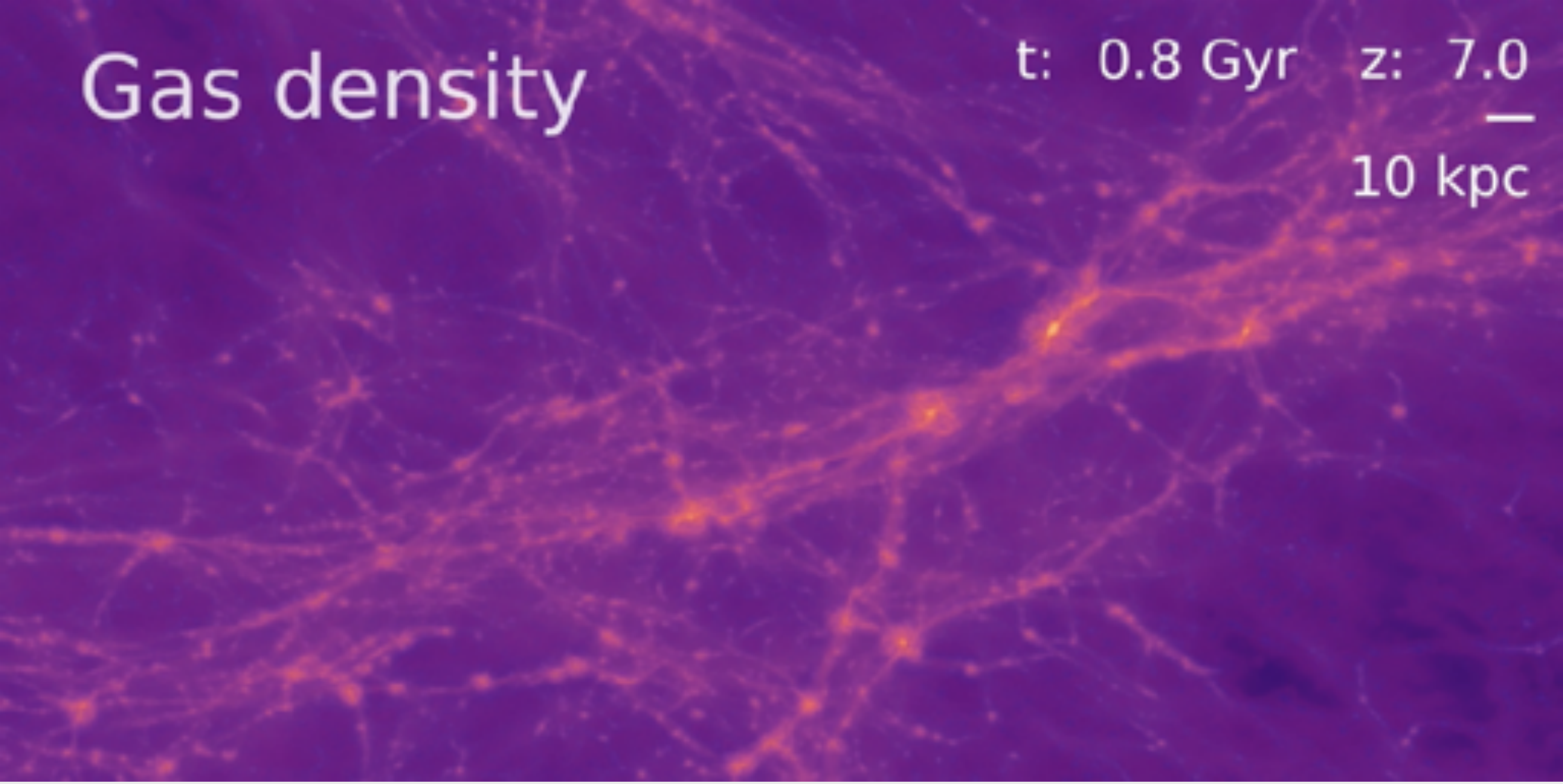
Enhanced cool, dense gas in refined galaxy haloes

Freeke van de Voort

(MPA)



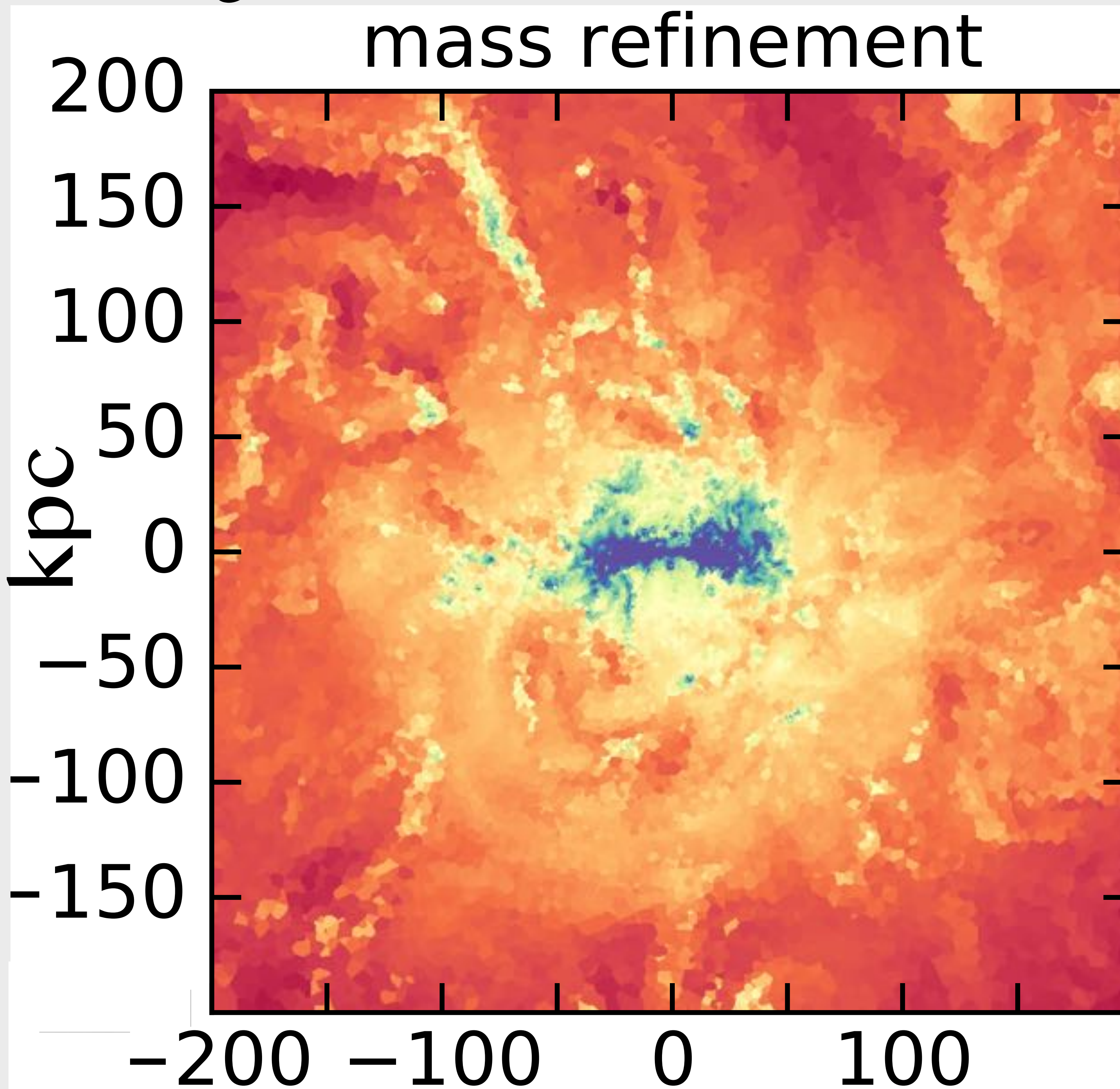
Grand et al. 2017

- We resimulate (with Arepo) a Milky Way-mass galaxy from the Auriga project with additional spatial refinement (maximum cell size of 2 kpc, 1 kpc, and 0.5 kpc) within the virial radius (down to z=0).

density (slice)

z=0

- Standard approach: resolution decreases with decreasing density, i.e. with galactocentric radius.

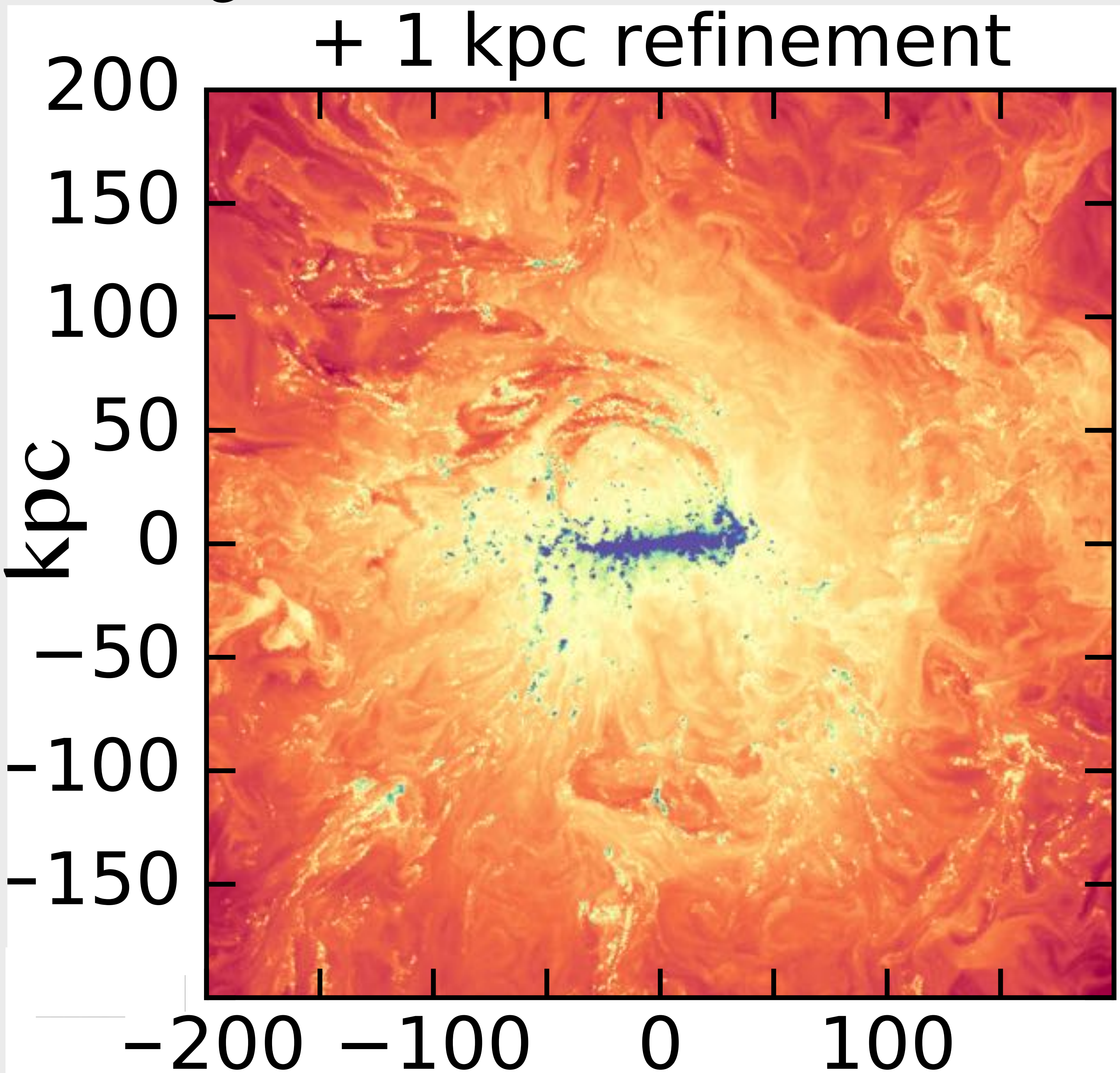


van de Voort et al. 2019

density (slice)

