SSG 2023

Characterizing the Spatial Extent of Protoclusters

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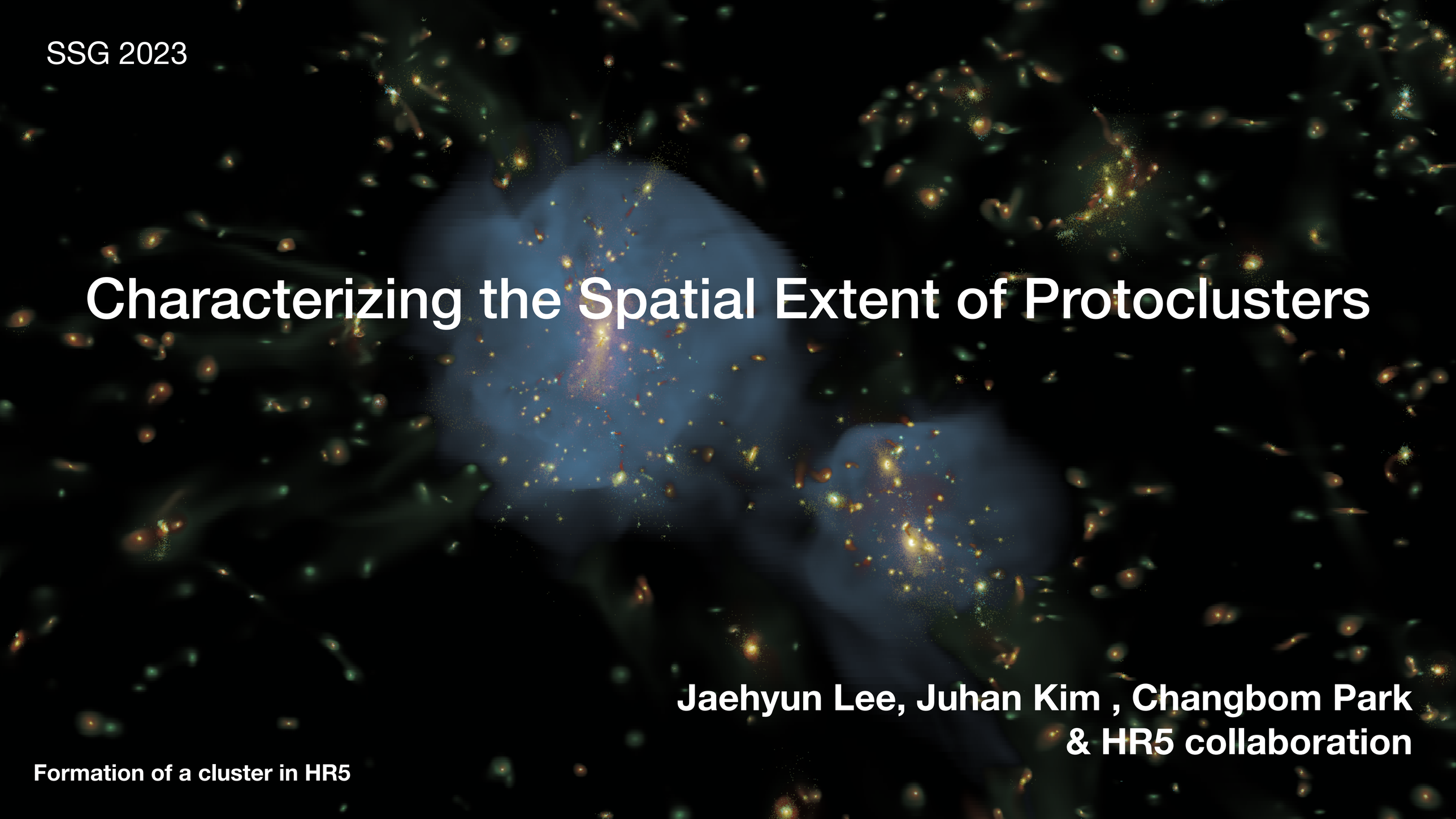
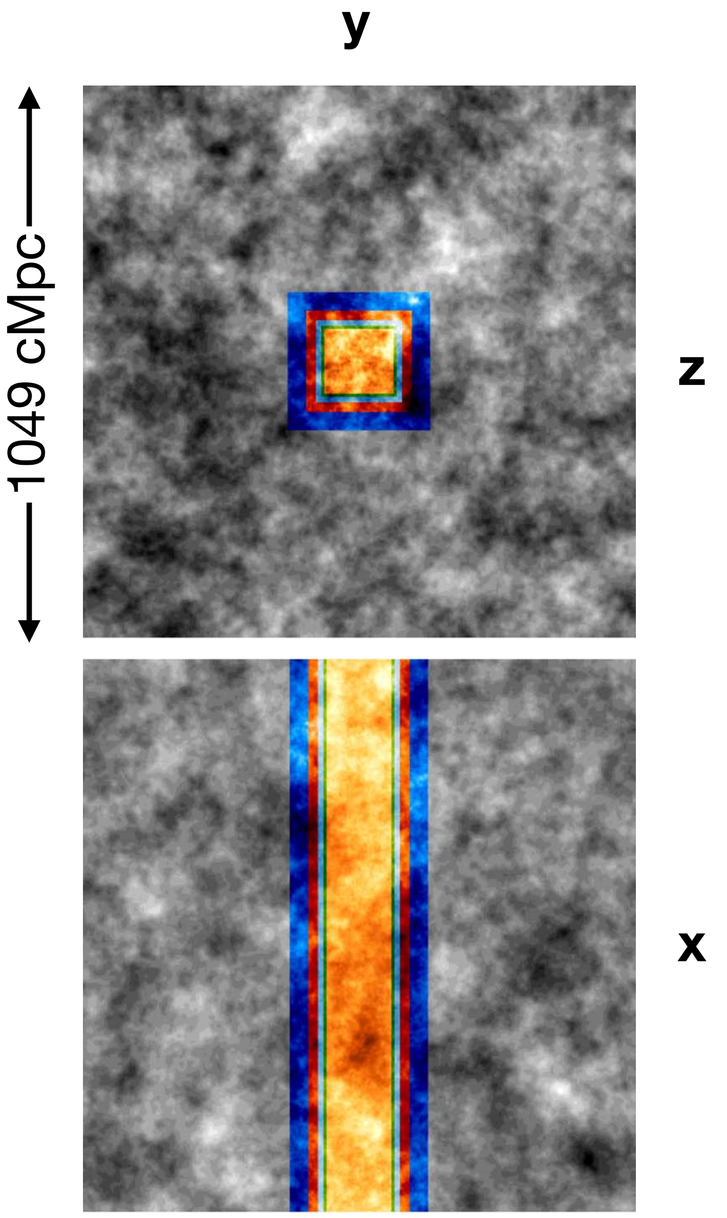
& HR5 collaboration



