

No. 2

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

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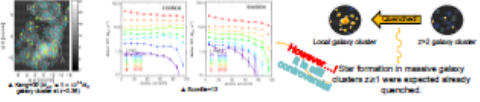


Introduction

Study galaxy overdensities at $z \sim 1$
 answer to "How did galaxies evolve in early universe?" & "How has the universe evolved?"

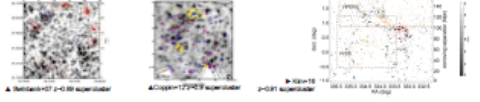
Galaxy cluster

- Useful objects to test cosmological model (Elnasto et al. 2011; Lim & Lee 2014)
- Massive Galaxy clusters are found unexpectedly at $z > 1$ (Kang & Im, 2009; Dumet et al. 2011; Toshikawa et al. 2012)
- Let us study when were red sequence galaxies in local clusters quenched?



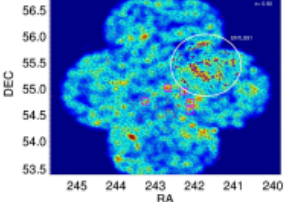
Supercluster

- Large scale structure in the universe (size up to 100-200 Mpc)
- Good laboratories to study galaxy evolution affected by their environment (various levels of environment : filaments, galaxy clusters, groups, voids)
- Very limited number of superclusters known $z \geq 1$



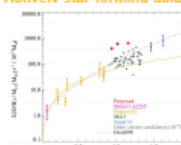
Results

Newly discovered LSSs at $z \sim 0.9$




- Among the 1046 galaxy group/cluster candidates, we found large scale structure named EN1LSS1 at $z \sim 0.9$ at the northern part of Swinbank et al. (2007) supercluster which was found using early release data of UKIDSS-DXS.
- Interestingly the new LSSs are more massive and much larger than the supercluster of Swinbank.
- To confirm this LSSs, we performed Hectospec/MMT observation in 2018A.
- With 74.6% completeness, we could confirmed 7 galaxy clusters in EN1LSS1.

Actively star-forming galaxy clusters at $z \sim 1$



- EN1CL9, EN1CL1, EN1CL18 show a 10 times higher SFR than other clusters at similar or lower redshift.
- They occupy about 10% of the cluster candidates with $M > 10^{14} M_{\odot}$ at $z \sim 1$ which are thought to be already quenched in star formation!

Cluster Selection



- Divide redshift bins : $0.4 < z < 1.6$ (z step size = 0.02)
- Measure number density within 1Mpc for all galaxies in each redshift bin
- Select galaxies having density $> 3\sigma$
- Link 1st candidates using Friend-of-Friend(FoF) algorithm (linking length=2Mpc)
- Find overlapped candidates from different redshift bins having $r < 1\text{Mpc}$ and $\text{err}(z) < 0.025$ for every candidate \rightarrow define new center position

Data & Data Analysis

ELAIS-N1 (European Large Area ISO Survey North 1 region)

Instrument	Band	RA (J2000)	Dec (J2000)
Planck (DR5)	galaxy	245.0 (245.0) 231.2 (231.2)	-
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CHIME - Magellan	-	-	-
Hyper Suprime-Cam (HSC)	galaxy/clusters	245.0 (245.0) 231.2 (231.2)	23.0
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Infrared Multi-color Survey (IMS)	-	-	-
The UKIRT Infrared Deep Sky Survey (UKIDSS)	galaxy/clusters	245.0 (245.0) 231.2 (231.2)	23.0
The Subaru Wide-area Infrared Photometric Survey (SWIPS)	3 Bands (g, r, i)	245.0 (245.0) 231.2 (231.2)	23.0

Data Analysis (Other properties)

- Photometric redshift
 - Using EAZY (Brammer, van Dokkum & Coppi 2009)
 - Root Mean Square Error(RMSE) : 0.0304
 - Outlier Fraction ($(\Delta z / (1 + z_{phot})) > 0.15$) : 0.1252
- Cluster mass estimation
 - Using richness-mass relation
 - $\log M = 0.5408 \log N_{rich} + 13.3298$
- Stellar mass & Star formation rate
 - Using FAST code (Kriek et al. 2009)
 - Accuracy of measurement in stellar mass : Comparison between Mendel et al. 2014 $\Delta \log M_{*} = 0.0761$ ($\sigma = 0.185$)

