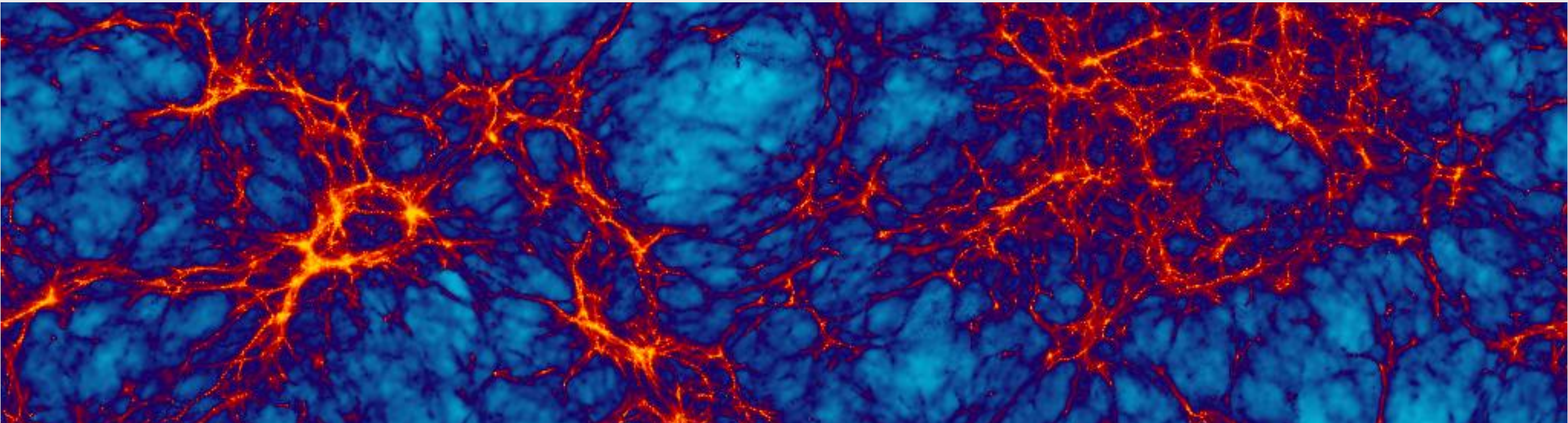
The CGM of a simulated Milky Way-mass galaxy at 1 kpc resolution

Freeke van de Voort

HITS & Yale

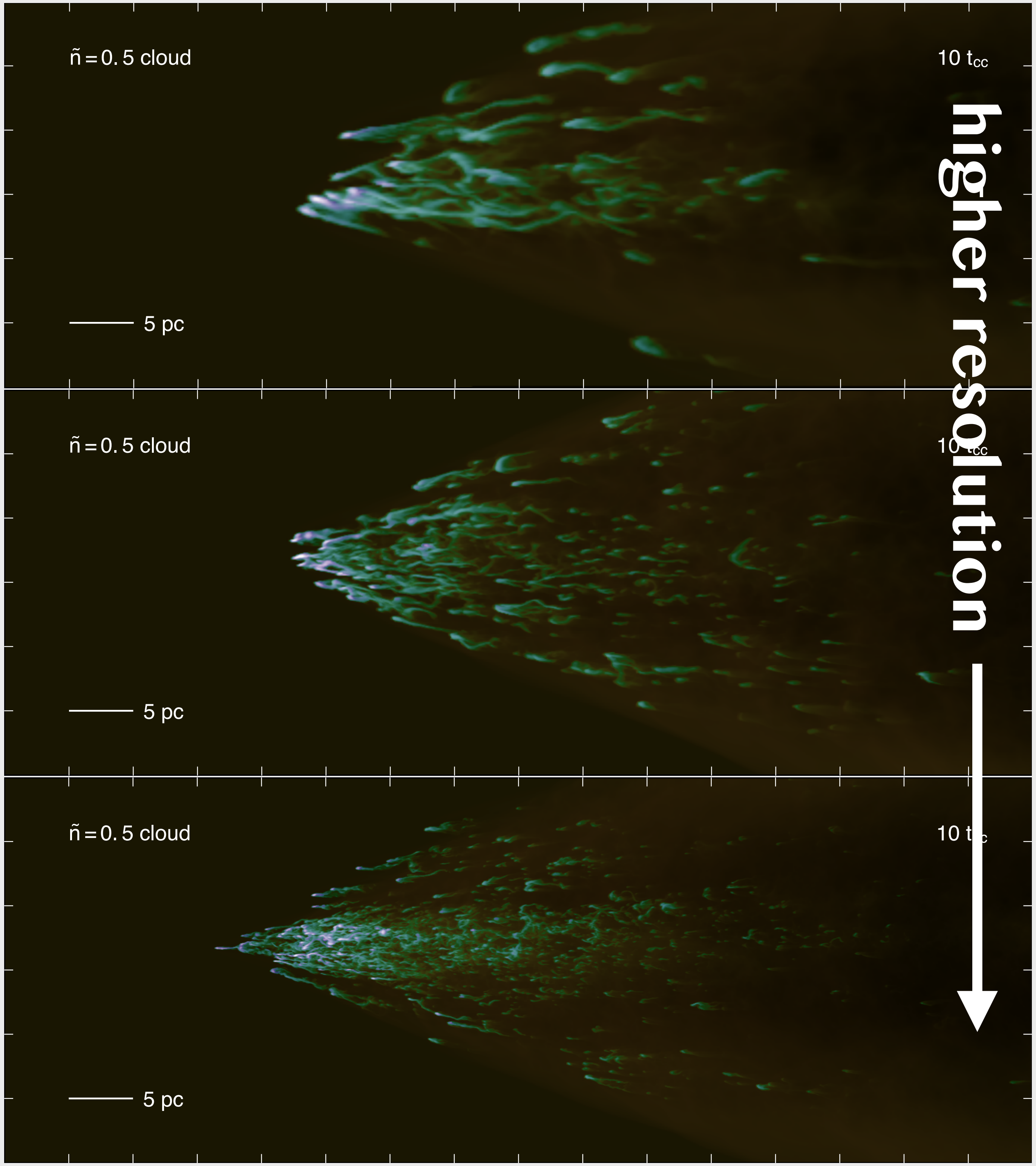
cosmological simulations

- Cosmological simulations have to cover a huge dynamic range, from the ISM to the low-density IGM.
- They generally do this by keeping the mass of resolution elements approximately fixed, so that the highest densities (galaxies) have the best resolution.
- It is often assumed that the hydrodynamical processes in the haloes around galaxies are well-resolved.



