Panoramic mapping of star formation in/around distant clusters of galaxies

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1. Introduction

2. H_\alpha mapping of a z=0.4 cluster with Suprime-Cam

3. H_\alpha + MIR mapping of a z=0.8 cluster with MOIRCS/AKARI

4. MAHALO-Subaru

5. Summary
Clusters are filled with red early-type (E/S0) galaxies, while general fields are dominated by blue spirals. Why? It's still a mystery.
Galaxy properties vs. Environment

“Morphology-Density Relation (Dressler 1980)”

Early-types (E/S0) are in cluster, late-types (Sp/Irr) are in field

red, old, low SF activity
blue, young, high SF activity

c.f. morphology/colour/SF-density relation from SDSS (e.g. Goto+03, Gomez+03, Tanaka+04, Balogh+04)
Environment changes galaxy properties?

Physical mechanism?

- Galaxy-galaxy interaction
  \((Toomre \text{ and } Toomre 1972)\)
- Ram-pressure stripping
  \((Gunn \text{ and } Gott 1972)\)
- Strangulation
  \((Larson \text{ et al.} 1980)\)
  .... etc.
Environmental effects (examples)

* **merger/interaction**
  (produce Es after intense starburst ?)

* **Strangulation**
  (mildly stripping the gas in galaxies)

* **ram-pressure stripping**
  (stripping cold gas by cluster hot gas)

(Kawata & Mulchaey 2008)

(Roediger+2007)
Galaxy Clusters as "laboratories" for the environmental effects

Note: galaxies in nearby clusters are fully evolved.
→ observation of clusters in the distant Universe is needed

Coma cluster (z=0.024)
SF activity in distant clusters

Butcher-Oemler effect (BO-effect)

Discovery of a high fraction of blue galaxies in distant clusters

\( f(\text{blue}) \) for each cluster

redshift

(Butcher & Oemler 1984)
Optical colour information is insufficient

Some red galaxies also have significant SF (dusty red galaxies)

ex.) Abell 1689 cluster at $z=0.18$

MIR study with ISO

( Fadda et al. 2000 )

CM diagram

Red Sequence

UV

Dust

MIR - FIR

( Duc et al. 2002 )
This talk

(1) Direct mapping of Hα (or [OII]) lines with Subaru
(2) Unveil the obscured SF in the z=0.8 cluster with AKARI
Hα imaging survey for the Abell851 cluster at z=0.41 with Suprime-Cam
(~4Gyr ago)

The Abell851 cluster at $z=0.41$

Panoramic BVRI imaging of A851 with Suprime-Cam

30’

~12Mpc

@ $z=0.4$

Kodama et al. (2001)
The Abell851 cluster at $z=0.41$

$30' \parallel ~12\text{Mpc} @ z=0.4$

- Red galaxies
- Blue galaxies

HST/ACS FoV
Important role of cluster outskirts

Sharp color transition in the “medium-density” regions.

Group is key environment for evolution of cluster galaxies?

Kodama et al. (2001), see also Tanaka+05 and Koyama+08 for other redshifts
Important role of cluster outskirts

Sharp color transition in the “medium-density” regions.

Group is key environment for evolution of cluster galaxies?

Kodama et al. (2001), see also Tanaka+05 and Koyama+08 for other redshifts
□: normal H$\alpha$ emitters
□: weak H$\alpha$ emitters
(SFR<0.75Msun/yr)
□: red H$\alpha$ emitters
(B-I>2)
**normal Hα emitters**

**red Hα emitters**

**weak Hα emitters** (SFR < 0.75 Msun/yr)

(Koyama et al. 2011)
Environment of red Hα emitters

Red Hα emitters are most numerous in group-size environment and ~ 20-30% of Hα emitters in groups have red colours.

Koyama et al. (2011)
Hα+MIR imaging for RXJ1716+6708 cluster at z=0.81 with MOIRCS/AKARI (~7Gyr ago)

Target: RXJ1716+6708 cluster at z=0.81

Panoramic VRi'z' imaging of RXJ1716 cluster at z=0.81

with Suprime-Cam/Subaru

30' ~ 25Mpc @z=0.8

FOV of HST/ACS

FOV of Spitzer /MIPS
Again, sharp color transition in the “medium-density” environment (i.e. cluster outskirts / groups / filaments)

Color-density plot for RXJ1716 (z=0.8)

galaxy density (environment)
Mapping star formation around the RXJ1716 cluster at $z=0.81$ with H$\alpha$ and MIR

Subaru/S-Cam ($VRi'z'$) MOIRCS ($J$, NB119) AKARI/IRC (N3,S7,L15)

Subaru / AKARI Joint Survey

Mapping star formation around the RXJ1716 cluster at z=0.81 with Hα and MIR

Subaru/S-Cam (VRi'z') MOIRCS (J, NB119) AKARI/IRC (N3,S7,L15)

L15 SED of starburst @z=0.81 (SFRIR >~ 15Msun/yr)

J

NB119 Hα (6563Å)@z=0.81 (SFRHα >~ 1Msun/yr)

