Delaying the formation of the first stars

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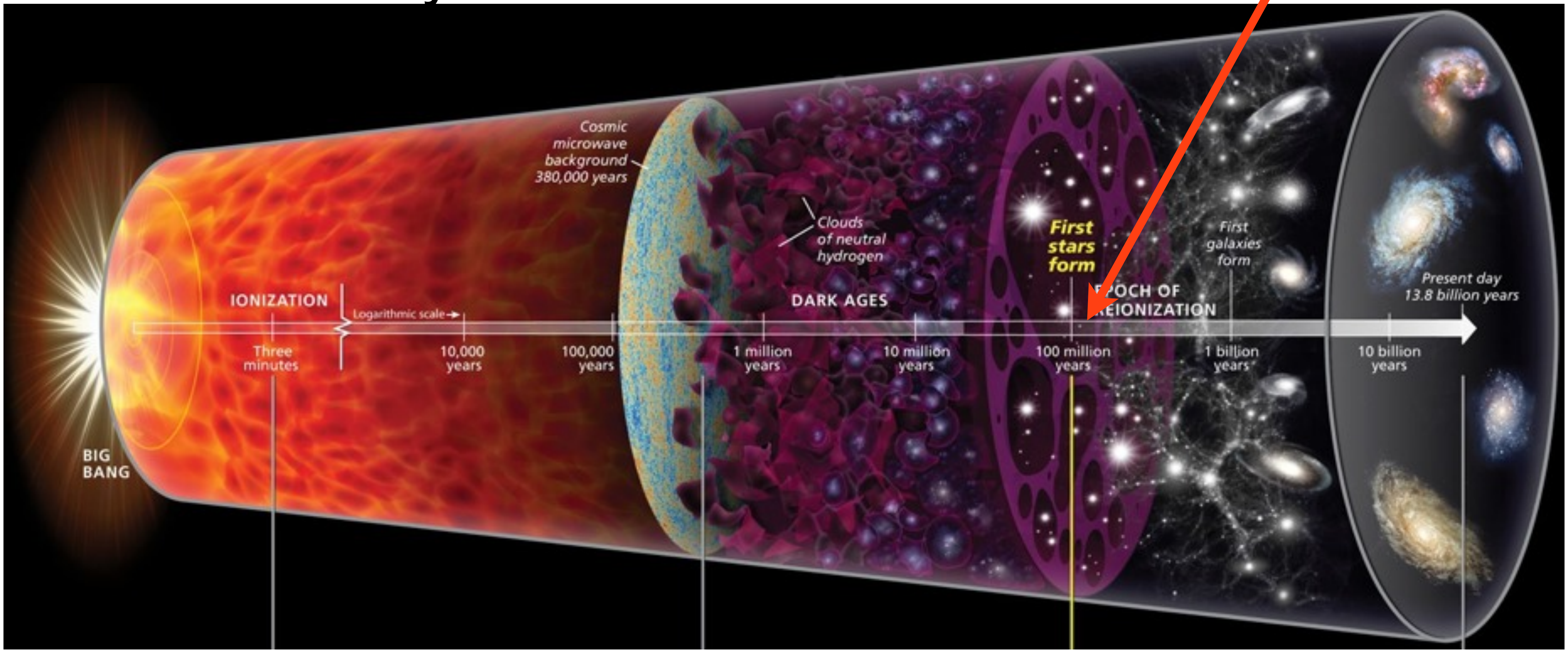
Firenze

first galaxies and first stars

- the gas composition is completely primordial
- star formation takes place in minihalos (10^5 - $10^7 M_\odot$)
- cooling has to proceed via H_2 (and HD)
- the mass of the first stars is very uncertain
- we have to rely on simulations

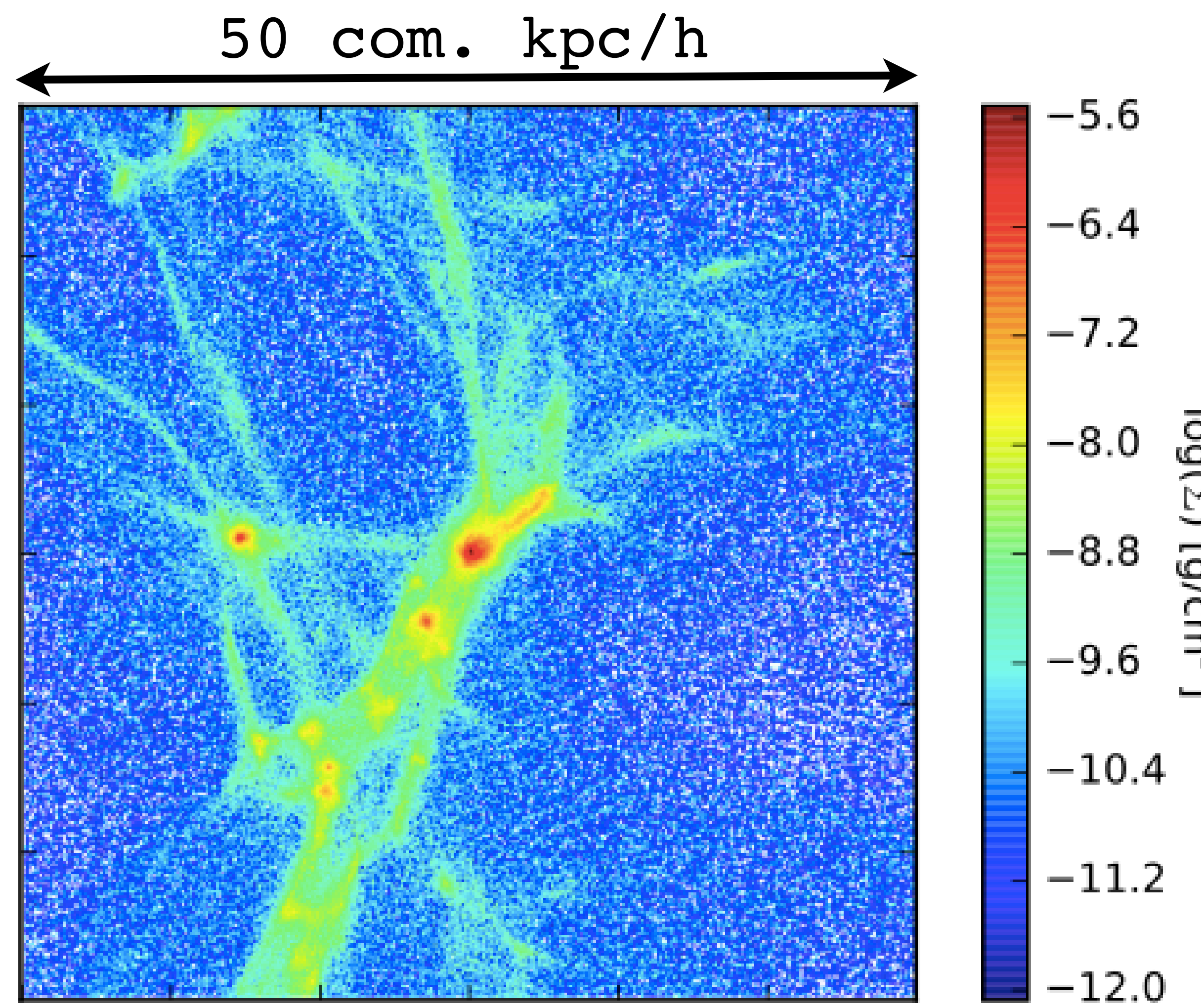
z = 15 - 25



http://discovermagazine.com/~/media/Images/Issues/2014/April/21-centimeter-cosmology.jpg

simulations

code	AREPO + primordial chemistry
box size	$(1\ \mathrm{Mpc}/h)^3$
DM particles / gas cells	1024^3 each
mass resolution	$19\ M_\odot$ (gas), $99\ M_\odot$ (DM)
smoothing length	20 pc/h (2 pc at z=15)



