MApping H Alpha and Lines of Oxygen with Subaru

Mapping star formation at the peak epoch of galaxy formation and evolution

A Subaru Intensive Program for S10B-S11A

"MAHALO-Subaru"

Taddy Kodama (Subaru Telescope),

Masao Hayashi (NAOJ) “Ha survey in USS1558 (z=2.53)”,
Yusei Koyama (Univ of Durham, UK / NAOJ),
Kenichi Tadaki (NAOJ/Univ of Tokyo),
Ichi Tanaka (Subaru Telescope), et al.
What’s the origin of the environmental dependence

morphology - density relation
(Dressler 1980)

log surface density (Mpc$^{-2}$)

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)
Why Subaru?

Final cluster with $M=6 \times 10^{14} M_\odot$, $20 \times 20$ Mpc$^2$ (co-moving) (Yahagi et al. 2005; ν GC)
"MAHALO-Subaru"

MApping HAlpha and Lines of Oxygen with Subaru

NB mapping of star forming galaxies at the peak epoch of galaxy formation

Pilot obs (5 nights) + Intensive (10 nights @S10B-11A) + Normal (3 nights @S11B)

<table>
<thead>
<tr>
<th>environment</th>
<th>target</th>
<th>$z$</th>
<th>line</th>
<th>$\lambda$ (\text{\textmu}m)</th>
<th>camera</th>
<th>NB-filter</th>
<th>continuum</th>
<th>status</th>
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<td>H$\alpha$</td>
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<td>Suprime-Cam</td>
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<td>RXJ1716+6708</td>
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<td>[O II]</td>
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<td>MOIRCS</td>
<td>NB1190</td>
<td>$J$</td>
<td>not yet</td>
</tr>
</tbody>
</table>

Kodama, T. (PI), Hayashi, M., Koyama, Y., Tadaki, K., Tanaka, I., et al.
Why $1.5 < z < 3$? $(4 > T_{\text{univ}}(\text{Gyr}) > 2)$

The peak epoch of star formation and AGN activities.
The formation epoch of massive galaxies (SMG, red sequence).

Cosmic star formation rate density

Number density of AGNs

※$z \sim 2.8$ is the upper limit where we can capture $\text{H}a$ ($\sim 2.5 \mu m$) from the ground.

Fan et al. (2006)

Hopkins and Beacom (2006)
Unique sets of Narrow-Band Filters on Suprime-Cam and MOIRCS

The existing Suprime-Cam NB-filters capture emission lines from known good targets. The MOIRCS NB-filters were specifically designed for good targets at frontier redshifts.

4 narrow-band filters

7 narrow-band filters

NB1190, NB1550, and NB2095 are a coordinated set filter to target [OII], Hβ, Hα lines at z=2.19
How does NB imaging work?

Hα emitters in and around RXJ1716 cluster (z=0.81)

A colour-colour diagram is used to separate out our wanted line from other contaminant lines. (or photometric redshifts can be used)

Koyama et al. (2010)
Inside-out propagation/truncation of star formation activities in clusters

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

$\Delta$ R.A. [Mpc (physical)]

$\Delta$ Dec. [arcmin]

0.5 x $R_{200}$

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

Koyama, et al. (2011)

$\Delta$ R.A. [arcmin]

$\Delta$ Dec. [arcmin]

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

Hayashi, et al. (2010)
Hidden star formation in the red sequence and in groups?

Lots of star formation is hidden in the optical (rest UV) surveys!

The red Hα emitters are dusty star-forming galaxies in groups, and the key populations under the influence of environmental effects.
ClG J0218.3-0510 (a x-ray cluster at z=1.62) in SXDF

[OII] emitters are traced by Suprime-Cam/NB973-filter

The cluster is embedded in LSS of a scale of ~20Mpc.

No environmental dependence is seen at z~1.6.

Tadaki et al. (2011b), submitted
Examples of FMOS spectra of the [OII] NB emitters with the presence of Hα emission lines, which confirm their membership of the large scale structure in and around the cluster at $z \sim 1.6$.

New data just taken in Jan 2012 by Hayashi, Tadaki et al.
**Ha emitters in two high-z proto-clusters at z>2**

“Red emitters” tend to favor high density regions!

What’s the nature of “red” Hα emitters?
- Dusty+SF (SF mode)?
- Passive+AGN (AGN activity)?

Hayashi et al. (2012),
See Hayashi’s talk
Hα emitters at $z=2.19$ (NB2095)

SXDF/CANDELS (J-ALMA Deep Field?)

Hα emitters at $z=2.53$ (NB2315)
Subaru is best suited for NIR spectroscopic follow-up!

redshifts, velocity dispersion, dust extinction (Hβ/Hα), AGN contribution (BPT diagram), and gaseous metallicity (N2, O3N2).
“Mahalo-Subaru”
MApping HApha and
Lines of Oxygen with Subaru

“Gracias-ALMA”
GRAphing CO Intensity
And Submm with ALMA

CO(3→2) @ z~2.5 @100GHz → M_{gas}
Dust conti. @450 μm–1.1 mm → Dusty SFR
resolving spatially (<0.1”), kinematically (~50km/s)

\[
\begin{align*}
\text{SFE} & \quad \left( \frac{\text{SFR}}{\text{M}_{\text{gas}}} \right) \\
\text{f(gas)} & \quad \left( \frac{\text{M}_{\text{gas}}}{\text{M}_{\text{gas}}+\text{M}_{\text{star}}} \right)
\end{align*}
\]

Distribution and motion of gas

→ Merger induced starburst at the center?
or Extended star formation over the disk?

USS1558 proto-cluster (z=2.53)

<table>
<thead>
<tr>
<th>L: SFR &gt; 100M_{☉}/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>M: &gt; 50 M_{☉}/yr</td>
</tr>
<tr>
<td>S: &lt; 50 M_{☉}/yr</td>
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Merger induced starburst at the center? or Extended star formation over the disk?
Summary

- **Mahalo-Subaru** is mapping out star formation activities across time and environment at the peak epoch of galaxy formation and evolution.

- **Red emitters** are the key populations under the influence of environmental effects.

- **Inside-out propagation of SF** activities in clusters since z~2.5.

- Need **NIR spectroscopy** to know why.

- **Gracias-ALMA** will reveal the mode of SF and evolutionary states of galaxies at the peak epoch of galaxy formation.
The End