Exploring Galaxy Proto-Cluster Cores at z ~ 2

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(1) Introduction

✦Galaxy Clusters

- most massive system in the universe
- member galaxies:
  - quiescent galaxies
  - elliptical galaxies
  - top-heavy stellar mass function

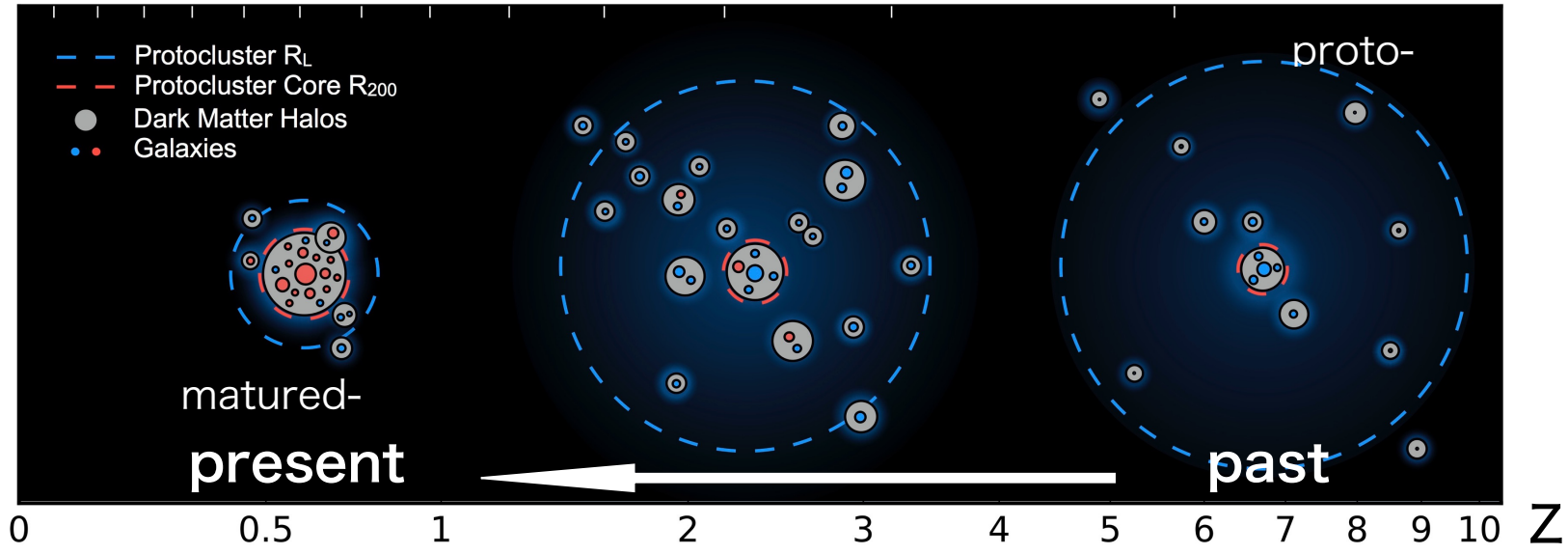
➡ **How and when did these properties appear?**

