Cool-Core Demographics and Evolution Unveiled: Insights From TNG-Cluster

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TNG-Cluster

New simulations, which allow comparisons of the current state-of-the-art in theory and data at the highest-mass end.

Co-PIs

Annalisa Pillepich

Dylan Nelson

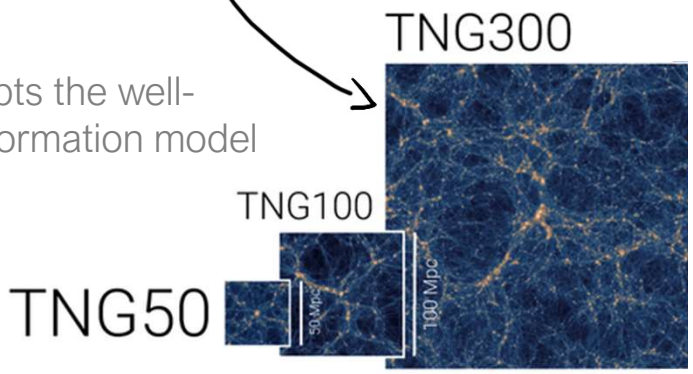
TNG-Cluster – A spin-off from the IllustrisTNG simulation

The IllustrisTNG Collaboration

We can study the ICM in a full cosmological framework, under the influence of rich galaxy evolution physics.

Keeping the same resolution as in TNG300

TNG-Cluster adopts the well-validated galaxy formation model from IllustrisTNG.



TNG-Cluster – A spin-off from the IllustrisTNG simulation

The IllustrisTNG Collaboration

- **Cosmological hydrodynamical** simulation, solving **gravity** and ideal **MHD** in an expanding spacetime.

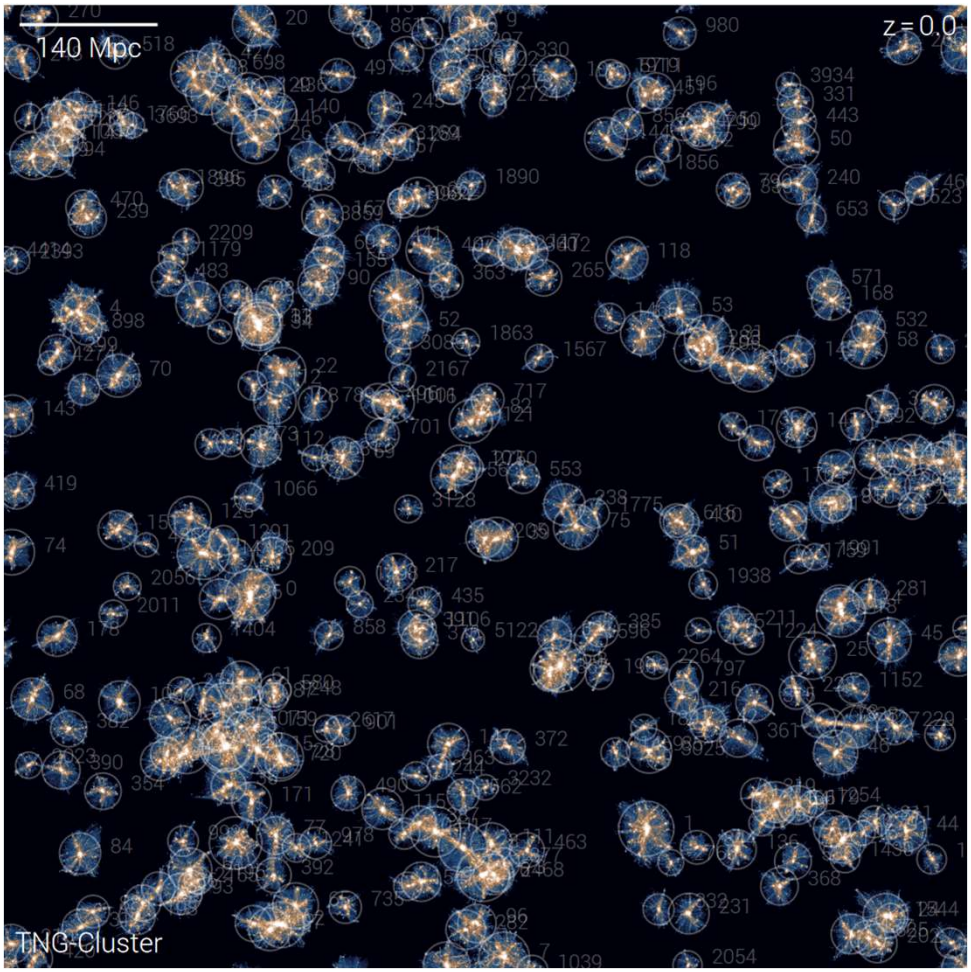
- With galaxy physics:
  - Heating and cooling of the gas (>10^4 K)
  - Star formation, evolution, enrichment, stellar feedback
  - Tracking of 11 elemental abundances
  - SMBH seeding, growth, merging, multimode SMBH feedback
  - Seeding and evolution of magnetic fields

- 10^7 $M_\odot$ baryonic mass resolution

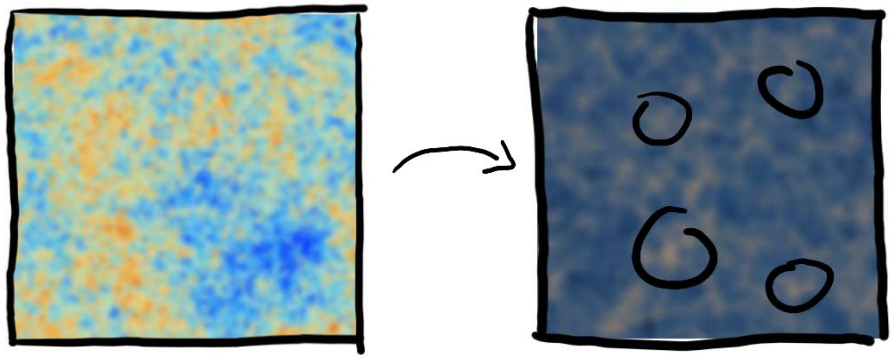
- It is a collection of 352 zoom simulations

- We have already a few papers, data release in 2024/2025

Nelson+2024
Ayromlou+2024
Lehle+2024
Rohr+2024
Lee+2024
Truong+2024



TNG-Cluster is a patchwork of 352 zoom simulations



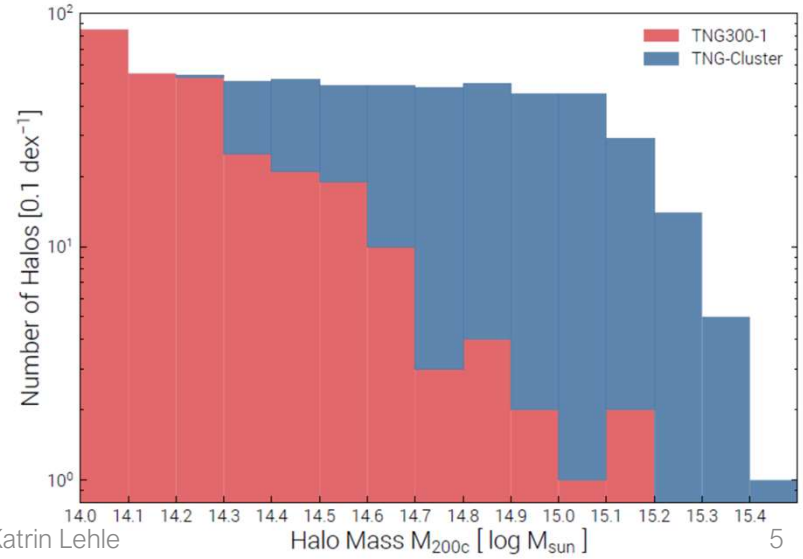
Halos are selected solely based on mass at z=0.

