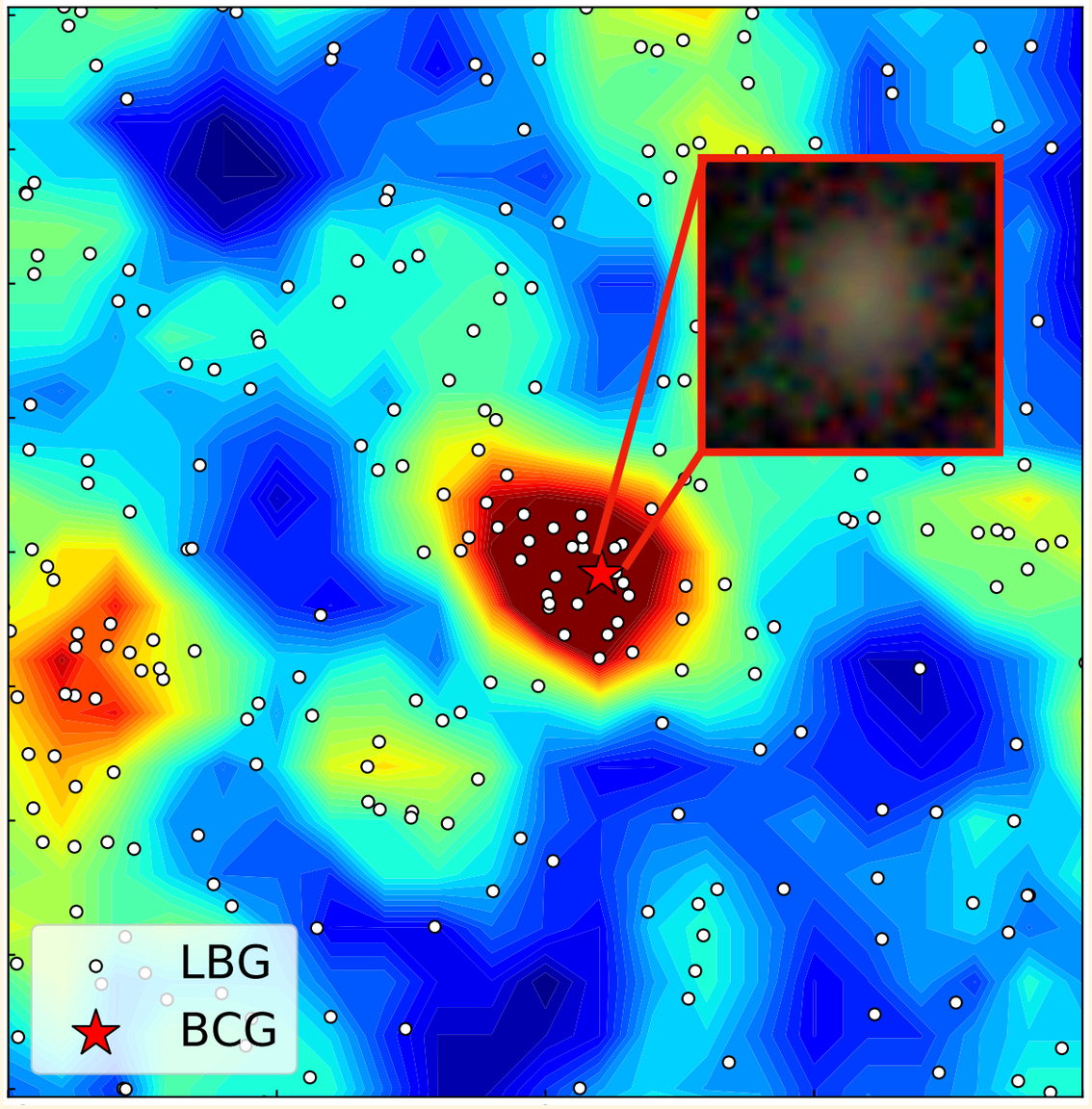
The brightest UV-selected galaxies in protoclusters at z∼4: Ancestors of Brightest Cluster Galaxies?



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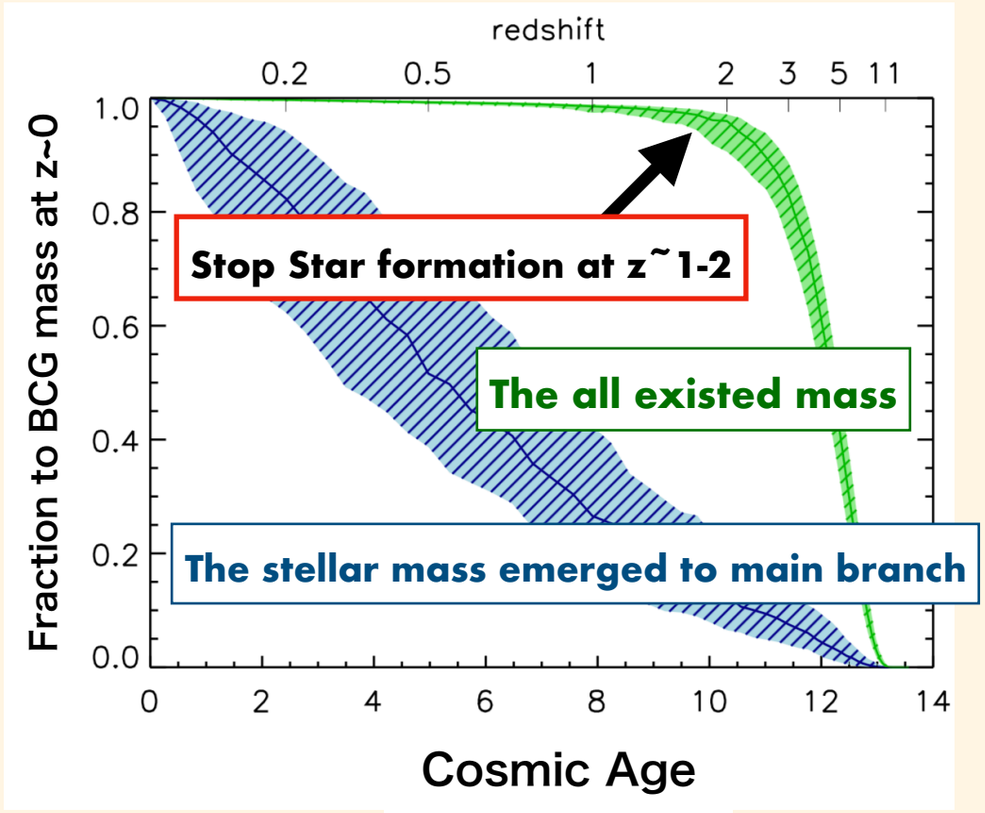
Nobunari Kashikawa, Jun Toshikawa, Roderik Overzier, Masayuki Tanaka, Mariko Kubo,
Takatoshi Shibuya, Shogo Ishikawa, Masafusa Onoue, Hisakazu Uchiyama, Yongming Liang,
Ryo Higuchi, Crystal L.Martin, Chien-Hsiu Lee, Yutaka Komiyama, and Song Huang

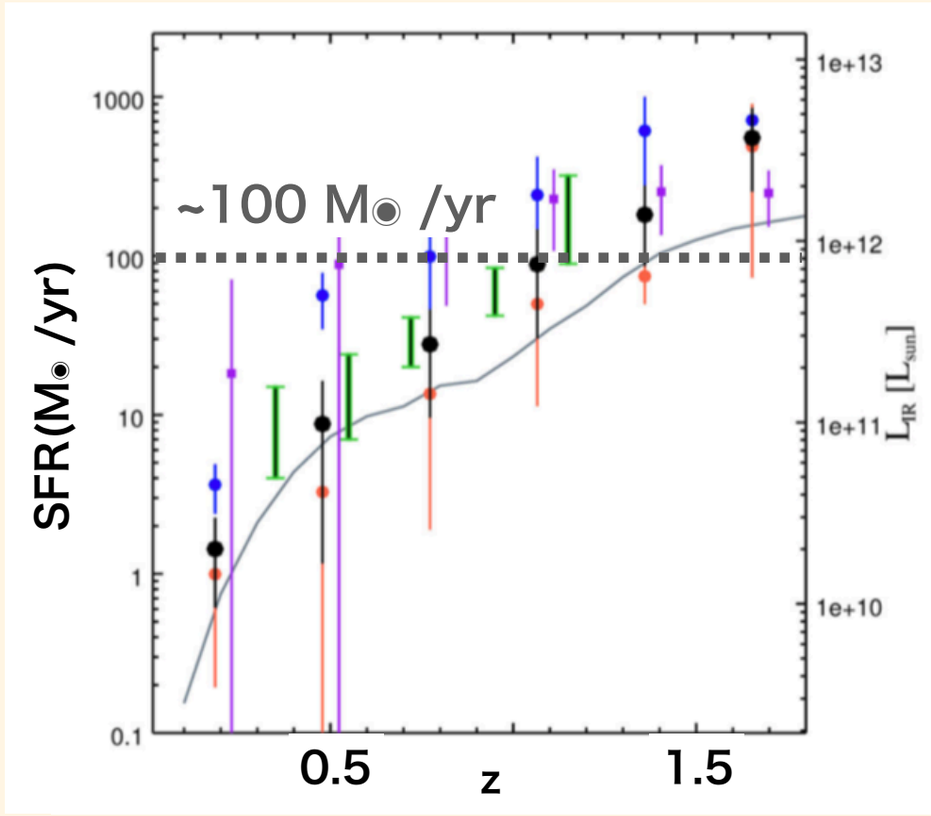
Ito et al. (2019) ApJ, In Press (arXiv:1904.01597)

