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Cluster candidates with massive quiescent galaxies at $z \sim 2$

Tomokazu Kiyota (SOKENDAI/NAOJ)

Makoto Ando, Masayuki Tanaka, Alexis Finoguenov, Sadman Shariar Ali, Jean Coupon, Guillaume Desprez, Stephen Gwyn, Marcin Sawicki, Rhythm Shimakawa

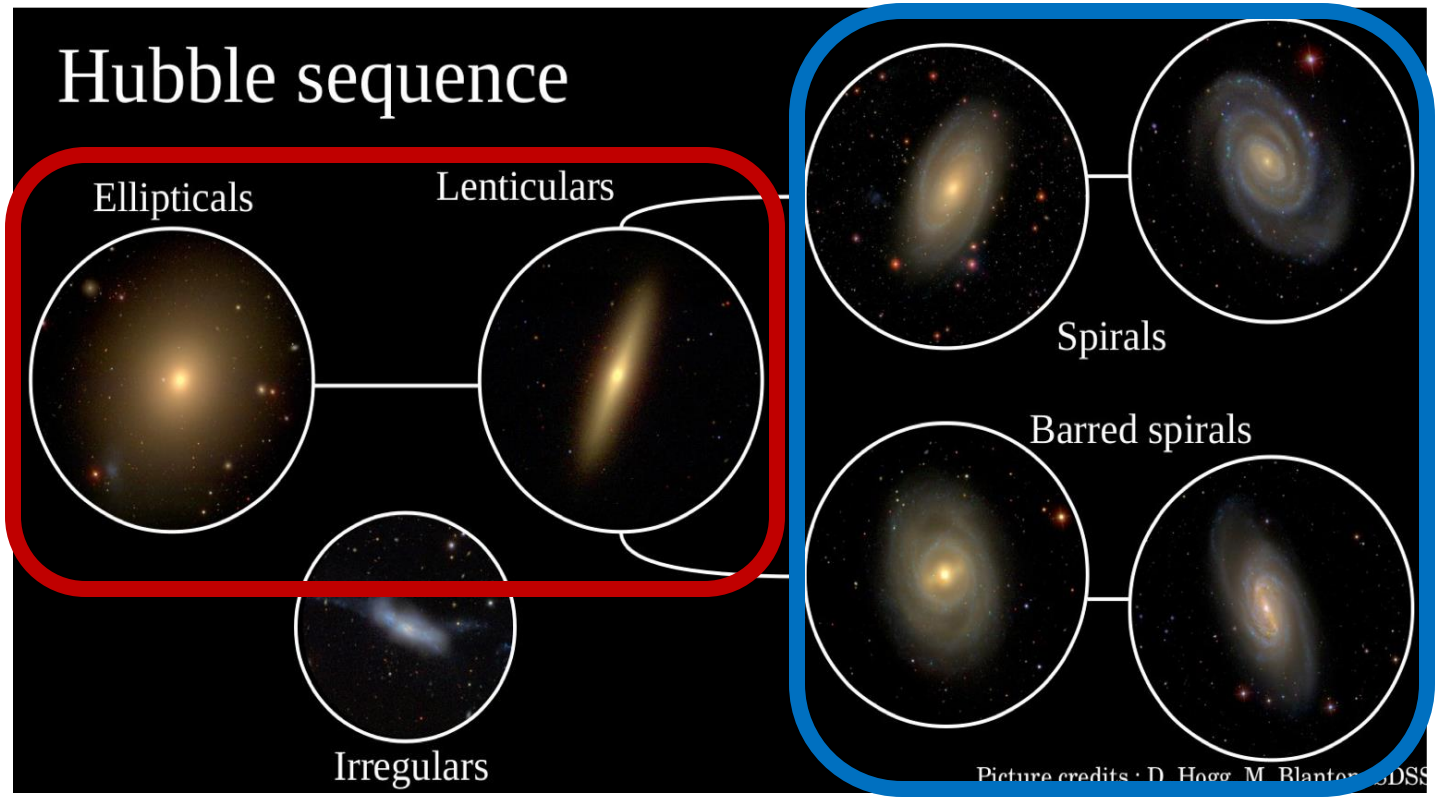
Kiyota et al. 2025, accepted for publication in ApJ (arXiv:2406.02849)