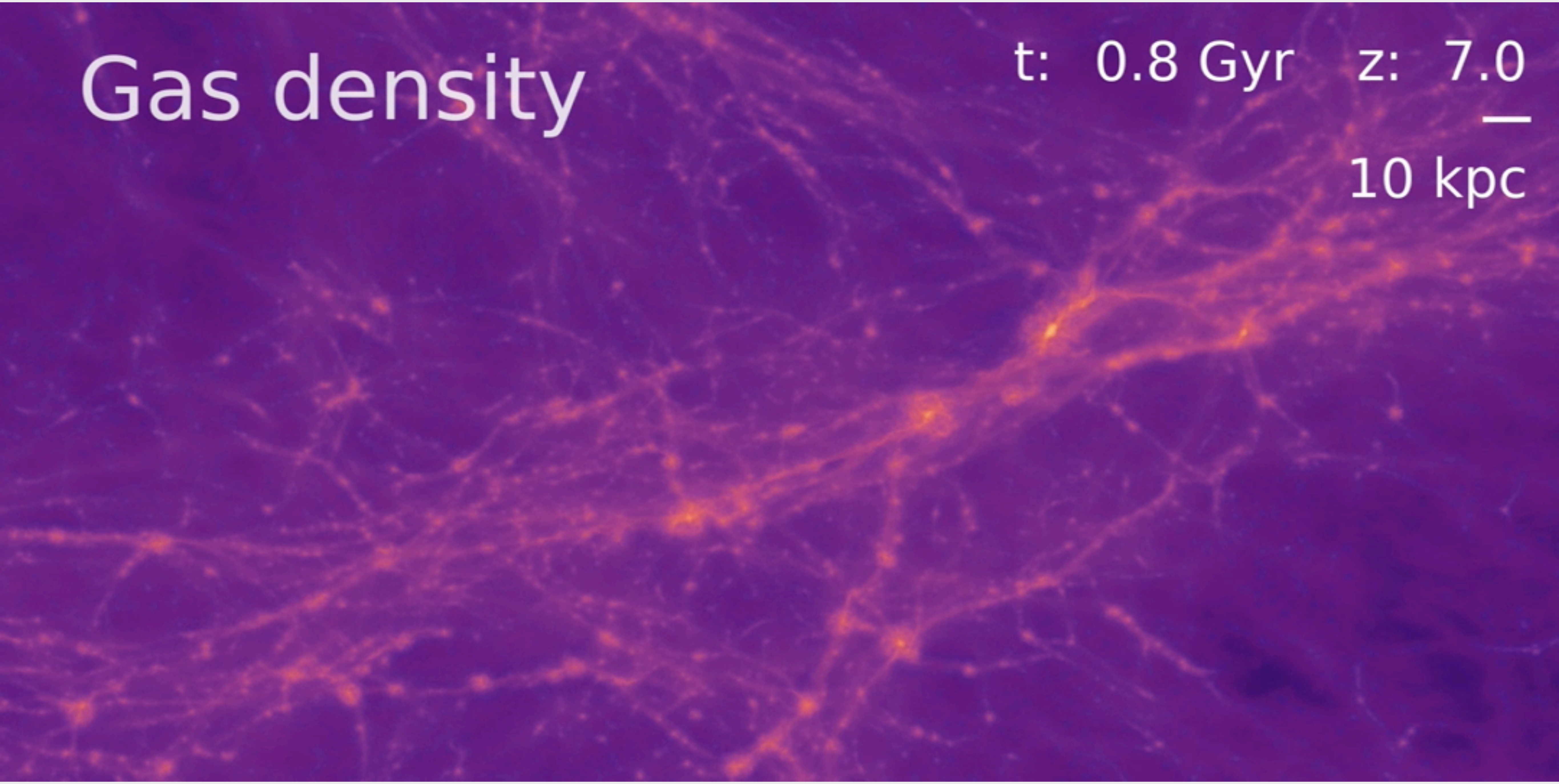
the CGM is multi-phase

- The circumgalactic medium is multi-phase with hot and cool gas.
- Many idealized studies found that properties change considerably with improved resolution.
    - For example, a cold cloud in a hot wind has smaller structures and is accelerated less with increased resolution.



Schneider & Robertson 2017

zoom-in simulations

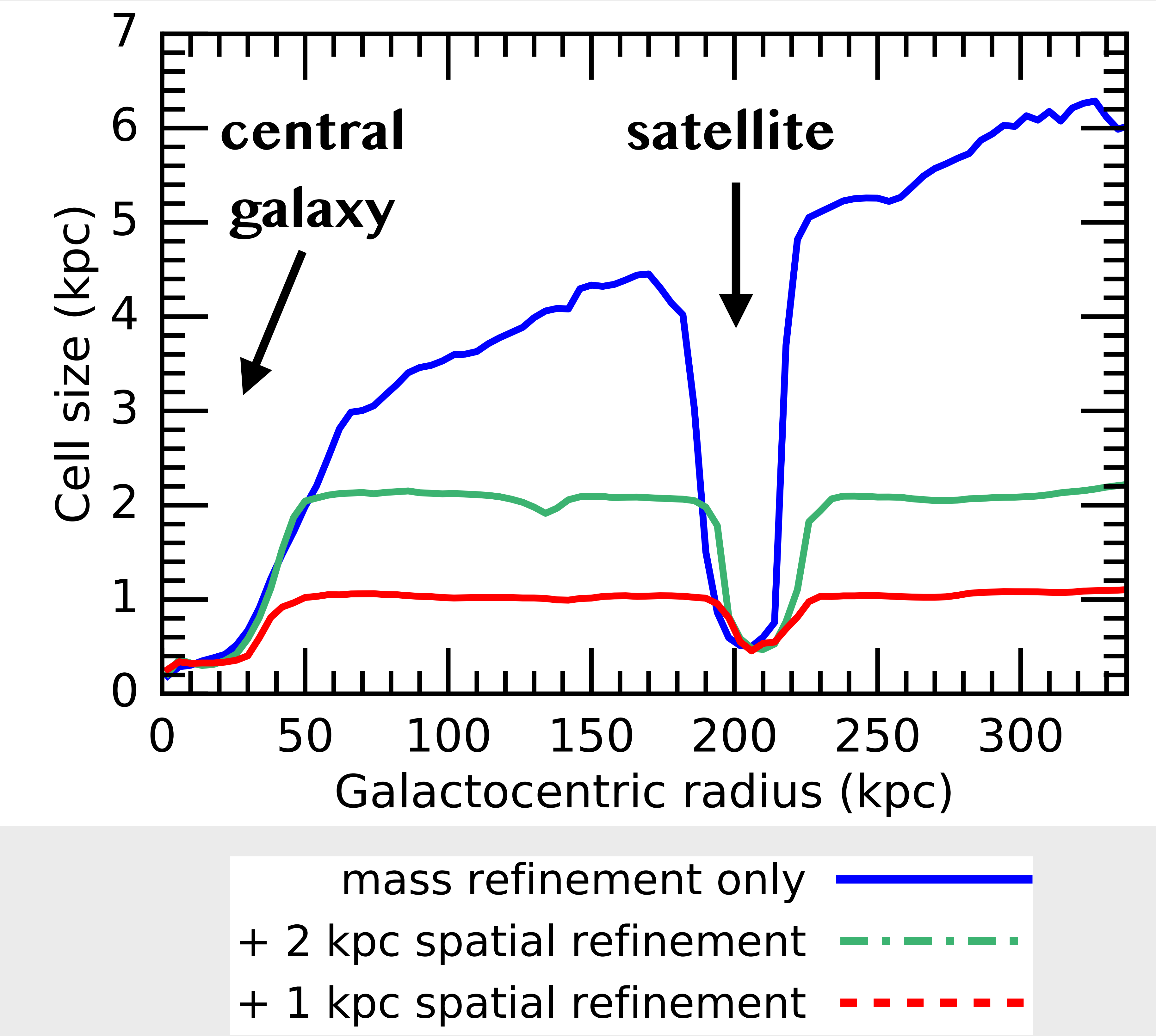


- We resimulate one of the Milky Way-mass galaxies from the Auriga project with 3 different CGM resolutions.

Grand et al. 2017

cell size

- Standard approach: resolution decreases with decreasing density, so with galactocentric radius.
- We use additional **uniform spatial refinement** within 1.2x the virial radius of each galaxy.



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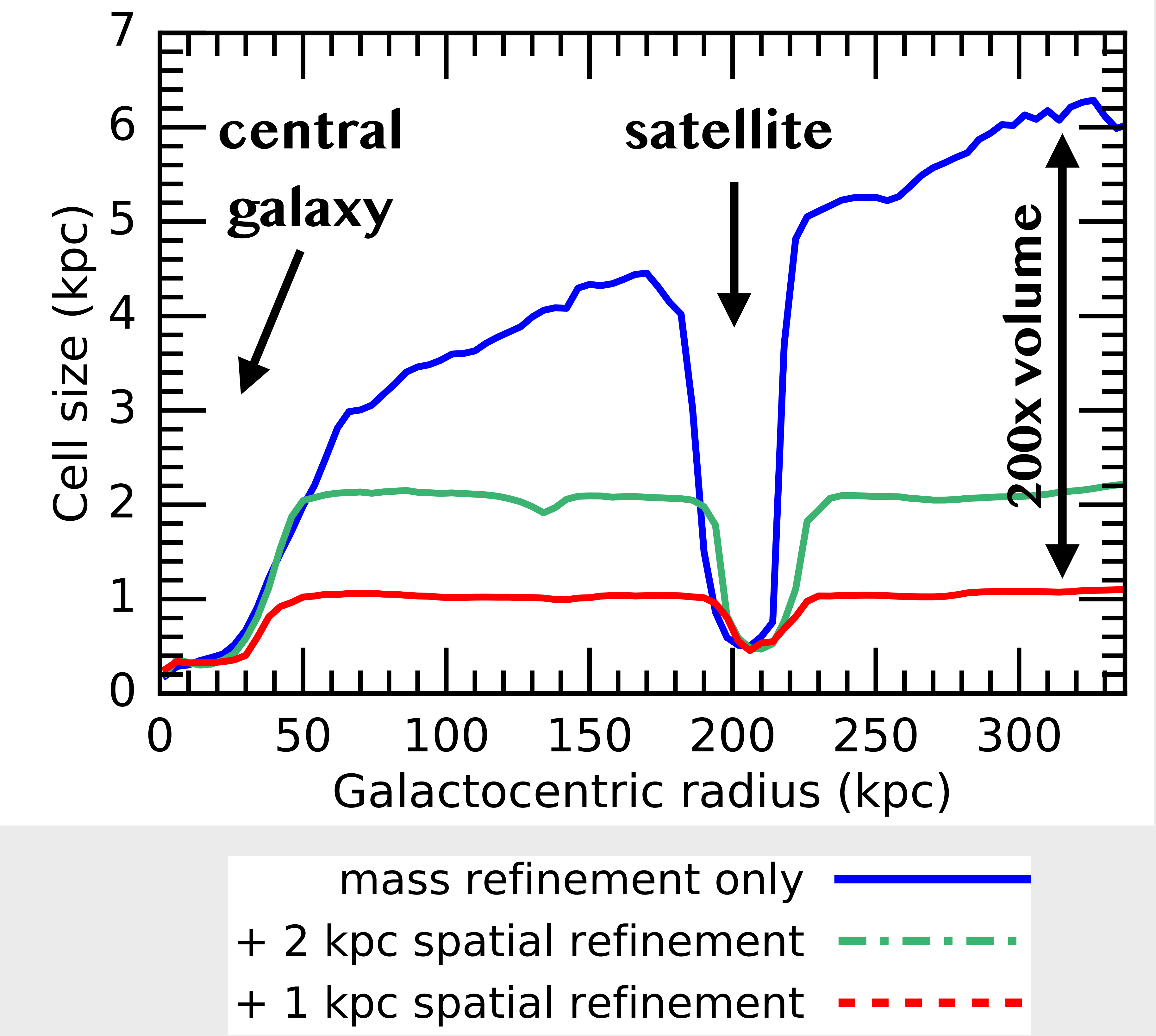

density (slice)

