Identification of the Progenitors of Rich Clusters and Member Galaxies in Rapid Formation at $z > 2$

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Galaxy clusters are the largest self-gravitational system in the Universe, in which member galaxies have some unique characteristics in their morphology, dynamics and such as. However, nobody has not reached yet on revealing their physical origins observatinally.

Such an environmental dependence of galaxy formation seen in between galaxy clusters and general fields is a key issue to understand an entire picture of galaxy formation process. In order to resolve this problem, protoclusters above the redshift of two are the ideal laboratories since cluster galaxies are still in vigorous forming processes in those regions.

With this background, we conducted the near-infrared spectroscopic observation to Hα-selected galaxies associated with two rich protoclusters (PKS1138–262 at z=2.2 and USS1558–003 at z=2.5) in March–April 2013. These protoclusters are found by our distant-protocluster survey named 'MAHALO-Subaru' [1]. The observation motivates on confirming dynamical masses and velocity structures of the protoclusters [2], and also on studying physical properties of star-forming galaxies in them. This will provide us with crucial insights on searching for an early phase of environmental dependence of galaxy formation.

As a result, total integration time of more than 2 hrs for each target gave us with line spectra located at 1.3–2.5 μm in 27 & 36 objects in PKS1138–262 and USS1558–003, respectively. Those data were derived from low resolution grism (HK500) attached with MOIRCS, near-infrared multi-object spectrograph on the Subaru telescope. We observed 80 % out of the targets during 5 nights, and then finally confirmed 70 % spectroscopically among them (Fig. 1).

Founded on the datasets, we explore the dynamical masses of the protoclusters by using velocity dispersion of the members located at those cluster cores. The results show that both of two protoclusters have about $10^{14}\,M_\odot$. Interestingly, this exactly follows the typical mass growth history of today's most massive class of galaxy clusters ($\sim10^{15}\,M_\odot$) predicted by cosmological simulations [3,4].

So far, we have some non-confirmed members and need to investigate more details of velocity structures of these quite rich protoclusters. Future MOSFIRE (on the Keck I telescope) observation will satisfy such requirements.

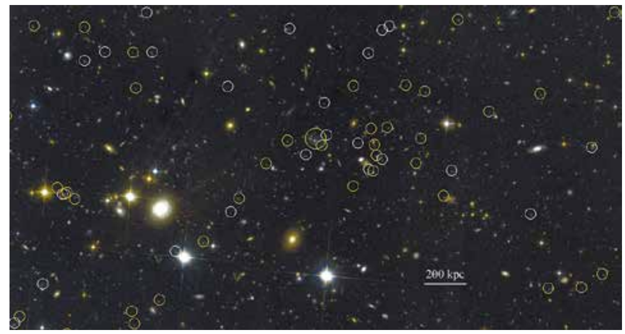

Figure 1: Composite color image of the protocluster PKS1138–262, based on the data taken by Hubble Space Telescope (F814W & F475W). Yellows are spectroscopically confirmed members including the past works. Whites do not still have spectroscopic data, and yet are Hα-selected galaxies by our past narrow-band imaging.

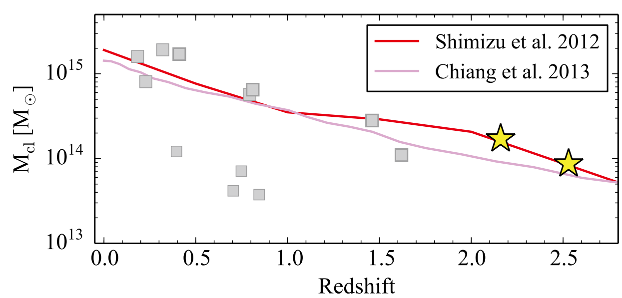

Figure 2: Redshift versus cluster dynamical masses. The yellow stars show our results and the others are derived from the past works. The red and the pink lines are the typical mass growth history of massive cluster haloes with $1\text{–}2\times10^{15}\,M_\odot$ predicted by theoretical simulations [3,4].

References

[1] Kodama, T., et al.: 2013, *IAUS*, **295**, 74.
[2] Shimakawa, R., et al.: 2014, *MNRAS*, **441**, L1.
[3] Shimizu, I., et al.: 2012, *MNRAS*, **427**, 2866.
[4] Chiang, Y.-K., et al.: 2013, *ApJ*, **779**, 127.