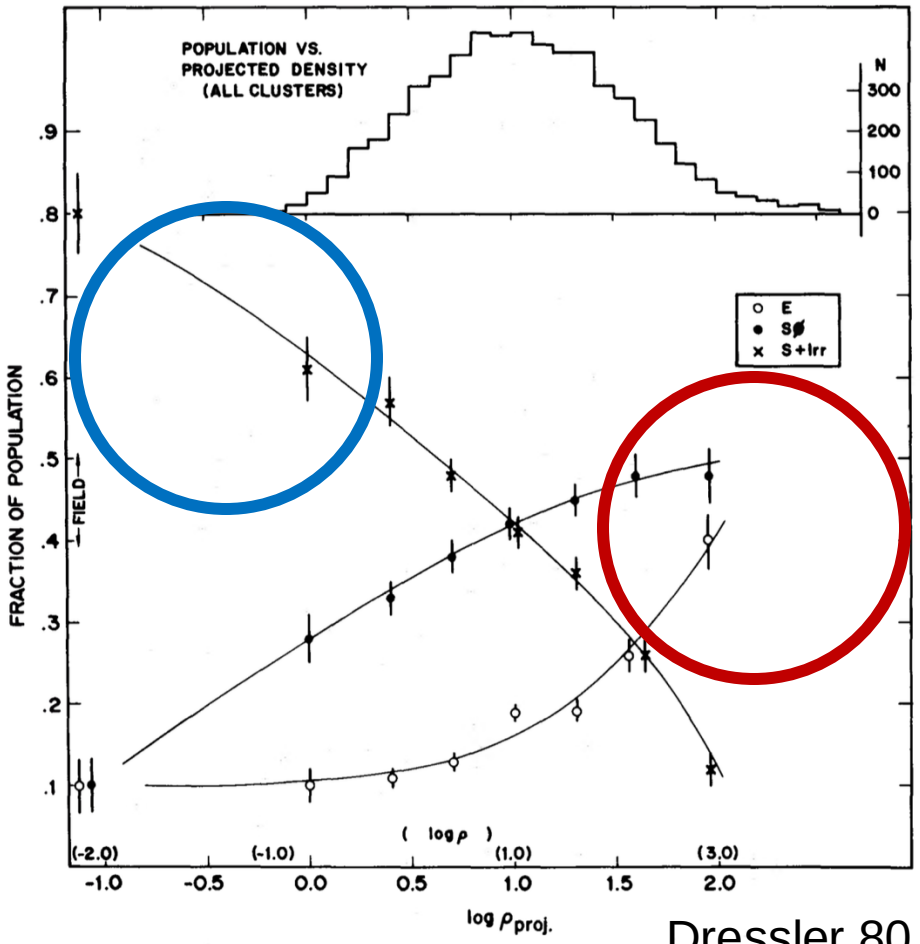
Introduction

- Galaxy segregation in the local Universe (e.g., Dressler 80)

Clusters, groups
→ red galaxies

Field
→ blue galaxies





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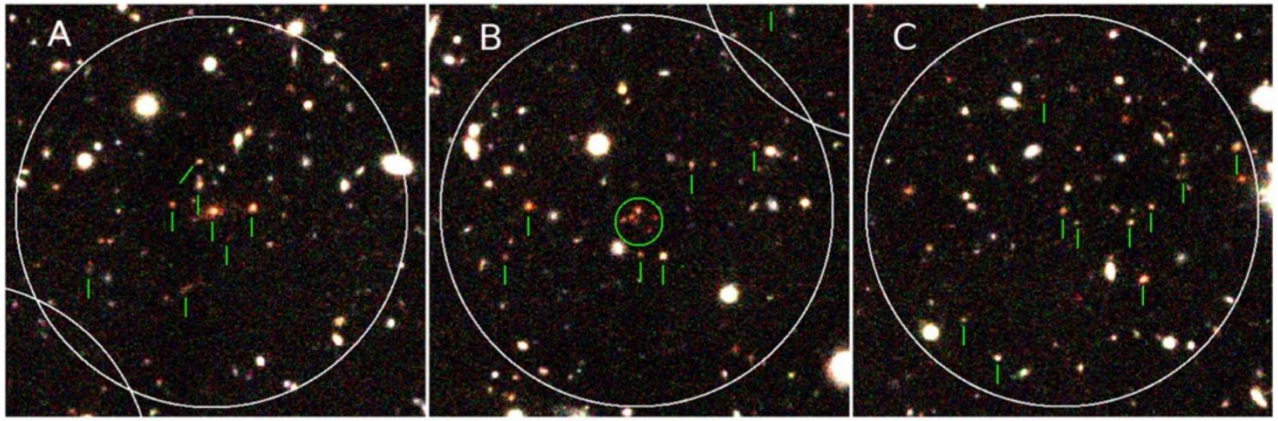
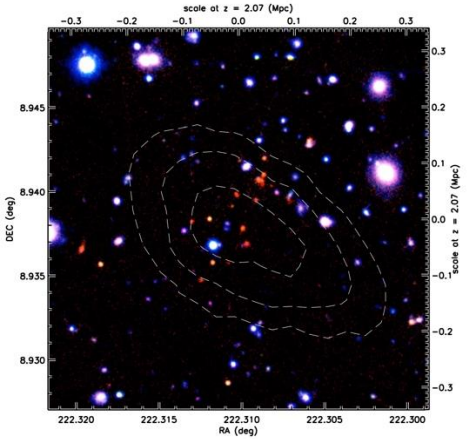
Dressler 80

Introduction

- The origins of this segregation remain unclear.
  (cf. ram-pressure stripping, starvation, galaxy merger, etc.)
- One approach: Investigating high-redshift overdensities/clusters
- Higher redshift mature clusters ($z > 2$) remain largely unexplored.