z=0

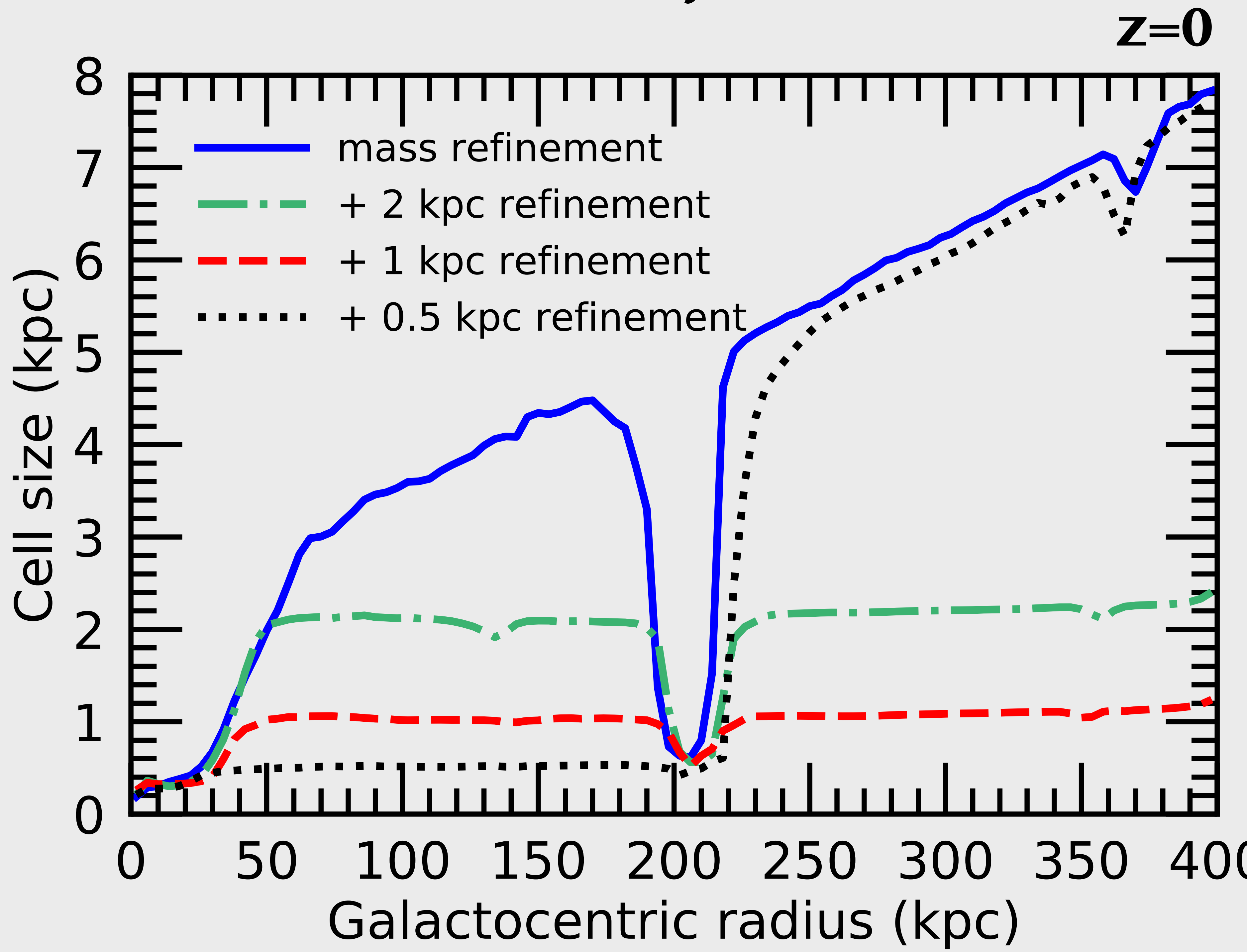
- Additional **uniform spatial refinement** within the halo.
- ~100x the resolution elements in the CGM for only 8x the CPU time.
- The ISM is treated the same as before.
- Smaller cold, dense gas clumps and more pronounced underdensities.



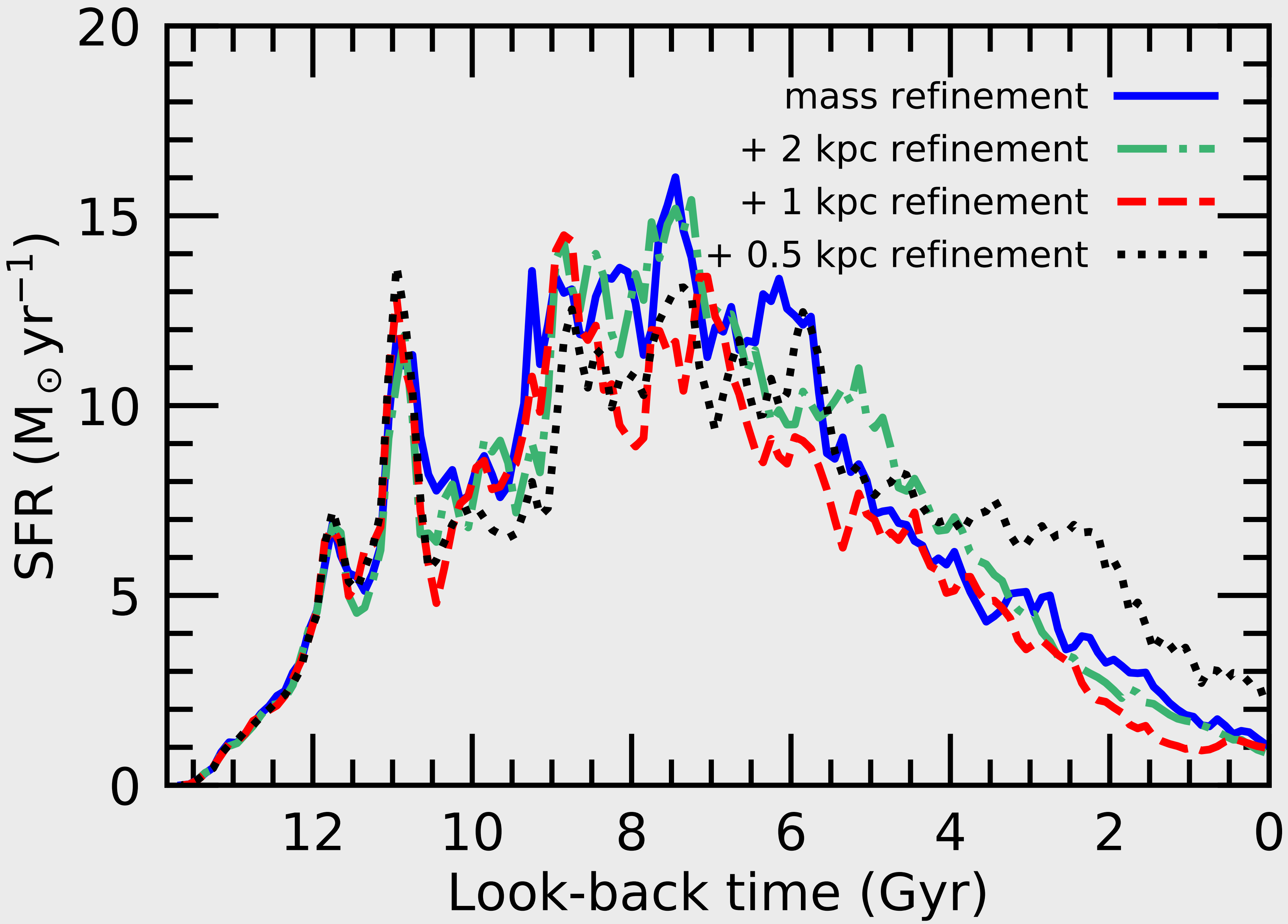
van de Voort et al. 2019

SURGE

- **S**imulating the **U**niverse with **R**efined **G**alaxy **E**nvironments
- We use additional **uniform spatial refinement** within the CGM of each galaxy.
- 4 simulations: standard resolution, +2 kpc, +1 kpc, and +0.5 kpc spatial refinement.



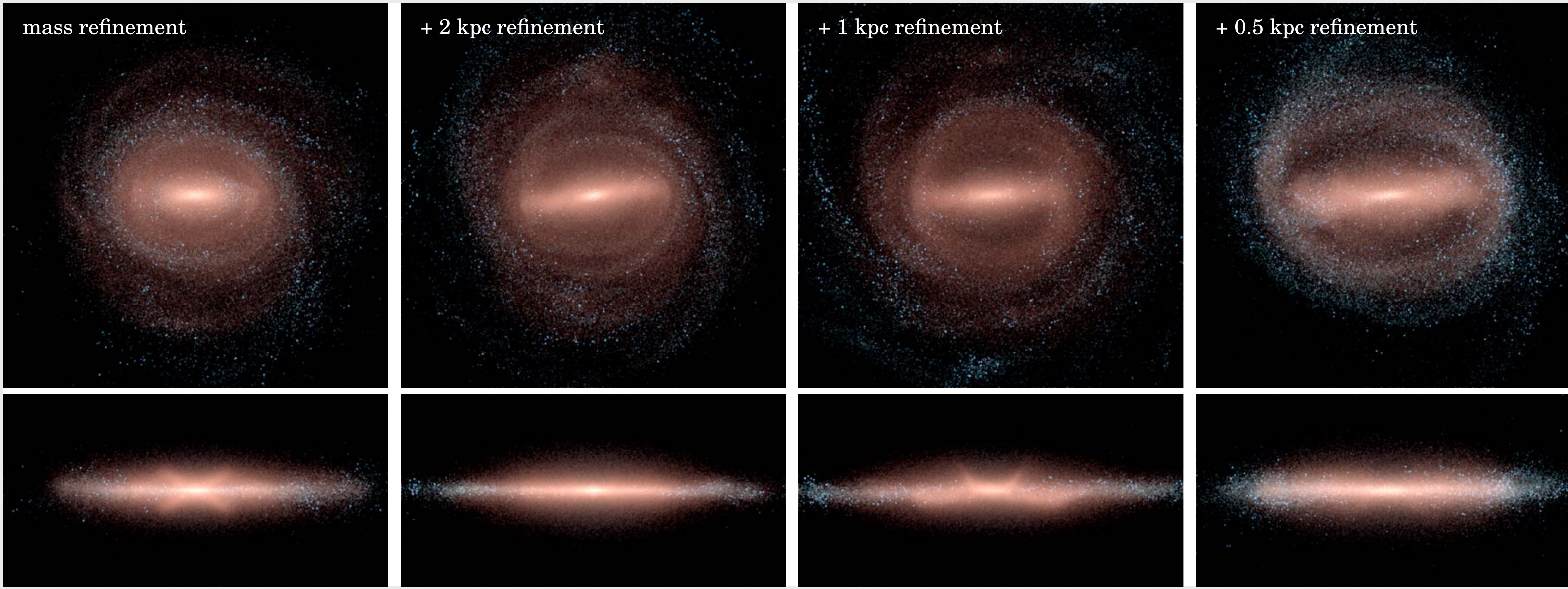
star formation history



- The star formation history is similar at early times, but in the last 4 Gyr the highest CGM resolution simulation experiences enhanced star formation.