Brightest Cluster Galaxies

- **Brightest Cluster Galaxies (BCG)**: The most massive and luminous cluster galaxy
  →Good example of galaxies affected by the environment
- **The formation of BCGs:**
  - Early stellar formation and minor merger (e.g., De Lucia & Blaizot 2007)
  - Continuing star formation even at low-z (e.g., Bonaventura et al. 2017)



De Lucia & Blaizot 2007

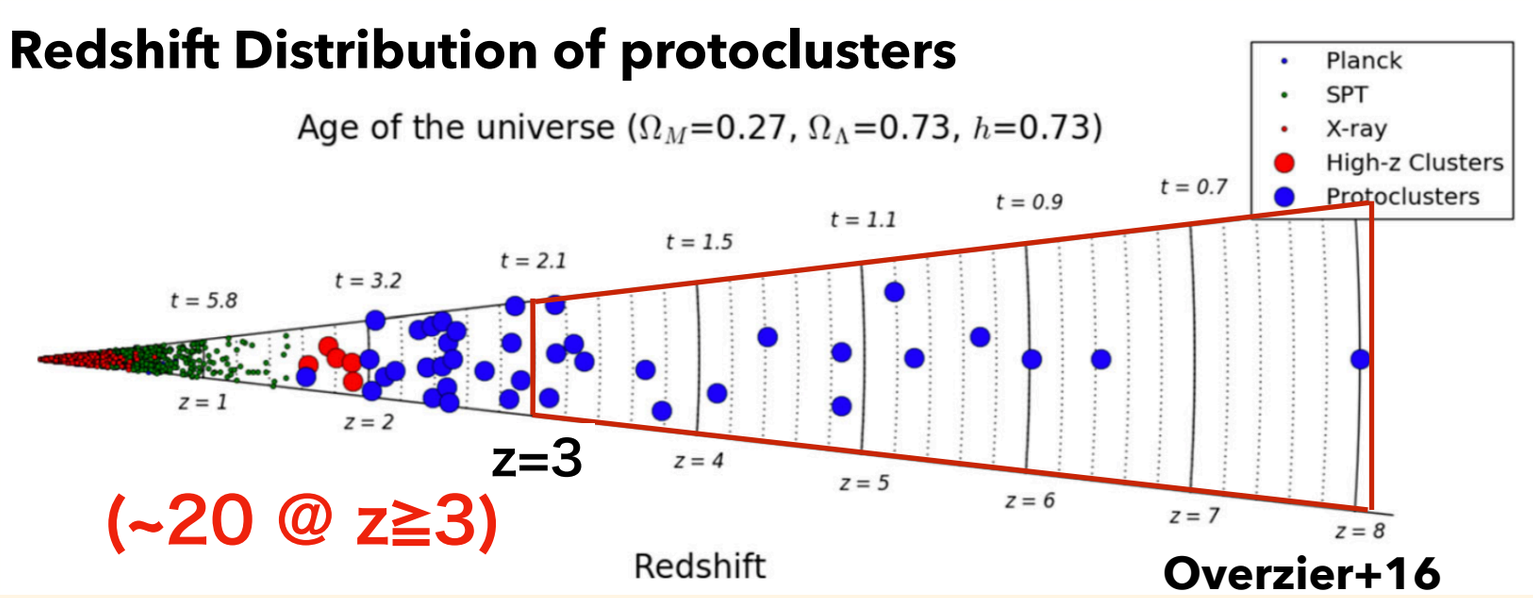


Bonaventura et al. 2017

When and how BCG are formed?

The current protocluster studies

- The difficulty of high-z BCGs research:
  The sample number of protoclusters (PCs) is extremely limited.



※Protocluster: a structure that will grow into $M_{halo} > 10^{14} M_\odot$ at z>0

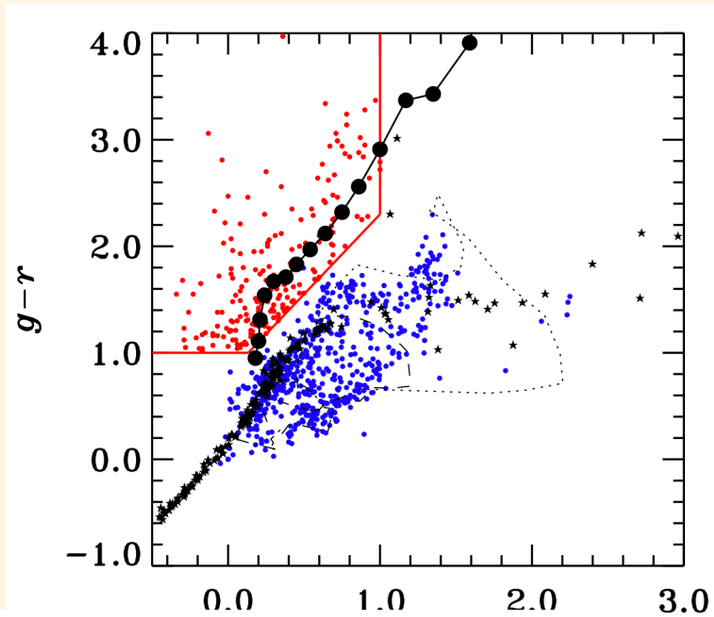
- Some protoclusters are found through radio galaxies/QSOs
  →They are biased protoclusters?

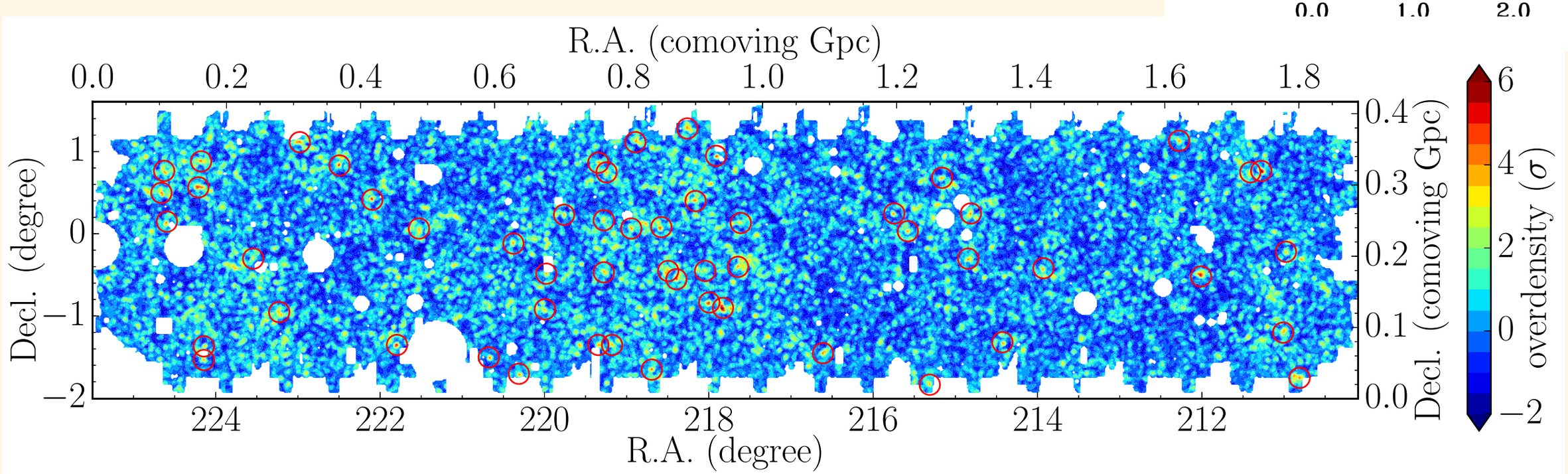
- Various tracer for finding overdense regions (LBGs, LAEs,HAEs…)

→ We need large and systematic PCs sample.

HSC Protocluster Survey at z~4

- Toshikawa et al. (2018)
  - We selected ~400K g-dropout sample.
  - Through the over density of them, we select overdensity > 4σ regions as protocluster candidates.