Halo selection criteria:

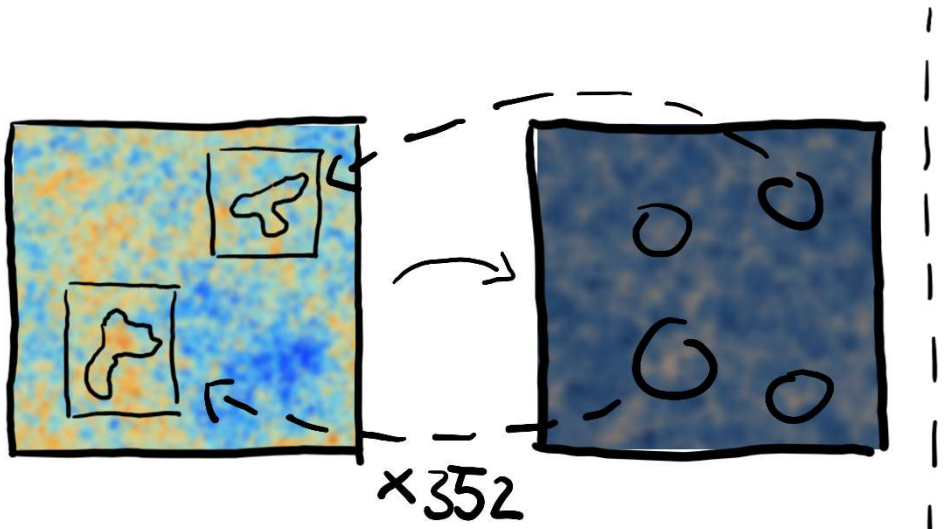
(i) include all halos with $\log(M_{200})>15.0\ M_{\odot}$

(ii) compensate the drop-off of statistics in TNG300 for lower mass halos

D. Nelson, A. Pillepich et al 2024 (+KL)



TNG-Cluster is a patchwork of ~350 zoom simulations



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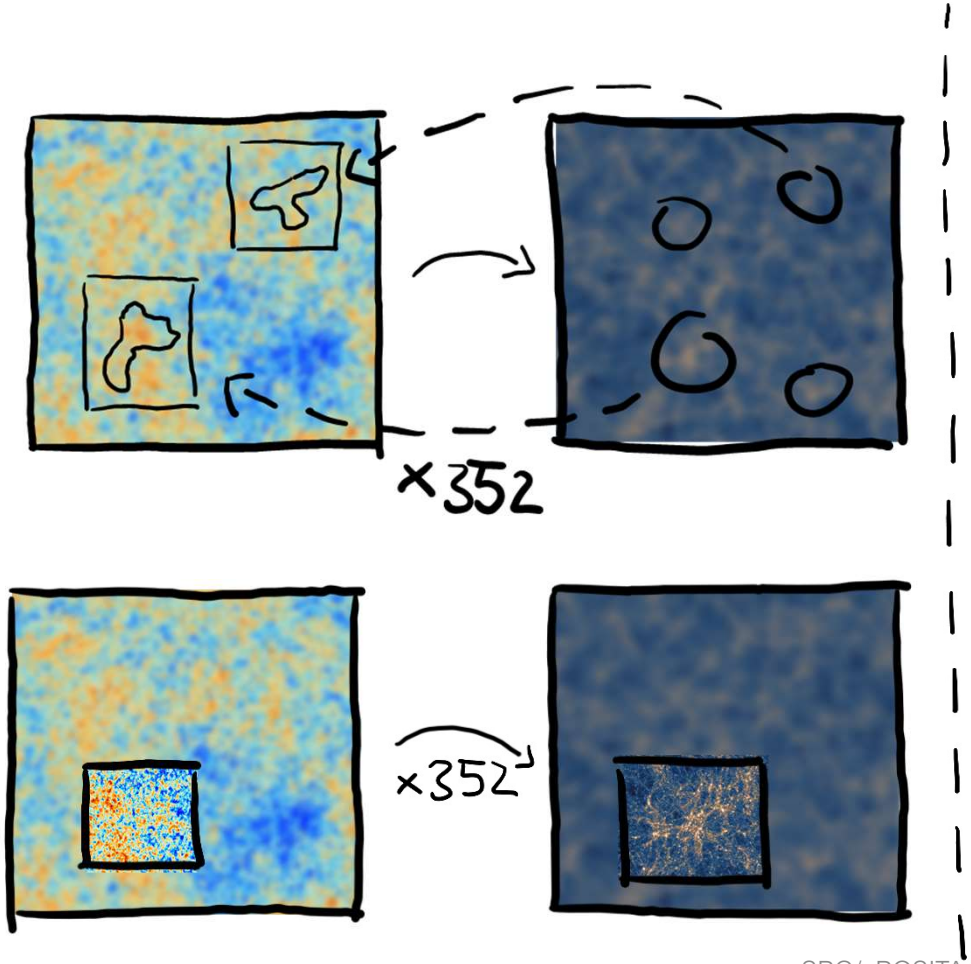
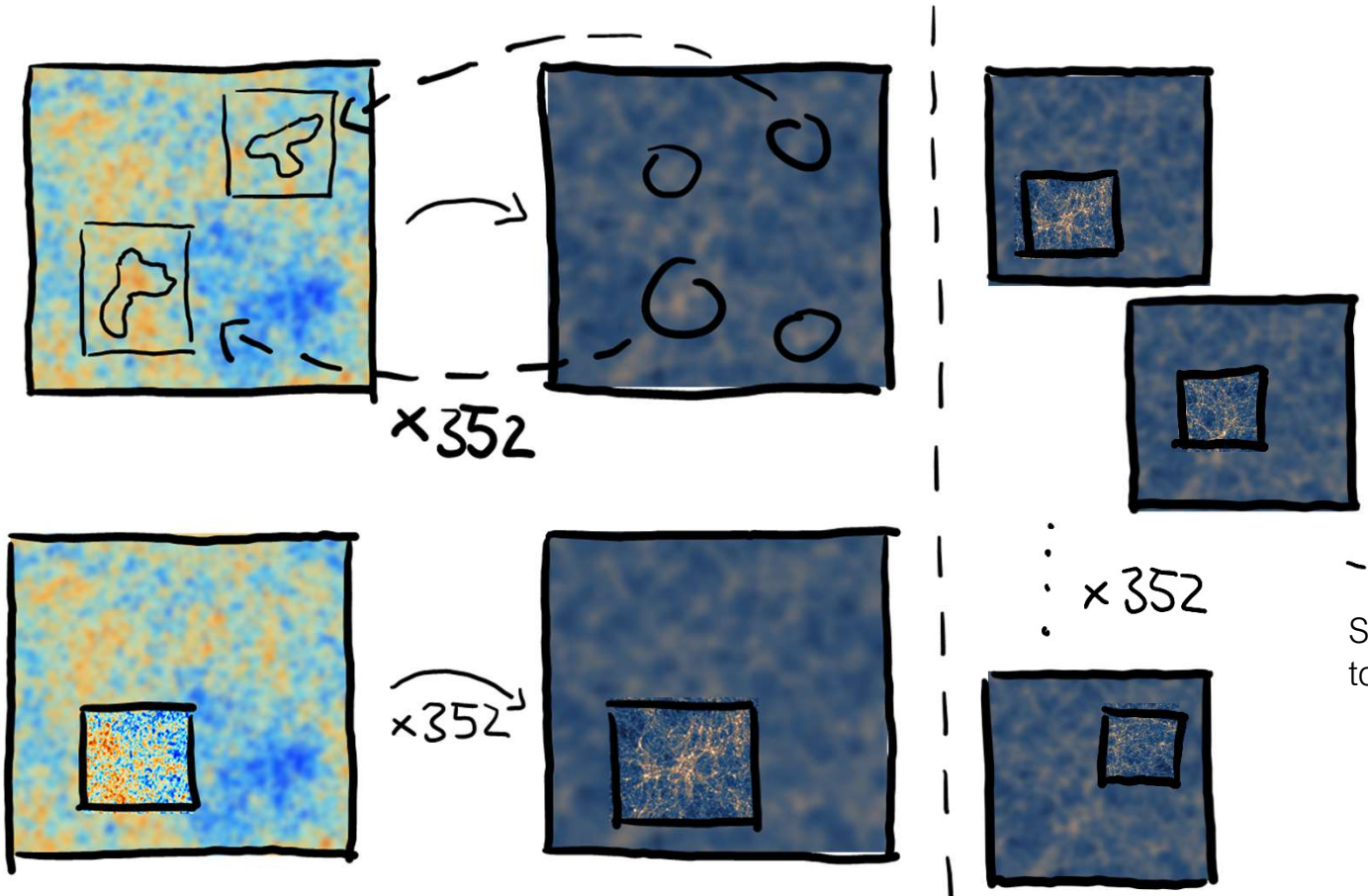