- Standard approach: fixed mass resolution to increase the resolution at high densities, i.e. inside galaxies.
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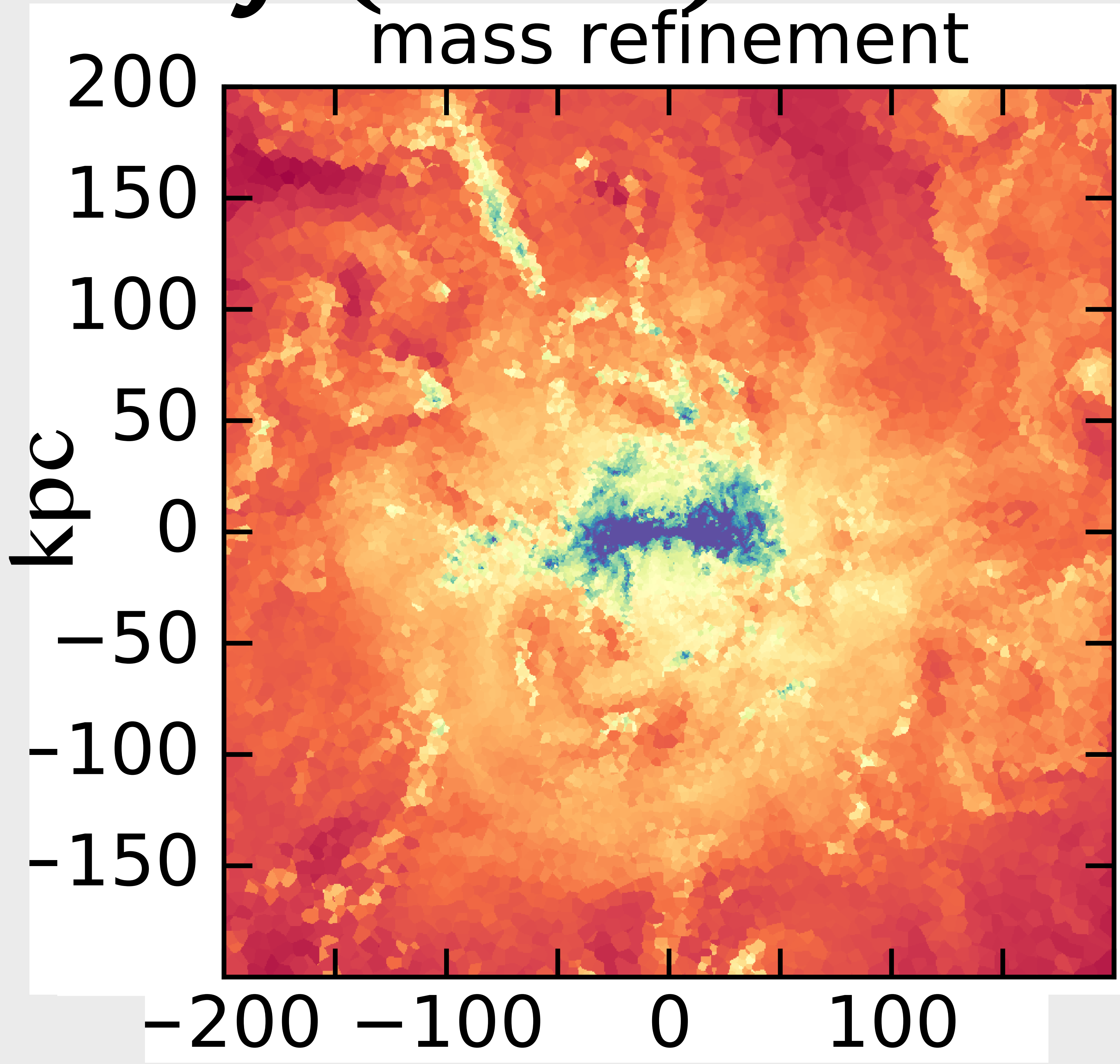

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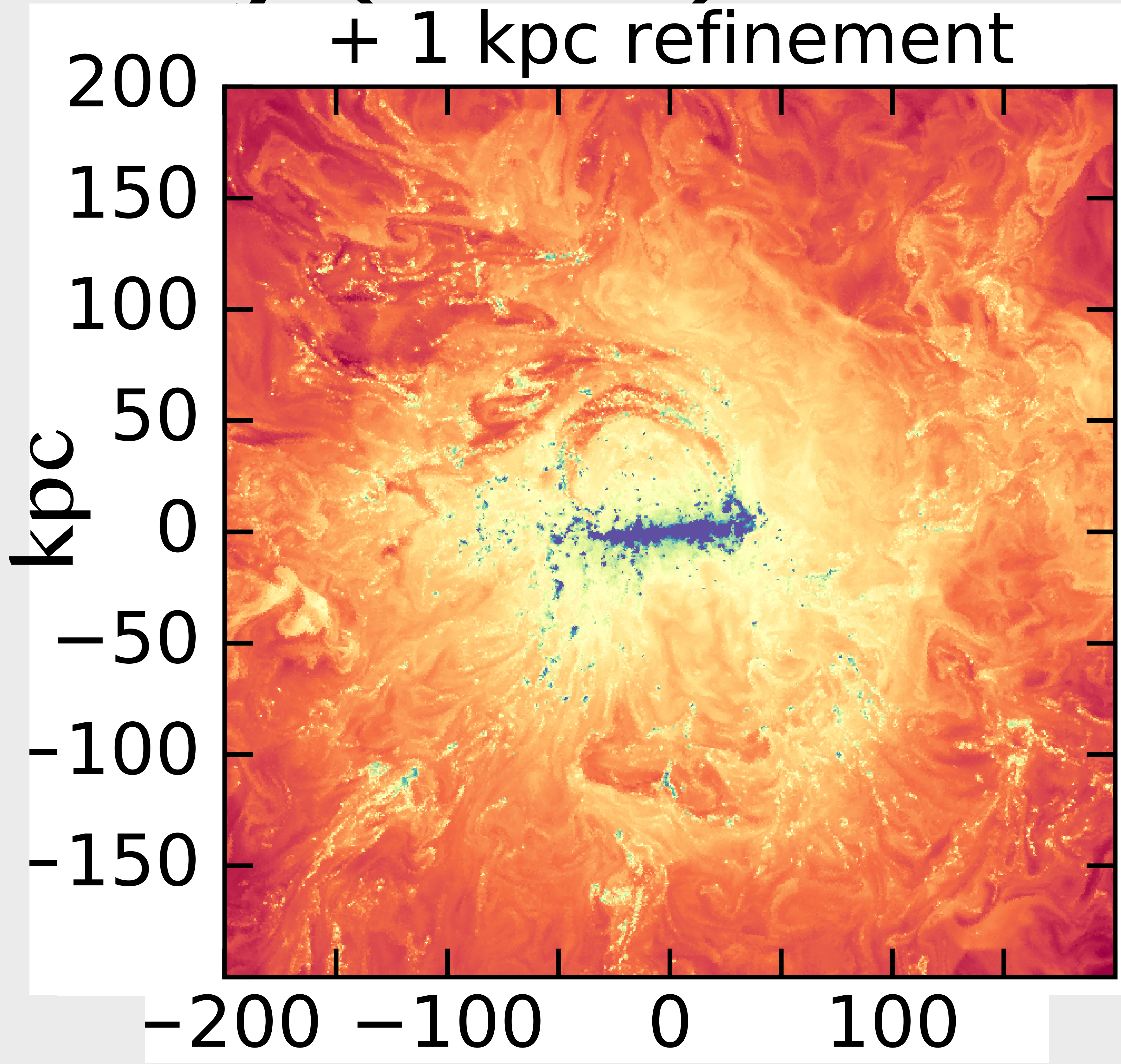
density (slice)

- Additional **uniform spatial refinement** within 1.2 R_{vir}.
- 80x the resolution elements in the CGM for 8x the CPU time.
- Smaller cold, dense gas clumps and more pronounced underdensities.



