Discovery of a Protocluster at $z \sim 6$

TOSHIKAWA, Jun, SHIBUYA, Takatoshi, ISHIZAKI, Yoshifumi
(Graduate University for Advanced Studies)

KASHIKAWA, Nobunari, HAYASHI, Masao
(NAOJ)

OTA, Kazuaki, NAGAO, Tohru
(Kyoto University)

MOROKUMA, Tomoki, SHIMASAKU, Kazuhiro, MOTOHARA, Kentaro
(University of Tokyo)

JIANG, Linhua, EGAMI, Eiichi
(University of Arizona)

MALKAN, Matthew A.
(University of California)

Exploring the structure formation and evolutionary history of the early universe is an issue of strong current interest in astronomy. In the cold dark matter model, clusters of galaxies form in the densest peaks of dark matter in the early universe. These grow by merging and by accreting material from surrounding low-density regions [1]. Theoretical models predict that galaxies lying inside these high-density regions may have formed earlier and/or evolved more rapidly, compared with their surroundings [2]. Clusters of galaxies are thus the noteworthy site of dark matter structure formation and galaxy evolution. Protoclusters in the early universe would provide a great deal of information on the primordial conditions of clusters at their birth.

We used the deep and wide field of the Subaru Deep Field. These images were constructed by stacking all the data taken from 2001 to 2008, containing almost 30 hours worth of integration time in total. We selected 258 $z \sim 6$ galaxy candidates using Lyman break technique. Figure 1 shows the sky distribution of the 258 $z \sim 6$ galaxy candidates. We found an apparently overdense region, centered in the southern part of the field. To determine the overdensity significance quantitatively, we estimated the local surface number density. We found that our region of interest appeared overdense at the 6σ significance level beyond the mean surface number density at the peak.

We carried out follow-up spectroscopy on the overdense region, using FOCAS on the Subaru telescope. We spectroscopically confirmed 15 $z \sim 6$ galaxies in the overdense region. Eight galaxies of them are apparently concentrating at $z \sim 6.01$ ($\Delta z < 0.05$). The redshift concentration at $z \sim 6.01$ is about seven times higher than the number density expected from a uniform distribution. Thus, this region is almost certain to be a galaxy protocluster at $z \sim 6.01$. If true, this protocluster would be the highest redshift large scale structure probed by the unique wide-field imaging capability of SuprimeCam.

The velocity dispersion of the eight protocluster members is 647 ± 124 km s^{-1}, which is about three times higher than that predicted by the standard cold dark matter model. From the three-dimensional distribution, we proposed two possible explanations for this discrepancy: either the protocluster is already mature, with old galaxies at the center, or it is still immature and composed of three subgroups merging to become a larger cluster. Further deep spectroscopic observations or multi-wavelength imaging to trace the rest-frame optical wavelengths would provide a clearer picture of the protocluster structure, as well as providing constraints for the galaxy/stellar populations of protocluster members [3].

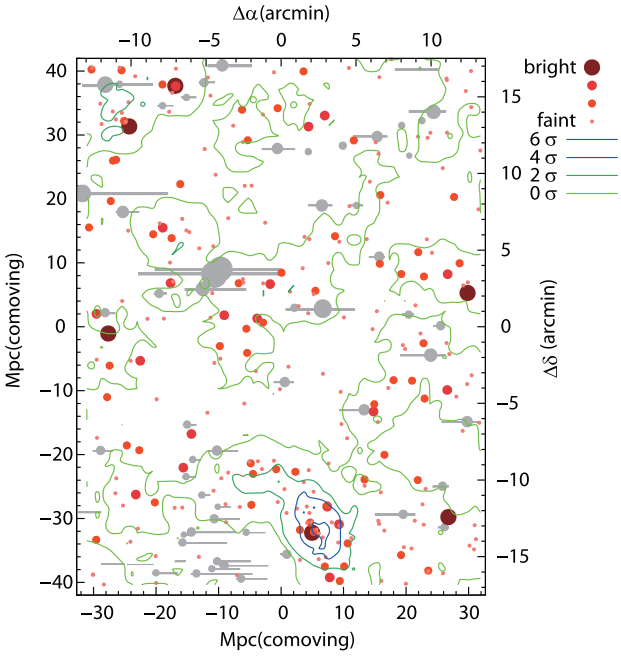

Figure 1: Sky distribution of 258 $z \sim 6$ galaxy candidates, with surface number density contours. The $z \sim 6$ galaxy candidates are represented by filled circles whose size is proportional to the z'-band magnitudes. The lines correspond to contours of surface overdense significance from 6σ to 0σ with a step of 2σ. The overdense region can be clearly seen at the southern edge of the plot.

References

[1] Springel, V., et al.: 2005, *Nature*, **435**, 629.
[2] De Lucia, G., et al.: 2006, *MNRAS*, **366**, 499.
[3] Toshikawa, J., et al.: 2012, *ApJ*, **750**, 137.