Formation of a cluster in HR5

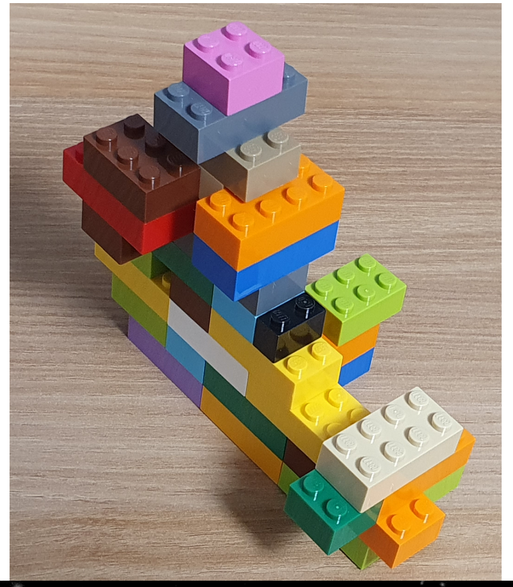
- What is a protocluster?
  - In theory- the group of structures that will collapse into a galaxy cluster
  - In observation - the region sufficiently overdense compared to surroundings
    - But, cluster progenitors are distributed over ~20-50 cMpc (e.g., Chiang+13, Muldrew+15)
      - Most progenitors are inevitably missing in the cores
- Main goal of this study
  - Finding a characteristic extent of protoclusters
  - Investigating the destination of protocluster galaxies

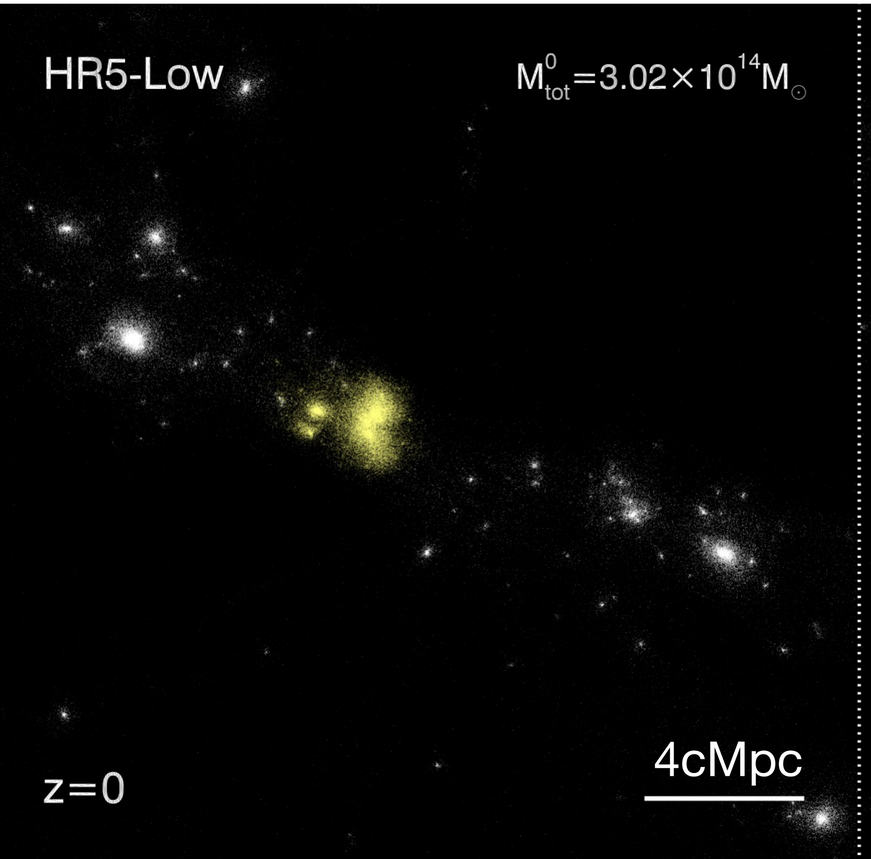
- Horizon Run 5 (HR5)
  - Adaptive Mesh Refinement code, **RAMSES** (Teyssier02, Dubois+14),
    - Optimized for MPI+OMP hybrid computing for **Nurion** at KISTI
  - Simulation box
    - Volume - $(1049\ \mathrm{cMpc})^3$
    - Zoomed region - $1049\times119\times127\ \mathrm{cMpc}^3$ (~1/80 of the entire volume), effectively ~ $(250\mathrm{cMpc})^3$
    - Resolution - down to 1pkpc in the zoomed region
    - Final snapshot - z=0.625
  - Cosmology - h=0.684, Ω_m=0.3, Ω_Λ=0.7 (compatible with the Planck data)

