# JCMT JCMT & HSC : JCMT Deep submm imaging of dusty starbursts in protoclusters at 2<z<6</td>

-Project summary and current status report-

On behalf of MAHALO-JCMT (PI: T. Kodama) and HSC-protocluster team



#### Minju Lee (The university of Tokyo, NAOJ)



### Galaxy evolution on the main seq. and its environ. dependence



#### Boylan-Kolchin+09

**MAHALO-Subaru** 

MApping HAlpha and Lines of Oxygen with Subaru



Unique sample of NB-selected SF galaxies across environments and cosmic times

|          | environ- | target                    | z     | line          | λ         | camera      | NB-filter      | conti-           | status           |
|----------|----------|---------------------------|-------|---------------|-----------|-------------|----------------|------------------|------------------|
|          | ment     |                           |       |               | $(\mu m)$ |             |                | nuum             | (as of Apr 2015) |
|          | Low-z    | CL0024+1652               | 0.395 | $H\alpha$     | 0.916     | Suprime-Cam | NB912          | z'               | Kodama+'04       |
| 7<1      | clusters | CL0939+4713               | 0.407 | $H\alpha$     | 0.923     | Suprime-Cam | NB921          | z'               | Koyama+'11       |
| 271      |          | CL0016+1609               | 0.541 | $H\alpha$     | 1.011     | Suprime-Cam | NB1006         | z'               | not yet          |
| clusters |          | RXJ1716.4+6708            | 0.813 | $H\alpha$     | 1.190     | MOIRCS      | NB1190         | J                | Koyama+'10       |
|          |          |                           |       | [O11]         | 0.676     | Suprime-Cam | NA671          | R                | observed         |
|          |          | RXJ0152.7–1357            | 0.837 | [O111]        | 0.920     | Suprime-Cam | NB921          | z'               | not yet          |
| -~15     | High-z   | XCSJ2215–1738             | 1.457 | [OII]         | 0.916     | Suprime-Cam | NB912, NB921   | z'               | Hayashi+'10, '12 |
| 2~1.5    | clusters | 4C65.22                   | 1.516 | $H\alpha$     | 1.651     | MOIRCS      | NB1657         | H                | Koyama+'14       |
| clusters |          | CL0332-2742               | 1.61  | [O11]         | 0.973     | Suprime-Cam | NB973          | $\boldsymbol{y}$ | observed         |
|          |          | ClGJ0218.3-0510           | 1.62  | [O11]         | 0.977     | Suprime-Cam | NB973          | $\boldsymbol{y}$ | Tadaki+'12       |
|          | Proto-   | PKS1138-262               | 2.156 | $H\alpha$     | 2.071     | MOIRCS      | NB2071         | $K_{\rm s}$      | Koyama+'12       |
|          | clusters | HS1700+64                 | 2.30  | $_{ m Hlpha}$ | 2.156     | MOIRCS      | $\mathbf{BrG}$ | $K_{\rm s}$      | observed         |
| -> 0     |          |                           |       | [O111]        | 1.652     | MOIRCS      | [Fe 11]        | H                | not yet          |
| Z>2      |          | 4C23.56                   | 2.483 | $_{ m Hlpha}$ | 2.286     | MOIRCS      | CO             | $K_{\rm s}$      | Tanaka+'11       |
| clustors |          | USS1558-003               | 2.527 | $_{ m Hlpha}$ | 2.315     | MOIRCS      | NB2315         | $K_{\rm s}$      | Hayashi+'12      |
| ciusters |          | MRC0316-257               | 3.130 | [O11]         | 2.539     | MOIRCS      | NB1550         | H                | not yet          |
|          |          |                           |       | [O111]        | 2.068     | MOIRCS      | NB2071         | $K_{ m s}$       | observed         |
|          | General  | SXDF-CANDELS              | 2.16  | $H\alpha$     | 2.071     | MOIRCS      | NB2071         | $K_{\rm s}$      | observed         |
|          | fields   | (90 arcmin <sup>2</sup> ) | 2.19  | $H\alpha$     | 2.094     | MOIRCS      | NB2095         | $K_{ m s}$       | Tadaki+'13       |
|          |          |                           | 2.53  | $H\alpha$     | 2.315     | MOIRCS      | NB2315         | $K_{\rm s}$      | Tadaki+'13       |
| -> 0     |          |                           | 3.17  | [O111]        | 2.093     | MOIRCS      | NB2095         | $K_{\rm s}$      | Suzuki+'14       |
| Z>Z      |          |                           | 3.63  | [O111]        | 2.317     | MOIRCS      | NB2315         | $K_{\rm s}$      | Suzuki+'14       |
| field    |          | COSMOS-CANDELS            | 2.16  | $H\alpha$     | 2.071     | MOIRCS      | NB2071         | $K_{ m s}$       | partly observed  |
|          |          | (90 arcmin <sup>2</sup> ) | 2.19  | $H\alpha$     | 2.094     | MOIRCS      | NB2095         | $K_{ m s}$       | partly observed  |
|          |          | GOODS-N                   | 2.19  | $H\alpha$     | 2.094     | MOIRCS      | NB2095         | $K_{ m s}$       | Tadaki+'11       |
|          |          | (70 arcmin <sup>2</sup> ) |       | [O11]         | 1.189     | MOIRCS      | NB1190         | J                | observed         |

~20 nights for imaging, >15 nights for spectroscopy

Kodama et al. (2013)

#### Spatial distributions of Ha emitters in two proto-clusters at z>2



Lots of HAEs live in proto-cluster cores, indicating strong SF activities there. Red HAEs (J-Ks >1.38; dusty starbursts) tend to favor dense cores/clumps!