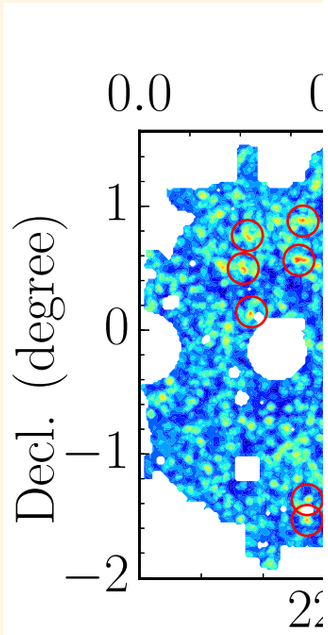


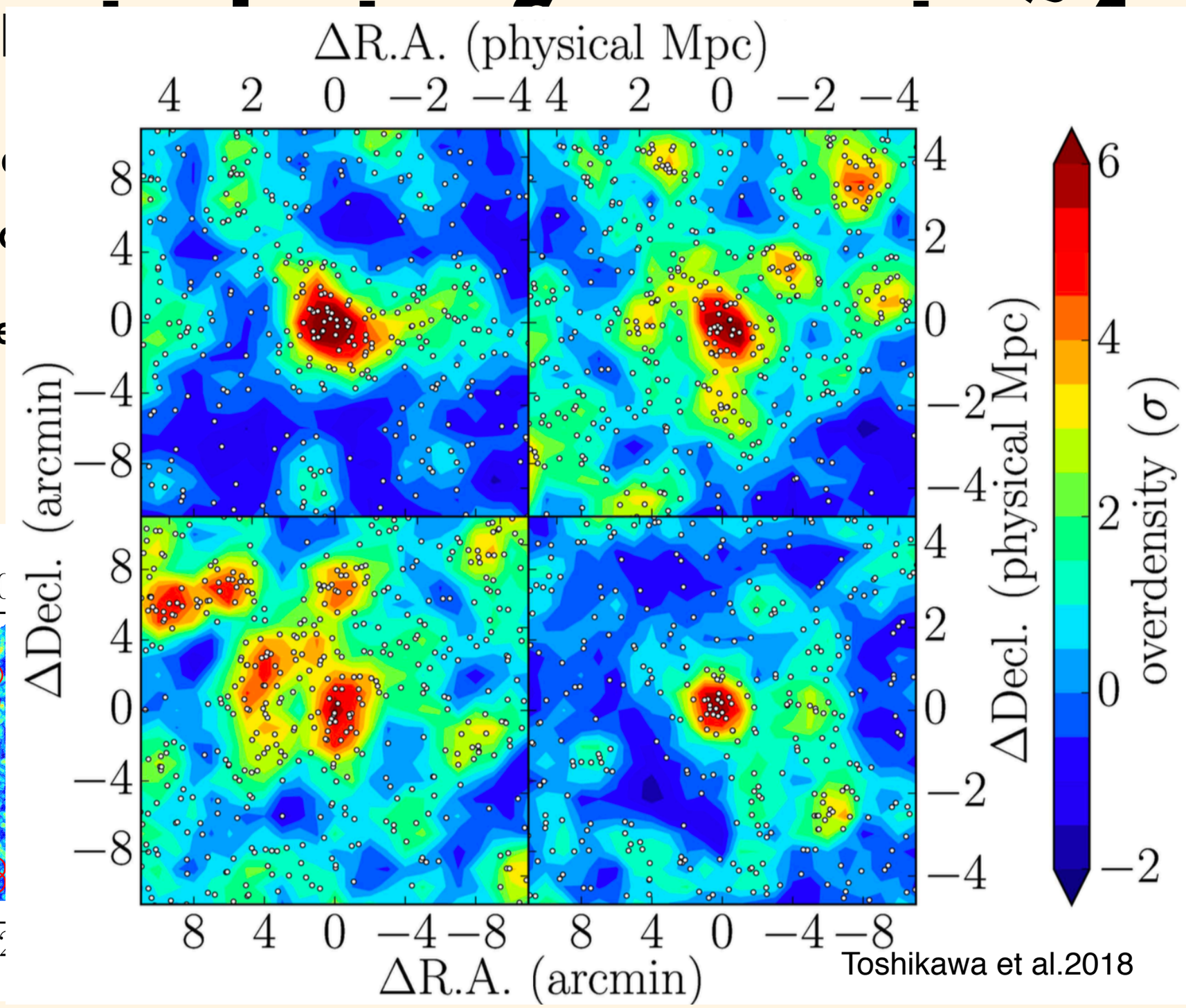


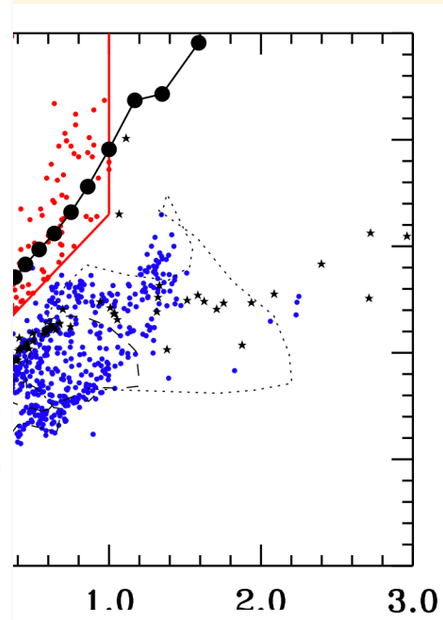
179 PCs from 121deg² (~10 times larger than the previous sample)

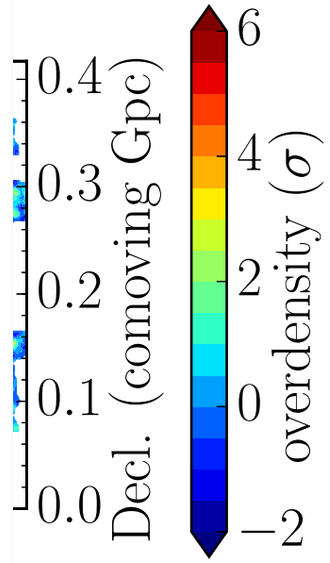
HSC P

- Toshikawa
  - We selecte
  - Through the









Toshikawa et al.2018

179 PCs from 121deg² (～10 times larger than the previous sample)

Aim of this Study

- **Selecting the UV-brightest galaxies in each z∼4 HSC protocluster**

  - UV-brighter galaxies should be more massive (M*-SFR relation)
    → **Candidates of the progenitor of BCGs** (proto-BCGs)

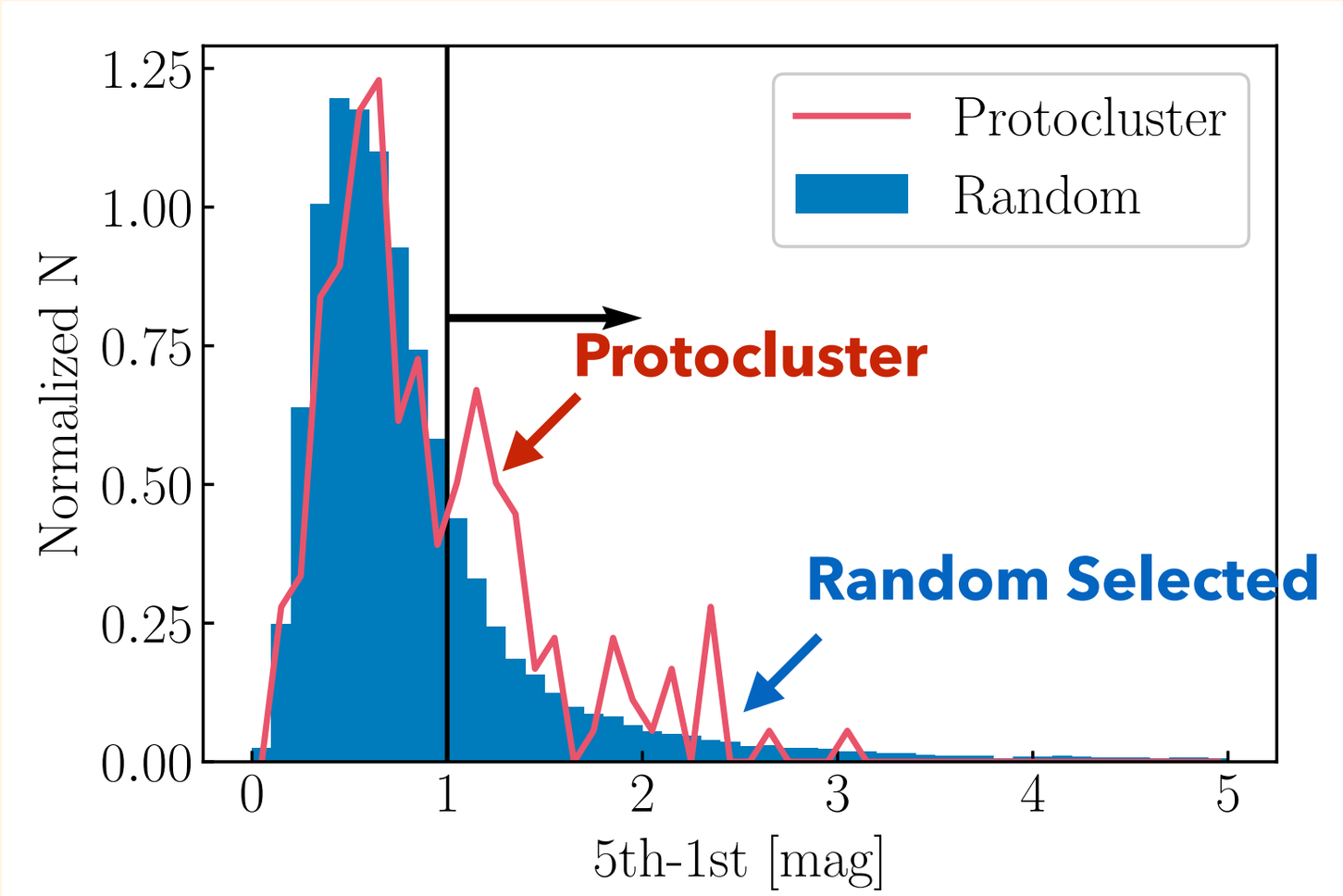
- **Investigating properties of proto-BCGs**
  - color and radial profile
  - any difference with field gal. at z∼4?