Spatial distribution of $\text{H}\alpha$ emitter/MIR source

MOIRCS FoVs

- $\text{o}$: phot-$z$ member
- $\Box$: $\text{H}\alpha$ emitter
- $\Diamond$: red $\text{H}\alpha$ emitter ($R-J>2.0$)
- $\bullet$: 15$\mu$m source
Spatial distribution of Hα emitter/MIR source

Δ R.A. [Mpc (comoving)]
Δ R.A. [Mpc (comoving)]

Δ Dec. [arcmin]
Δ Dec. [arcmin]

Δ R.A. [arcmin]
Δ R.A. [arcmin]

Chandra X-ray map (3’ x 3’) (Jeltema+05)
Spatial distribution of $\text{H}_\alpha$ emitter/MIR source

Δ R.A. [Mpc (comoving)]

Δ Dec. [arcmin]

$\text{H}_\alpha$ fraction

$log\Sigma_5$ [Mpc$^{-2}$]  $R_c$ [Mpc]

Chandra X-ray map (3' x 3')

(Jeltema+05)
Optical colours of Hα emitters/MIR sources

MIR galaxies are dusty and tend to be redder than Hα emitters. Red SF galaxies are preferentially found in groups/filaments.

(Koyama et al. 2010)
SFR($\text{H}\alpha$) vs SFR(IR)

SFR($\text{H}\alpha$) is underestimated especially for group/filament galaxies.

![Graph showing SFR($\text{H}\alpha$) vs SFR(IR)]

- $A(\text{H}\alpha) \sim 3$
- Red: red galaxies ($R-J > 2.0$)
- Blue: blue galaxies ($R-J < 2.0$)
- ○: cluster
- △: group/filament
- □: field
SFR(H\(\alpha\)) vs SFR(IR)

SFR(H\(\alpha\)) is underestimated especially for group/filament galaxies

H\(\alpha\)+MIR detected galaxies only

A(H\(\alpha\))\(\sim\) 3

SFR(IR) = SFR(H\(\alpha\))

red: red galaxies (R-J\(\geq\)2.0)
blue: blue galaxies (R-J\(<\)2.0)

○ : cluster member
△ : group/filament
□ : field
☆ : galaxy with A\(H\alpha\)>3
What is the trigger of starbursts?

Galaxy-galaxy interactions in small infalling groups should contribute to gas consumption and SF quenching (at least partly).
[OII] imaging survey for XCS2215 cluster at $z=1.46$ with **Suprime-Cam**
(~9Gyr ago)

SF activity in $z \sim 1.5$ cluster

XCS2215: one of the most distant X-ray detected clusters

SF activity is surprisingly high even in the cluster core!

(Hayashi et al. 2010)
High SF activity in $z=1.5$ cluster

$\text{H}\alpha$ emitters at $z=0.81$ (RXJ1716)

$\text{[OII]}$ emitters at $z=1.46$ (XCS2215)

Koyama et al. (2010)

Hayashi et al. (2010)

Propagation of active SF site from centre to outer region?

( active SF in cluster core @ $z=1.5$ → outskirts/groups @ $z=0.8$ )
\( z = 0 \): passive red galaxy

\( \star \): normal SF galaxy

\( \star \): dusty SF galaxy

(red emitters/MIR gals)

\( z = 0.4 - 0.8 \)

\( z = 1.5 \)

Evolution of SF activity in clusters (schematic diagram)
Global evolution of SF activity in clusters

Sharp decline in cluster-mass-normalized SFR ($\sum\text{SFR}/\text{M}_{\text{cl}}$) since $z\sim1$. (Note: this trend is steeper than that for general field).

Need a larger sample, and in particular, higher redshift cluster sample!
**MAHALO-Subaru Quick Overview**

*(PI: T. Kodama)*

**MAApping H-Alpha and Lines of OII with Subaru**

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

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**Table 2: The complete list of our NB imaging surveys for star-forming galaxies, including the past observations.**

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<th>environment</th>
<th>target</th>
<th>z</th>
<th>line</th>
<th>λ (μm)</th>
<th>camera</th>
<th>NB-filter</th>
<th>continuum</th>
<th>ALMA visibility</th>
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<td>Koyama+’10,’11</td>
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<td>(2.5 pointings)</td>
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<td>MOIRCS</td>
<td>NB1190</td>
<td>z', J</td>
<td>Yes</td>
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</table>
Final goal of MAHALO-Subaru project

Tadaki et al. (2011)
Conclusions

- **Panoramic mapping of SF activity in distant clusters**
  - $\text{H}_\alpha (+\text{MIR})$ mapping of $z=0.4/0.8$ clusters with Subaru and AKARI

- **Dusty galaxies in the cluster surrounding environment**
  - Dusty red galaxies (red $\text{H}_\alpha$ emitters and/or MIR sources) are most numerous in group-scale environment
  - $\text{H}_\alpha$ also underestimate SFR ($A(\text{H}_\alpha)>3$ in extreme cases)
  - Probably progenitors of present-day cluster early-types.

- **Sharp decline in cluster SFR since $z\sim1.5$**
  - SF site changes from core ($z\sim1.5$) to outskirt ($z\sim0.8$)?
  - “MAHALO-Subaru” cultivates the frontier redshift.