➡ **need to search for the high-z counterpart: proto-cluster**

(1) Introduction

✦Growth of Galaxy Clusters

based on Chiang+17

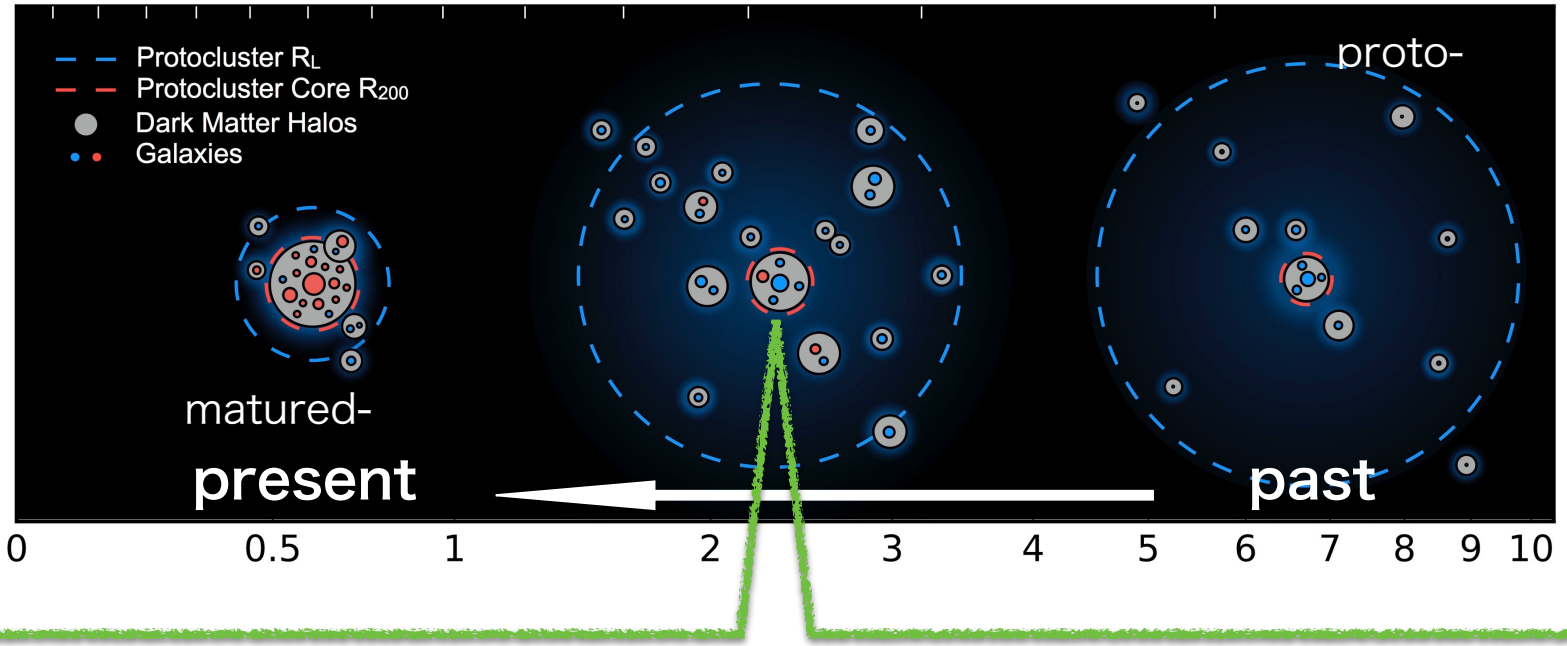


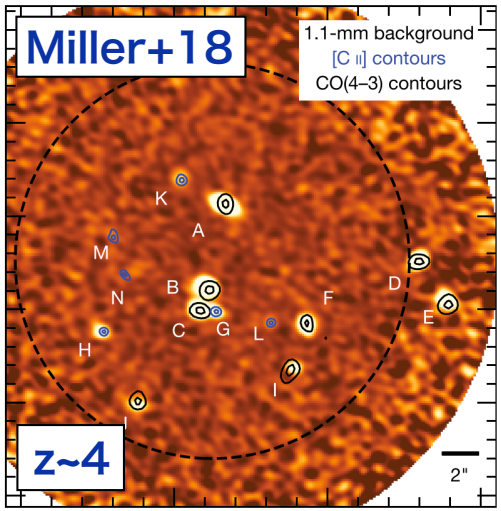
- Growth of cluster -> host dark matter halo(DMH) growth.
  - ✓cluster DMH mass: $M_{\rm DH} \geq 10^{14}\,M_\odot$
  - ✓At high-z, whole structure have not collapsed yet.
  - ✓Central DMH have already collapsed:
    - ➡ **proto-cluster core**

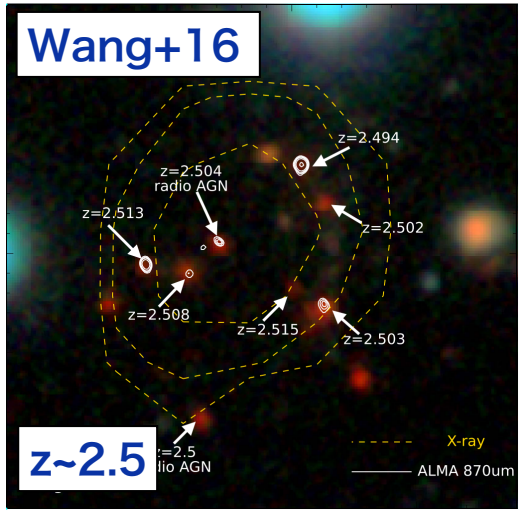
(1) Introduction

✦Growth of Galaxy Clusters

based on Chiang+17





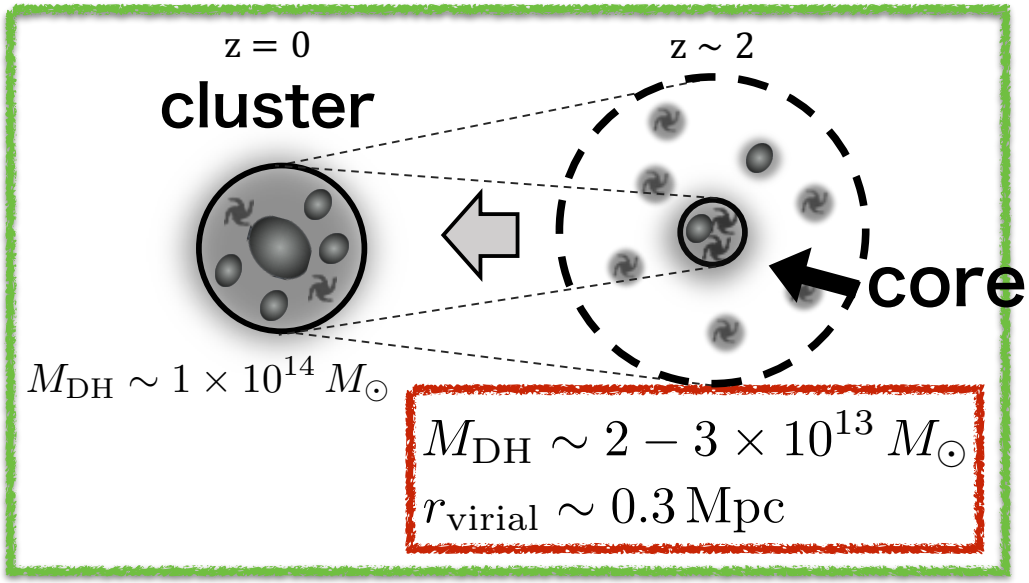


✦Proto-Cluster Core

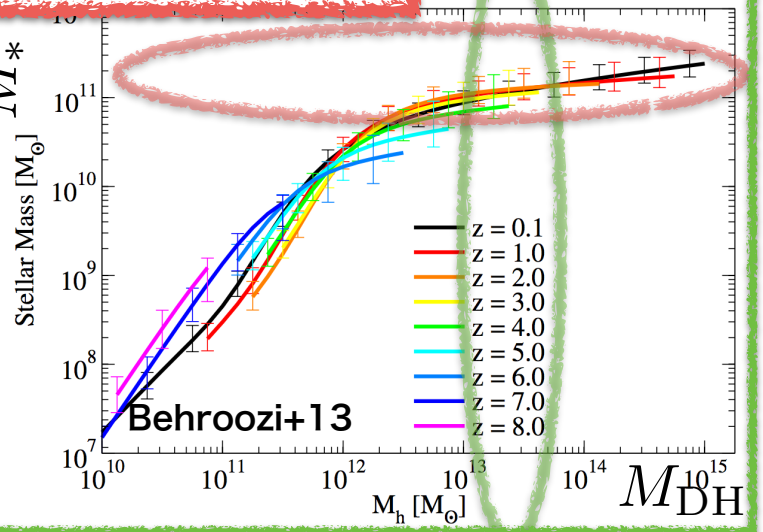
- **most massive DMHs**
- active SF / BCG formation?
- core sample is still limited