- **The 1st systematic search of proto-BCGs at z∼4**
- **Using 10 times larger PC sample**

proto-BCG Candidate Selection

proto-BCGs: uniquely brightest protocluster galaxy compared to other galaxies

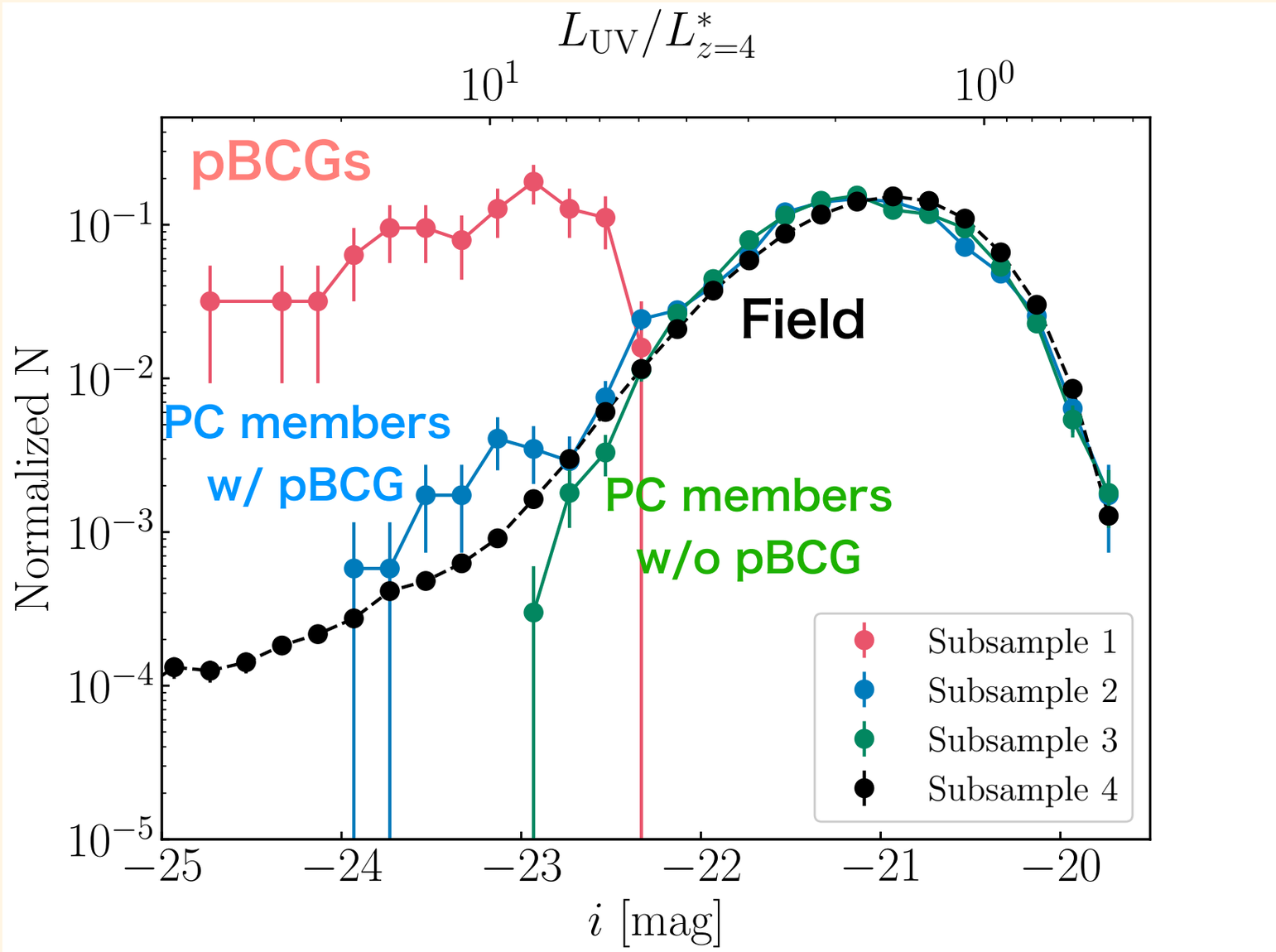
1. Define PC members within 3 arcmin from the overdensity peak.
2. Select "proto-BCG" as **the brightest objects that are 1 mag or more brighter than the 5th brightest objects** in each PC.
   →Select 63 objects totally



p~3.5×10^{-3} @AD-test

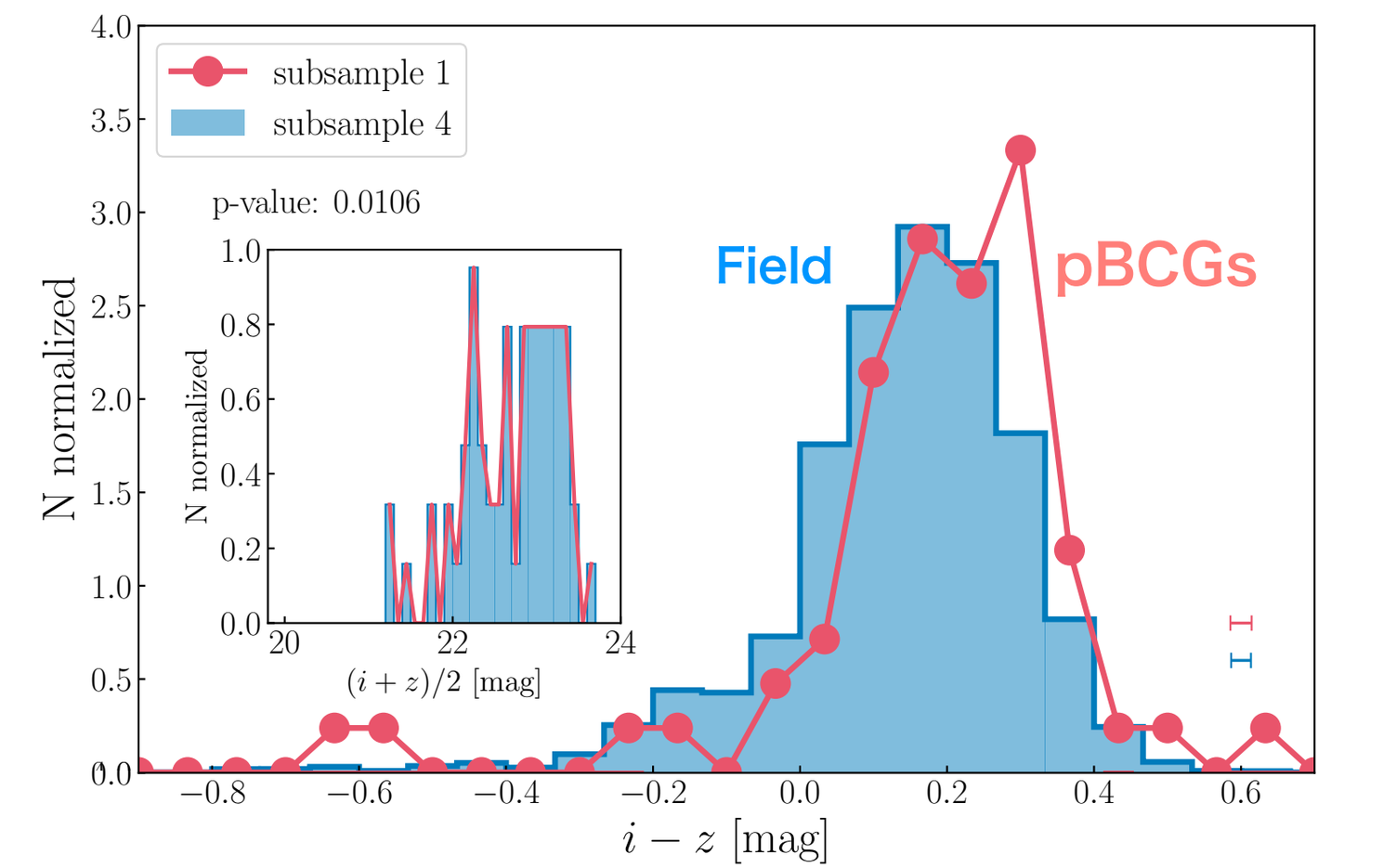
Subsamples

- **We construct 4 subsample**
  - proto-BCGs
  - PC member w/ proto-BCGs
  - PC member w/o proto-BCGs
  - Field galaxies



i-z color comparison (proto-BCGs)