TNG-Cluster is a patchwork of ~350 zoom simulations



Stitch together

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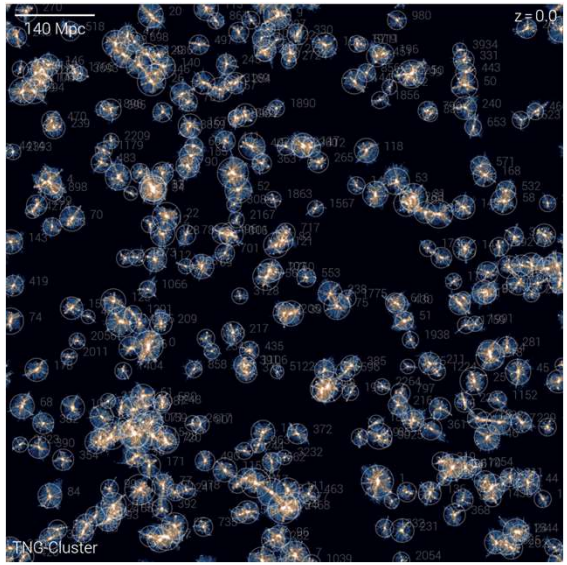
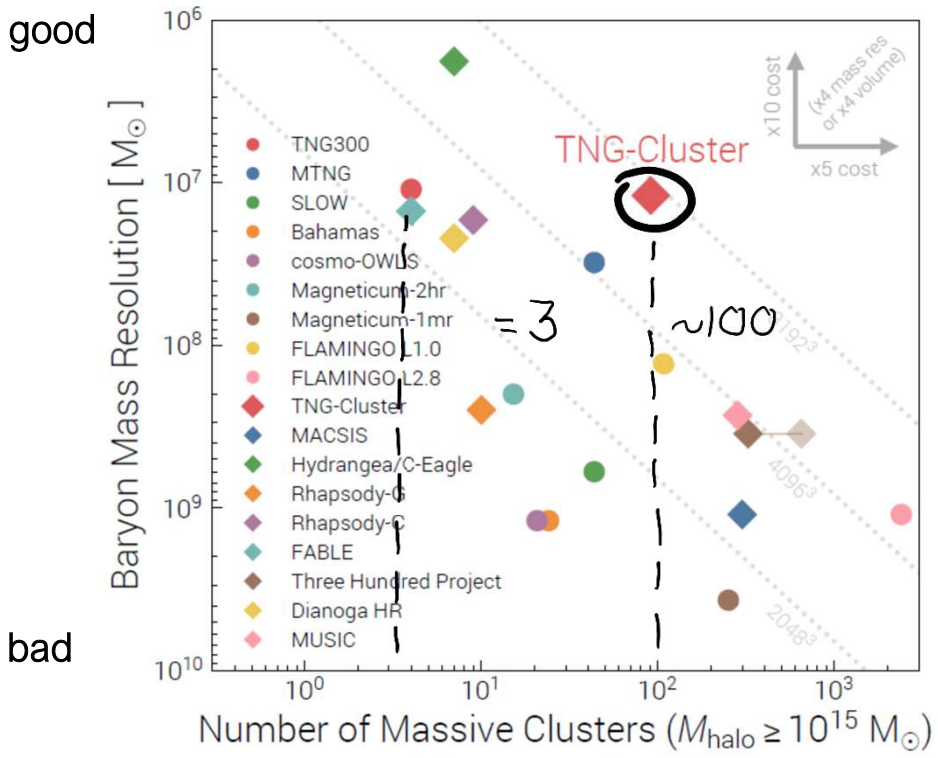


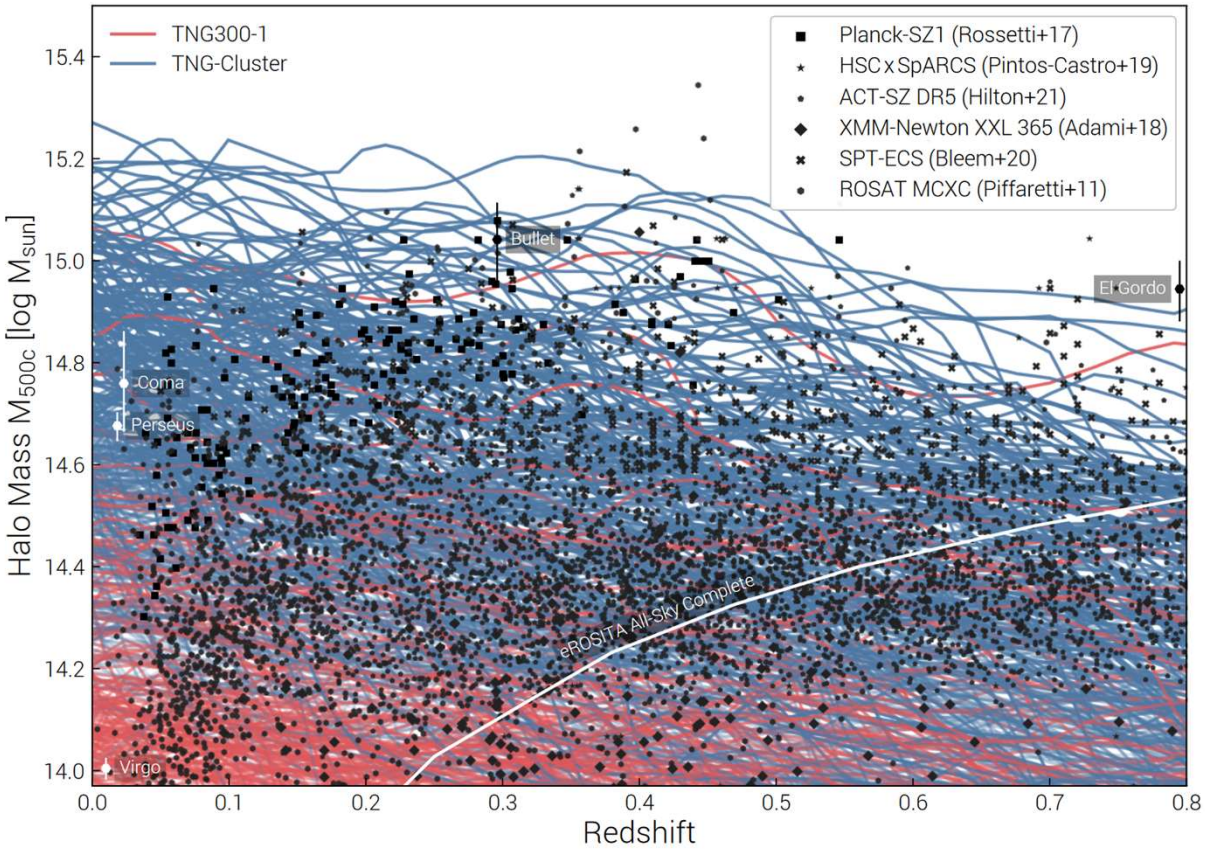
Virtual TNG-Cluster box

TNG-Cluster offers a unique combination of high-mass galaxy clusters and high resolution