Summary

- We found 1,054 galaxy cluster/group candidates at $0.2 < z < 1.6$ in ELAIS-N1 field.
- We performed MMT/Hectospec observation for confirmation of large scale structure at $z \sim 0.9$ named EN1LSS1, which is more dense and larger than the supercluster of Swinbank 2007. 7 cluster/group candidates in EN1LSS1 was confirmed.
- We also found actively star forming cluster candidates at $z > 1$, and one of them was observed via GMOS-N in 2018A. The data reduction is on-going.

Introduction

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Large Scale Structures at $z \sim 1$ in ELAIS-N1 field*

Study galaxy overdensities at $z \sim 1$?

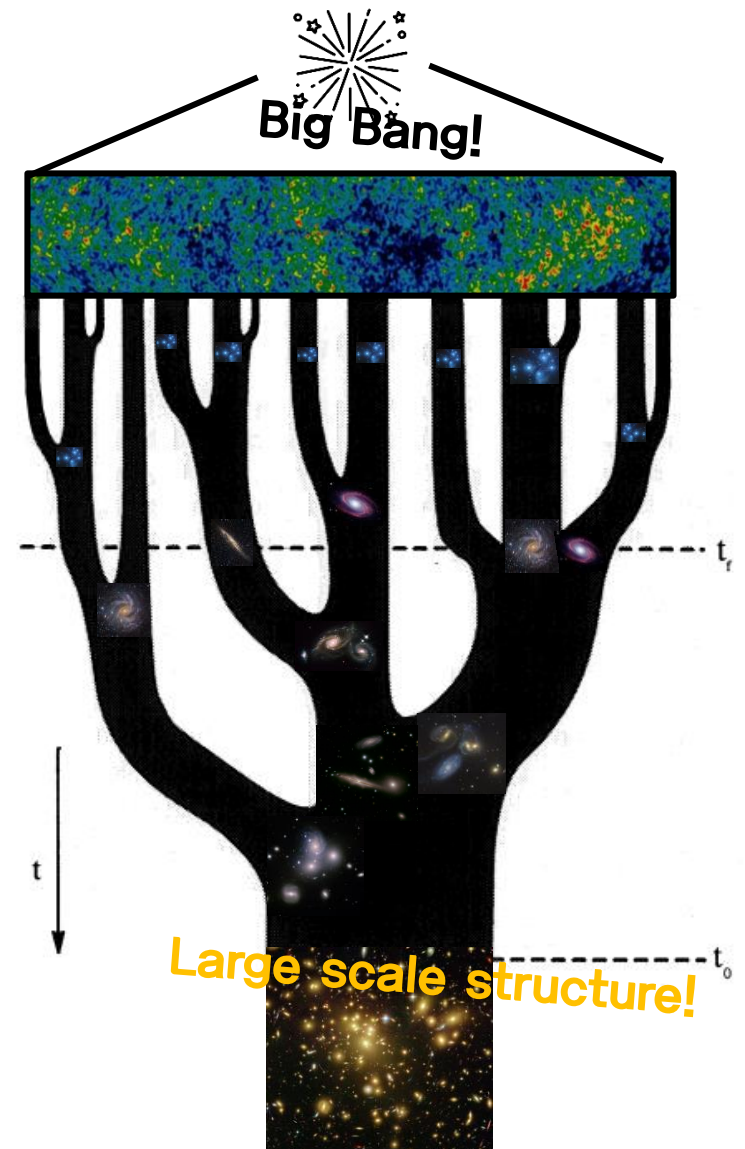
: answer to “How did galaxies evolve in early universe”
& “How has the universe evolved”

Galaxy cluster

- Useful objects to test cosmological model
- Massive Galaxy clusters are found unexpectedly at $z > 1$
- When were red sequence galaxies in local clusters quenched?