- **i-z distribution of proto-BCG and Field gals.**



	median
proto-BCG	0.1771±0.0254 [mag]
Field gal.	0.1423±0.0010[mag]

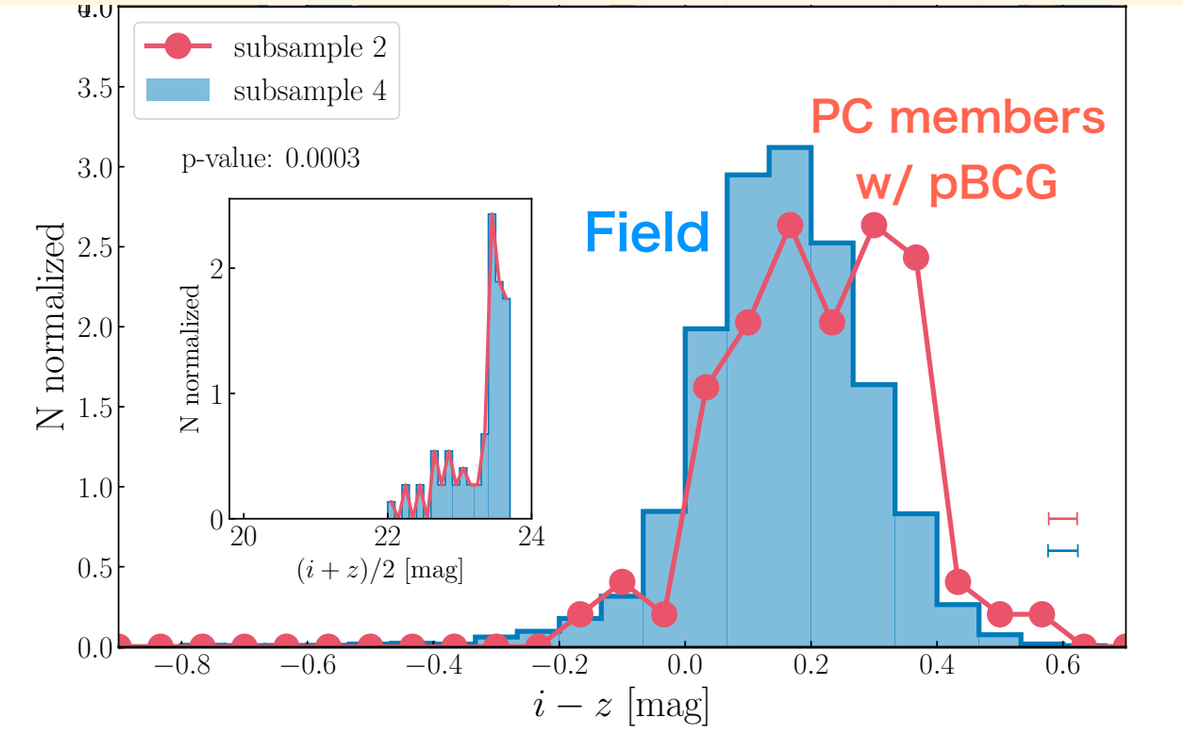
→proto-BCGs have redder color than Field gal.

… significant at 2σ from Anderson-Darling test (p=0.01)

i-z color comparison (PC member)

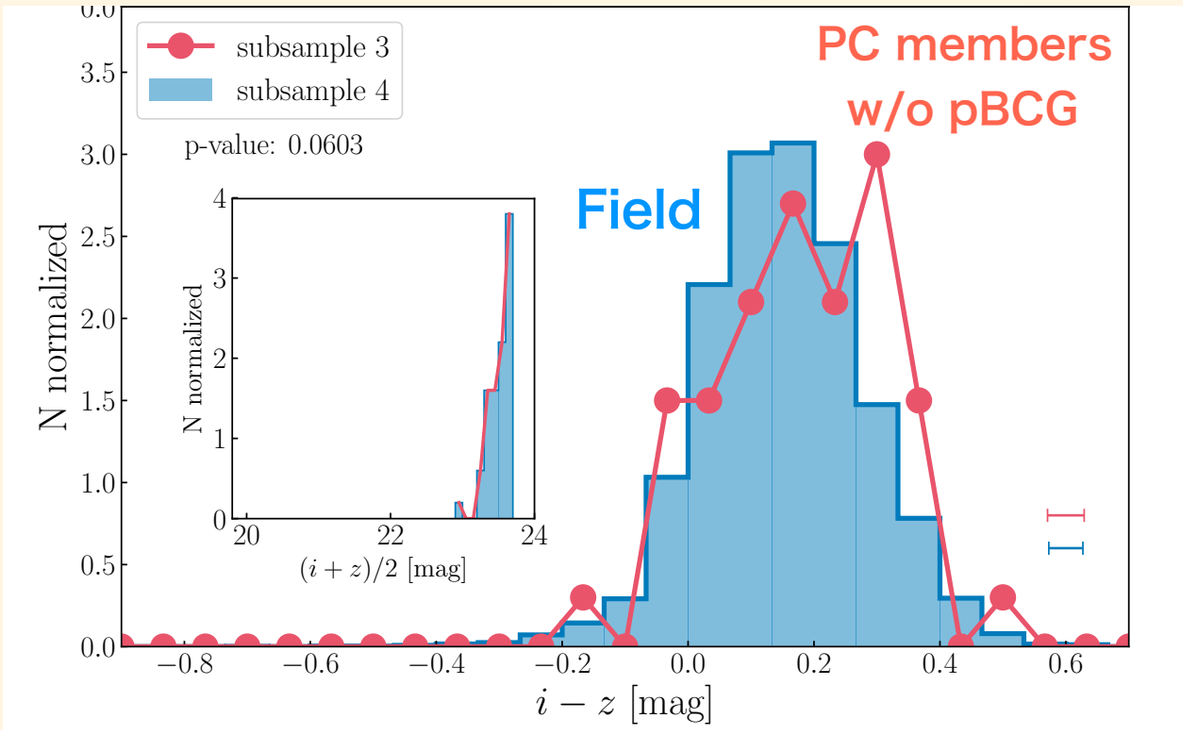
- **i-z color comparison between each PC member and field gal.**

PC members w/ pBCG



	median
PC member w/ pBCG	0.212±0.016 [mag]
Field gal.	0.154±0.001[mag]

PC members w/o pBCG



	median
PC member w/o pBCG	0.183±0.019 [mag]
Field gal.	0.152±0.001mag]

→PC member w/ pBCG are redder than field gal. (p=0.0003)
PC member w/o pBCG have **the same color** with Field gal. (p=0.06)

proto-BCG and surrounding gal. are redder than Field gal. and other PC members

The cause of the i-z difference

- **What causes the i-z difference?**

- The factor determining i-z (UV slope): Dust, Age, Metallicity
- Bouwens et al. (2009) evaluated the effect of the change of each factor and conclude that the dust is the most prominent.