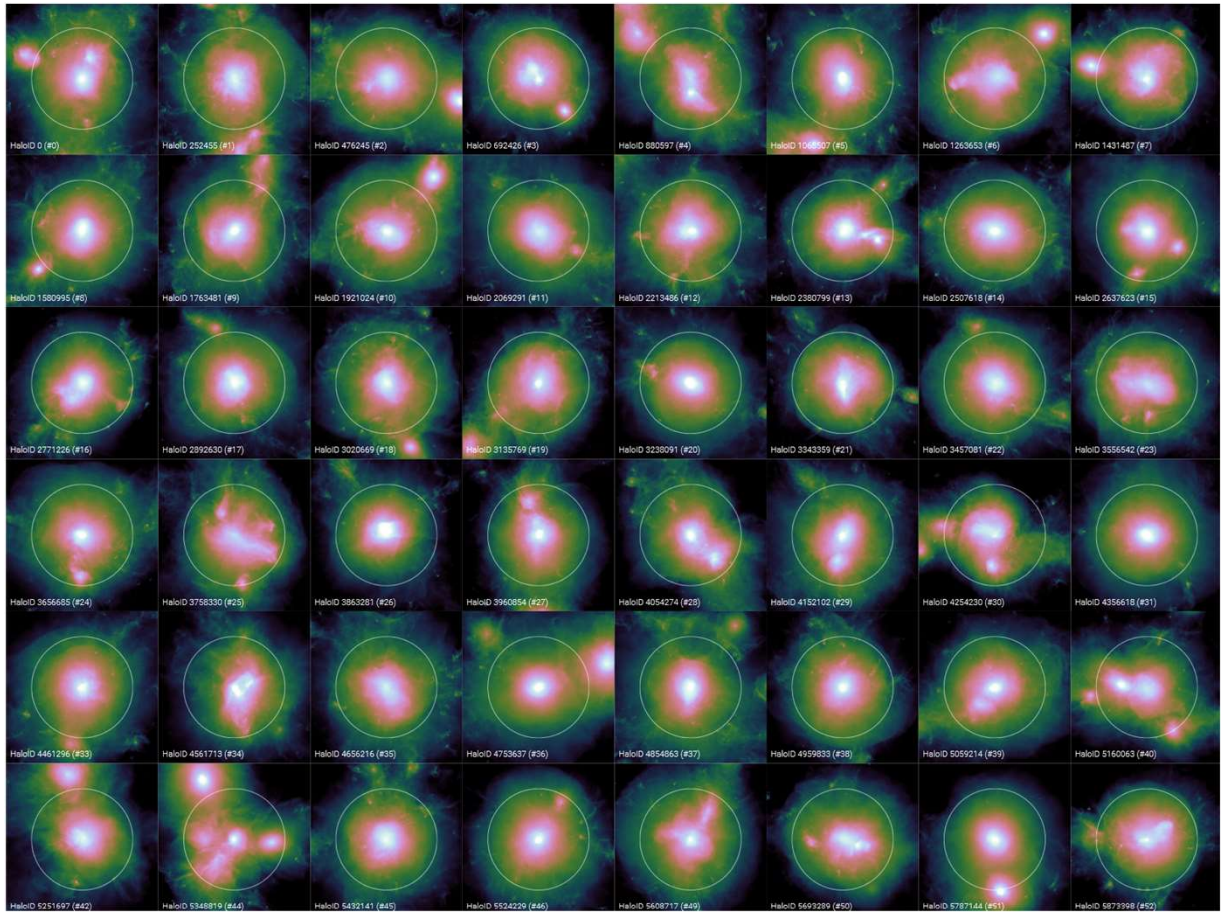
D. Nelson, A. Pillepich et al 2024 (+KL)

The large sample in TNG-Clusters allows powerful connections to observations.



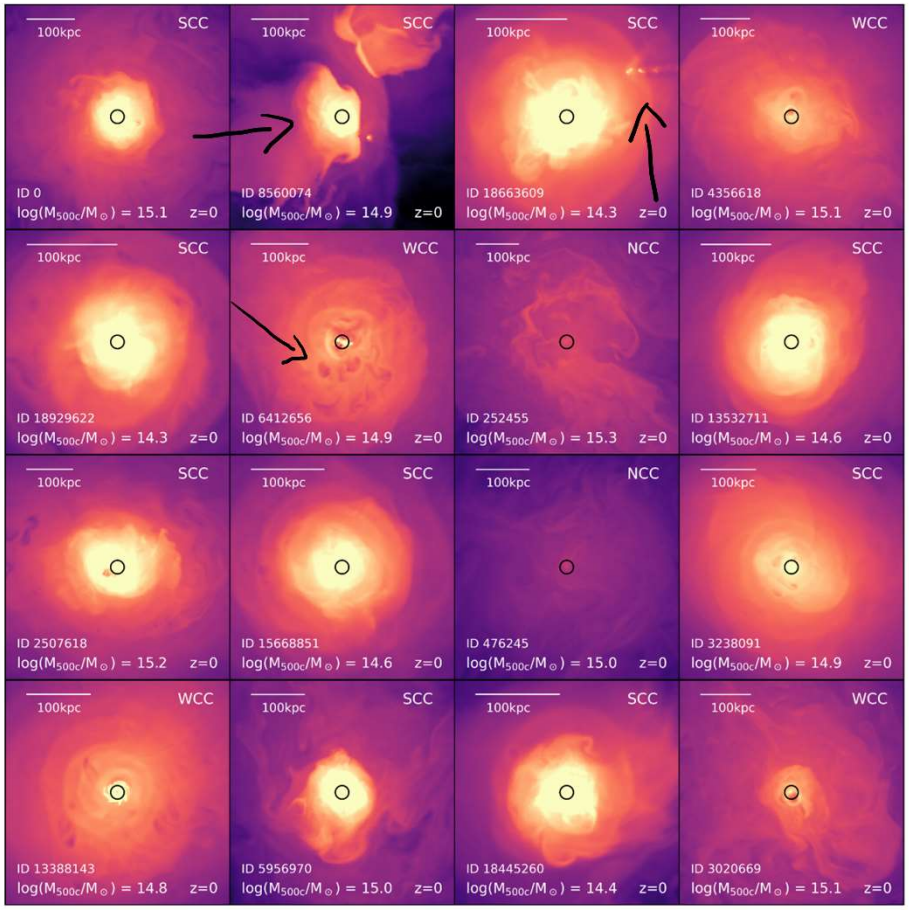
D. Nelson, A. Pillepich et al 2024 (+KL)

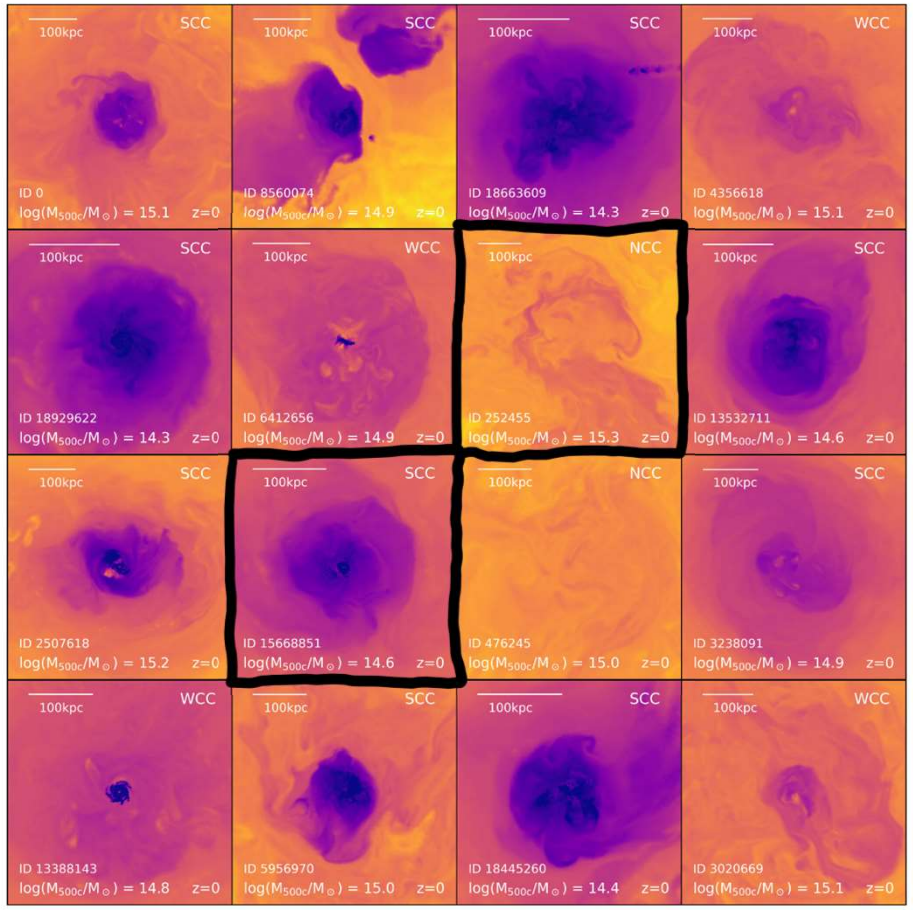
TNG-Cluster offers large statistics in X-ray morphologies



D. Nelson, A. Pillepich et al 2024 (+KL)

Simulated cluster cores resemble structures from known halos.

