z= 180.40

Searching for Proto-clusters in HR5

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& HR5 collaboration

3 cMpc

Formation of a cluster in HR5

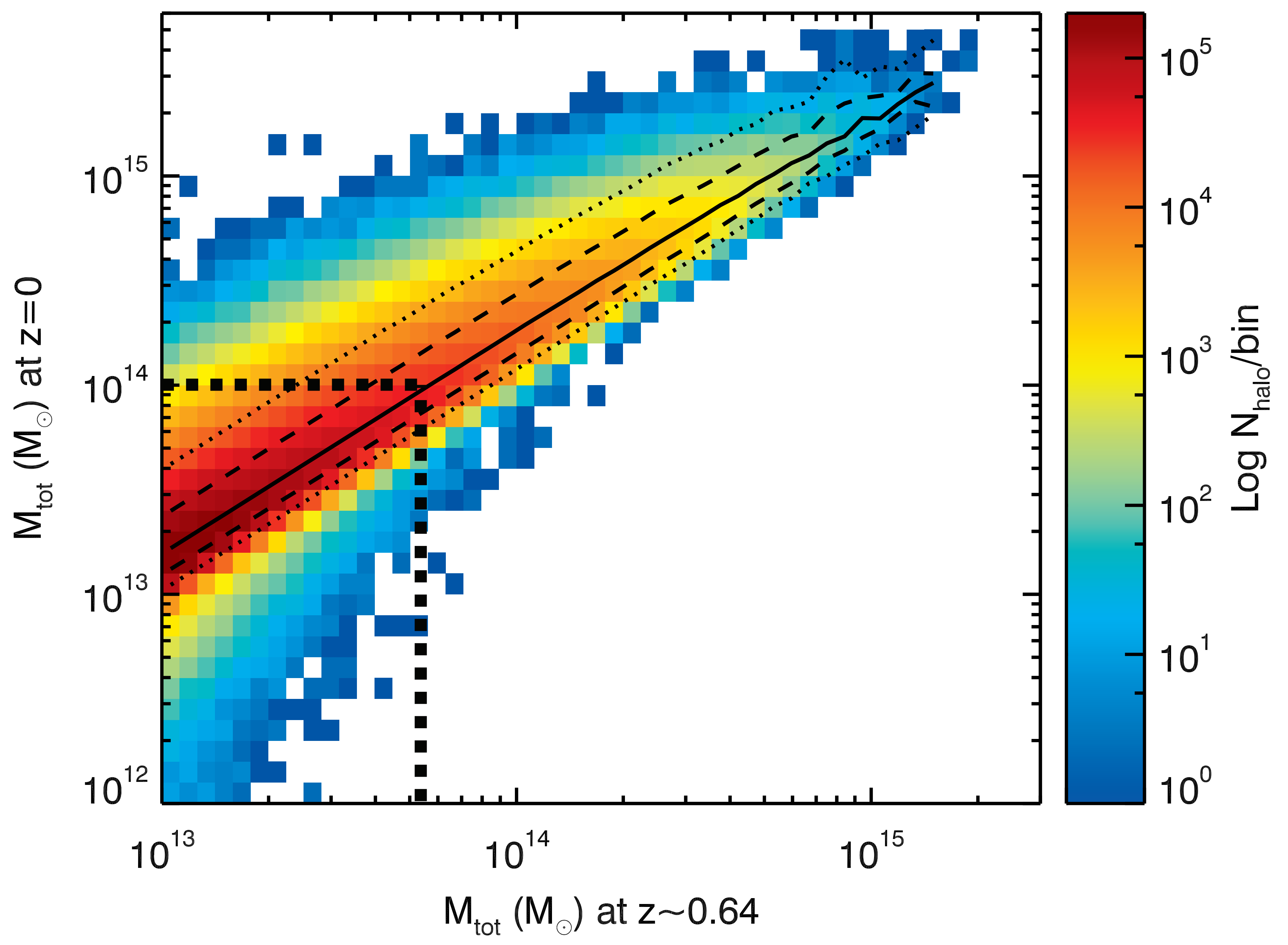
- What are proto-clusters?
  - In theory - A structure that will collapse into a galaxy cluster
    - Valid only when progenitors/descendants are able to be traced
  - In observations - A structure that is sufficiently overdense compared to surroundings
    - Progenitors that have not developed density peaks yet can be missed

- Main aim of this study
    - Investigating (physically) a robust definition of a proto-cluster region
    - Finding relevant tracers of proto-clusters, to support observational studies
    - Providing theoretical predictions for proto-clusters and their galaxies

- Horizon Run 5 (HR5)
  - Adaptive Mesh Refinement code, **RAMSES** (Teyssier02, Dubois+14),
    - Optimized for MPI+OMP hybrid computing by KIAS+KISTI for **Nurion** at KISTI
  - Simulation box
    - Volume - $(1049\ \mathrm{cMpc})^3$
    - Zoomed region - $1049\times115\times115\ \mathrm{cMpc}^3$ (~1/80 of the entire volume), effectively ~ $(240\mathrm{cMpc})^3$
    - Resolution - down to 1kpc in the zoomed region
    - Final snapshot - z=0.625
  - Cosmology - h=0.684, Ω_m=0.3, Ω_Λ=0.7 (compatible with Planck)
  - Outputs- snapshots, lightcone space data, and 5 cluster data with high time resolution

