

KIAS cosmology workshop (Nov 3rd, 2020)

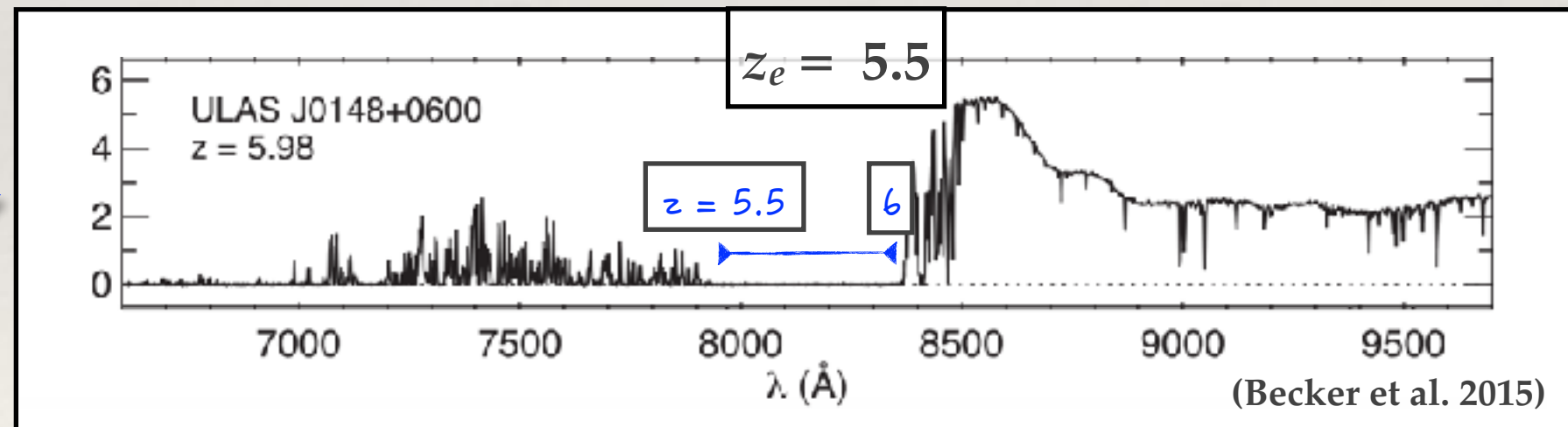
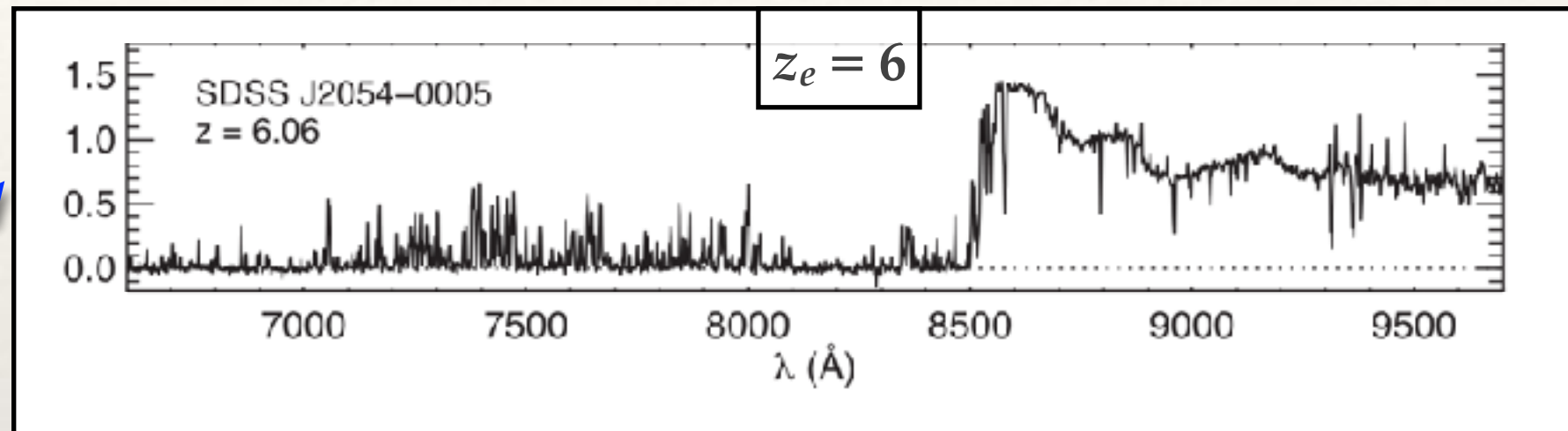
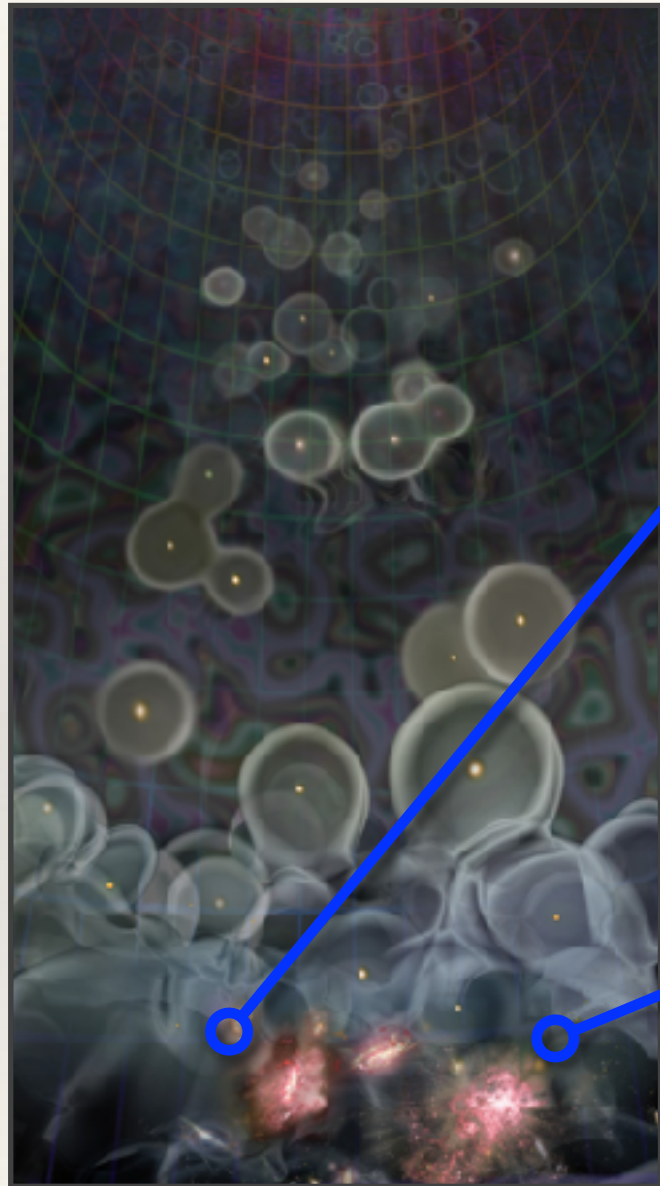
**Large-scale Variation in Reionization
History Caused by Baryon-Dark Matter
Streaming Motion**

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ArXiv:2010.12374

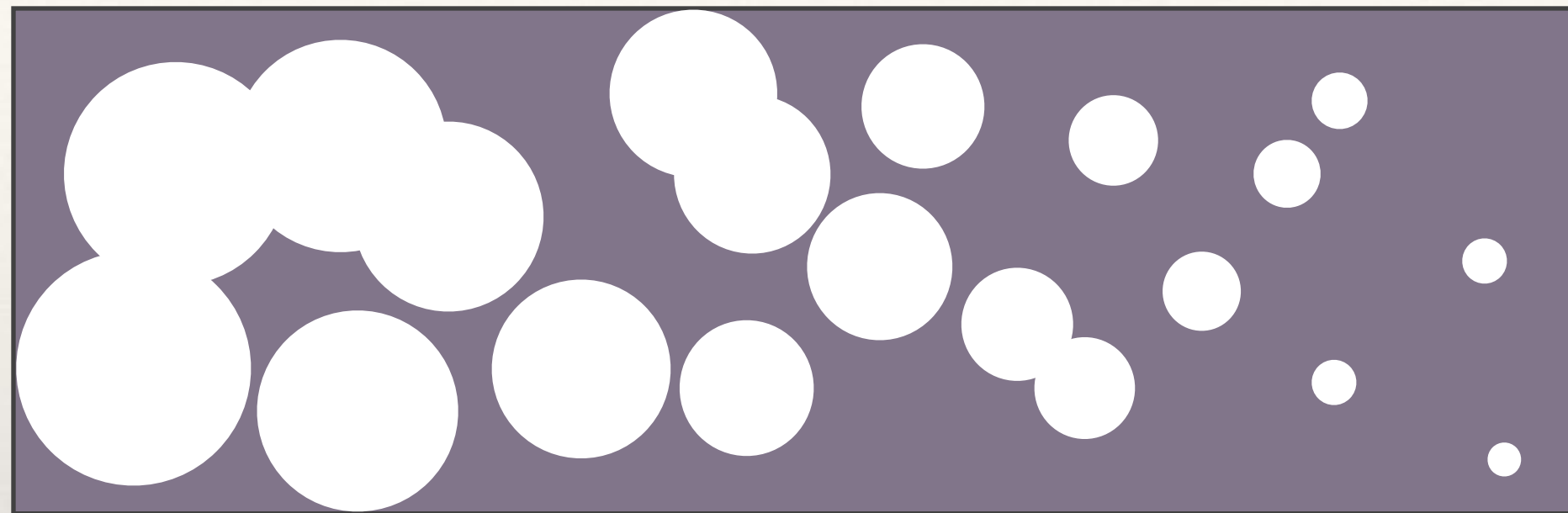
Multiplicity of the end-of-reionization

Quasar Spectrum



The reionization history seems to have a large scatter near the end.

