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

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1.5 pMpc
Protoclusters

- Protocluster (PC): “progenitor” of galaxy cluster with $M_{\text{halo}} > 10^{14} M_\odot$ 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.
Protocluster and galaxy evolution

• At $z \sim 2$, 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!

Current Understanding

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

- HSC-SSP protocluster selection at z~4 (Toshikawa et al. 2018)

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The density map of LBGs at z~4

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)
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.

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

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

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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**

- **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.
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

\[ \rightarrow \text{Galaxies in protoclusters at } z \sim 4 \text{ is more evolved than field galaxies, but still in the middle of the evolution.} \]
**Stellar Mass Function**

- Assuming the $M^*-M_{UV}$ relation of field galaxies.
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- PC SMF is steeper than low-z (Proto)Cluster SMF

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

![Graph showing Stellar Mass Function](image)

*Shimakawa+18, Nantais+16, van der Burg+13,18, Calvi+13*
Stellar Mass Function

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- PC SMF is much top-heavy compared to the field SMF
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$\rightarrow$ Galaxies in protoclusters at $z\sim4$ is more evolved than field galaxies, but still in the middle of the evolution.

![Graph showing SMF comparison between field and protocluster galaxies](image-url)
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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- Subdividing protocluster sample to 4 subsample according to overdensity
- Same faint-end, but **higher bright-end in more massive PCs**
• 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**