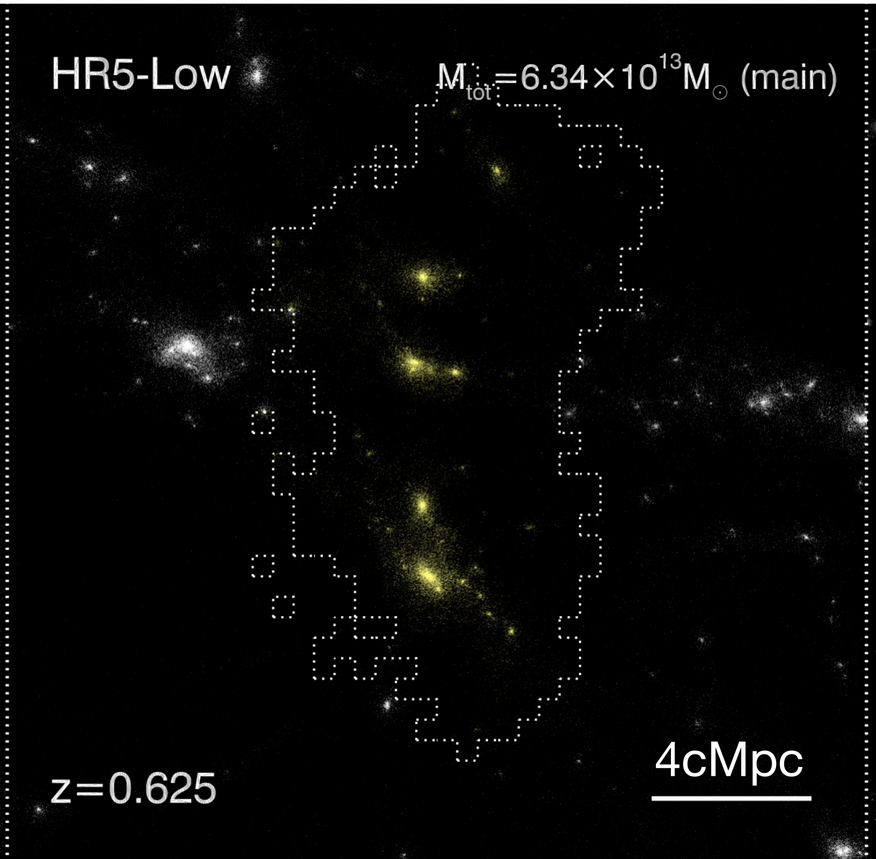


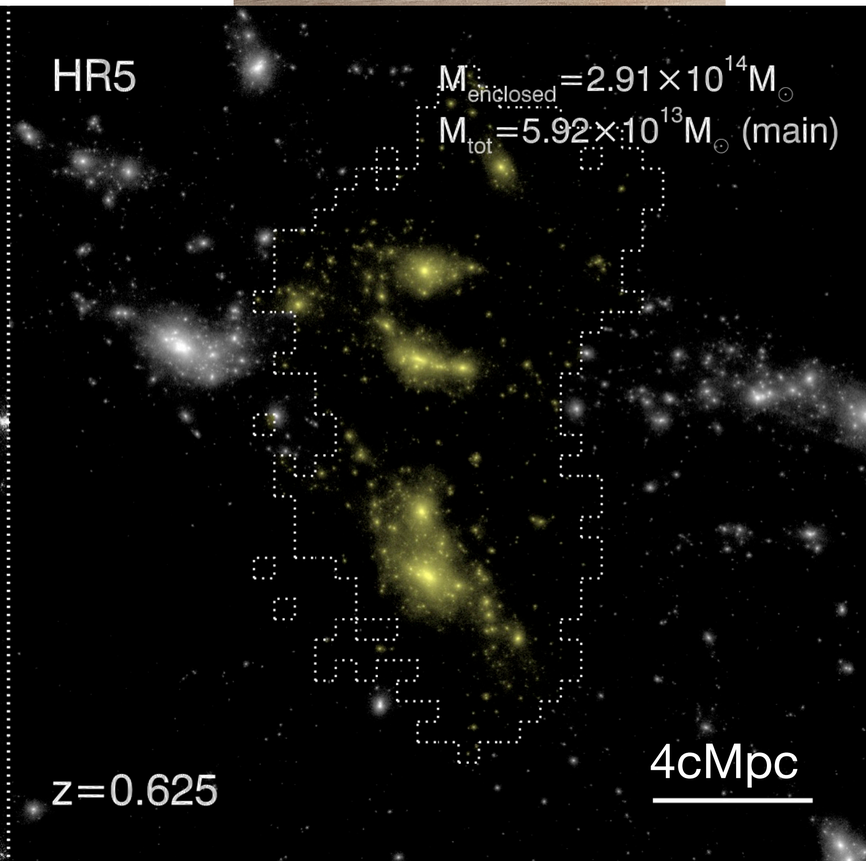
HR5 zoomed region in the initial condition (z=200)

- Identification of cluster candidates in HR5
  - Final epoch : z=0.625, t_{age}=7.7 Gyr - many structures are underdeveloped yet (~60 clusters of $M_{tot}>10^{14}M_{\odot}$ identified)
  - Running HR5-Low simulation based on the initial condition of HR5 with Δx_{min}=16 kpc, down to z=0. ~190 clusters are identified at z=0