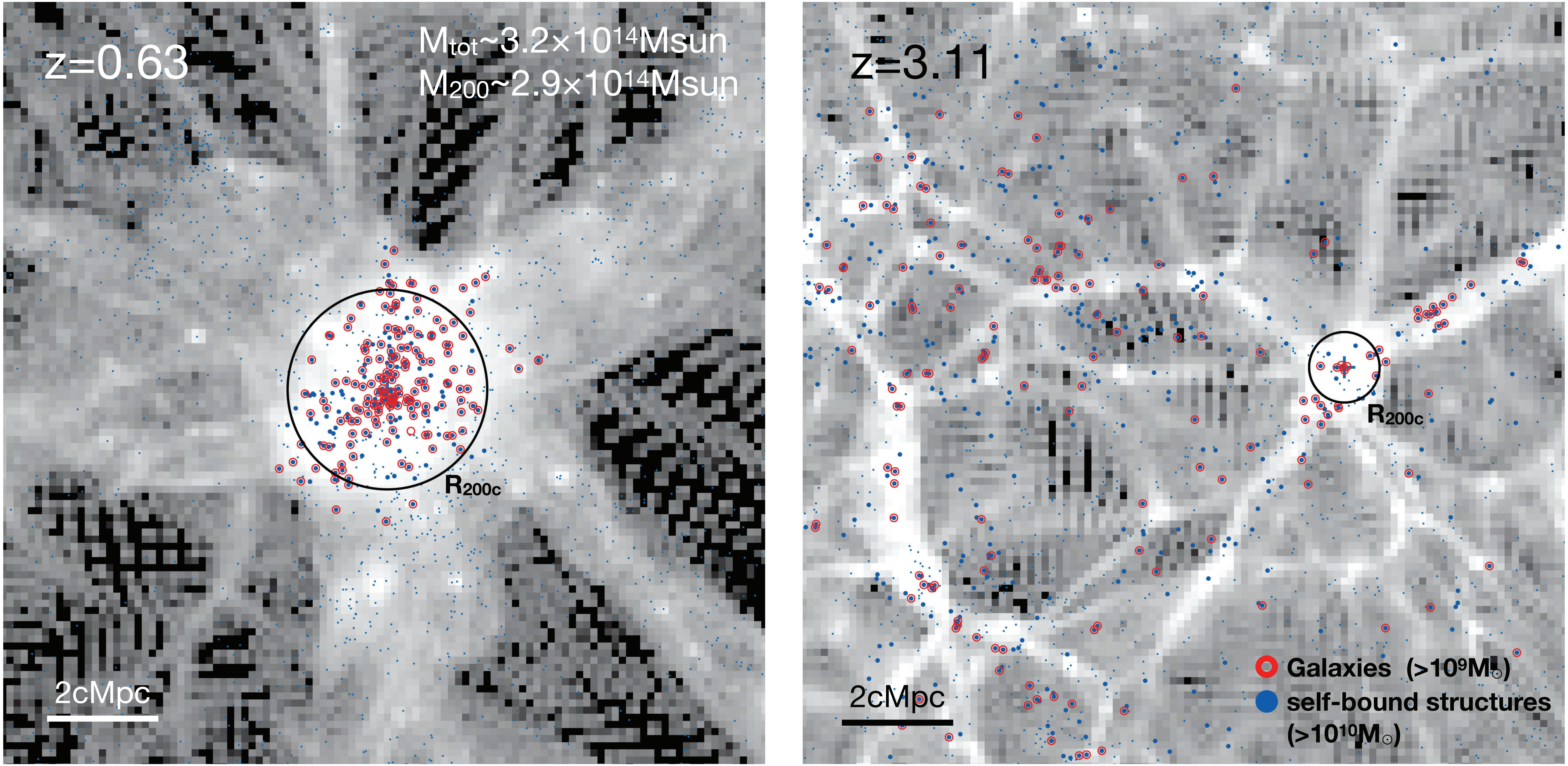
- Identifying cluster candidates in Horizon Run 5 (HR5)
  - The final snapshot of HR5 : z~0.63
  - Haloes with $M_{tot}>10^{14}M_\odot$ are defined as “galaxy clusters”
  - ~200 clusters are expected in the zoomed region of HR5 at z=0
  - In Horizon Run 4, majority of haloes with $M_{tot}>5\times10^{13}M_\odot$ at z~0.63 form cluster-scale haloes until z=0
    - In the zoomed region of HR5, 190 haloes are found in $M_{tot}>5\times10^{13}M_\odot$ at z=0.63
    - 63 haloes already reach $M_{tot}=10^{14}M_\odot$ before z~0.63
  - The progenitors of the cluster candidates are traced across the cosmic time along merger trees

The final mass of haloes at z=0.64 in Horizon Run4 (DM only)