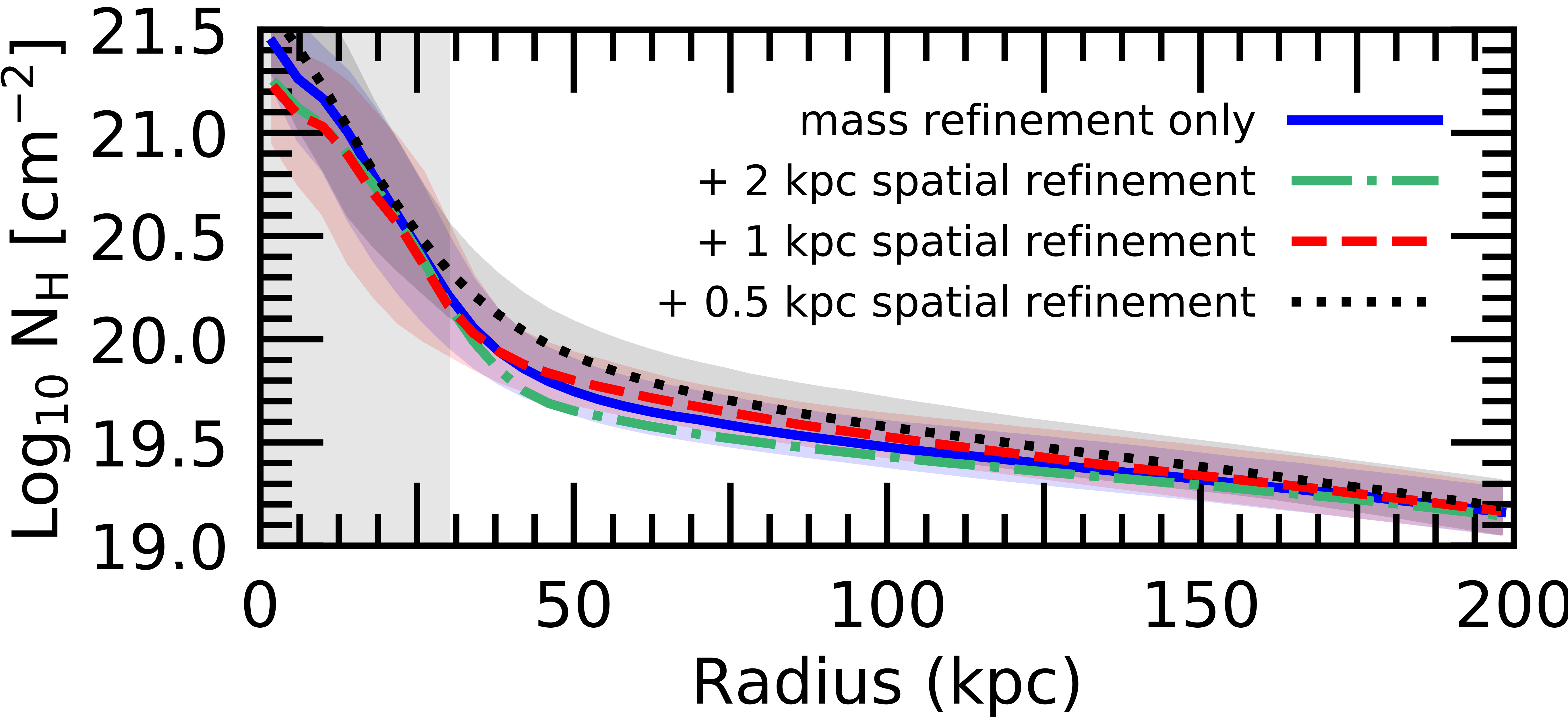
galaxy morphology

standard | **+ 2 kpc** | **+ 1 kpc** | **+ 0.5 kpc**



- The mass of the galaxy varies by only 0.07 dex.
- The bulge-to-total ratio is very similar in all three cases.
- The galaxy is bluer in the highest CGM resolution simulation.

CGM density profile$_{z=0.3-0}$

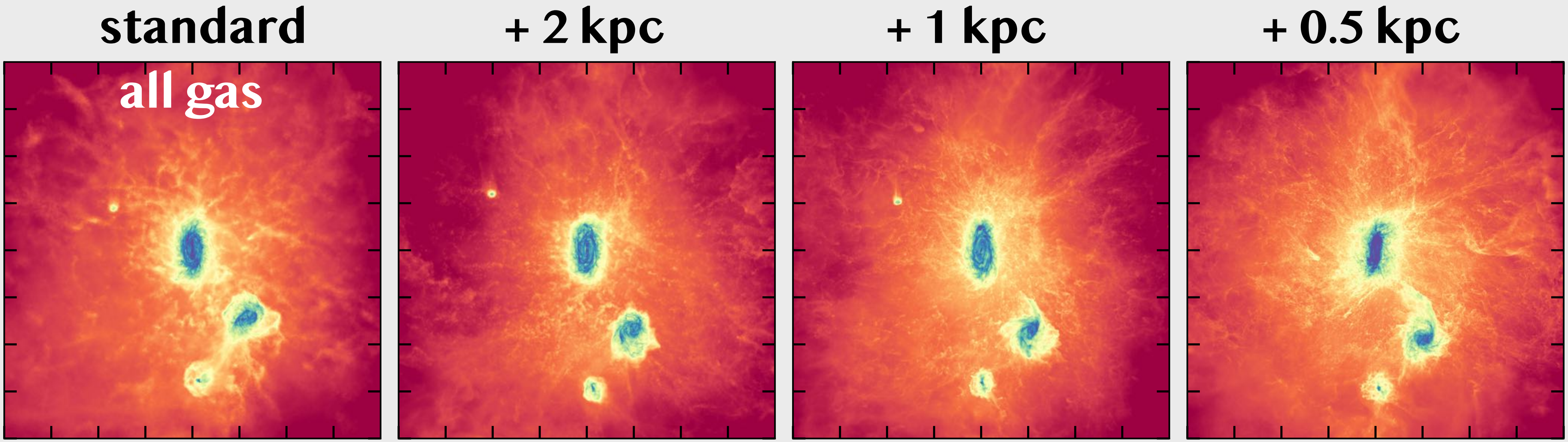


- N_H is the hydrogen column density along 600 kpc sightlines.
- No large or systematic differences in the median density profile of the CGM.

van de Voort et al. 2019

CGM density (N_H)

z=0.1



- N_H is similar (but has finer CGM structure).

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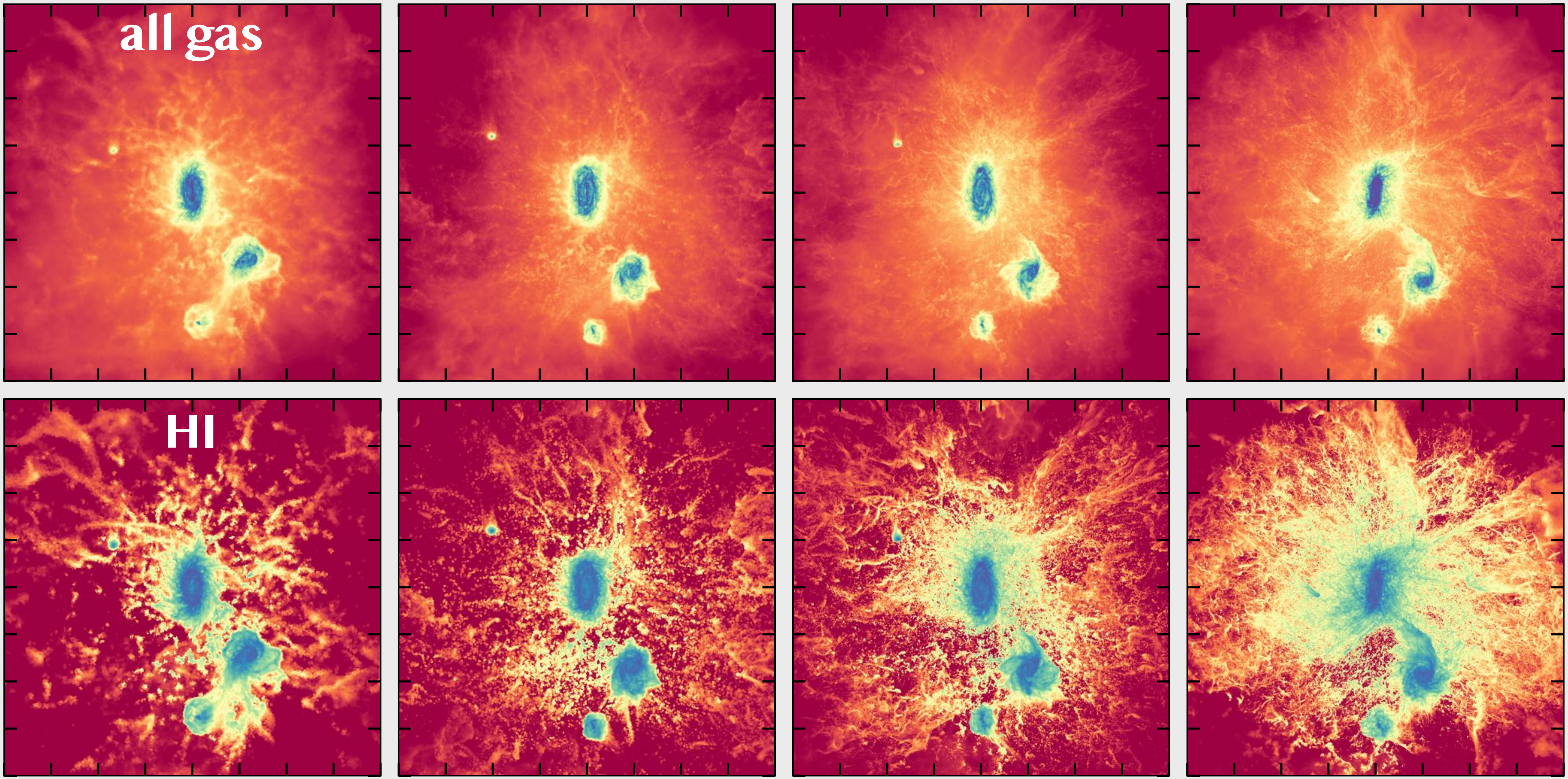
column density (N_{HI}) z=0.1

