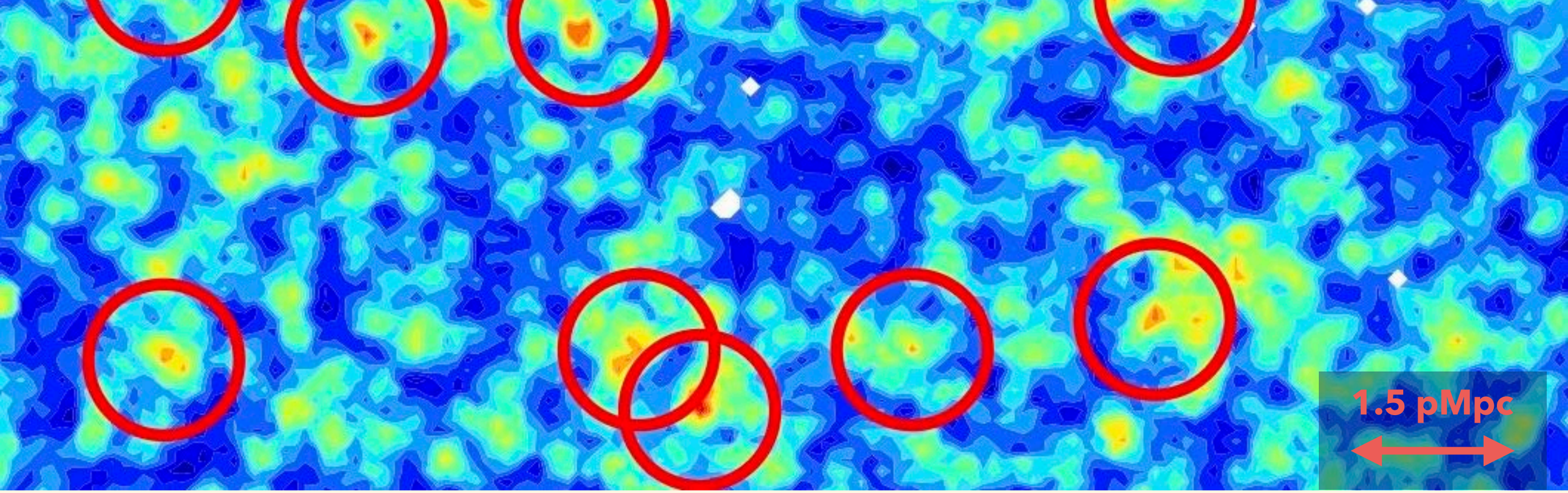


The rest-frame UV luminosity function of protocluster galaxies at z~4 revealed by HSC-SSP

Kei Ito (SOKENDAI/NAOJ)

Nobunari Kashikawa, Jun Toshikawa, Roderik Overzier, Mariko Kubo, Hisakazu Uchiyama, Yongming Liang, Masafusa Onoue, Yu Komiyama, Chien-Hsiu Lee, Yen-Ting Lin, Murilo Marinello, Crystal L. Martin, Takatoshi Shibuya

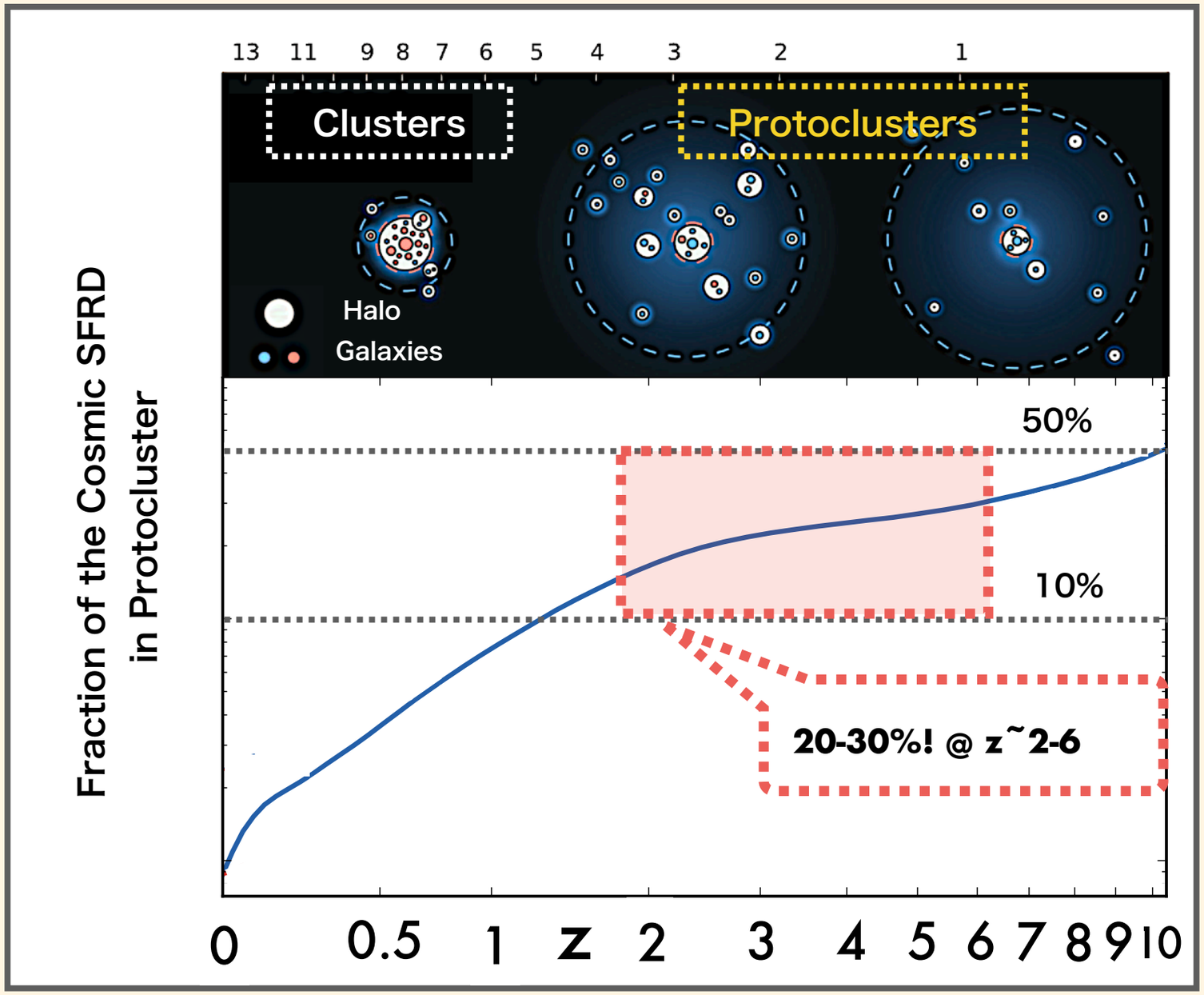
National Astronomical Observatory of Japan

SOKENDAI

Ito et al., ApJ, 2020

Protoclusters

- Protocluster (PC): "**progenitor" of galaxy cluster with** $M_{\rm halo} > 10^{14} M_{\odot}$ at $z \sim 0$
- Unique laboratory for understanding the impact of the large-scale structure on galaxy properties
- Simulations predict that protoclusters contribute significantly to the cosmic SFRD.

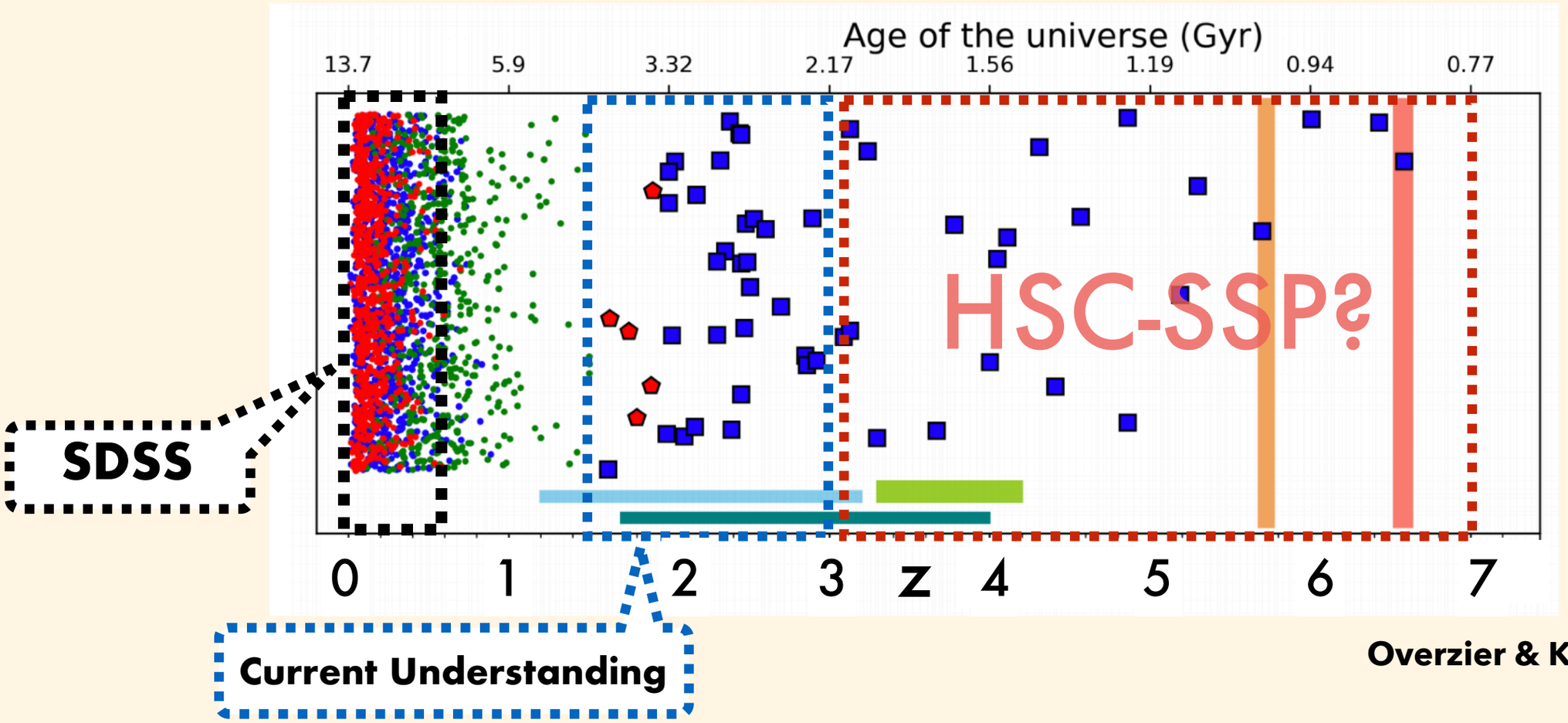


c.f. Chiang+17

Protocluster and galaxy evolution

- At z~2, PC galaxies have higher SFR, and more massive (e.g, Koyama+13, Shimakawa+18)
  → Suggesting the more active star formation in protoclusters?
- At z>3, it is not clear due to the insufficient protocluster sample (~20)
  → **We need a large and systematic sample!**

HSC-SSP can break the obstacle!