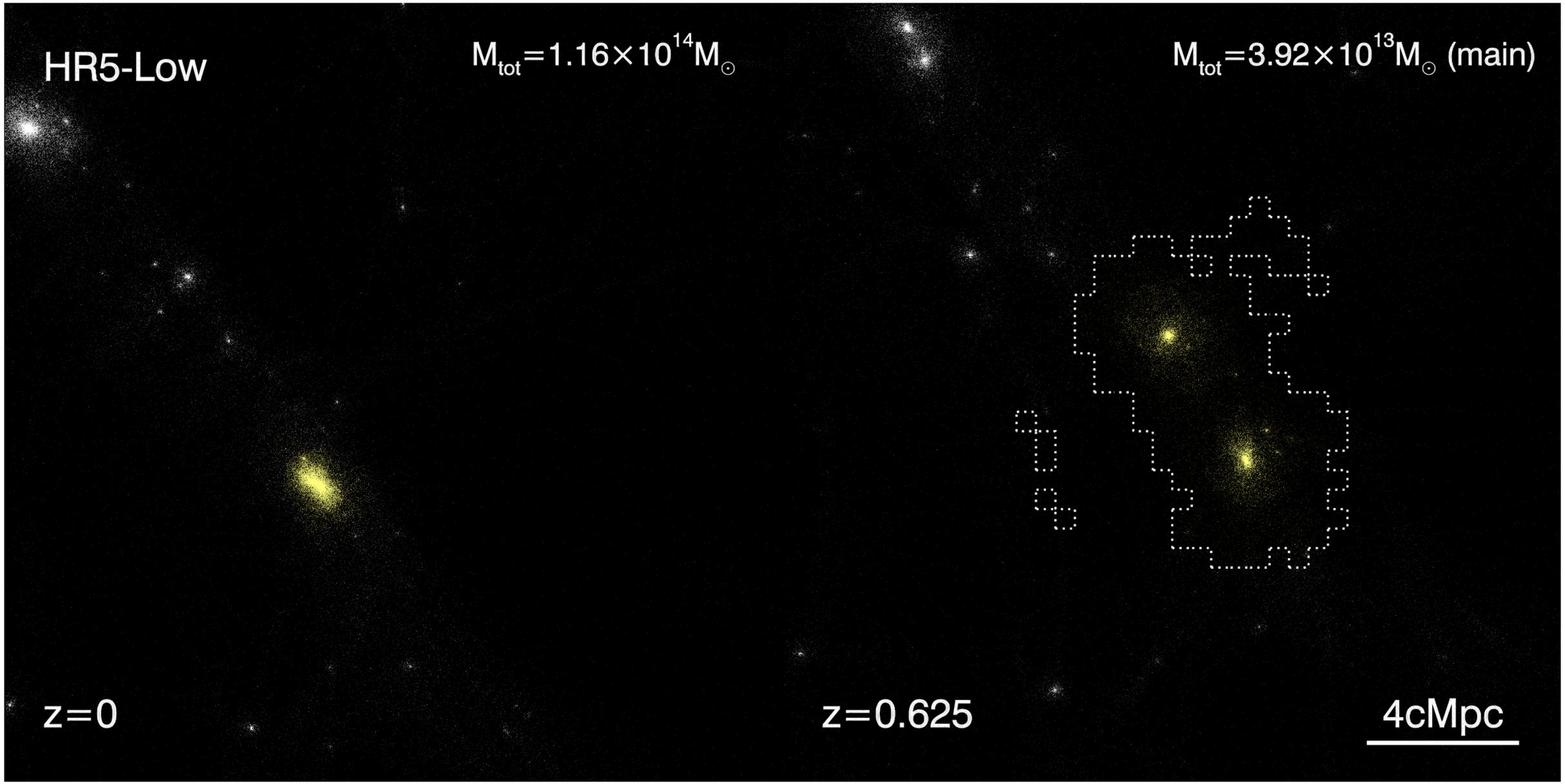




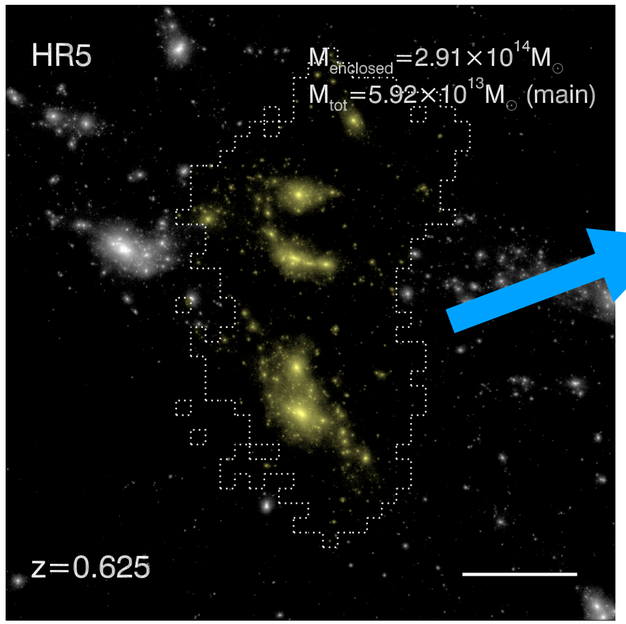


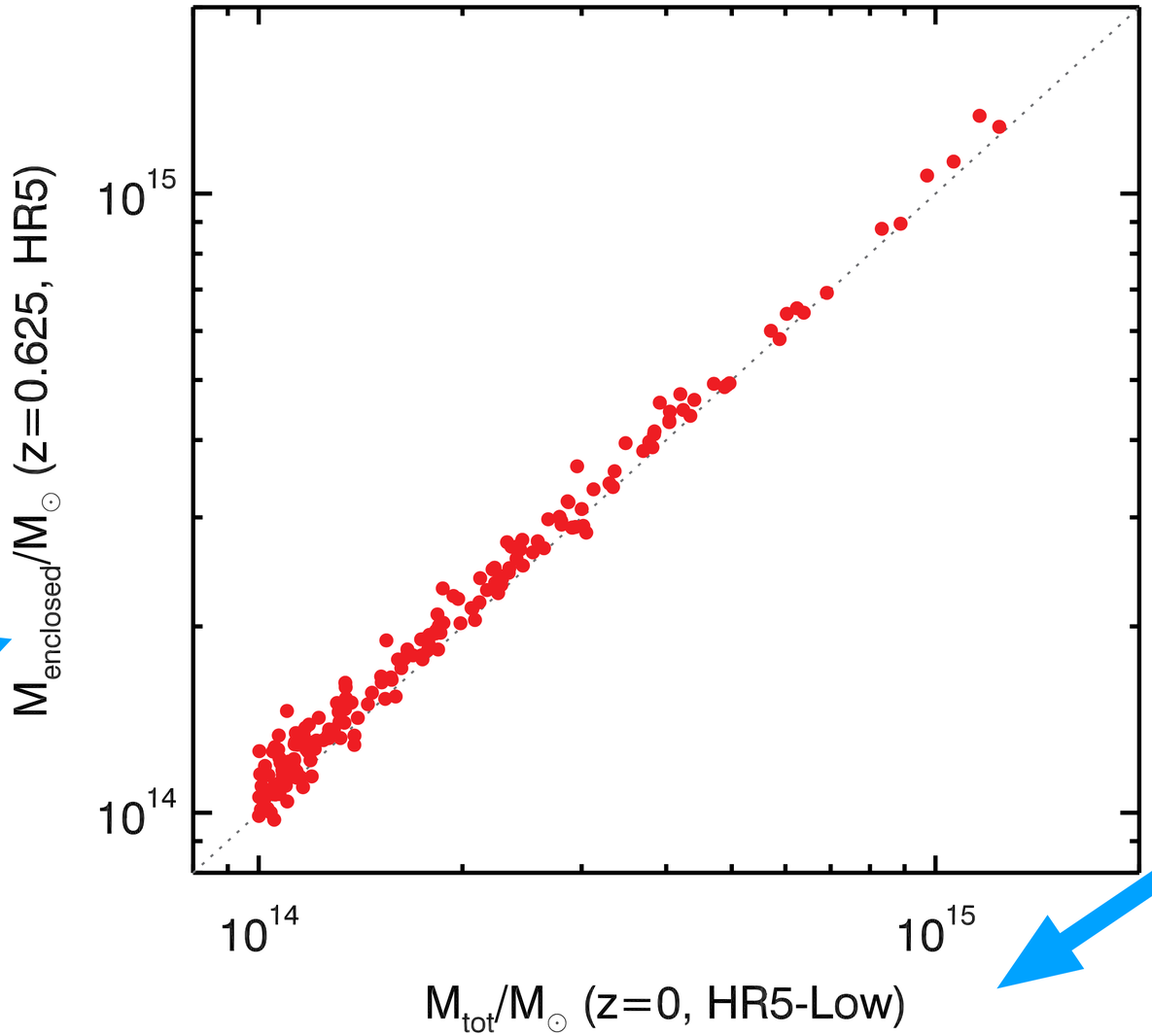


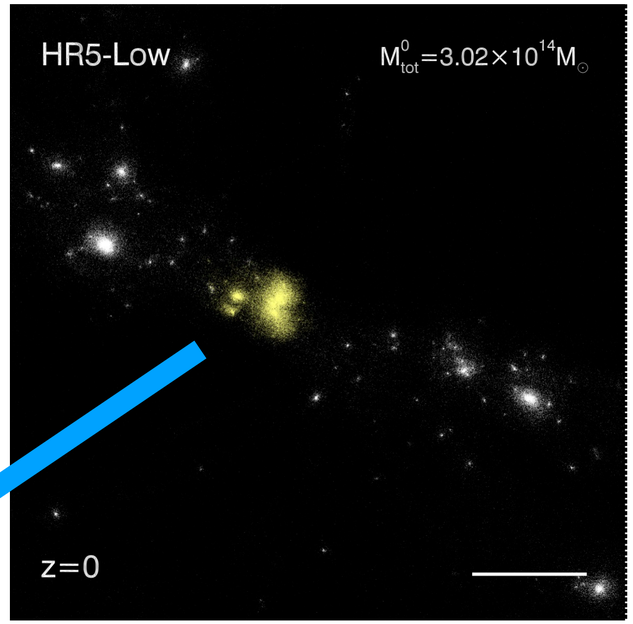
- Cluster candidates in HR5-Low and HR5 (3)