standard **+ 2 kpc** **+ 1 kpc** **+ 0.5 kpc**

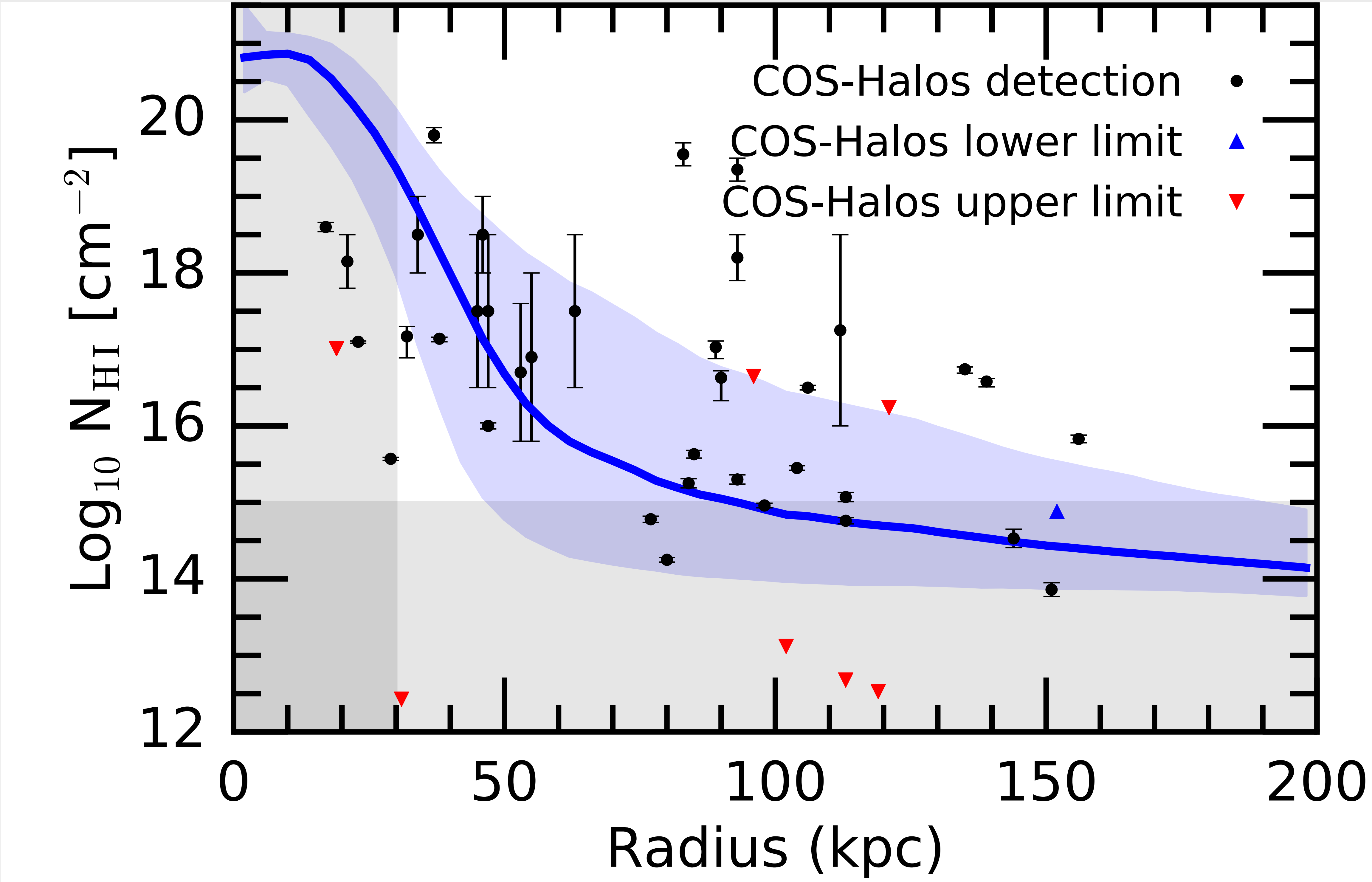


- N_H is similar, while N_{HI} (neutral hydrogen) is much higher with additional 1 kpc or 0.5 kpc spatial resolution.

van de Voort et al. 2019

HI density profile

z=0.3-0

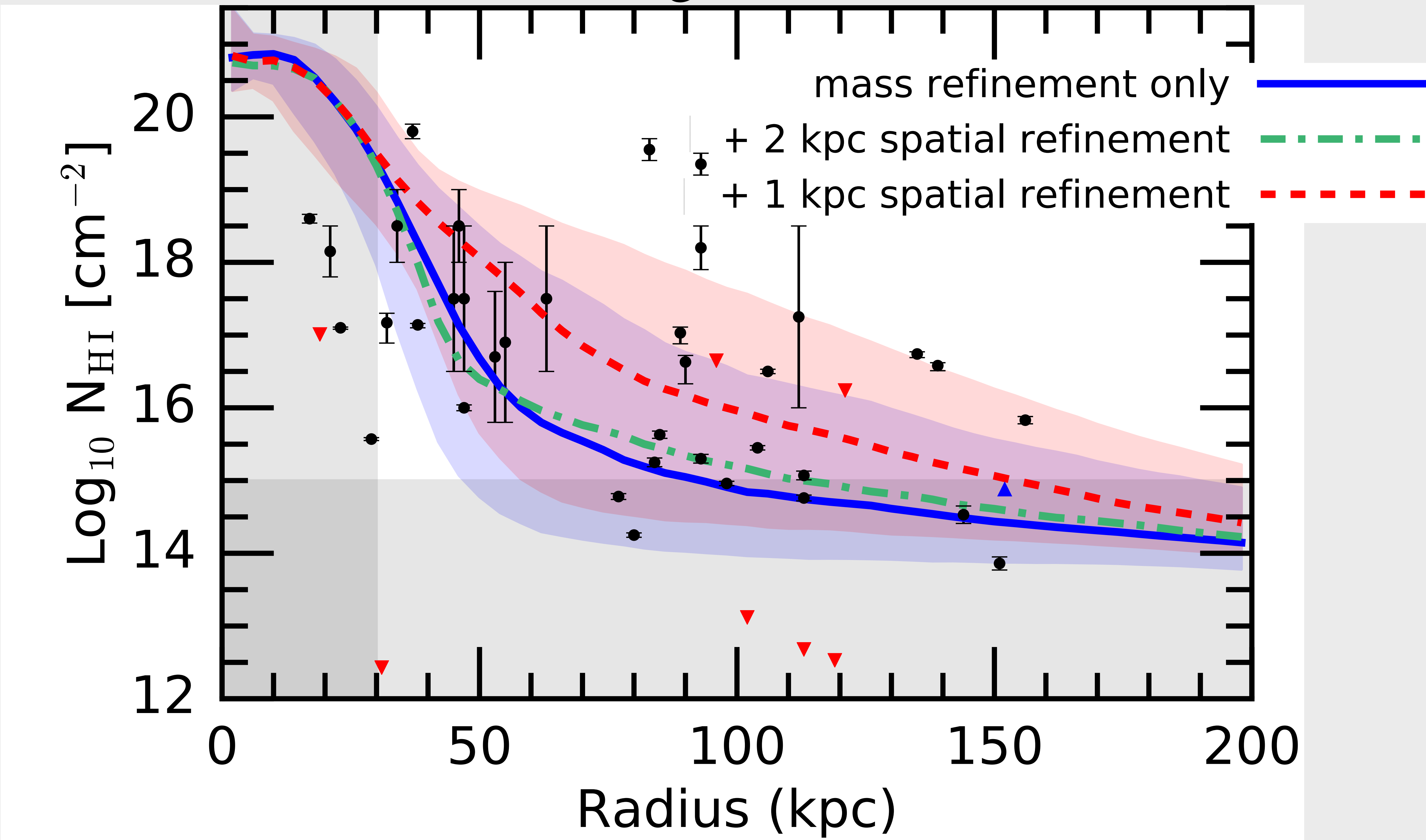


- Neutral hydrogen column density profile for a standard mass refinement simulation.

van de Voort et al. 2019

HI density profile

z=0.3-0

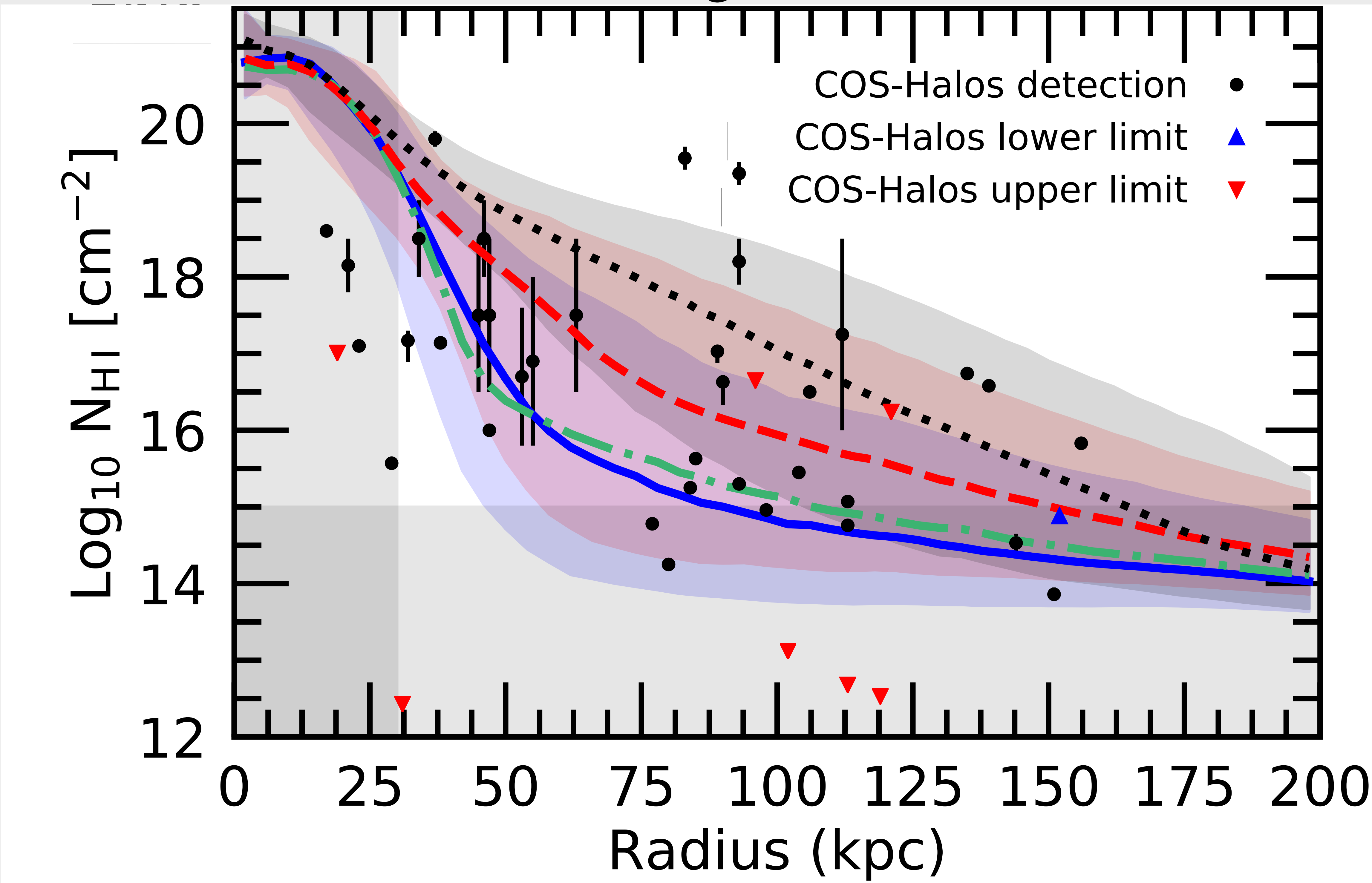


- Strong increase in HI for the 1 kpc spatially refined simulation (up to 1.6 dex).