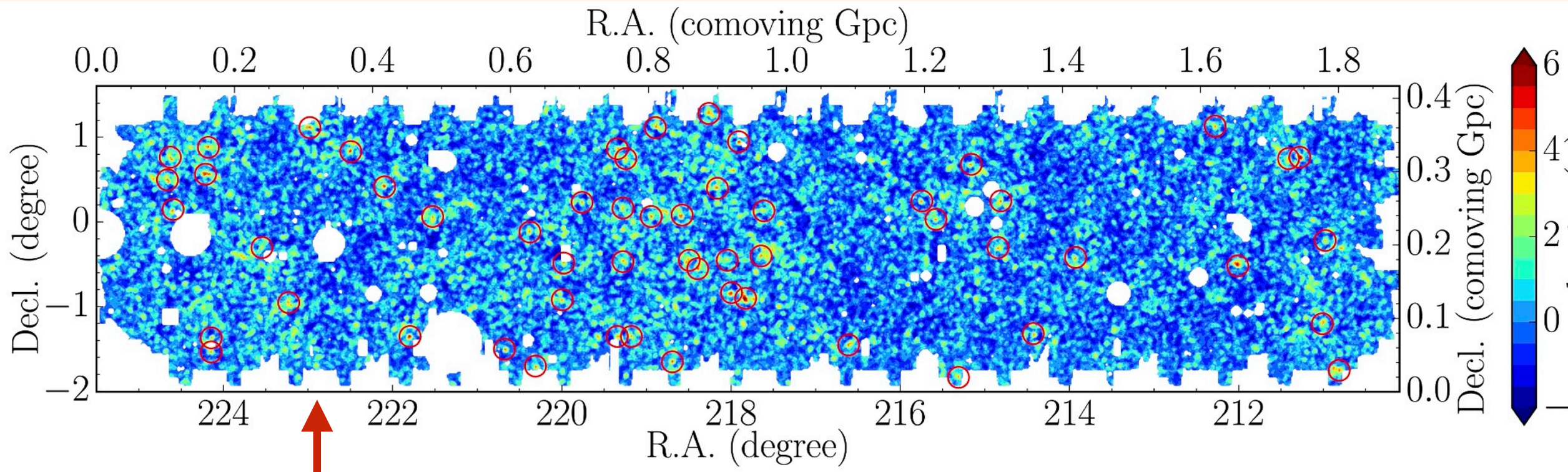


Overzier & Kashikawa19

Protocluster Selection

- HSC-SSP protocluster selection at z~4 (Toshikawa+18)

1. Selecting g-dropout galaxies
2. Plotting their overdensity with 1.8' aperture
3. Selecting overdensities with >4σ as protoclusters



The density map of LBGs at z~4

Protocluster Selection

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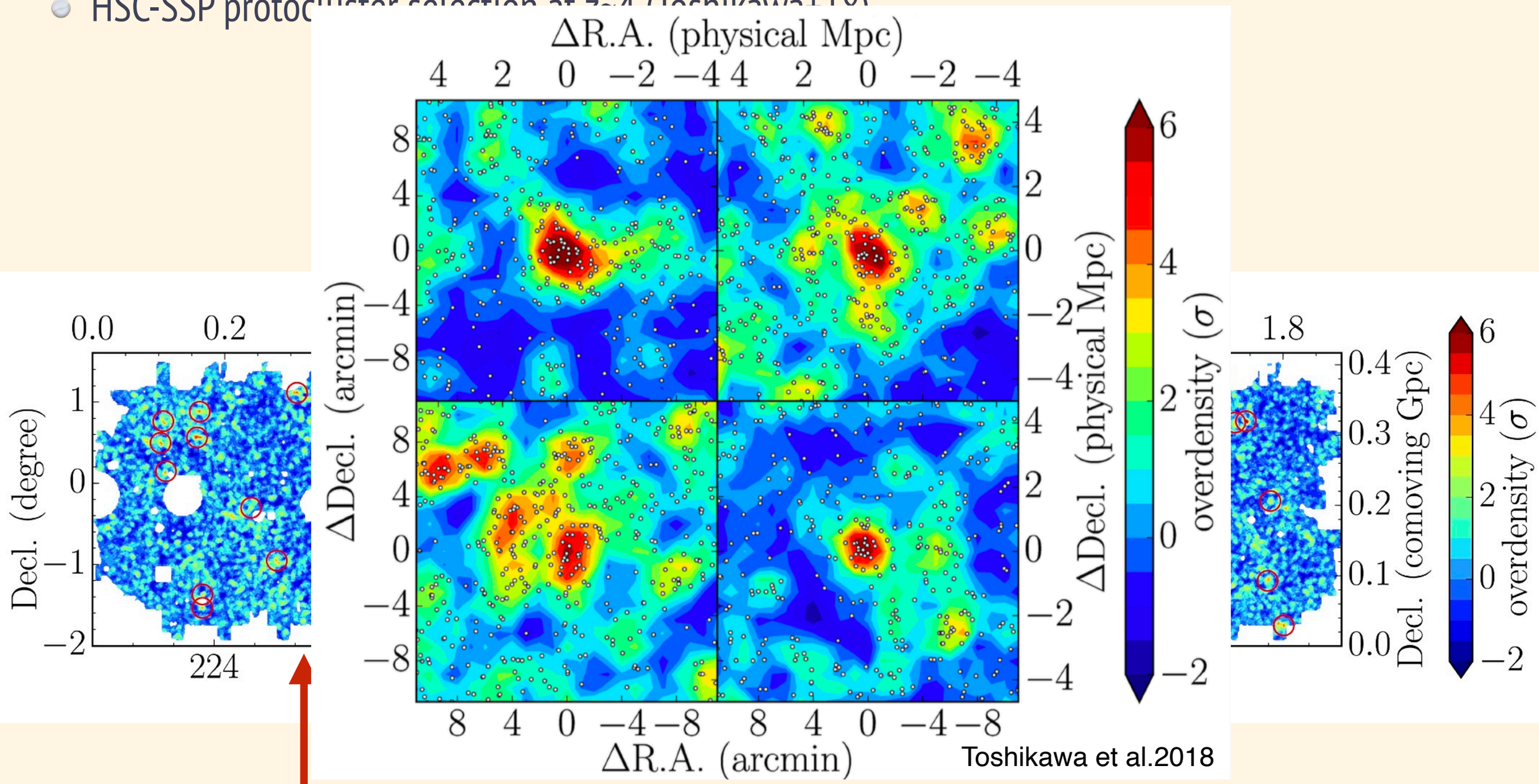


Toshikawa et al.2018

We detected 179 protocluster candidates at z~4!

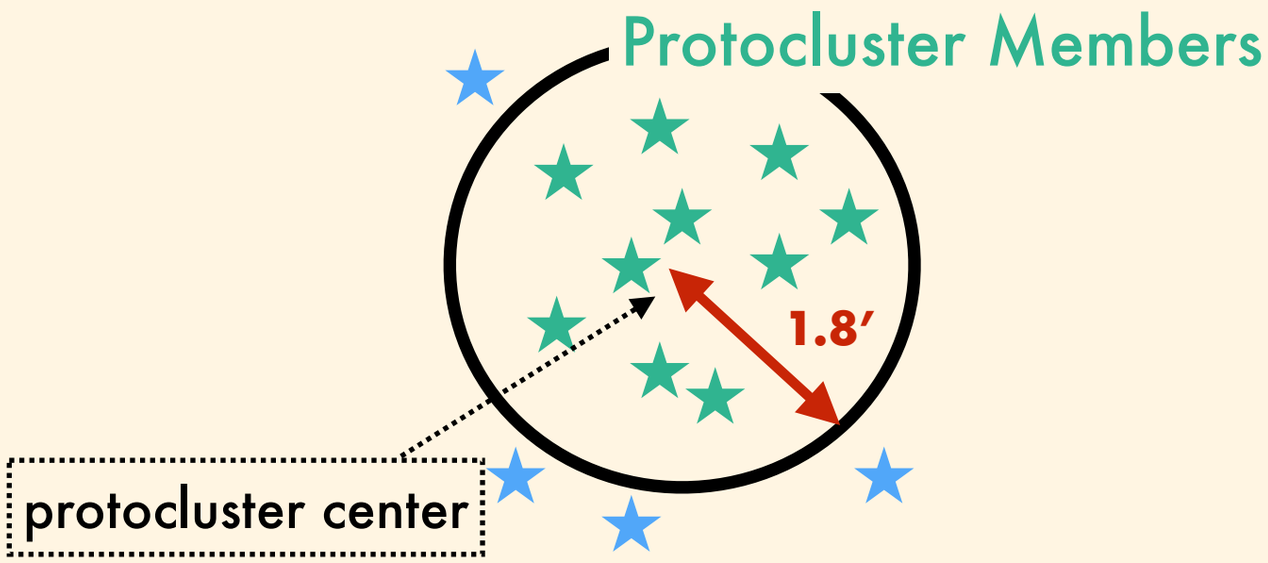
Protocluster galaxy UV luminosity function