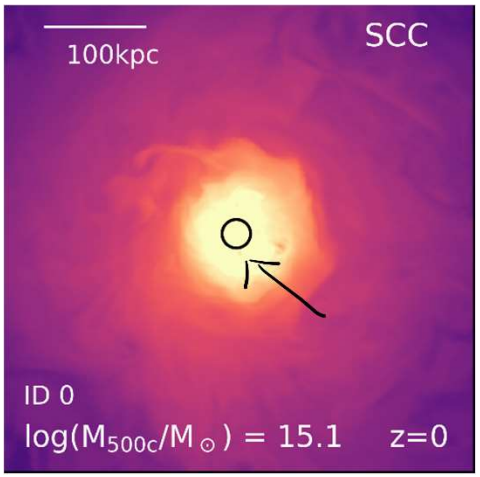




K. Lehle, D. Nelson, A. Pillepich, et al. 2024

We use 6 metrics to define the (non-)cool-core state of a cluster

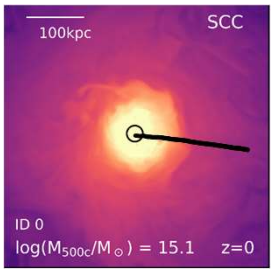
3D

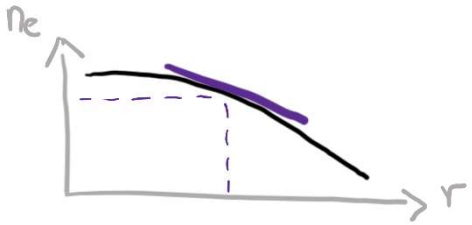


Mass-weighted mean of cooling time, entropy or electron number density within aperture of r = 0.012 r_{500}

$t_{cool,0}$ K_0 $n_{e,0}$

3D

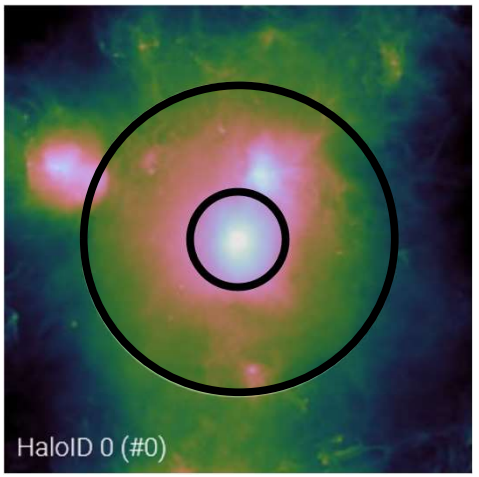




Slope of the electron number density profile at r = 0.04 r_{500}

$\propto$

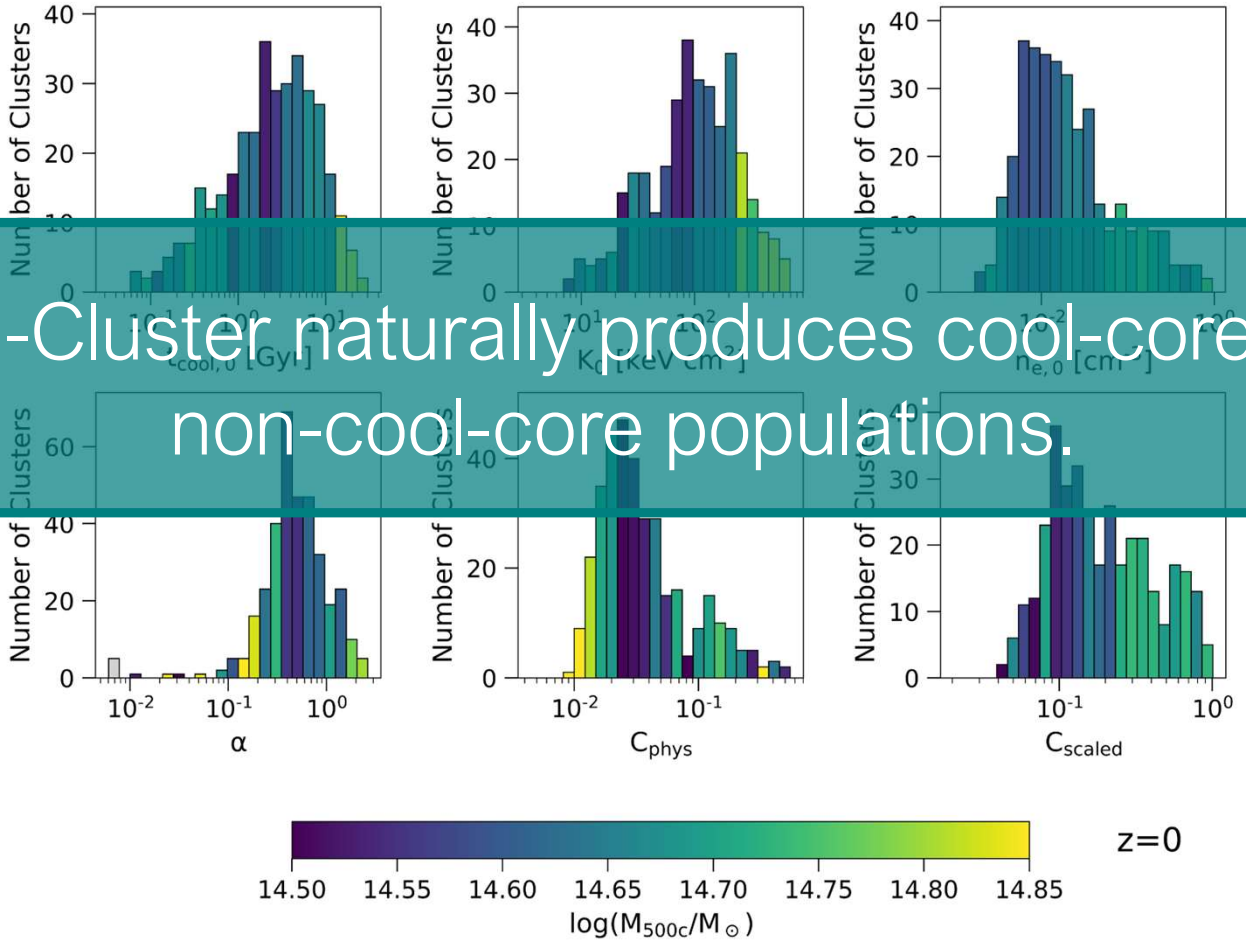
2D



Concentration of X-ray luminosity within two apertures

c_{phys} c_{scaled}

Core properties are unimodally distributed, with no a-priori cluster selection.



TNG-Cluster naturally produces cool-core and non-cool-core populations.

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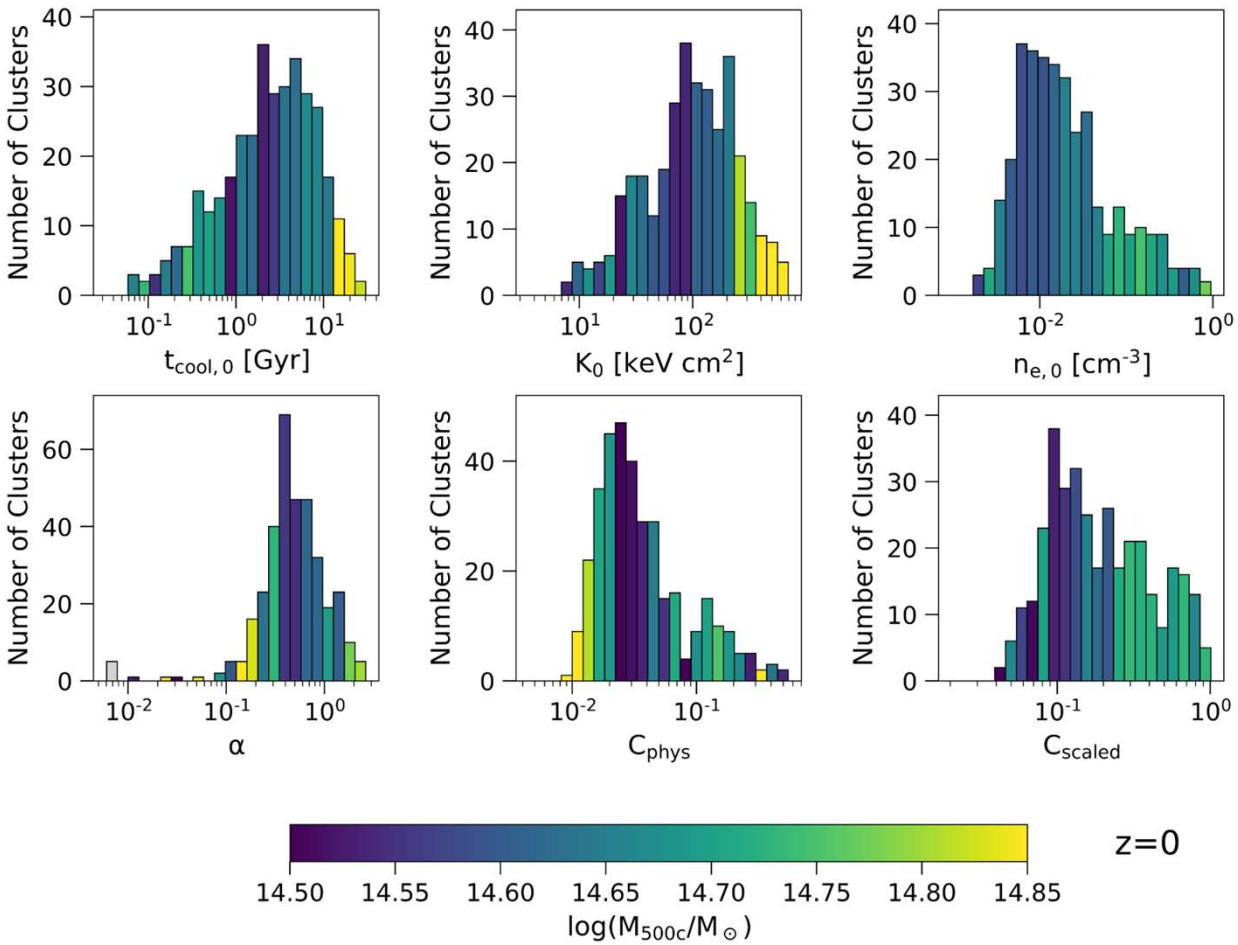