Multiplicity of the end-of-reionization

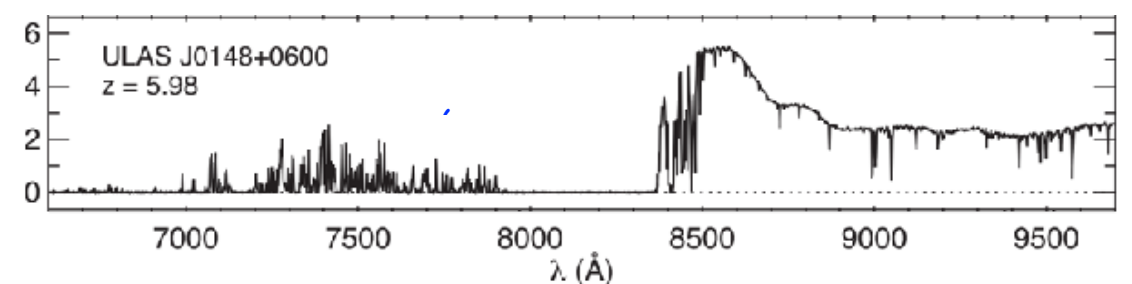
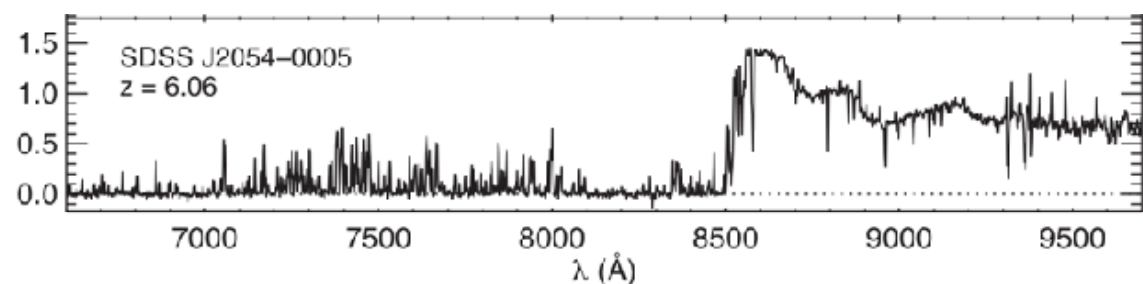
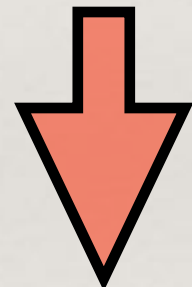
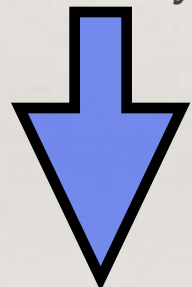


Early reionization ($z_e = 6$)

~ 150 cMpc

Late reionization ($z_e = 5.5$)

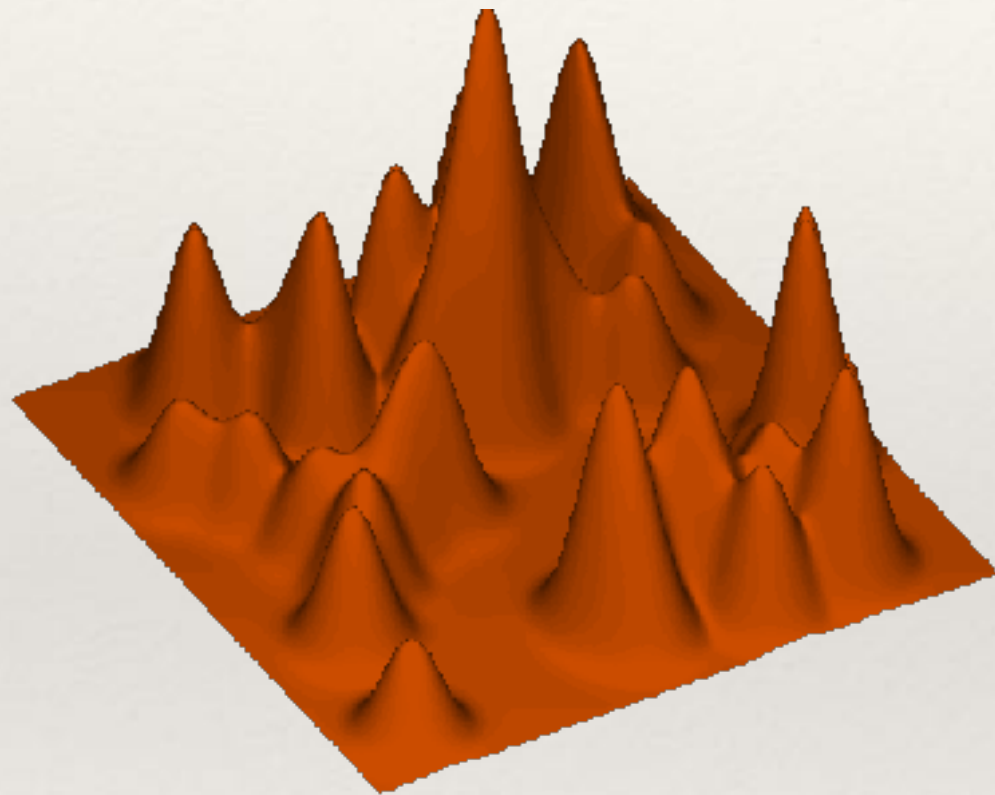
Mpc $\approx 3 \times 10^6$ lightyears $\approx 3 \times 10^{21}$ m



The density fluctuations of the universe is small at scales of > 50 Mpc.
Difficult to explain the reionization process being inhomogeneous over ~ 150 Mpc.

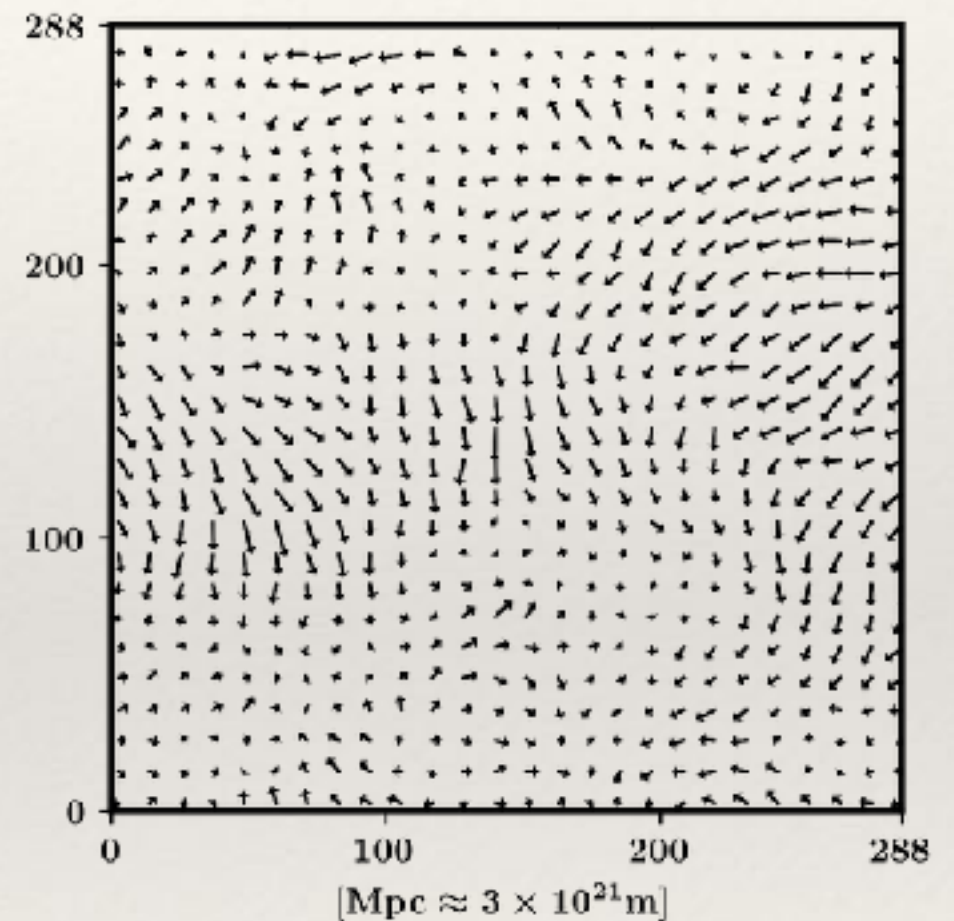
Baryon-Dark Matter Streaming Motion

$z > 1090$ ($t_{\text{age}} < 4 \times 10^5$ yrs)



... pressure of photon-baryon fluid generates the Baryonic Acoustic Oscillations.
This acoustic motion created a *relative motion* between baryon and dark matter.