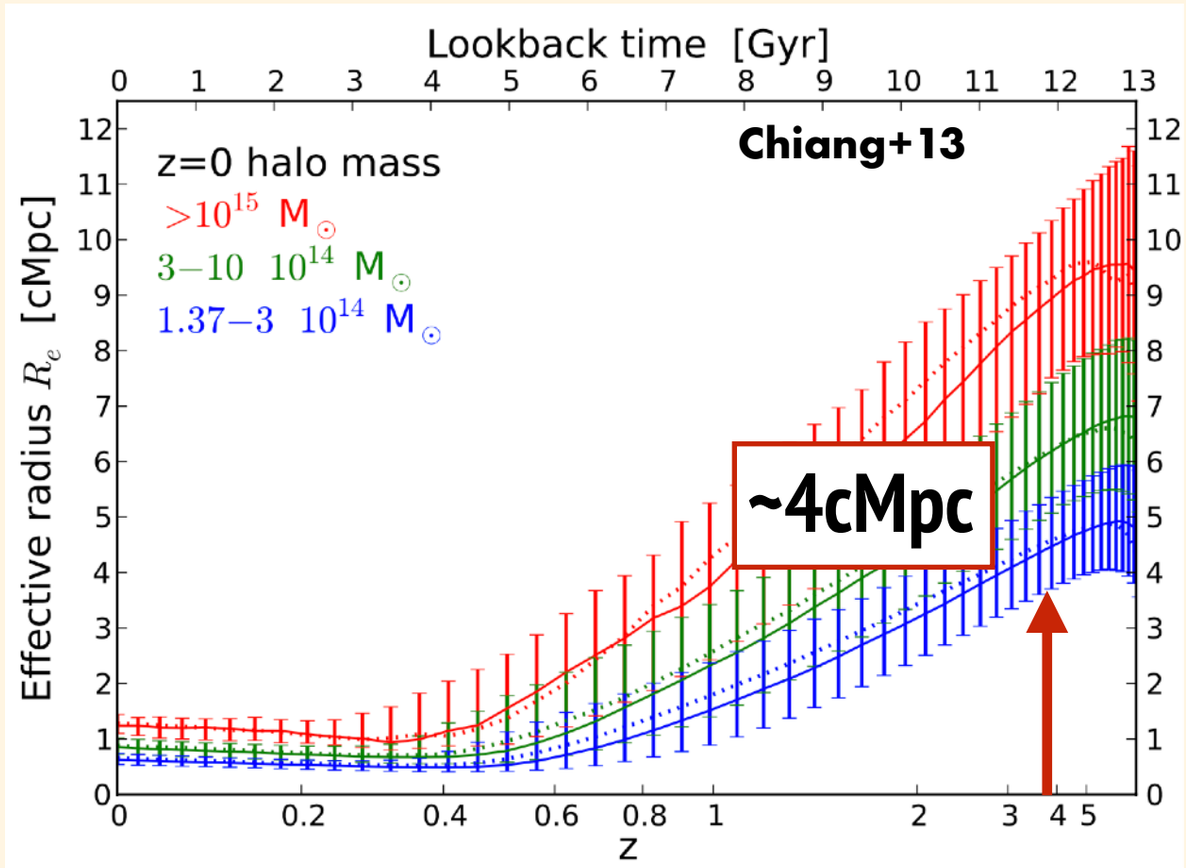
- Do protocluster members have different star formation compared to field galaxies?

  →**Deriving the rest-UV luminosity function (UVLF) as a proxy of SFR distribution**

- Defining protocluster members

  - g-dropout galaxies within 1.8' from the density peak (typical scale of protocluster)



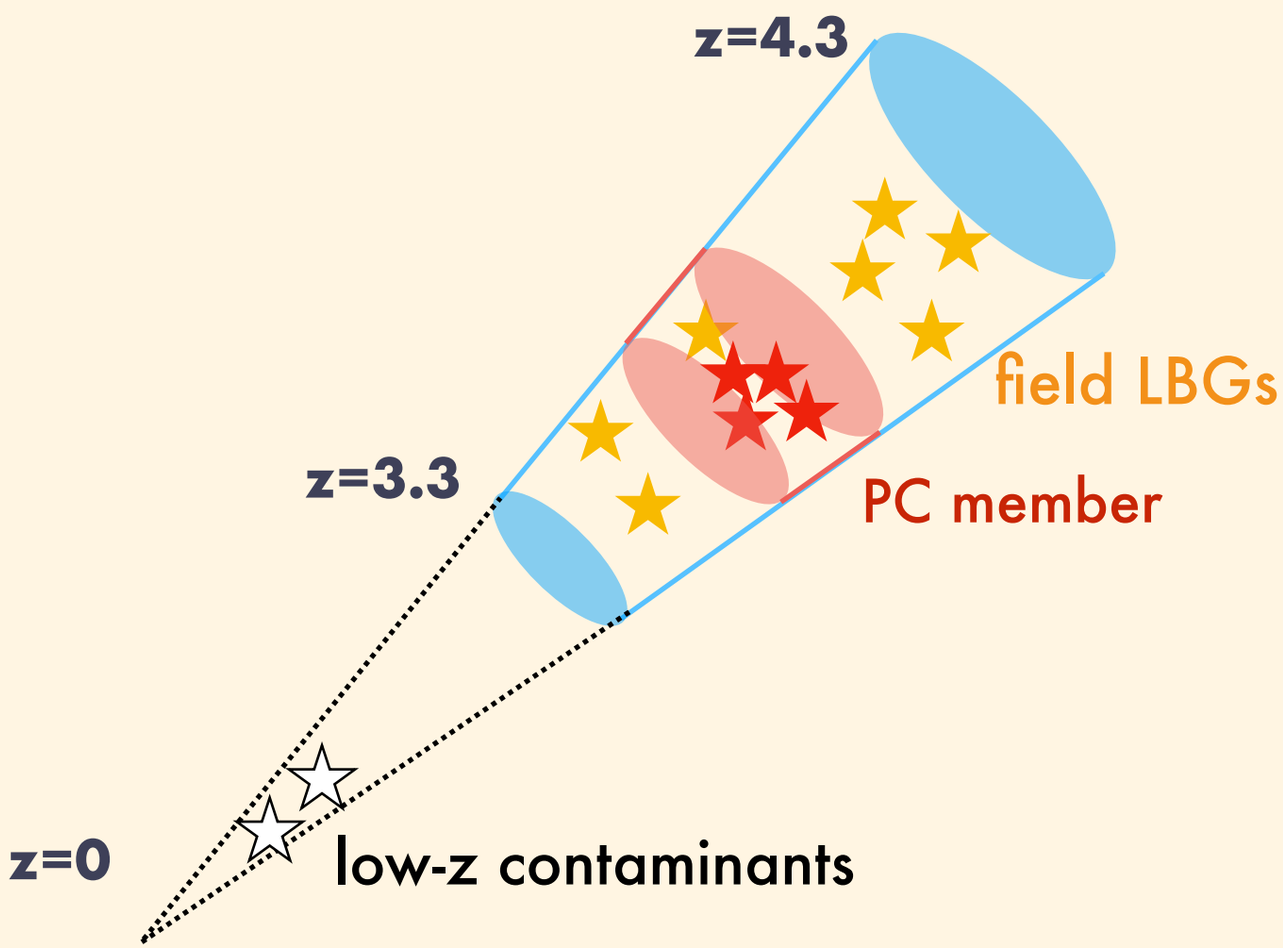


Formulation of PC UVLF

- **The estimation of the PC UVLF**
- The largest sample, but not all galaxies are spectroscopically confirmed

  →Possibility of interlopers

  →**They are uniformly distributed, so we exclude statistically.**



$$\Phi_{\mathrm{PC}}\left(M_{\mathrm{UV}}\right)=\frac{1}{F\left(M_{\mathrm{UV}}\right)}\left(\frac{n_{\mathrm{obs,PC}}\left(M_{\mathrm{UV}}\right)}{V_{\mathrm{eff}}\left(M_{\mathrm{UV}}\right)}-\Phi_{\mathrm{field}}\left(M_{\mathrm{UV}}\right)\right)$$

- $n_{\mathrm{obs,PC}}\left(M_{\mathrm{UV}}\right)$: The observed number of protocluster galaxy
- $\Phi_{\mathrm{field}}\left(M_{\mathrm{UV}}\right)$: Field galaxy UVLF without contamination treatment (☆+★)
- $V_{\mathrm{eff}}\left(M_{\mathrm{UV}}\right)$: Effective Volume of g-dropout gals. **(blue)**
- $F\left(M_{\mathrm{UV}}\right)$: The volume ratio of PC and field (**blue V.S. red**)

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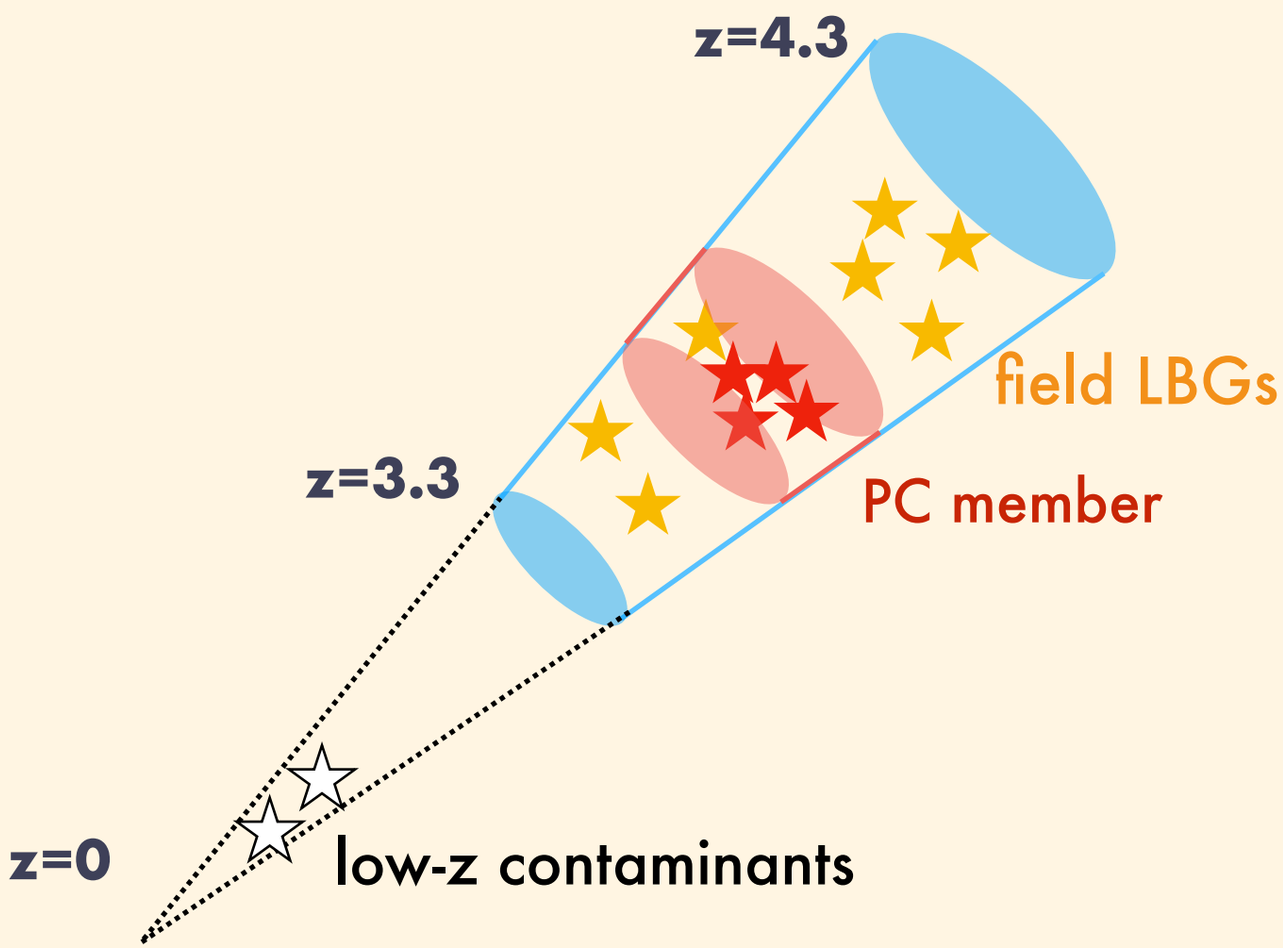

