A Study of Galaxy Overdensities at $z \sim 1$ in ELAIS-N1 Field

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A Study of Galaxy Clusters and Large Scale Structures at $z \sim 1$ in ELAIS-N1 Field

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01 | Introduction
What are galaxy clusters?

Merging by gravity

Bigger

And Bigger!
What are galaxy clusters?

The “Largest” gravitationally bound system

- Size: $1 \sim 10 \ Mpc$
- Mass: $10^{14} - 10^{15} \ M_\odot$
What are galaxy clusters?

The "Peak" of dark matter distribution

- Galaxy cluster = Massive dark matter halo
- Observational tool for testing cosmological model
What are galaxy clusters?

The “Extremely Dense” environment of galaxies

- Dozens to thousands of galaxies are clustered.
- Environment affects on galaxy evolution.

**Diagram:**

- Population vs. Projected Density (All Clusters)

**Legend:**

- S0
- E
- Sp + Irr

**Axes:**

- Population fraction
- Galaxy density

**Source:**

What are galaxy clusters?

The “Extremely Dense” environment of galaxies

- Dozens to thousands of galaxies are clustered.
- Environment affects on galaxy evolution.

Cluster galaxies ———
Field galaxies ————

Kim et al. 2015

Lee et al. 2015

Kim et al. 2015

Lee et al. 2015


Quiescent galaxy fraction

Population vs. projected density (all clusters)

Galaxy density

Star formation
How we study $z>1$ galaxy cluster?

Star formation activities in galaxy clusters at $z>1$ \(\rightarrow\) Controversial!

- Quenched!
- Local galaxy cluster
- z$\geq$2 galaxy cluster
- When? How fast?

- <Observation>
- More Star Forming

- <Simulation>
- Redshift
- Galaxy density

- Hopkins & Beacom 2006
- Bouwens et al. 2010
- Scoville et al. 2013

<z ranges>
- 0.15-0.35
- 0.35-0.60
- 0.60-0.80
- 0.80-1.00
- 1.00-1.25
- 1.25-1.50
- 1.50-2.00
- 2.00-3.00
Study of supercluster at $z \sim 1$

Superclusters

- size up to 100~200 Mpc
- Useful objects to test cosmological model (Einasto et al. 2011; Lim & Lee 2014)
- Show various galaxy environment (filaments, galaxy clusters and groups)
- Very limited number of superclusters know $z \gtrsim 1$

$z > 0.9$ : A special epoch of superclusters?

- Recently, a large number of (or some) superclusters have been found at $z \sim 0.9$
  (e.g. Swinbank 2008; Coppin et al. 2012; Faloon et al. 2013; Kim et al. 2016; Hyun et al. 2019, in prep.)
The limitation of the previous studies

**NIR data is essential for studying high-z:**

- Spectral features move from Opt. to NIR

**Not many known galaxy clusters or superclusters at z>1**

- Lack of wide & deep and Optical – NIR dataset
- Previous methods: FIR selected, Radio selected, Color techniques, and etc.
  - good methods but could make selection bias
ELAIS-N1 field

European Large Area ISO survey – North 1

Strength 1 : Wide!
- Area : 8.75 deg² (UKIDSS)
- RA&DEC : 16:11:00 +55:00:00 (J2000)
ELAIS-N1 field

European Large Area ISO survey – North 1

Strength 2: wide wavelength
- Various wavelength datasets from Optical to MIR
- IMS Infrared Medium-deep Survey
  (Im et al. 2019, in prep.)
- HSC Hyper Suprime-Cam Subaru Strategic Program
  (Ahihara et al. 2018)

: UKIDSS DXS J & K

Optical

NIR

MIR
ELAIS-N1 field

European Large Area ISO survey – North 1

Strength 3 : Deep!

1. Deep optical data
   • HSC-SSP deep (g/r/i/z/Y/NB921) : $i \sim 26.5$
   • Pan Starrs (g/r/i/z/Y) : $i \sim 23.5$
   • Canada France Hawaii Telescope (z) : $z \sim 25.0$
   • Issac Newton Telescope (U/g’/r’/I’/Z) : $U \sim 24.2$
ELAIS-N1 field

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ⓒ HSC Subaru Strategic Program
European Large Area ISO survey – North 1

Strength 3 : Deep!