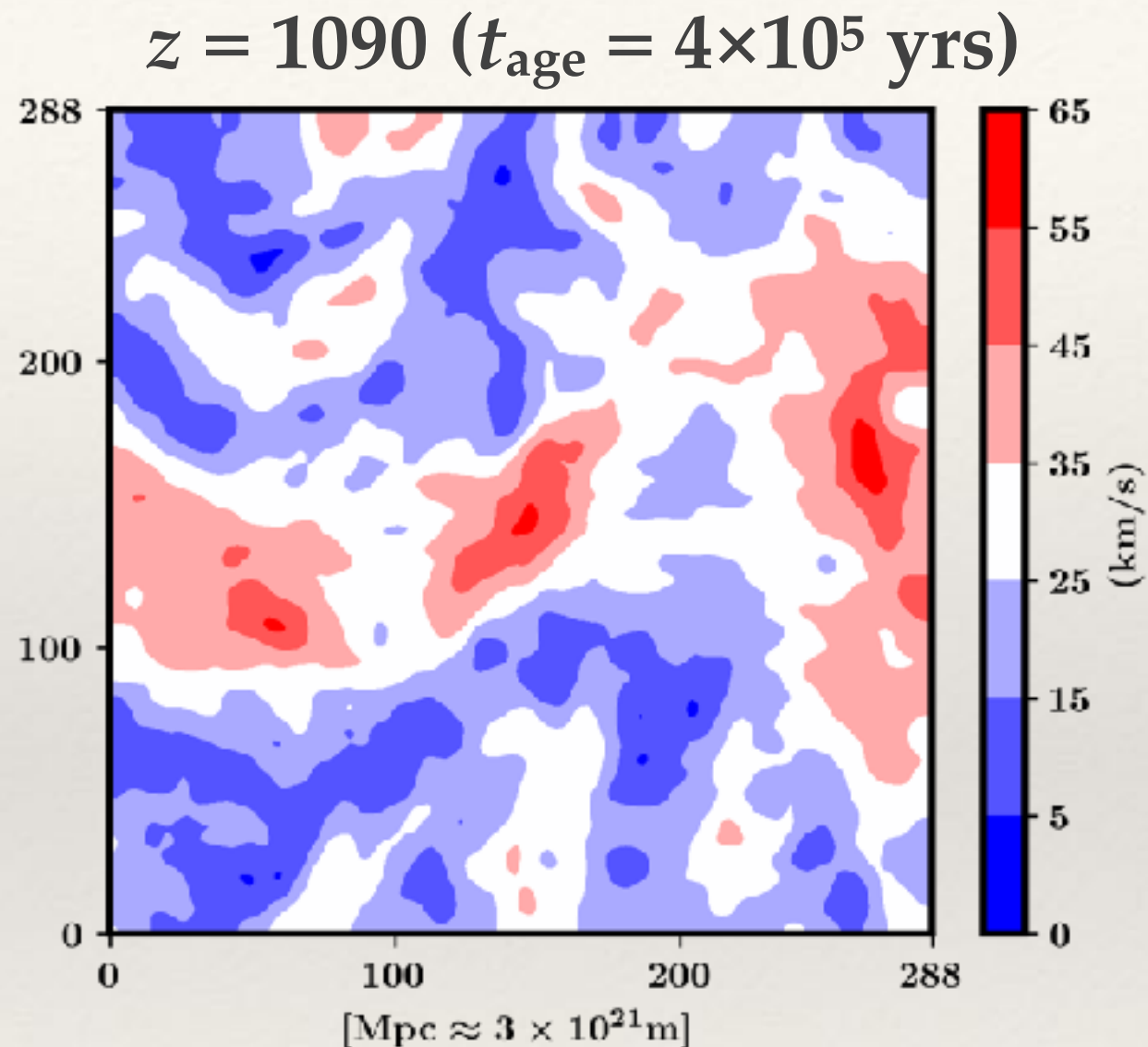
$z = 1090$ ($t_{\text{age}} = 4 \times 10^5$ yrs)



... the streaming motion freezes out with the cosmic recombination.

(Tseliakhovich and Hirata 2010)