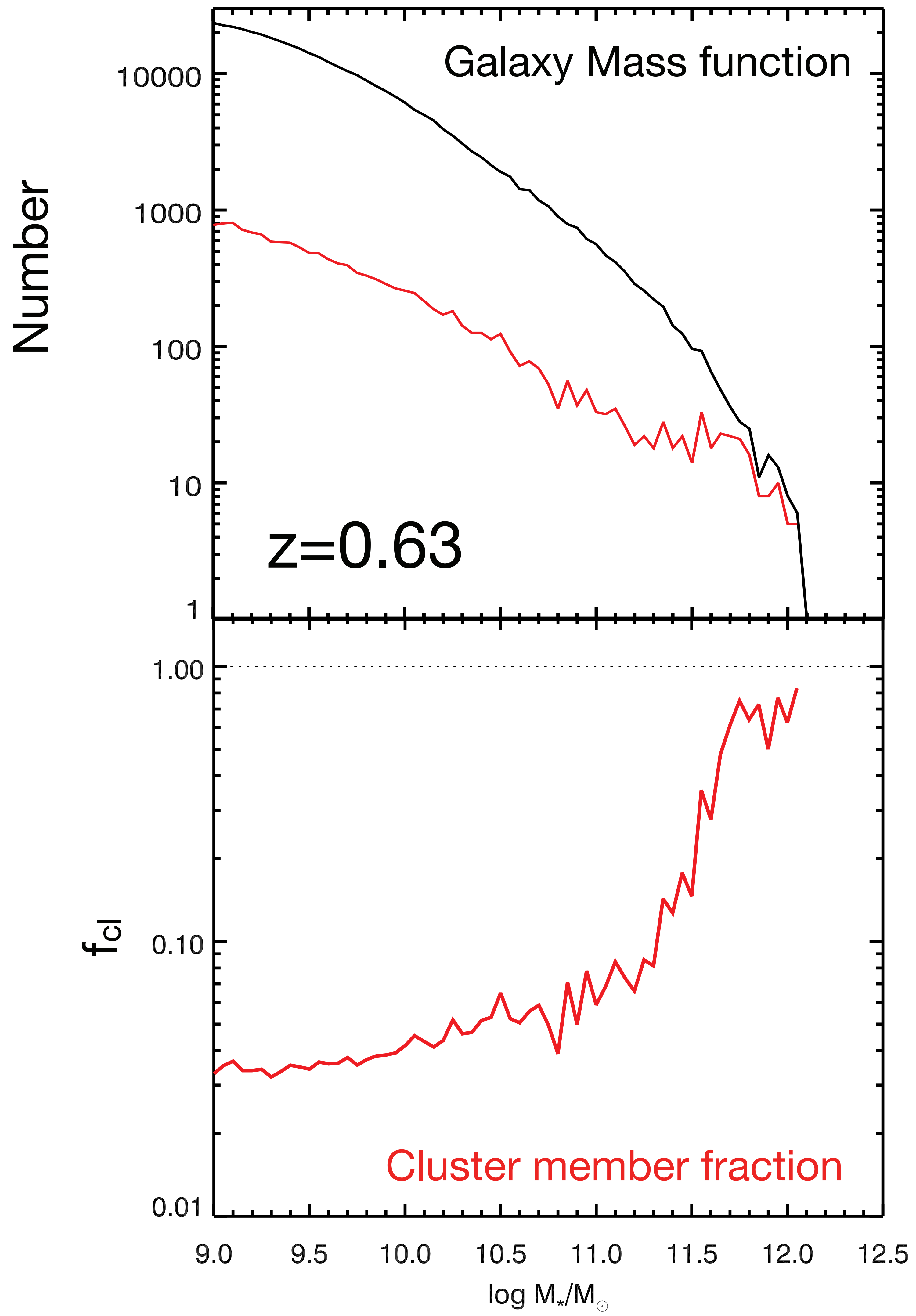


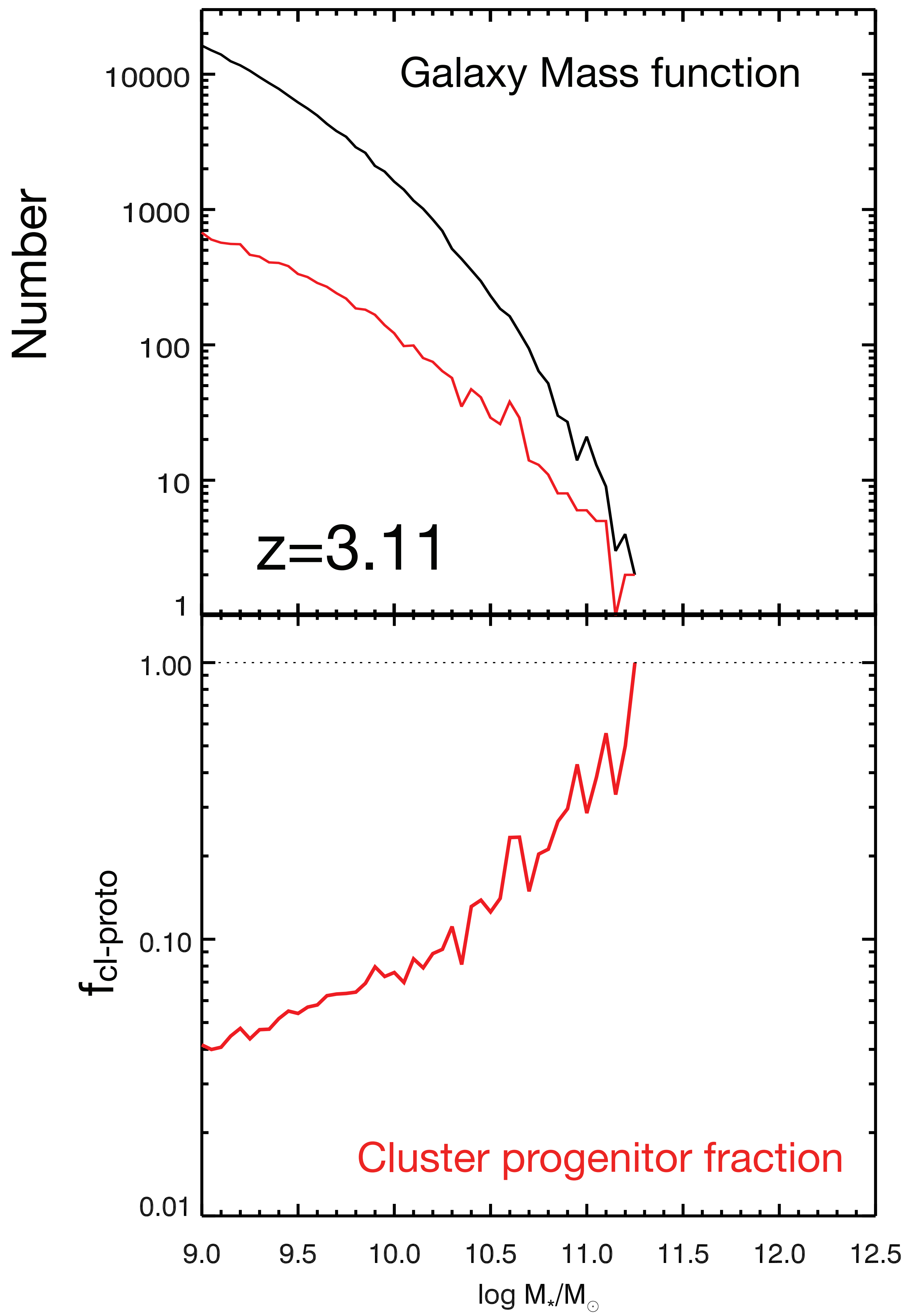
- A cluster at z=0.63 and its progenitors at z=3.11

Background shade: matter density (DM+gas+star)

