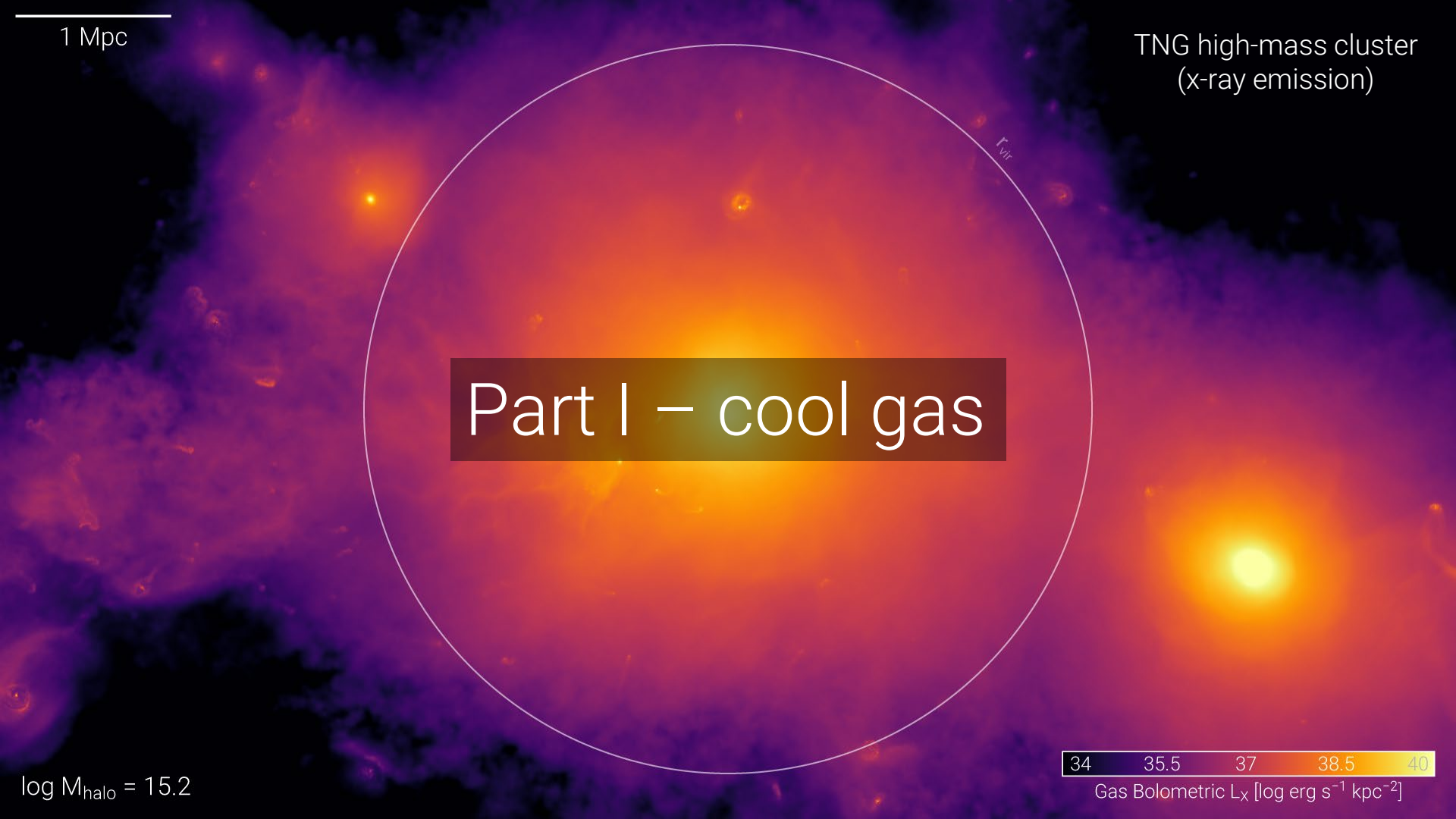
The ICM in cosmological simulations:

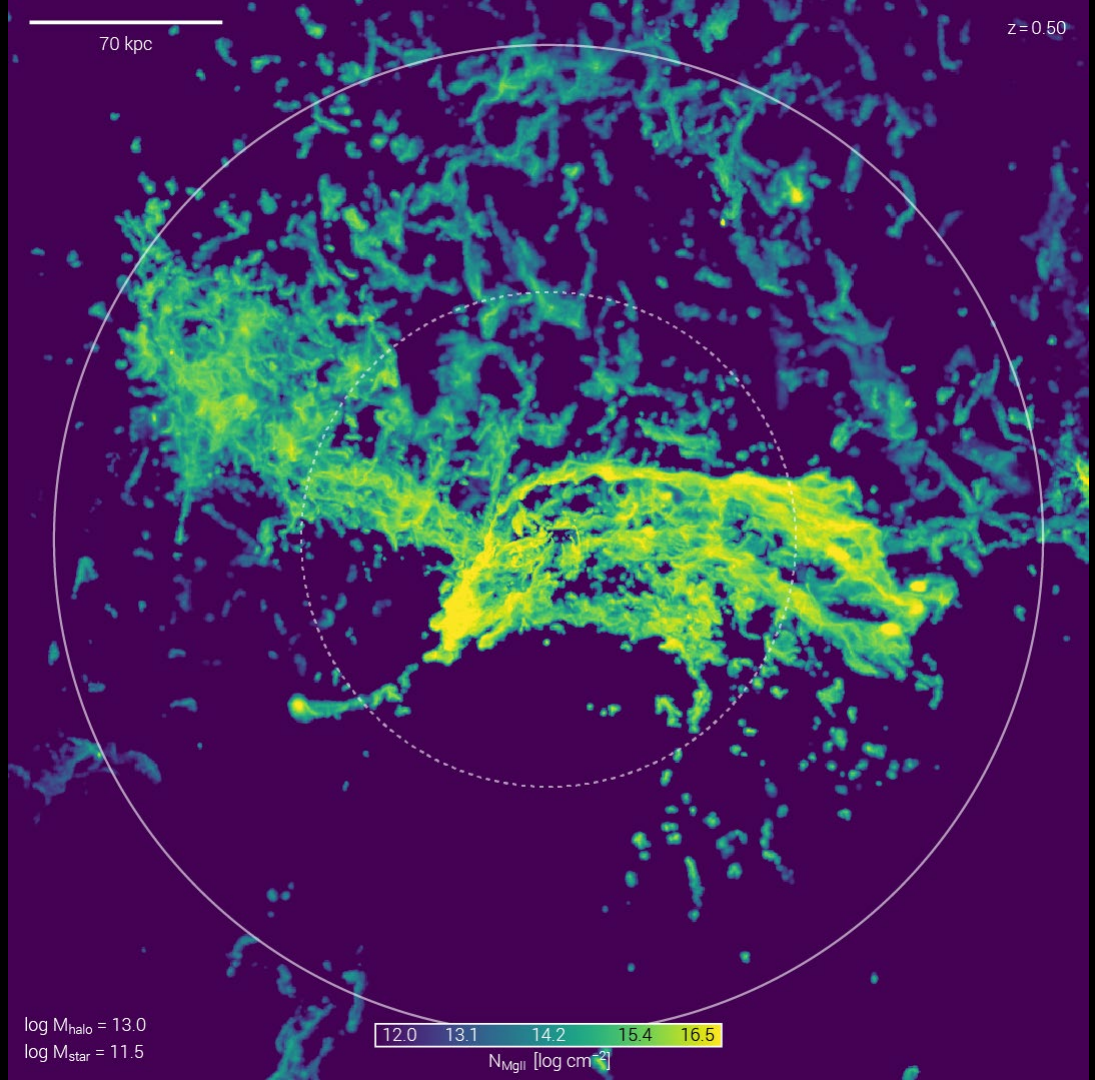
(I) cool gas, (II) closure, and (III) the future

Dylan Nelson (Heidelberg University)

