Panoramic Views of Cluster Evolution with Subaru

Taddy Kodama (Subaru Telescope, NAOJ)

Overview

• Introduction

• **PISCES** (Broad-band)
  large scale structures at all $z \leq 1$

• **MAHALO-Subaru** (Narrow-band)
  galaxy formation bias at $z > 1.5$?

• Summary
What’s Subaru (昴)?

“Subaru” is “Pleiades” (a star cluster M45)

“Subaru” originally means “cluster” (verb) in old Japanese

Galaxies are “Subaring” (clustering)

“Pleiades”: a star cluster M45

A galaxy cluster CL0024 (z=0.4)

Subaru Telescope is “Cluster” Telescope!
Why Subaru?

★Distant X-ray clusters (0.4<z<1.5): Suprime-Cam, MOIRCS
Kodama, M.Tanaka, Koyama, Hayashi, et al. (PISCES team)

★Proto clusters around RGs/QSOs (2<z<5.2): MOIRCS
Kodama, I.Tanaka, Kajisawa, De Breuck, Miley, Kurk, et al. (HzRG team)

Final cluster with $M=6 \times 10^{14} M_\odot$, $20 \times 20$Mpc$^2$ (co-moving) (Yahagi et al. 2005; v GC)
What’s the origin of the environmental dependence

morphology - density relation (Dressler 1980)

Nature? (intrinsic)

- Need to go higher redshifts when it becomes more evident.

Nurture? (external)

- Need to go outer infall regions to see directly what’s happening there.

Spirals

Lenticulars

Ellipticals

Star-forming (young)

No/little SF (old)

log surface density (Mpc⁻²)

z~0

Nature? (intrinsic)

Nurture? (external)
RXJ0152-13 at $z=0.83$

$VRizK$ photometry + ~200 spectra

Courtesy: Masayuki Tanaka
Panoramic Views of Cluster Assembly

RXJ 0152.7-1357 cluster (z=0.83; ~7Gyrs ago)

phot-z members ($\Delta z = -0.05\sim+0.03$; Vri’z’)

spec-z members (~200 redshifts)

Kodama, et al. (2005) v GC simulation

Tanaka, TK, et al. (2007)
The Cosmic Web at $z=0.55$ across $\sim 50$ Mpc
(80’x80’ by 7 S-Cam pointings!)

CL0016 cluster ($z=0.55$)

Dots: red sequence galaxies in V-I
Red: spectroscopically confirmed members
Blue: spectroscopically confirmed non-members

~1200 secure redshifts!

Millenium Simulation
(Springel et al. 2005)

Tanaka, M. et al. (2009)
ESO 41/09 - Science Release
Sharp colour transition is seen at medium ("group") density regions!

Tanaka, TK, et al. (2005)

Kodama et al. (2001)
What’s responsible for the truncation of star formation activity?

• **Ram-Pressure Stripping** (~$10^7$ yrs)
  Gas in galaxies is stripped off as they fall into cluster environment. This is not efficient in group environment where travelling velocities of galaxies are not very high (~200-300km/s).

• **Galaxy-Galaxy Mergers** (~$10^8$ yrs)
  Gas in galaxies is quickly consumed as a burst or stripped off due to galaxy-galaxy interaction/mergers. **Starburst is expected.**

• **Suffocation (hot gas stripping)** (~$10^9$ yrs)
  Weak interaction/ram-pressure can still expel the loosely bound gas in the halos, and star formation activity in the disks is eventually terminated without any further gas supply from the reservoir (halo). **No starburst is expected.**
Star-forming galaxies can be traced by narrow-band imaging surveys!

Star-forming galaxies show strong nebular emission lines (e.g., [OII], Hα). If an emission line of a galaxy just falls in a narrow-band, it shines brighter than others.
Importance of narrow-band surveys ($\text{H}\alpha$, [OII])

**Advantages:**

1. Good indicators of SFR, especially $\text{H}\alpha$ (low reddening, well calibrated)
2. "Unbiased" sample (no pre-selection of targets is required).
3. "Complete" census of star forming galaxies to a certain limit in SFR.
4. Membership can be confirmed by the presence of emitters in NB +colours.
5. On top of the phot-z selected members (e.g. "passive" galaxies), we can pick out “active” galaxies which tend to be missed by phot-z selection.
“MAHALO-Subaru”
MApping HAlpha and Lines of Oxygen with Subaru
Subaru Intensive Program (S10B, S11A)

Narrow-band emitters (Hα, [OII]) surveys at 0.4<z<2.5

Targets: 12 clusters/proto-clusters and 2 blank fields, of which 4 clusters and a blank field have been completed.
A narrow-band Hα imaging of RXJ1716 cluster (z=0.81) with NB119 on MOIRCS

J-NB119 colour excesses + appropriate broad-band colours

SFR (Hα) > 1.7 M☉/yr (5σ)


See Koyama’s lunch talk
Spatial distribution of Hα emitters/MIR sources


Chandra X-ray map
(3’ x 3’)

Hα emitters (MOIRCS)
● 15μm sources (AKARI)

Interacting galaxies in the strong 15μm (AKARI) sources located in the outskirt of the cluster.