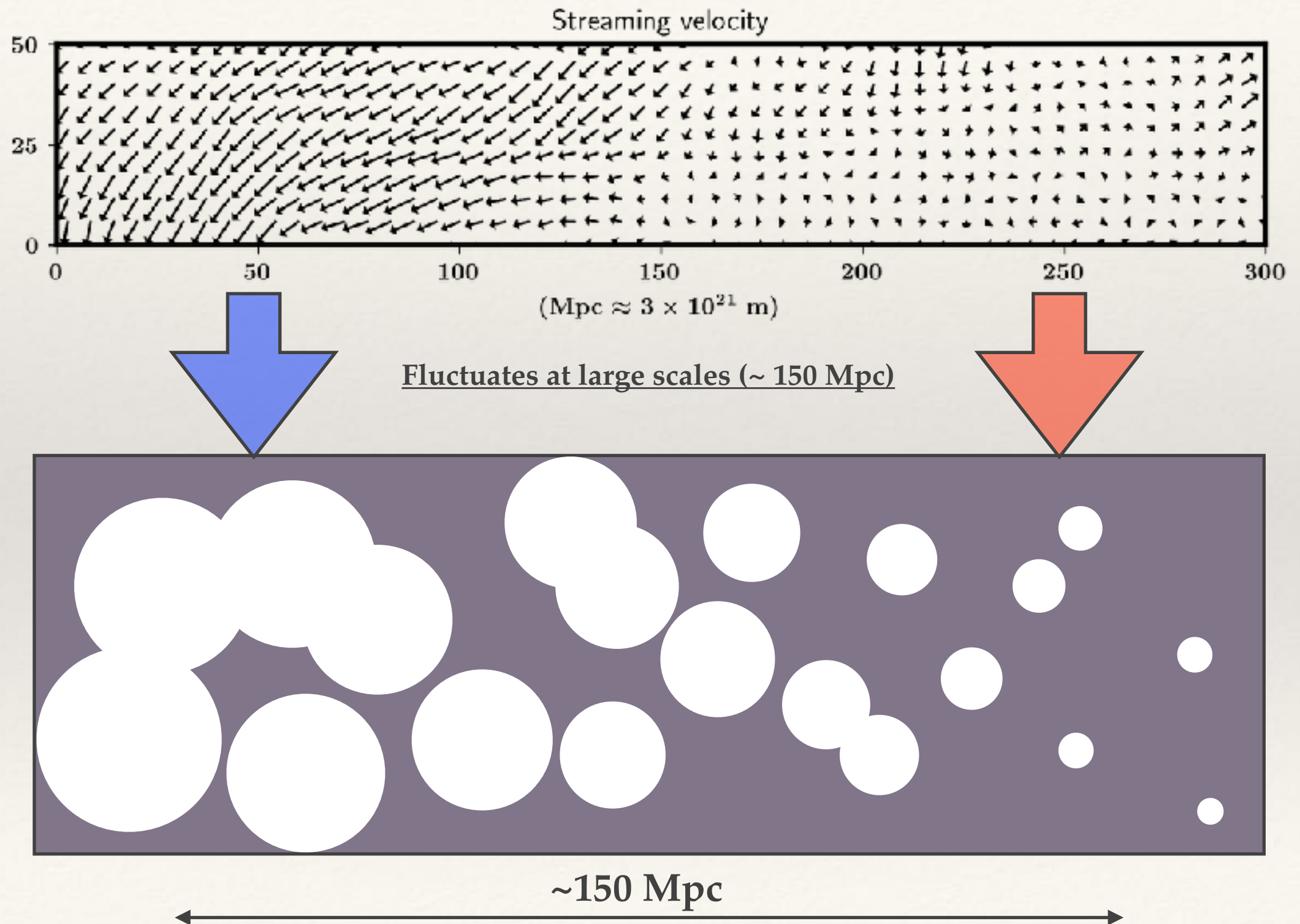
Baryon-Dark Matter Streaming Motion



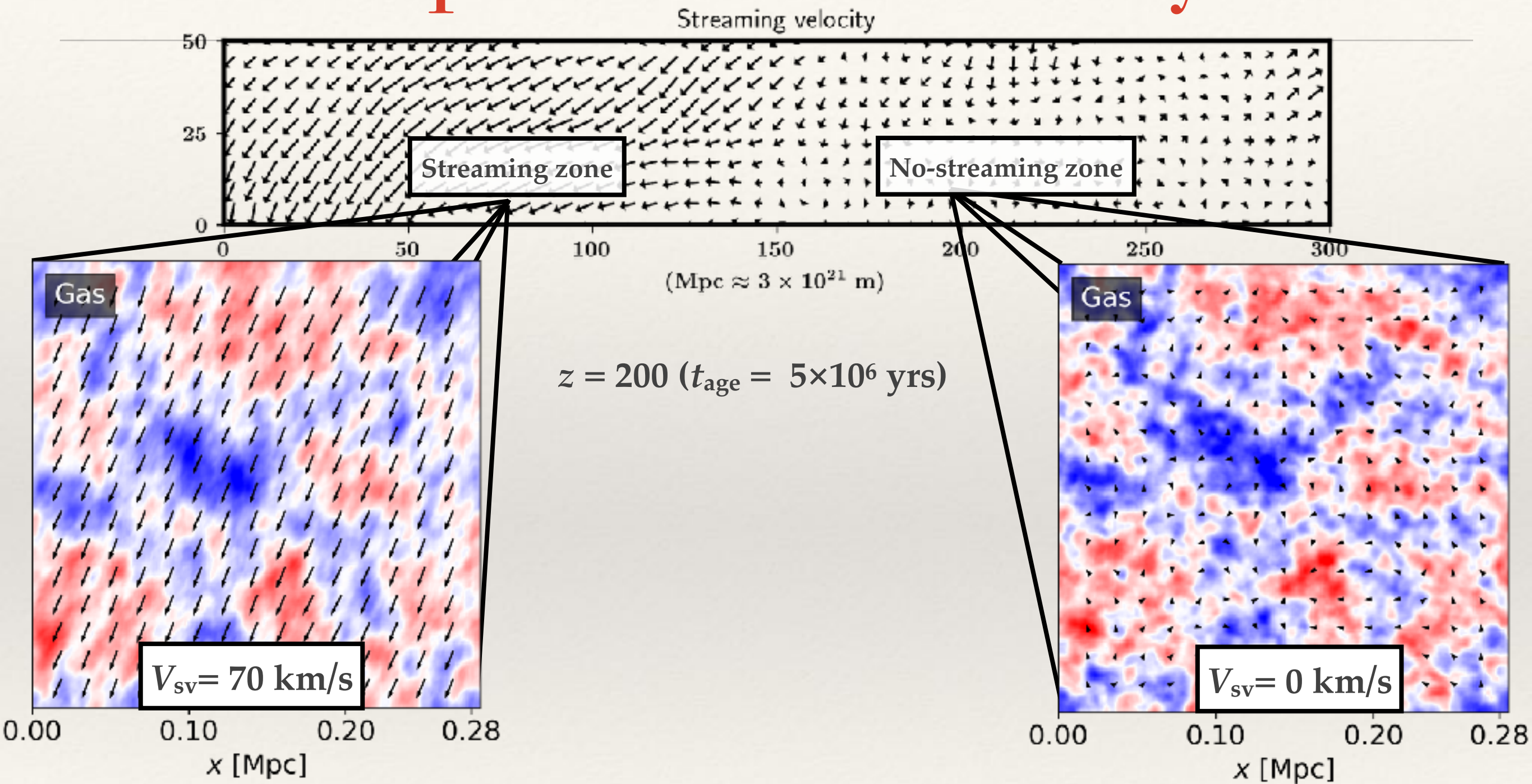
- Mostly (98%) ranges between 5 - 55 km/s.
- Decays as $(1+z)$. Unimportant at the late time in cosmic history.
- Fluctuates at large scales (~ 150 Mpc).

(Tseliakhovich and Hirata 2010)

Motivation: Can streaming motion affect reionization?



Impact on Gas Density



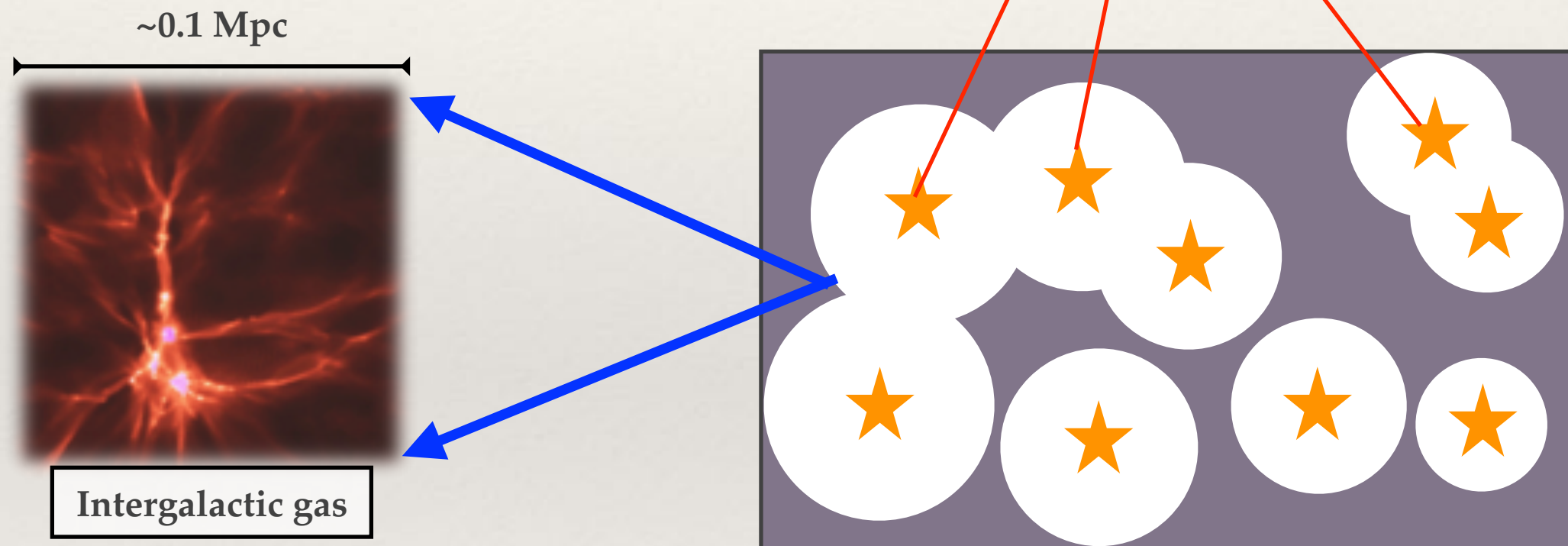
Gas density gets smoothed by the streaming motion.

Small-scale Gas Structure during Reionization

$$\bar{n}_H \dot{Q}_{\text{HII}} = \langle \mathcal{I} \rangle - \langle \mathcal{R} \rangle$$