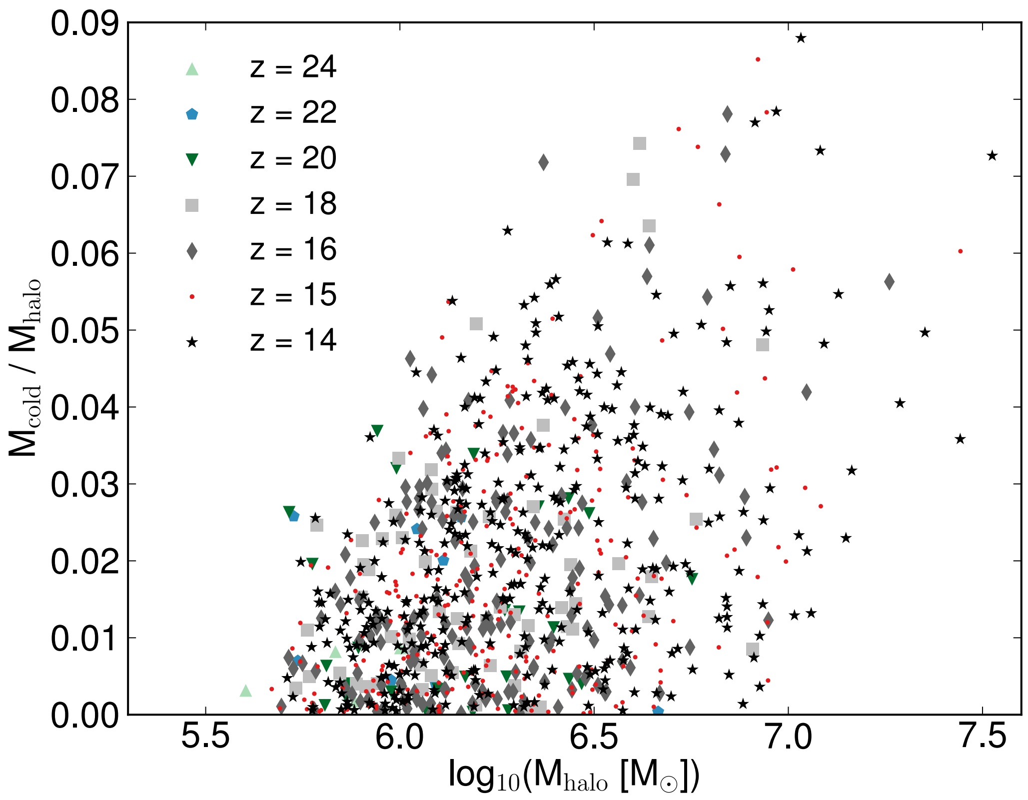
gas projection at z=15

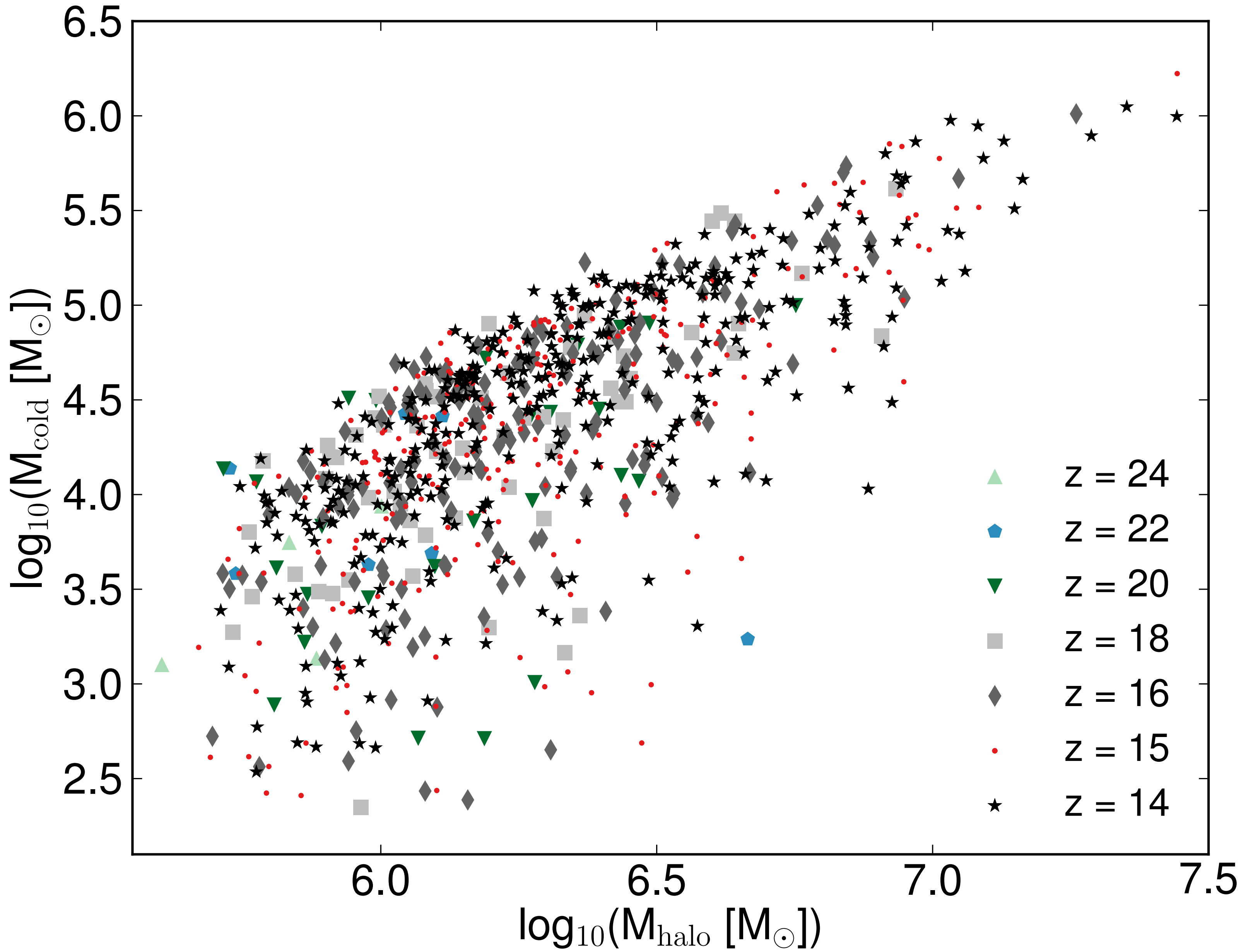
Picture from Bachelor Thesis of Maik Druschke