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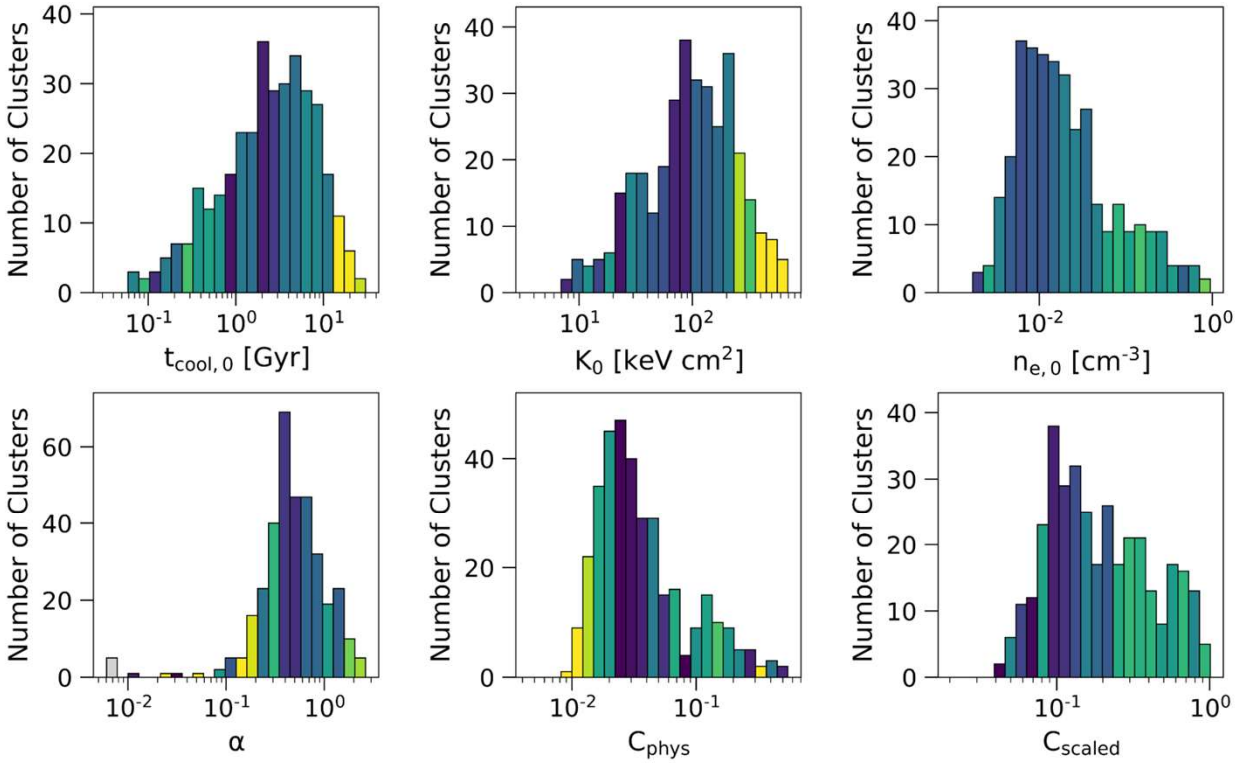

Physical property		Aperture	SCC threshold	WCC threshold	NCC threshold
Central cooling time	$t_{cool,0}$	$0.012\,r_{500c}$	< 1 Gyr	$1\,\mathrm{Gyr} \leq t_{cool,0} < 7.7\,\mathrm{Gyr}$	≥ 7.7 Gyr
Central entropy	K_0	$0.012\,r_{500c}$	$\leq 22\,\mathrm{keV\,cm^2}$	$22 < K_0/(\mathrm{keV\,cm^2}) \leq 150$	$> 150\,\mathrm{keV\,cm^2}$
Central electron density	$n_{e,0}$	$0.012\,r_{500c}$	$> 1.5 \cdot 10^{-2}\,\mathrm{cm^{-3}}$	$0.015 \geq n_{e,0}/\mathrm{cm^{-3}} > 0.005$	$\leq 0.5 \cdot 10^{-2}\,\mathrm{cm^{-3}}$
Cuspiness	α	$0.04\,r_{500c}$	> 0.75	$0.75 \geq \alpha > 0.5$	≤ 0.5
Physical concentration	C_{phys}	40 kpc, 400 kpc	> 0.155	$0.155 \geq C_{phys} > 0.075$	≤ 0.075
Scaled concentration	C_{scaled}	$0.15\,r_{500c}, r_{500c}$	> 0.5	$0.5 \geq C_{scaled} > 0.2$	≤ 0.2

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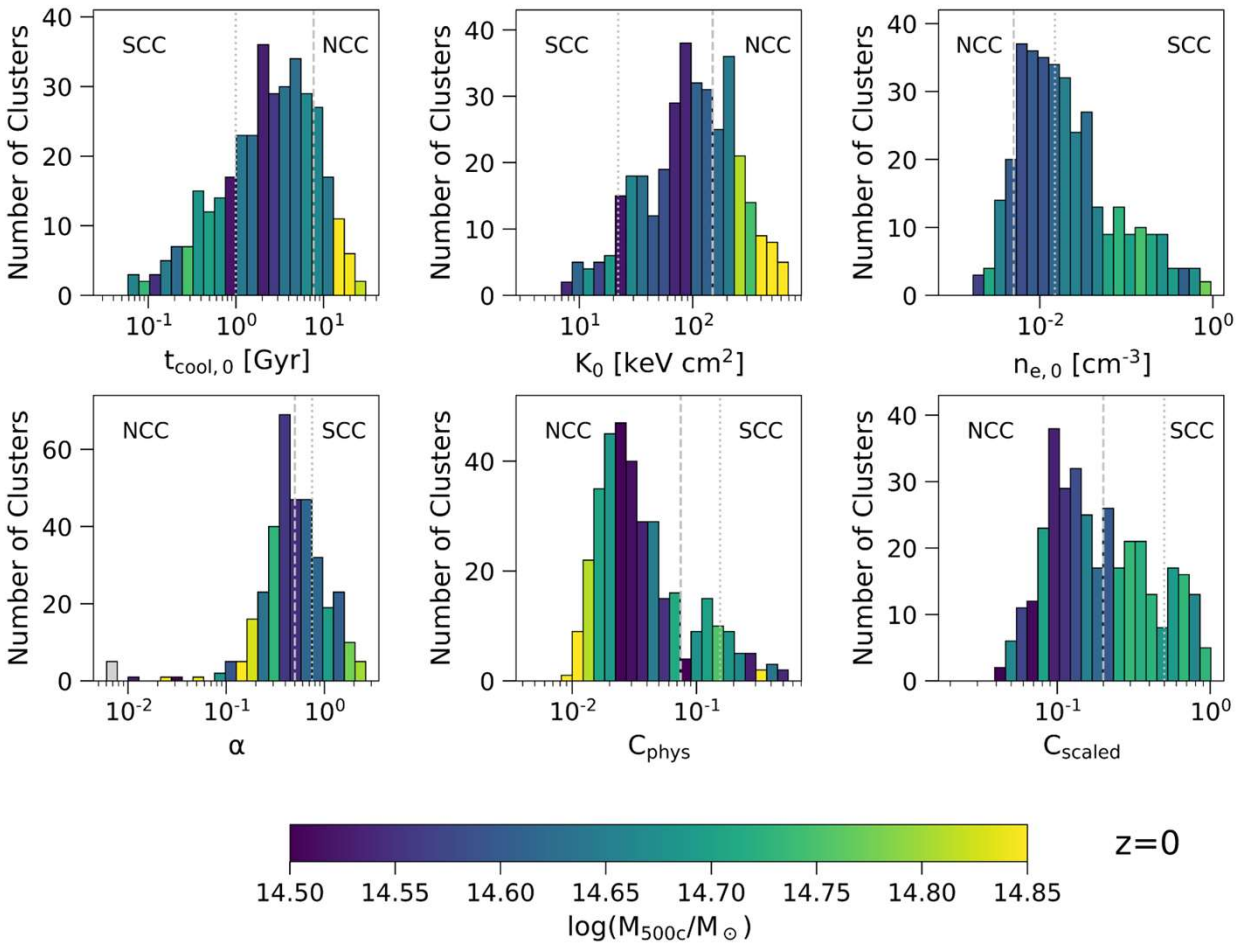