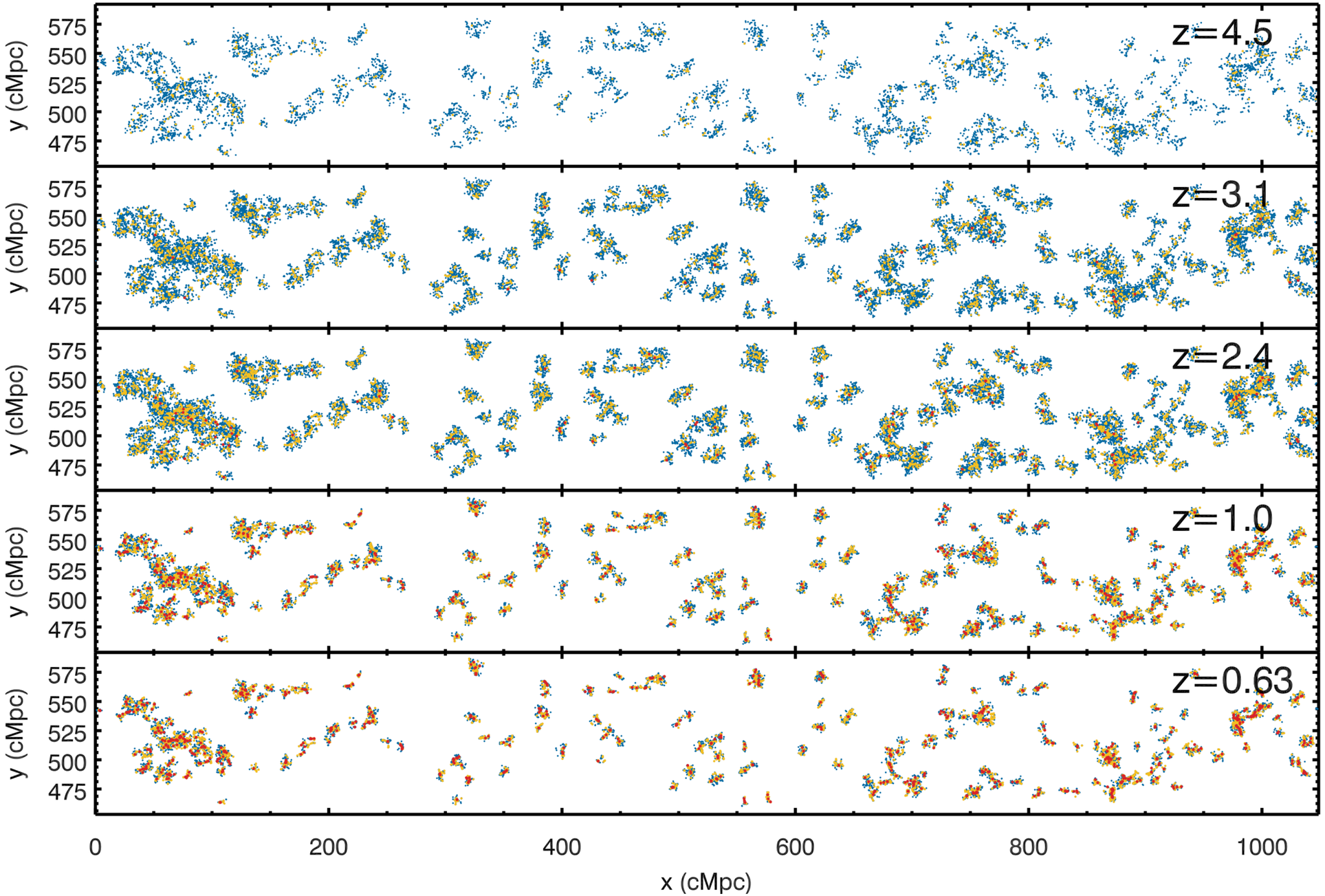
- Enclosed mass inside the grids of cluster DM particles
  - Total mass inside the grids in HR5 well agrees with the total mass of final clusters found in HR5-Low