van de Voort et al. 2019

HI density profile

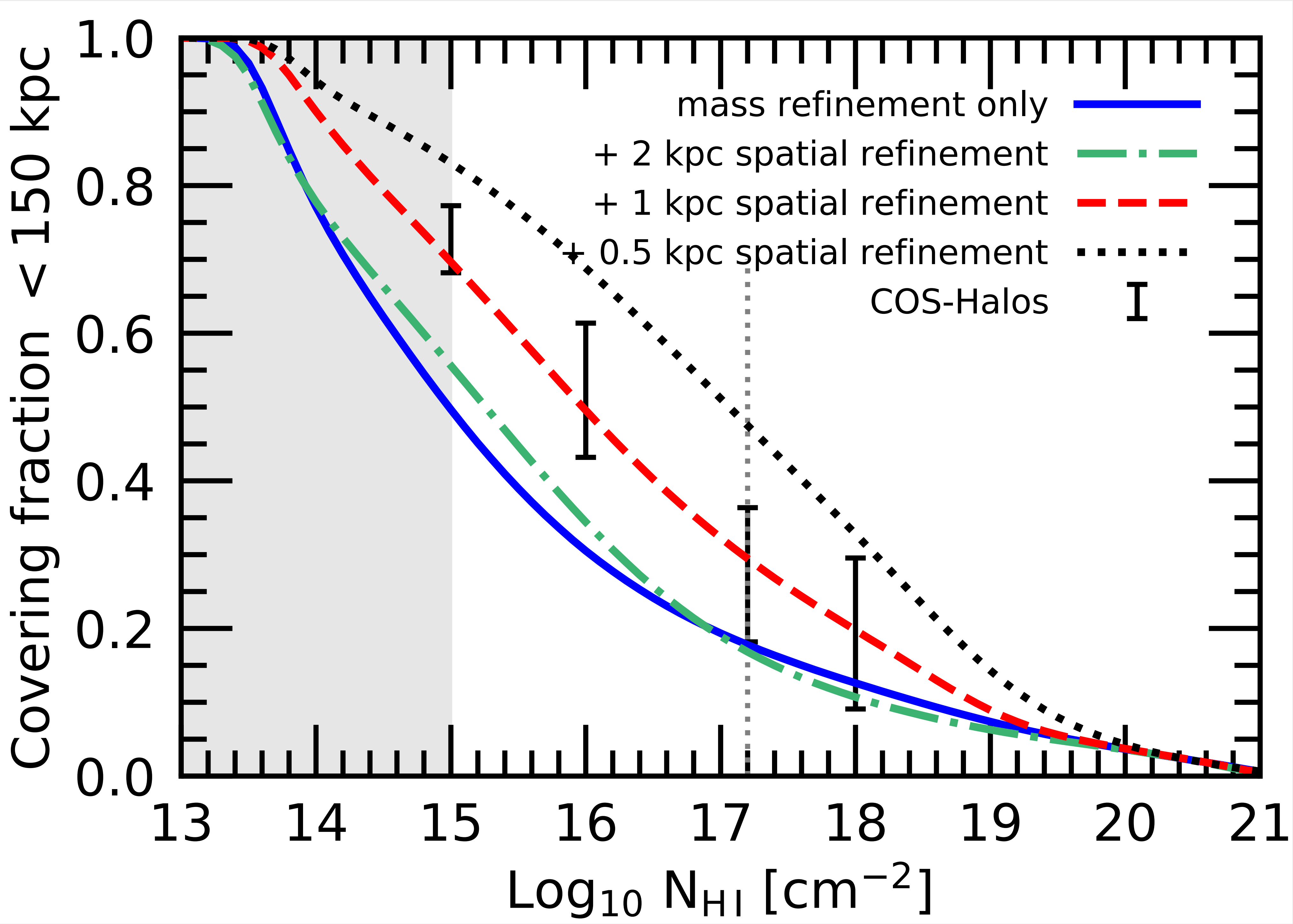
z=0.3-0



- Even stronger increase in HI for the 0.5 kpc spatially refined simulation (by more than 2 orders of magnitude).

covering fraction

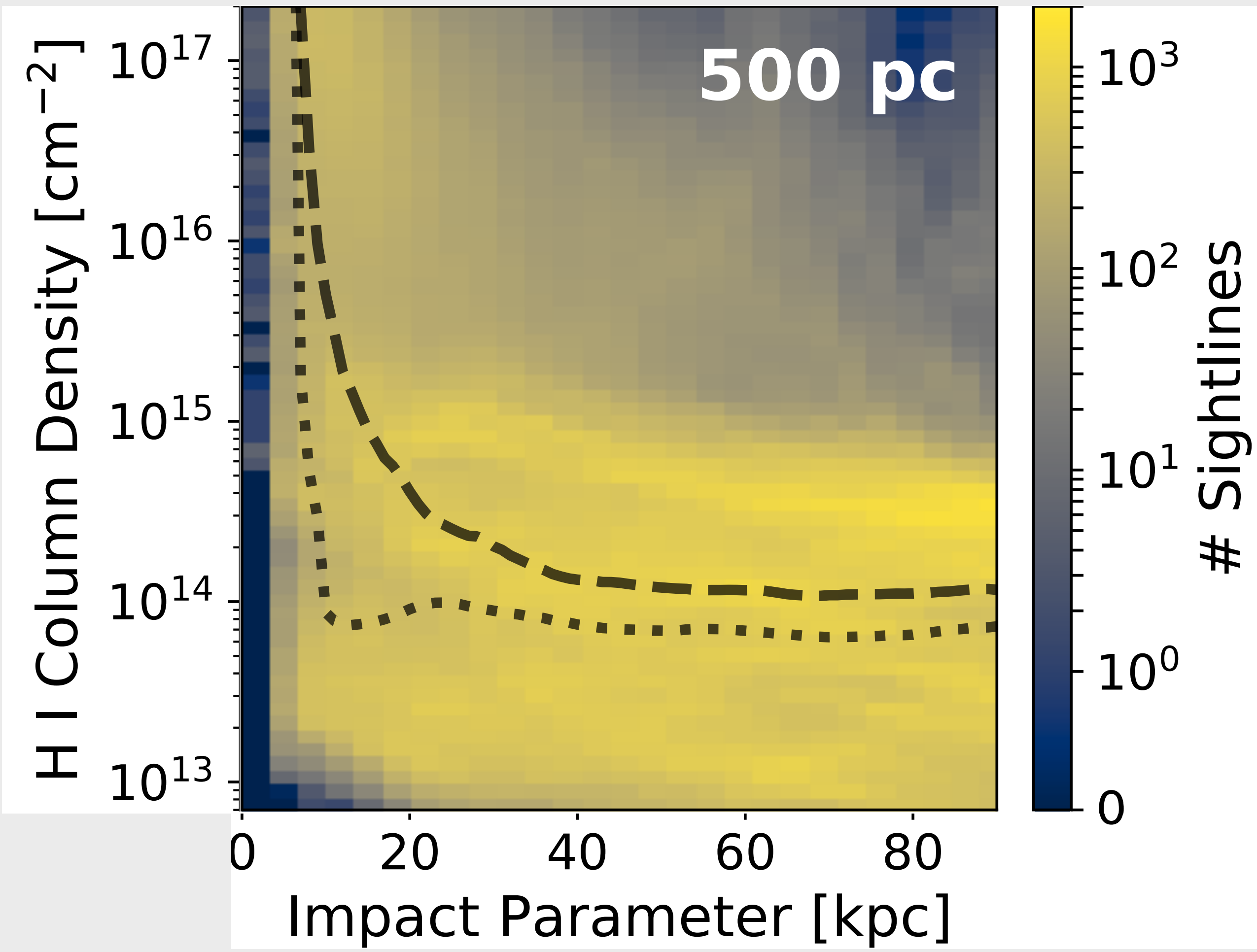
z=0.3-0



- No convergence yet regarding neutral hydrogen in the CGM.
- Now seem to overproduce the amount of cold gas in the CGM.