cold gas mass - halo mass relation

Cold mass: sum of all cold, dense, H_2-rich gas in halo

- $T < 500$ K
- H_2 abundance $> 10^{-4}$
- (physical) n [cm^{-3}] > 100





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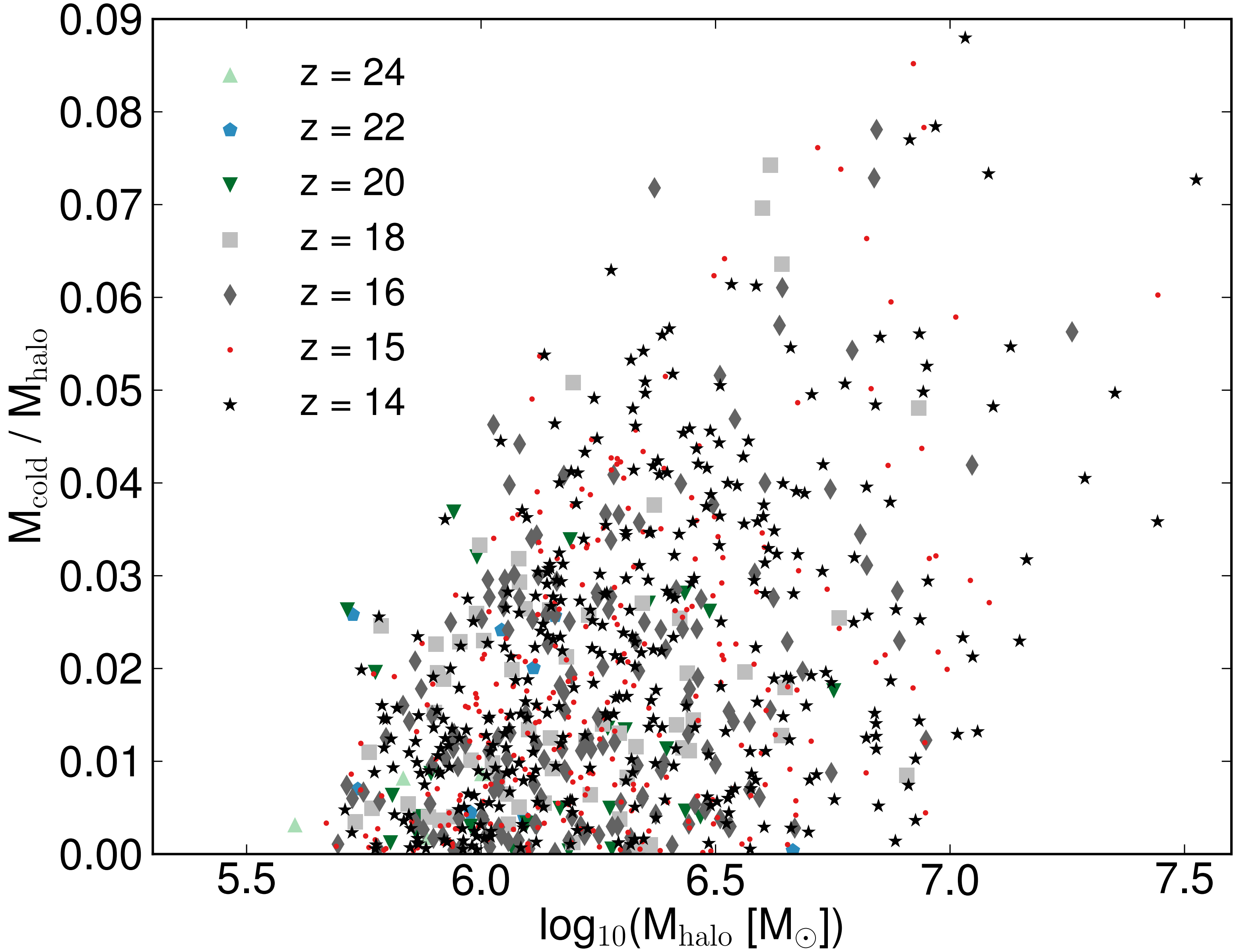
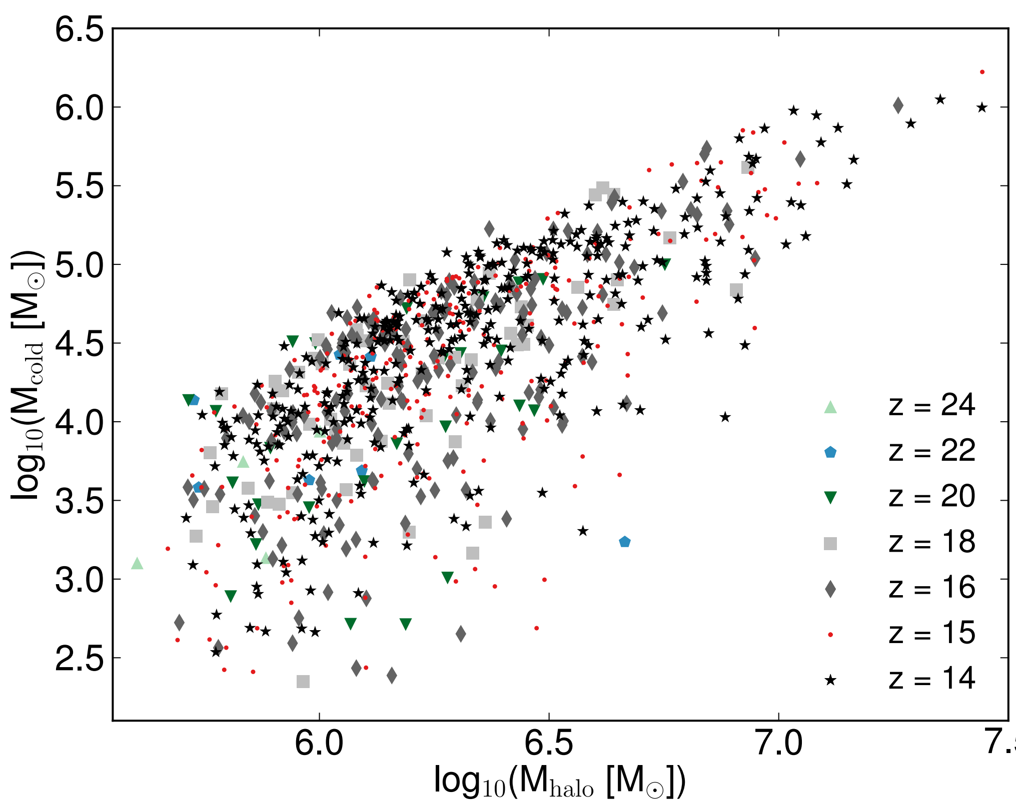
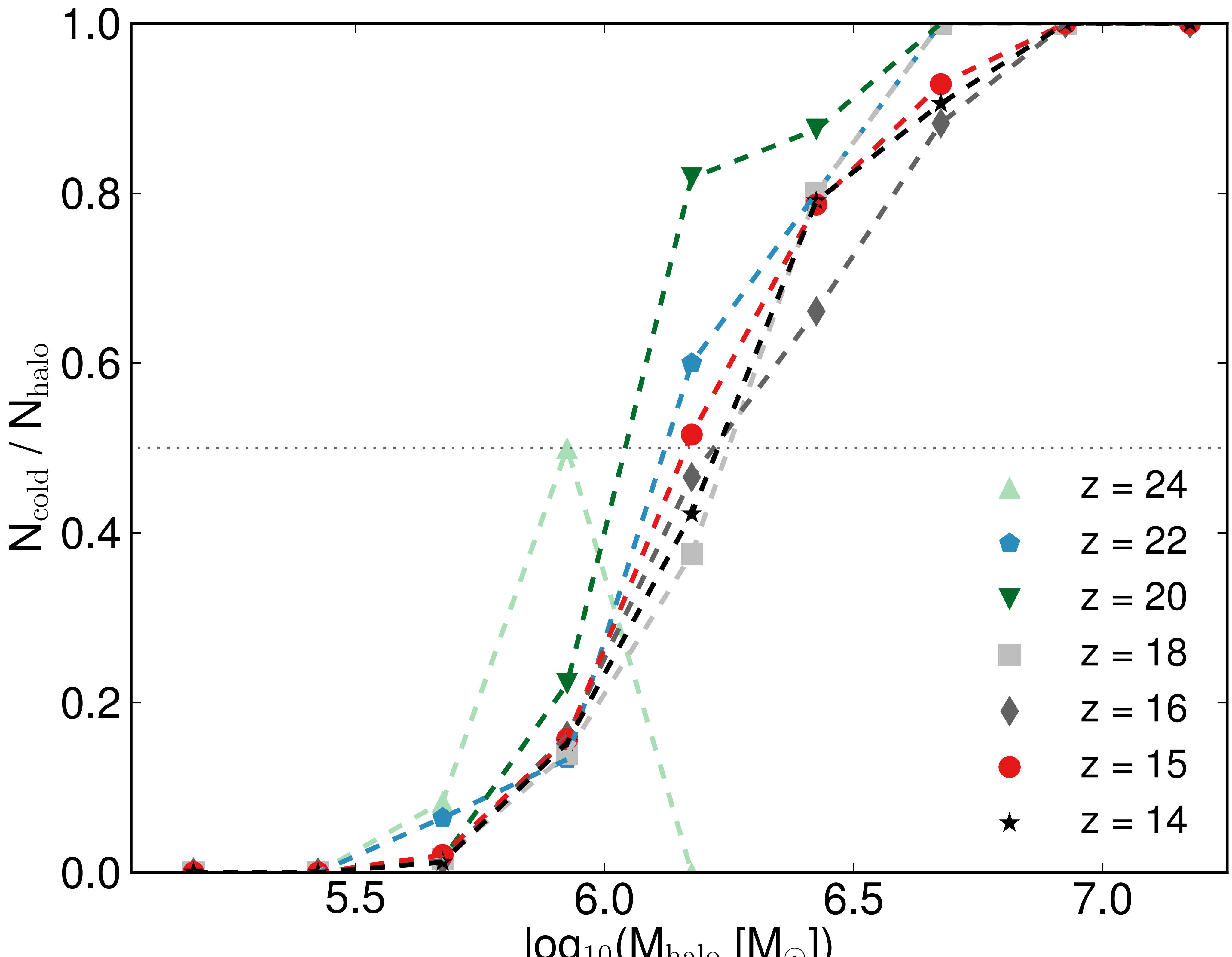
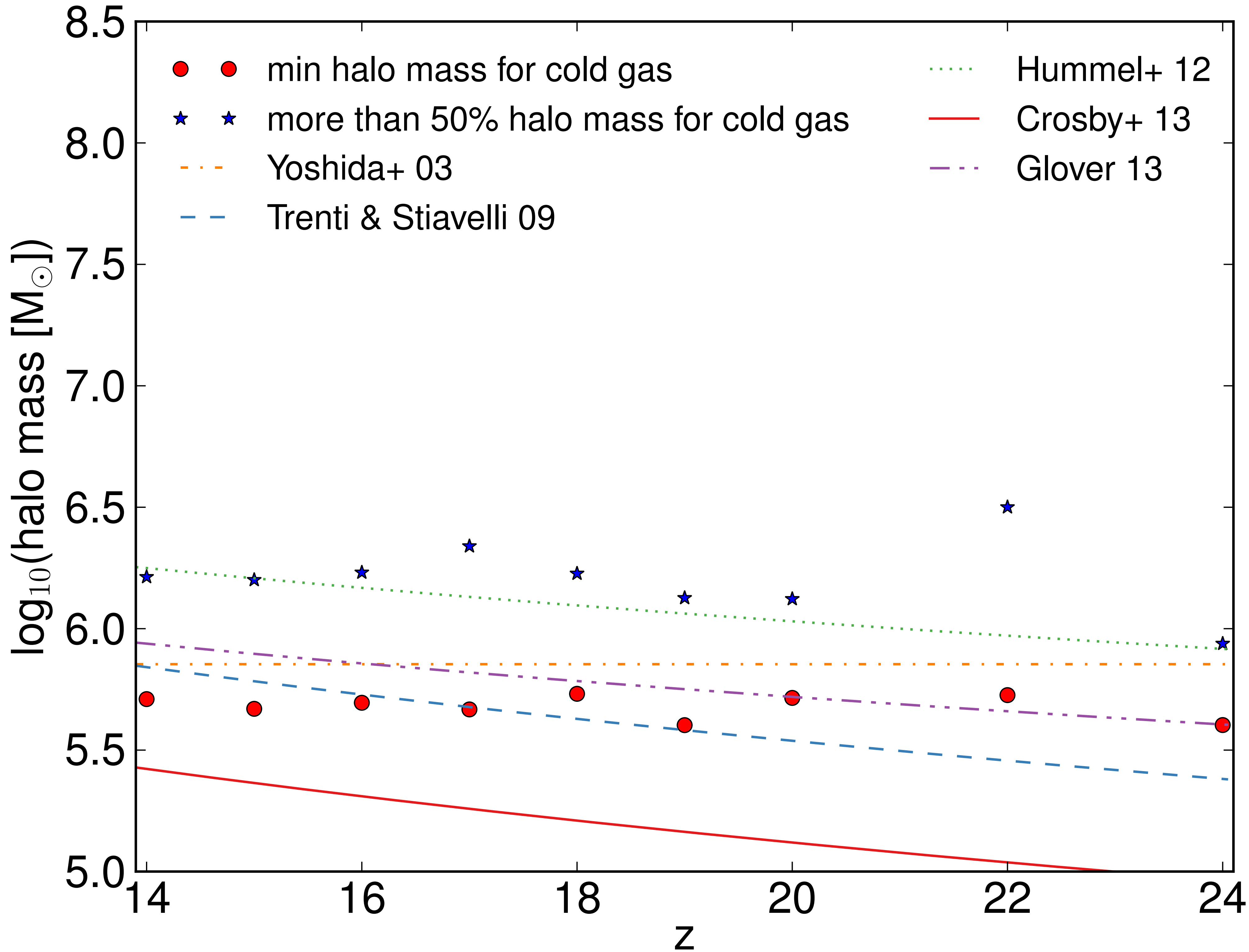