z=2.1, Spitler+12

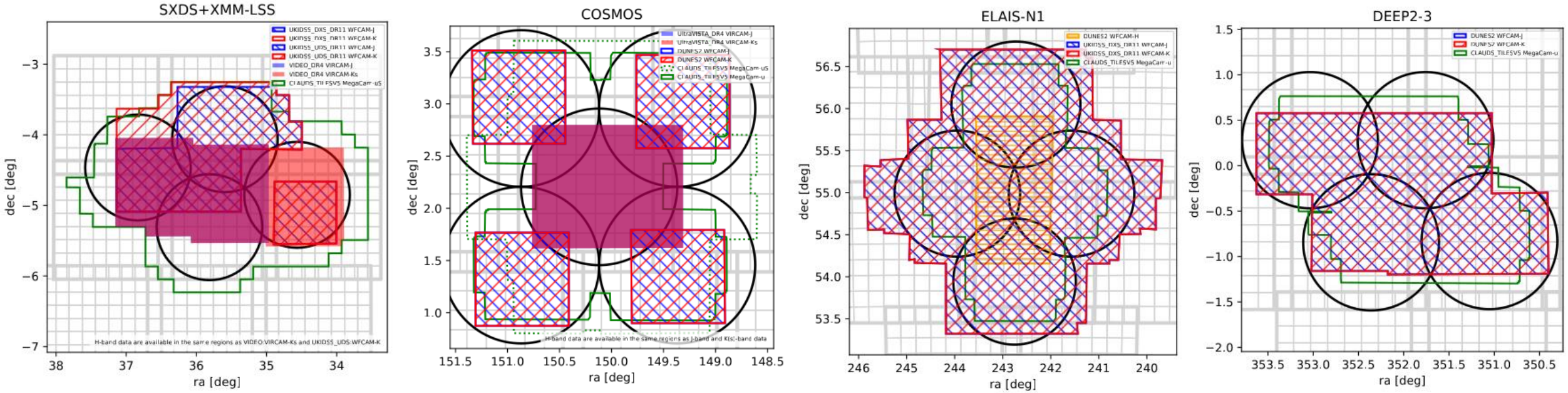


z=2.0, Gobat+11

- **<u>This research:</u>**
  <u>Searching for high redshift clusters with large statistics</u>

Data

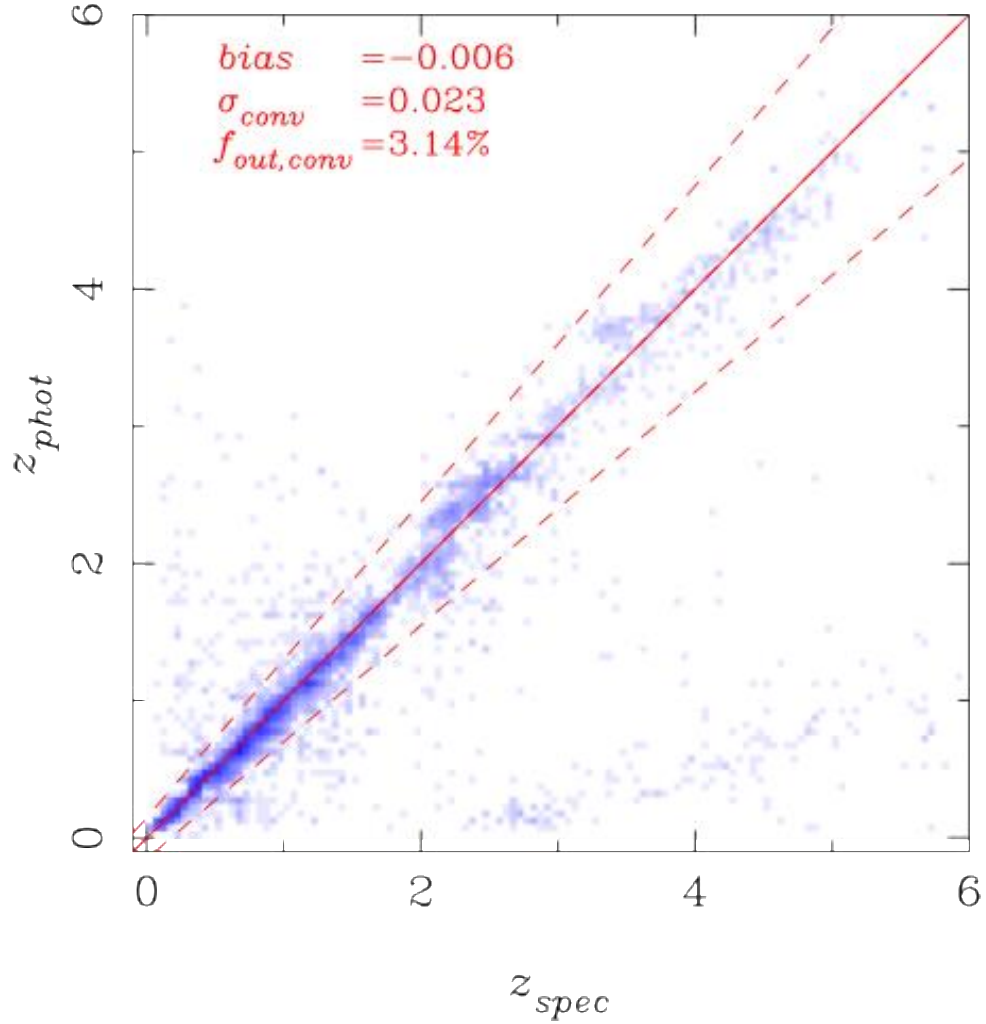
- u2k catalog (deep multiband photometry catalog, u band to K band)
  - HSC-SSP and other collaborative/public surveys
  - Wide (17 deg^2) and deep (K=23-25 mag)
  - Using SED fitting, we estimate photometric redshift, stellar mass, and star formation rate (SFR).