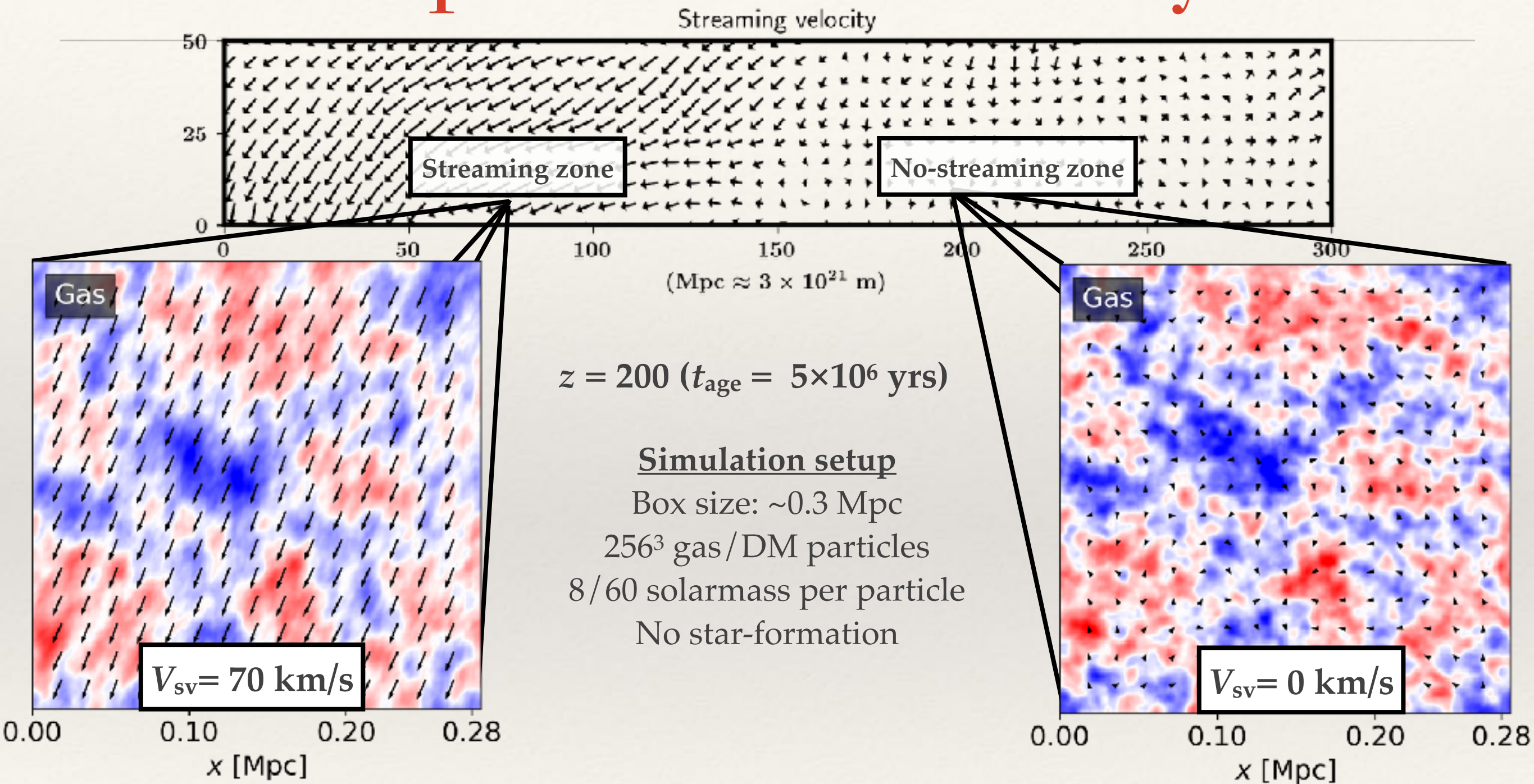
Net Ionization Production by galaxies Recombination by gas structures

$M \sim 10^7$ solarmasses galaxies
Not affected by the streaming motion

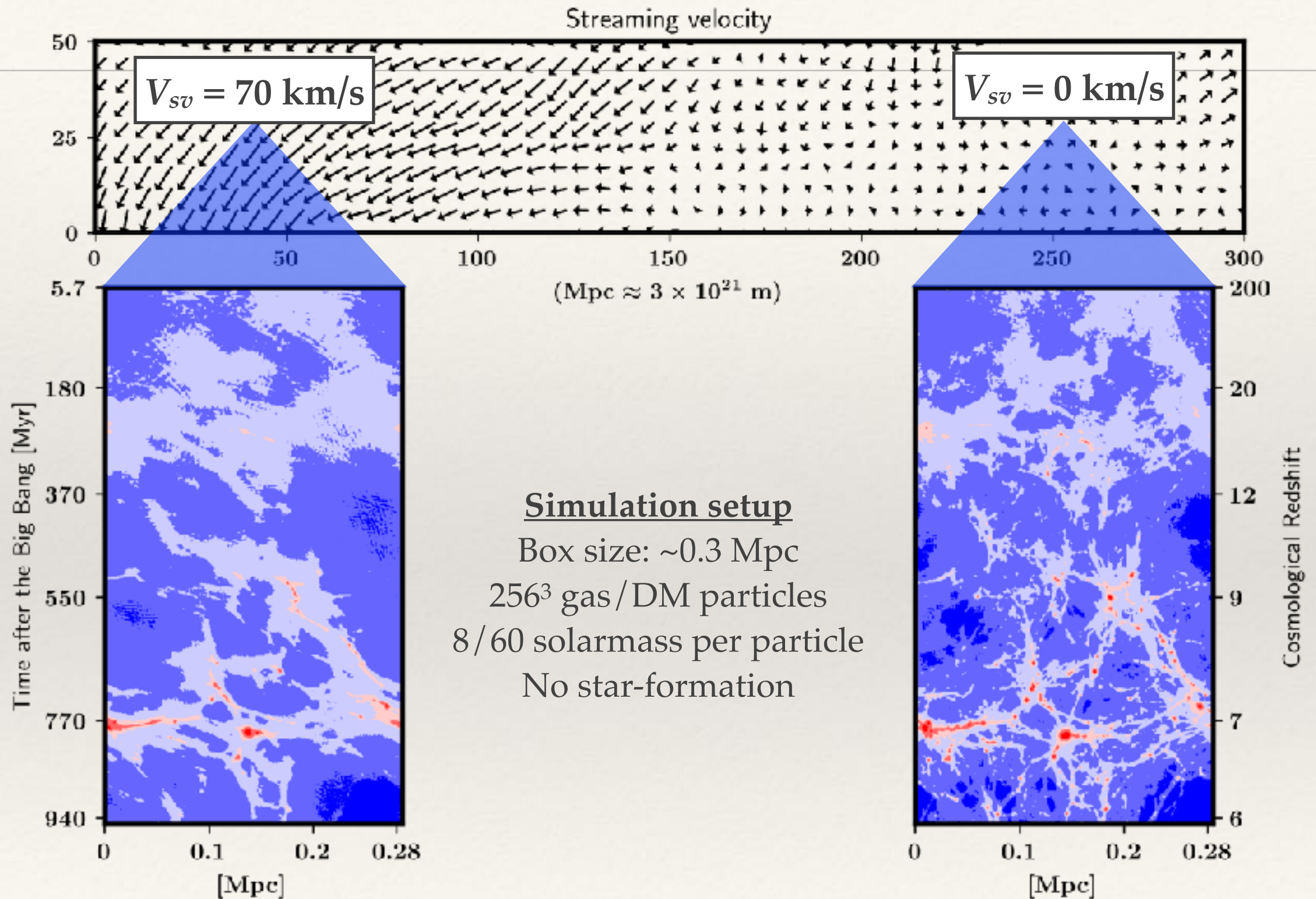


Intergalactic gas structures consumes extra photons.
They are mostly $M \ll 10^7$ solarmasses.
Maybe affected by the streaming motion?