2. Deep NIR data
   • The UKIRT Infrared Deep Sky Survey
     : Deep Extragalactic Survey (UKIDSS – DXS)
       • K dual mode with Source Extractor
       • $J_{\text{AB}} = 23.1$ $K_{\text{AB}} = 22.6$

   • Infrared Medium–deep-Survey (IMS, Im et al. in prep.)
     : Y/J imaging of ~ 150 deg$^2$ extragalactic fields
       (J : UKIRT WFCAM / Y : Maidanak, McDonald+)
   • ELAIS-N1 : J band only ($J_{\text{AB}} = 23.1$)
03 | Methods
Methods

Photometric redshift

- Using EAZY (Brammer, van Dokkum & Coppi 2008)
- Root Mean Square Error (RMSE) : 0.031
- Outlier Fraction (\(|\Delta z/(1 + z_{spec})| > 0.15\)) : 0.163

Cluster mass estimation

- Using mass – richness relation (Longair & Seldner 1979; Muzzin et al. 2007; Kim et al. 2016)
- \(\log M = 0.5408 \log n_{200} + 13.3298\)

Stellar mass & Star formation rate

- Using FAST code (Kriek et al. 2009)
- Comparison between Mendel et al. 2014 (N=184)
  \(\Delta \log M_* = 0.0761 (\sigma = 0.185)\)
Cluster Finding Algorithm

Measure galaxy density
\[ D = 1 \text{Mpc} \]

- Divide redshift bins: \( 0.6 < z < 1.5 \) (\( z \) step size = 0.05)
  - bin size: \( z \pm (1+z)0.031 \)
- Measure number density within 500kpc for all galaxies in each redshift bin
- Gaussian fit & select galaxies having density > 3\( \sigma \)
- Reject galaxies if \( \delta_{\text{within } 300 \text{kpc}} < \delta_{300\text{~}500 \text{kpc}} \)
- Merge candidates identified, based on distance, \( z \) and richness

Finally, we found \( \sim 800 \) galaxy cluster/group candidates
04 | Results
Result I: LSSs at $z \sim 0.9$

- Spec-z data
- Phot-z data
- Red galaxy
- Blue galaxy
- Red core galaxy cluster
- Blue core galaxy cluster

Swinbank+2007’s Supercluster at $z \sim 0.9$
Result I: LSSs at $z \sim 0.9$

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Result I: LSSs at $z \sim 0.9$

- Supercluster from Swinbank et al. 2007
- Spectroscopic confirmed 5 galaxy clusters
- $M > 10^{13.5} M_\odot$
- Using DXS early data release (EDR; Dye et al. 2006)
- Spread across 30Mpc
Result I: LSSs at z~0.9

Supercluster from Swinbank et al. 2007

- Spectroscopic confirmed 5 galaxy clusters
- $M > 10^{13.5} M_\odot$
- Spread across 30Mpc
- Using DXS early data release (EDR; Dye et al. 2006)
- Color selection technique

Cluster | RA (h m s) | Dec. (° ″ ′) | $n_{\text{slits}}$ | $n_{\text{el}}$ | $z$ | $\sigma$ (km s$^{-1}$) | $\sigma'$ (km s$^{-1}$)
--- | --- | --- | --- | --- | --- | --- | ---
DXS1 | 16 08 27.0 | +54 35 47 | 26 | 5 | 0.8800[19] | 1030 ± 270 | 640 ± 330
DXS2 | 16 08 26.9 | +54 45 12 | 25 | 9 | 0.8960[19] | 700 ± 230 | 440 ± 170
DXS3 | 16 09 05.7 | +54 57 23 | 29 | 17 | 0.8970[14] | 730 ± 220 | 570 ± 160
DXS4a | 16 13 01.7 | +54 46 06 | ... | 5 | 0.8800[12] | 660 ± 180 | 470 ± 230
DXS4b | | | 25 | 8 | 1.0918[14] | 1200 ± 340 |
DXS5 | 16 10 43.6 | +55 01 35 | 29 | 12 | 0.8920[20] | 1000 ± 290 | 550 ± 240

$z = 0.89 ± 0.01$
Result I : LSSs at $z \sim 0.9$
Result I: LSSs at $z \sim 0.9$

- Larger
  - $\sim 3$ degree
  - ($\sim 165$ Mpc in commoving scale)

- More Massive
  - $\sim 50$ galaxy Clusters/groups having $M > 10^{13.9} M_{\odot}$ each
Result I: LSSs at $z \sim 0.9$
Result I: LSSs at $z \approx 0.9$

- Swinbank+2007’s Supercluster at $z \approx 0.9$
- Spec-z data
- Phot-z data
- Red galaxy
- Blue galaxy
- Red core galaxy cluster
- Blue core galaxy cluster