Data

- Photometric redshift
  - Photo-z code from Tanaka (2015)
  - $\sigma(|\Delta z|/(1+z)) \sim 0.023$
    ($\sigma_z \sim 0.07$ at z~2)
  - Outlier rate: $f \sim 3\ \%$
    ($|\Delta z|/(1+z) > 0.15$)
  - Reliable data to search for high-z clusters

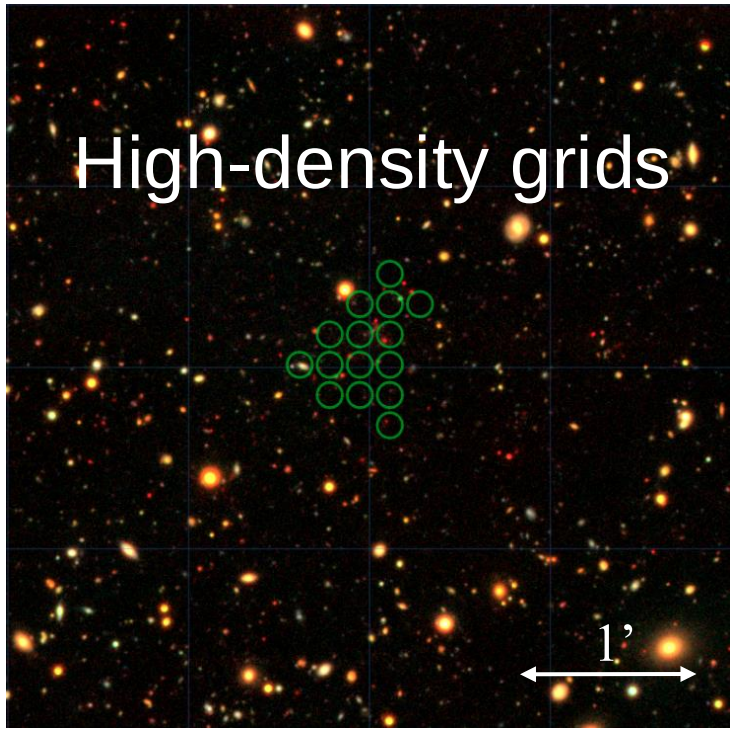
Photo-z vs. spec-z



Analysis

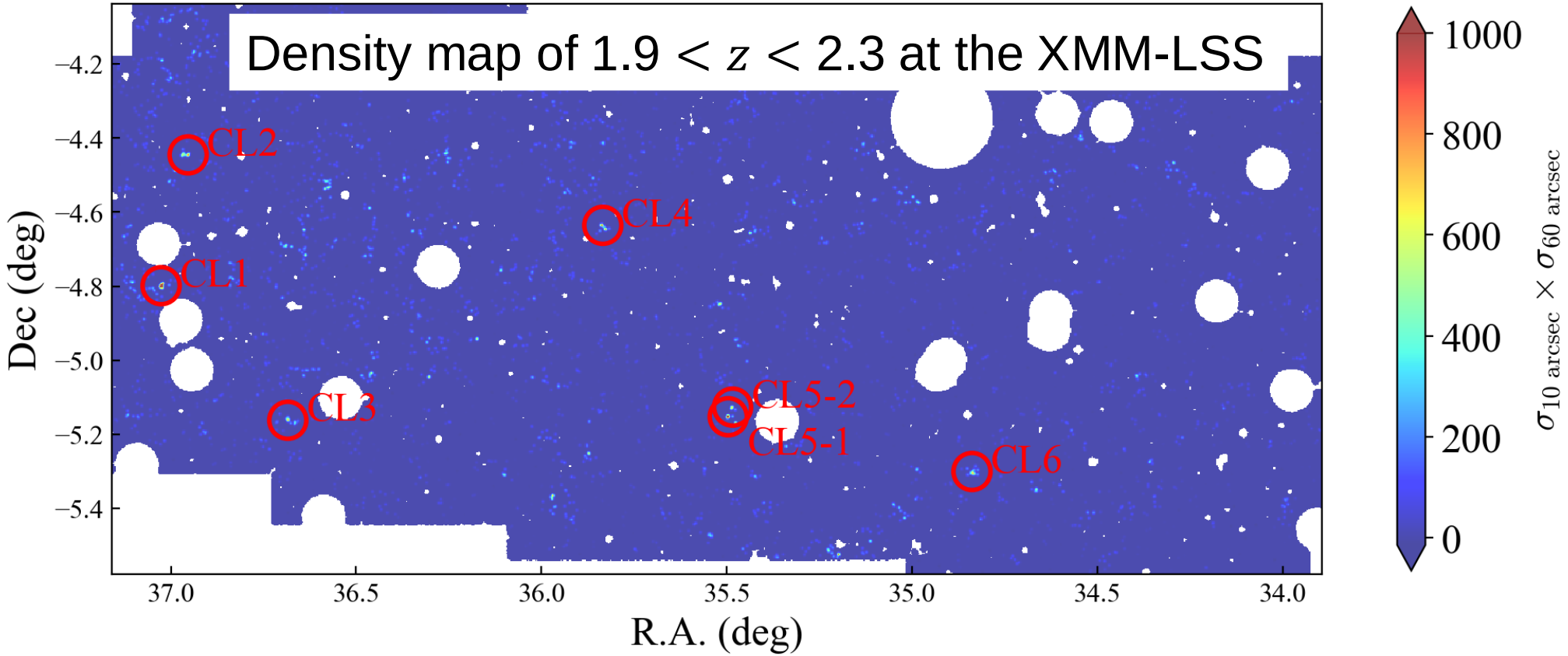
- We made a 2D density map of massive quiescent galaxies.
  - XMM-LSS field (3.5 deg^2)
  - Kernel density estimate (Gaussian kernel with 10” and 60” widths).
  - We searched for the region with $\sigma_{10''} \times \sigma_{60''} > 600$.