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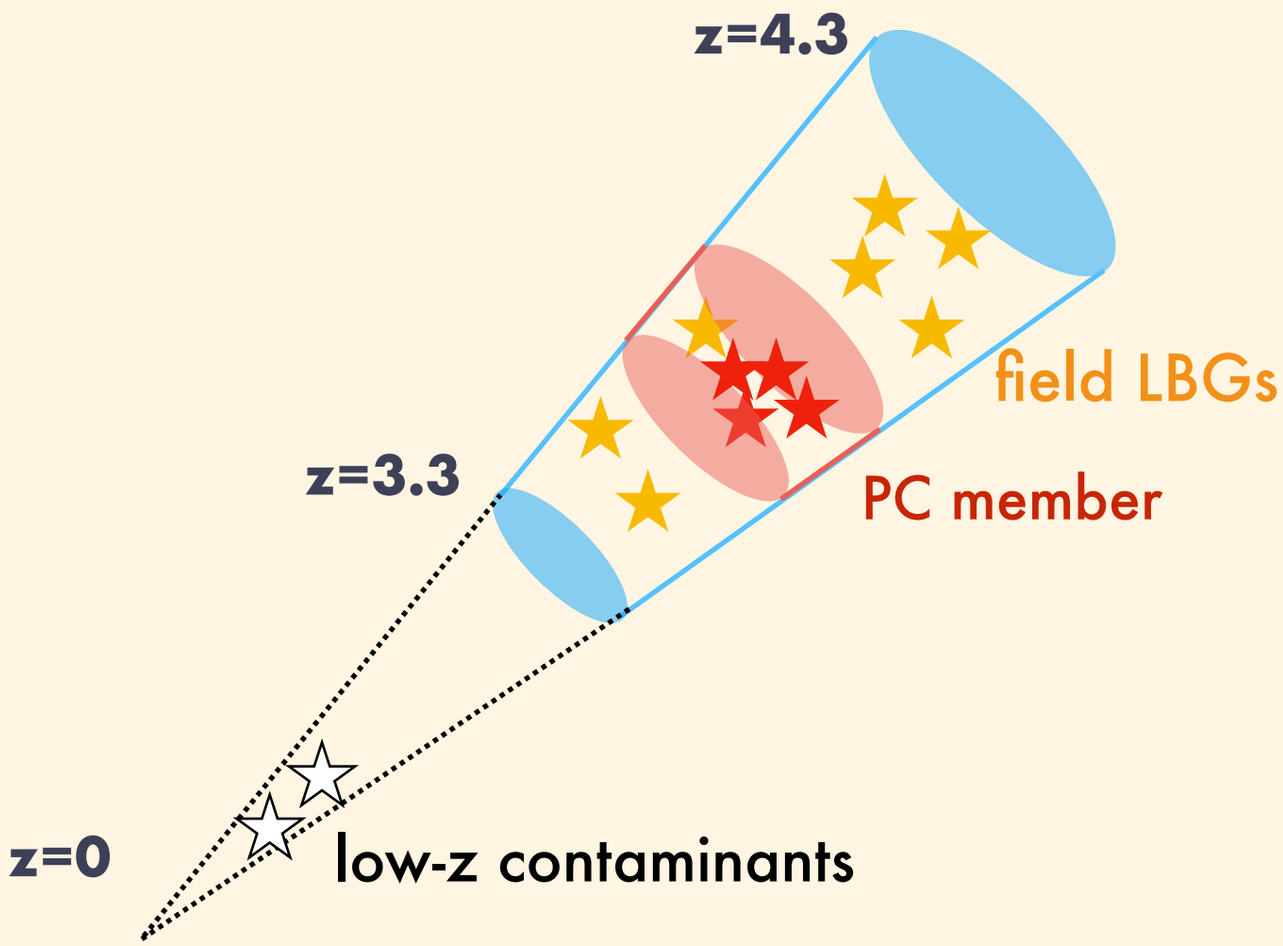

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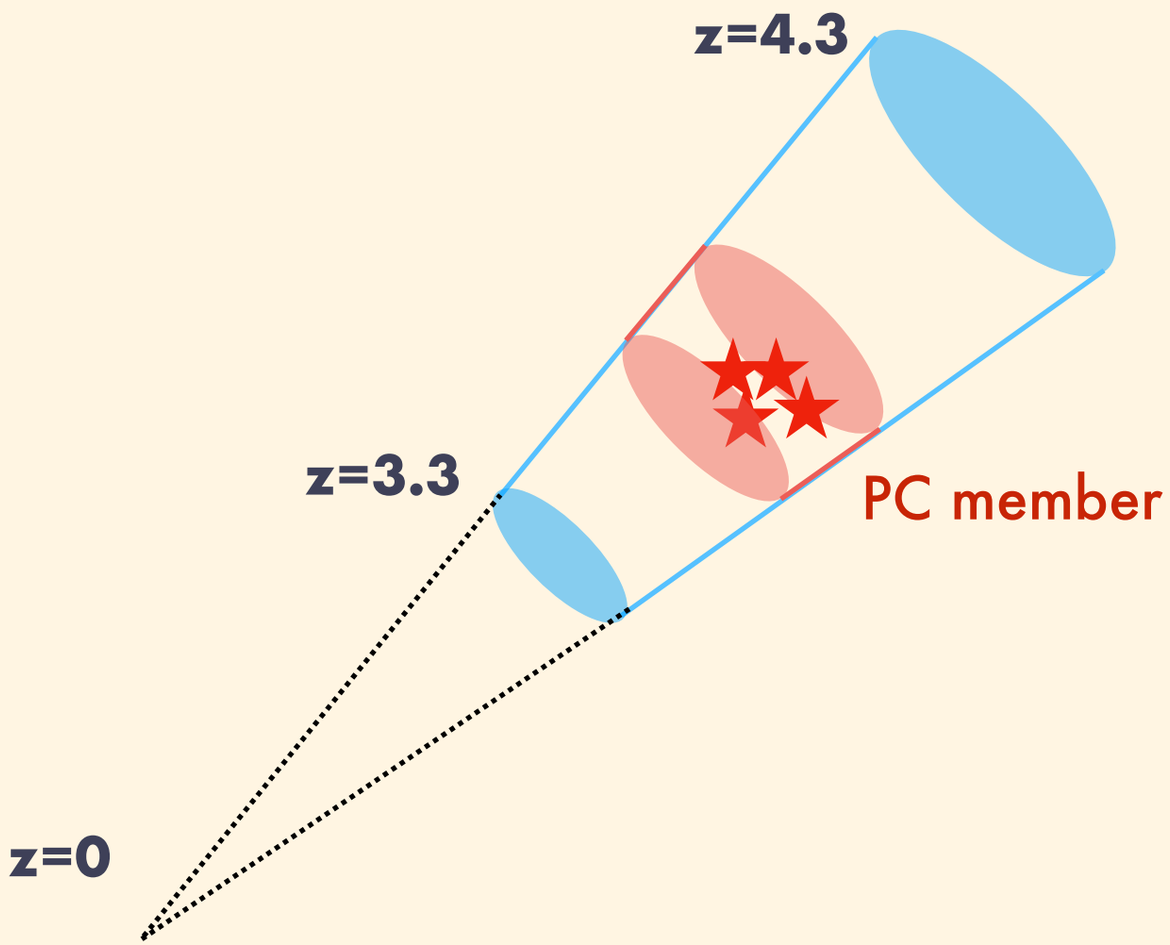

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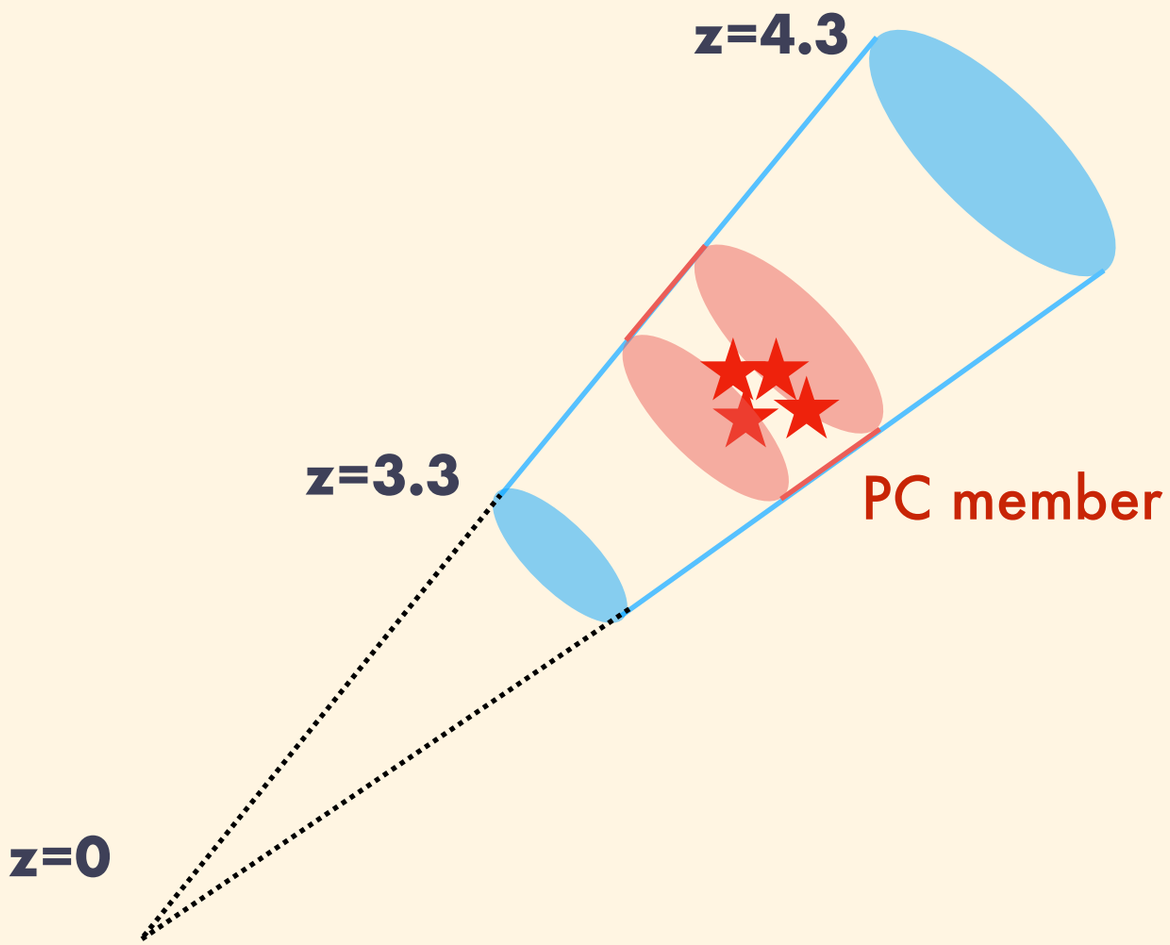