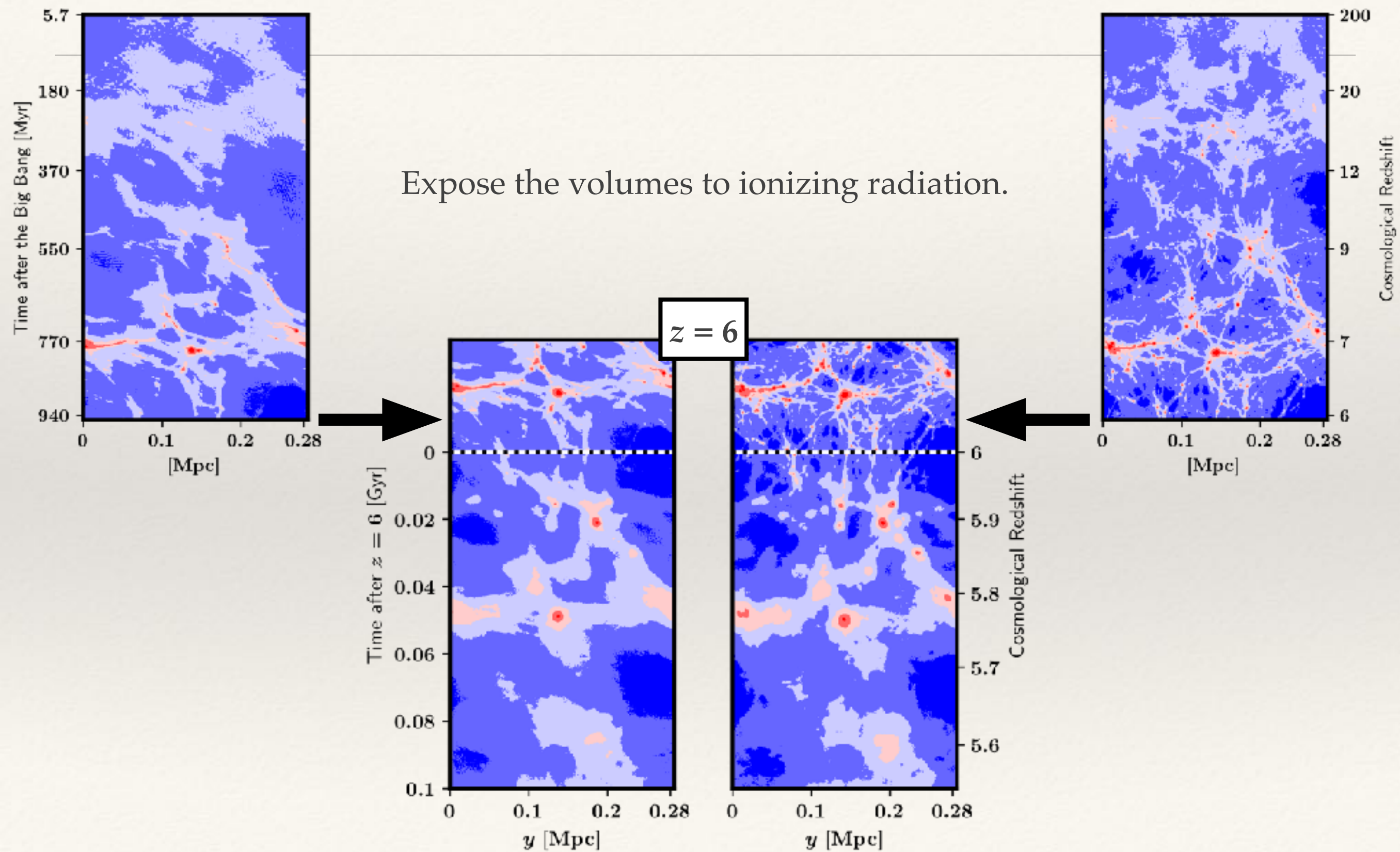
Impact on Gas Density



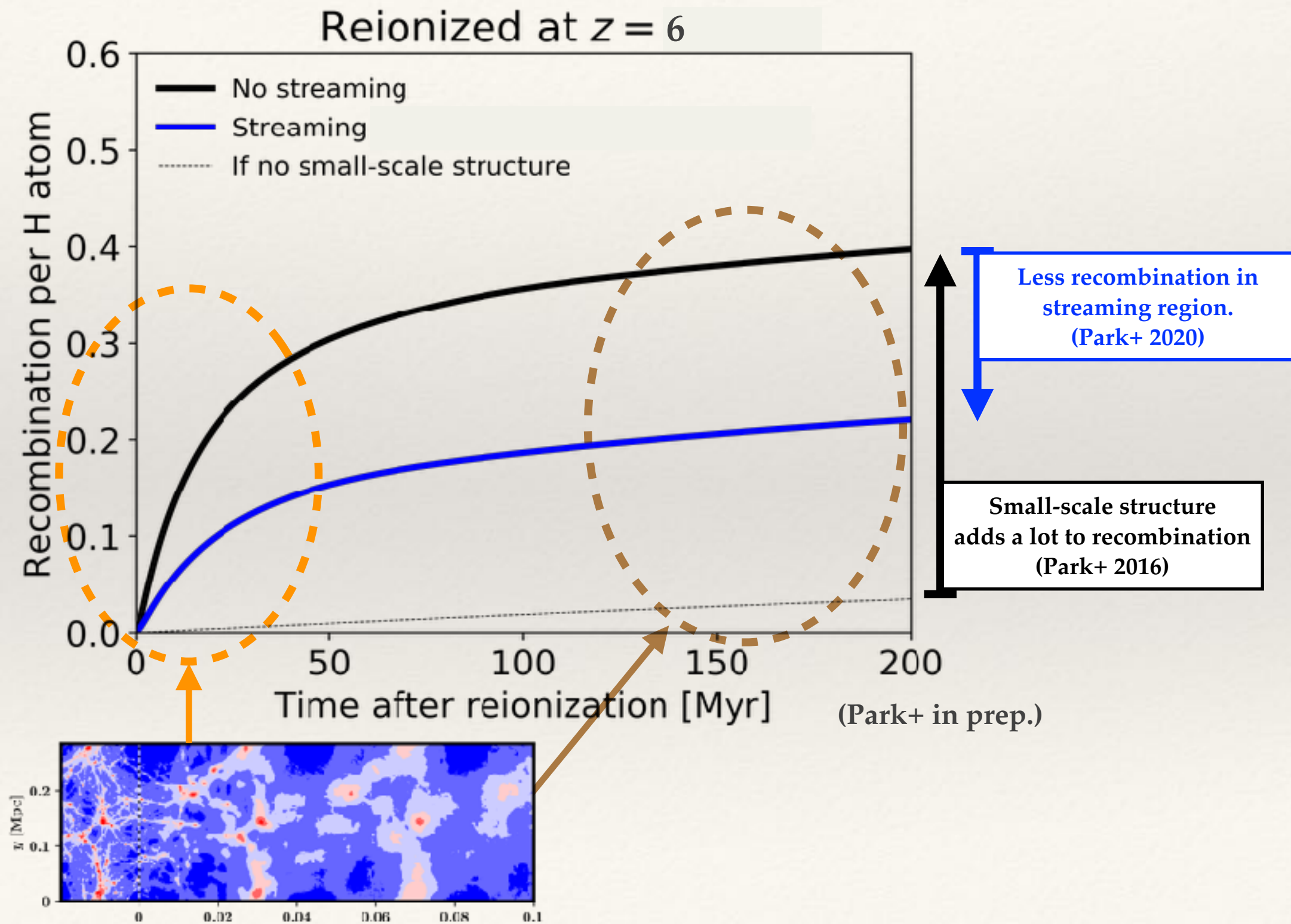
Gas density gets smoothed by the streaming motion.

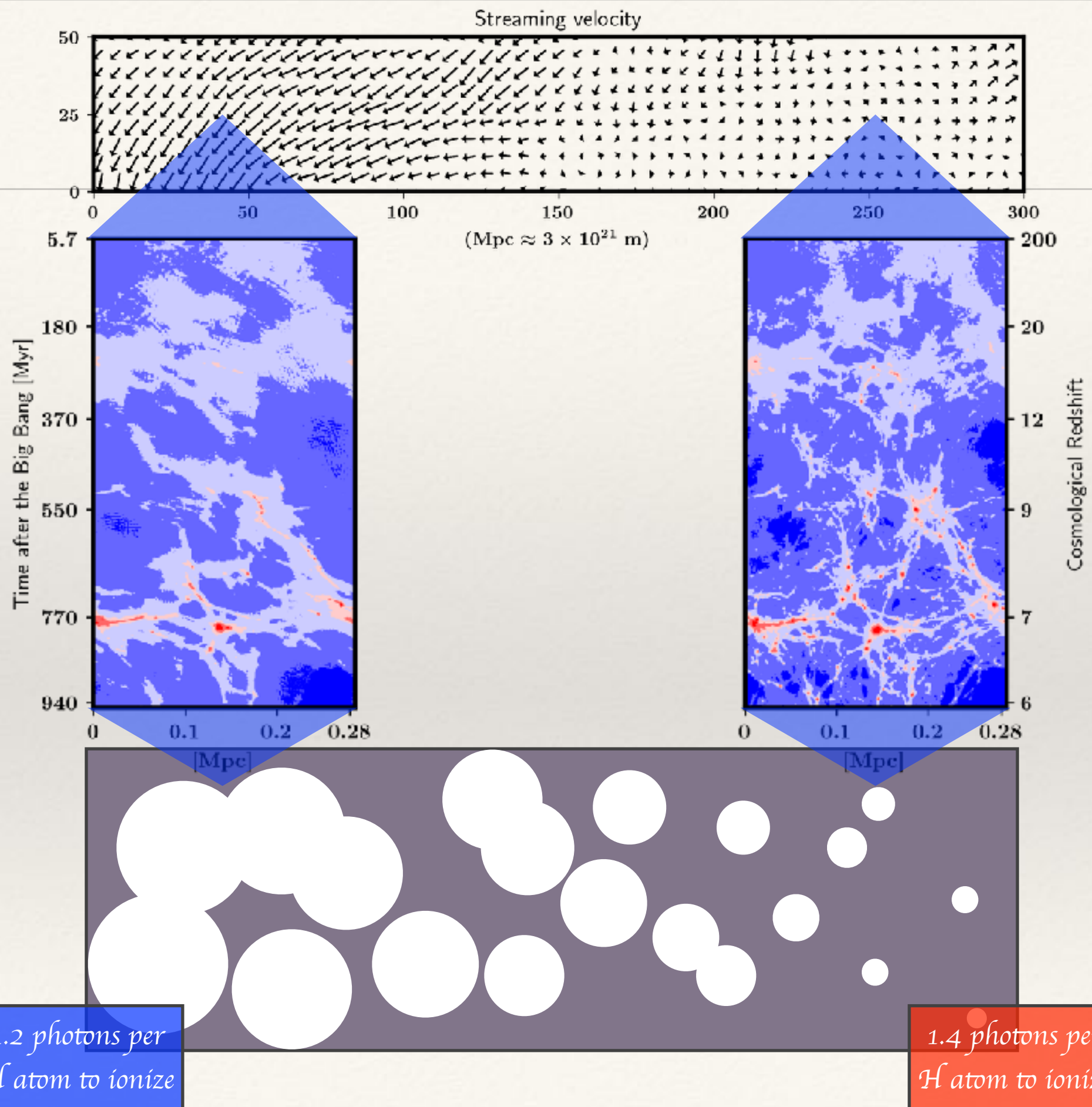


Small-scale ($\ll 10^8 M_\odot$) structures strongly suppressed by the streaming V .