Swinbank+2007’s Supercluster at $z \approx 0.9$
Result I: LSSs at $z \sim 0.9$

- Swinbank+2007's Supercluster at $z \sim 0.9$

- Spec-z data
- Phot-z data
- Red galaxy
- Blue galaxy
- Red core galaxy cluster
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Swinbank+2007’s Supercluster at $z \sim 0.9$
Result I : LSSs at z~0.9

Spectroscopic observation

MMT-Hectospec in 2018A

- PI : Myungshin Im
- Earned 1 day

- 4 configurations submitted (minimum separation = 20")

- 300fibers per each configuration
  - Cluster galaxies (z~0.8, 0.9 & 0.6)
  - Field galaxies
  - Sky
  - 4 quasars (in prep. Shin)

- 2 configurations were observed
Result I : LSSs at z~0.9

Spectroscopic observation

Data Reduction : HSRED

Redshift Measurement : Specpro

Total : 486 objects

Flag 1 : high confidence 363(75%)
Flag 2 : low confidence 99(20%)
Flag 3 : faint, featureless 10(2%)
Flag 4 : M type star 14(3%)
- galaxies at $z \sim 0.9$ (literature)
- galaxies assigned as Hectospec fibers at ($z \sim 0.9$)
- galaxies confirmed at $z \sim 0.9$ from Hectospec obs.
- : galaxies at $z \sim 0.9$ (literature)
- : galaxies assigned as Hectospec fibers at $(z\sim0.9)$
- : galaxies confirmed at $z\sim0.9$ from Hectospec obs.

\[\triangle/\Delta = 186/276\]

(67.3%)
EN1CL59, EN1CL1, EN1CL18 show a 10 times higher SFR than other clusters at similar or lower redshift.

They occupy about 10% of the cluster candidates in mass at z≈1 (M >10^{14} M_☉) which are thought to be already quenched in star formation!!
Result II : Actively SF galaxy clusters at z ~ 1

Spectroscopic observation

- K-GMT proposal for Gemini-N in 2018A
  - Earned 4.4 hours
  - Nod and Shuffle mode
  - R150, OG 515 filter
Result II: Actively SF galaxy clusters at $z \sim 1$

Spectroscopic observation

Gemini-N 2018A KASI block run in May

- May 17 to May 20 (4 days)
- Observers: Dr. Ho-Gyu Lee (KASI), Dr. Dohyeong Kim (SNU), Minhee Hyun (SNU)
But the weather was...

Poor weather on Maunakea 18A semester so far

Dear Gemini PIs,

Maunakea has been experiencing unusually poor weather this semester and so far we have lost almost 75% of the time. Even in late April, there was snow and ice at the summit. This is why there may have been little or no progress on your program.

If you wish to make any changes to your observing strategy, revise condition constraints, or update timing windows, please email your contact scientists and they will be happy to assist you. Anything you can do to make it easier to schedule and execute your program will help.

If you are curious, you can access Maunakea weather info through the following websites:

https://www.gemini.edu/sciops/telescopes-and-sites/weather/mauna-kea
http://mkwc.ifla.hawaii.edu/forecast/mko/

Regards,

Atsuko Nitta (GN Head of Science Operations) & The GN Science Operations Team
Result II: Actively SF galaxy clusters at $z \sim 1$

However!!!
Result II: Actively SF galaxy clusters at $z \sim 1$

However!

Dr. Dohyeong Kim

Me
Result II: Actively SF galaxy clusters at z ~ 1

Spectroscopic observation

- Observed in May, 2018
  - R150
  - 2x2 binning
  - OG515 filter
  - 3 hr integration time on source
  - 1” width and 3” long microslits
  - N&S mode
  - 30 slits in one mask (cluster galaxy/sky/stars)
  - 770nm/780nm
Result II: Actively SF galaxy clusters at $z \sim 1$

Spectroscopic observation

: Observed in May, 2018
- R150
- 2x2 binning
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- 770nm/780nm

Data reduction is on-going
05 | Summary
Galaxy clusters and superclusters are good laboratories to study how galaxies are evolving with their environment.

We found ~800 galaxy cluster candidates based on photometric redshifts calculated from deep and wide multi-wavelength dataset (HSC to DXS).

We found a new supercluster candidate at z~0.9 stretching about 100 Mpc in co-moving scale. MMT-Hectospec observation for confirmation was performed in May, 2018.

Among the candidates, we found unique galaxy clusters at z≥1 which show high star formation rate and they was observed with Gemini-N.