From panoramic to microscopic: probing the nature of cluster galaxy population across cosmic time with Subaru

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MAHALO-Subaru collaboration
Galaxy clusters today

• Clusters are dominated by red, dead, early-types: the site of galaxy death (environment quenching).
• Most of stars in present-day cluster galaxies are formed in the early universe.
• Our goal: Tracking down the cluster galaxy properties across cosmic time.
Star Formation “Main Sequence”

= SFR-M★ relation for star-forming galaxies

Elbaz et al. (2007)
Environmental independence of the SF main sequence at $z=0$

(Peng et al. 2010)
Environmental independence of the SF main sequence at z=0

What about in the high-z universe?

(Peng et al. 2010)
Big advantage of Subaru

$z = 30$

$z = 5$

$z = 3$

$z = 2$

$z = 1$

$z = 0$

MOIRCS (4' x 7')

IRCS (1' x 1')

Suprime-Cam (34' x 27')

$M = 6 \times 10^{14}$ Msun, 20Mpc $\times$ 20Mpc (co-moving)

Yahagi et al. (2005)
High-z structures revealed by **MAHALO**

(Talk by T. Kodama)

- **$z=0.4$** (Koyama+11)
  - $H\alpha$, S-Cam, NB921

- **$z=1.5$** (Hayashi+10, 11, 14)
  - $[OII]$, S-Cam, NB912
  - $H\alpha$, MOIRCS, NB1657

- **$z=1.5$** (Koyama+13)
  - $H\alpha$, MOIRCS, NB2071

- **$z=0.8$** (Koyama+10)
  - $H\alpha$, MOIRCS, NB119

- **$z=1.6$** (Koyama+14)
  - $[OII]$, S-Cam, NB973

- **$z=2.2$** (Tadaki+12)
  - $H\alpha$, MOIRCS, NB2315

- **$z=2.5$** (Hayashi+12, 16)
  - $H\alpha$, MOIRCS, NB2071
Environmental dependence of SFMS is always small since $z \sim 2$

Based on H$\alpha$ selected galaxies sample from MAHALO-Subaru (cluster) and HiZELS (field) by Koyama et al. (2013)
Looking for the signatures of environmental effects...
Dusty red SF galaxies in cluster surrounding groups at $z=0.4$

Hα emitter survey with Suprime-Cam of a rich cluster Cl0939 at $z=0.41$ (Koyama et al. 2011)
Dust extinction levels of SF galaxies changes with environment

(A(Hα) from IR/Hα

Hα emitters in cluster at z=0.4

A(Hα) from M★

A(Hα) from SFR_{IR,Hα}/SFR_{Hα,obs}

A(Hα) from stellar mass

A(Hα) from M★

(Garn & Best 2010)

(Koyama et al. 2013)
IFU spectroscopy of dusty red galaxies with GMOS/Gemini(N)
IFU spectroscopy of dusty red galaxies with GMOS/Gemini(N)
Spatially resolved SFR, M★, [NII]/Hα from deep GMOS IFU spectroscopy

\[ Σ(Hα) \]

\[ Σ(M★) \]

\[ \text{log(SSFR) per pixel [1/yr]} \]

\[ \text{log} Σ(M★) [M\odot/kpc^2] \]

- Rmajor < 2.5 kpc
- 2.5 < Rmajor < 5.0 kpc
- 5.0 < Rmajor < 7.5 kpc
- 7.5 < Rmajor < 10.0 kpc
- 10.0 < Rmajor < 12.5 kpc
- 12.5 < Rmajor < 15.0 kpc
Red SF galaxies in the core of $z>2$ proto-cluster environment

Subaru MOIRCS H$\alpha$ survey of a proto-cluster at $z=2.2$ (Koyama+2013)
Red SF galaxies in the core of z>2 proto-cluster environment

Subaru MOIRCS Hα survey of a proto-cluster at z=2.2 (Koyama+2013)
Clumpy galaxies in $z>2$ proto-clusters

Rest-frame UV morphologies of $z=2.2$ Hα emitters in PKS1138 proto-cluster env.

M: 24um source
X: X-ray source

HST/i-band snapshots (4″×4″=30 kpc for each)

(Koyama et al. 2013a)
Clumpy galaxies in $z>2$ proto-clusters

Rest-frame UV morphologies of $z=2.2$ Hα emitters in PKS1138 proto-cluster (Koyama et al. 2013a)
Rest-optical morphologies with Subaru IRCS+AO (K-band) imaging

Further follow-up observation with:
- ALMA Band-3 (CO$_3$→2) : delivered
- ALMA Band-7 (dust): scheduled (cycle3/4)
- KMOS/VLT : delivered

Stay Tuned!
GANBA-Subaru: IRCS+AO188+NB(Hα)
imaging of distant galaxies

Galaxy Anatomy with Narrow-Band AO imaging with Subaru

(Y. Minowa & Y. Koyama et al.)

(See talk on ULTIMATE-Subaru by Y. Minowa)
Summary

• MAHALO-Subaru is an extensive NB imaging survey of distant (proto-)clusters with Subaru.
• The environmental impact on the SF main sequence is small over the last ~10-Gyrs.
• SF galaxies in z>2 proto-cluster are significantly more massive than field counterparts.
• Environment of dusty SF galaxies changes with time.
• We are undertaking many follow-up programs on the massive/red/clumpy galaxies in distant cluster environment.