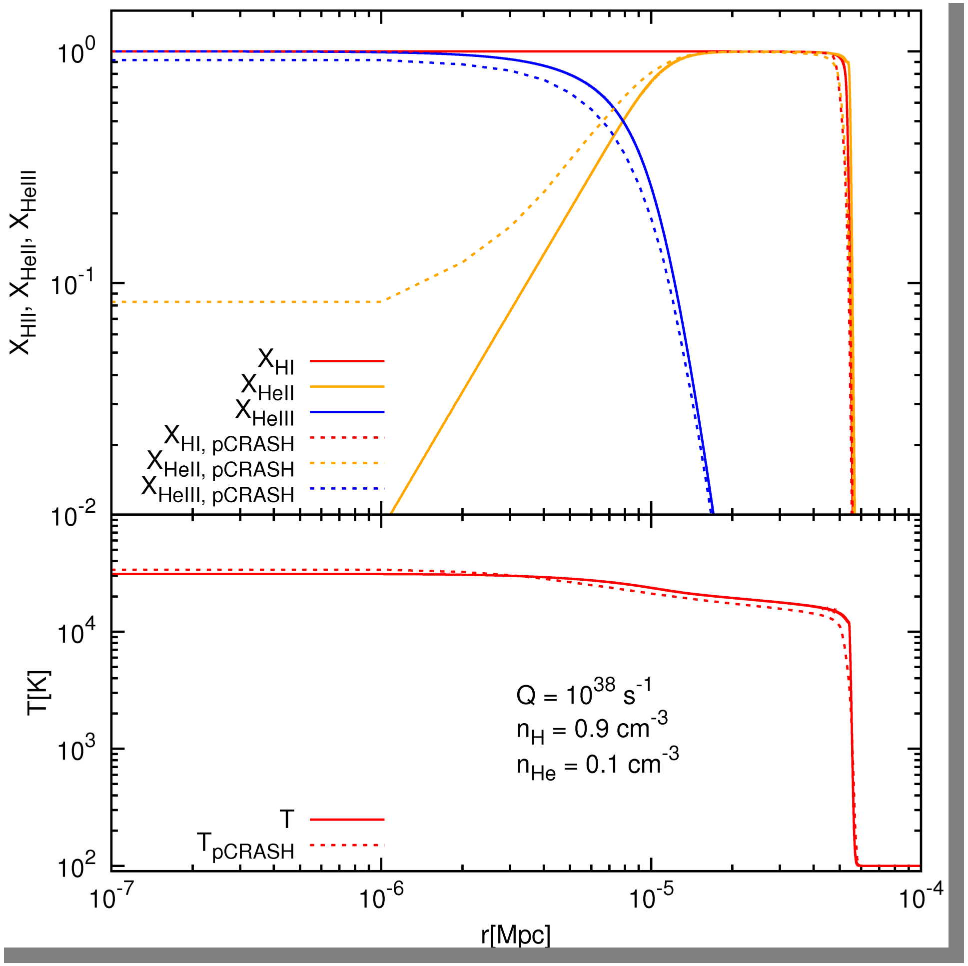
$$0=\frac{dn_{HeII}}{dt}=\gamma_{HeI}n_{HeI}+\beta_{HeI}n_e n_{HeI}-\beta_{HeII}n_e n_{HeII}-\alpha_{HeII}n_e n_{HeII}+\alpha_{HeIII}n_e n_{HeIII}$$

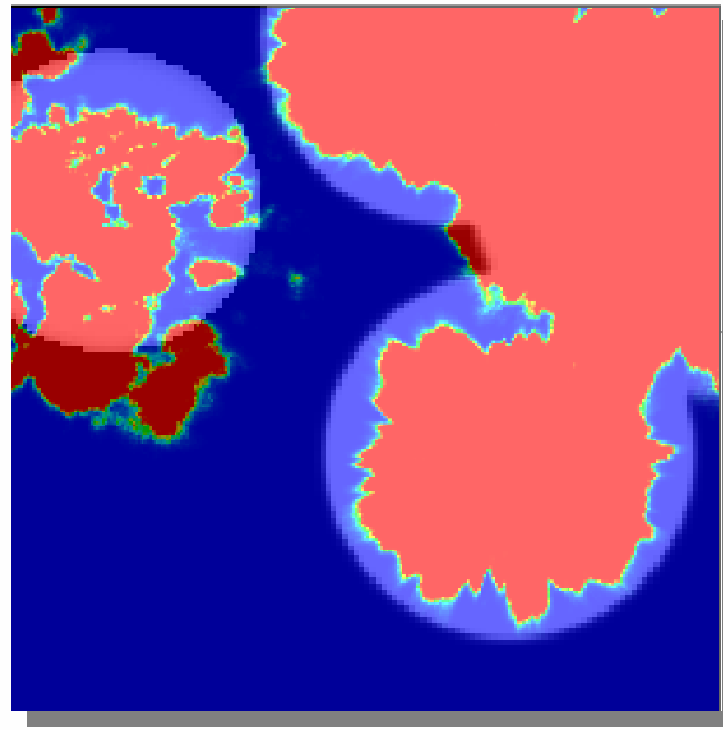
$$0=\frac{dn_{HeIII}}{dt}=\gamma_{HeII}n_{HeII}+\beta_{HeII}n_e n_{HeII}-\alpha_{HeIII}n_e n_{HeIII}$$