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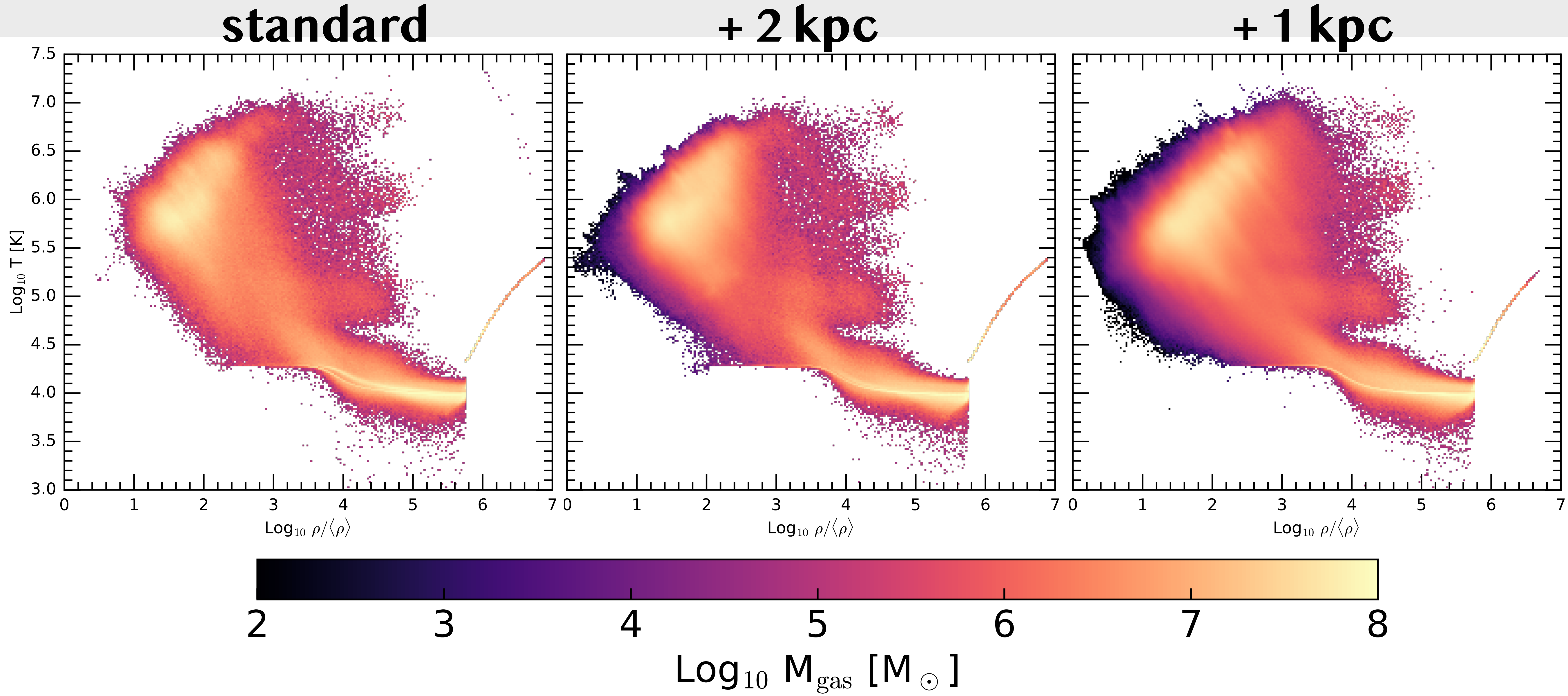
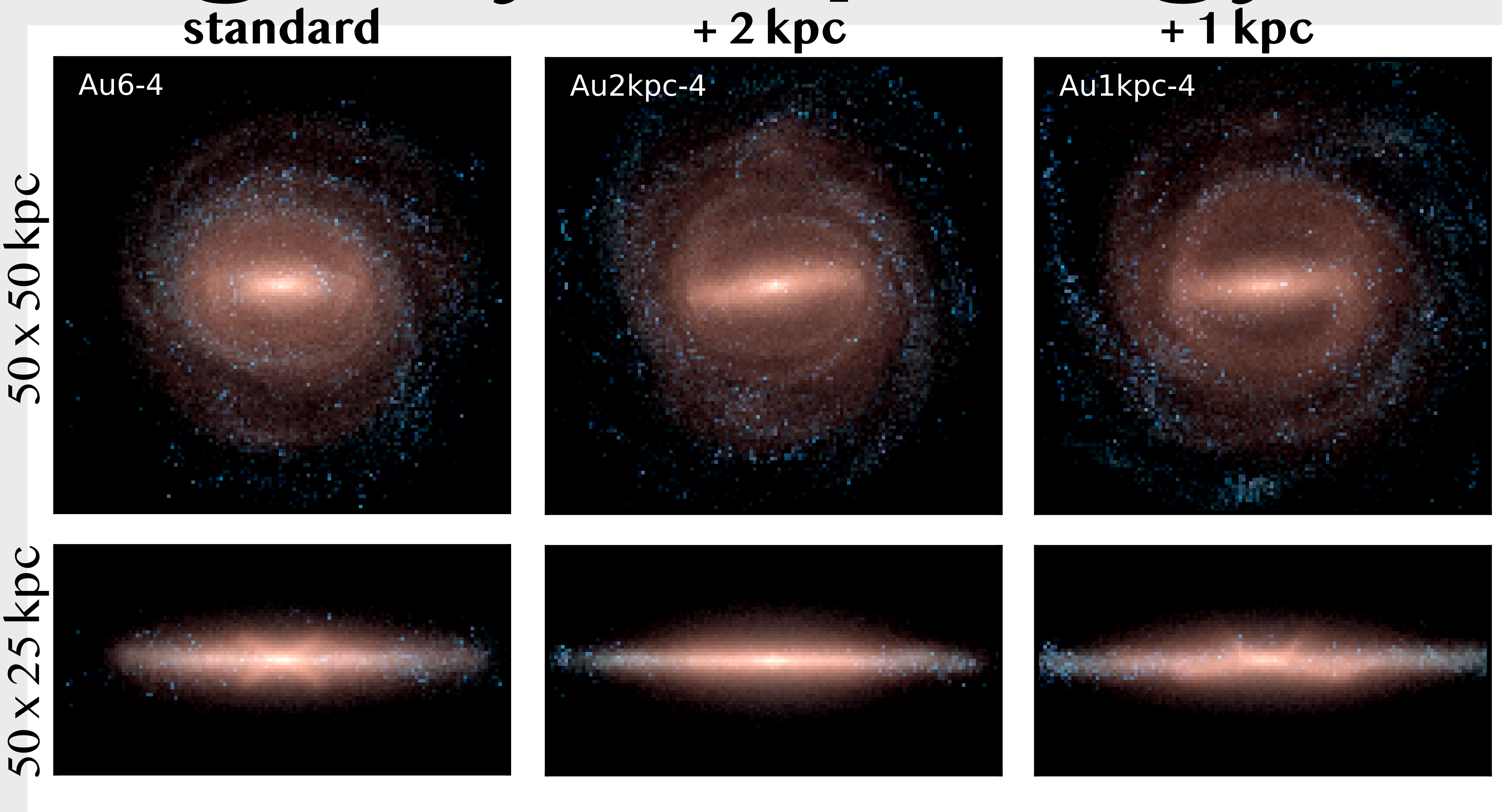
temperature - density



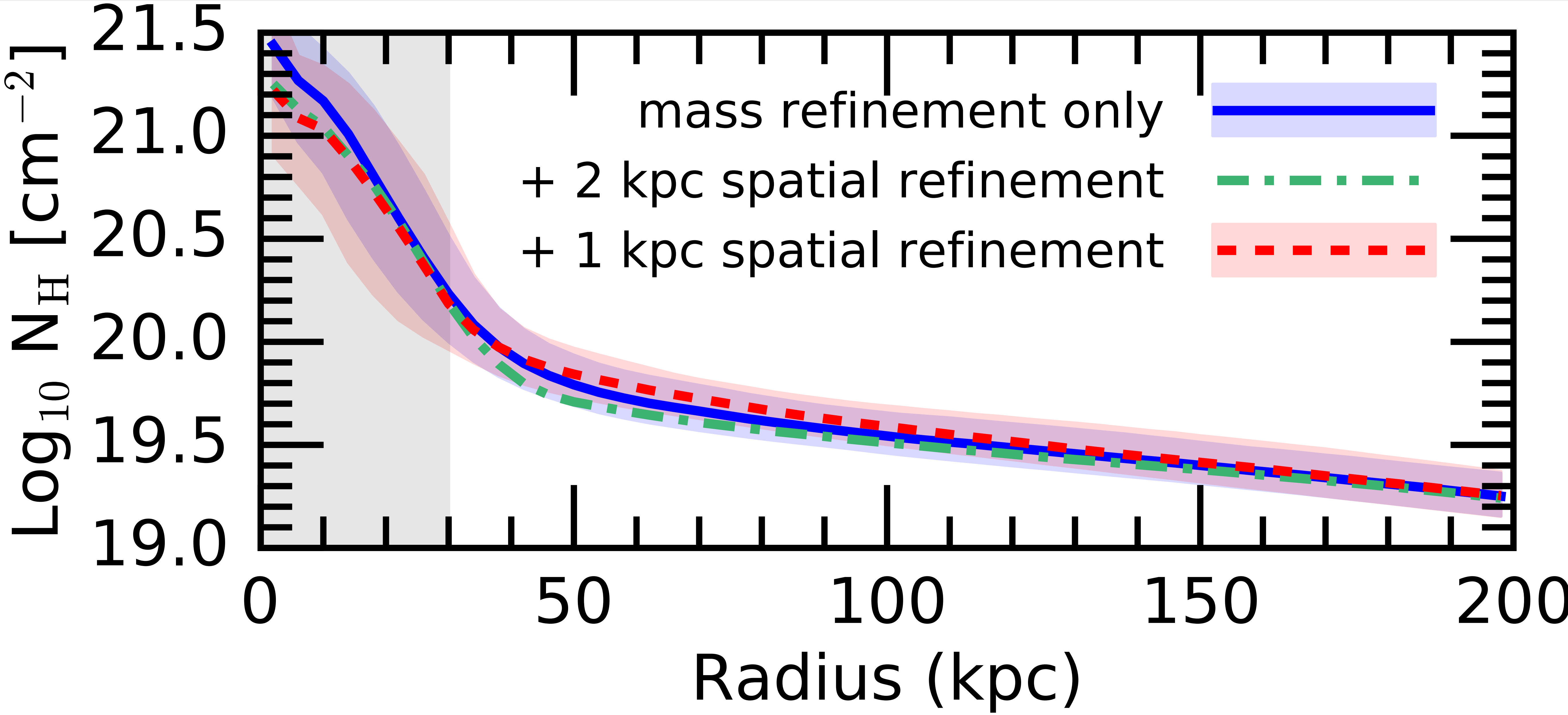
- Similar temperature-density structure, but better sampling of extremes at improved CGM resolution.
- The better resolved CGM structure could be crucial for e.g. cooling and gas accretion, metal mixing, and derived observables.