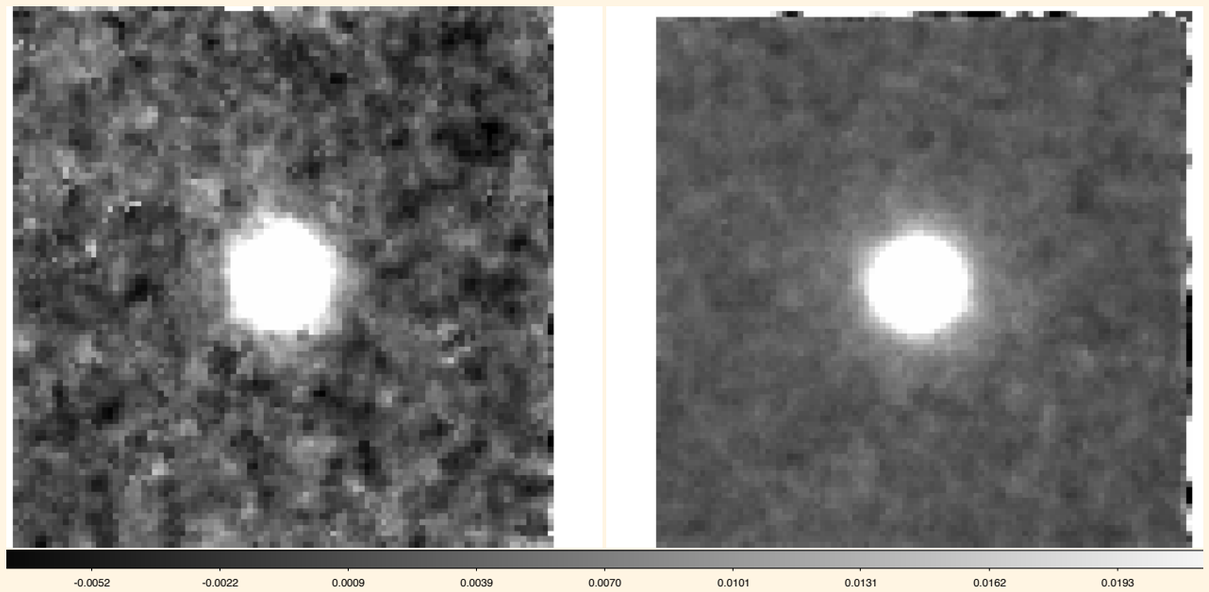
→The dust can be the primary cause for i-z difference

- **The cause of the dust enrichment**

1. Star formation from the early period
2. The existence of the discrete Starburst phase

→proto-BCG and surrounding gal. have experienced different SFH?

Radial Profile

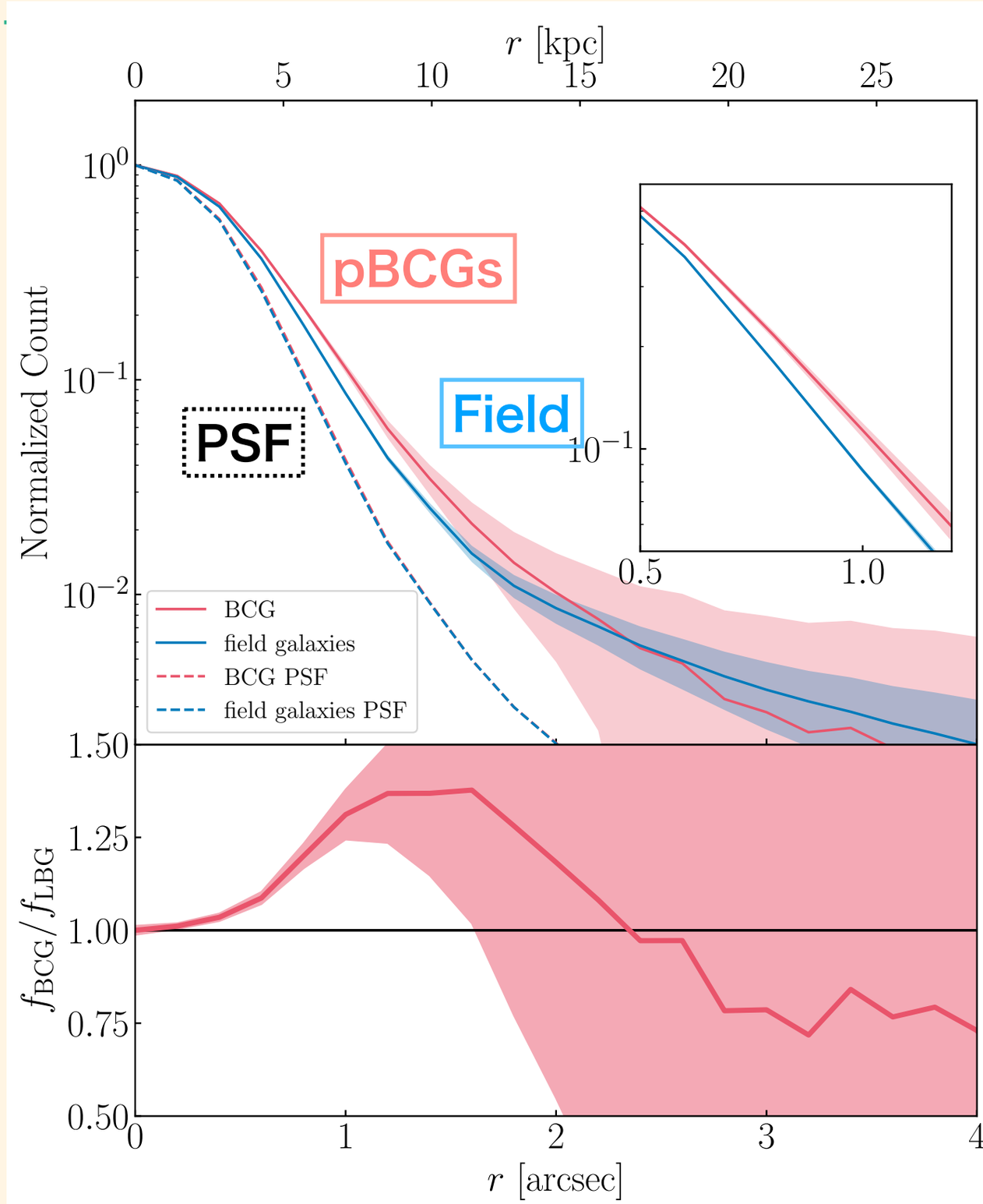


proto-BCG
63 objects

field galaxies
628 objects

※ HSC i-band images

- **Compare proto-BCG's size with that of Field gal.**
  →Compare "average" profile by Stacking
- **proto-BCGs have more extended radial profile than that of Field gal.**
- **~25%** flux excess at r~1"

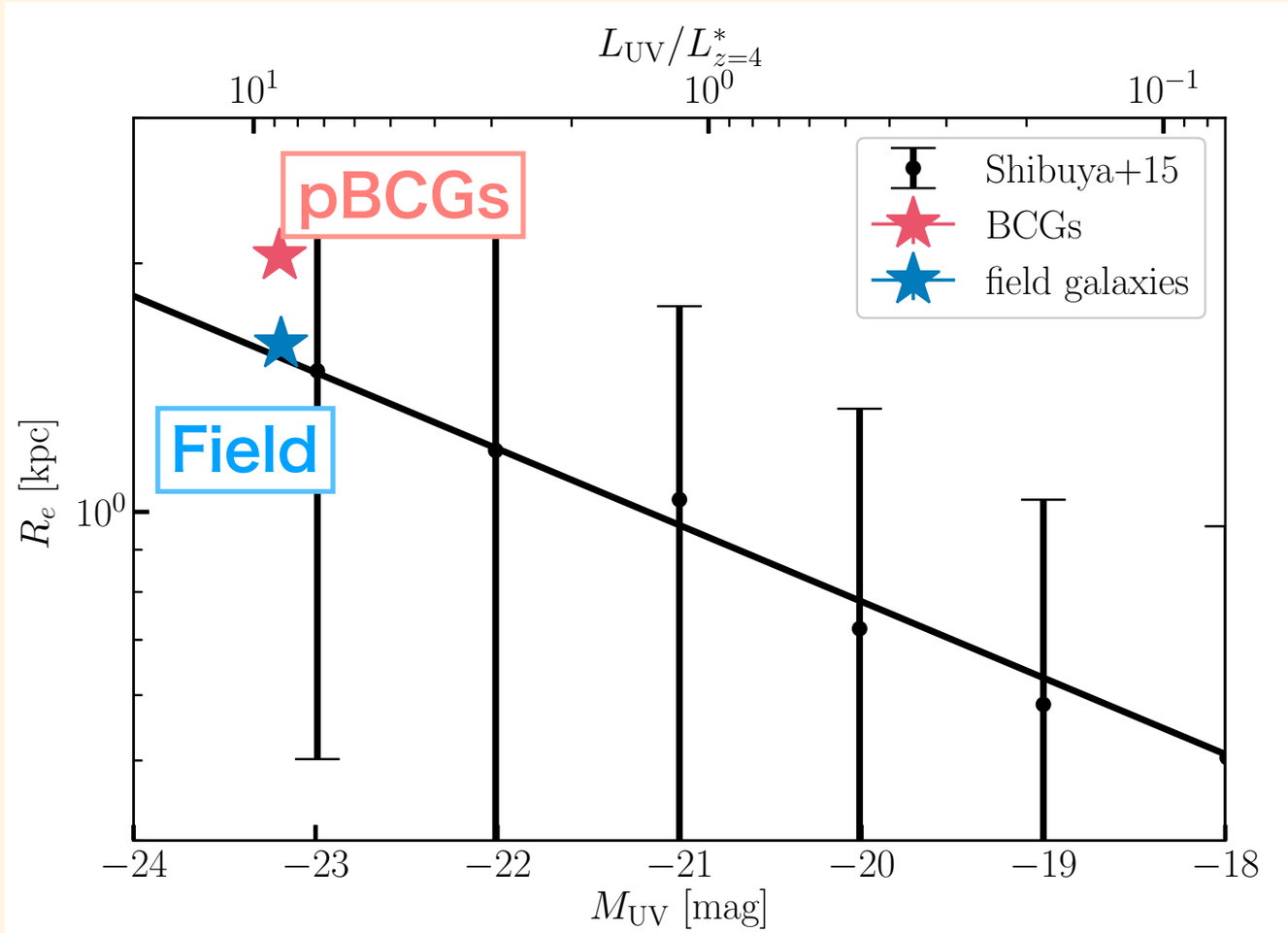


Size Estimation

- Estimate the effective radius in Sersic Profile by GALFIT
- n=1.5 in Sersic Index

$$I(r) \propto \exp[-b_n(\frac{R}{R_{eff}})^{1/n}]$$

- **proto-BCG is 28% larger than field gal.** $(r_{e,\,\mathrm{BCG}} = 2.042^{+0.012}_{-0.013}\ \mathrm{kpc})$