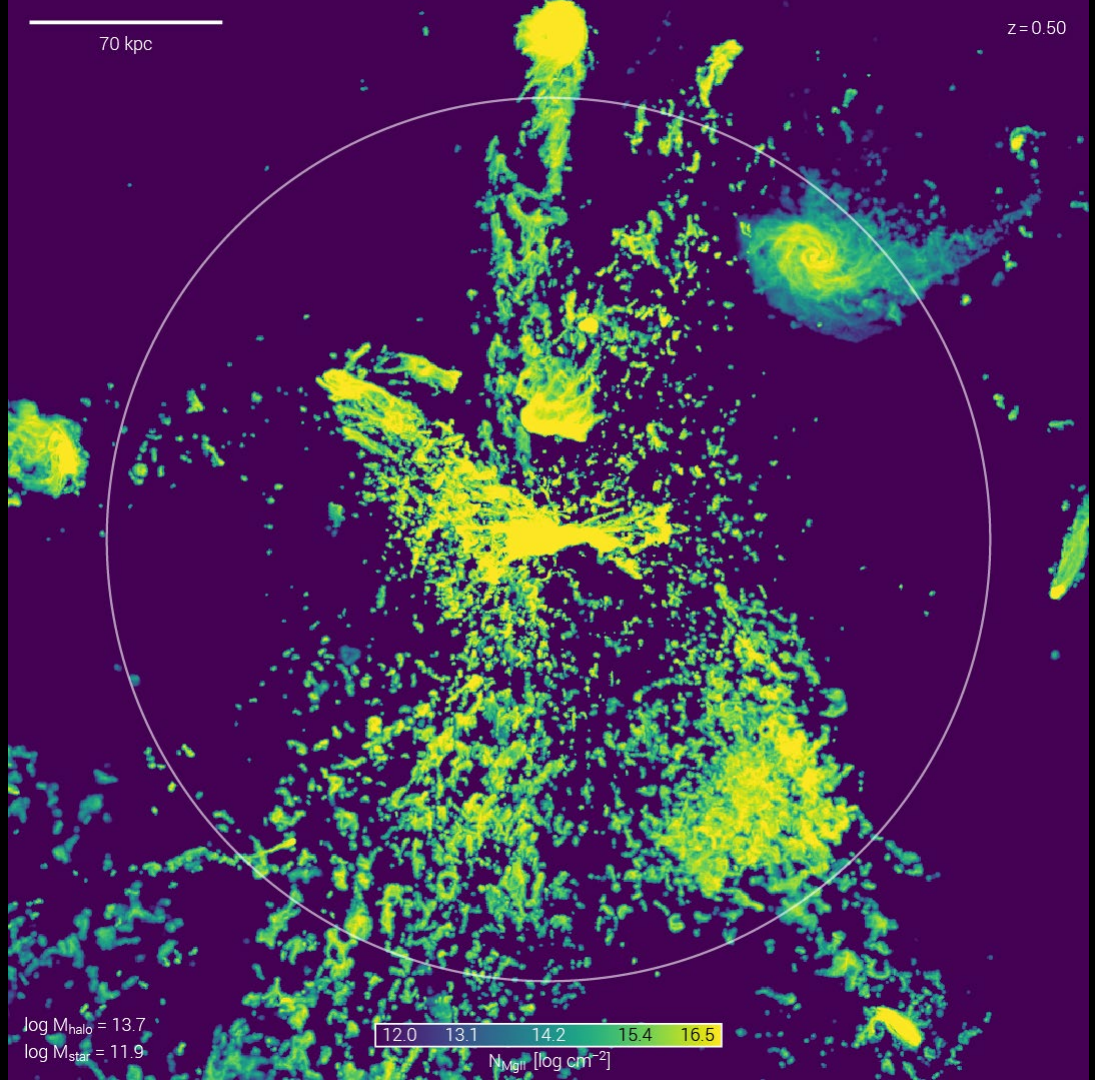
6th ICM Theory and Computation Workshop, Copenhagen, 15 August, 2022


1 Mpc
TNG high-mass cluster
(x-ray emission)
r_{vir}
Part I – cool gas
log M_{halo} = 15.2
34
35.5
37
38.5
40
Gas Bolometric L_X [log erg s^{-1} kpc^{-2}]

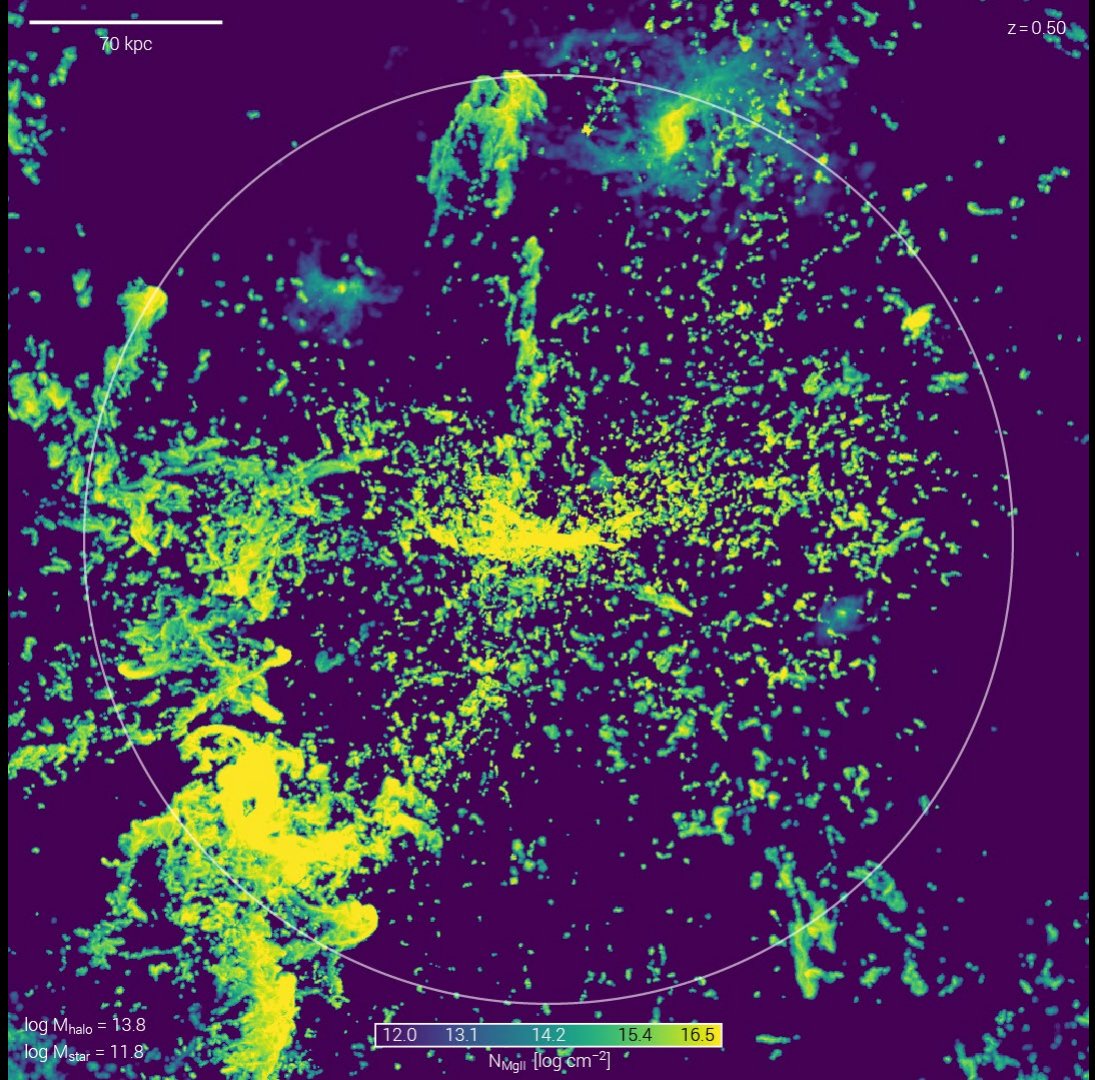
TNG50
high-mass halo
(cold gas)