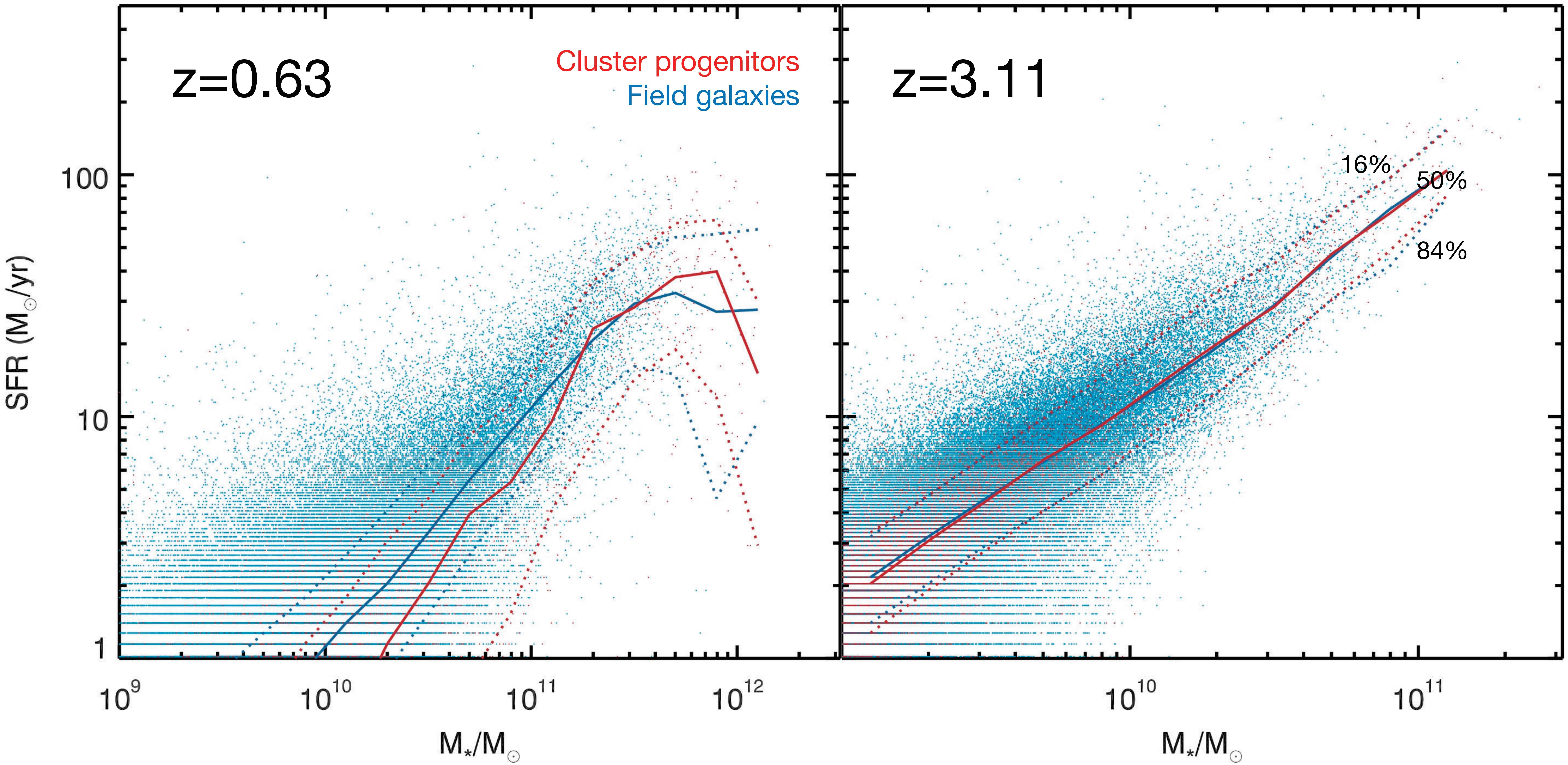


- Mass functions of cluster (progenitor) galaxies
  - Massive-end is dominated by cluster (progenitor) galaxies in the entire volume

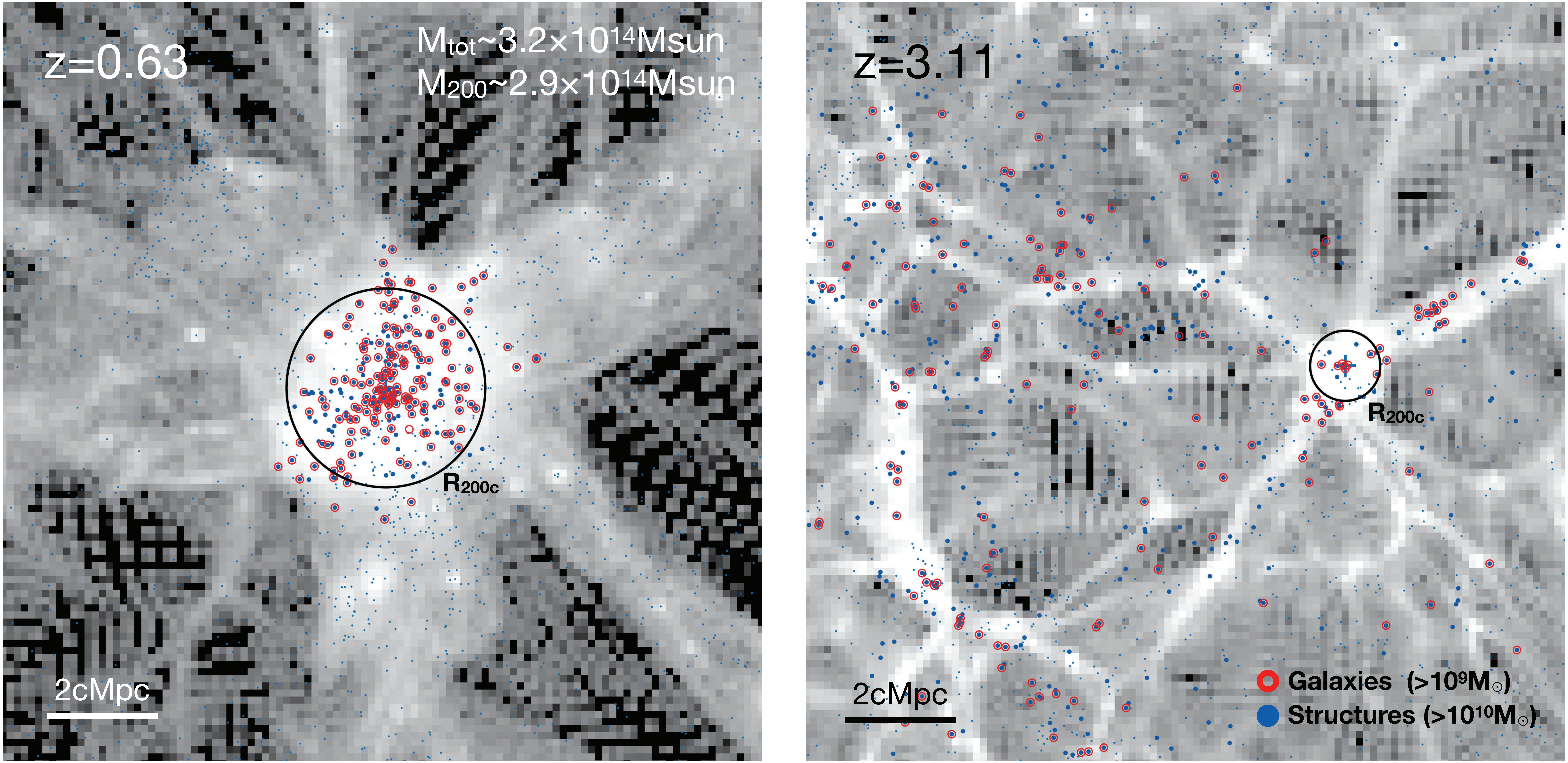




- SFR-M_* relation
  - No difference is seen between cluster progenitors and the rest at z~3.1