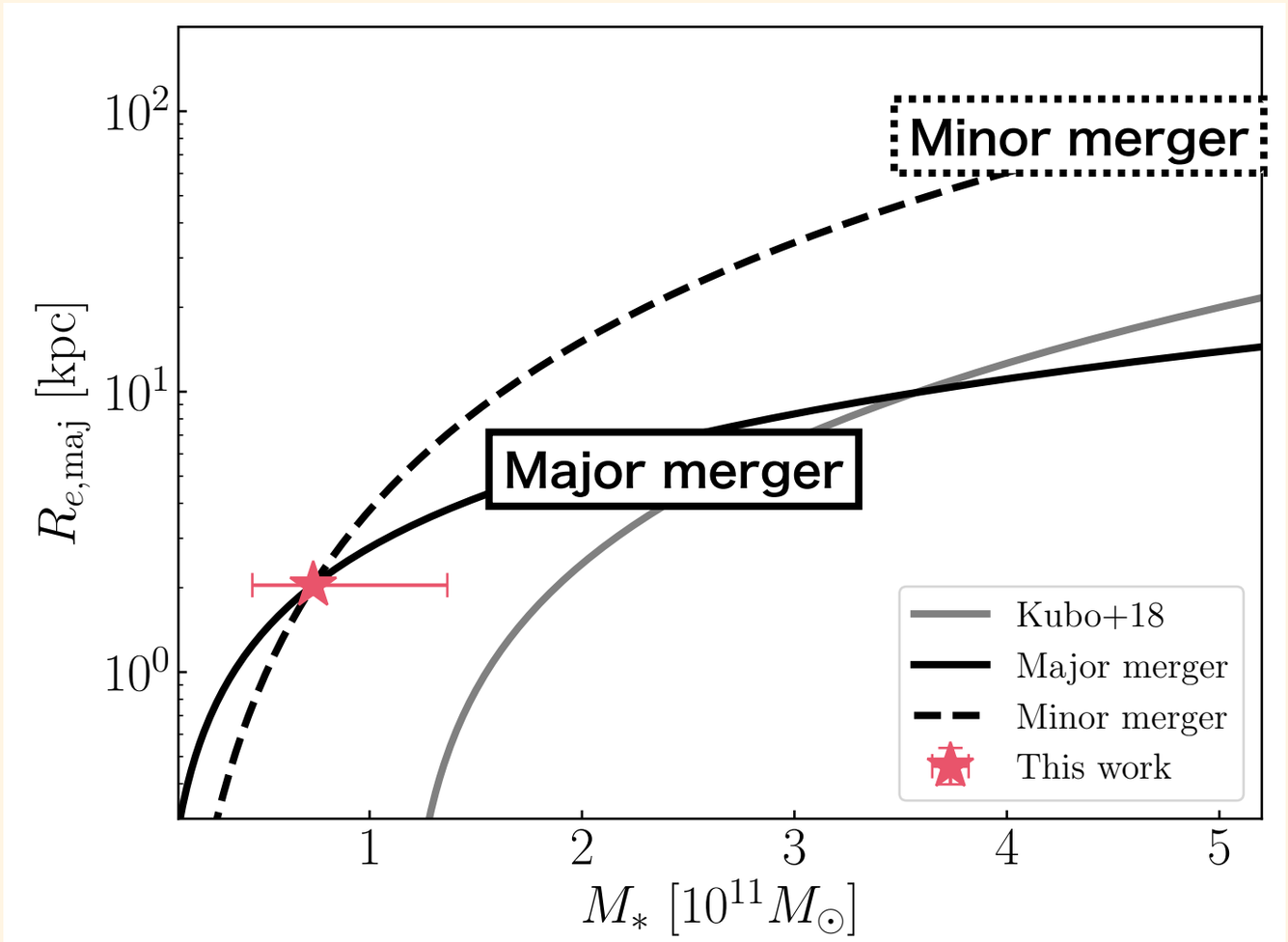
- **The possible origin of the profile difference**

1. Concentration of the dust at center
2. The existence of satellite gal. around the outer part of proto-BCGs

Suggestion to the BCG's evolution

- Size-Mass Growth
- Stellar mass: estimated from SF main sequence (Song+16)

$$\log M_*/M_\odot = 10.87 \pm 0.2$$



- Estimate the growth-track from the toy-model (Bezanson+09)
  →Suggest mainly evolve through the minor merger
  →The possibility to evolve into $M_* \sim 3-4\times10^{11} M_\odot$ at z~0 from the minor merger

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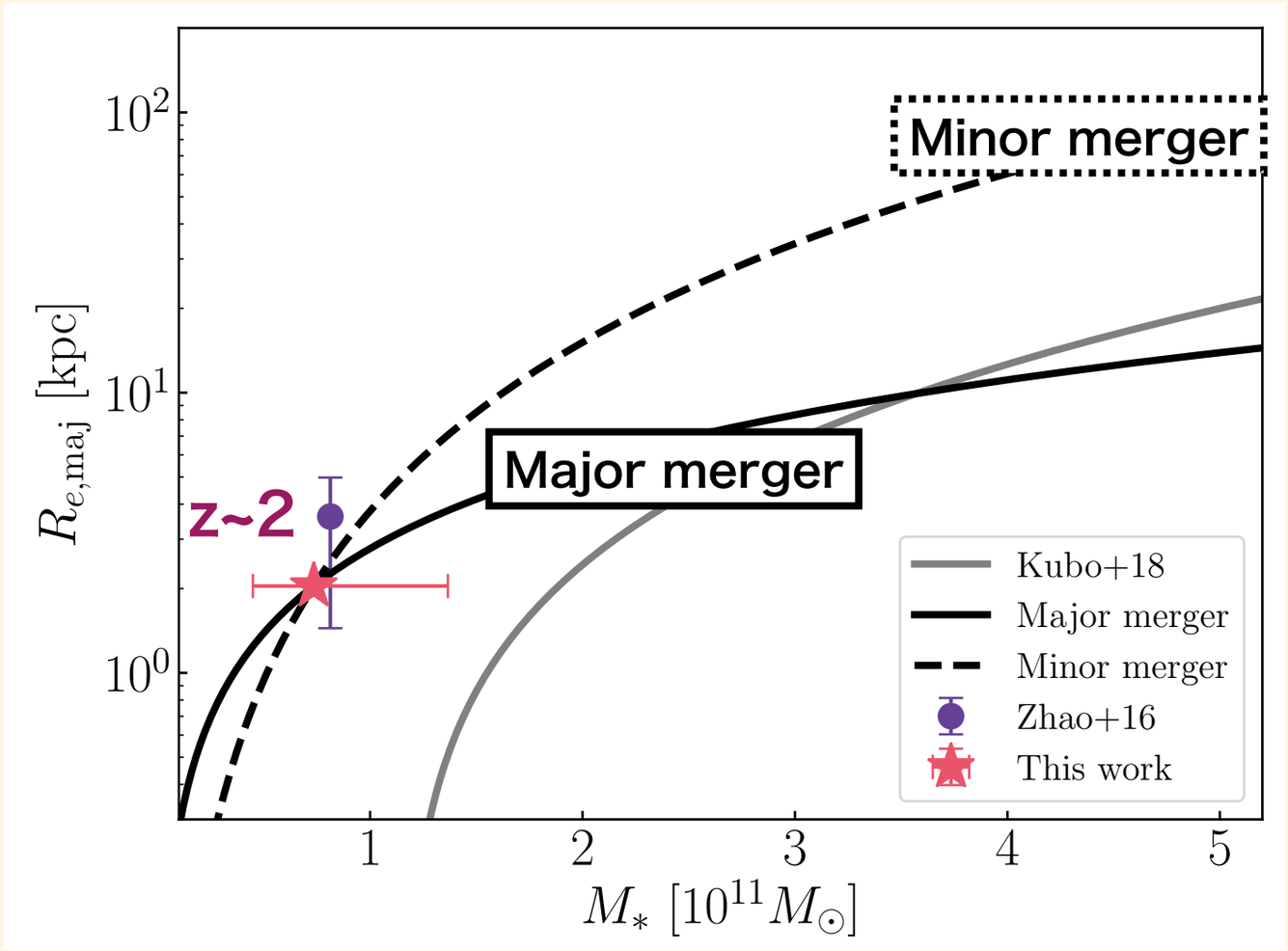