Criteria of massive quiescent galaxy
Massive: mass > 3×10^{10} $M_\odot$
Quiescent: sSFR < 10^{-10} yr $^{-1}$
(sSFR: Specific Star Formation Rate)



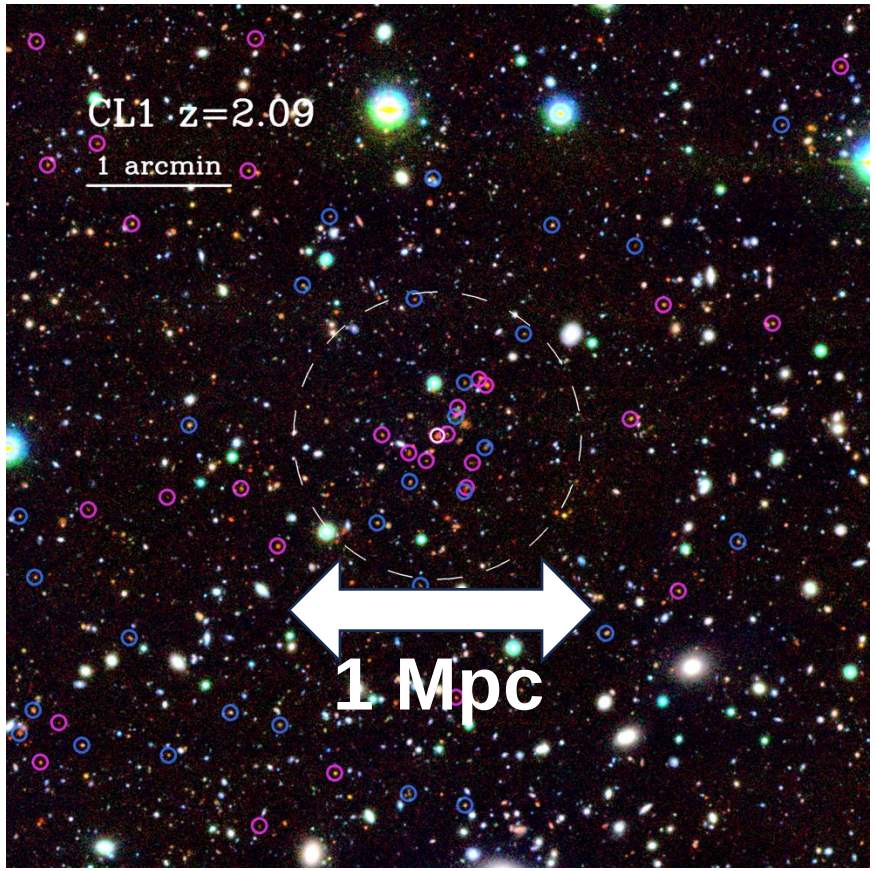
Results – Density Map

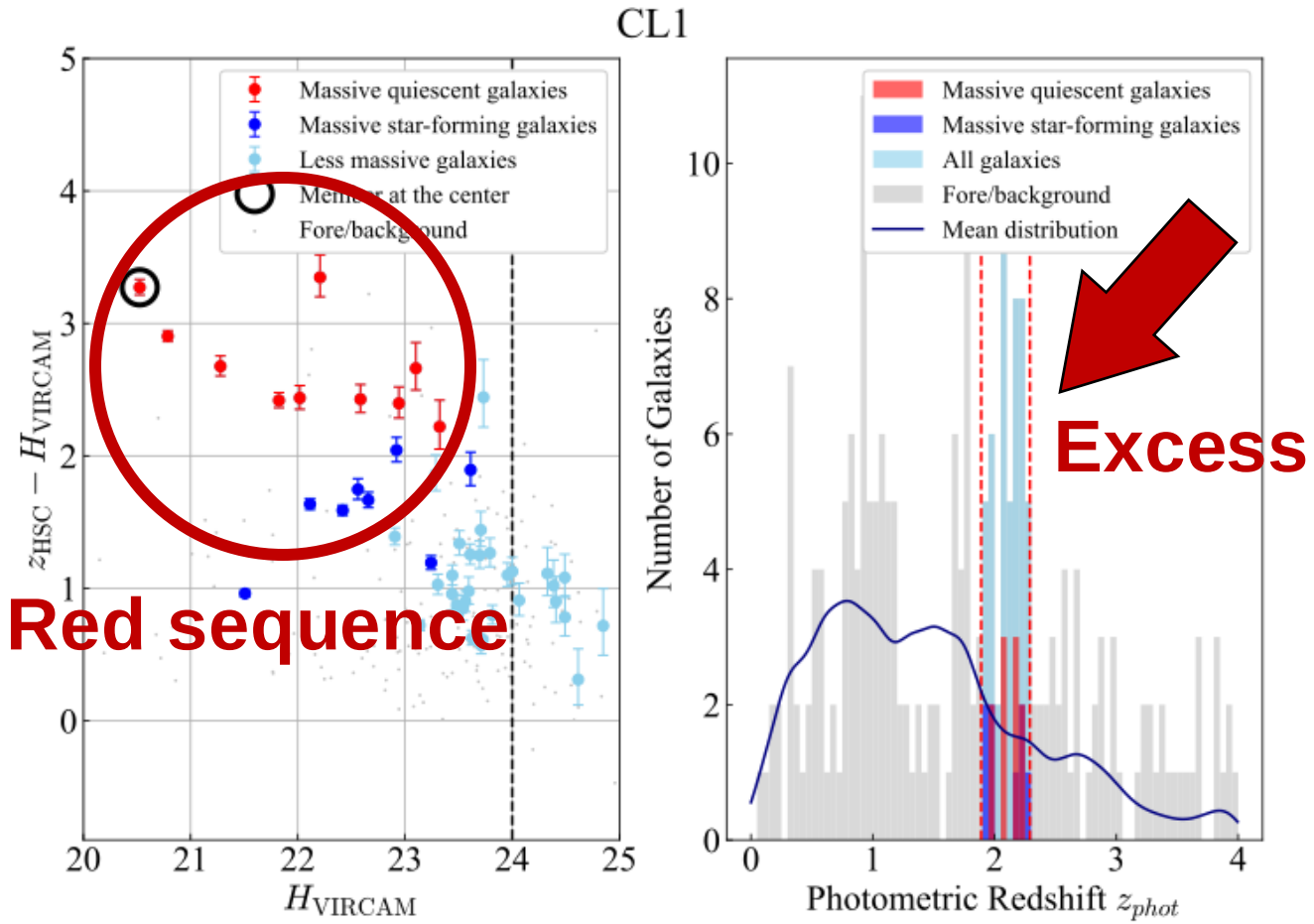
- **We find seven overdensities of massive quiescent galaxies at $z \sim 2$ in the XMM-LSS field.**
  - They satisfy $\sigma_{10''} \times \sigma_{60''} > 600$, ($\sigma_{60''} \gtrsim 6, \sigma_{10''} \gtrsim 100$).