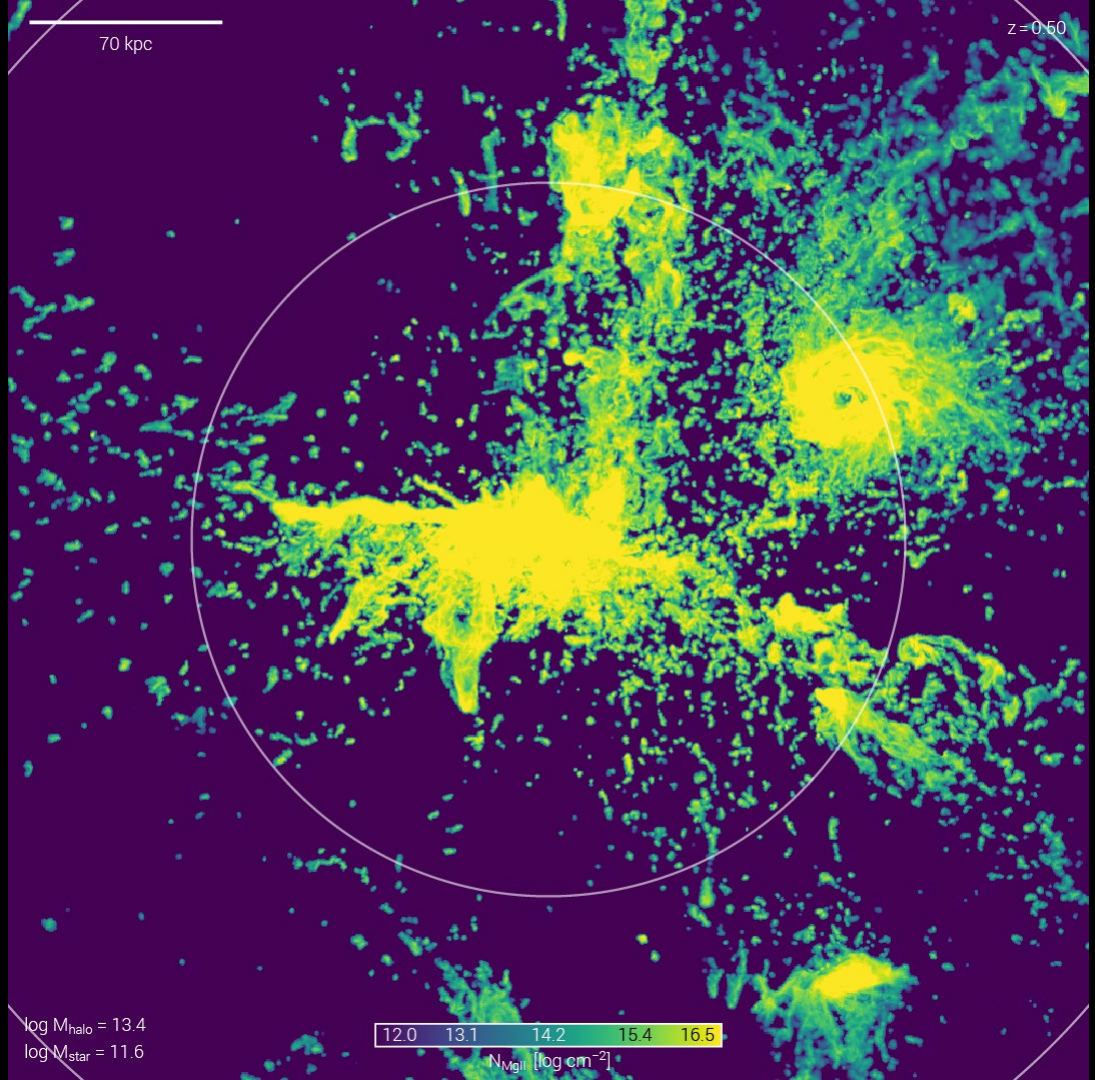
TNG50
high-mass halo
(cold gas)



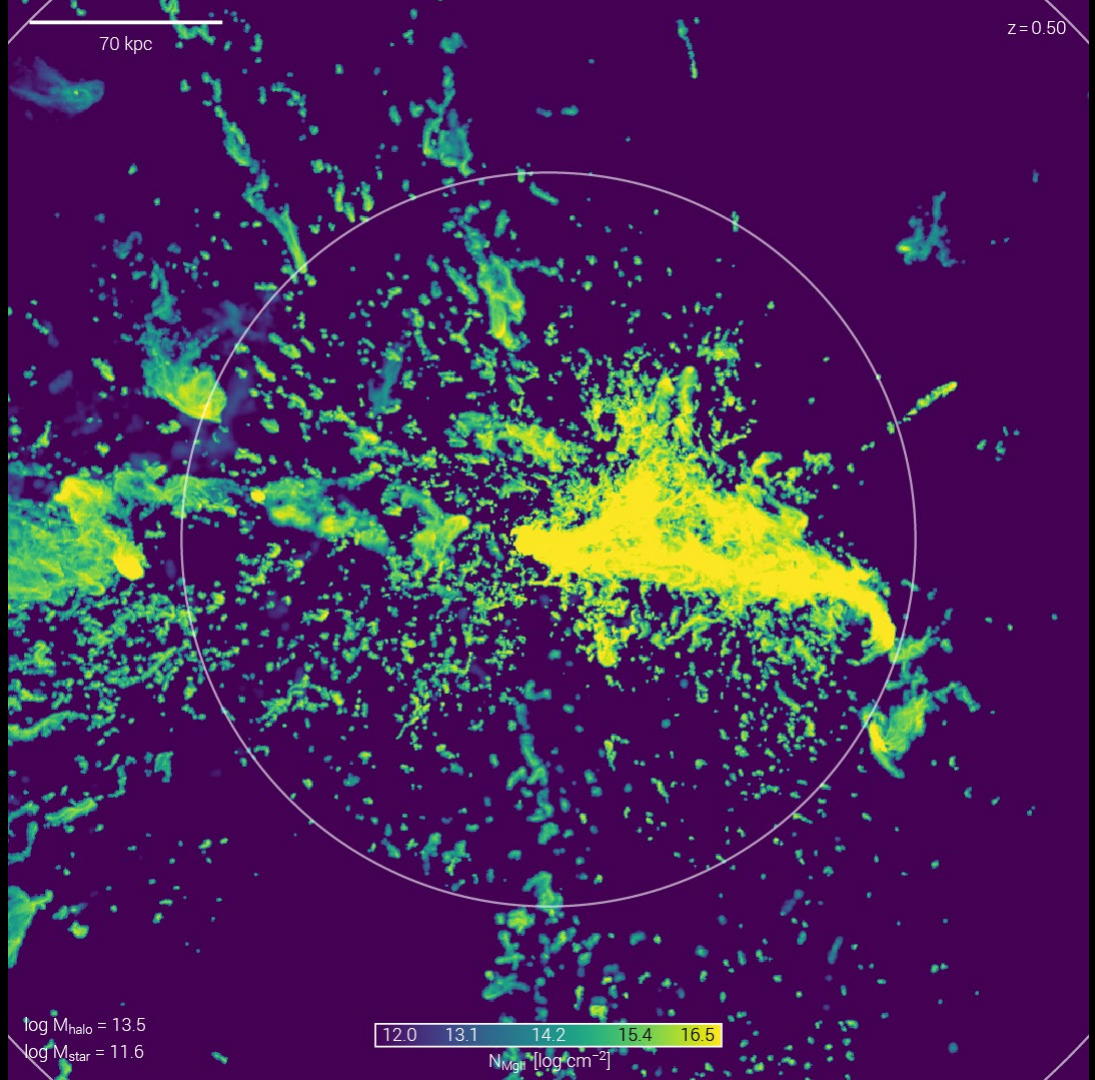
TNG50
high-mass halo
(cold gas)



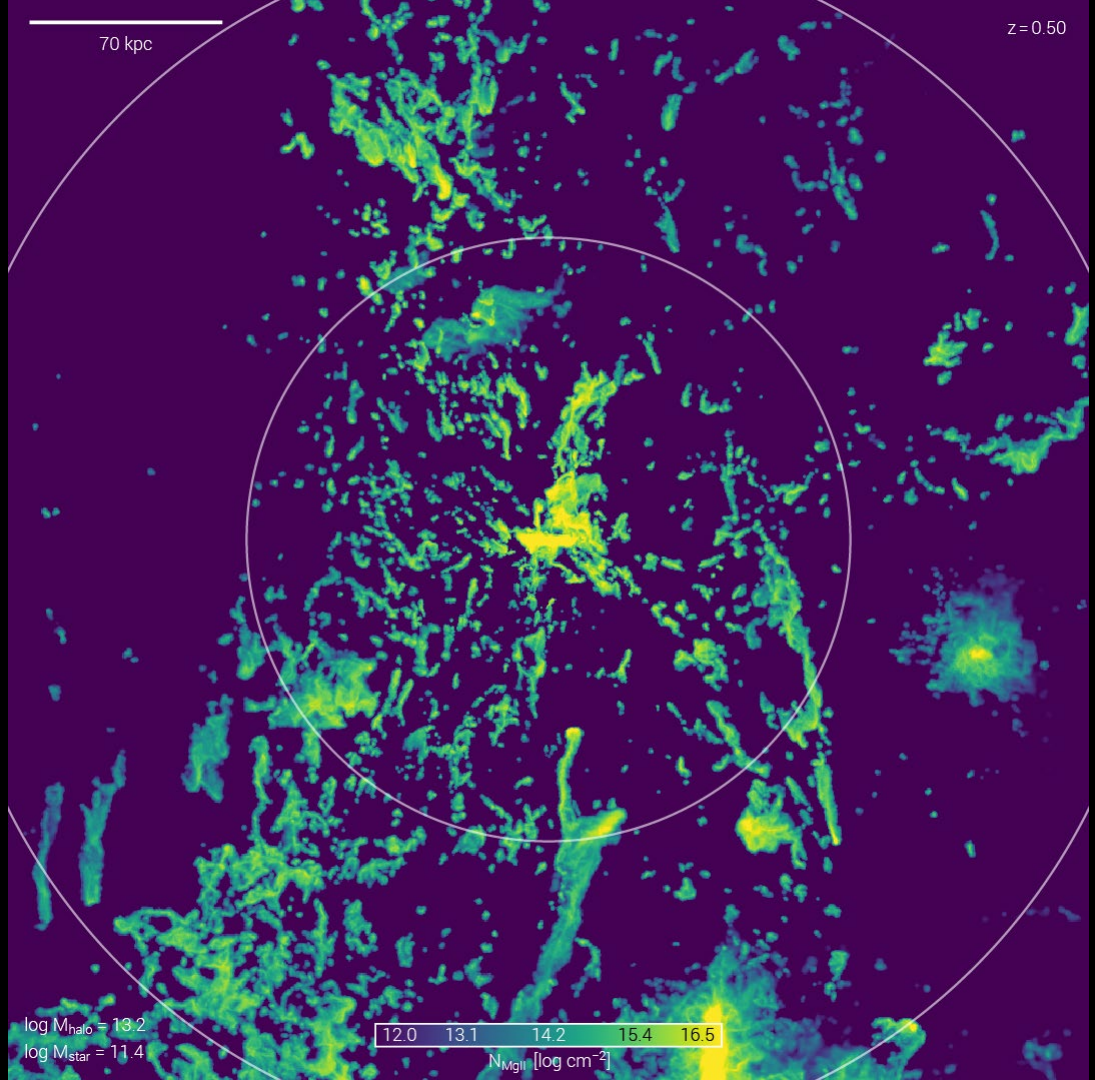
TNG50
high-mass halo
(cold gas)