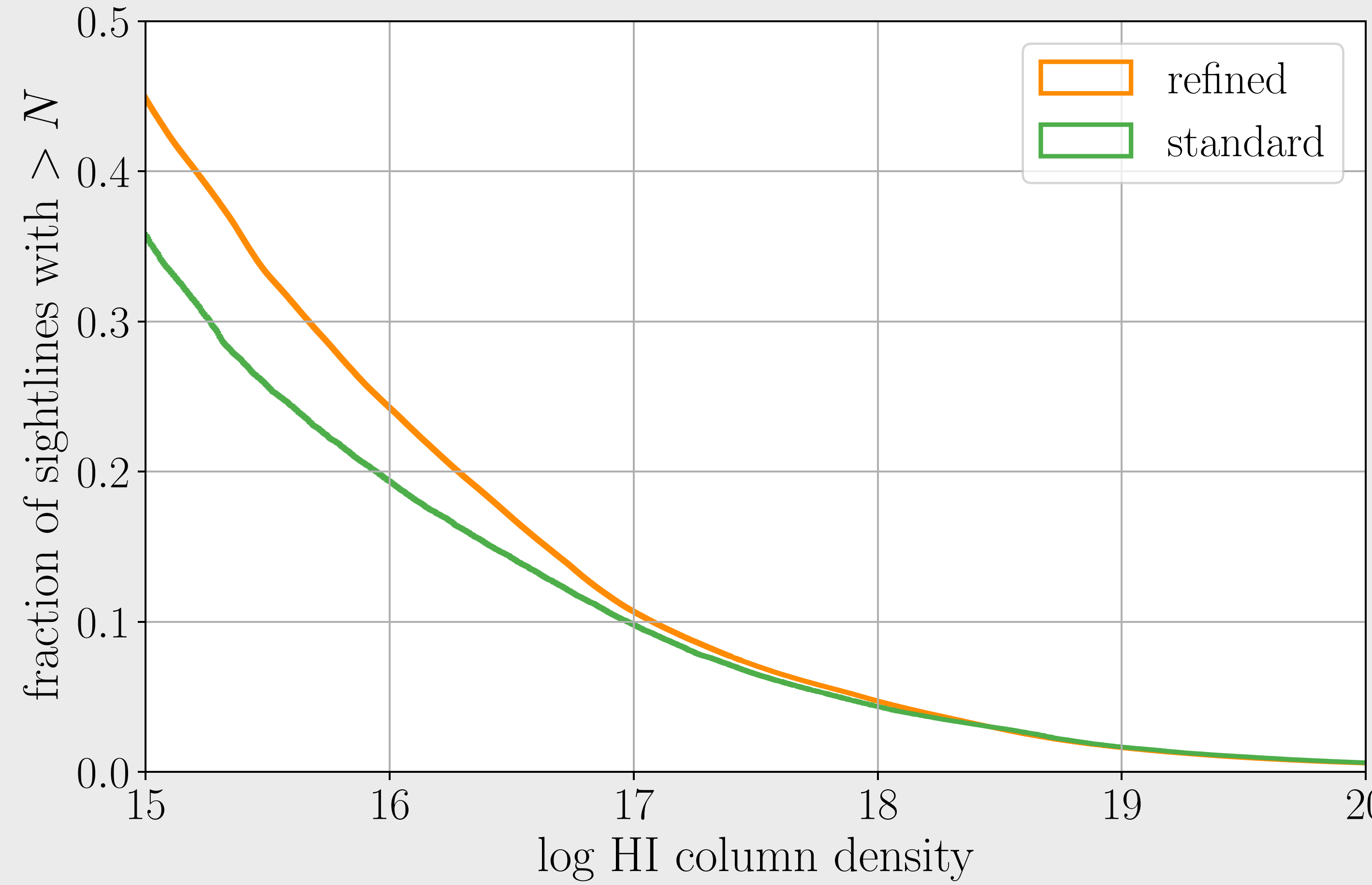
other work

z=1



Hummels et al. 2018; Tempest

z=2



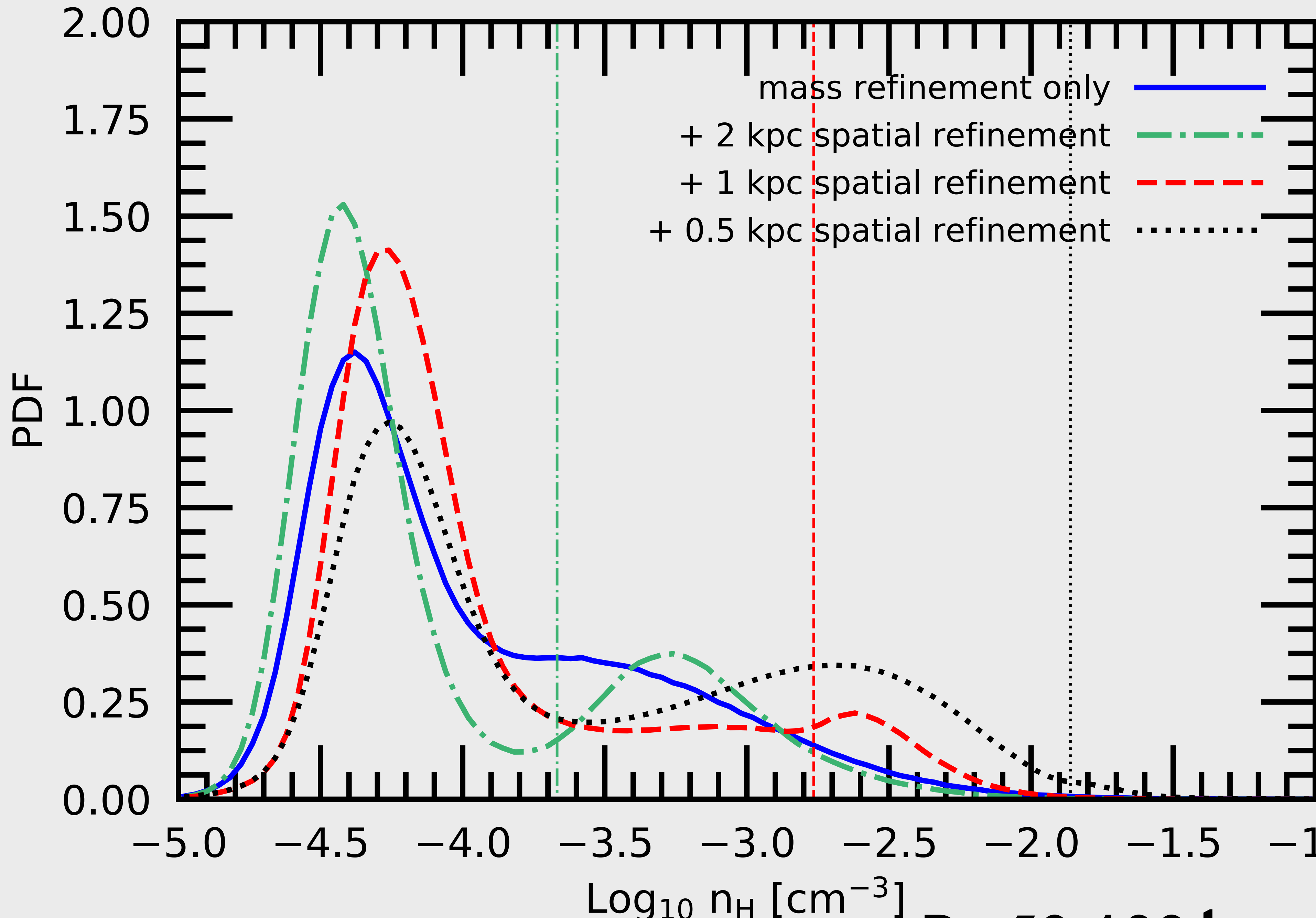
Peeples et al. 2019; FOGGIE

- Other work using static mesh simulations (AMR + uniform spatial refinement) find qualitatively similar trends at higher redshifts, but the difference is much smaller.
- Due to lower galaxy mass, higher redshift, less efficient feedback, no self-shielding?

CGM density

- With additional resolution, a high-density, phase builds up. (becoming similar in mass as the hot halo gas.)
- Less gas at intermediate densities.

z=0.3-0

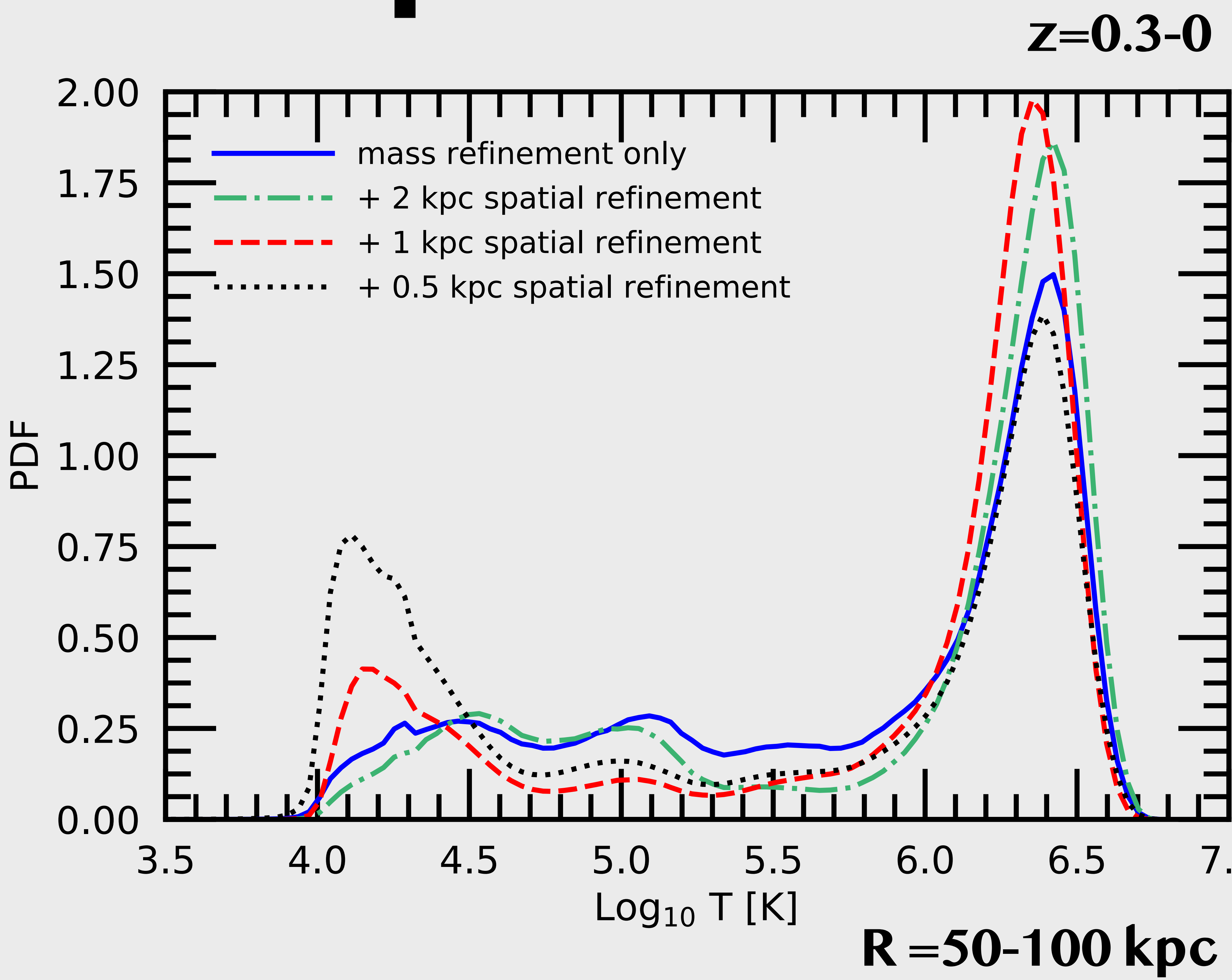


R =50-100 kpc

in preparation

CGM temperature

- With additional resolution, a high-density, low-temperature phase builds up. (becoming similar in mass as the hot halo gas.)
- Less gas at intermediate densities and temperatures.

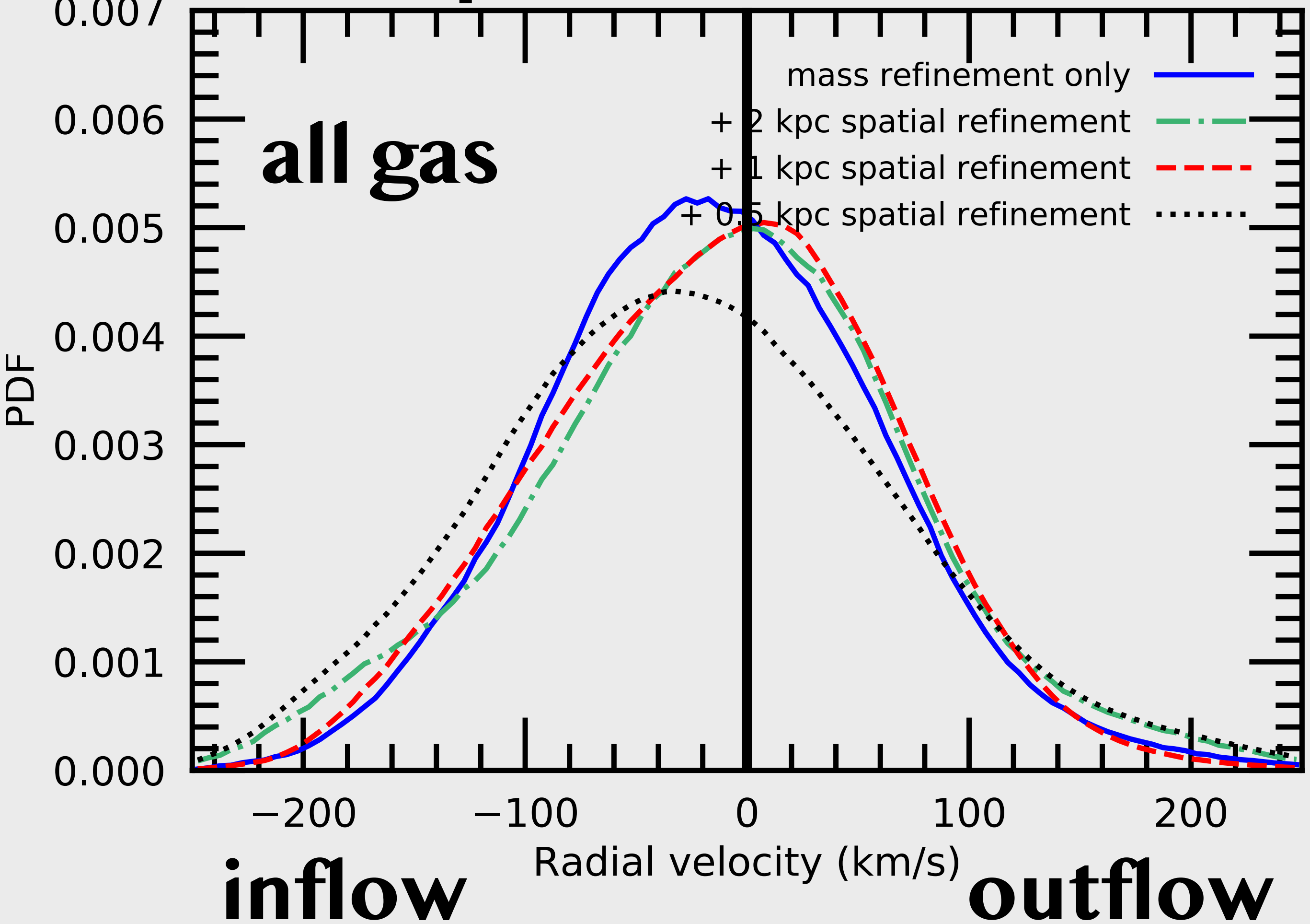


- Caveats: no radiative cooling below 10,000 K, no thermal conduction, no cosmic rays, simplified self-shielding.