Results – Image

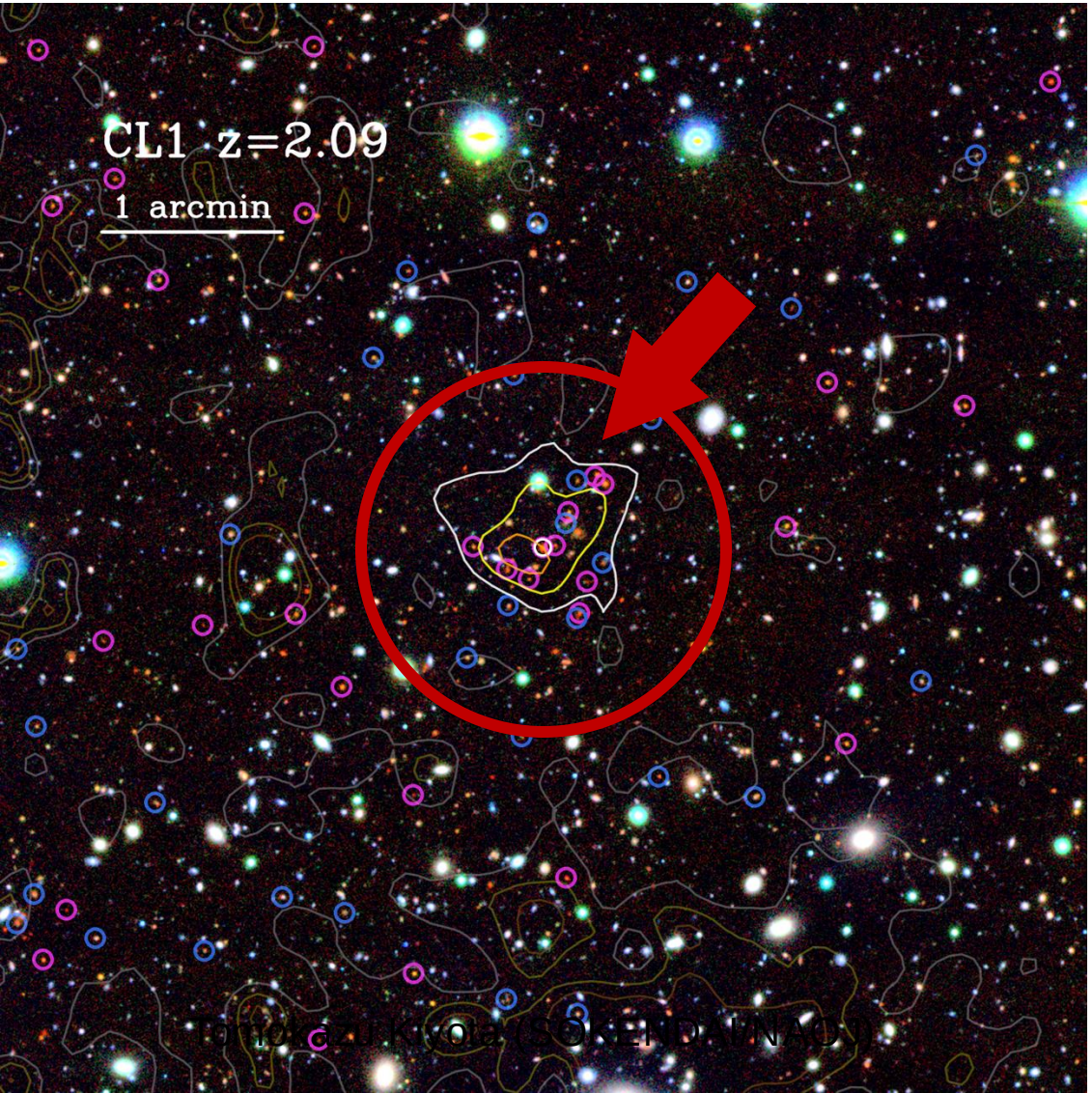
- Image, color-magnitude diagram, and redshift histogram