➡ **systematic search**

(1) Introduction - outline



$M_* \geq 1 \times 10^{11}\, M_\odot$



pair: multiple system of very massive galaxies

clustering-based mass estimation

➡confirming “core” candidates

Properties of member galaxies

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(2) Data & Method - samples

✦Data

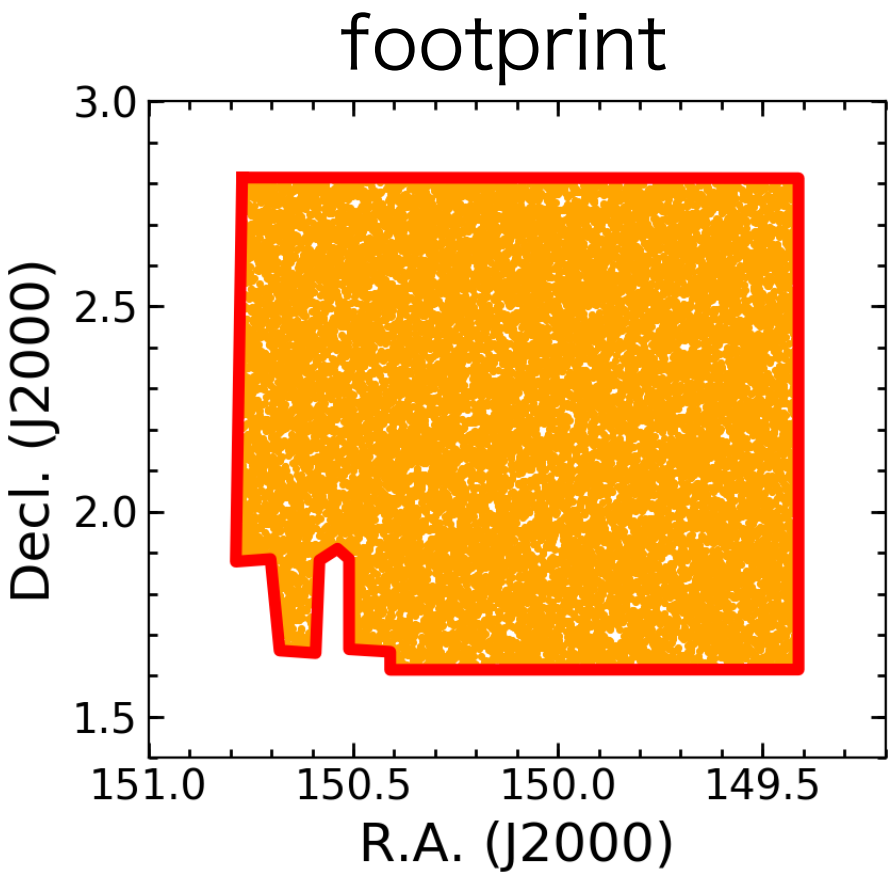
- COSMOS 2015 catalog (Laigle et al. 2016)
  - ✓photo-z catalog
  - ✓stellar mass
  - ✓Passive/SF classification(UVJ)

✦Subsample1 (massive galaxy)

- redshift: $1.5 \leq z_{\rm phot} \leq 3.0$
- stellar mass: $M_{\rm star} \geq 10^{11}\ M_{\odot}$
- total: 1745 galaxies

✦Subsample2

- redshift: $1.25 \leq z_{\rm phot} \leq 3.25$
- mag(Ks): $mag(Ks) \leq 24$ (3sigma lim. of catalog)



(2) Data & Method - “Pair” finding method

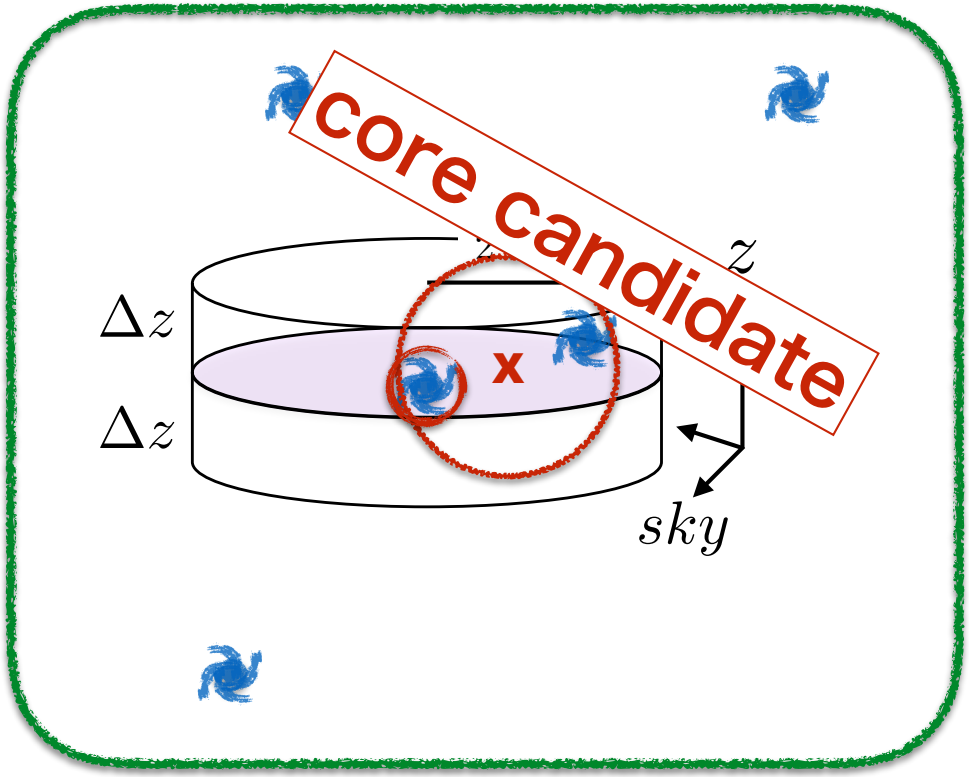
✦Finding Massive Galaxy Pair

(1) Pick up one galaxy and count neighbors within:

- ✓ $\Delta\theta \leq 2 \times 25'' \sim 2 \times 0.2\,\mathrm{Mpc}\ (z \sim 2)$ -- core size
- ✓ $\Delta z \leq 0.12$ ---------- z uncertainty

(2) All neighbors are regarded as core members.

(3) 3D position of core = average position of member galaxies.