- Progenitors are widely distributed in varying environments at high redshifts
    - They do not necessarily represent the densest environments



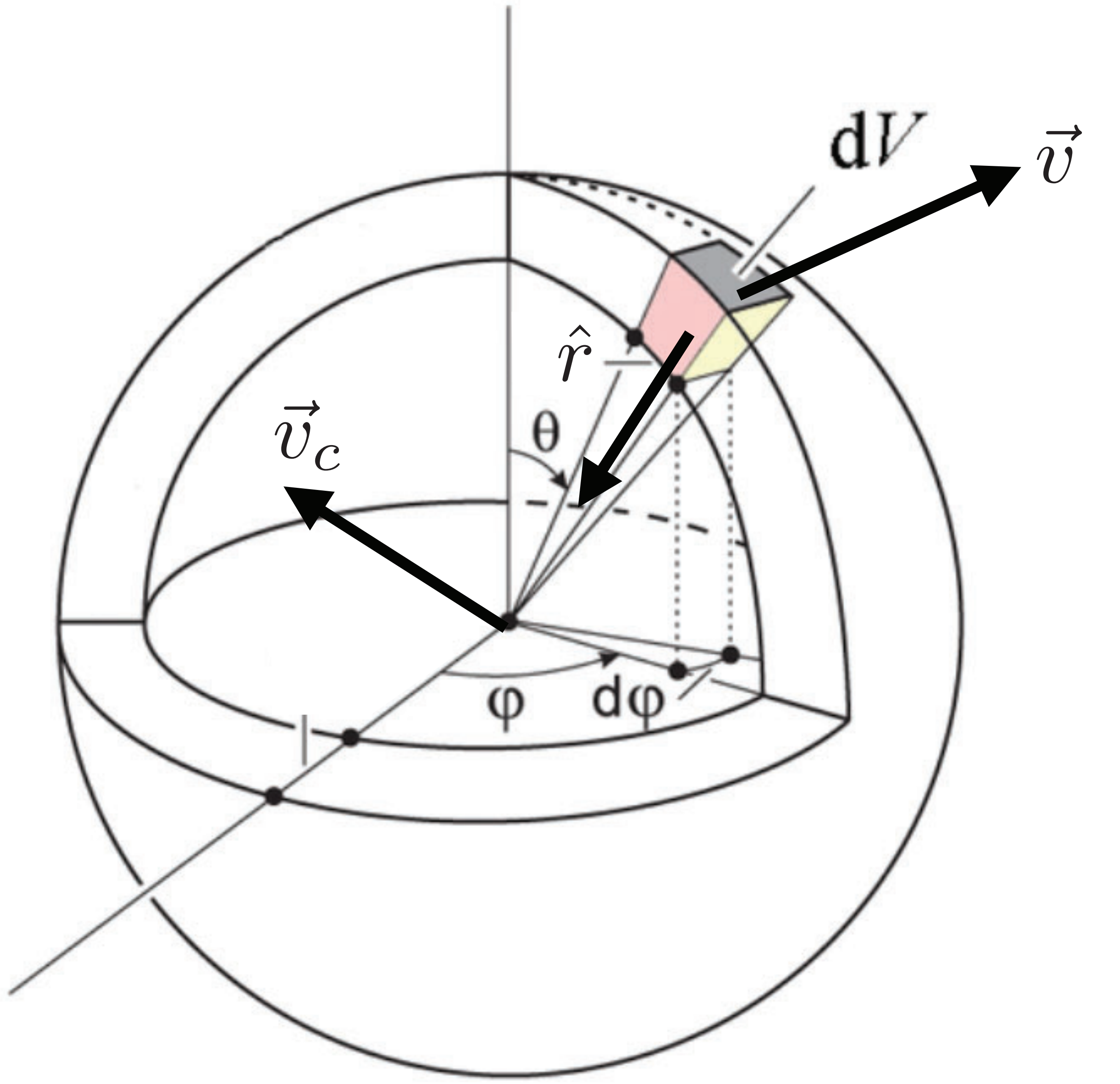
- What is the boundary of (proto-)clusters?
  - Turnaround radius - the distance from the center of a cosmic structure to the shell at which the Hubble flow counter-balances gravitational collapse (e.g. Gunn&Gott 72, Peebles 80)
  - Radial velocity is computed for spherical shells from the density peaks of (proto-)cluster regions