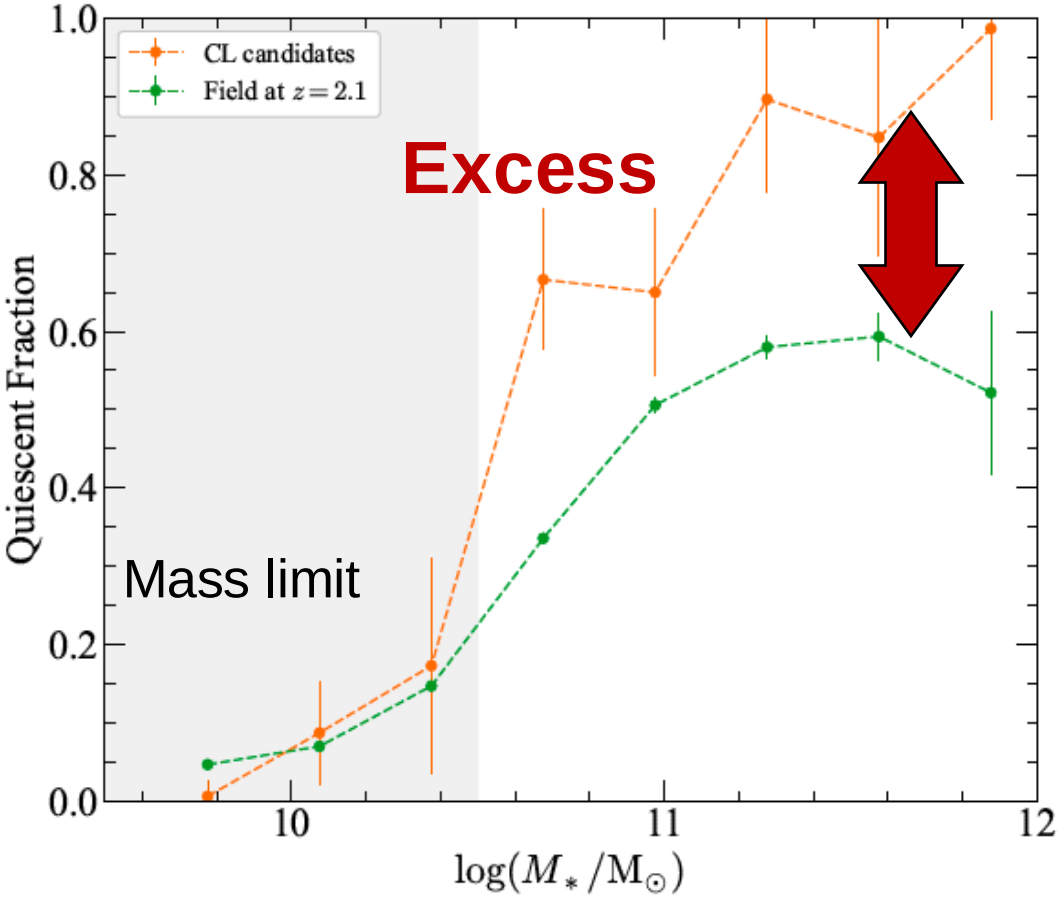
O massive quiescent O massive star-forming O the most massive galaxy