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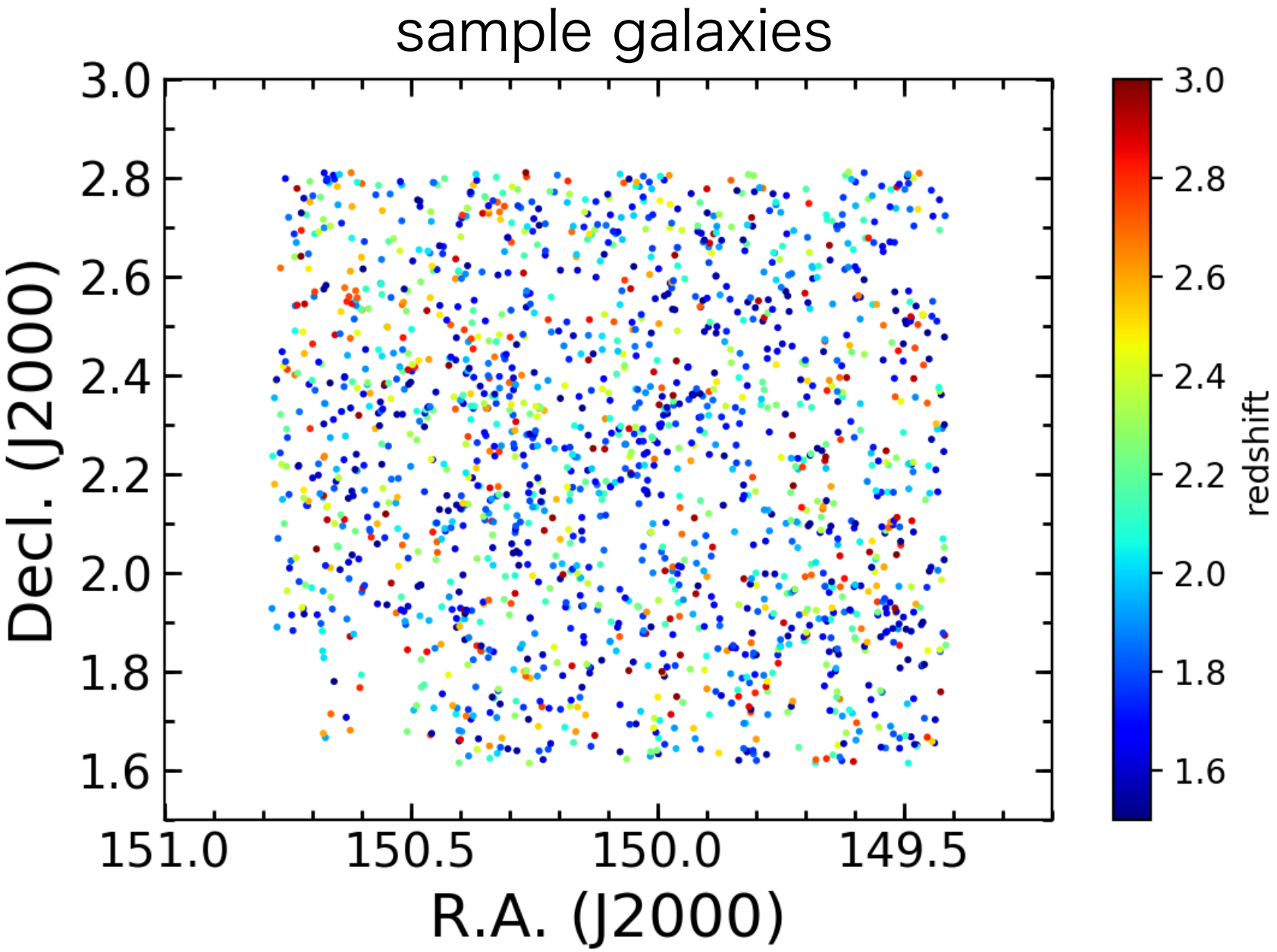
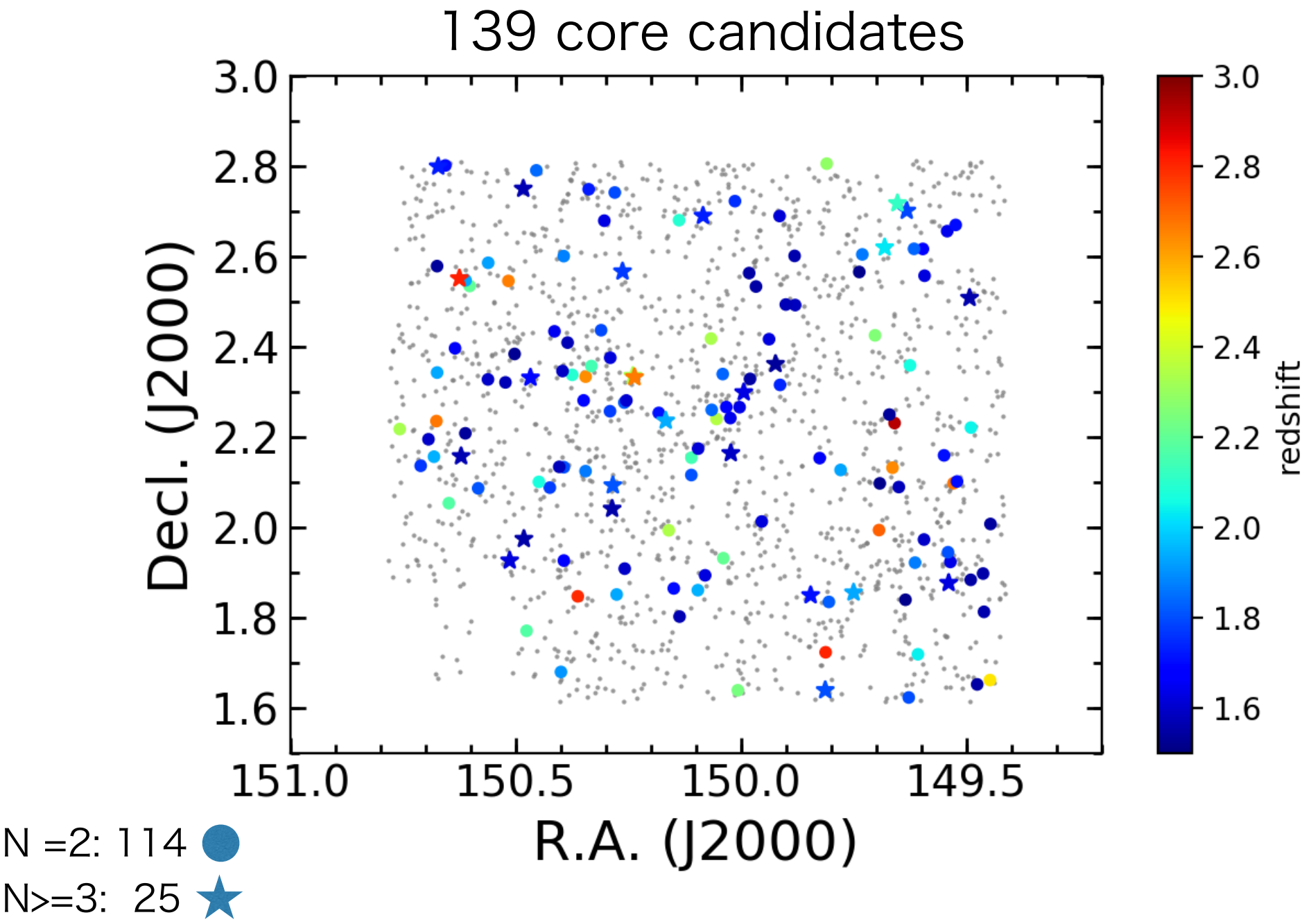
(2) Result


sample galaxies
Decl. (J2000)
R.A. (J2000)
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
151.0
150.5
150.0
149.5
redshift