$$v_r = H(z)r + \hat{r} \cdot (\vec{v}_p - \vec{v}_c)$$

Hubble flow from the (proto-)cluster center

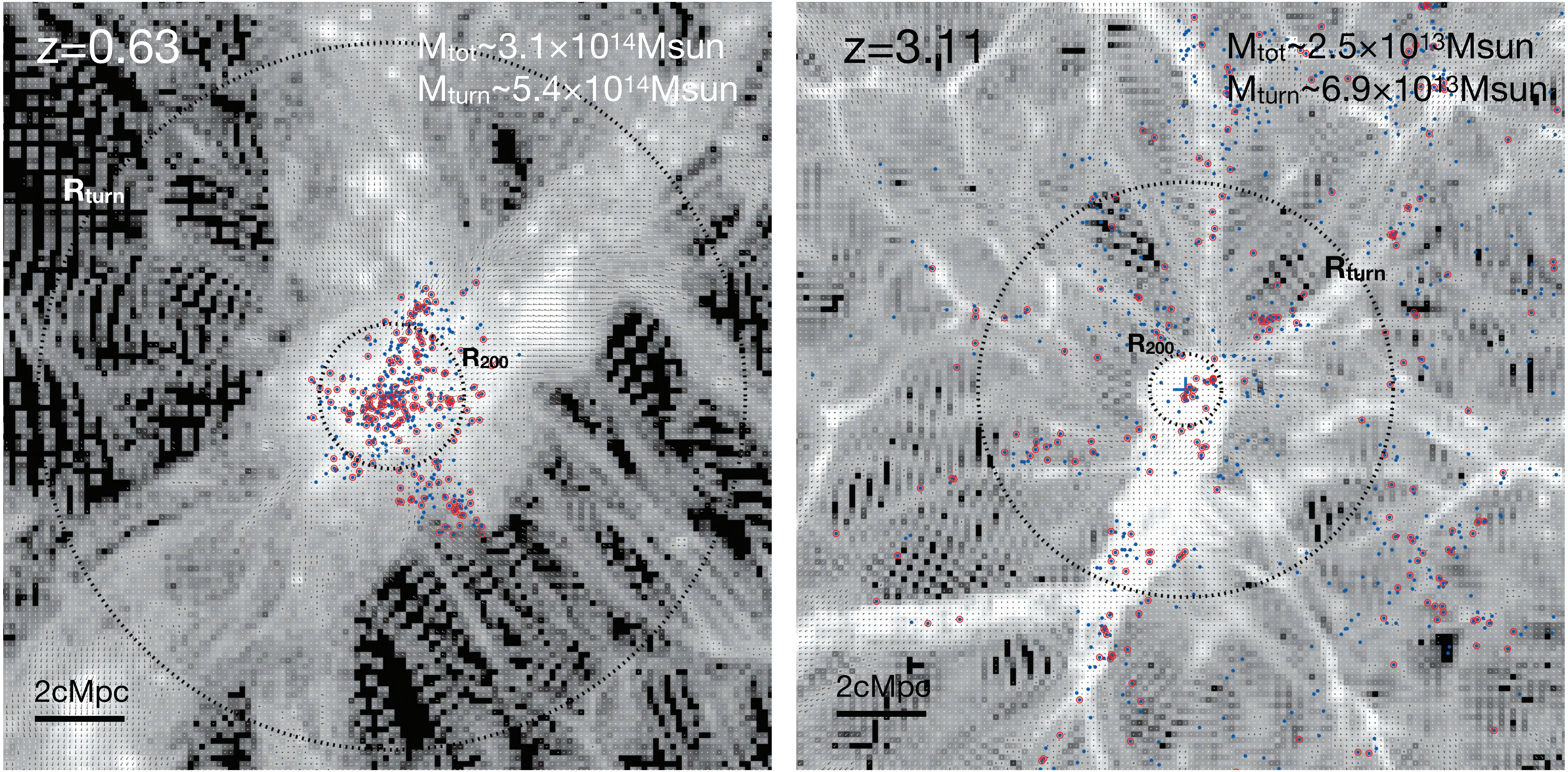
peculiar velocity

(proto-)cluster center velocity

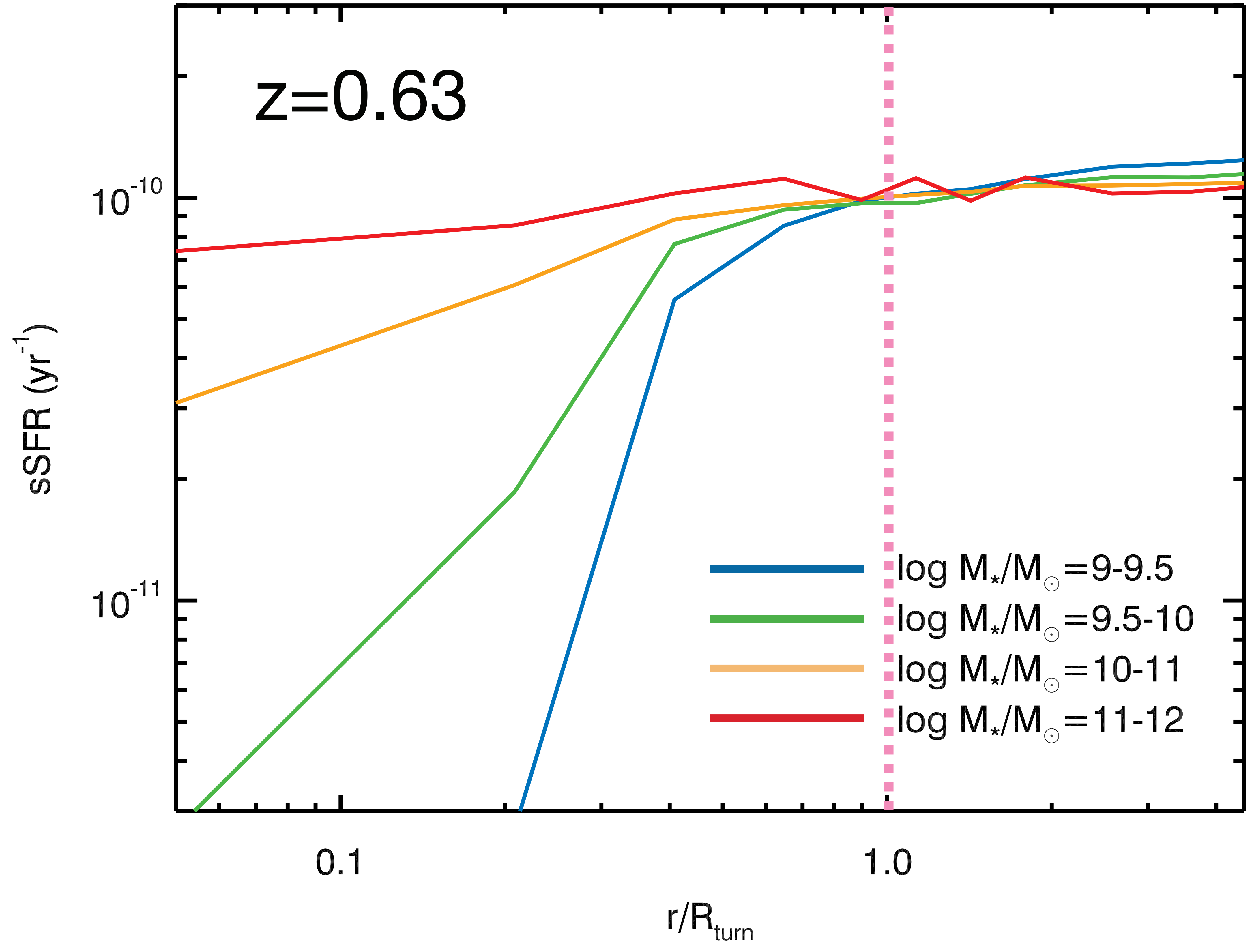


(Proto-)cluster

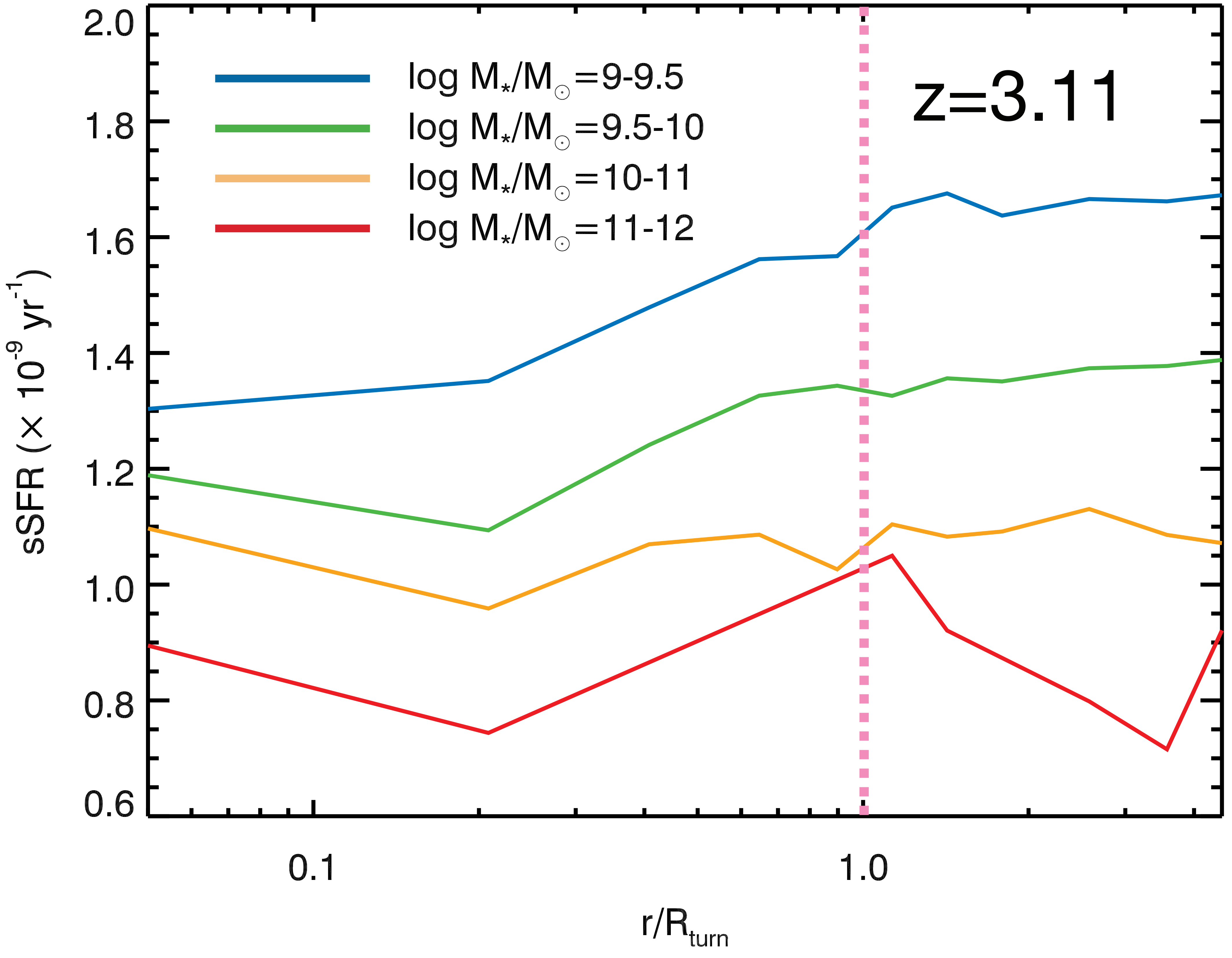