in preparation

radial velocity

R =50-100 kpc **z=0.3-0**

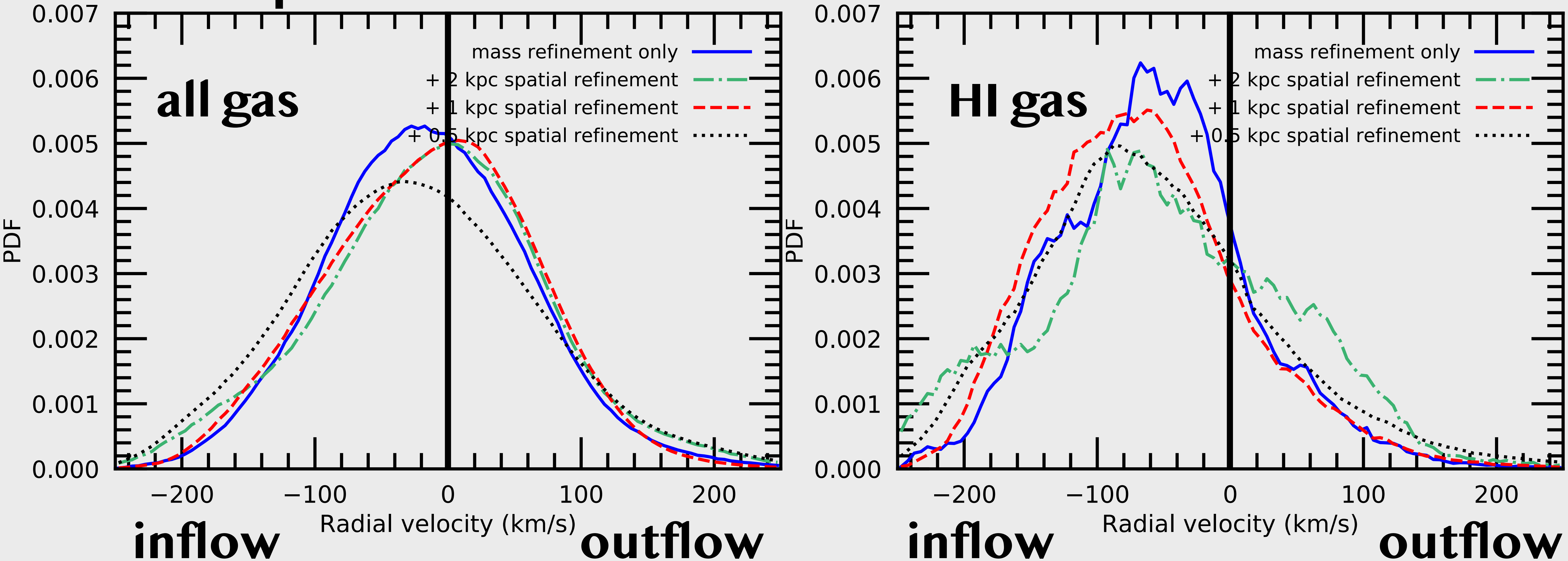


- The halo gas has almost equal amounts currently inflowing towards and outflowing from the central galaxy.

in preparation

radial velocity

R =50-100 kpc **z=0.3-0**



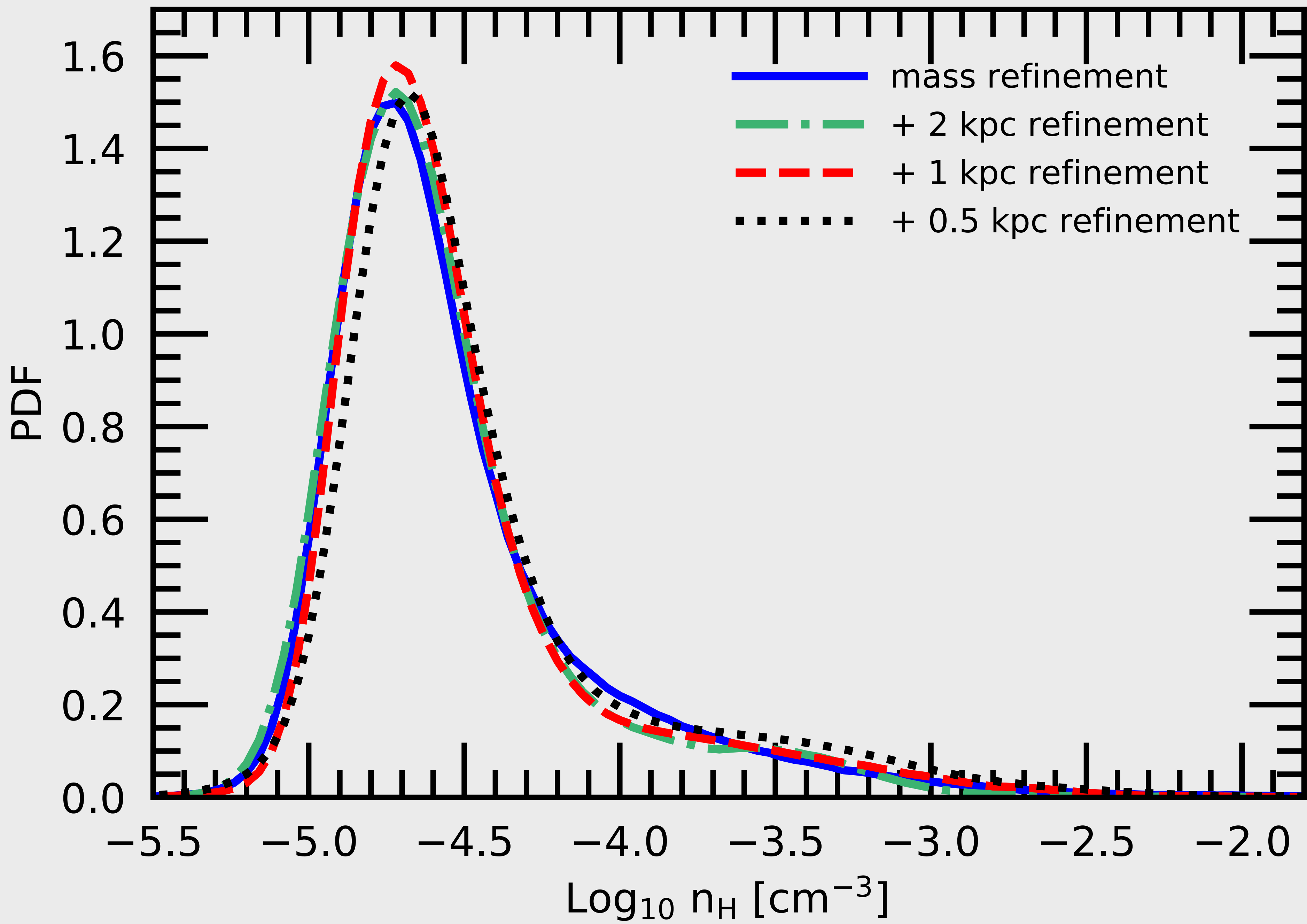
- The halo gas has almost equal amounts currently inflowing towards and outflowing from the central galaxy.
- The neutral gas is strongly inflowing and therefore more likely to accrete onto the galaxy and fuel future star formation.
- This appears to be independent of the CGM resolution.

in preparation

outer CGM density

- The density in the outer CGM does not change with resolution and is therefore reasonably well converged.
- This explains why the difference in HI profiles decreases towards larger radii.