fraction of cold halos

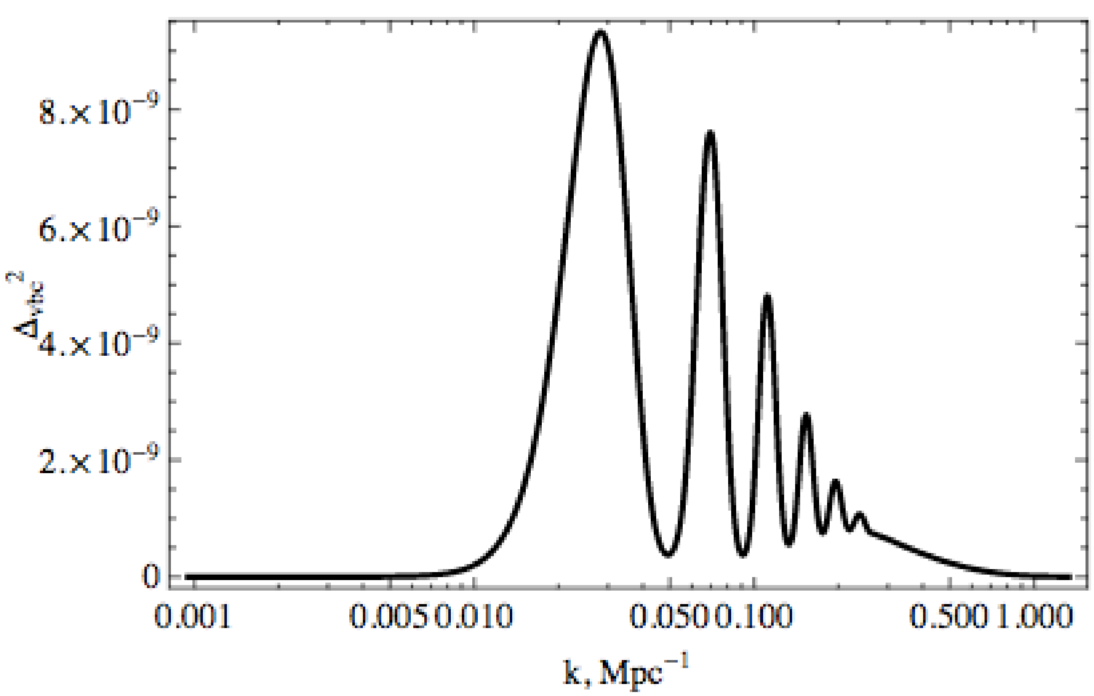


halo masses of cold halos



streaming velocities

- 2^{nd} order perturbation in velocities at recombination
- coherent over ~ 3 Mpc
- decaying with 1/(1+z)
- 1 sigma at z=1100: 30 km/s, at z=200: 6 km/s



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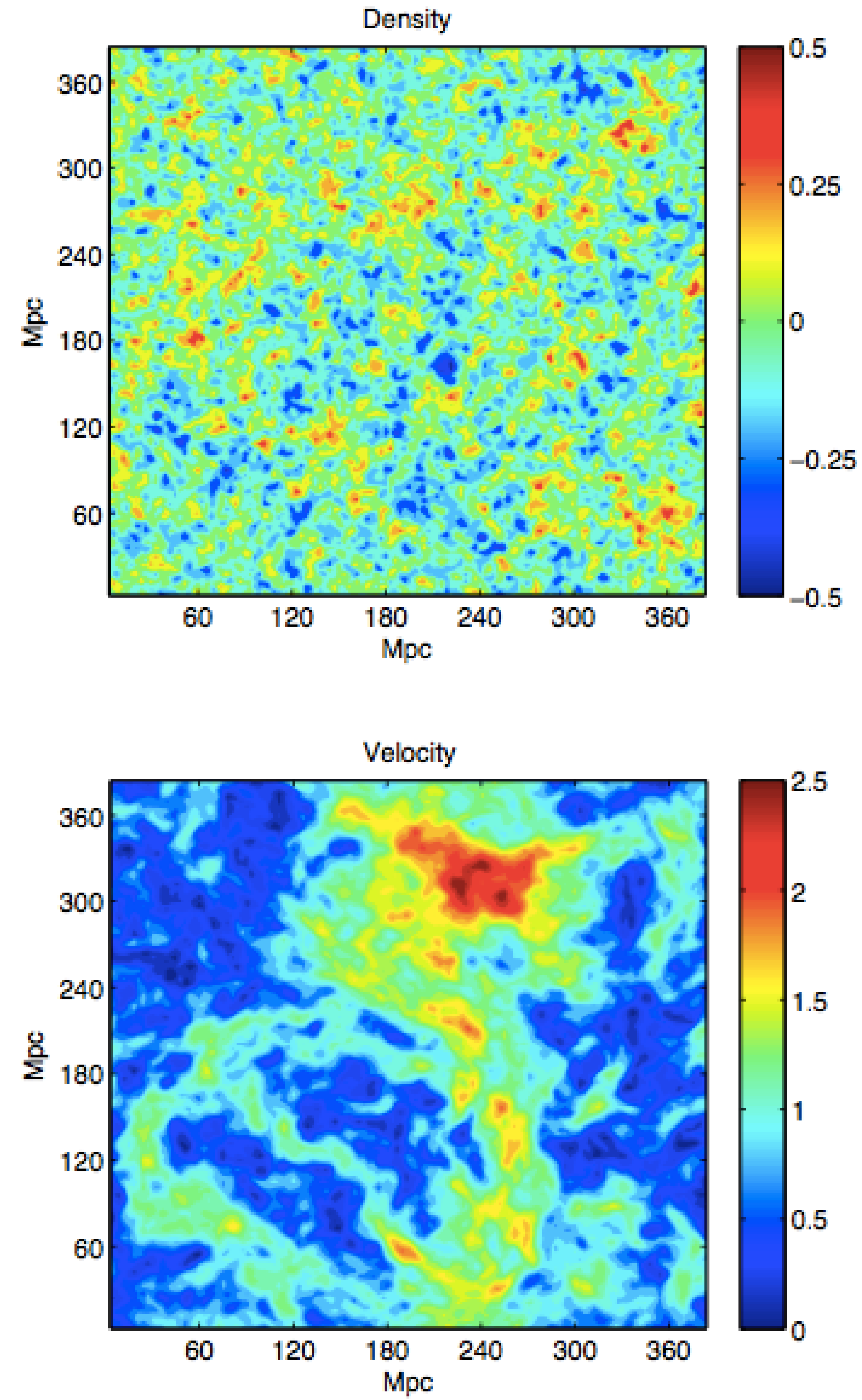

z=20, Fialkov+ 13

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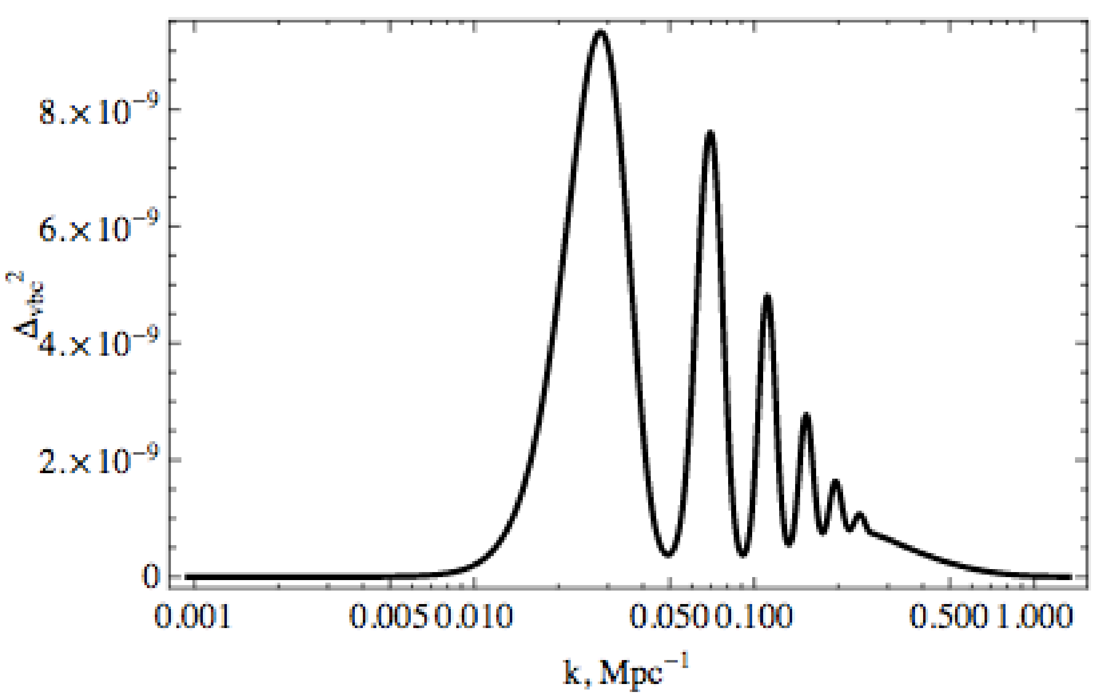