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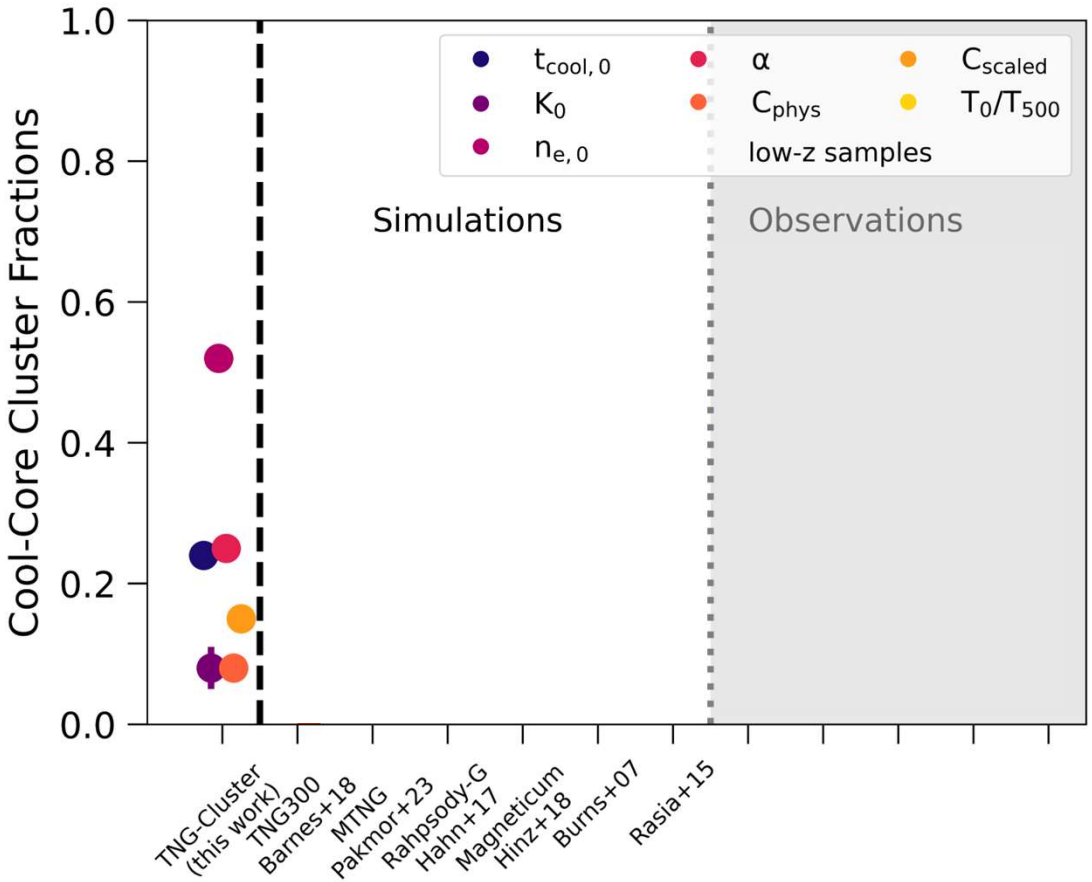
TNG-Clusters produces realistic cool-core fractions.



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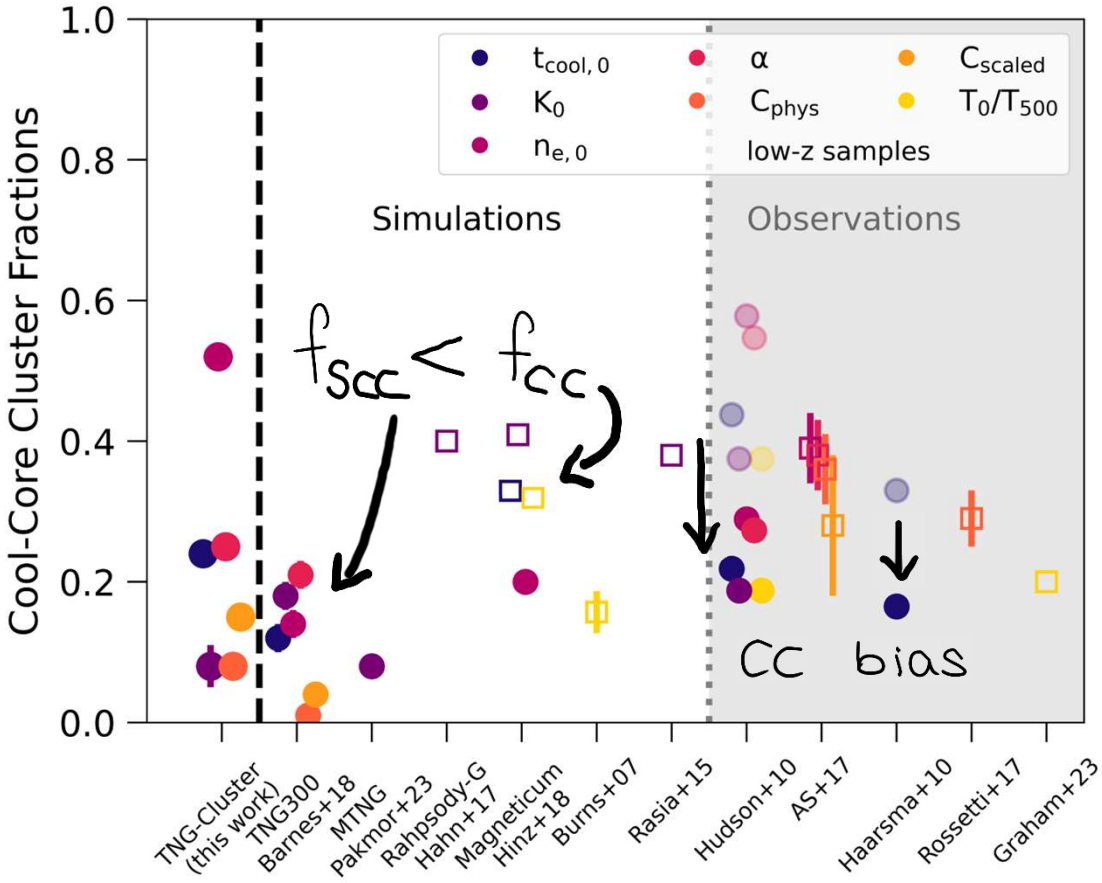

