Searching for NIR-selected massive galaxies in a proto-cluster selected by LAEs at z =2.39

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Abstract

A proto-cluster around a radio galaxy 53W002 at z =2.39 was discovered as a density excess of Lyman Alpha Emitters (LAEs). We searched for massive galaxies at the same redshift in the 53W002 field, using JHK_s-bands imaging data taken with Subaru/MOIRCS. The JHK_s-selected massive galaxy candidates are preferentially located toward the highest density region of LAEs rather than around 53W002 itself. The number counts of the JHK_s-selected galaxies with K_s < 21 shows a significant excess in the highest density region. There are also a few galaxies with the similar colors as 53W002 and the red sequence of massive galaxies might be forming in the proto-cluster. The HSC narrow-band surveys are expected to provide large samples of proto-clusters selected by LAEs. The NIR follow-up observations of these clusters will allow us to reveal the formation and evolution of cluster galaxies.

1. Introduction

It is known that early-type galaxies in nearby clusters are composed of old stars formed at z >2 (e.g., Bower et al. 1992, MNRAS, 254, 601).
⇒ It is important to directly investigate proto-clusters at z >2 in order to understand the formation process of early-type galaxies in the high-density environments.

A region around the radio galaxy 53W002 at z = 2.4

There are many LAEs at the same redshift of the radio galaxy (e.g., Pascarelle et al. 1996, Nature, 383, 45). Recently, Mawatari et al. (2012, ApJ, 759, 133) found that the highest density region (HDR: orange rectangle) of LAEs at a distance of ~1 Mpc from the radio galaxy and the radio galaxy (red cross) exists at the rim of HDR.

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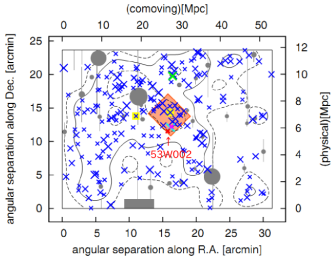
However, LAEs typically have small stellar mass and young stellar age, which are completely different from those of massive early-type galaxies in the present clusters. It is important to investigate the massive galaxy population in high-z proto-clusters selected by LAEs in order to understand the formation and evolution of early-type galaxies in high-density environments.

In order to probe massive galaxies in the proto-cluster, we analysed near-infrared JHK_s-bands imaging data of the 53W002 field taken with Subaru/MOIRCS.

Spatial distribution of LAEs (Mawatari et al. 2012)



2. Data & source detection

We performed the JHK_s-bands imaging observation with the MOIRCS field (4' × 7')

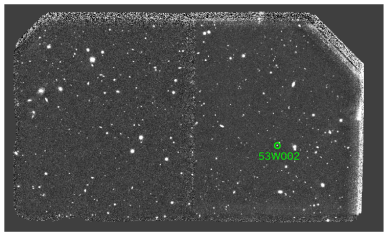
Table1 : Limiting magnitudes ($0.9''\varphi, 5\sigma$)

Band	Exposure time (sec.)	$m_{\rm lim}$ (Vega mag.)	$FWHM$ (arcsec)
J	4410	24.2	0.39
H	4080	23.5	0.43
K_s	5560	22.2	0.43

Source detection & photometry

- Source detection was performed in the K_s-band image using the SExtractor.
- We adopted MAG_AUTO from the SExtractor as the total K_s-band magnitude of detected objects.
- For the color measurements, we used 0.9" ϕ aperture on the PSF-matched images (0.4" FWHM).

Final composite K_s-band image

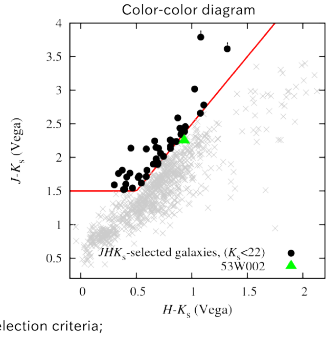


3. Sample

Selection of massive galaxy candidates at z ~2.4

We applied JHK_s-bands two-color selection for galaxies at z ~2.4 (Kajisawa et al. 2006, MNRAS, 371, 577) to K_s-selected galaxies with K_s < 22.

Color-color diagram



Selection criteria;

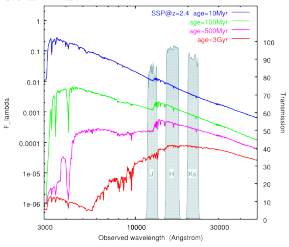
$$J - K_s > 2(H - K_s) + 0.5$$
$$J - K_s > 1.5$$

→ There were 41 JHK_s-selected galaxies

Note that the radio galaxy 53W002 itself is located slightly outside the color-selected region due to the effect of the very strong emission lines from AGN on JHK_s bands.

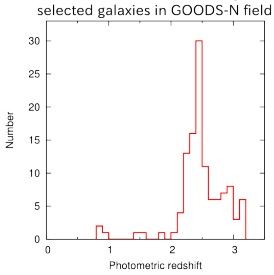
The right figure shows the distribution of photometric redshift for the same JHK_s-selected galaxies with K_s < 22 in the GOODS-N field (Kajisawa et al. 2011, PASJ, 63S, 379K).