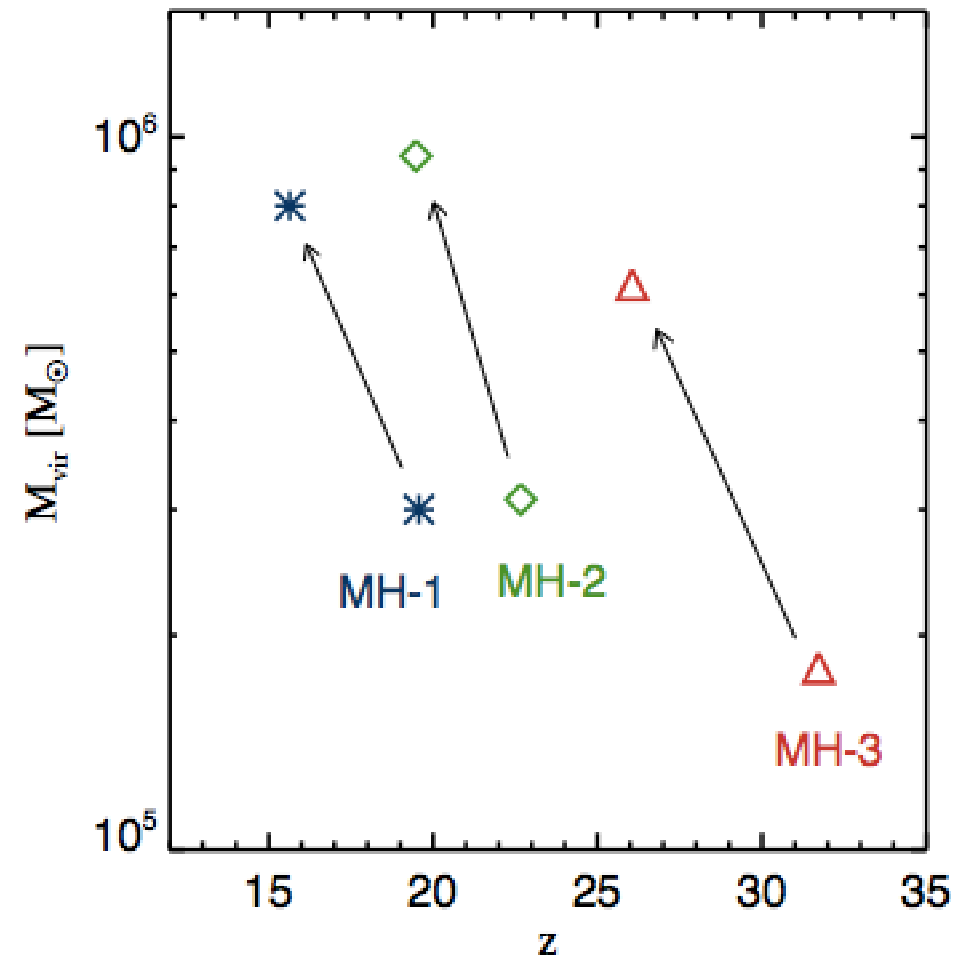


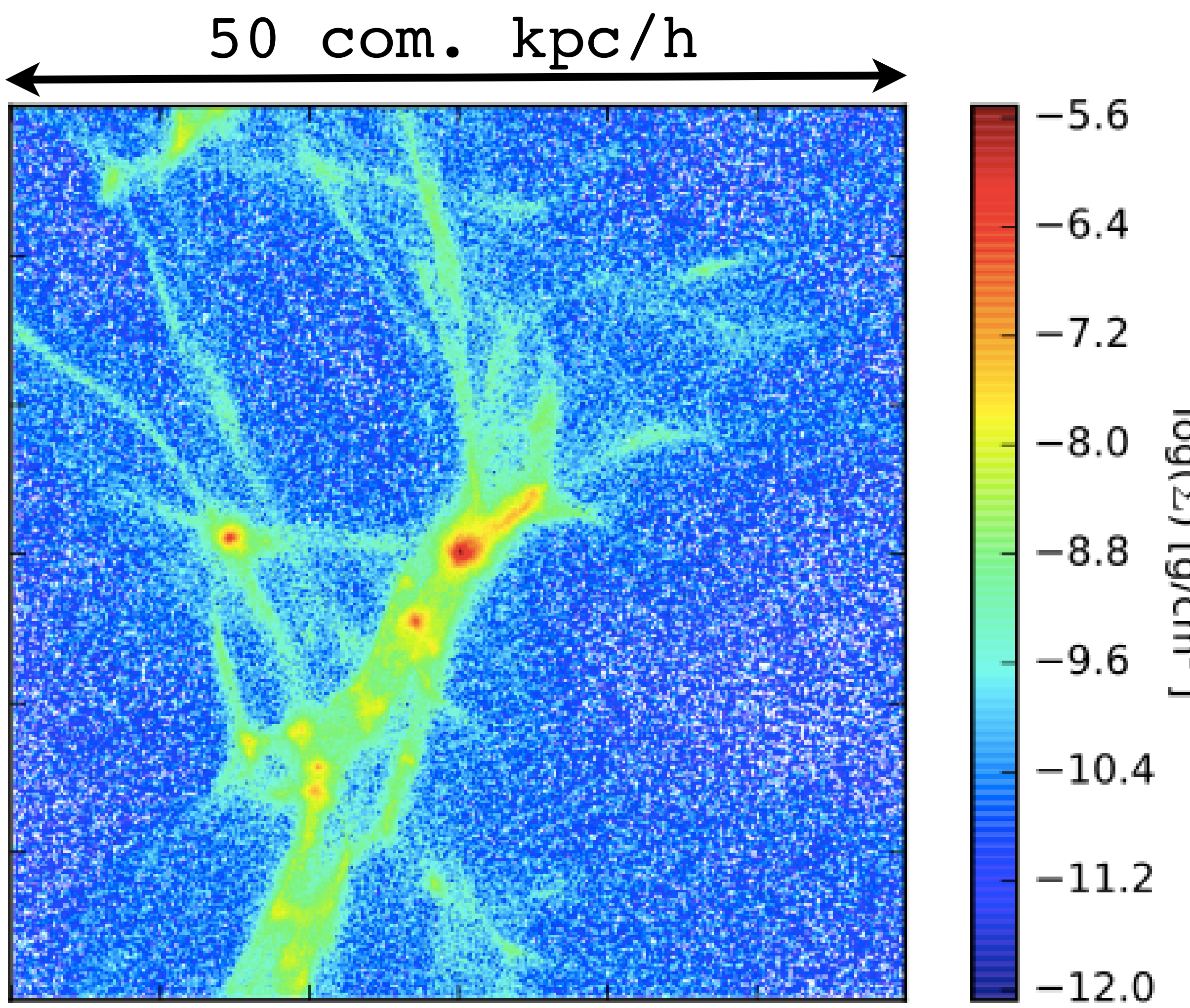
FIG. 3.— The virial masses and collapse redshifts of all minihalos for no streaming velocities (lower symbols), and for an initial streaming velocity of 3 km s^{-1} at $z = 99$ (upper symbols). As indicated by the arrows, the virial mass required for efficient cooling is typically increased by a factor of $\simeq 3$, which delays Pop III star formation by $\Delta z \simeq 4$.

Tseliakhovich & Hirata 10

Greif+11

simulations

code	AREPO + primordial chemistry
box size	SB: $(1\ \mathrm{Mpc}/h)^3$ LB: $(4\ \mathrm{Mpc}/h)^3$
DM particles / gas cells	1024^3 each
mass resolution	SB: 19 $M_\odot$ (gas), SB: 99 $M_\odot$ (DM)
smoothing length	20 pc/h (2 pc at z=15)
streaming velocity values	SB: 0, 1, 2, 3 sigma LB: 3 sigma



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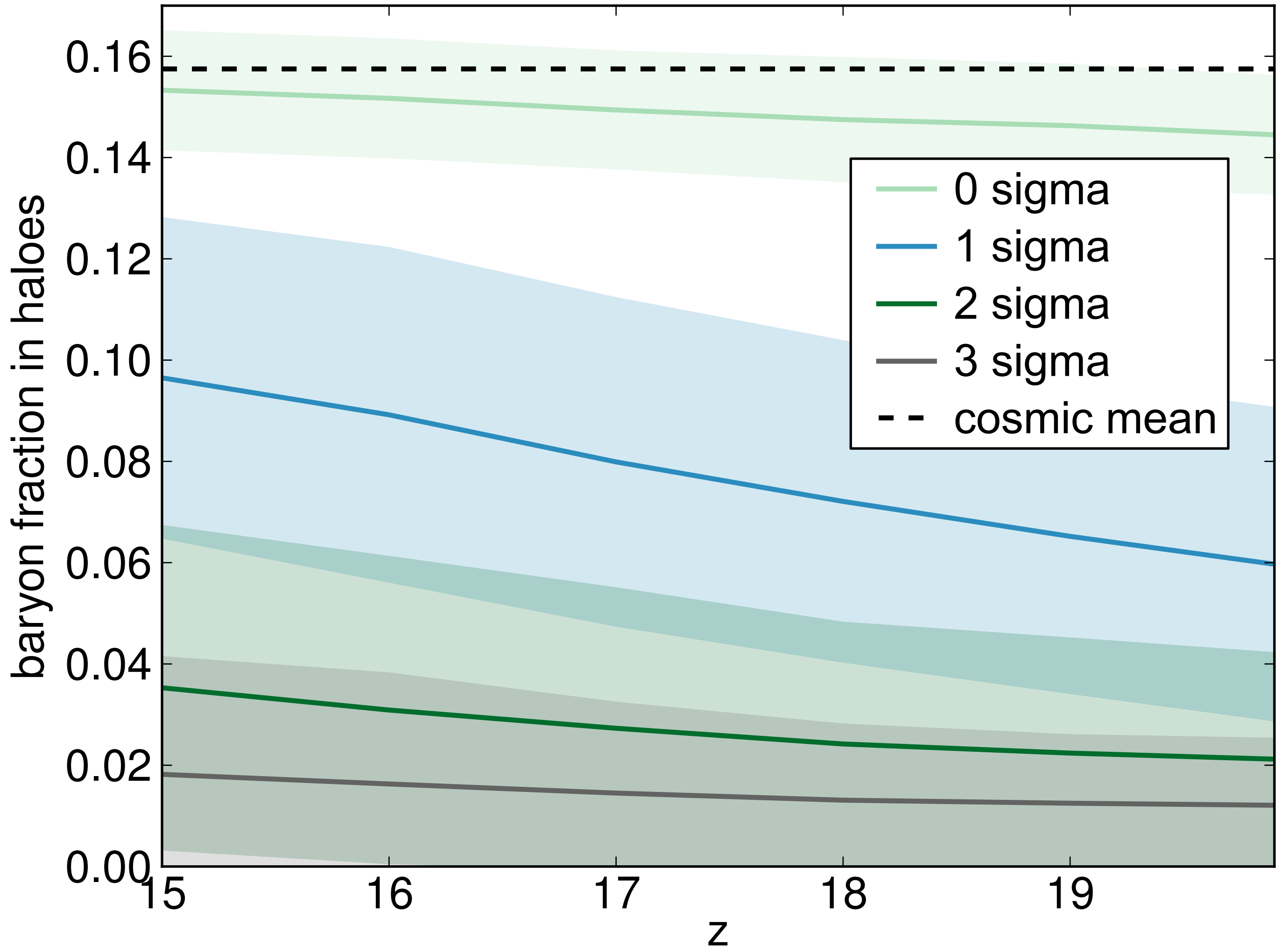
basic results