Recombination in Small-scale Gas Structure





Scatter in Reionization History

Scatter in End-of-reionization

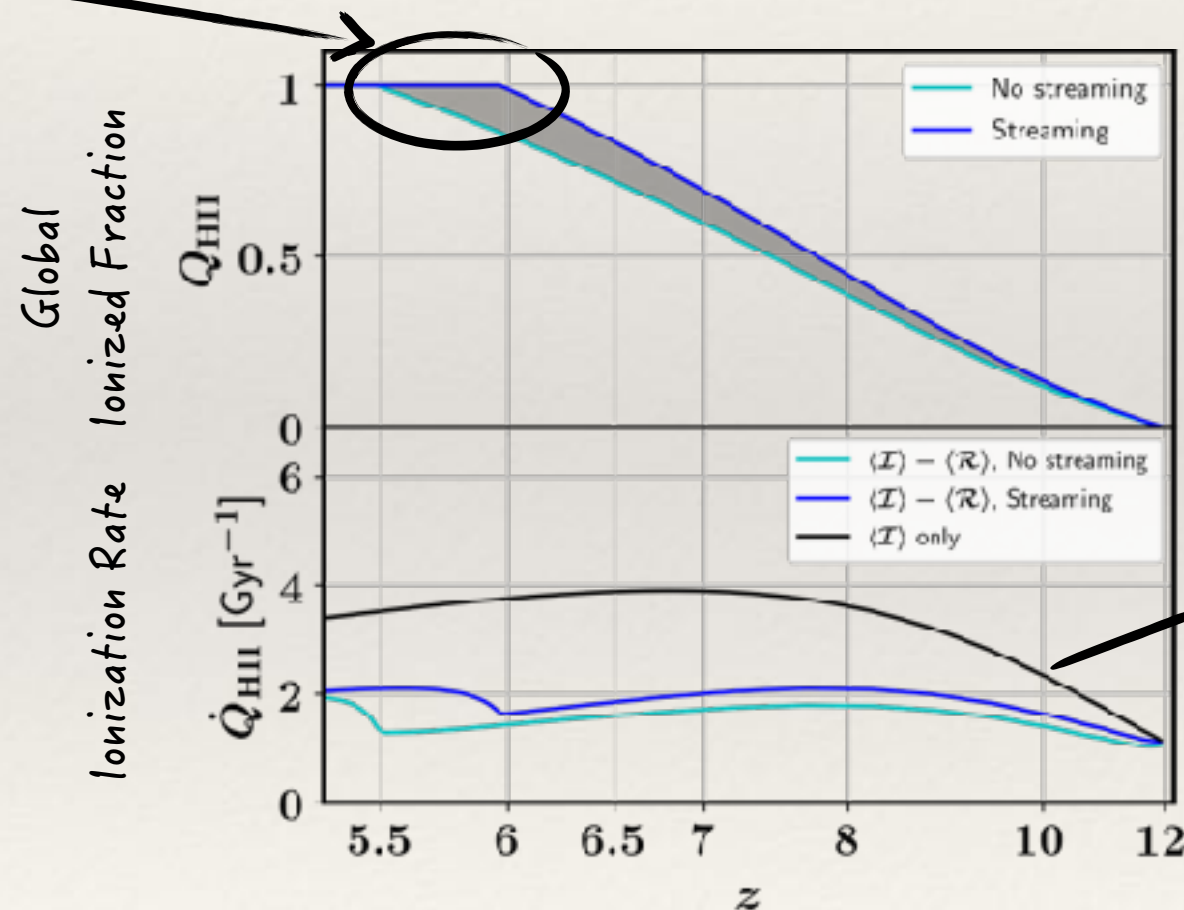
$$z_e = 5.5 - 6$$

$$\bar{n}_H \dot{Q}_{\text{HII}} = \langle \mathcal{I} \rangle - \langle \mathcal{R} \rangle$$

Net Ionization

Production

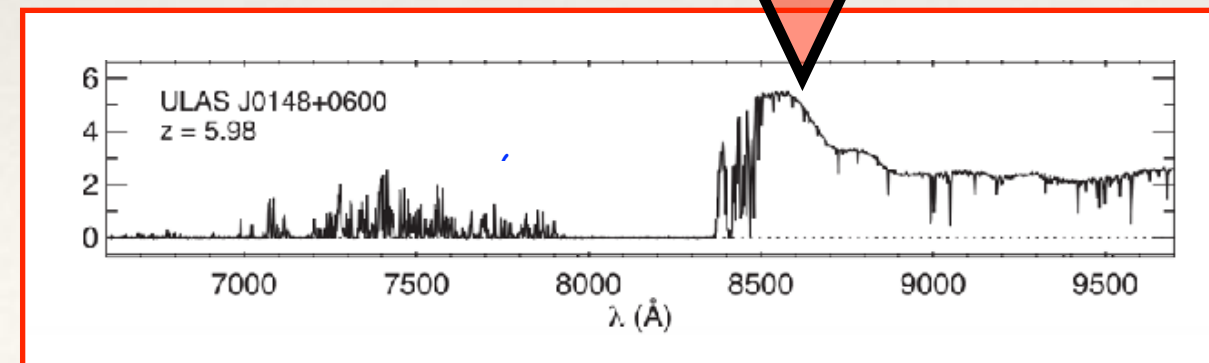
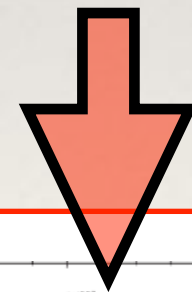
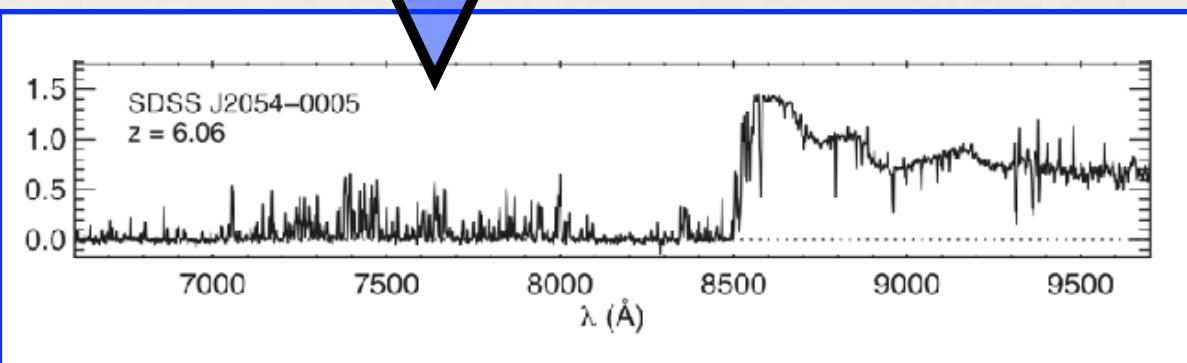
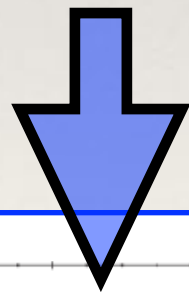
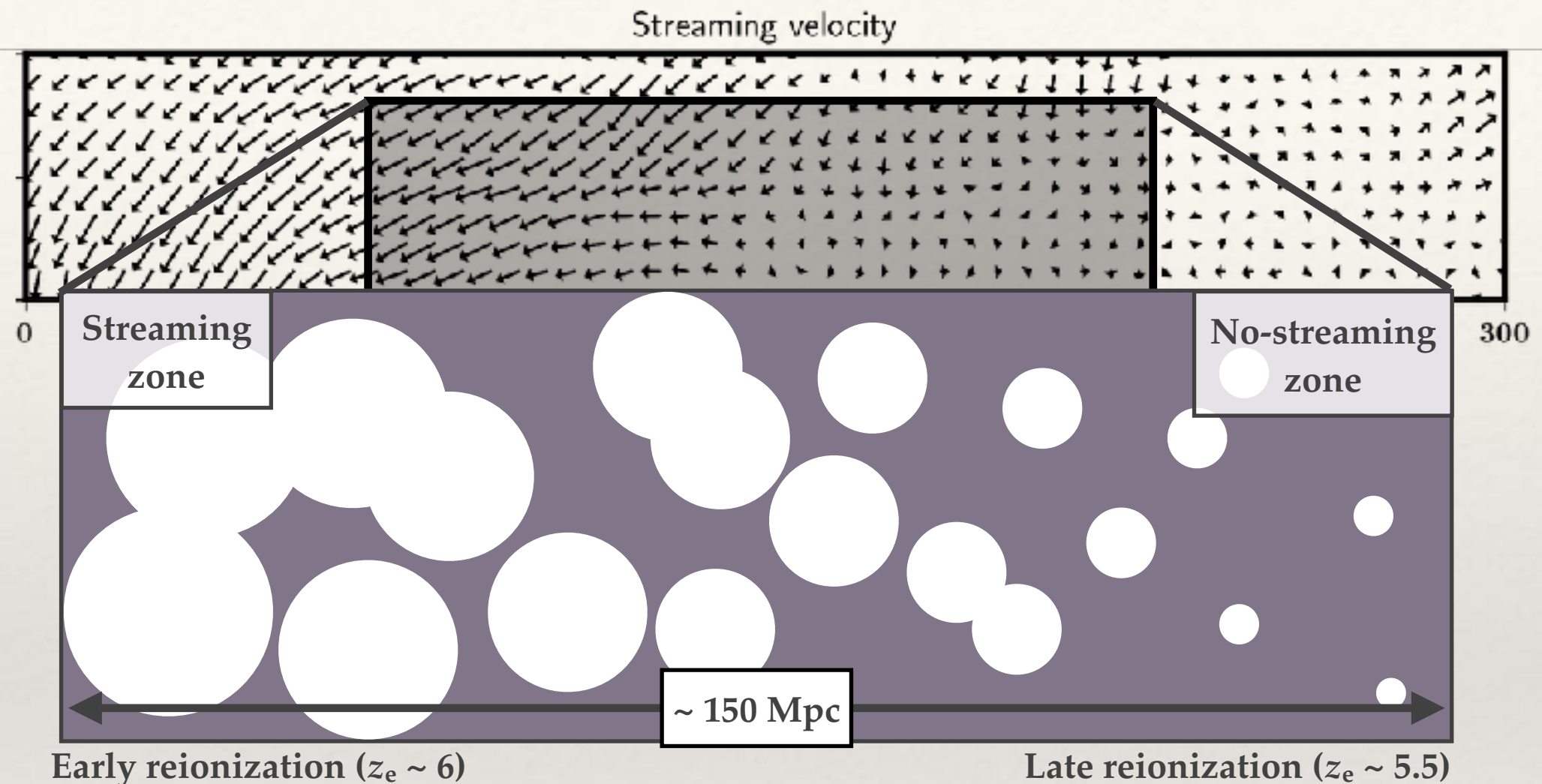
Recombination