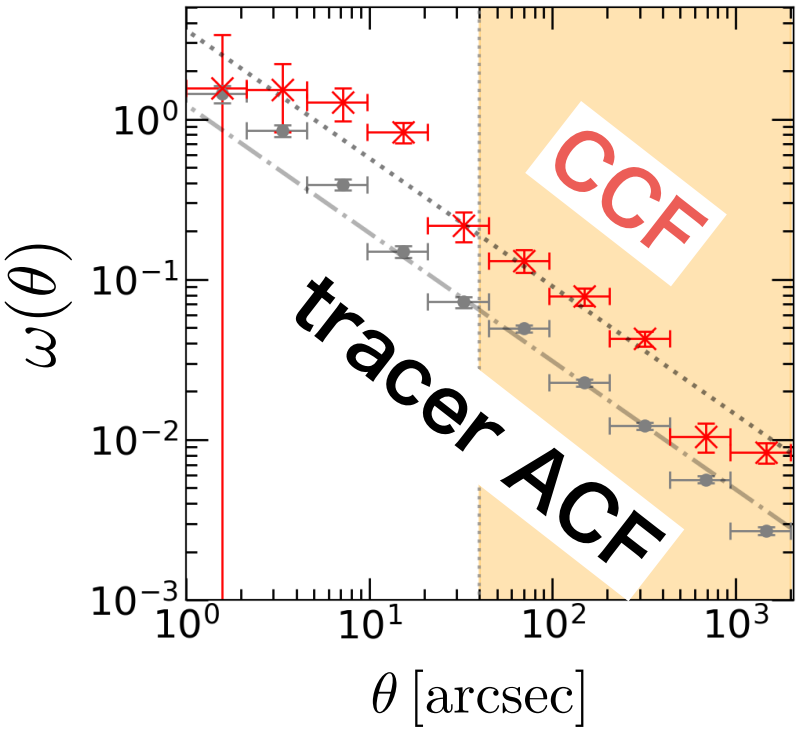
(2) Result

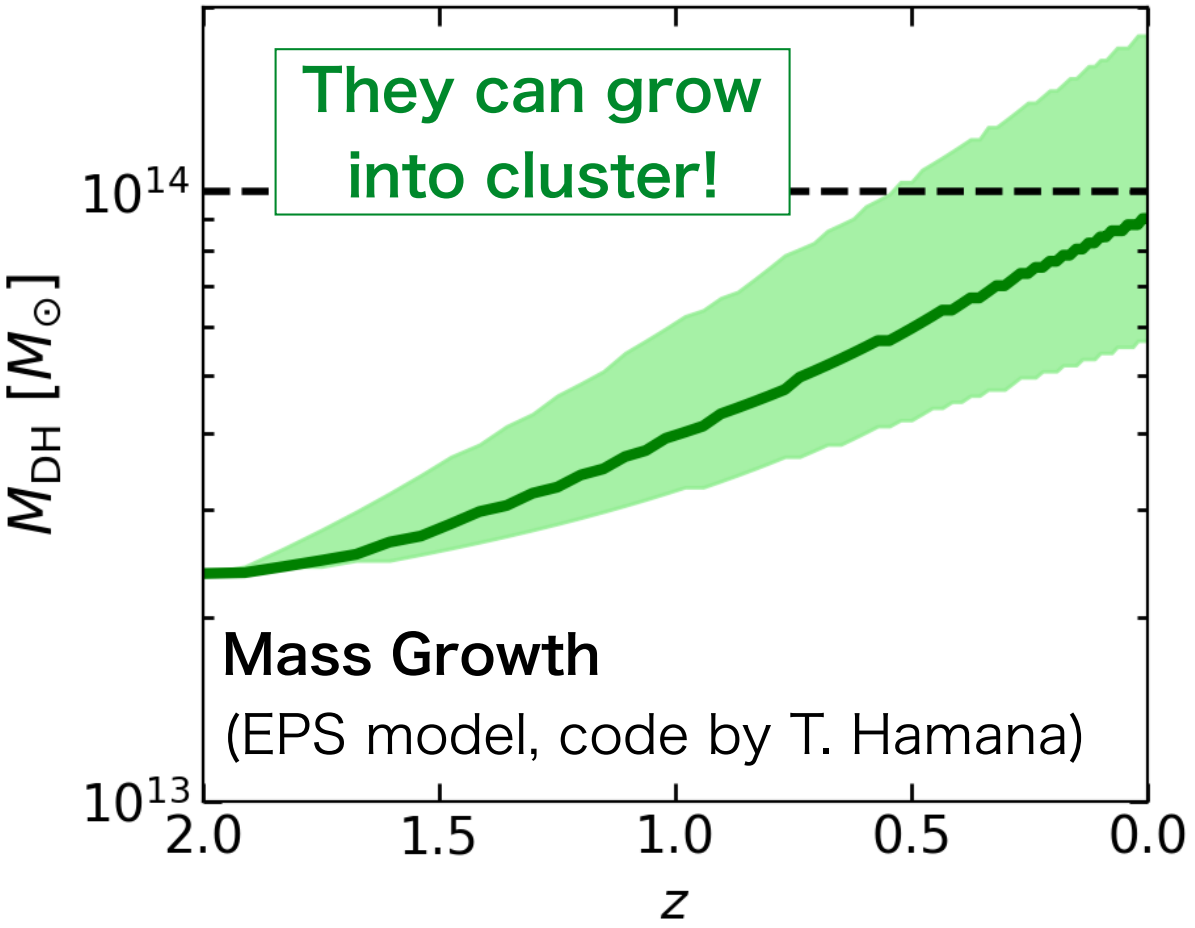

139 core candidates
Decl. (J2000)
R.A. (J2000)
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
151.0
150.5
150.0
149.5
redshift
N =2: 114
N>=3: 25