- Velocity field around (proto-)clusters and turnaround radii



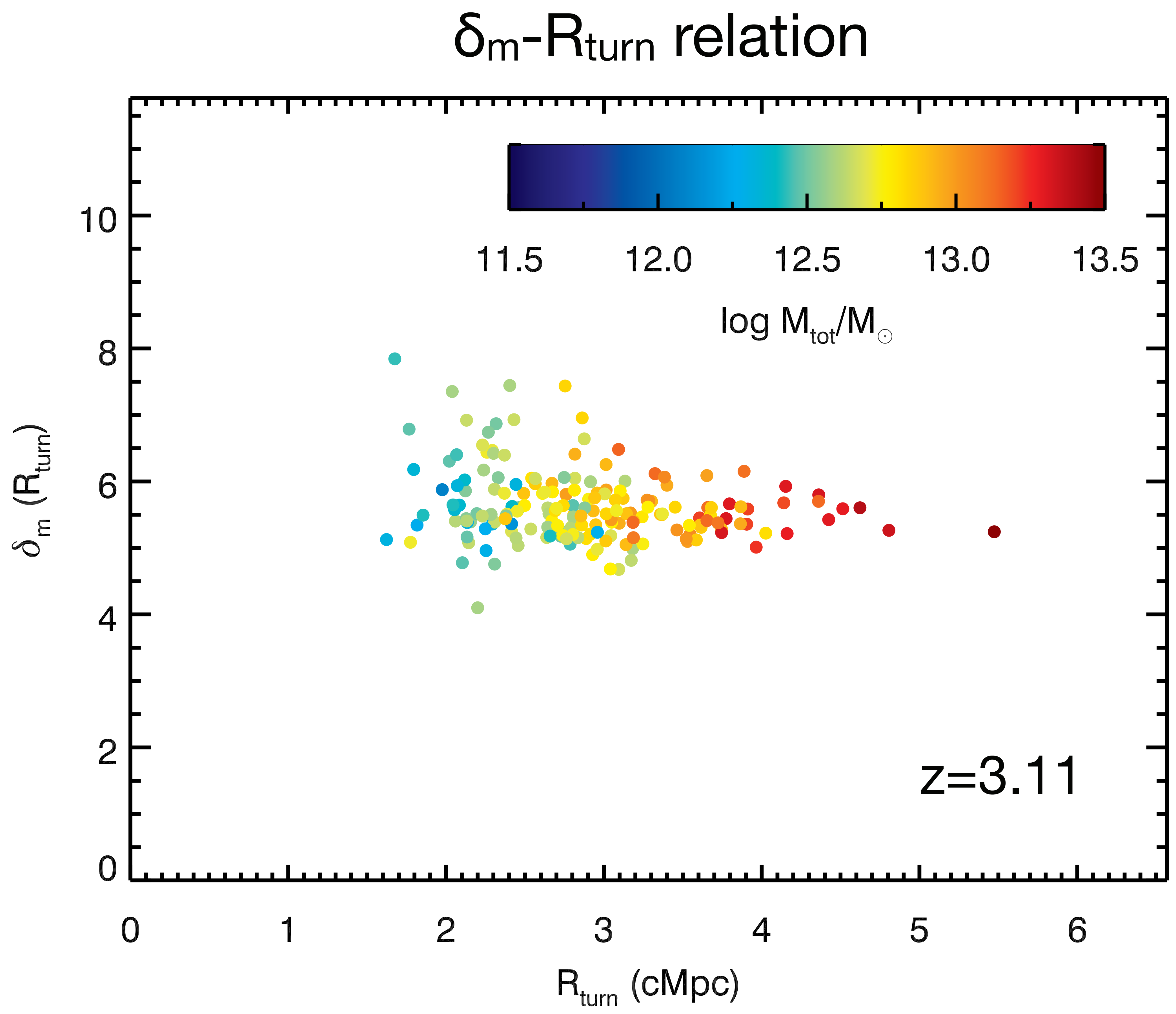
- sSFR as a function of turnaround radius
  - Environmental effects are weekly seen at z~3.1 around proto-clusters while it strongly suppresses star formation of small galaxies in well developed structures in $r<R_{turn}$ at z~0.63