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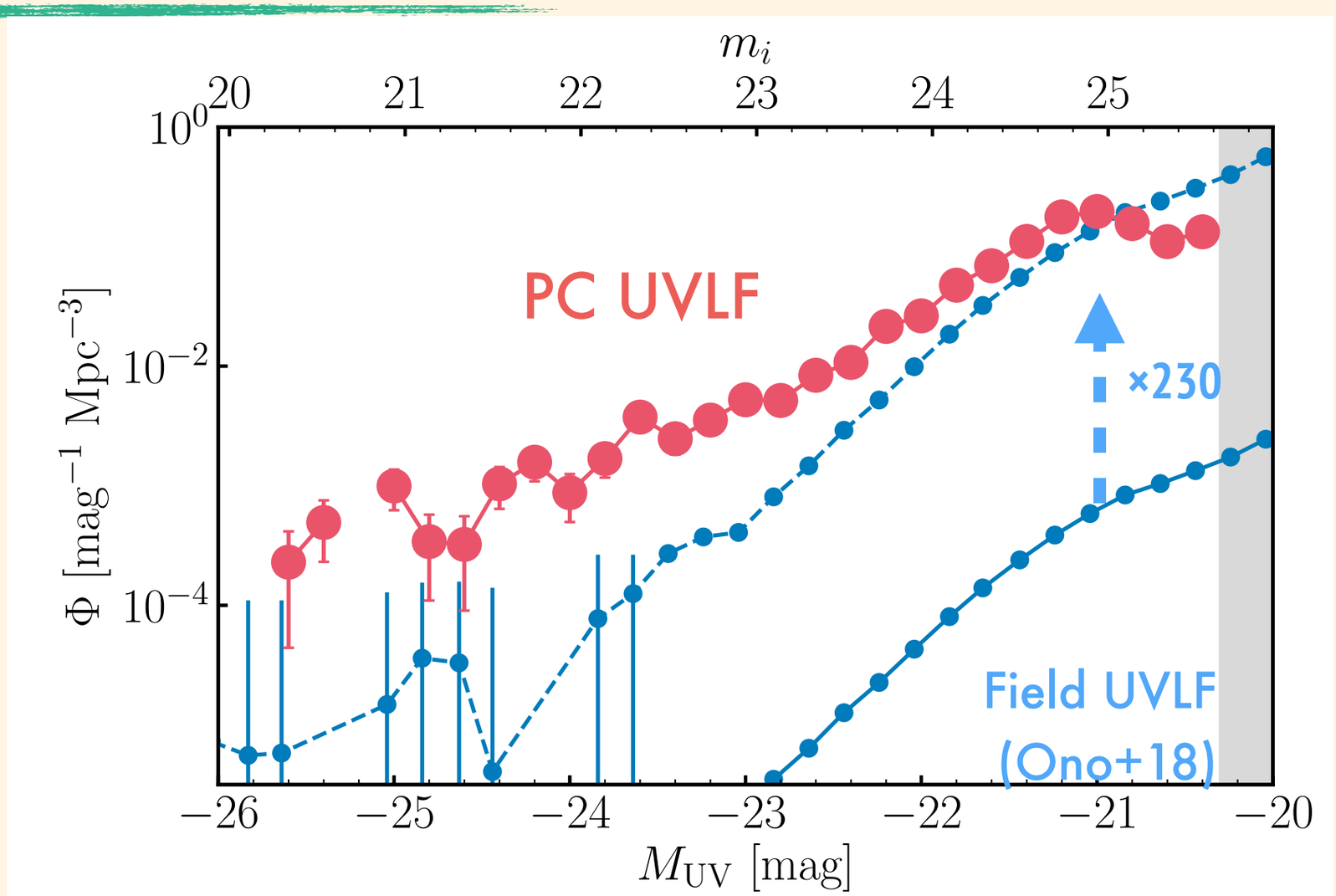
PC UVLF



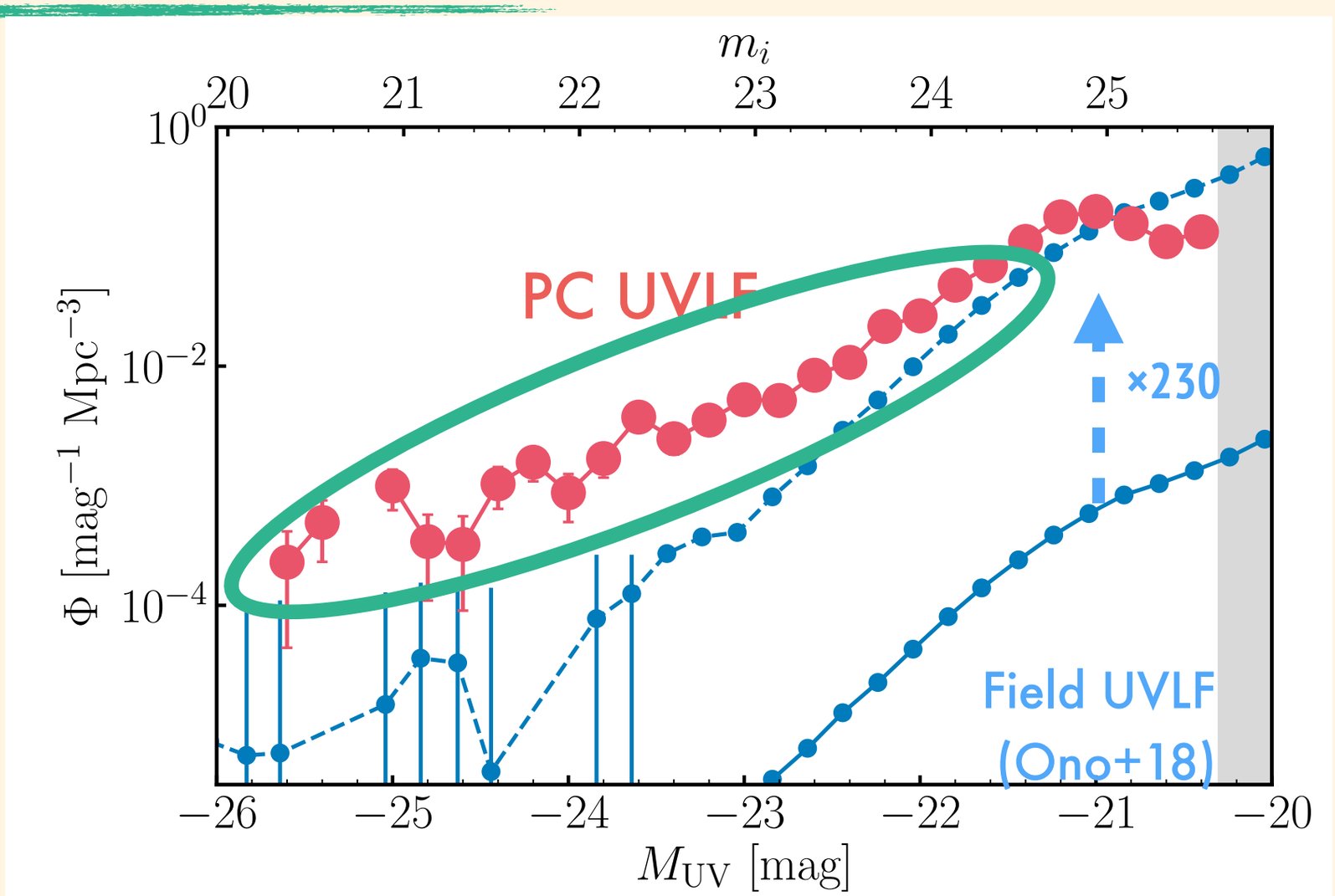
- **Differences between PC UVLF and field UVLF**

  1. High Amplitude
  2. **The bright-end excess**

→Protocluster galaxies tend to have higher SFR even at z~4.

※AGNs are not likely the only reason of the bright-end excess.