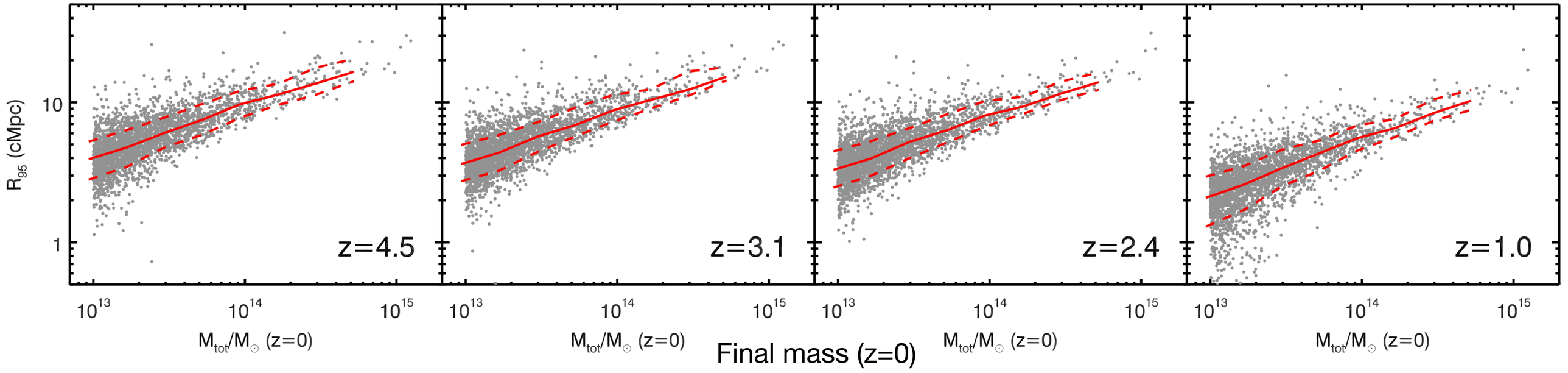


- Distribution of protocluster galaxies



log M★/M⊙= 9-10
log M★/M⊙=10-11
log M★/M⊙=11-12

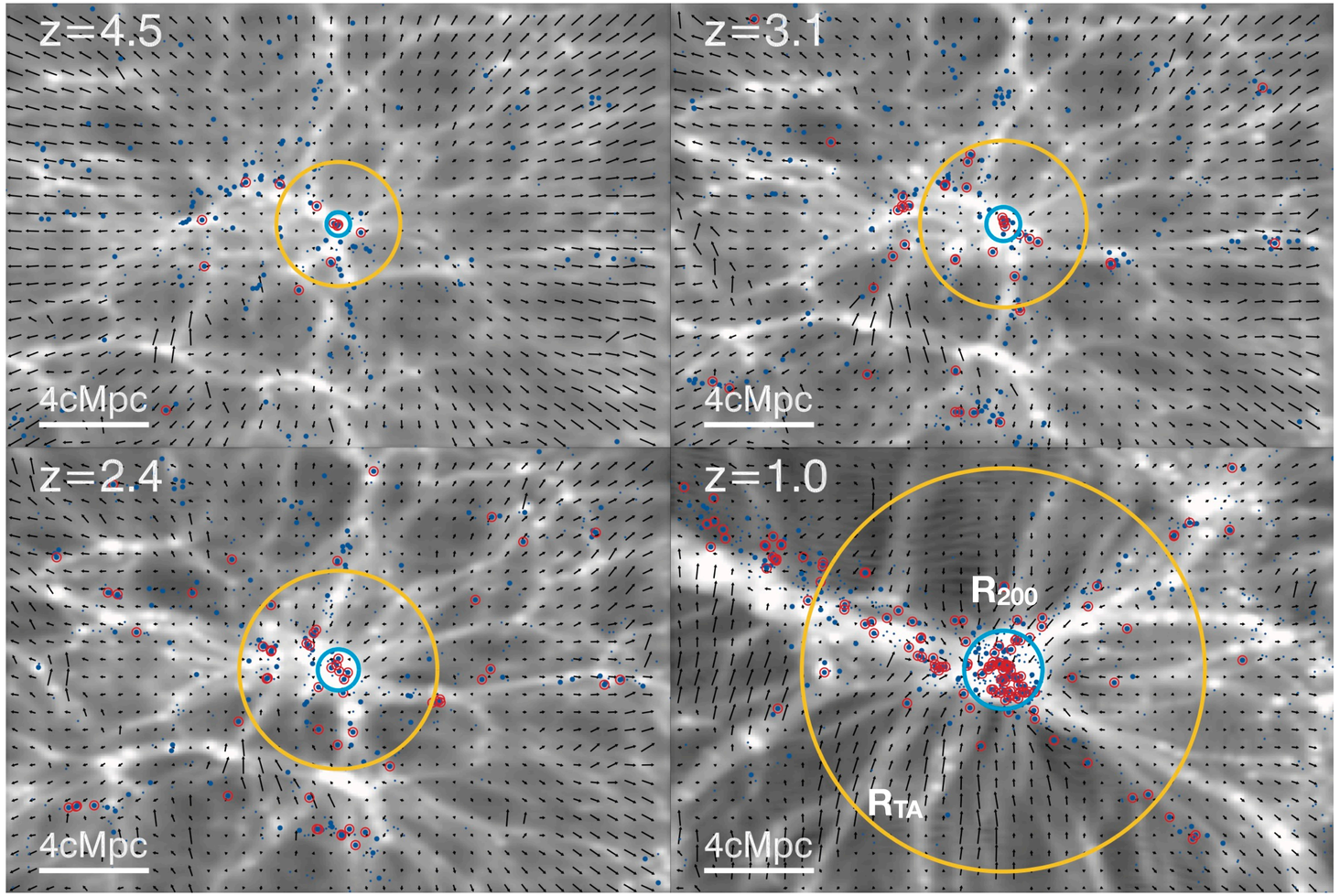
- Distribution of the progenitors of clusters
  - Measured using 95% radius of galaxy stellar mass
  - Ranging from 10cMpc up to 30cMpc
    - Too large for the progenitors to be bound to each other.
    - Virial radius only encloses very central region of protoclusters.
    - New definition is required to characterize the extent of protoclusters