Similar to the model of Finkelstein et al. 2019

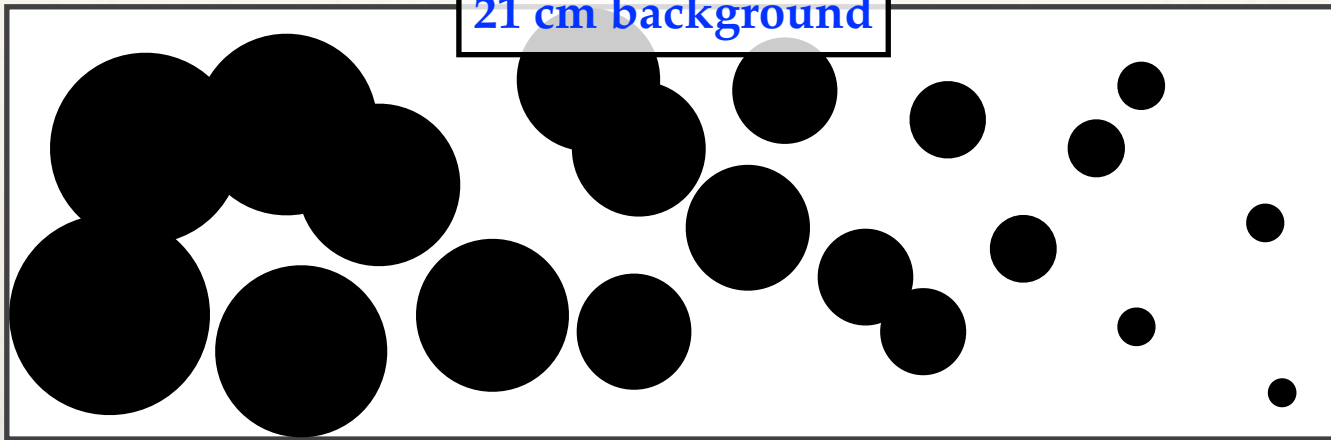
End of reionization scattered by $\Delta z = 0.5!$

Potential Explanation for the end-of-reionization scatter

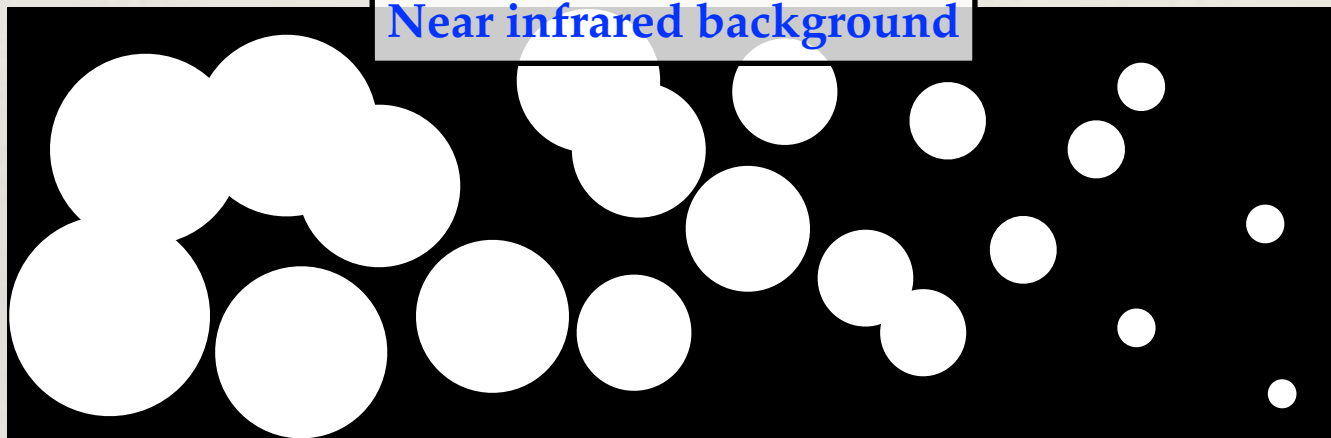


Observational Prospect

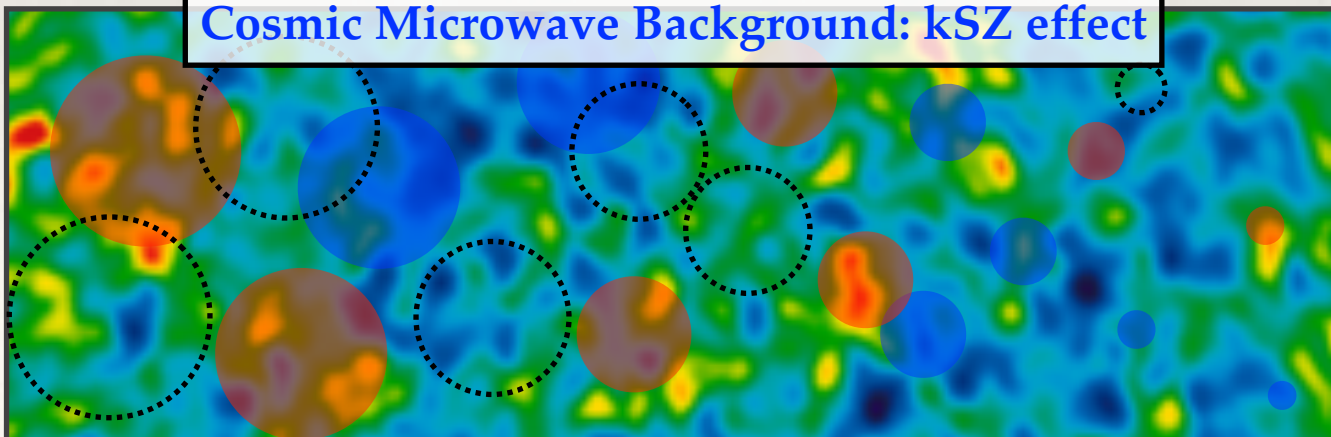
21 cm background



Near infrared background



Cosmic Microwave Background: kSZ effect



LOFAR



SPEHREx Satellite



Simons Observatory



Summary

Baryon-dark matter streaming motion...

- ➔ suppresses small-scale gas structures at $z \sim 6$.
- ➔ adds a scatter in the end-of-reionization redshift of up to $\Delta z \sim 0.5$.
- ➔ may help explaining the observed scatter in end-of-reionization.
- ➔ will impact the observables of the reionization era. (21cm, NIR, CMB, LAE)