PC UVLF



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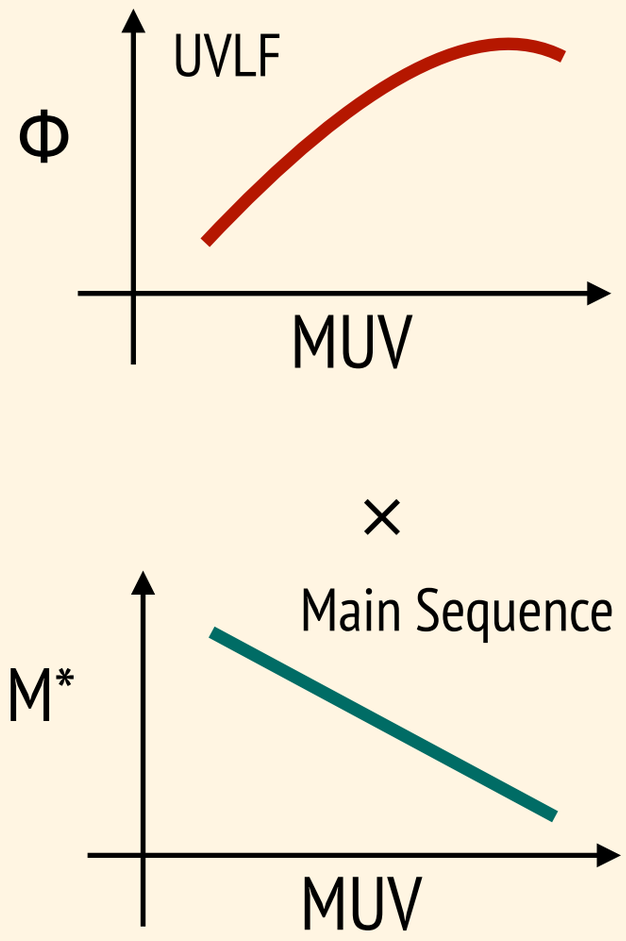
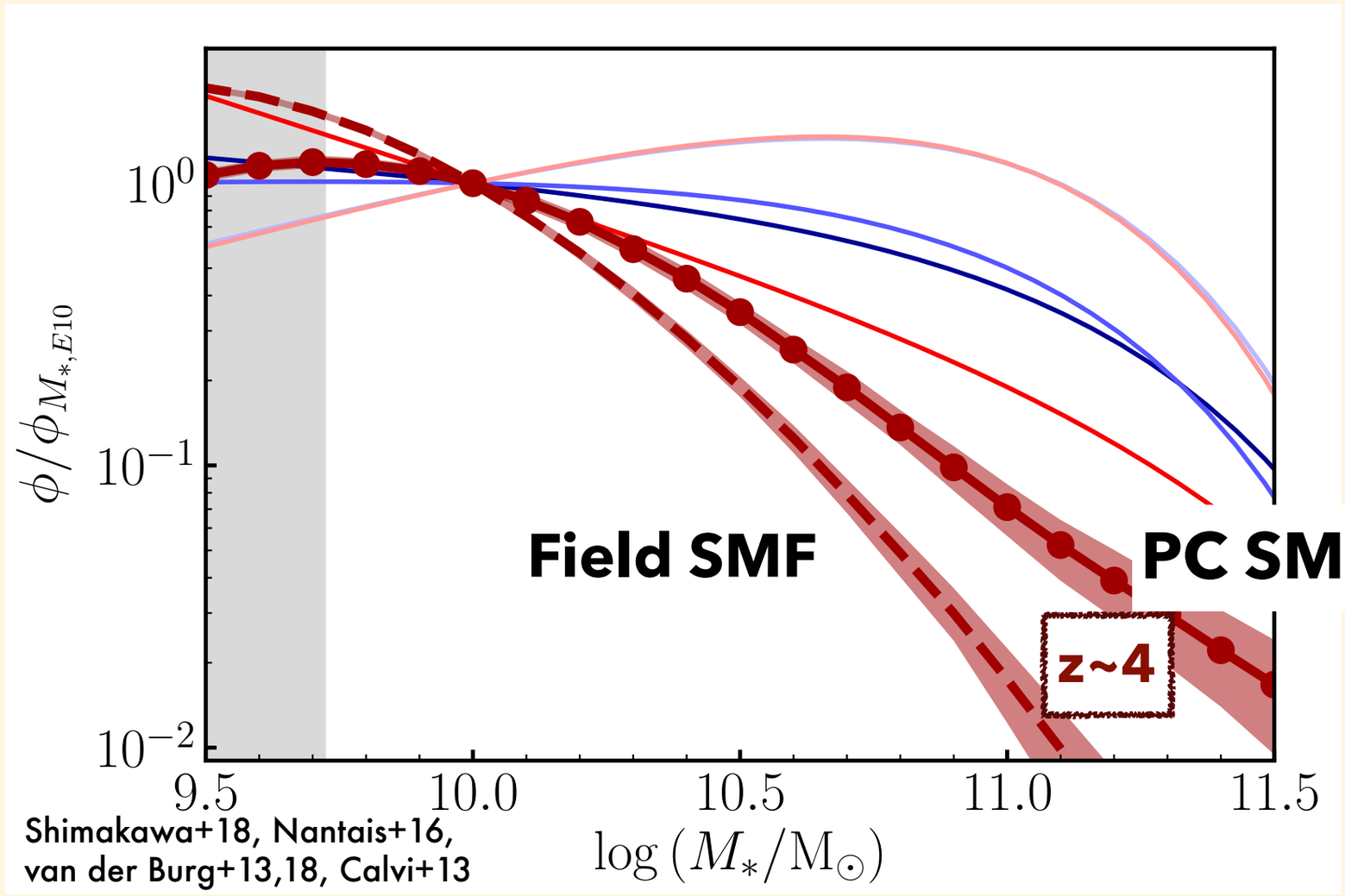
Stellar Mass Function

- Assuming the M*-Muv relation of field galaxies.
- PC SMF is much top-heavy compared to the field SMF
- PC SMF is steeper than low-z (Proto)Cluster SMF

→ **Galaxies in protoclusters at z~4 is more evolved than field galaxies, but still in the middle of the evolution.**





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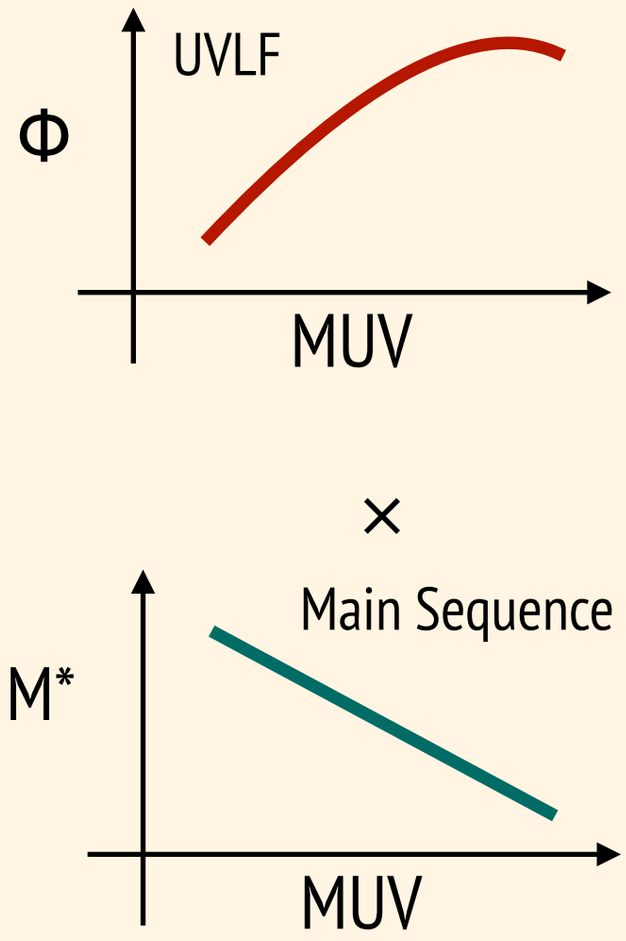