galaxy morphology



- The mass of the galaxy varies by only 0.07 dex.
- The bulge-to-total ratio is the same in the three cases.

CGM density profile



- No large or systematic differences in the median density profile of the CGM.

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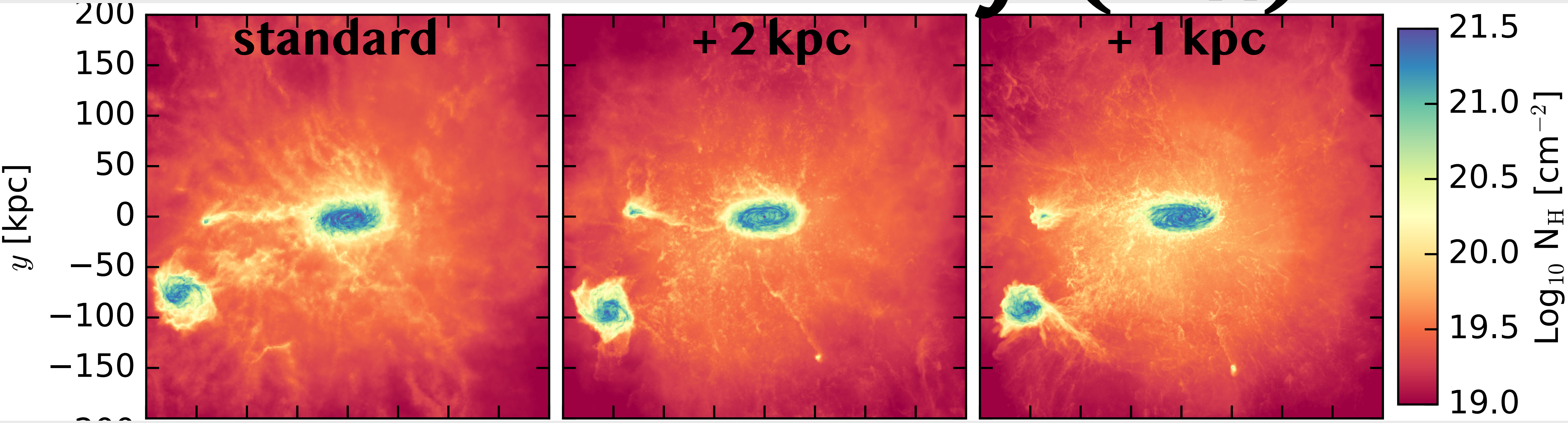
CGM density (N_H)



- N_H is similar.

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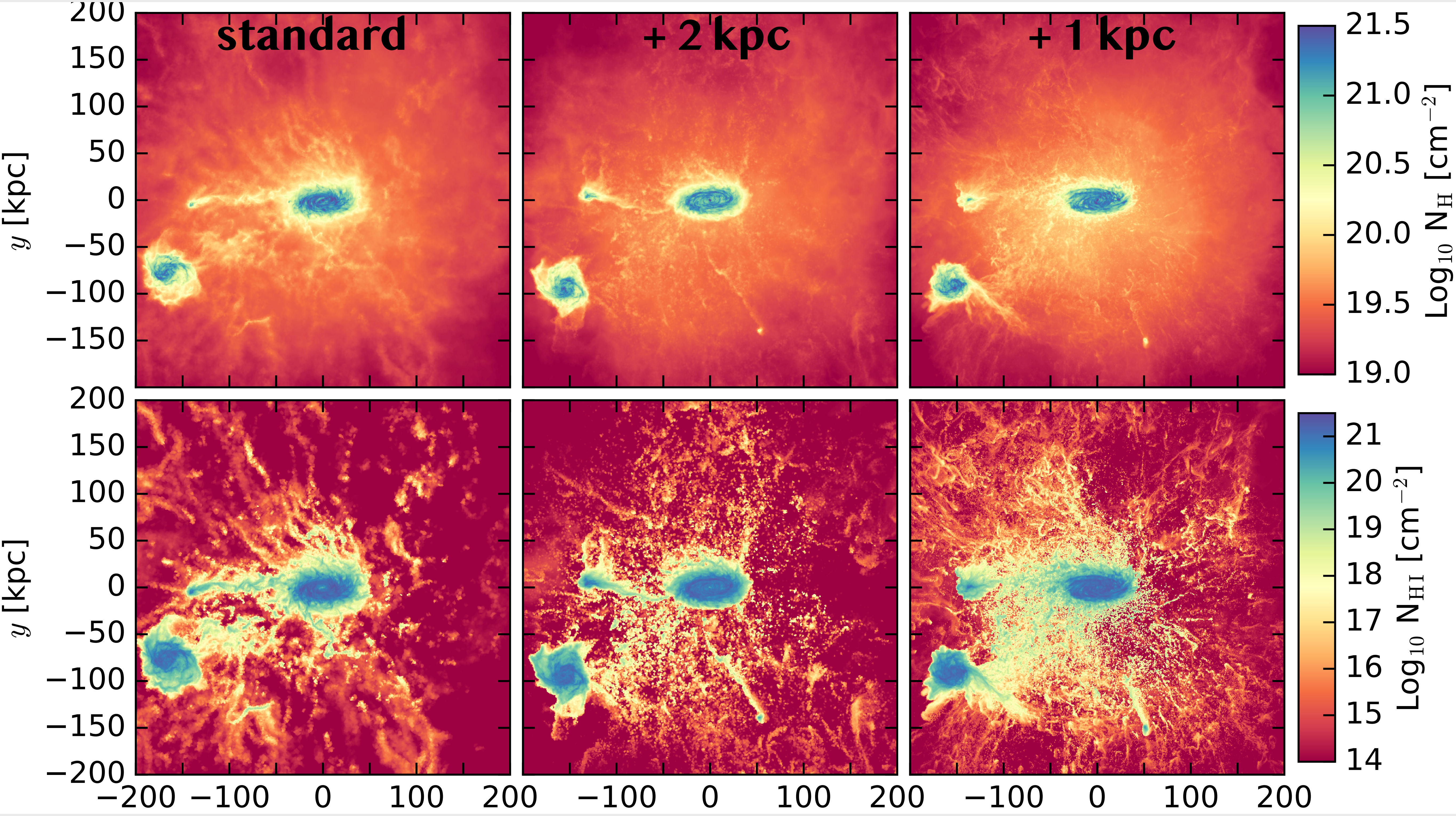
N_H and N_{HI}



- N_H is similar, while N_{HI} is much higher with 1 kpc resolution.