Results – Extended X-ray Emission



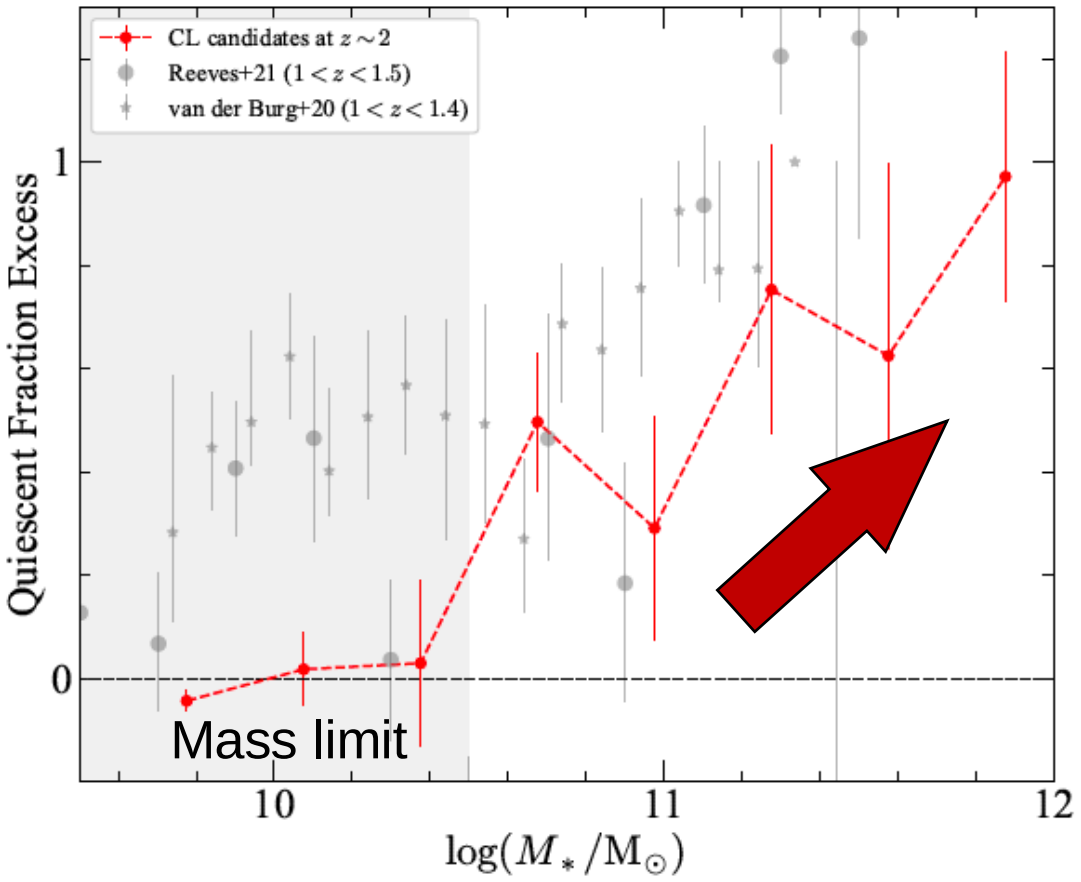
- X-ray data (XMM-SERVS; Chen+18)
  - **CL1 is detected as an extended source (4.1 σ).**
    → suggesting virialized nature
    - $L_{\mathrm{X}} = (1.46 \pm 0.35) \times 10^{44}$ erg s^{-1}
    - $M_{200} = (7.75 \pm 1.15) \times 10^{13}\ \mathrm{M}_{\odot}$
  - A point source is detected near the center of CL2.
    → indicating that its central galaxy is an AGN

Discussion – Quiescent Fraction



- Quiescent Fraction (QF)
  ($N_{\text{quiescent galaxies}}/N_{\text{all galaxies}}$)
  - More massive galaxies have higher QF.
  - QF of the cluster candidates is significantly higher than that of the field.
    → Galaxy segregation even at $z \sim 2$

Discussion – Quiescent Fraction Excess



- Quiescent Fraction Excess (QFE)

$$\mathrm{QFE}(M_*) = \frac{f_{\mathrm{Q,cluster}}(M_*) - f_{\mathrm{Q,field}}(M_*)}{1 - f_{\mathrm{Q,field}}(M_*)}$$

  - Higher QFE for higher-mass galaxies
  - Similar trend at z~1.5
    (e.g., Reeves+21, van der Burg+20)
- **First statistical evidence that shows mass-dependent quenching at z~2**

Summary

- We search for high-z clusters using the u2k catalog.
- **We find seven cluster candidates dominated by massive quiescent galaxies at z~2 in the XMM-LSS field.**
  - CL1: Extended X-ray emission (XMM-SERVS)
- QF of the candidates is larger than that of the field.
  → galaxy segregation even at $z \sim 2$
- QFE has an increasing trend in stellar mass.
  → **First statistical evidence of mass-dependent quenching at z~2**

- Future works
  - Spectroscopic follow-up observations / Surveys in other fields