(3) DH Mass Estimation

✦clustering analysis

- cross-correlation between c
- $10.2 < \log(M_*/M_\odot) < 11.0$ / mc





$$M_{\rm DH} = 2.36^{+0.66}_{-0.58} \times 10^{13}\, M_\odot$$

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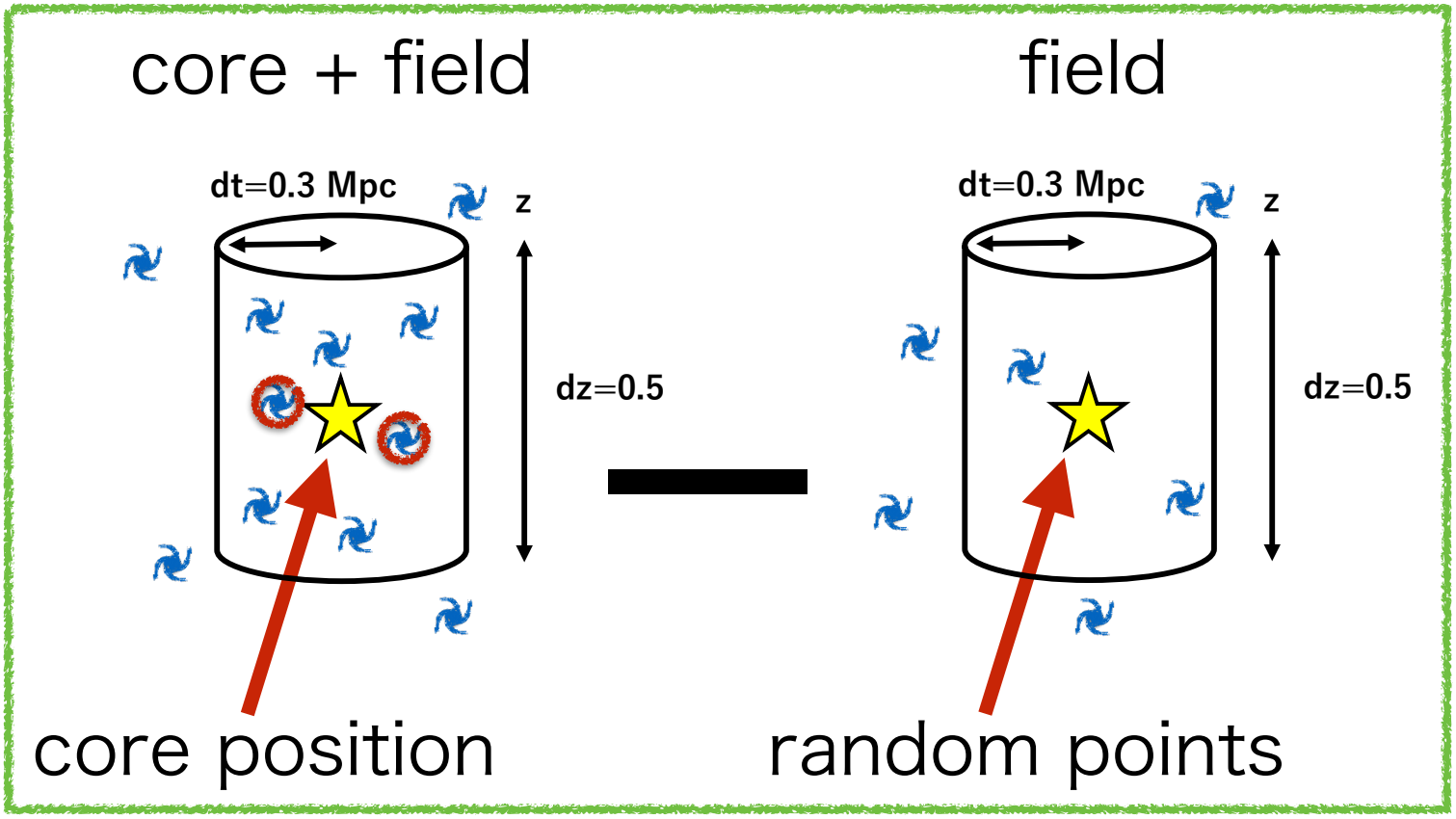
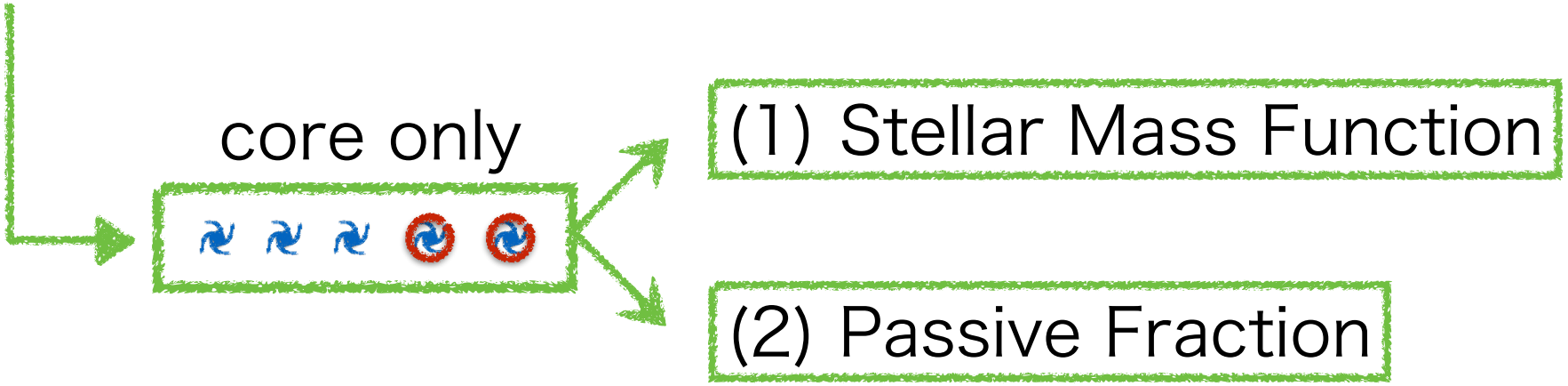
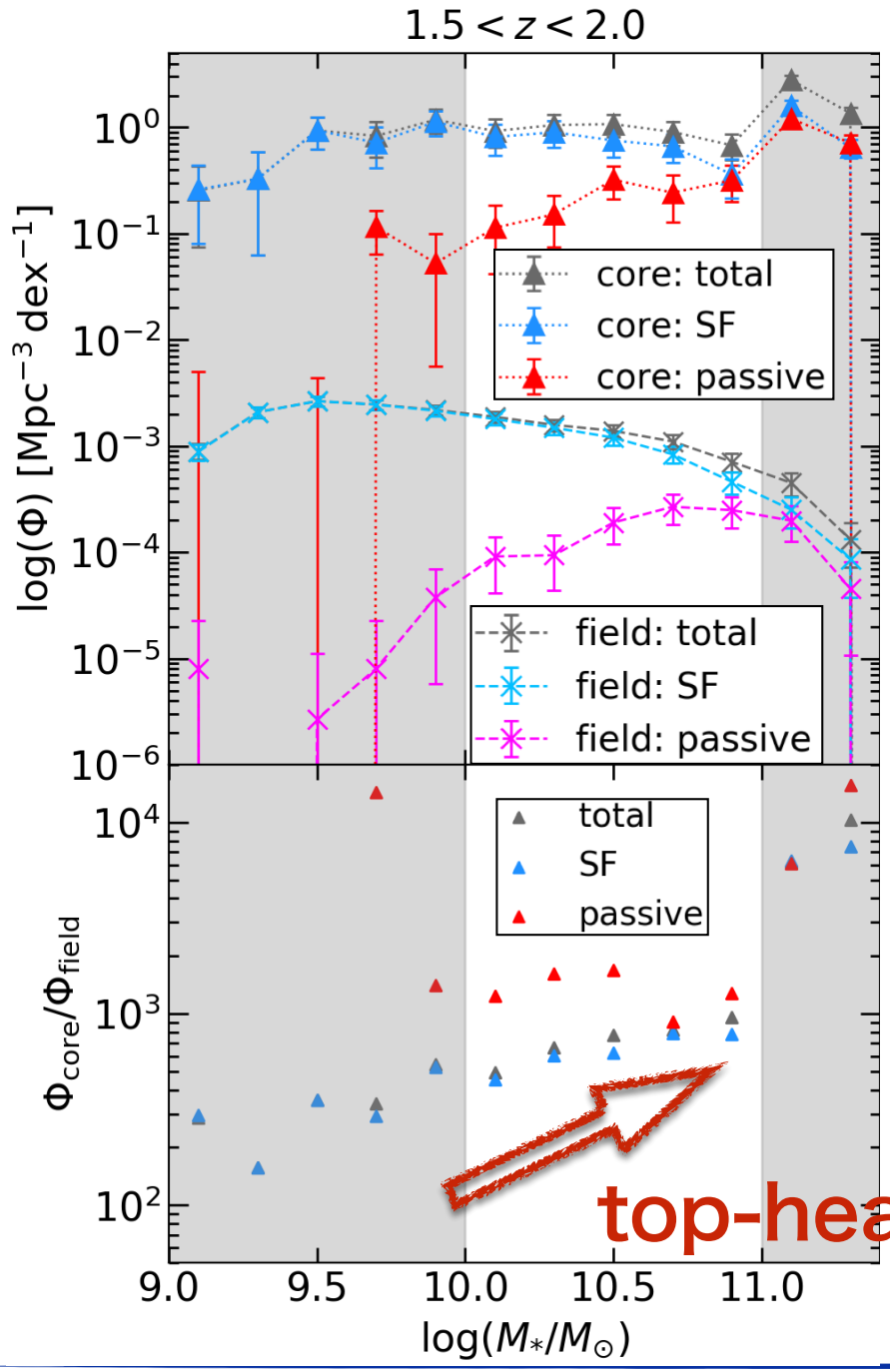
(4) Member Galaxies - field subtraction