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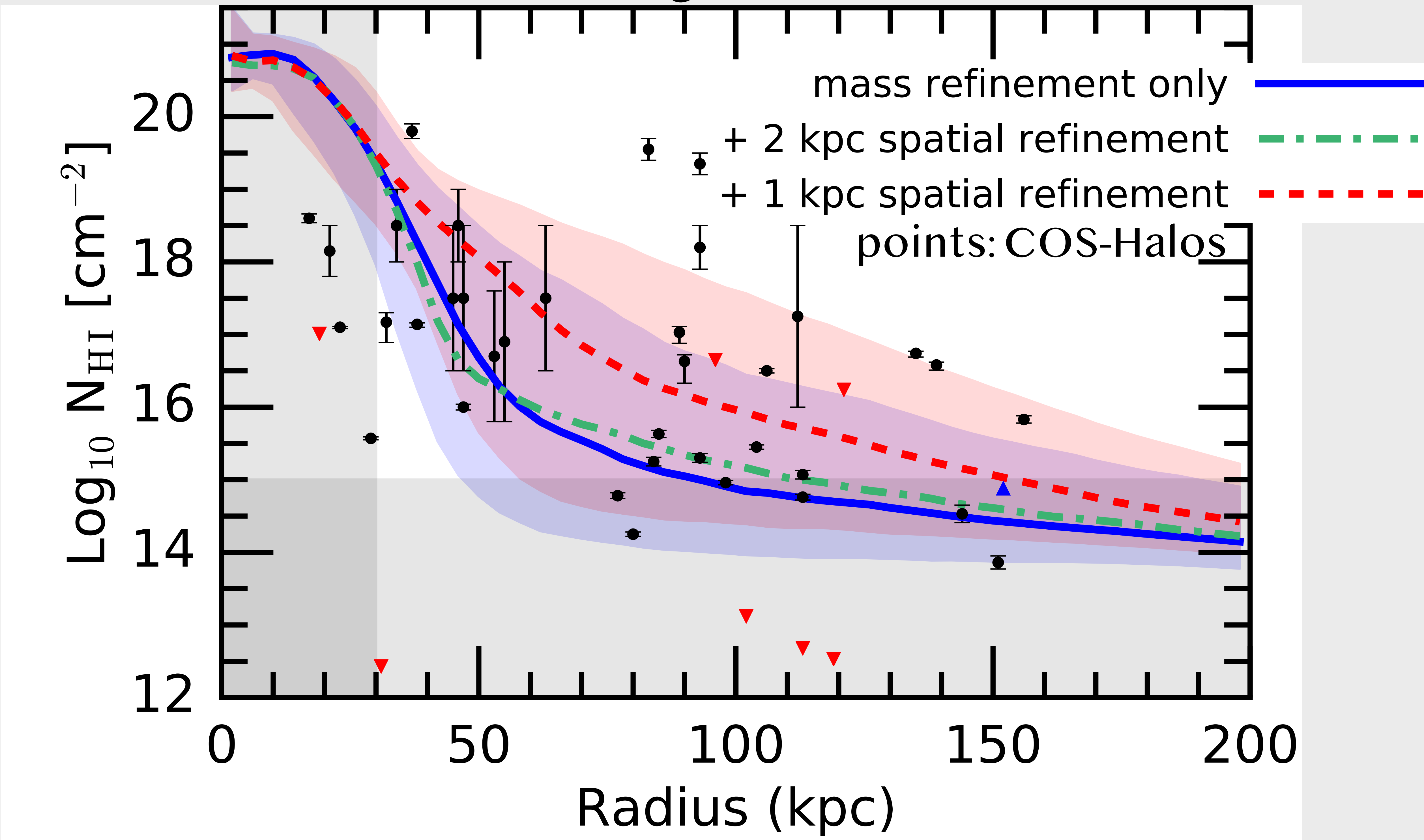
HI density profile



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

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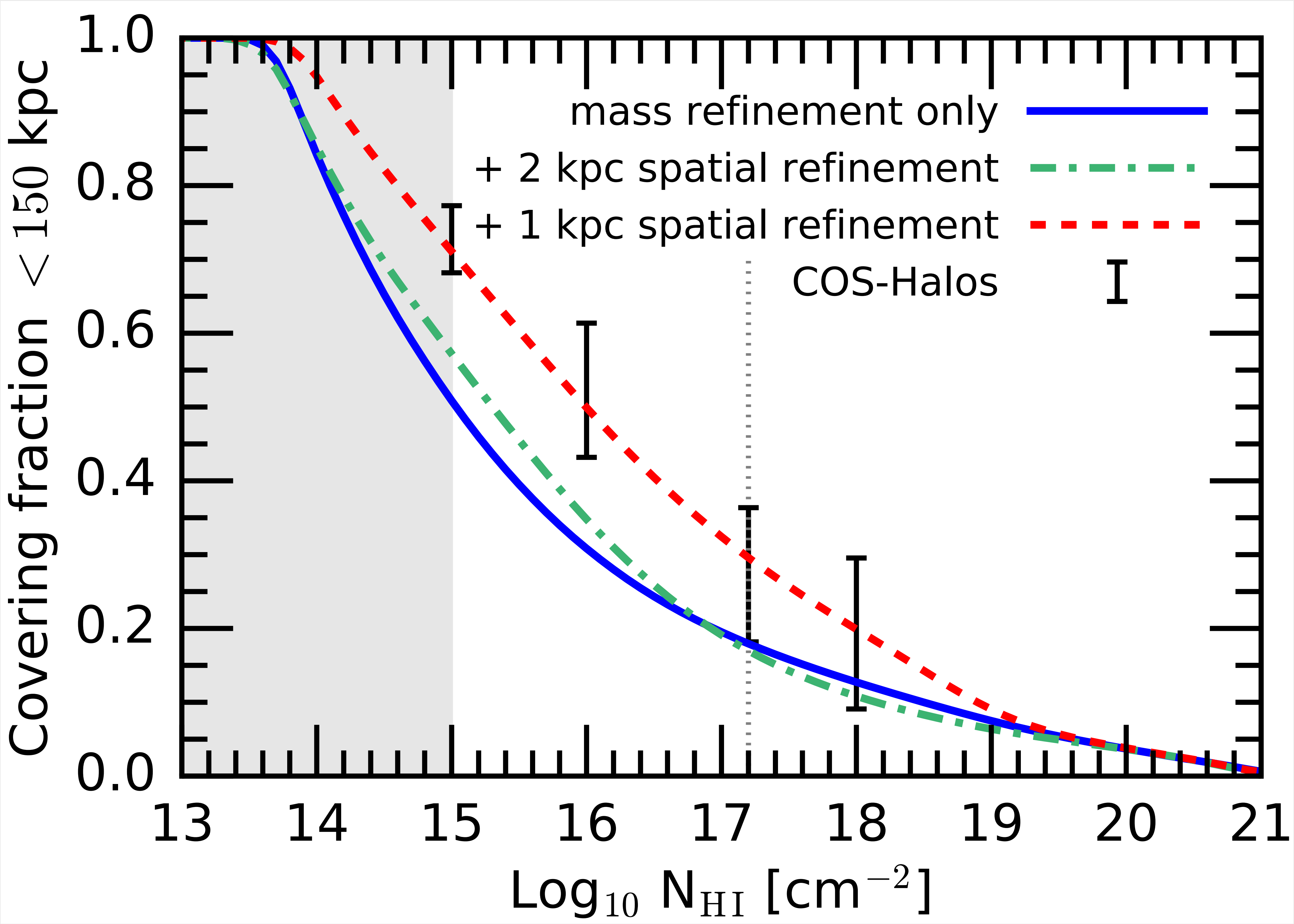
covering fraction



- The covering fraction of LLSs ($N_{HI} > 10^{17.2}$ cm^{-2}) within 150 kpc increases from 18 to 30 per cent.