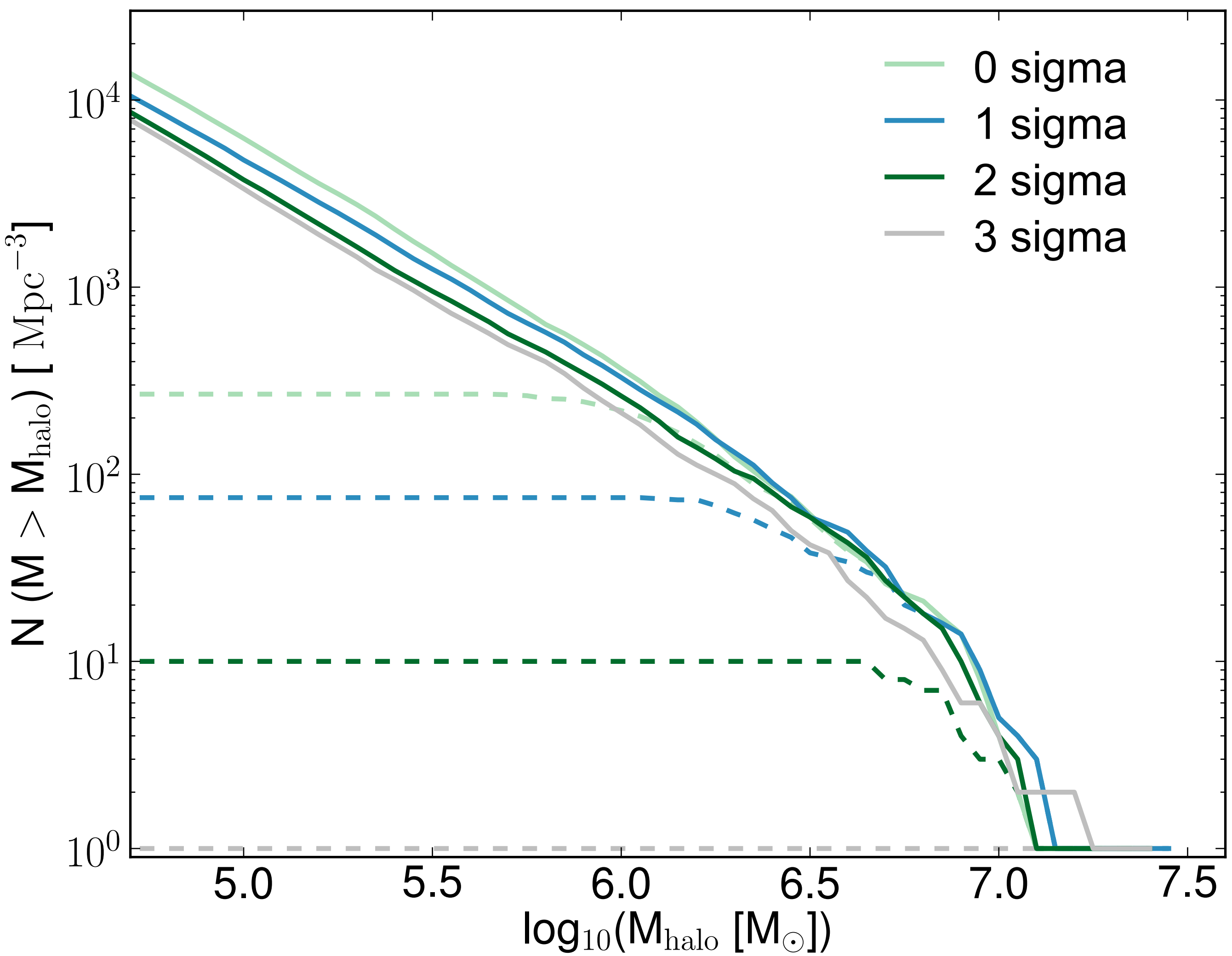


baryon fraction

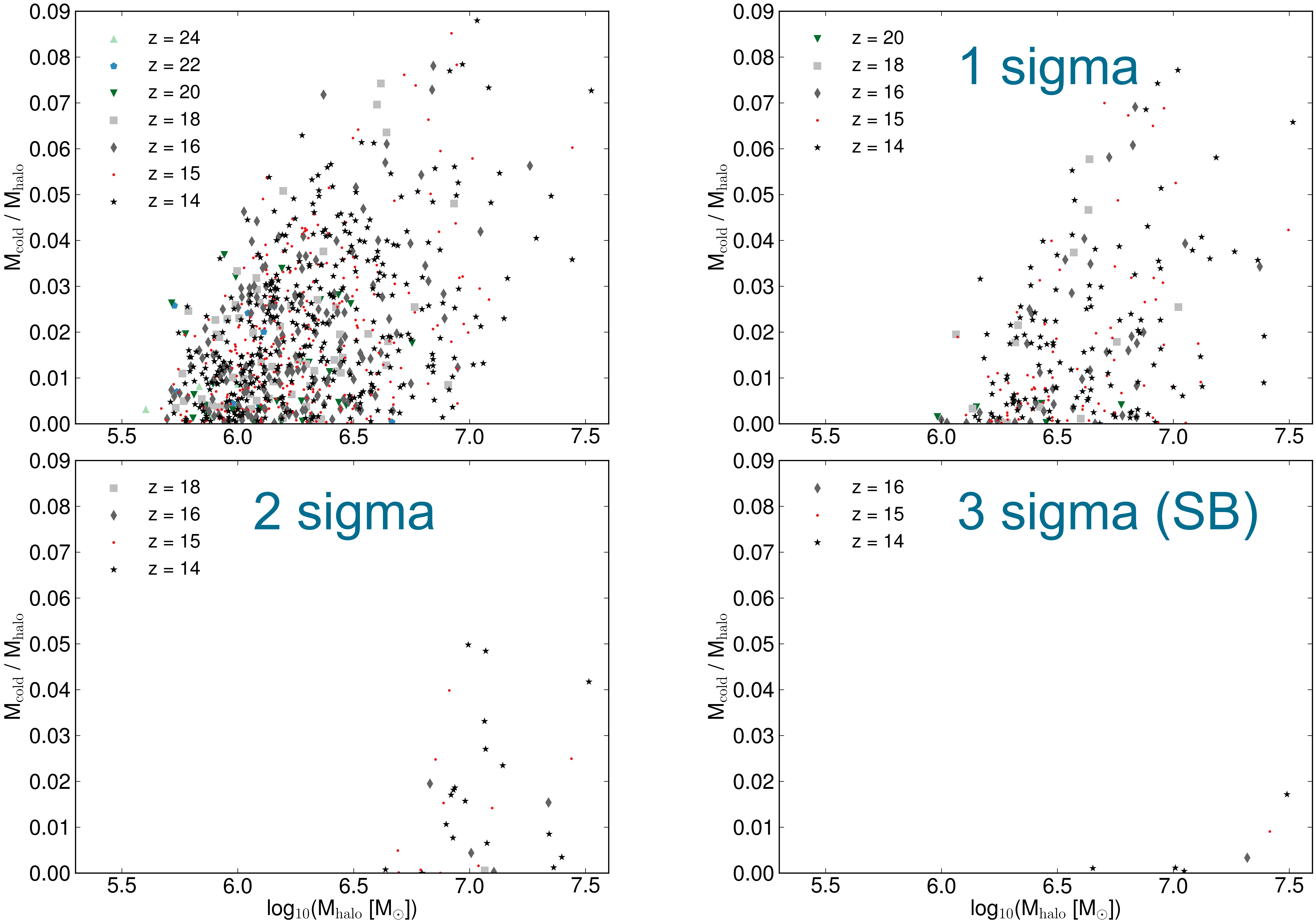
- increases with redshift
- for streaming velocities: far below cosmic mean