(4) Member Galaxies - Stellar Mass Function



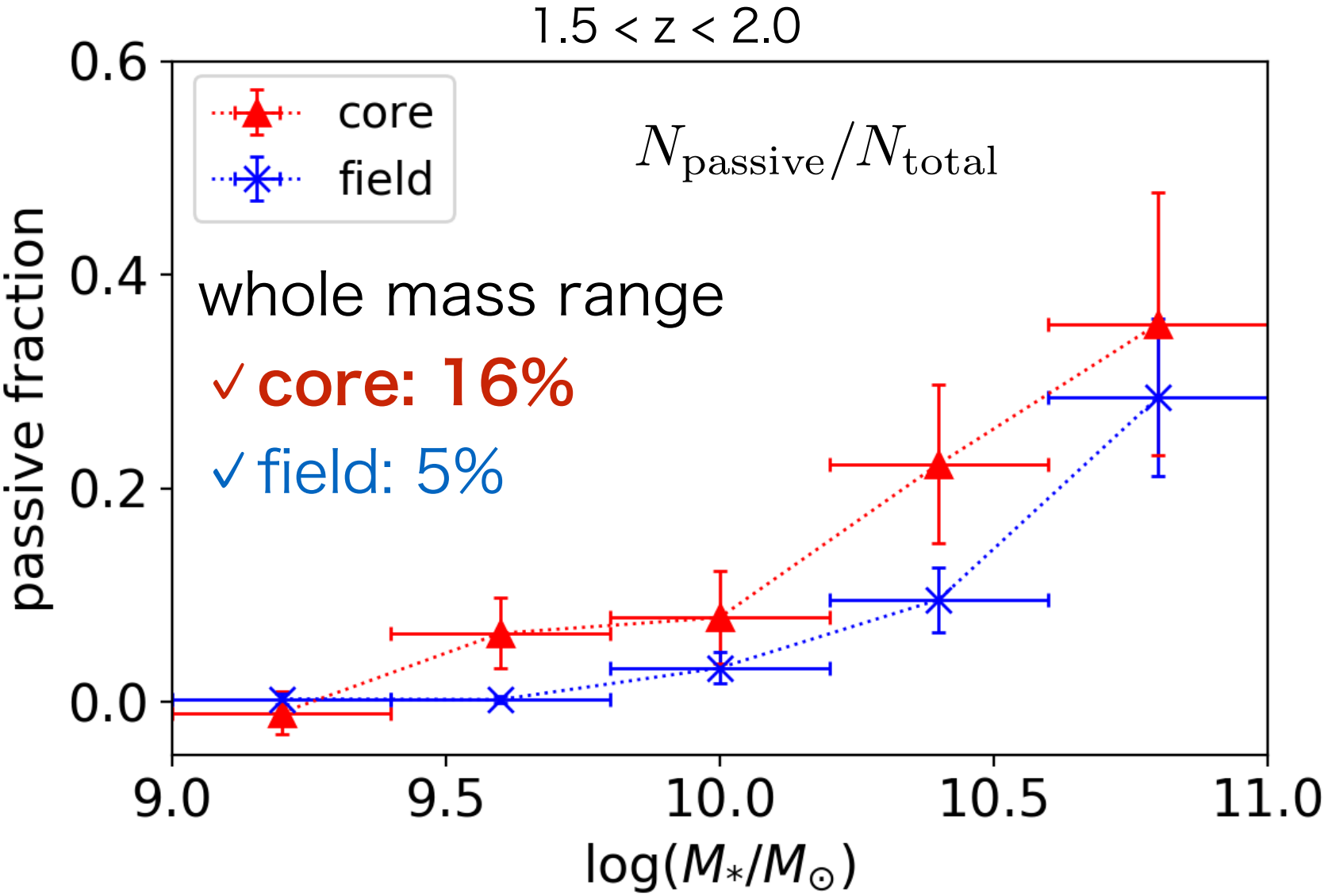
✦**core member galaxy**

✓top-heavy SMF

- early formation of massive galaxies
- disruption and merger of low-mass galaxies

✓consistent with simulation (e.g. Muldrew+18)

(4) Member Galaxies - Passive Fraction



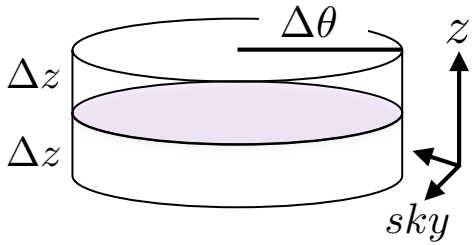
✓3 times higher passive fraction (due to environmental effect?)

- core galaxies experience earlier quenching?

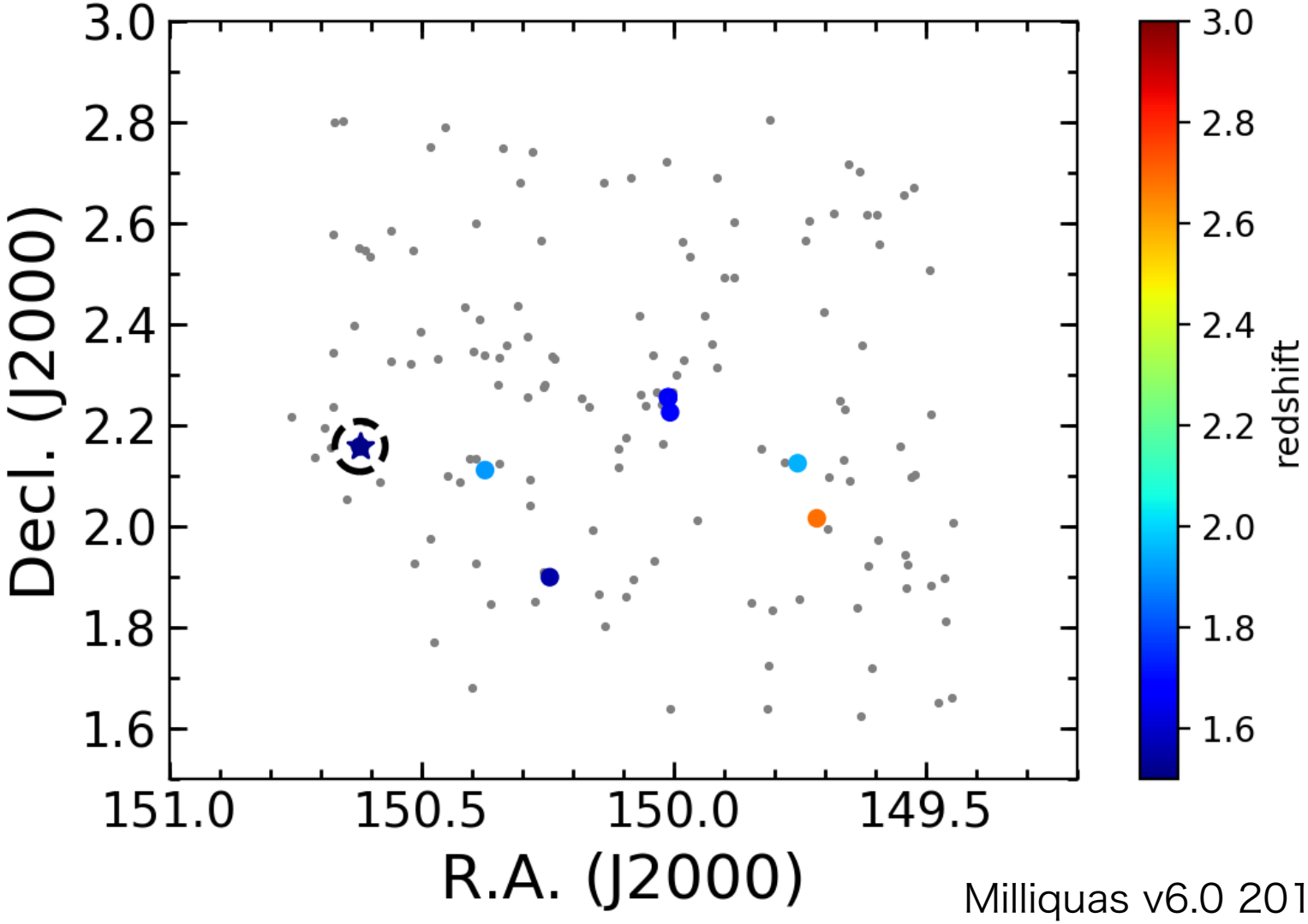
(4) Member Galaxies - QSO distribution

cores with QSO: 1/139 ($< 0.3\,\mathrm{Mpc}$) ★

8/139 ($< 1.0\,\mathrm{Mpc}$) ●



$\Delta z \leq 0.12$



Milliquas v6.0 2019 update, Flesch+15

Summary

- We have identified 139 galaxy proto-cluster cores using pairs of very massive galaxies as tracers.

- Their viral masses are high enough to grow into present-day clusters.

- Core galaxies have
  - ✓Top-heavy SMF.
  - ✓3 times higher passive fraction than field ones.

- Only one core harbors a QSO.