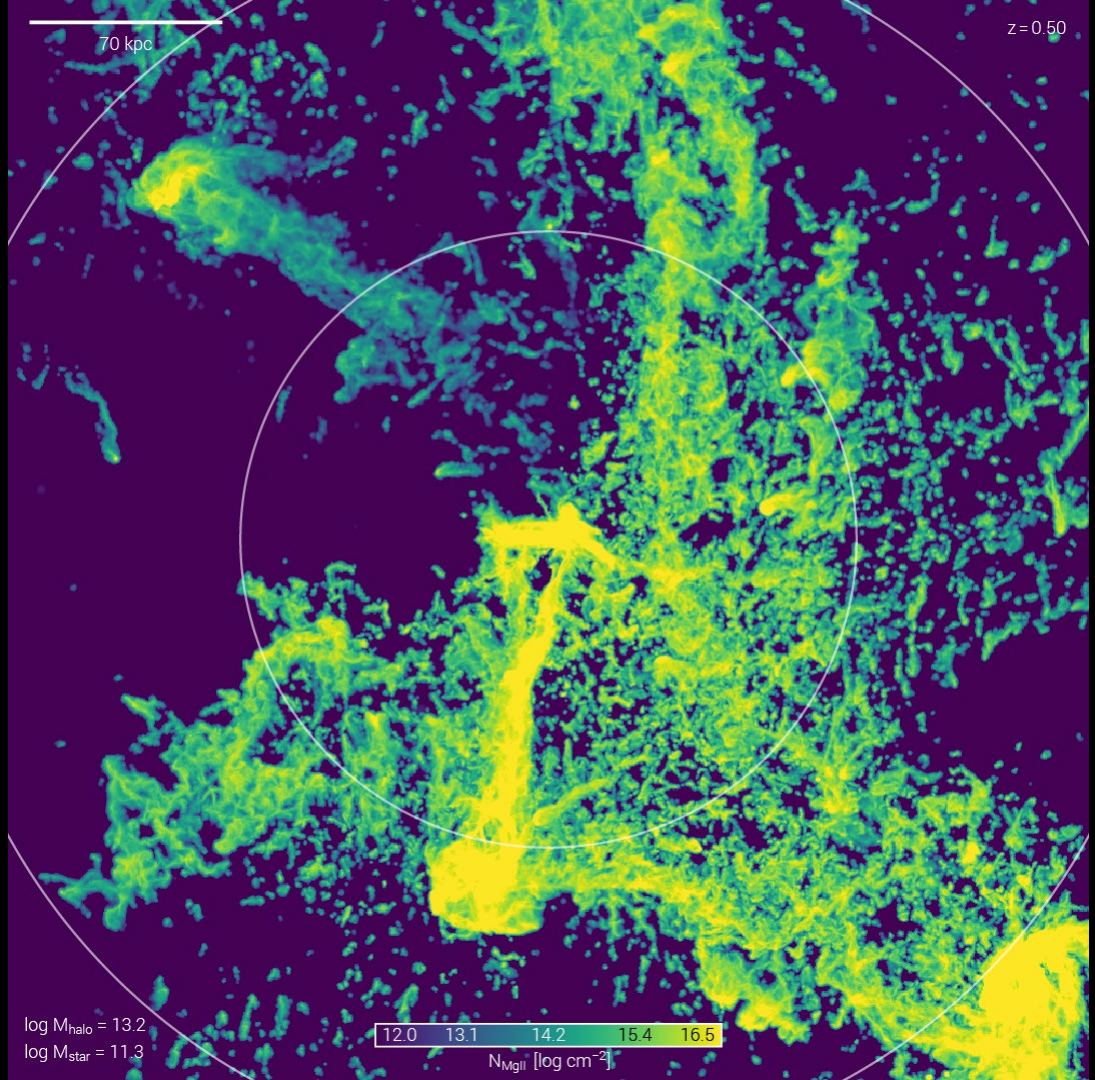
TNG50
high-mass halo
(cold gas)



TNG50
high-mass halo
(cold gas)

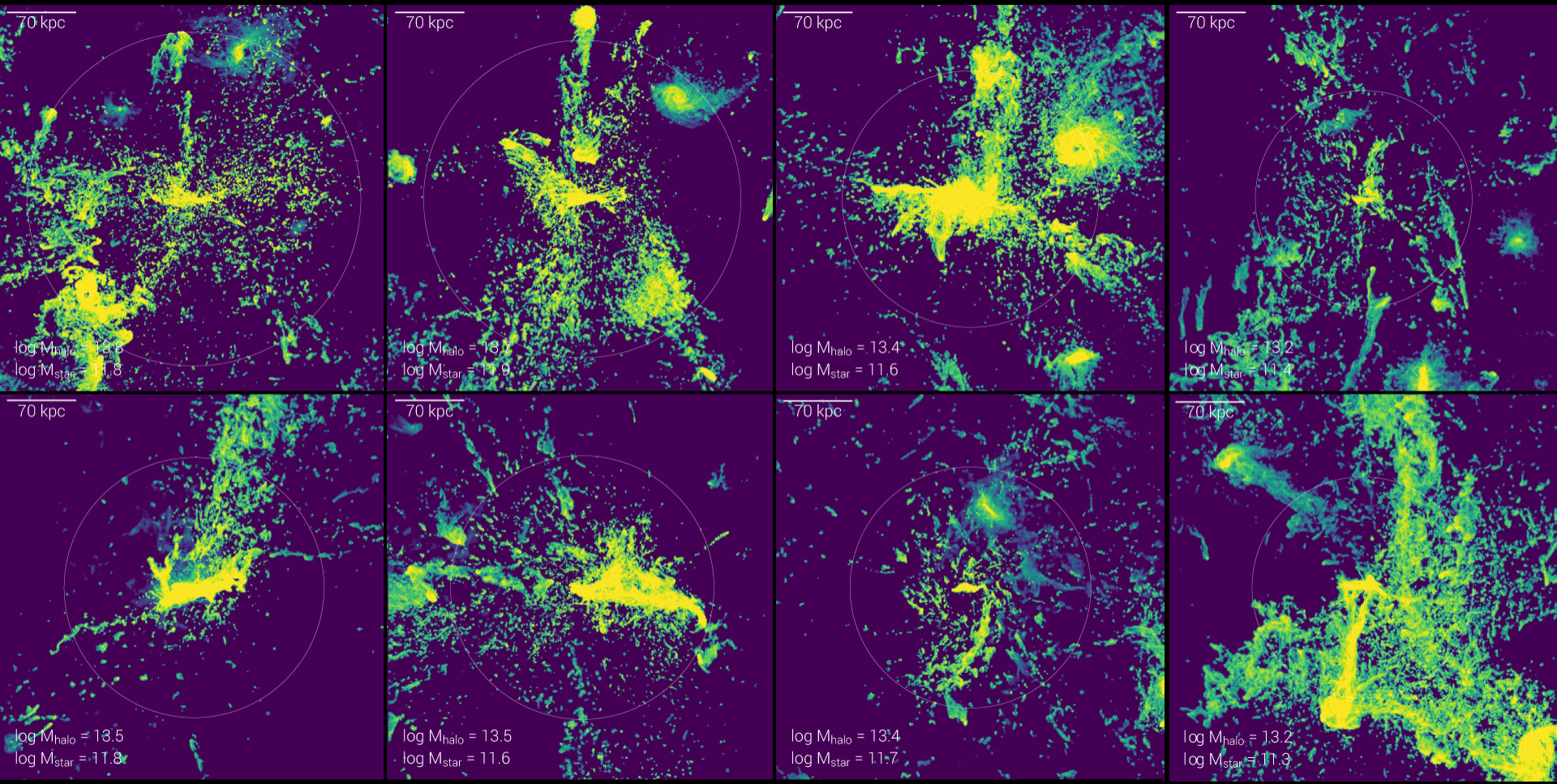


TNG50
high-mass halo
(cold gas)