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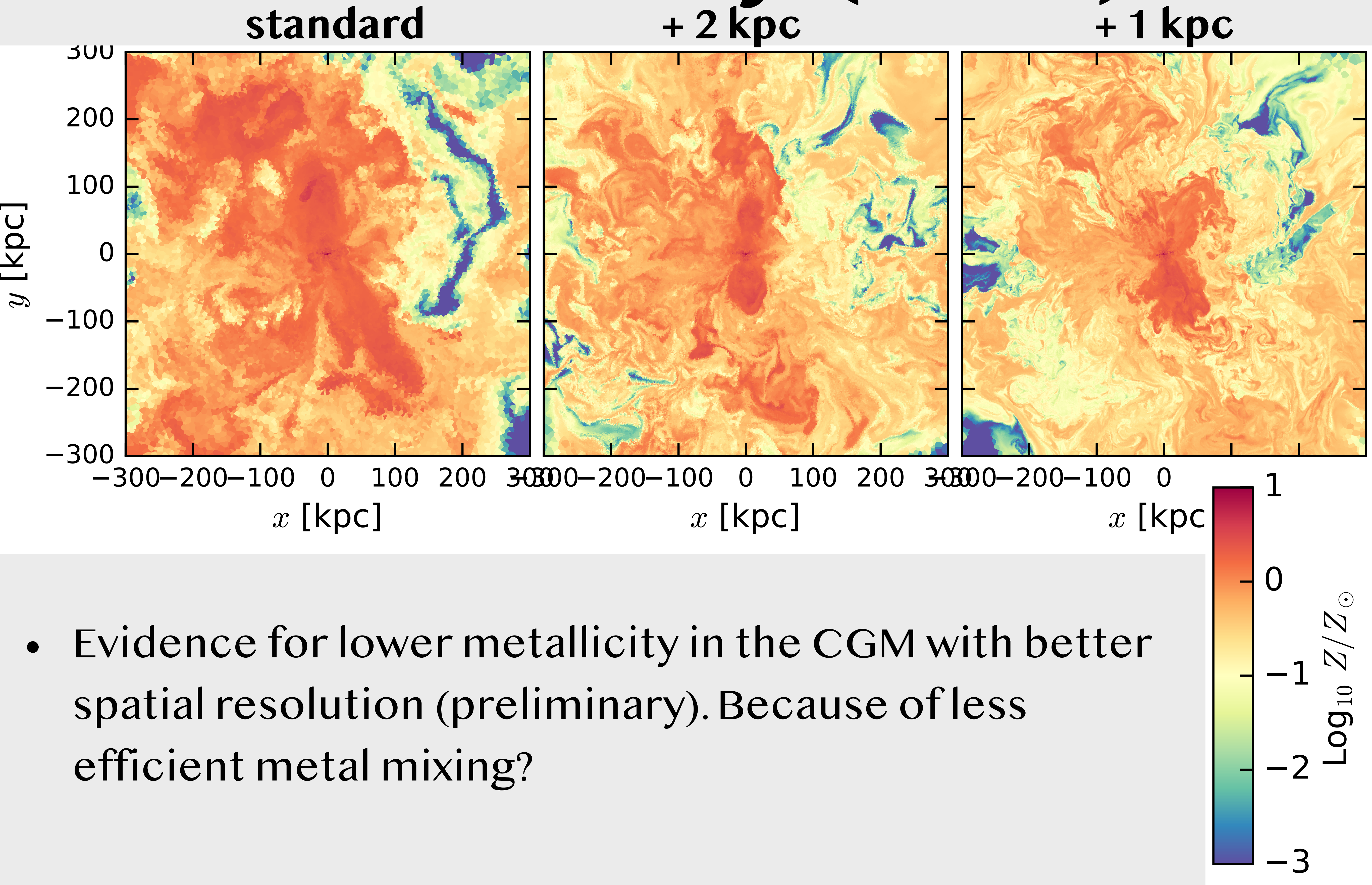
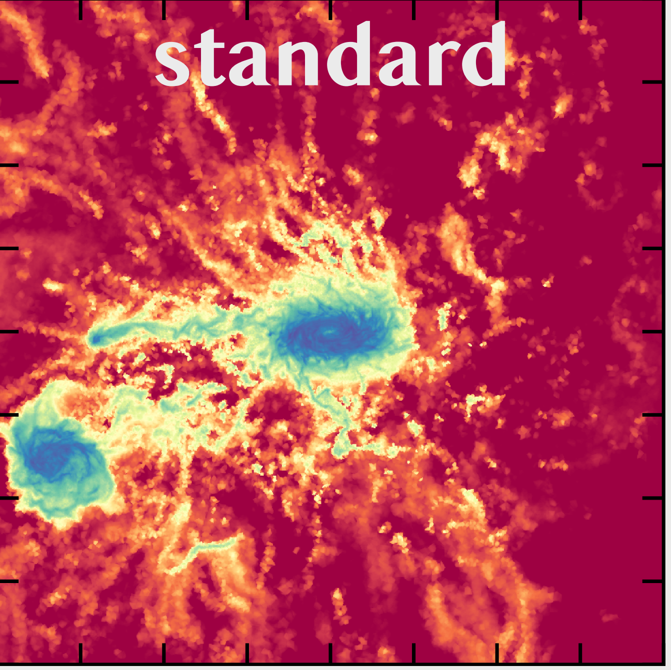
metallicity (slice)

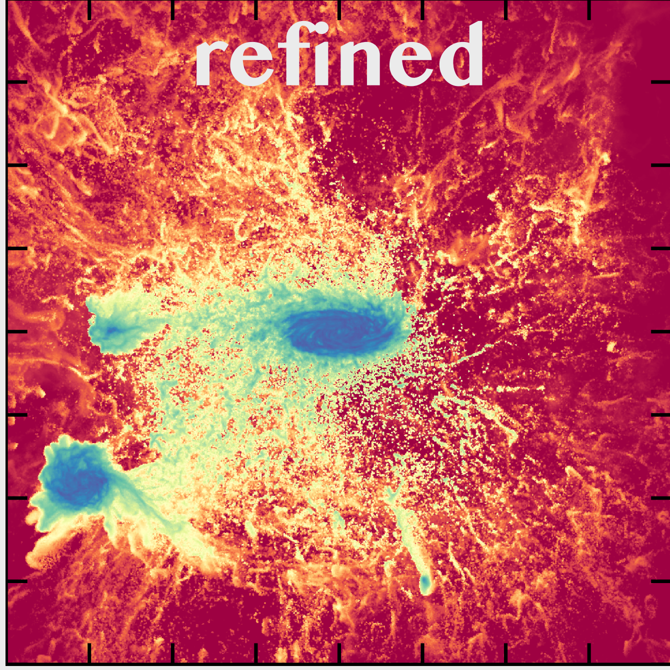


- Evidence for lower metallicity in the CGM with better spatial resolution (preliminary). Because of less efficient metal mixing?



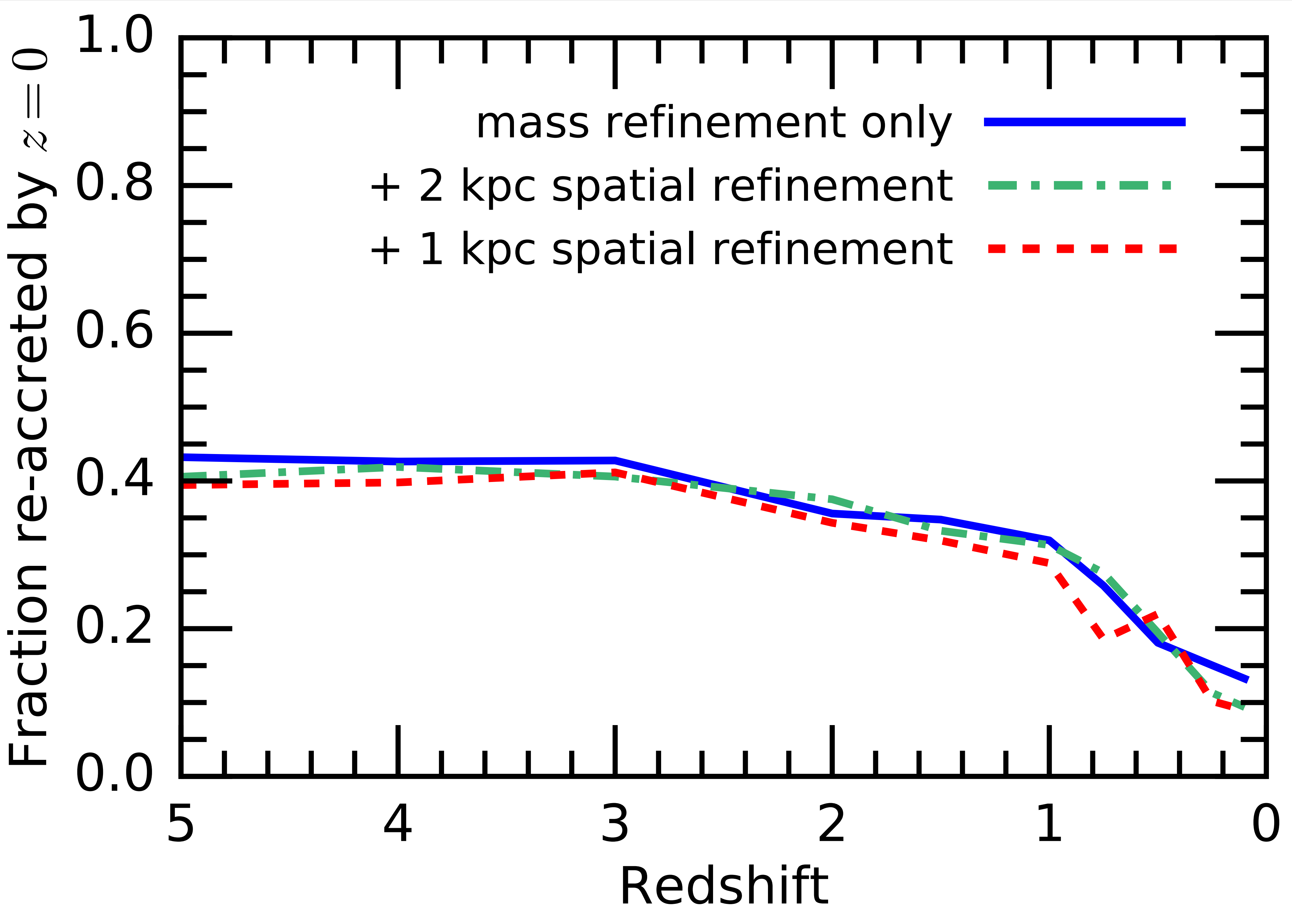
conclusions

arXiv: 1808.04369



- Increasing the CGM resolution while treating the galaxies as before is a promising and computationally efficient method.
- Whether this is important depends on the topic of interest:
- The improved spatial resolution does not strongly impact the central galaxy or the average density & temperature of the CGM.
- It drastically increases the radial profile of the HI column density: the covering fraction of Lyman-Limit Systems within 150 kpc is almost doubled.
- It possibly also affects CGM metallicities (stay tuned).

re-accretion of winds



- ~40% of gas ejected in galactic winds at high z re-accretes by $z = 0$.
- No strong CGM resolution dependence (preliminary).