It is found that the JHK_s selection can sample galaxies around at z ~2.4 with a very small contamination of z < 2 galaxies. We expect that the JHK_s-selected galaxies in this analysis also have the similar redshift distribution.



The SSP spectra of galaxies at z =2.4 from the GALAXEV model. Since the Balmer / 4000 Å break of these galaxies is in between J and H bands, J band is fainter than H and K_s bands. Thus these galaxies lie at the upper-left region of relatively red J-K_s and blue H-K_s colors on the two-color diagram.
These JHK_s-bands selection could miss galaxies with very young average stellar ages (< ~100 Myr), which do not show the strong Balmer/4000 Å break.

Phot-z distribution of the JHK_s-selected galaxies in GOODS-N field



4. Results

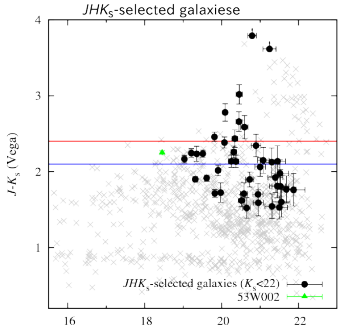
(1) Color-magnitude diagram

The right figure shows J-K_s vs. K_s diagram for the JHK_s-selected galaxies.

We can see a few galaxies which have the similar colors as the radio galaxy 53W002 and 1-2 mag fainter in K_s-band magnitudes. Also, there are many galaxies at fainter K_s-band magnitude with redder and bluer than the radio galaxy.

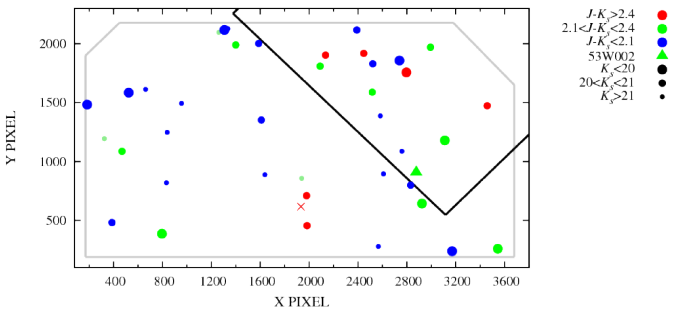
To analyse separetely in color, we divided these galaxies into the redder (J-K_s > 2.4), similar (2.1 < J-K_s <2.4), and bluer (J-K_s < 2.1) color samples.

Color-magnitude distribution of the JHK_s-selected galaxiese



(2) Spatial distribution

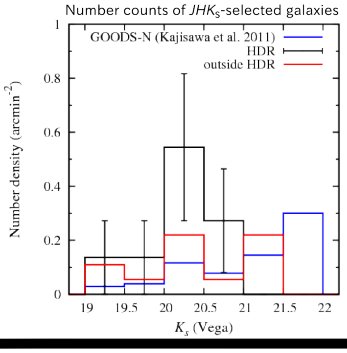
Spatial distribution of the JHK_s-selected galaxies



The upper figure shows the spatial distribution of the JHK_s-selected galaxies in the 53W002 field.
- relatively red galaxies with J-K_s > 2.1;
they preferentially located toward the HDR of LAEs rather than around 53W002, although the MOIRCS data, where 53W002 itself is located at the center of a detector of MOIRCS, cover only a part of the HDR.
- relatively blue galaxies with J-K_s < 2.1;
they distributed in the whole MOIRCS region.

(3) Number counts

Number counts of JHK_s-selected galaxies



The left-side figure shows the K_s-band number counts of the JHK_s-selected galaxies. For comparison, we also show the JHK_s-selected galaxies with K_s < 22 in the GOODS-N field (Kajisawa et al. 2011)

The density in the HDR is 3-5 times larger than that in the GOODS-N field at K_s < 21 although we cannnot make a fair comparison at K_s > 21.5 because of the incompleteness.

The JHK_s-selected galaxies with the similar colors as the radio galaxy also have K_s < 21 (the above figure).

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If these galaxies actually exist at z =2.4 and make the density excess, the red sequence of massive galaxies might be forming the color-magnitude relation in the proto-cluster

5. Summary

(1) We discovered 41 massive galaxy candidates with K_s < 22 in the proto-cluster region around 53W002 at z = 2.4 using the JHK_s-bands color selection technique.
(2) There are a few JHK_s-selected galaxies with the similar colors as the radio galaxy at K_s=19-20 mag.
(3) The JHK_s-selected galaxies with J-K_s > 2.1 are preferentially located toward the HDR of LAEs rather than around the radio galaxy.
(4) The number counts of the JHK_s-selected galaxies show the density excess at K_s< 21.0.
(5) The JHK_s-selected galaxies with the similar colors as the radio galaxy have K_s < 21, where the number density excess of the JHK_s-selected galaxies is seen. We might see the formation process of the red sequence in the proro-cluster.
(6) The HCS narrow-band surveys are expected to find many high-density regions of high-z LAEs. The NIR follow-up observations of such proto-clusters like this study will provide an unique opportunity to investigate the formation of galaxies in high-density environments at high redshift.