outer = r_{vir} / 4

inner = r_{vir} / 4

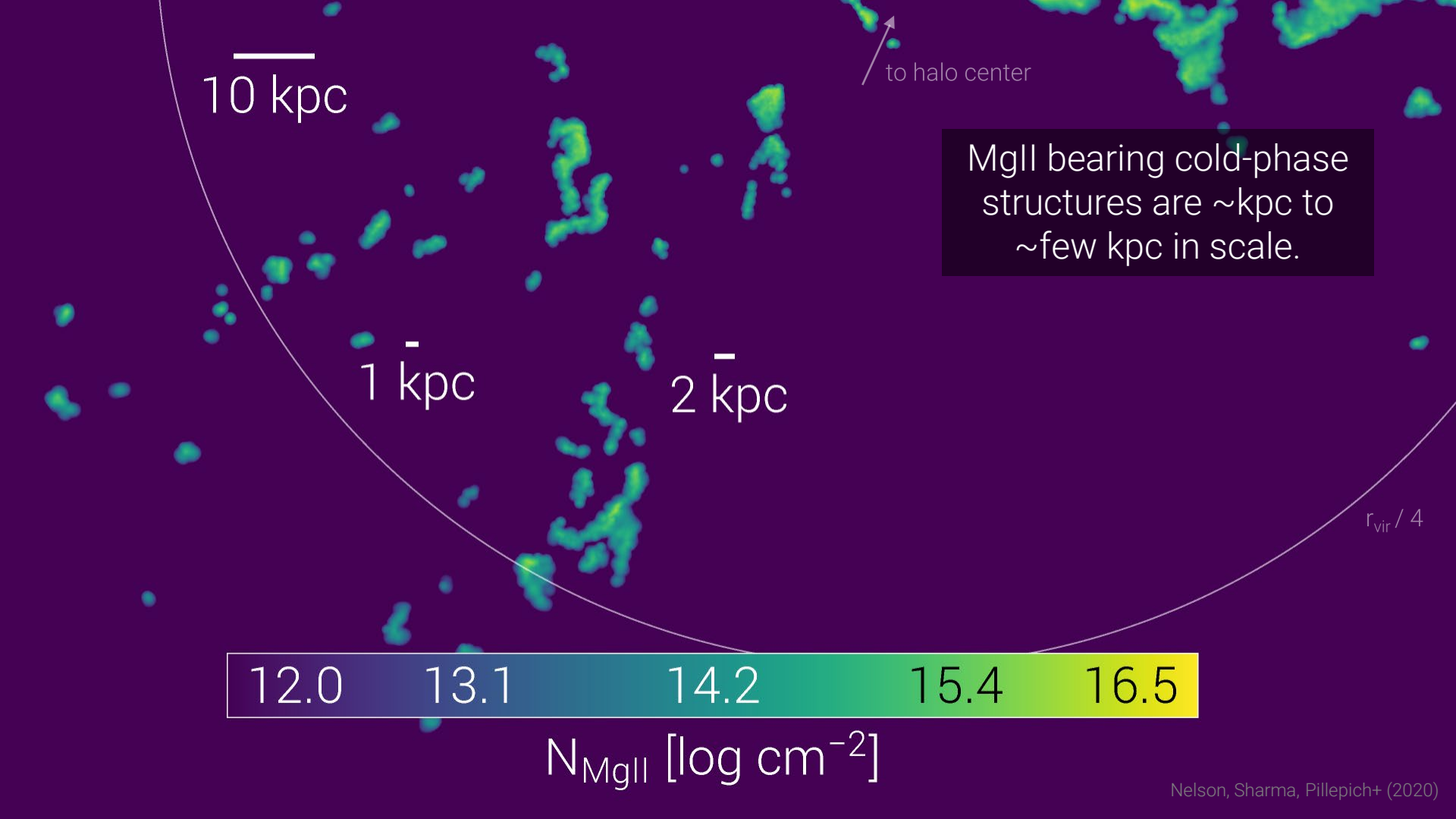


TNG50 high-mass halos (cold gas)

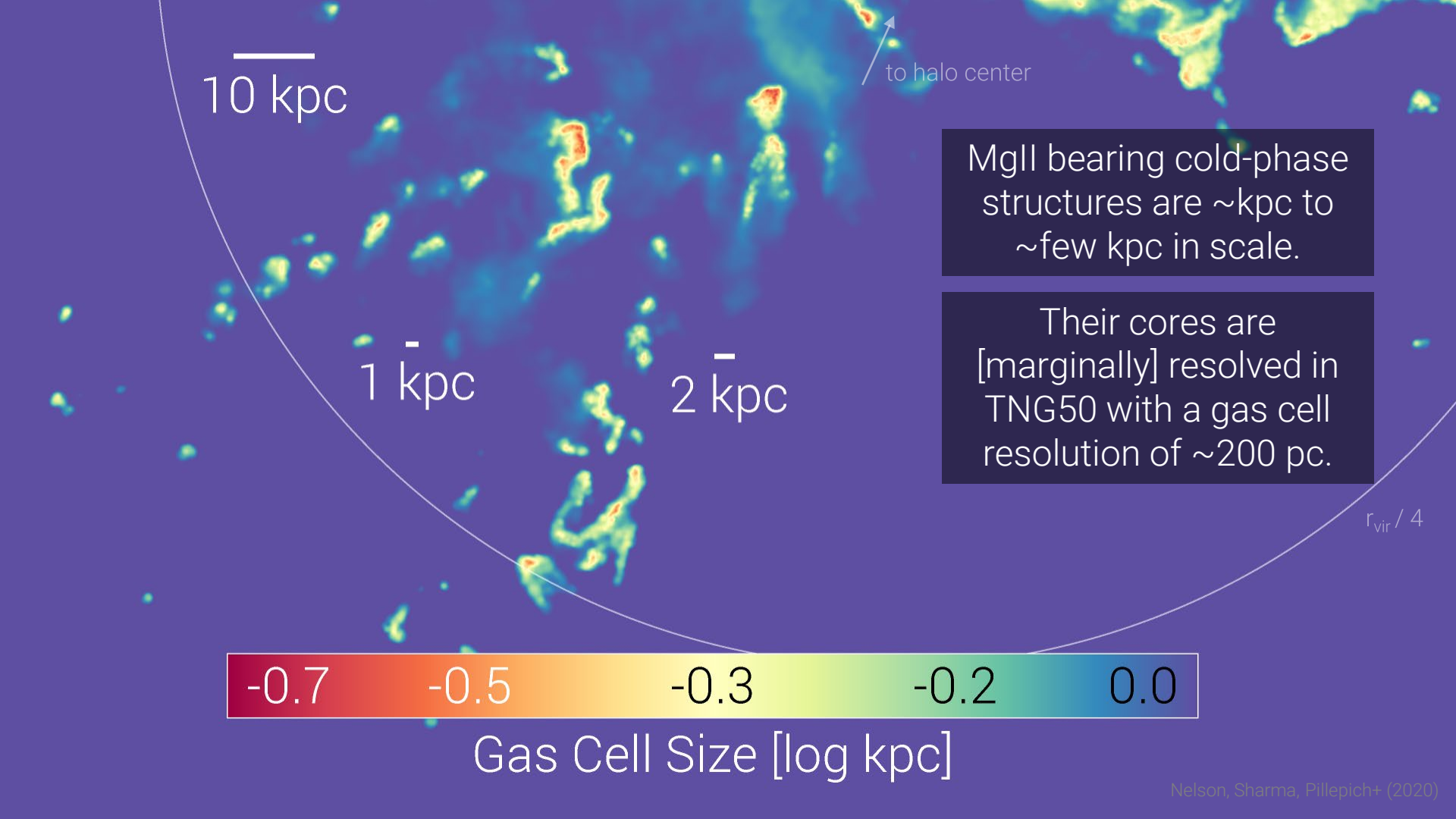
12.0 13.1 14.2 15.4 16.5

N_{MgII} [log cm^{-2}]