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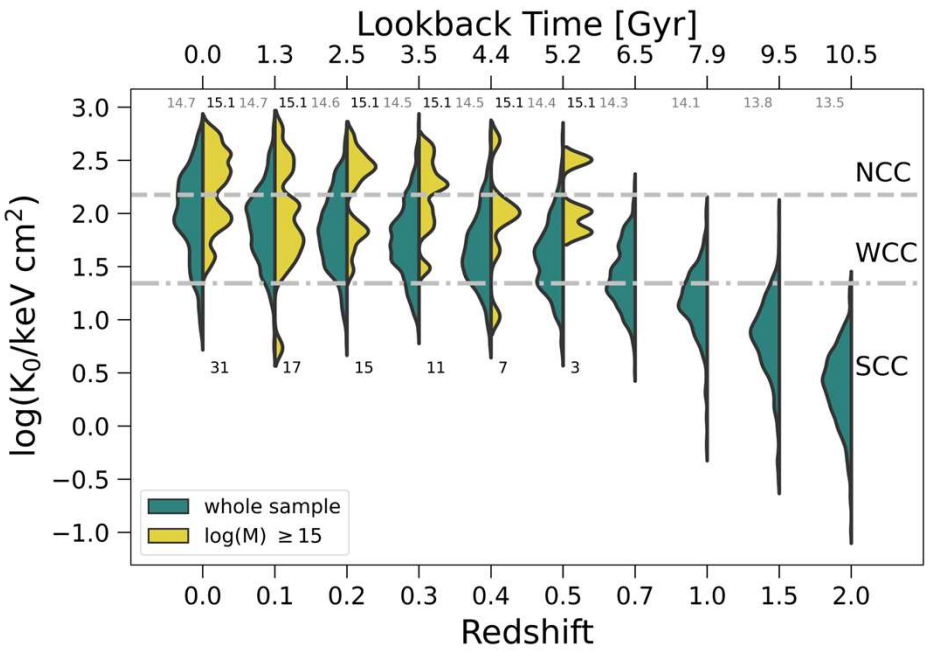
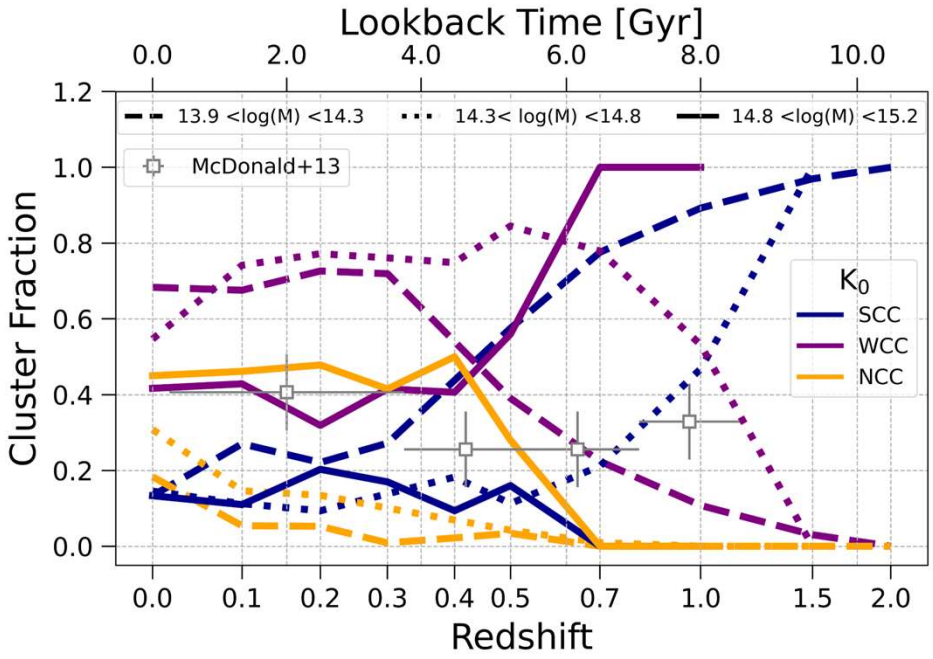
In the high-mass sample core properties are preserved on long timescales.





The evolution of the whole population is set by the **decrease in sample mass**, while we observe **weak core evolution**, in the high mass bin.

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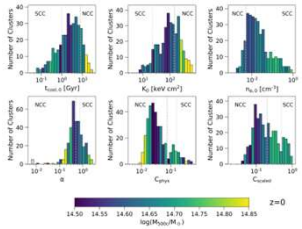
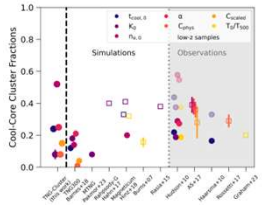
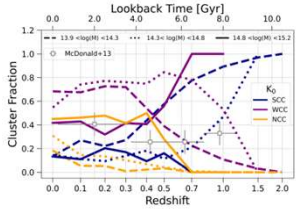
Main statements addressed in this talk:



→ TNG-Cluster produces a variety of CCs and NCCs across epochs.



→ At face-value, the CC population is comparable to observations at z=0 and higher redshift.

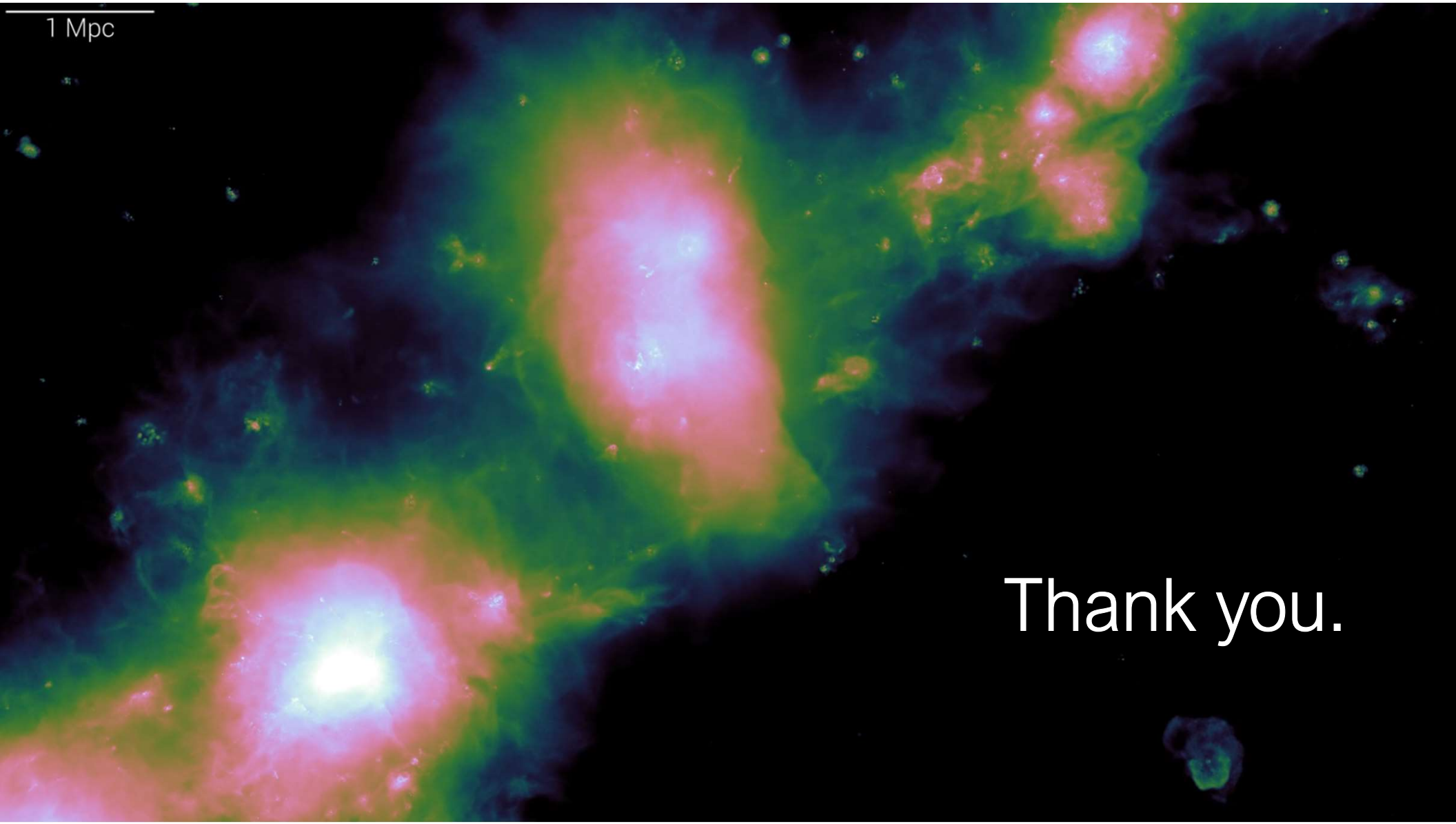


→ CC fractions of the most massive halos show weak redshift evolution.

Next step: We study transformations of clusters and the drivers of these transformations

More broadly:

The TNG-Cluster simulations are realistic, diverse, and highly resolved enough to interpret many existing observations and predict upcoming X-ray observations.


1 Mpc
Thank you.