z=0.3-0

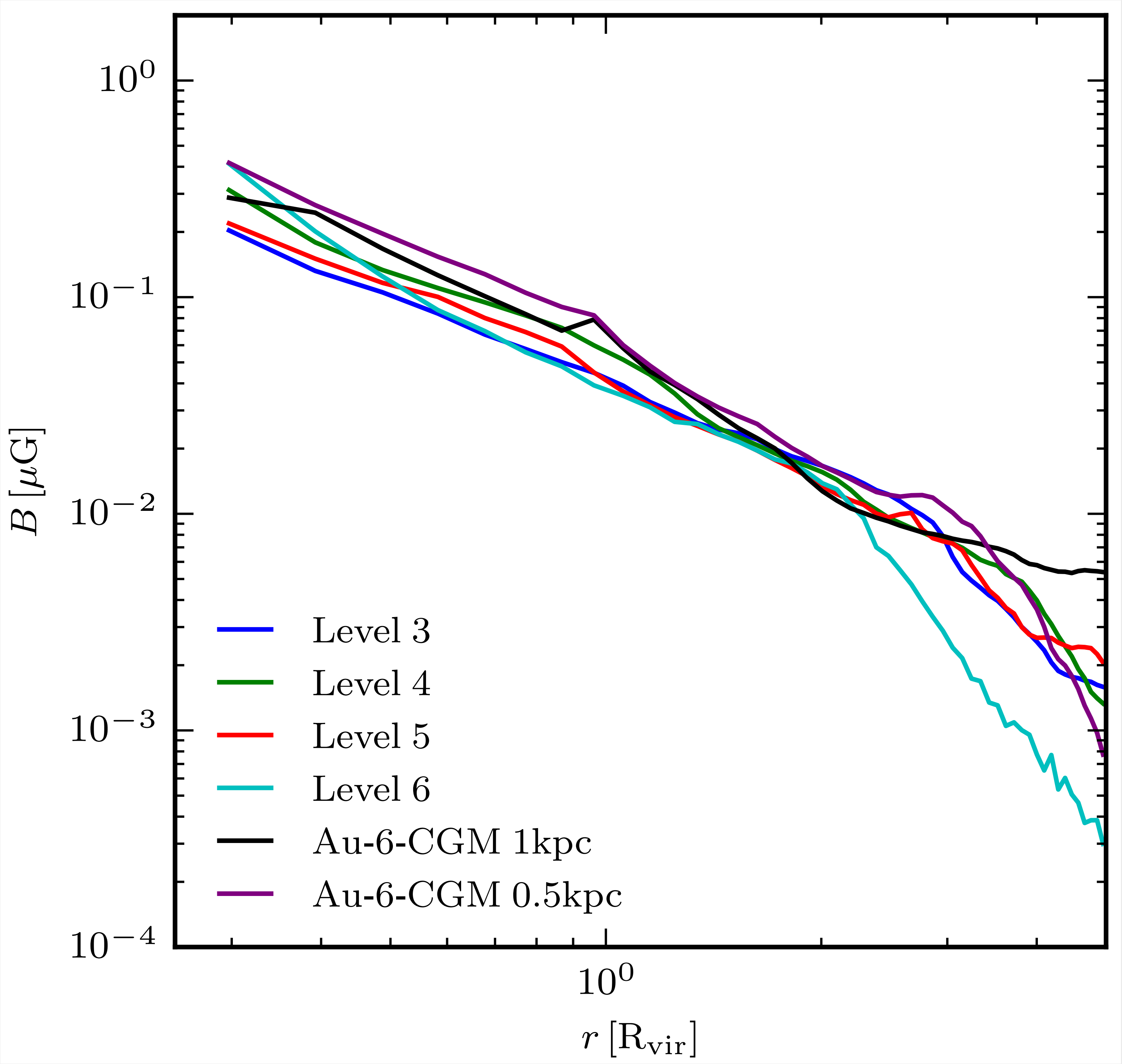


R =150-200 kpc

in preparation

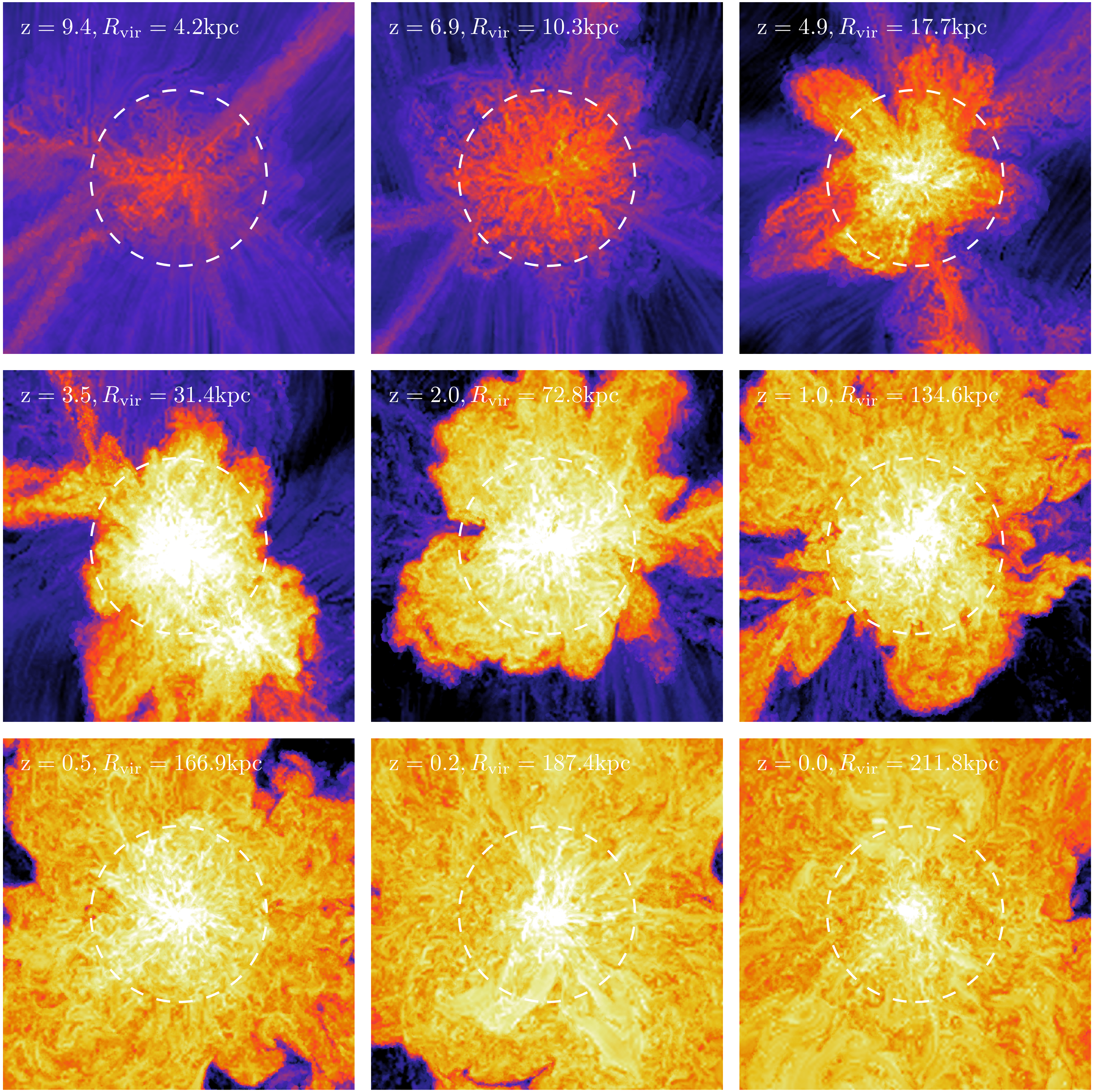
magnetic field strength

- Factor of ~2 variation in magnetic field strength in simulations spanning over 4 orders of magnitude in resolution.



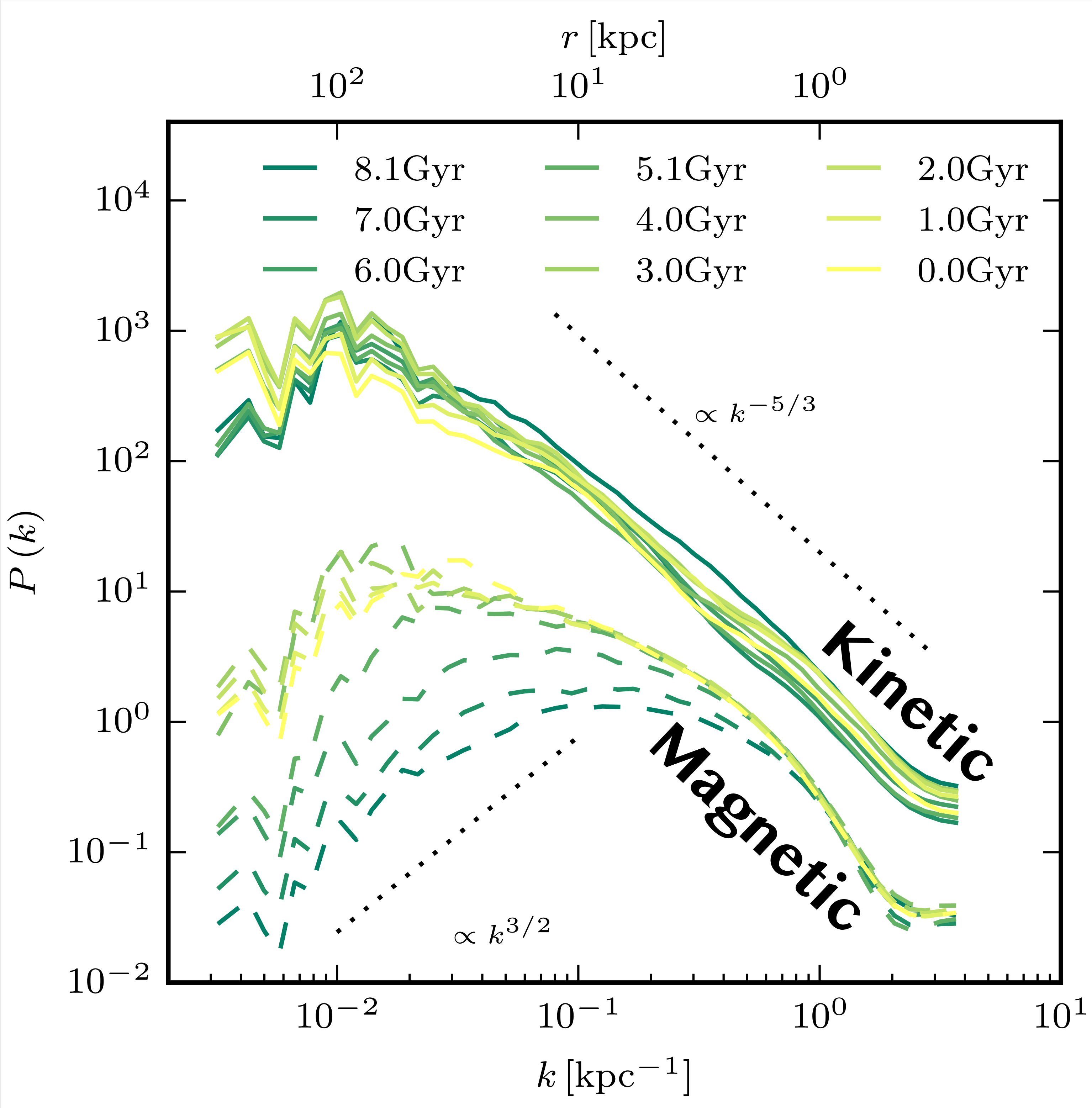
Pakmor et al. (in prep.)

- Magnetic field strength & direction from z = 9-0
- Outflows push magnetic fields from the galaxy into the halo.
- A turbulent dynamo enhances the magnetic field strength in the halo.

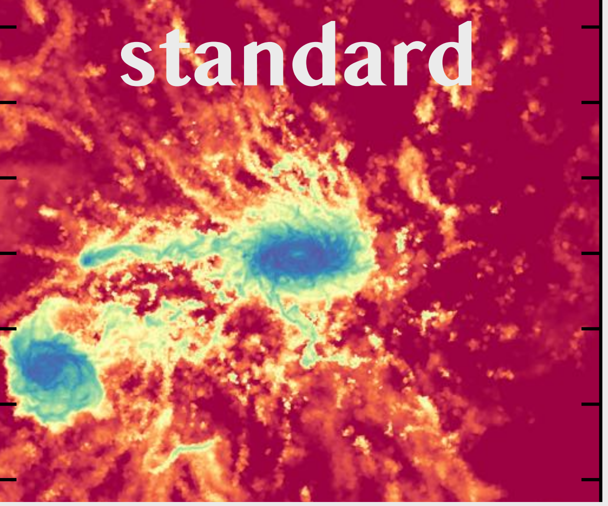


power spectra

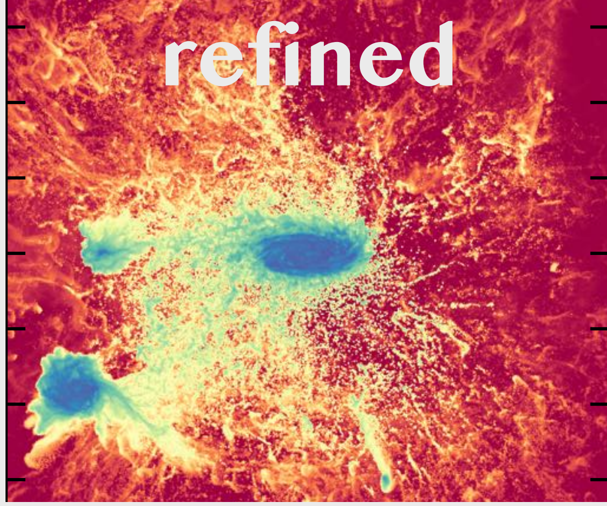
- **Kinetic** energy follows Kolmogorov turbulent spectrum, driven at ~100 kpc scales, cascades down to resolution limit.
- **Magnetic** field amplification is driven by turbulent dynamo (small eddies turn around faster, so small scales saturate faster).
- Magnetic power at large scales increases until z=0.4, where it saturates.



Pakmor et al. (in prep.)



conclusions



- **SURGE**: Increasing the CGM resolution while treating the galaxies as before is a promising and efficient method.
- Whether this is important depends on the topic of interest:
  - The improved spatial resolution does no strongly impact the central galaxy or the average density profile of the CGM.
  - Improved resolution increases the amount of cool, dense gas in the halo, resulting in a substantially enhanced N_{HI}.
- Magnetic fields in the CGM are pushed out of the galaxy and generated in situ by a turbulent dynamo.
- Now running refined simulations without self-shielding, with thermal conduction, with cosmic rays, with cooling < 10,000 K.