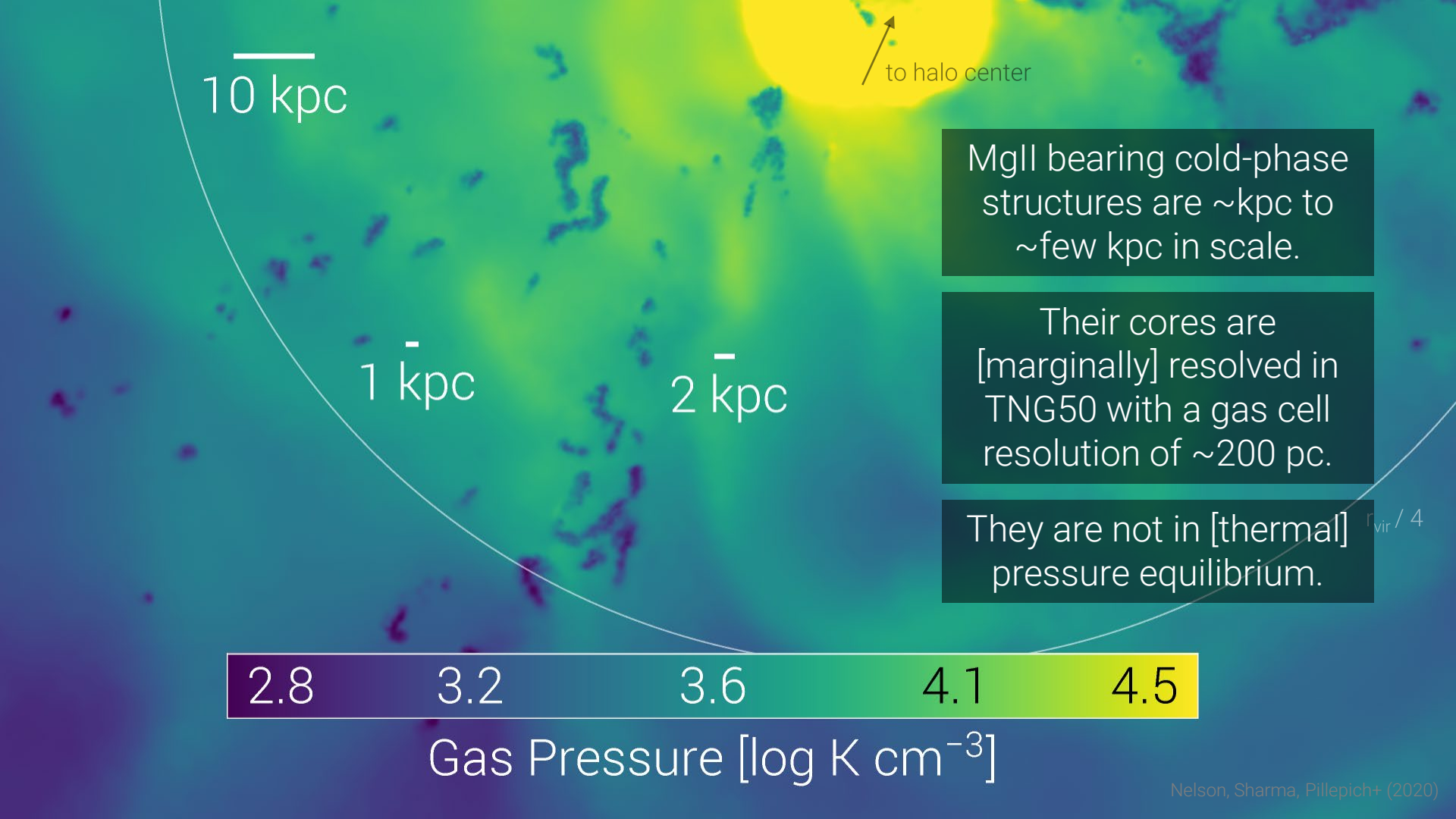
Nelson, Sharma, Pillepich+ (2020)



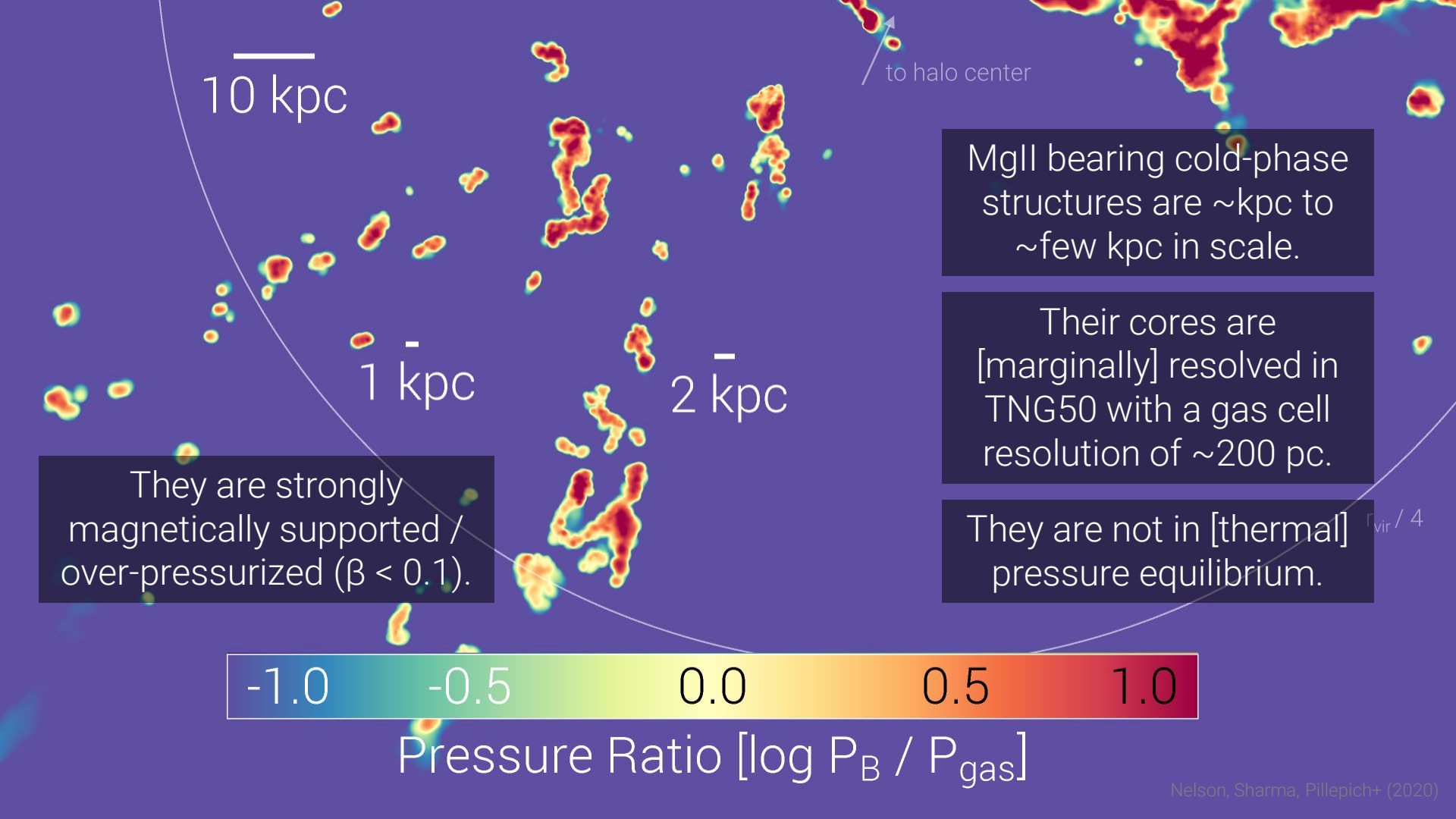
Nelson, Sharma, Pillepich+ (2020)



Nelson, Sharma, Pillepich+ (2020)