(3)

Comparing pCRASH & approximate scheme

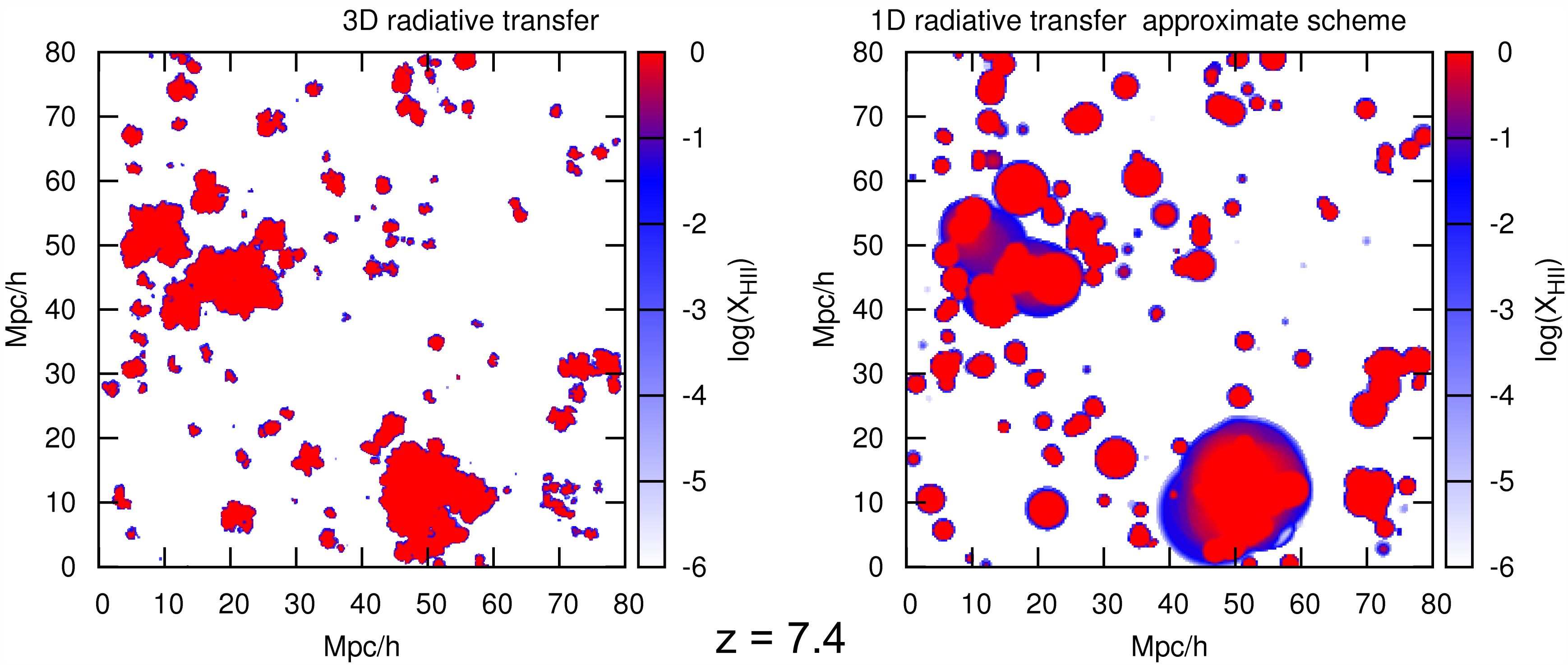




pCRASH: ionized/neutral

approximate scheme: ionized/neutral

Reionization simulation: comparing results of pCRASH & approximate scheme



Approximate scheme:

Ionized bubbles are slightly larger due to density averaging

→ $R_S \sim n_H^{-2/3}$

Conclusions

- Self-consistent source model: stellar populations are defined by the star formation in the hydrodynamical simulation.
- Star formation rates and stellar masses for halos $|M_{UV}|>18$ are within observational limits.
- Process of reionization:
  - Sources are located in denser regions: Reionization proceeds from high to low density regions
  - Ionized regions grow as bubbles

    → approximate radiative transfer scheme (mapping spheres) works well.

→ The universe reionizes late.

- Quasars contribute to reionization. [Simcoe et al 2012, Mortlock et al. 2011]
- $f_{esc}>0.2$ if only stellar populations are considered.
- Faint galaxies contribute to reionization