A narrow-band [OII] imaging of XCS2215 cluster (z=1.46) with NB921 on Suprime-Cam

Hayashi, TK, et al. (2010)
See Hayashi’s poster (#14)
Spatial Distribution of the [OII] emitters (z=1.46)

Hayashi, TK, et al. (2010)

High star formation activity even in the cluster center?
High star formation activity all the way to the very centre of the cluster!

See Mark Brodwin’s talk for a very similar trend for a z~1.4 cluster!
Comparison of spatial distribution of star forming galaxies in cluster cores.

- Hα emitters at $z=0.81$ (RXJ1716)
- [OII] emitters at $z=1.46$ (XCS2215)


$L_x=2.7 \times 10^{44}$ erg/s

$L_x=4.4 \times 10^{44}$ erg/s


Star forming activity in the core is much higher in the higher redshift cluster!
Do we eventually see the reversal of the SFR-density relation at $z>1.5$ as a result of galaxy formation bias?
Proto-clusters around HzRG’s

Spatial distribution of NIR-selected member candidates and emitters
Kodama, et al. (2007)

PKS 1138–262 (z=2.156)

USS 0943–242 (z=2.923)

PKS 1138-262
(z≈2, 10.5Gyr ago)

USS 0943-242
(z≈3, 11.5Gyr ago)

simulation
Emergence of the red-sequence at z~2 in proto-clusters?

Spectroscopically confirmed proto-clusters in terms of Lyα emitters associated to RGs.

PKS1138 (z=2.16)  
USS0943 (z=2.93)

Kodama et al. (2007), but zero-p errors (0.1-0.3mag) have been corrected!

The bright end of the red sequence seems to be emerging between z=3 and 2. 
(2 < Tuniv [Gyr] < 3)
Radio galaxy (4C23.56) itself is not located at the centre of the Hα emitters.

There is a prominent in-falling group of Hα emitters to the East.

Tanaka, I. et al. (2010) to be submitted soon
Hα emitters in a proto-cluster 4C23.56 at z=2.48

NB2288 (CO filter) on MOIRCS
Hα @ z=2.483

Tanaka, I. et al. (2010; to be submitted soon)
Narrow-band multi-line survey of fields specifically at $z=2.2$

Our unique 4 coordinated NB-filters on Subaru MOIRCS/Suprime-Cam, specifically designed for this purpose!

<table>
<thead>
<tr>
<th></th>
<th>$z=0$</th>
<th>$z=2.2$</th>
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</thead>
<tbody>
<tr>
<td>$H_\alpha$</td>
<td>6563 Å</td>
<td>2.09 μm</td>
</tr>
<tr>
<td>$H_\beta$</td>
<td>4861 Å</td>
<td>1.55 μm</td>
</tr>
<tr>
<td>[OII]</td>
<td>3727 Å</td>
<td>1.19 μm</td>
</tr>
<tr>
<td>Lyα</td>
<td>1216 Å</td>
<td>3870 Å</td>
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A Pilot Survey on GOODS-N (2.5 MOIRCS FoV’s)  
Tadaki et al. in prep.  
reaching down to SFR=20M$_\odot$/yr  
(corrected for 1 magnitude of extinction)

13 H$\alpha$ emitters at $z=2.19$

SFR/SSFR are much lower than proto-cluster 4C23.56.

We will now extend the survey to SXDF.
Summary

- Starbursts/truncation in groups/outskirts of clusters at z<1
  - *External effects* (“Nurture”) (galaxy-galaxy interaction?)

- Formation of massive galaxies in cluster cores at z>1.5
  - *Intrinsic effects* (“Nature”) (galaxy formation bias?)
Marked similarities between galaxies and us!

Urban network
Migration to cities
Division of habitats (age segregation)
Interactions/mergers
Against wind (social)
Loss of personality
and etc, etc…

A map of Tokyo and Kanto-district