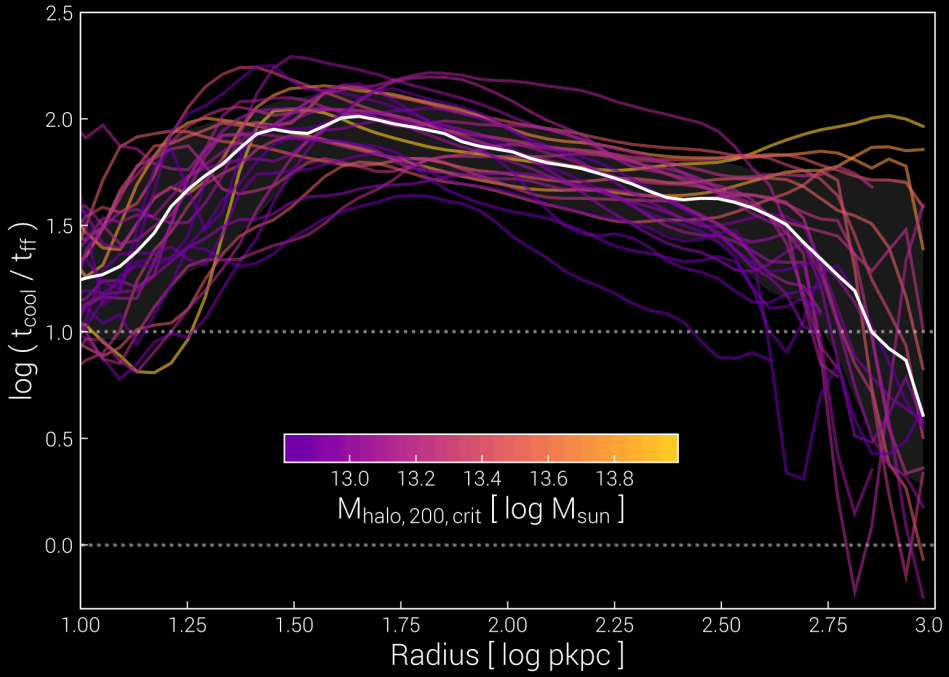


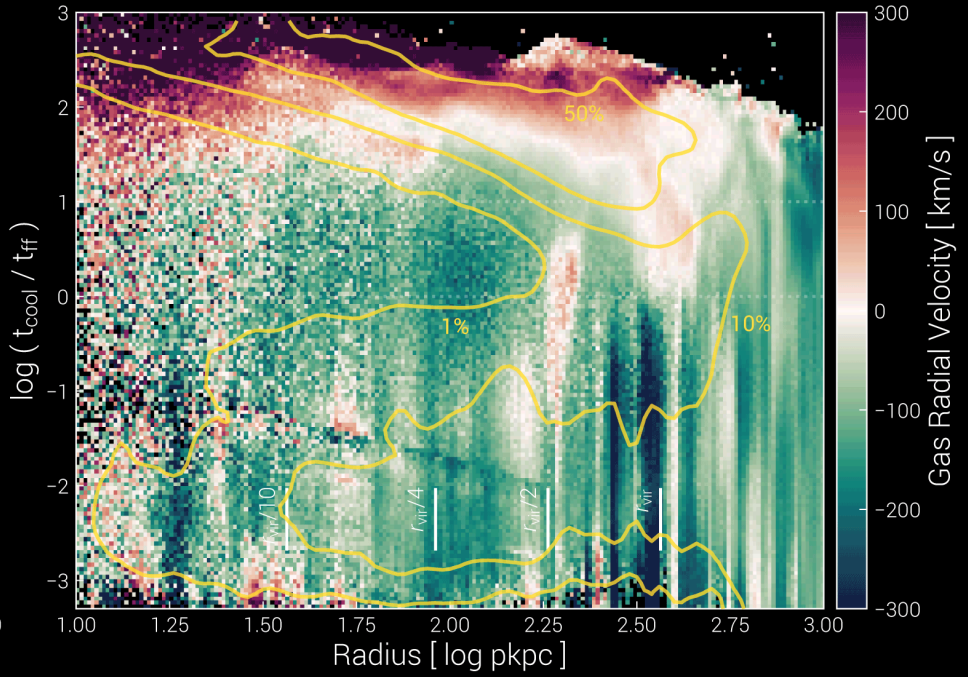
Nelson, Sharma, Pillepich+ (2020)



Nelson, Sharma, Pillepich+ (2020)

Is the (background) hot halo gas susceptible to thermal instability? Does it satisfy t_{cool}/t_{ff} < 1 or <10?

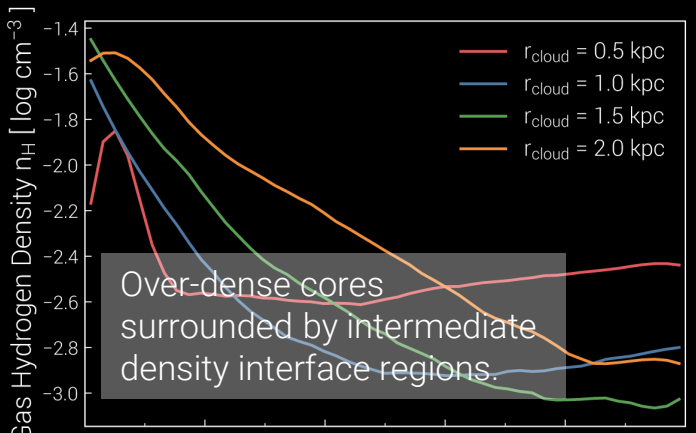


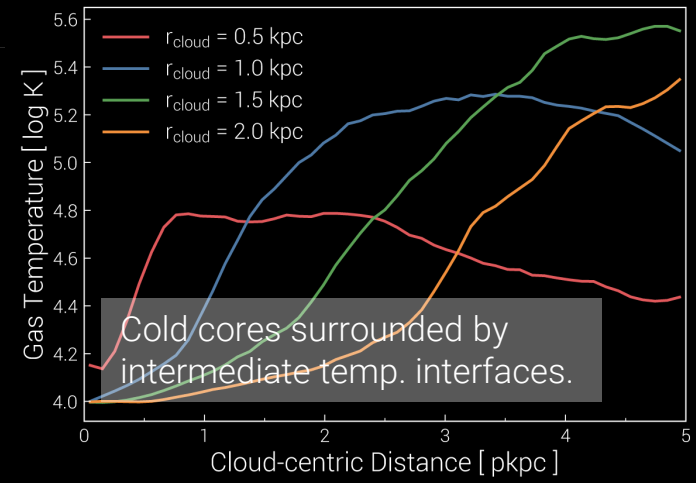


Globally:
t_{cool}/t_{ff} < 10 only in the very center (and outskirts) of the halo, not where most of the cold clouds are seen.

Locally:
t_{cool}/t_{ff} << 1 gas exists throughout the halo, and is preferentially inflowing towards the center. (localized in the interfaces around existing cold clouds).

How do clouds survive, and grow?

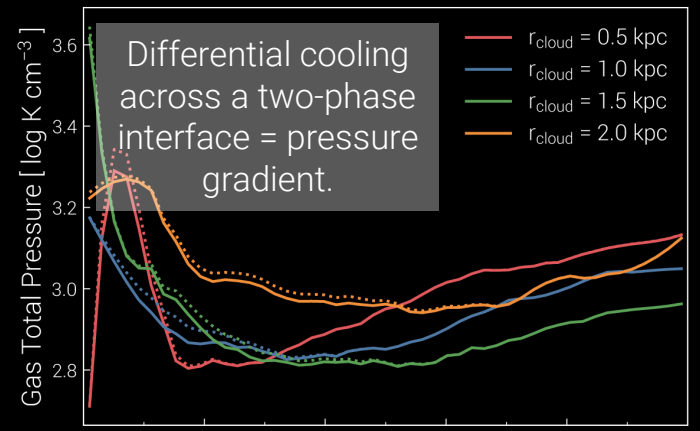


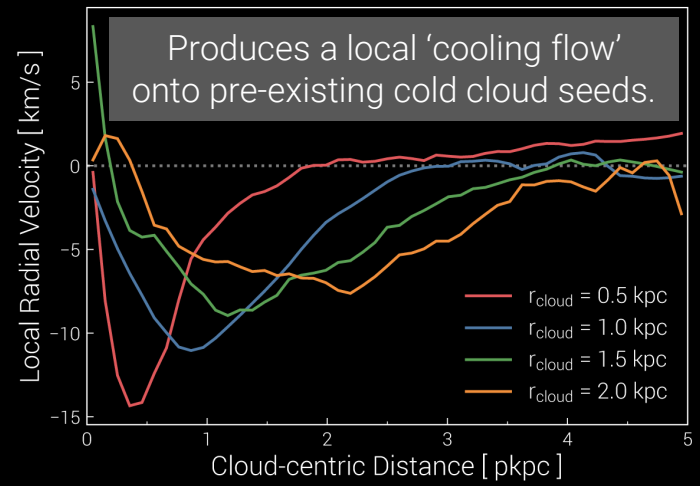


Radiative cooling sensitive to (n,T), and is effective.

Although halo is *globally* "t_{cool}/t_{ff} > 10 stable", gas is *locally* susceptible to TI near existing cold seeds.

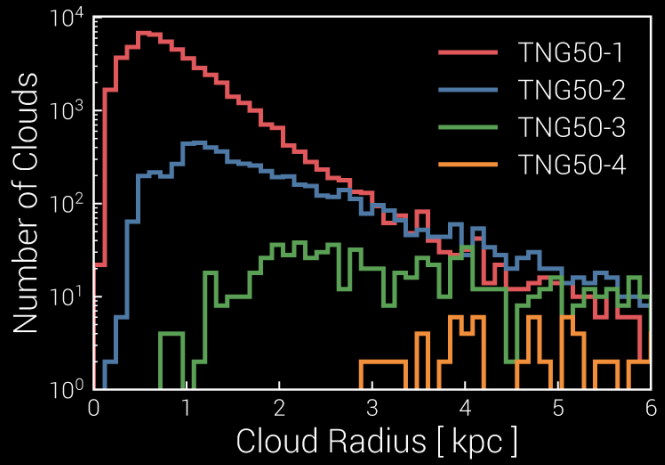
Initial seeds: stripping and perturbations arising from substructure i.e. satellite galaxies!