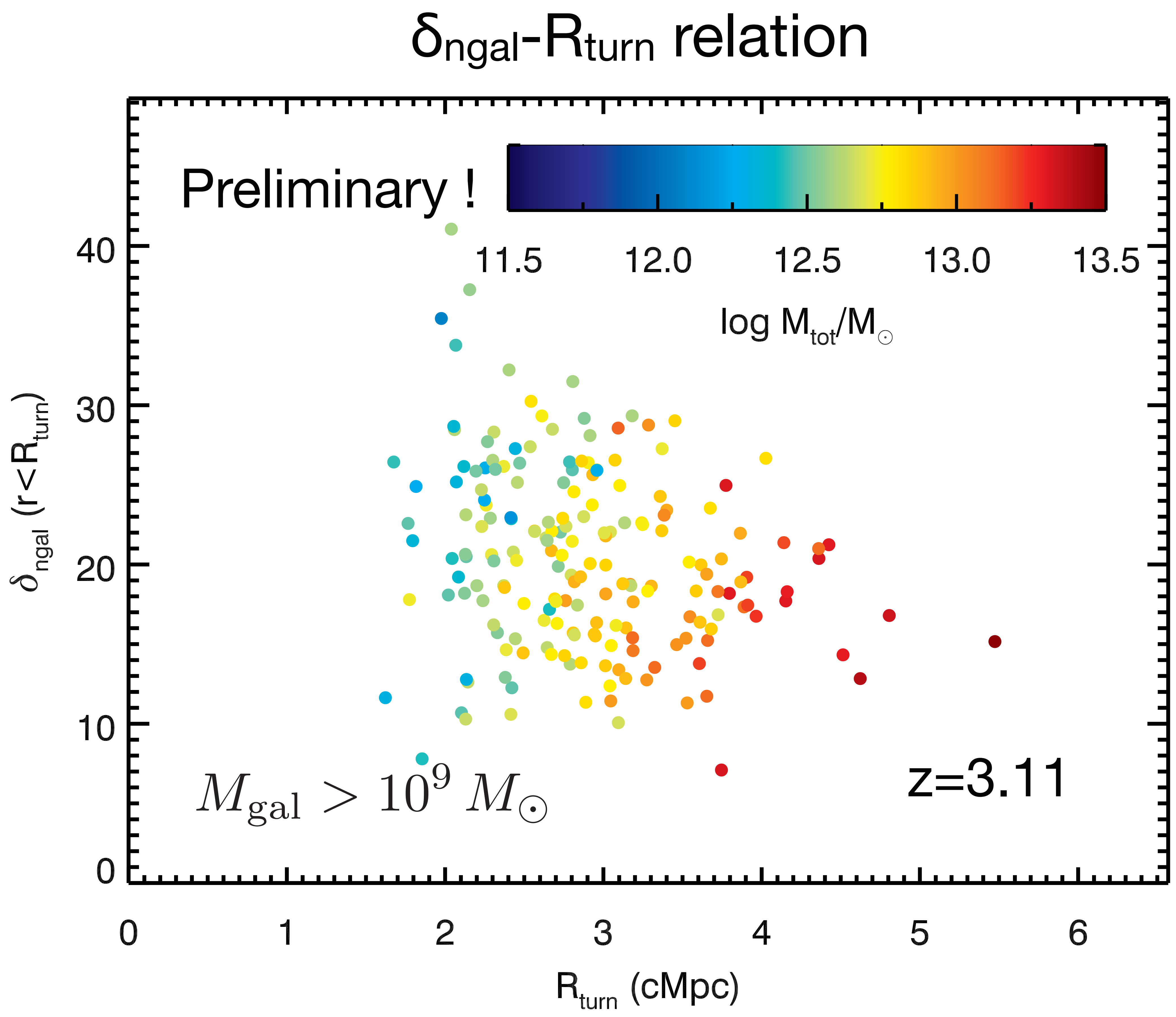


sSFR from (proto-)clusters stacked



- Turnaround radius and overdensity
  - δ_m~5.5 , δ_{ngal}~20 at z~3.11 inside R_{turn}





- Summary & Future work
  - 190 cluster candidates are found in HR5 at z=0.63
    - Environmental effects are evident in the cluster candidates
  - The progenitors of the cluster galaxies are identified using the merger trees of HR5
    - Cluster candidates are more massive (or formed earlier) than field galaxies
    - Cluster progenitors do not have particularly distinguished properties at z=3.1
  - In the turnaround radius, proto-clusters have $\delta_m \sim 5.5$, $\delta_{ngal} \sim 20$ at z=3.1
    - Environmental effects become effective at $r < R_{turn}$