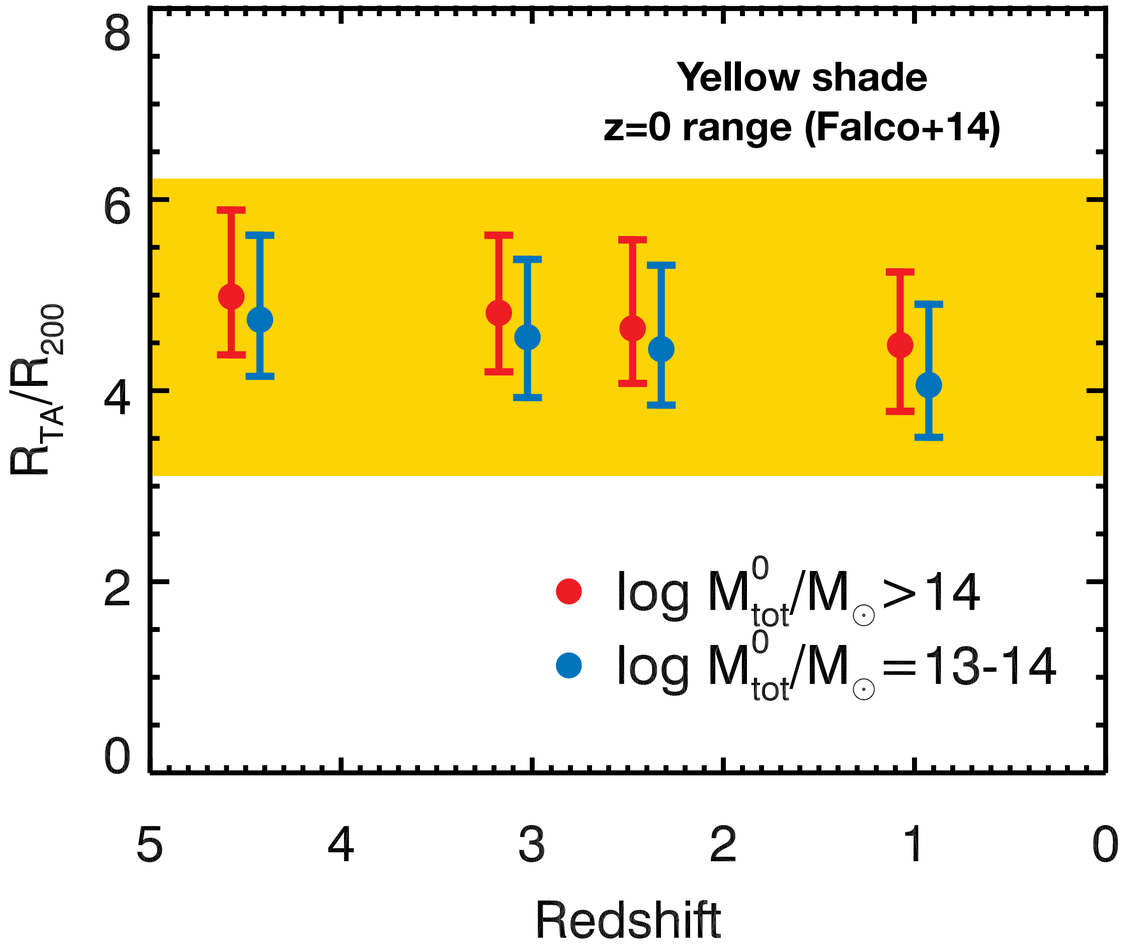
- Turnaround radius (R_{TA}) - the characteristic extent of protoclusters

  - Distance to the surface on which gravitational collapse counterbalances the Hubble flow

  - Measured from the velocity and density fields of entire matter (DM, gas, star)



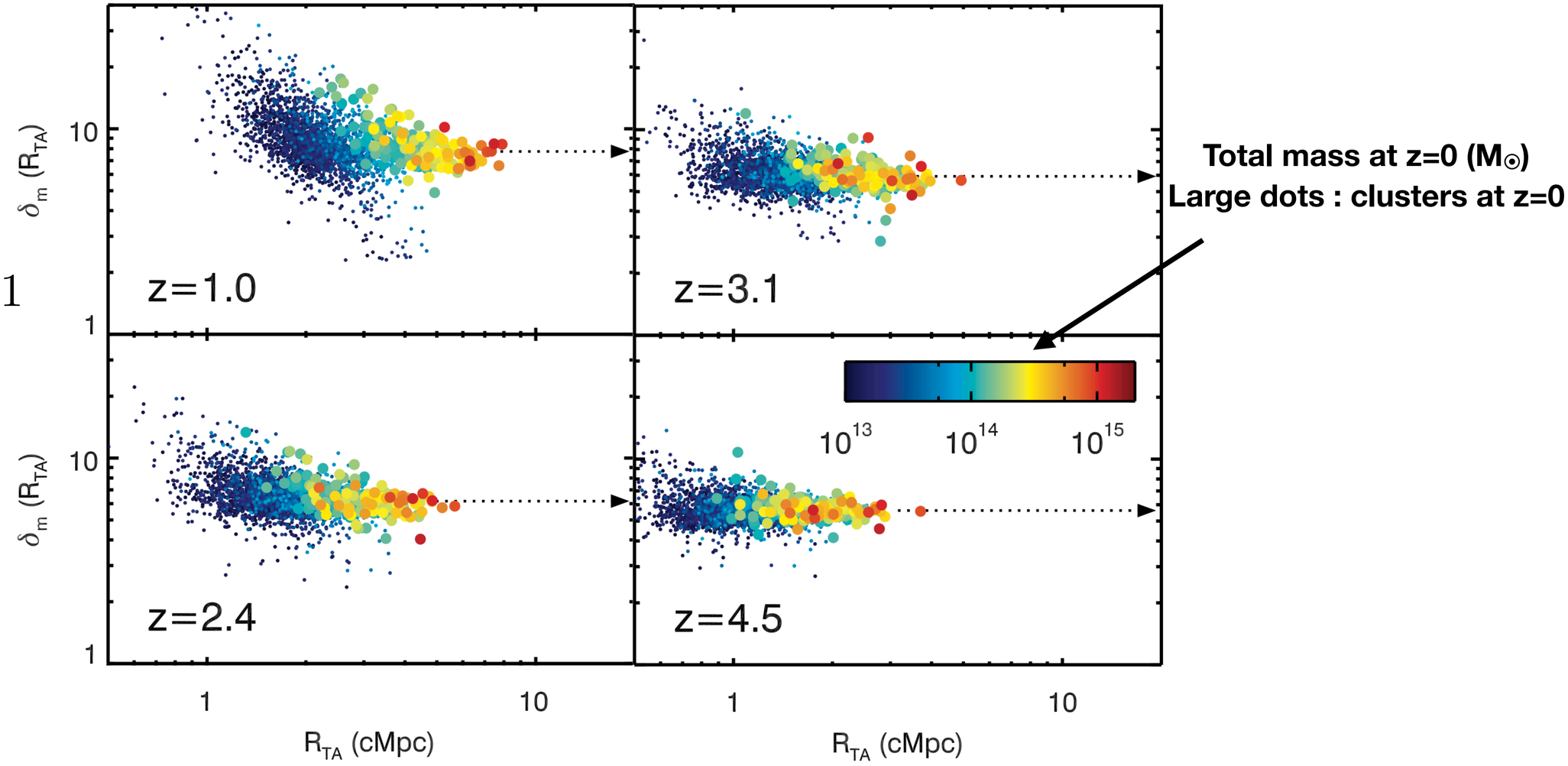
- Turnaround radius to M_{200} relation
  - The turnaround radius is closely connected to R_{200}
  - R_{TA}/R_{200} ~3-6 at z=0 (Falco+14) and the range of the radius ratio weakly evolves with increasing redshift