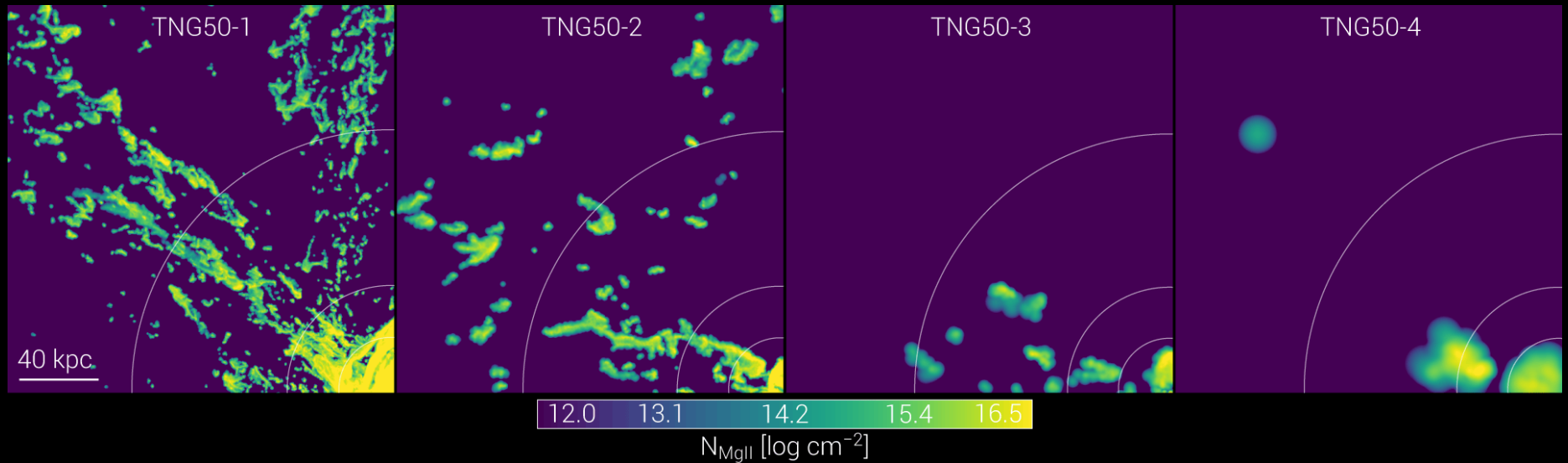


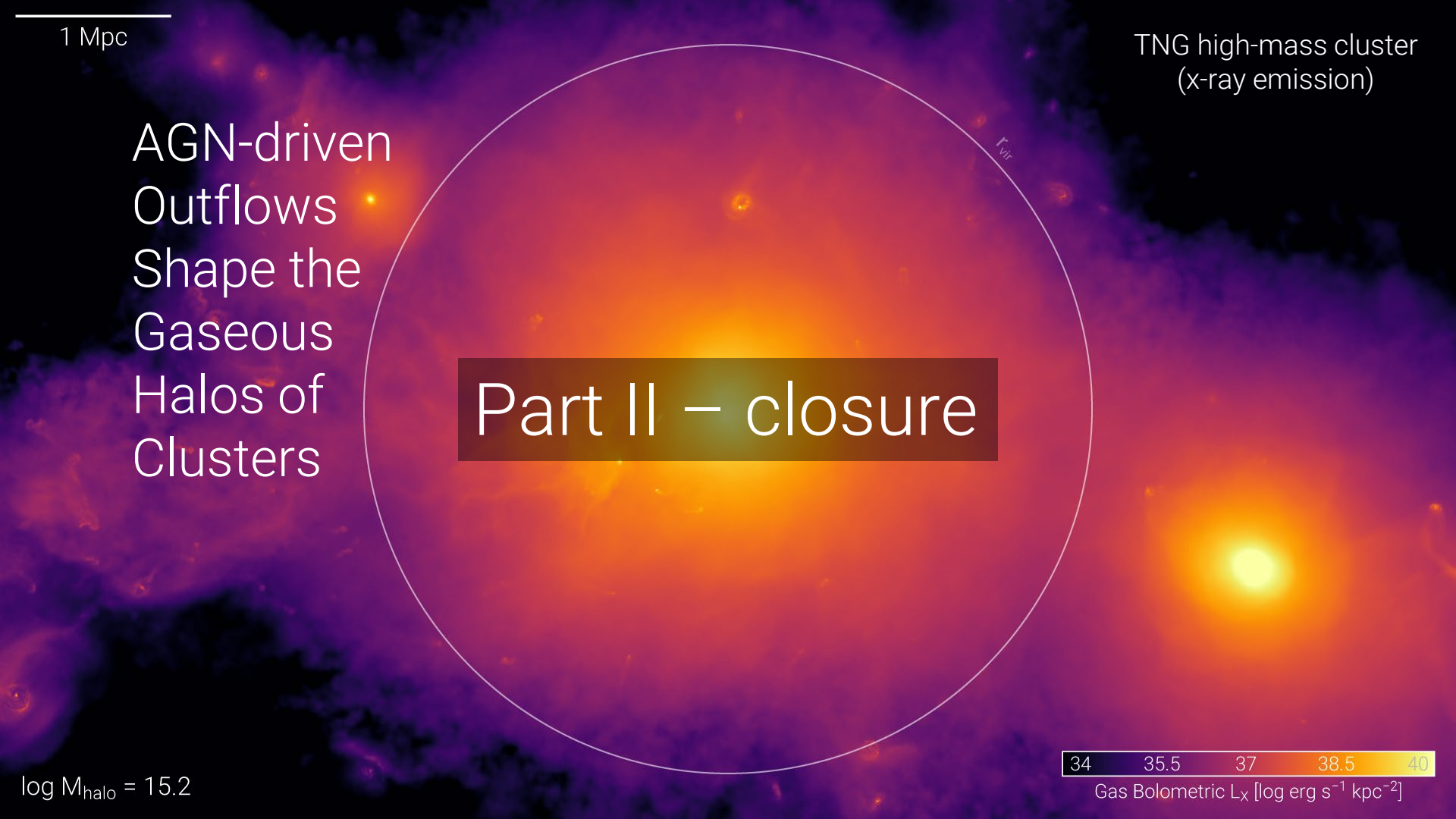


Such small-scale structure is due (predominantly) to the high-resolution of TNG50!

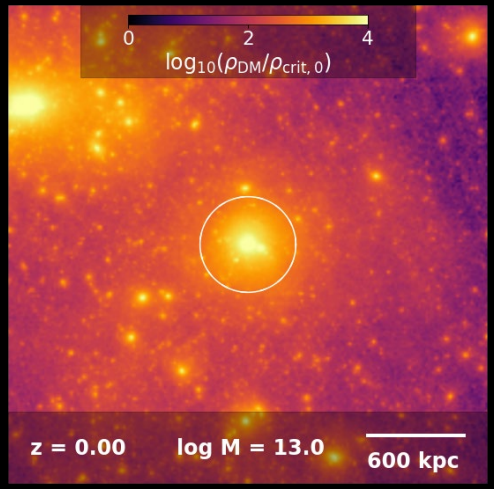
- Total cold gas mass in halos converged.
- Structure & cloud distribution is not.
- Fragmentation and breakup: always more, smaller clouds at higher resolution.



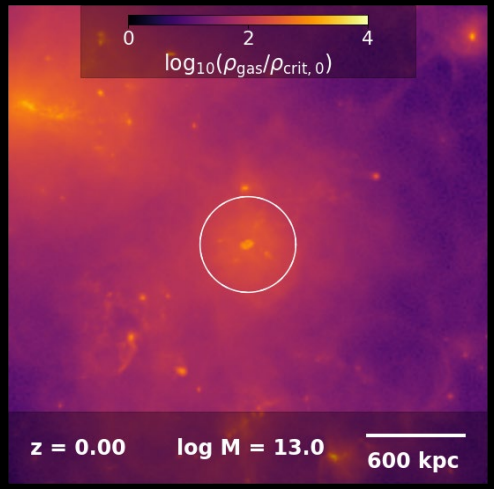



1 Mpc
TNG high-mass cluster
(x-ray emission)
AGN-driven Outflows Shape the Gaseous Halos of Clusters
Part II – closure
r_{vir}
log M_{halo} = 15.2
34
35.5
37
38.5
40
Gas Bolometric L_X [log erg s^{-1} kpc^{-2}]

DM



gas



Ayromlou, Nelson & Pillepich (2022)

Take home points:

1. High resolution hydro simulations (like TNG50) resolve a cold phase of halo gas: thousands of small, dynamic, clouds.

Nelson, Sharma, Pillepich (2020)

2. Significant redistribution of baryons far beyond R_{vir}. Different physics at different halo mass scales.

Ayromlou, Nelson, Pillepich (2022)

AGN feedback sets the "closure radius" of clusters at ~1-2 R_{vir} in TNG, ~1 R_{vir} in EAGLE, ~1-5 R_{vir} in SIMBA.

3. The future: stay tuned for TNG-Cluster!

Pillepich & Nelson