halo mass function

- number density decreases with streaming velocity



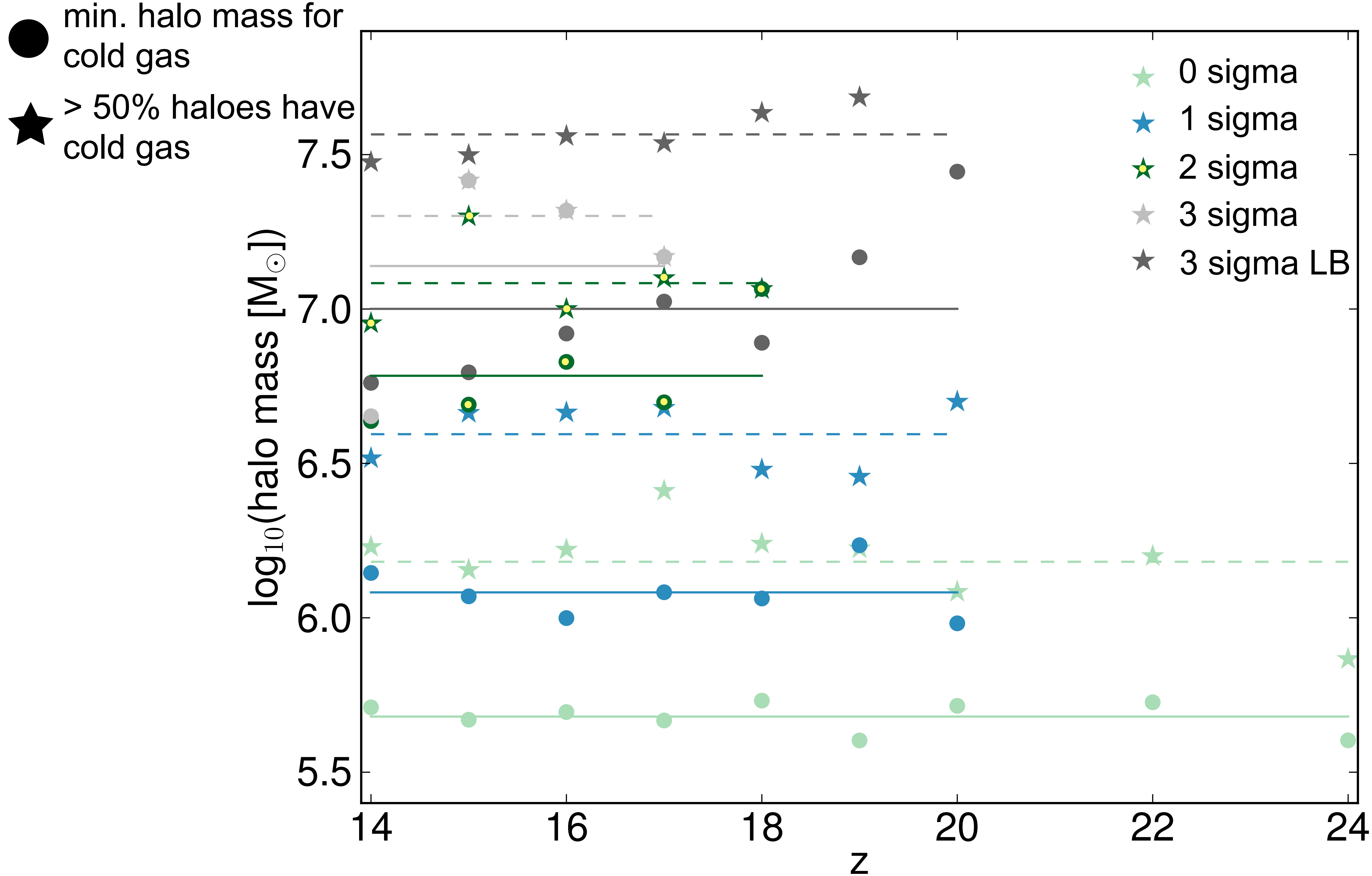
cold mass - halo mass: streaming



halo masses of cold halos: streaming

min. halo mass for cold gas

> 50% haloes have cold gas



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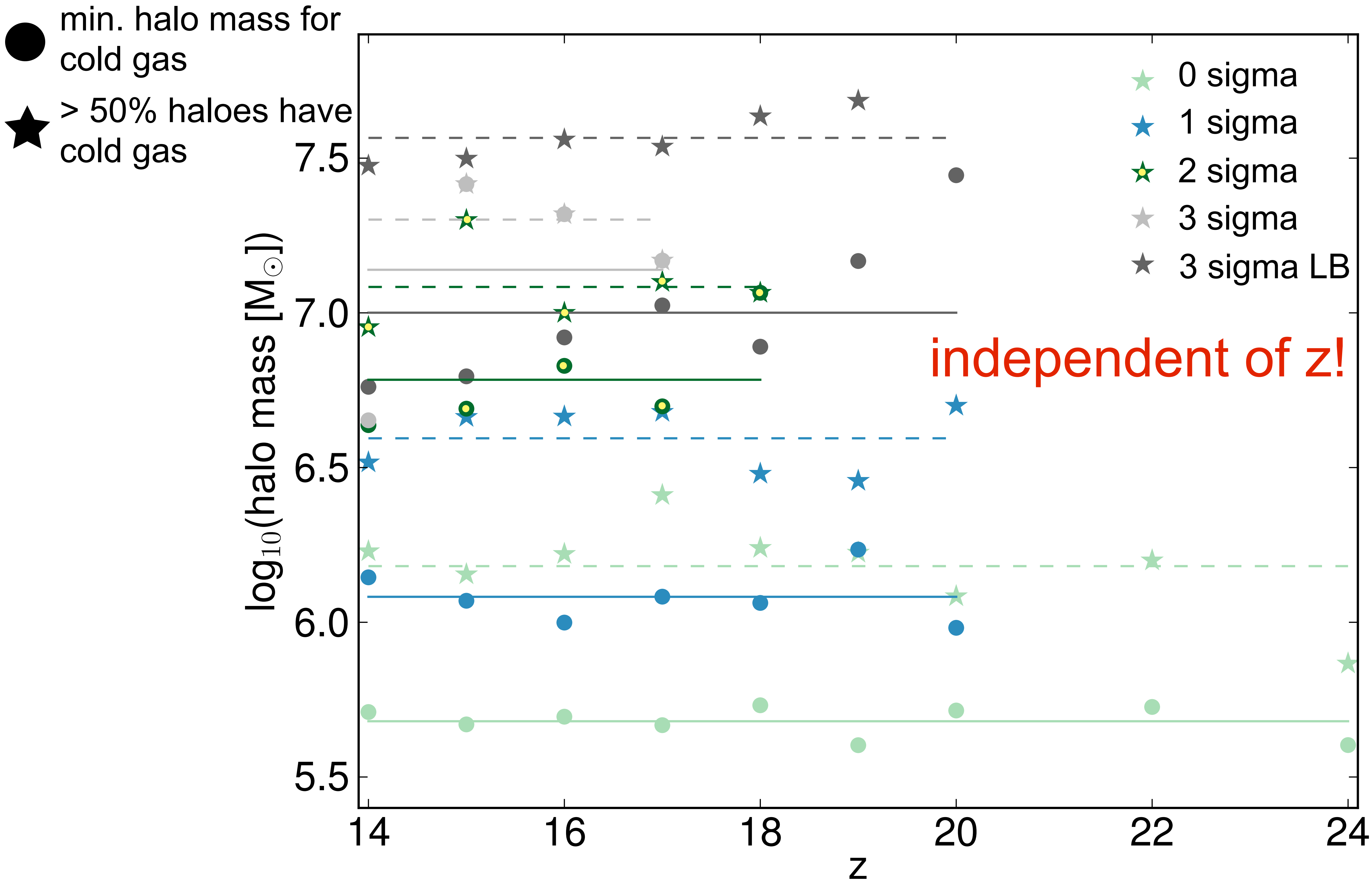


direct collapse black holes

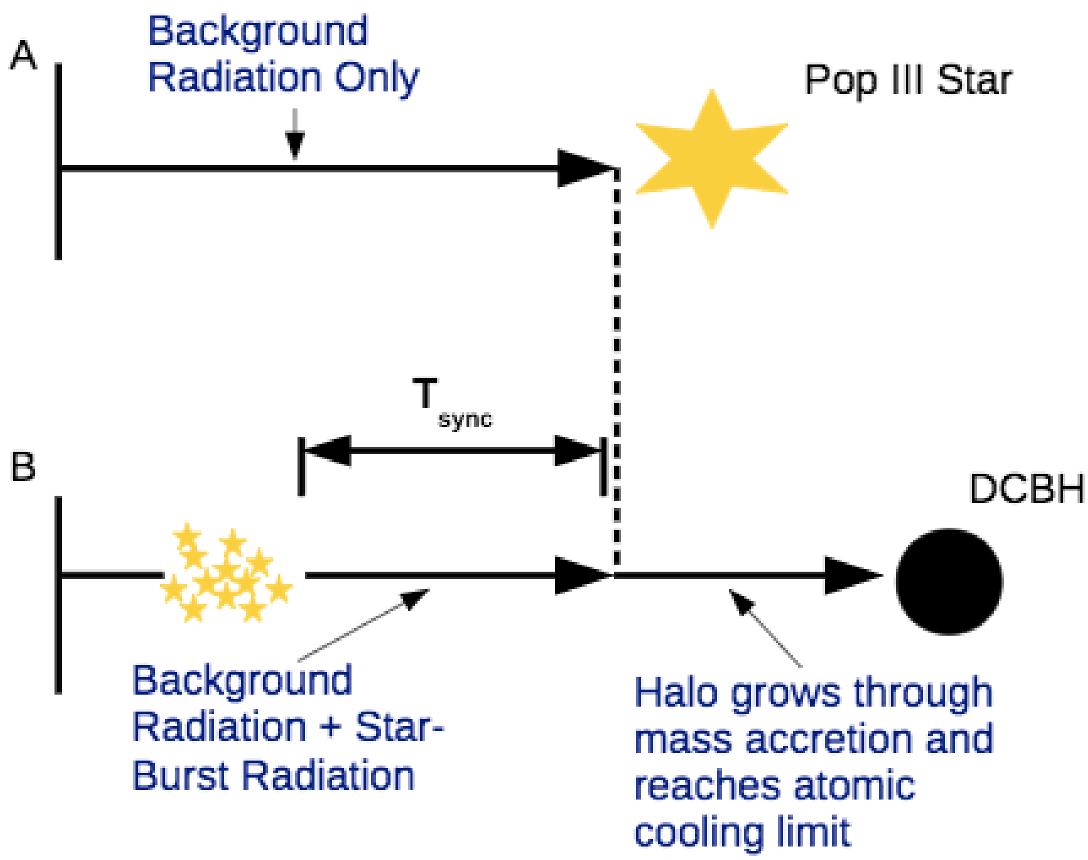
- observed high-redshift quasar number density:
  $n_Q \sim 1\ \mathrm{Gpc}^{-3}$ Fan 06
- problem: where do these objects come from?