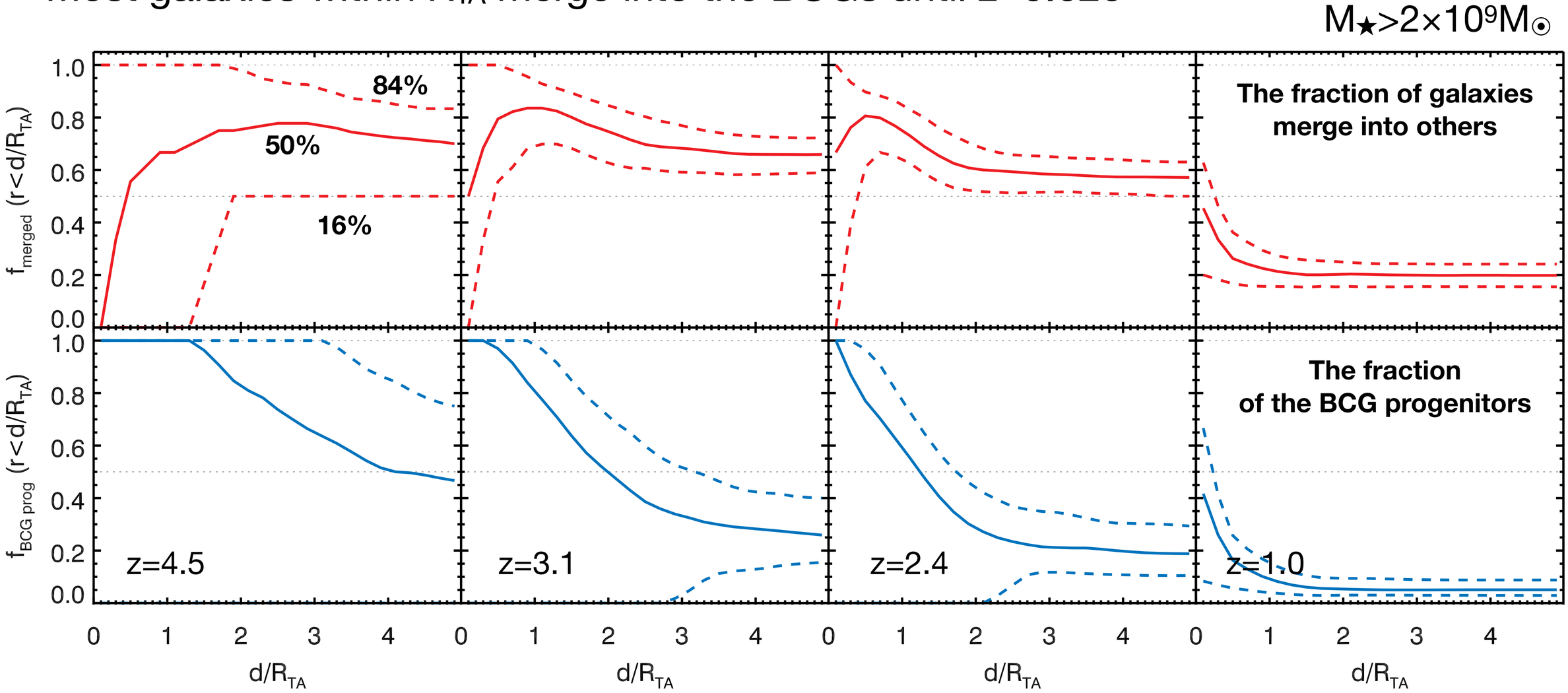
- Matter overdensity inside R_{TA}
  - Matter overdensity is almost constant within R_{TA}
  - Neighboring structures disturb R_{TA}, resulting in the scatter at low z

Overdensity

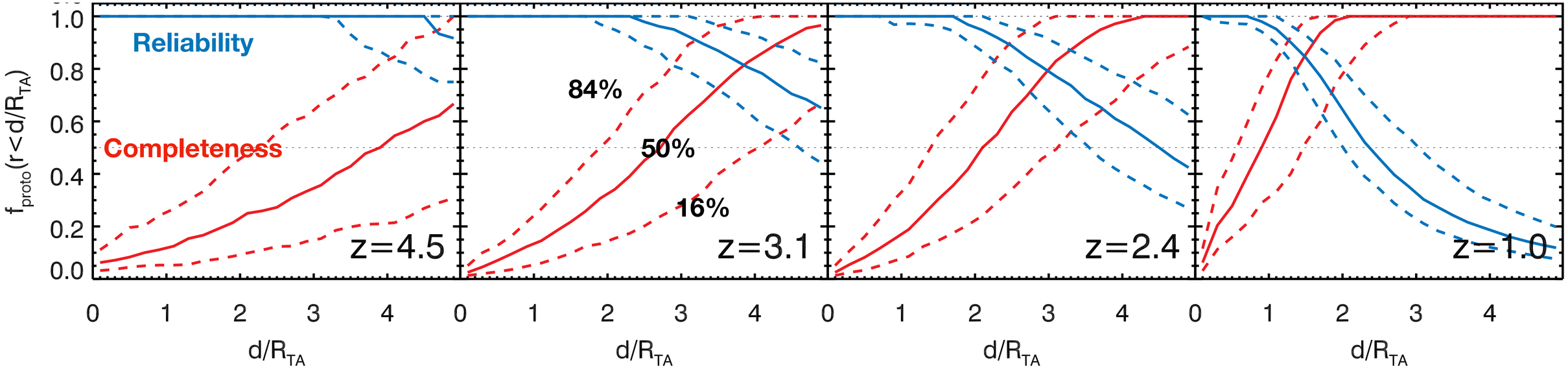
$$\delta_m \equiv \rho_m / \bar{\rho}_m - 1$$



- Fate of Protocluster galaxies as a function of R_{TA}
  - Majority of protocluster galaxies (~60% at z>2.4) merge into others until z=0.625
  - Most galaxies within R_{TA} merge into the BCGs until z=0.625



- Reliability and completeness of protocluster galaxies as a function of R_{TA}
  - ~60% of cluster progenitors are located within $5R_{TA}$ with >90% reliability
  - ~80% of galaxies within $4R_{TA}$ and $3R_{TA}$ are actual protocluster galaxies at z~3.1 and 2.4 with ~80% completeness



- Summary & Future work
  - ~190 cluster-candidates are identified at z=0.625 in HR5 using HR5-Low
  - Protocluster galaxies are distributed over the spherical regions of r~10-30 cMpc
  - We suggest the turnaround radius as the characteristic radius of protoclusters
  - Matter overdensity stays almost constant within R_{TA}
  - 60% of protocluster galaxies at z>2.4 merge into others until z~0.625
  - Most (~80%) galaxies within R_{TA} merge into the progenitors of the BCGs
  - Galaxies within $3R_{TA}$ are actual protocluster galaxies with >80% reliability at z>2.4