Supercluster

- Large scale structure in the universe (size up to 100~200 Mpc)
- Show various galaxy environment, filaments, galaxy clusters
- Very limited number of superclusters known $z \gtrsim 1$

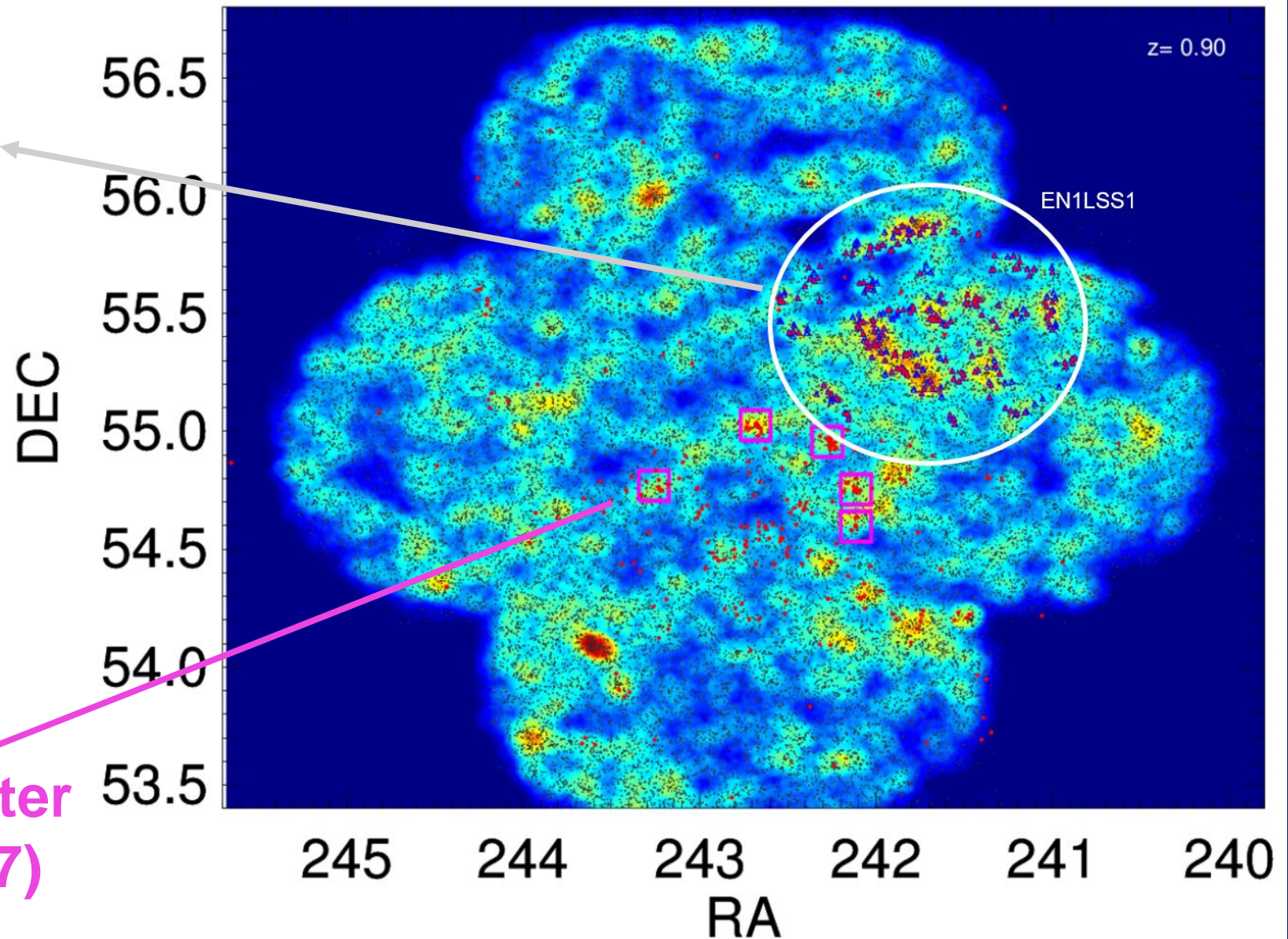


Results

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

**Newly discovered
Large scale structure
at $z \sim 0.9$
(spectroscopic obs.
Hectospec/MMT
in 2018A)**

**Swinbank's supercluster
(5 cluster/groups, 2007)**



Results

**still star-forming in massive galaxy cluster at $z \gtrsim 1$?
(spectroscopic obs. GMOS-N in 2018A)**