-> Eddington accretion on Pop III remnant

-> direct collapse black holes

- atomic cooling halo collapses to a supermassive star and then to a $10^{4\text{-}5}\ M_\odot$ BH
- H_2 in halo needs to be suppressed to not form stars

-> synchronized halo mechanism



Regan+17

3 sigma streaming regions -> DCBHs!

- collapsed halos: halo masses above atomic cooling limit!

-> no pollution of metals from minihalos

- all collapsed halos contain H_2 in their centers

-> no immediate DCBH formation

- close halo pair number density: Visbal+14

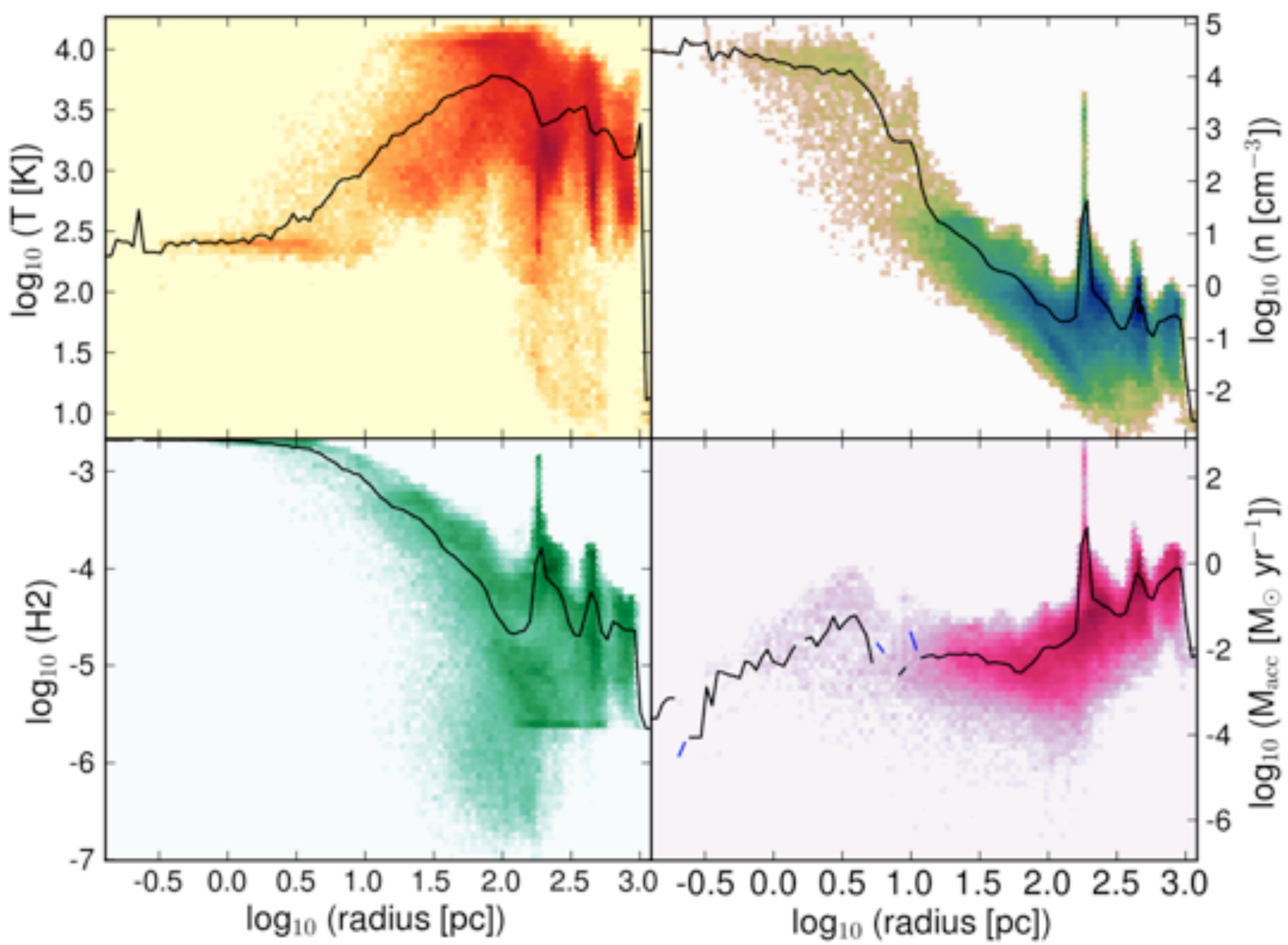
  $n_{CP} \sim 1.2 \times 10^{-4}$ Mpc^{-3}

- volume fraction with ≥ 3 sigma streaming:

  $\partial V/V \sim 6 \times 10^{-4}$

-> DCBH number density :

  $n_{DCBH} \sim 0.7$ Gpc^{-3}



Schauer+17 ArXiv 1705.02347, submitted to MNRAS

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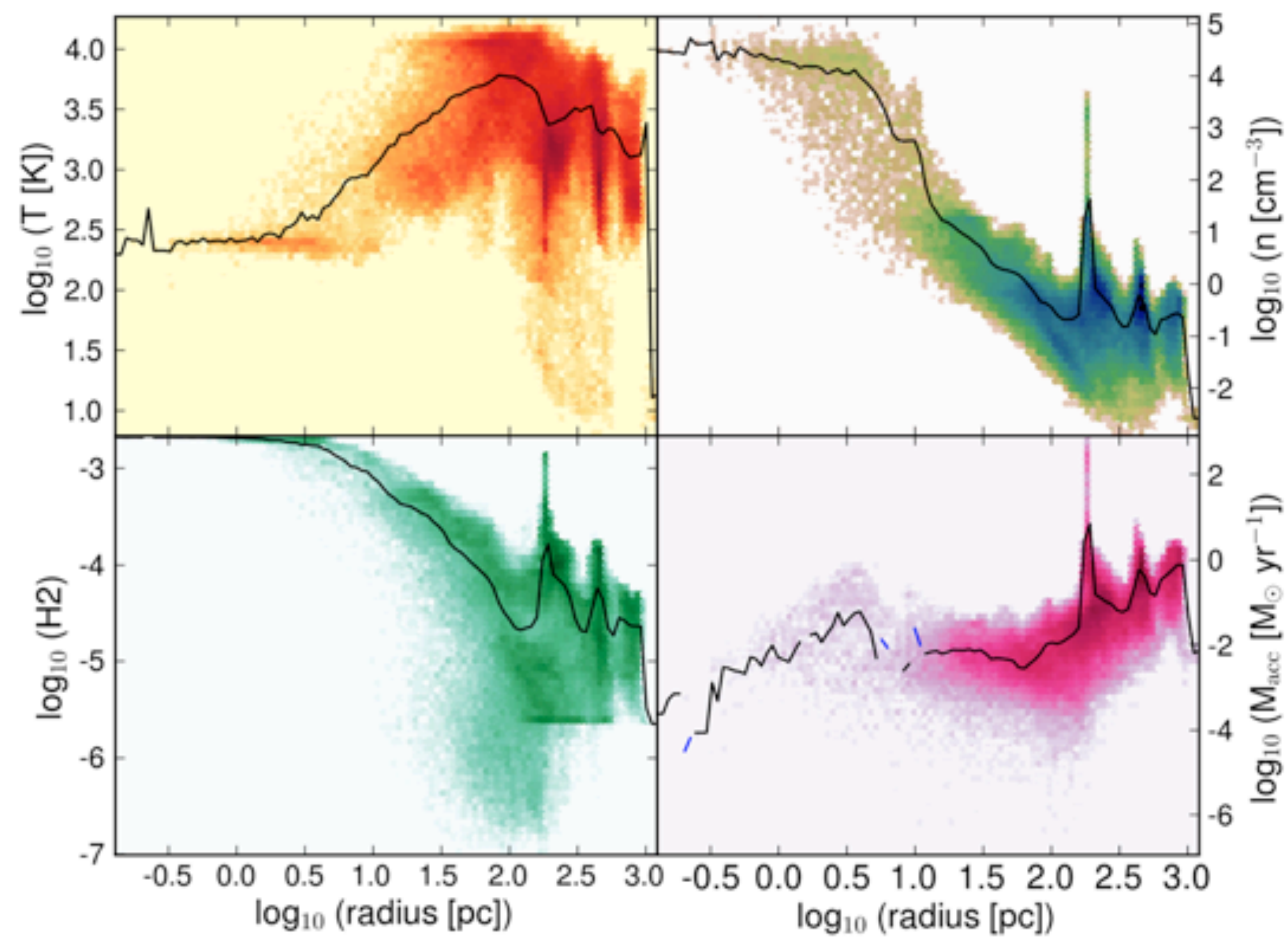

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conclusions

- The formation of the first stars takes place in minihalos with masses > $4 \times 10^5\, M_\odot$
- Streaming velocities are offset velocities between DM and baryons. Impacts on first star formation:
  - Lower gas content in minihalos
  - Halos start containing cold gas at later redshift
  - The halo mass threshold moves to higher values, with masses > $10^7\, M_\odot$ for 3 sigma streaming

Schauer+ in prep.

- 3 sigma streaming velocity regions are perfect environment for direct collapse black hole formation

Schauer+17 ArXiv 1705.02347, submitted to MNRAS