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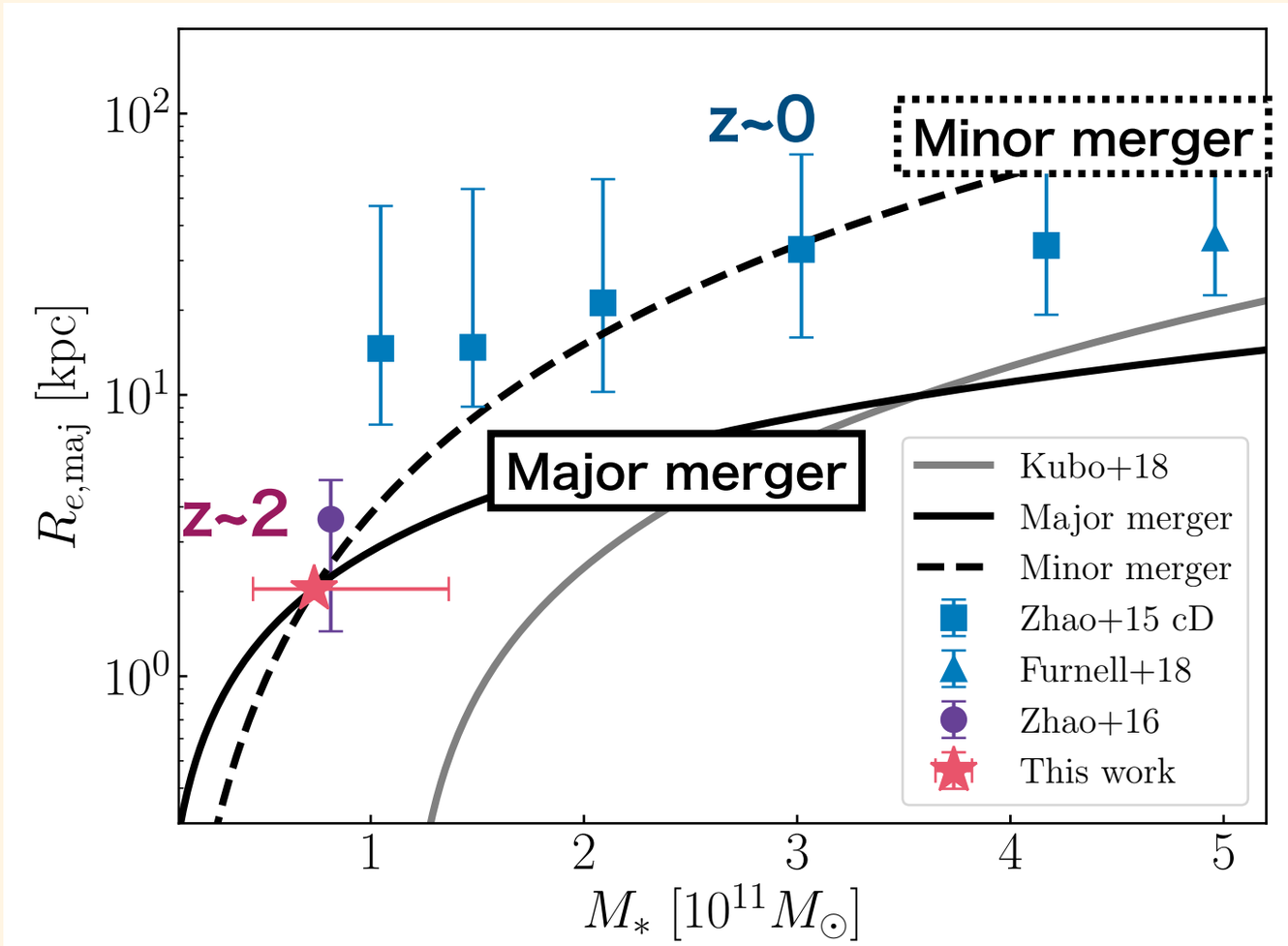

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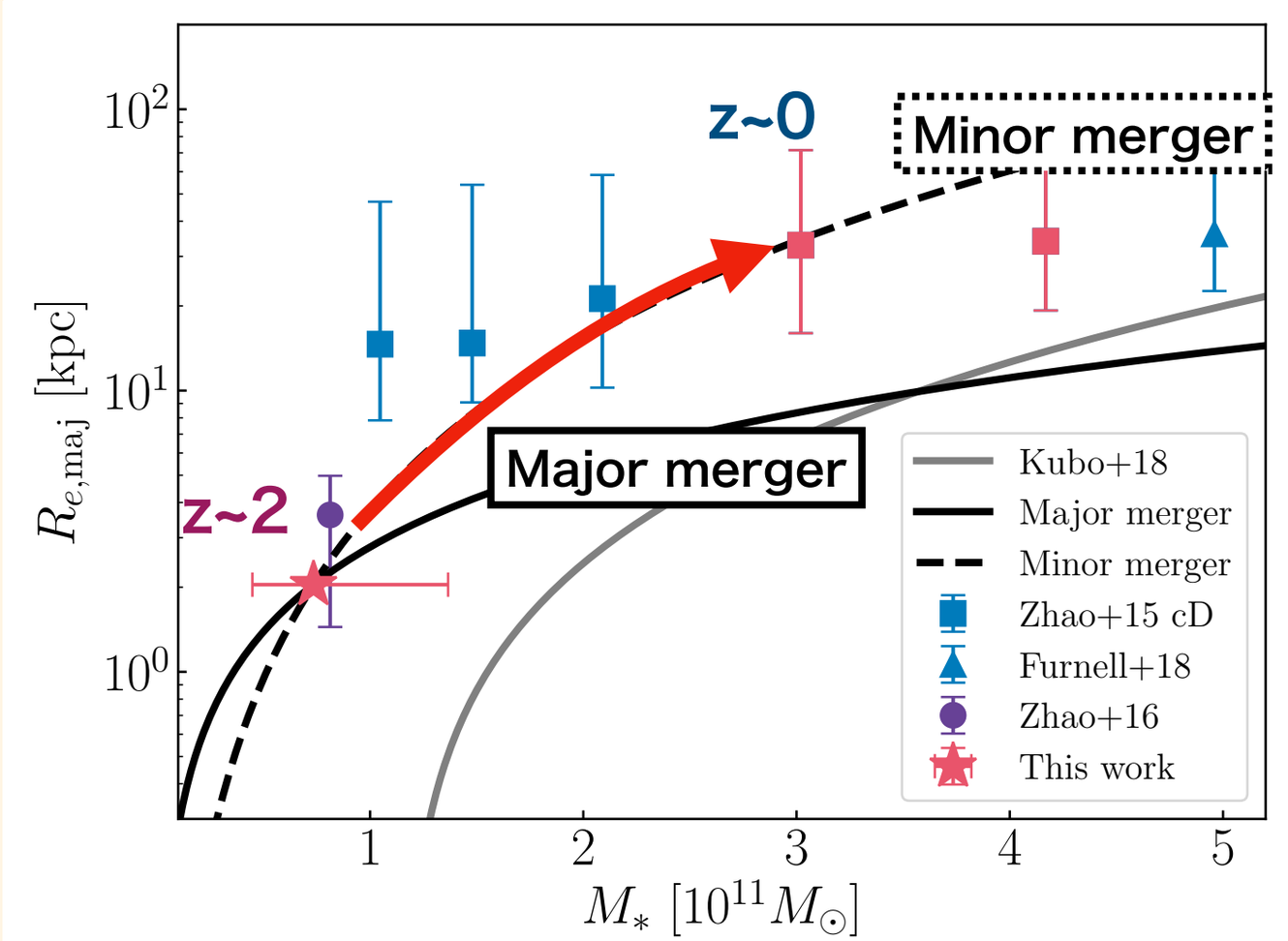

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Summary

- **Survey the UV brightest galaxies "proto-BCGs" from 179 z∼4 HSC PCs**
  (Ito et al. ApJ 2019 arXiv:1904.01597)

- 63 brightest galaxies that are 1mag brighter than the 5th brightest are selected.

- Proto-BCGs are redder in i-z than Field gal. considering the luminosity.
- PC member w/ pBCG are also **redder** but PC member w/o pBCG have the same
  →proto-BCG and surrounding gal. are **dustier**
  →Different SFH in protocluster regions compared to blank field?

- We compare average radial profile from stacking analysis.
  - proto-BCG's radial profile are **elongated** than Field gal.
  - proto-BCG's effective radius is **28%** larger than Field gal.
    →The concentration of the dust at the center?
    or
    The existence of the satellite galaxies?