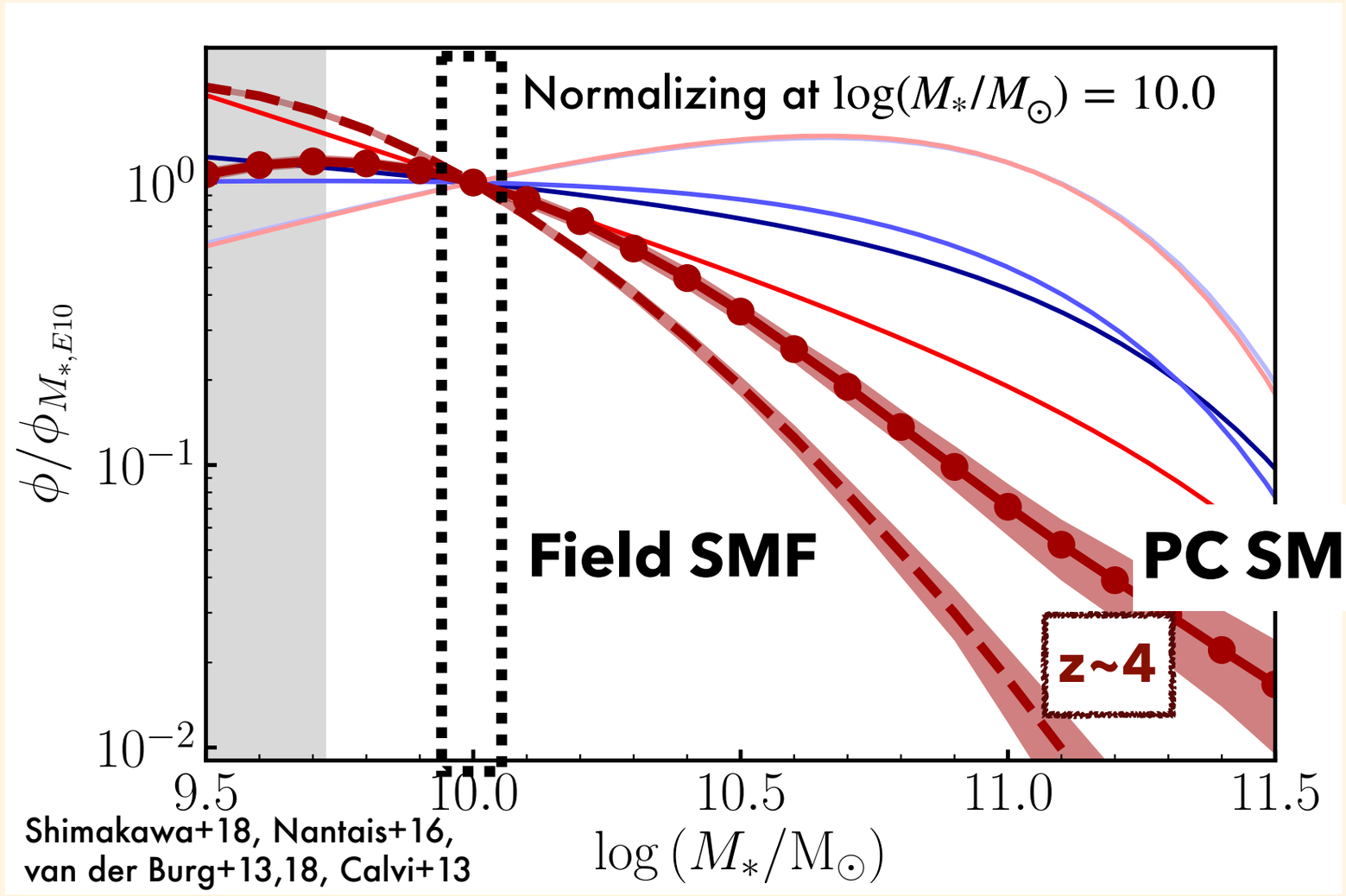

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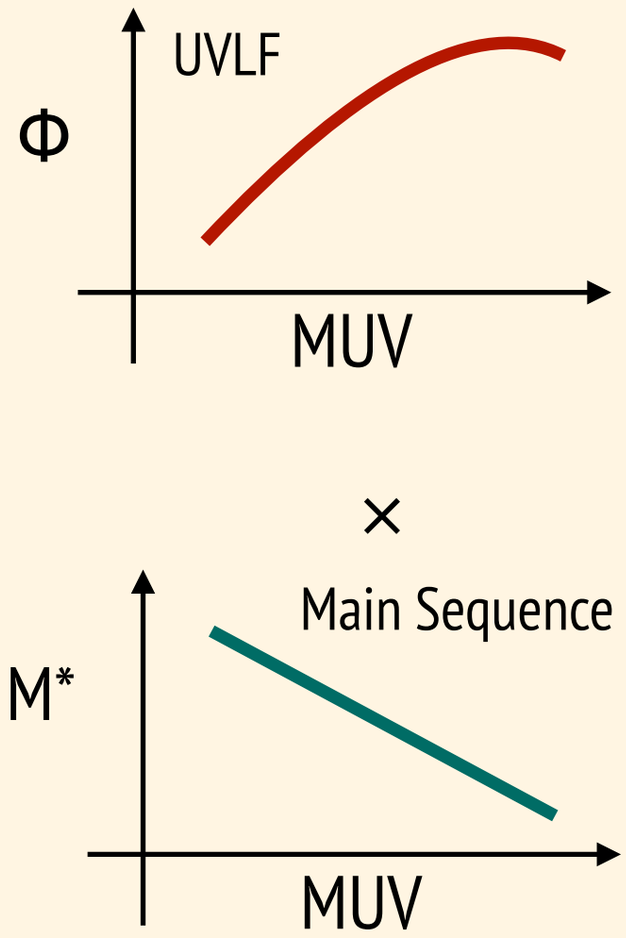
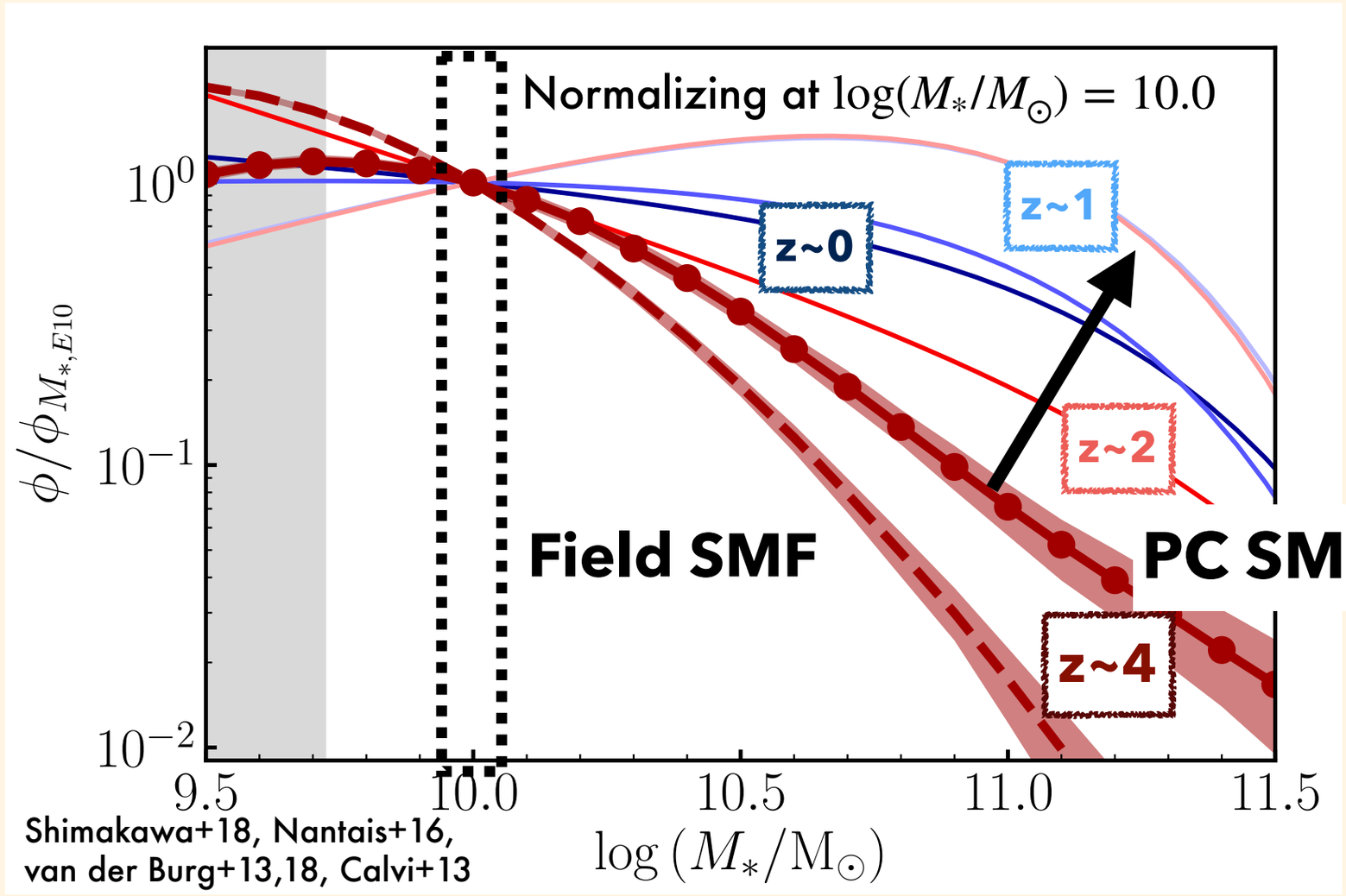
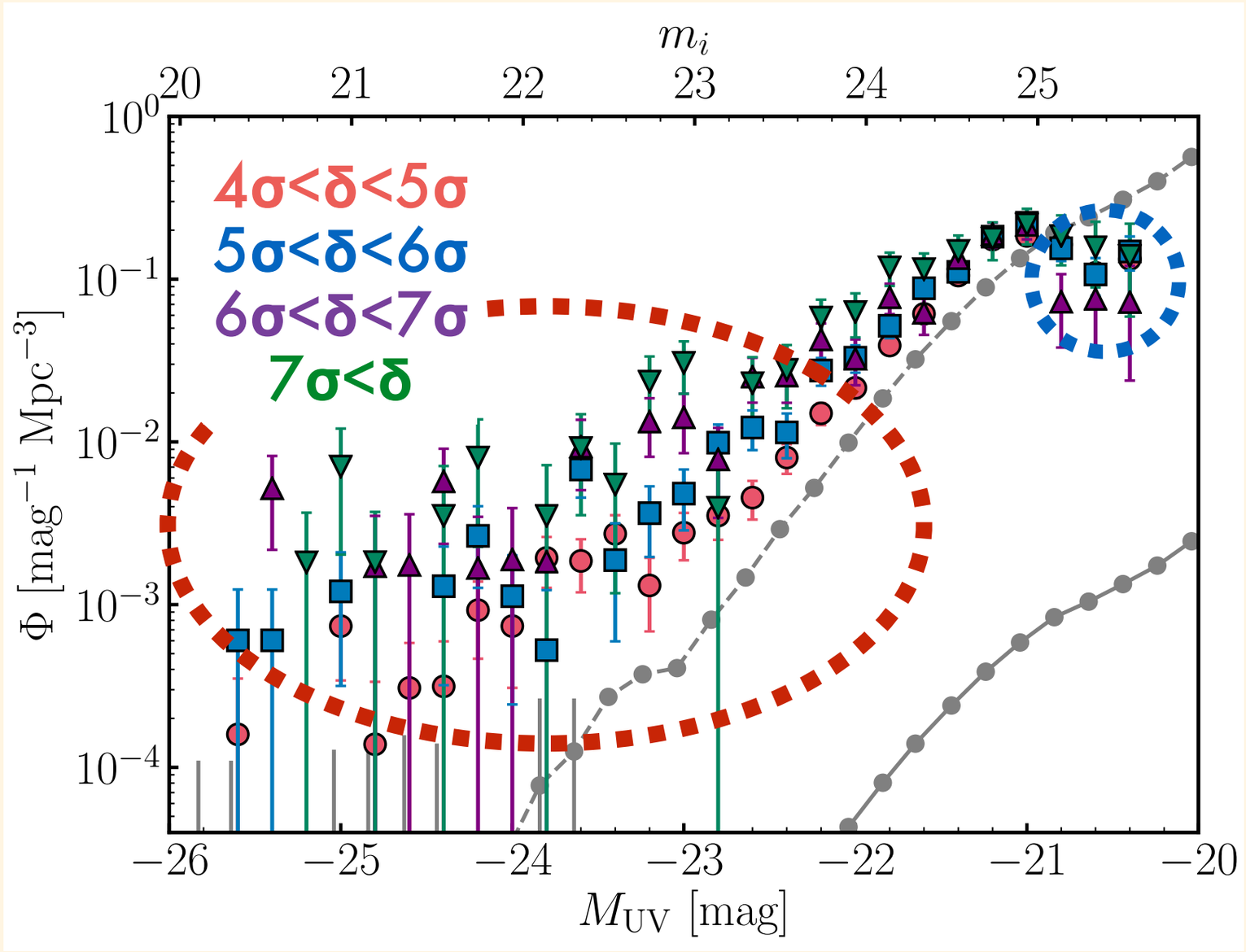




Overdensity Dependence

- Subdividing protocluster sample to 4 subsample according to overdensity
- Same faint-end, but **higher bright-end in more massive PCs**