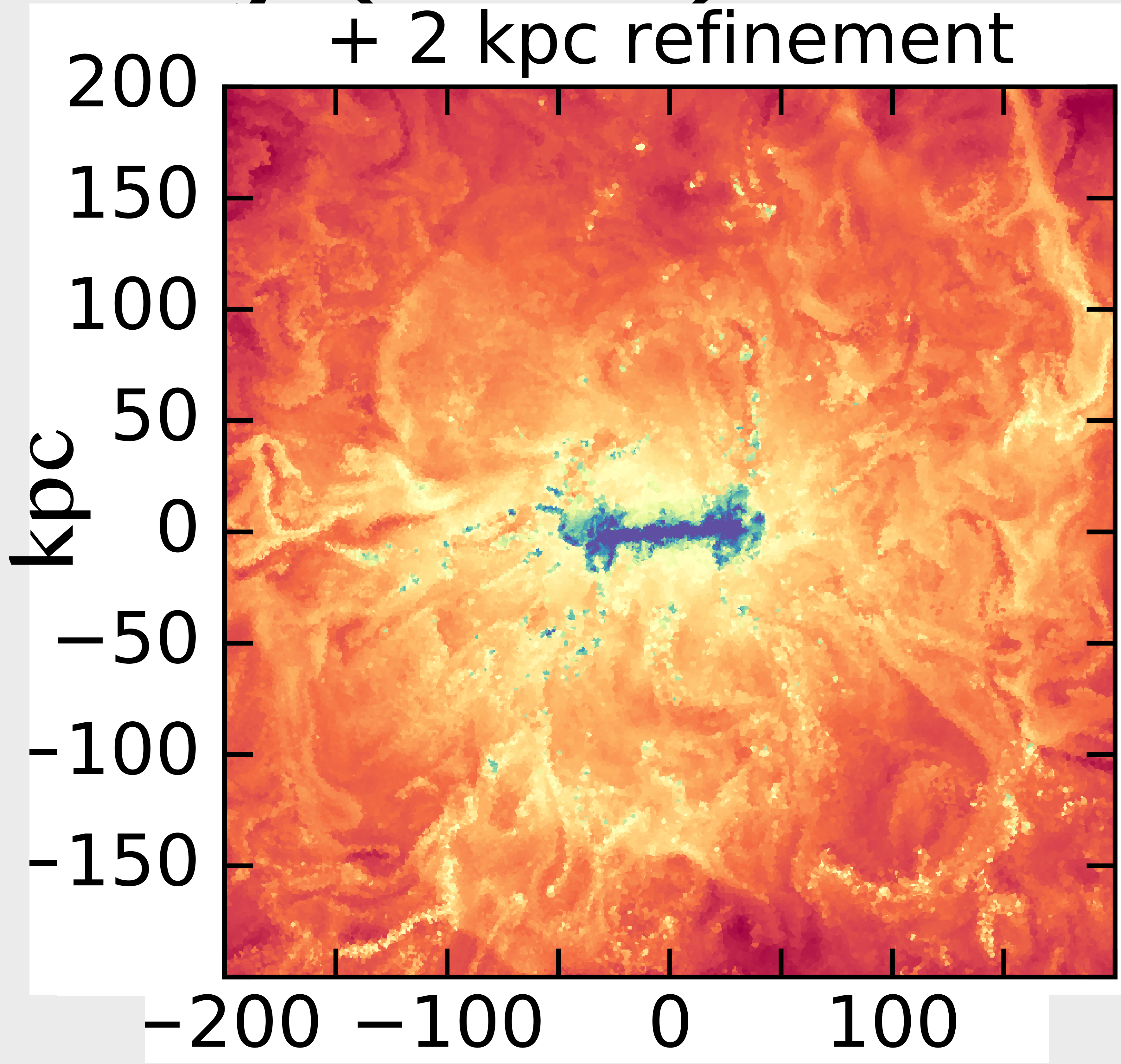
Title Text

Table 1. Properties of the galaxy and halo in our simulations at $z = 0$: simulation refinement strategy, virial radius of the halo ($R_{\rm vir}$), total stellar mass within 30 kpc from the centre ($M_{\rm star}$), total CGM mass ($M_{\rm CGM}$), total H I mass in the CGM ($M_{\rm CGM}^{\rm H\,I}$), number of gas cells in the CGM ($N_{\rm CGM}^{\rm cell}$).

simulation refinement	$M_{\rm star}$ ($\rm M_\odot$)	$M_{\rm ISM}$ ($\rm M_\odot$)	$M_{\rm CGM}$ ($\rm M_\odot$)	$M_{\rm CGM}^{\rm H\,I}$ ($\rm M_\odot$)	$N_{\rm CGM}^{\rm cell}$
mass only	$10^{10.73}$	$10^{9.48}$	$10^{10.97}$	$10^{10.26}$	1.6M
+ 2 kpc	$10^{10.72}$	$10^{9.41}$	$10^{10.91}$	$10^{10.24}$	16.3M
+ 1 kpc	$10^{10.67}$	$10^{9.52}$	$10^{10.96}$	$10^{10.29}$	132.4M

density (slice)

- In addition to standard mass refinement we also use **uniform spatial refinement** within the virial radius of each galaxy.
- 10x the resolution elements in the CGM for 2x the CPU time.



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density (projection)

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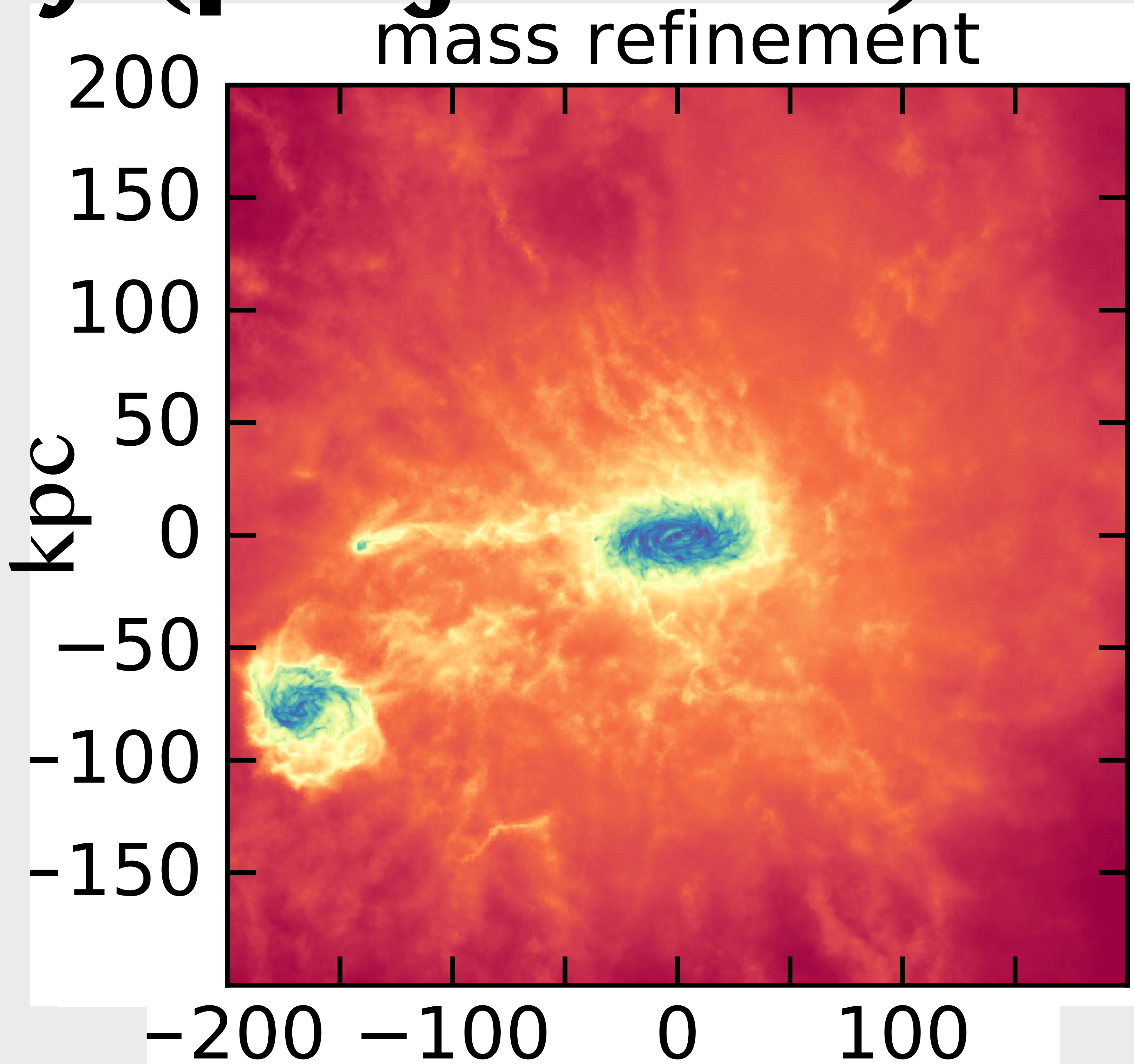
- Resolution decreases with decreasing density, so with galactocentric radius.



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radial velocity