## Massive + dusty galaxies in the proto-cluster core



Red Ha emitters are very massive ( $M \star > 10^{11} M_{\odot}$ ) and dusty star-forming galaxies. Many are detected at 24µm with MIPS.

 $\rightarrow$  Cluster specific/preferred phenomena at high-z, holding a key to understanding the early environmental effects.



## MAHALO-JCMT

USS1558-003 (z=2.53)



A coordinated program with JCMT (~100hrs) to map dusty starbursts in proto-clusters.

(15AB; Kodama et al.)

as of 2016/01/31

| Cluster       | Redshift | Integrat | tion |
|---------------|----------|----------|------|
| PKS1138-262   | 2.16     | 7.5 h    |      |
| 2QZ10hr       | 2.23     | 10.0 h   |      |
| 4C23.56       | 2.48     | 1.0 h    |      |
| USS1558-003   | 2.53     | 15.0 h   |      |
| USS0943-242   | 2.92     | 10.0 h   |      |
| MRC0316-257   | 3.13     | 13.0 h   |      |
| TNJ1338-1942  | 4.11     | 8.0 h    |      |
| SDF-z6cluster | 6.00     | 15.0 h   |      |

14hrs on-source integration with SCUBA-2 in DAISY mode (FoV~6')  $\rightarrow$  1.26mJy (3 $\sigma$ )=220M•/yr at center, 1.7mJy=300M•/yr at edge (@850µm)

## MAHALO-JCMT

Enhanced dusty starbursts (Twelve 850µm sources within the MOIRCS deep image). Spatial distributions are similar (NNE-SSW filament) between 850µm sources and HAEs.



# Subaru-HSC Legacy Surveys





# Science goals

| layer     | area (deg <sup>2</sup> )               | filters     | depth (mag)    |
|-----------|--|-------------|----------------|
| Wide      | 1400 (700 deg <sup>2</sup> × 2 fields) | grizy       | <i>i</i> ~25.9 |
| Deep      | 27 (7 deg <sup>2</sup> × 4 fields)     | grizy + 3NB | <i>i</i> ~26.8 |
| Ultradeep | 3.5 (1.8 deg <sup>2</sup> × 2 fields)  | grizy + 3NB | <i>i</i> ~27.4 |

- 1. Ultradeep/Deep layer (~27 deg2) ~10-20 protoclusters will be found at each redshift → redshift evolution of protoclusters
- 2. Wide layer (~1400 deg2)
  ~1000 protoclusters will be found at z~4 (g-dropout)
  → variety of protoclusters

# Expectation

| survey   | area                  | cluster number (dn/dz)                           |
|----------|-----------------------|--|
| HSC-Deep | 27 deg <sup>2</sup>   | 200 (>10 <sup>14</sup> $M_{\odot}$ ) at z=1      |
|          |                       | 6 (>10 <sup>14.5</sup> M <sub>•</sub> ) at z=1   |
| HSC-Wide | 1400 deg <sup>2</sup> | 10,000 (>10 <sup>14</sup> $M_{\odot}$ ) at z=1   |
|          |                       | 300 (>10 <sup>14.5</sup> M <sub>☉</sub> ) at z=1 |

Our recent JCMT program as **DDT pilot** (HSC protocluster followup) ( PI : M. Yuichi)

# SCUBA-2 mapping of HSC-selected galaxy clusters at 1 < z < 7

- 5-6 targets will be observed as DDT pilot program
- We are currently carefully brushing-up our final target source for the classical observation on July

# Summary

- The successful JCMT follow-up of galaxies detected with MAHALO-Subaru program
  - We are currently working on the *data reduction* (~80 % completion of the requested time)
    - for USS1558 : potential detection that are associated to colorselected (DRG) galaxies are to be followed-up by ALMA
    - other 5 protocluster : several detection above >  $5\sigma$ 
      - analysis is, and will be undertaken in detail
        - number density, SFRD etc.

#### • JCMT-HSC synergy :

- HSC protocluster survey is NOW dramatically increasing the number of protoclusters z>1 up to z=7
- 5-6 sources through the approved DDT program would open a new potential between JCMT and HSC synergy, in terms of starburst phase occurrence in over dense region and thus the galaxy evolution