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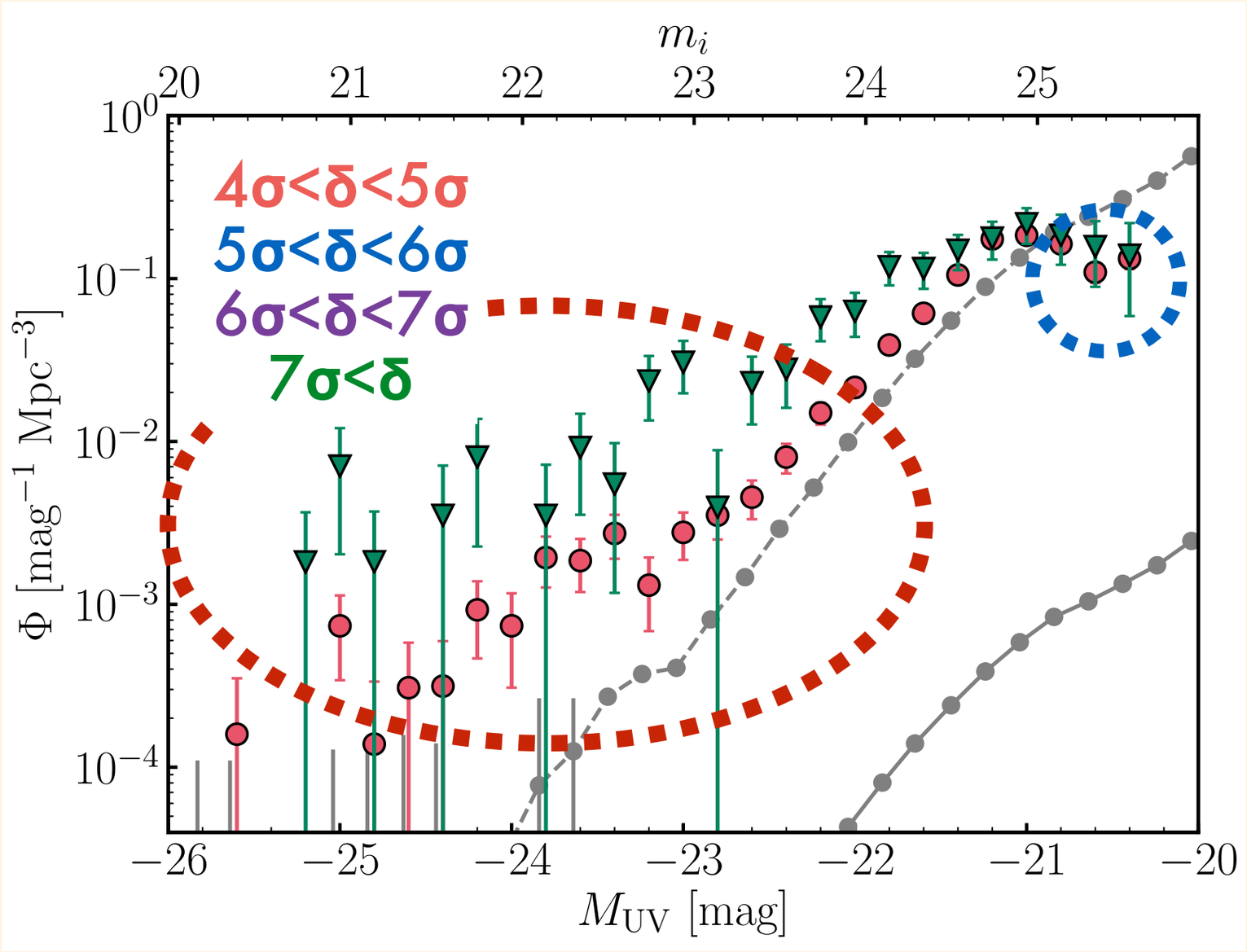
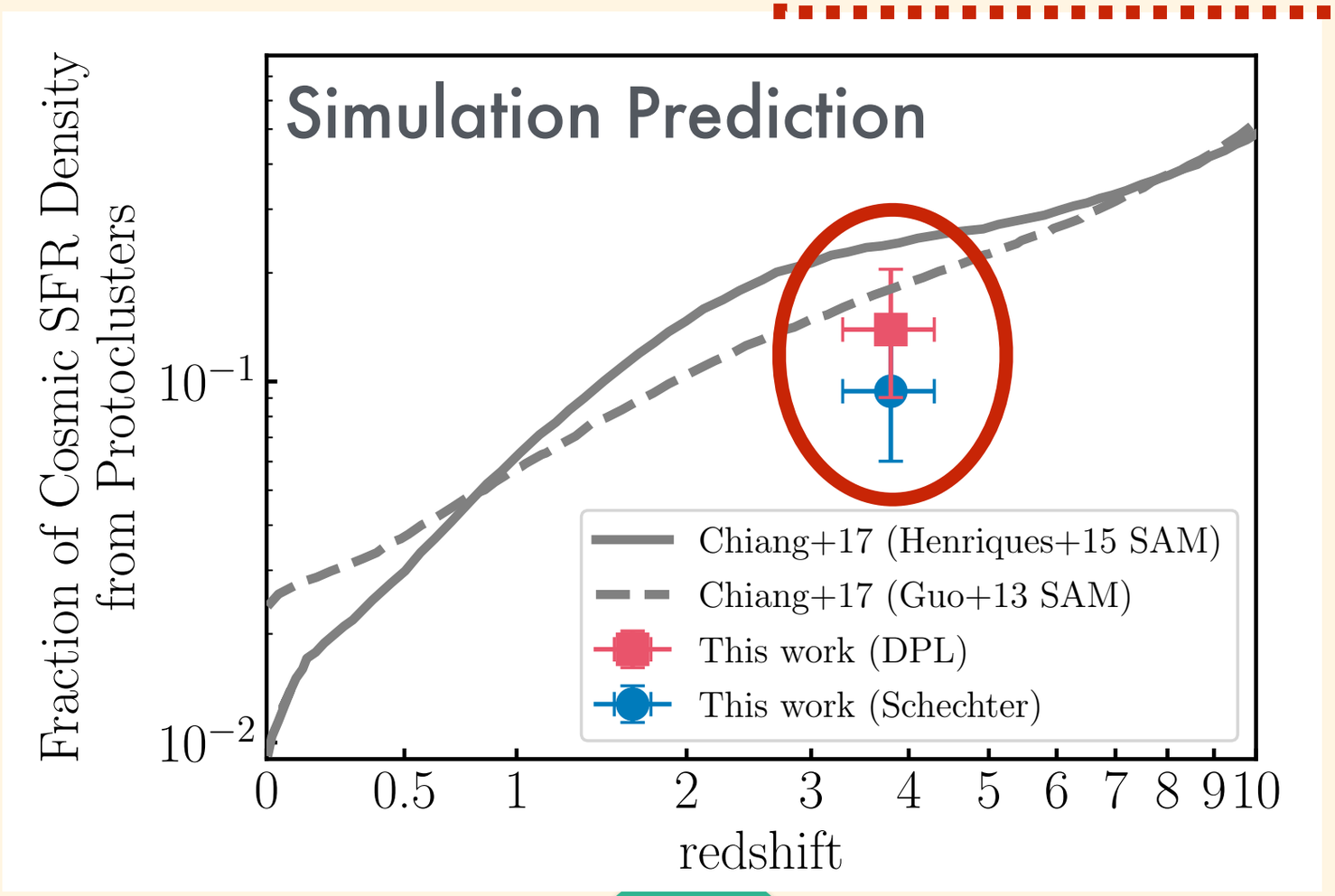


SFRD

- Our PC have 2.5 dex higher SFRD than the blank field.
- For estimating the fraction of the Cosmic SFRD, we need two corrections
  1. **Completeness** (What percentage of protocluster did we select?)
  2. **Purity** (How many our objects really evolve to cluster?)

6-20% of the total cosmic SFRD!



Galaxy Evolution in Protocluster regions

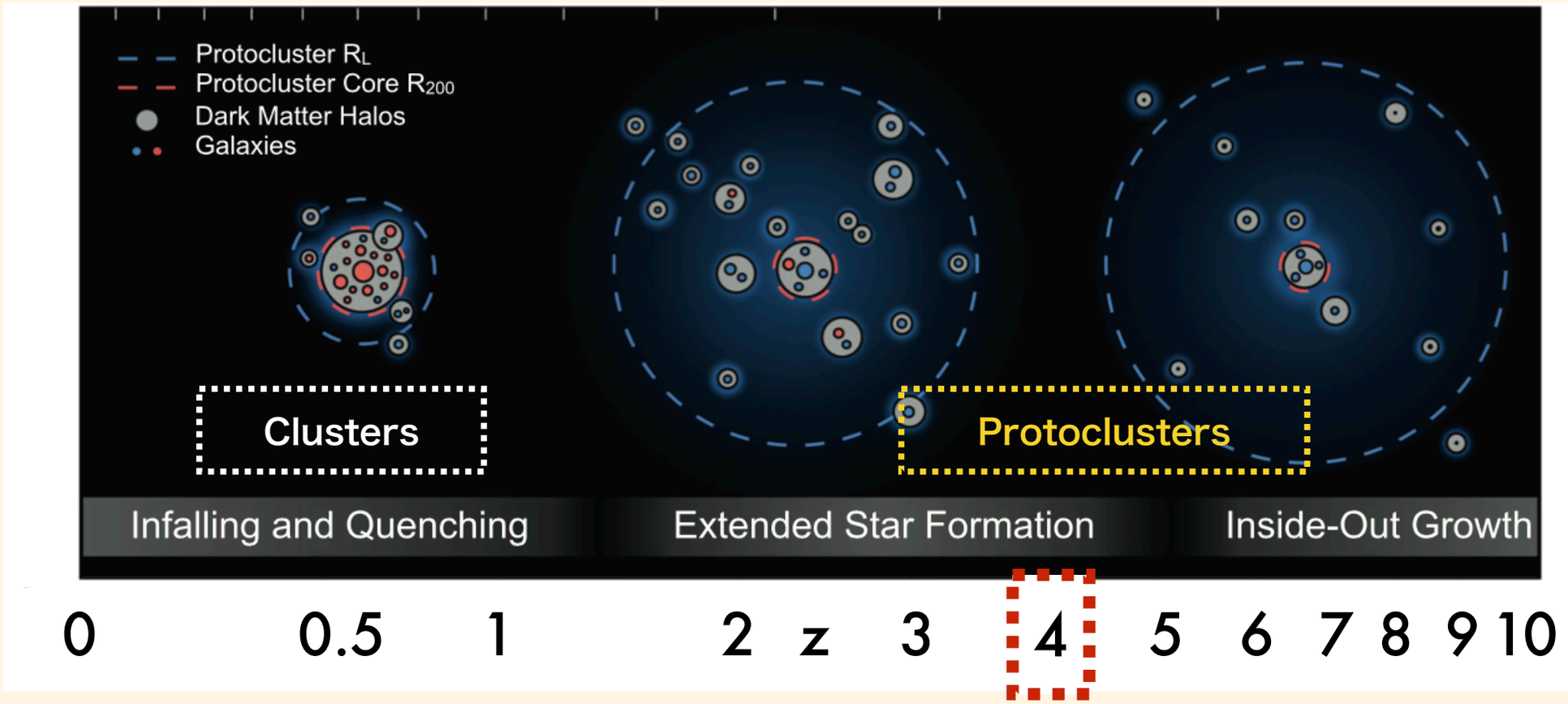
- **UV-bright protocluster galaxies at z~4**

  - Higher SFR (higher stellar mass) compared to field galaxies

  - in the middle of the evolution to low-z (proto) clusters

  - significant contribution to the cosmic star formation rate density

  →Observationally suggesting the advanced galaxy evolution in protoclusters?



Chiang+17

Summary

- Deriving the rest-frame UV luminosity function (UVLF) of members of protocluster found by HSC-SSP at z~4
- Protocluster UVLF has the bright-end excess compared to the field one
  →**Suggesting the higher SFR for protocluster members**
- Protocluster at z~ 4 has 6-20% of the cosmic SFRD
- **Observationally suggesting the active star formation in protoclusters at z~4**

Ito et al. (2020), ApJ, 899,5