Final Report of 2013 Summer Student Program

Understand the formation process of the youngest and yet most active star-forming galaxies

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1 Introduction

Searching for the first galaxies is an important issue in understanding the early history of the universe and the formation of galaxies. Lyman-α emitters (LAEs) are galaxies at $z = 2-7$ with fiant urltraviolet continuum and prominent Ly-α emission line. They are thought to be the progenitors of most modern galaxies because the strong emission lines might be related to photoionization by low metallicity star formation (eg. Tumlinson et al. 2001; Schaerer et al. 2003) or gas cooling during gravitational collapse (e.g. Haiman et al. 2000; Li et al. 2006). However, these LAEs are distant and faint, thus difficult for direct observation or further studies. Finding objects similar to the LAEs in our local universe would be very valuable to related studies.

The "r-Peas" or the "green Peas" are a special class of galaxies first identified in the internet forums of the Galaxy Zoo project. They were named "Peas" because of their unresolved, bright green SDSS (Sloan Digital Sky Survey) gri composite image. Fig. 1 shows the image of 3 SDSS r-Peas and the image of a elliptical galaxy at the same redshift (~ 0.2), the peas look very different than other typical stars or galaxies and raised discussions among internet users. Despite they are mostly classified as stars in the SDSS photometric pipeline (Lupton et al. 2001), they all had galaxy type spectral features. The r-Peas are $z \sim 0.3$ low mass galaxies ($M \sim 10^{8.5} - 10^{10} M_{\odot}$) of very high star formation rates ($\sim 10 M_{\odot} yr^{-1}$), low metallicities ($log[O/H] + 12 \sim 8.7$) and reside in low-density environments (Caradamone et al. 2009). The green color of the image is due to very strong emission lines of [OIII] 5007 $\AA$ in the r band. The Peas are local objects and share many similar characteristics with the active star forming galaxies at higher redshifts, thus making them interesting objects to study and observe.

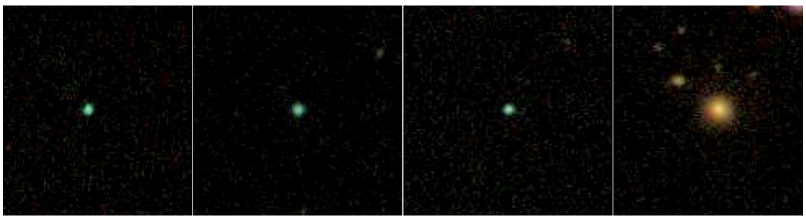

Figure 1: The left three images are examples of SDSS Pea images, they are very distinguishable from typical ellipitical galaxies (right hand image).

Bamford and Foucaud (in prep.) had extended the selection of Peas to $z < 1$ by applying similar color-color selection techniques for UKIDSS UDS (Ultra Deep Survey, Lawrence et al. 2007) third data release, including the i-Peas at $z = 0.45 - 0.7$ and z-Peas at $z = 0.7 - 0.95$. They have found 13 confirmed i-Peas and 7 confirmed z-Peas in the field of $0.88 \times 0.88 deg^2$.

The goal of this summer project is to extend the i-Peas and z-Peas selection to various fields, including the UKIDSS UDS DR8, COSMOS and AEGIS, and increase the amount of known pea candidates. In the future, we will study the pea properties such as mass, star formation rate, and metallicity with spectra from z-COSMOS and DEEP2 redshift survey. And eventually propose observations on pea candidates in order to probe peas directly. With ALMA, we will be able to probe the gas content of the pea galaxies, and study the relation of gas mass and SFR in peas.

2 Data

In this project, we uses the photometric catalogs from UKIDSS Ultra Deep Survey(UDS), the Subaru/ XMM-Newton Deep Survey(SXDS), Cosmic Evolution Survey (COSMOS) and All-wavelength Extended Groth strip International Survey (AEGIS).

SXDS is a multiwavelength observation project that covers a total area of 1.22 deg^2. The observation was carried out with the Suprime-Cam on Subaru Telescope in five broadband filters, B, V, R_c, i' and z' (Furusawa et al. 2008). UDS is the deepest survey among the five of the United Kingdom Infrared Telescope (UKIRT) Infrared Deep Sky Survey, it uses the UKIRT Wild Field Camera (WFCAM) to observe the sky in $ZYJHK$ bands. UDS centered on the field of SXDS and covers 0.78 deg^2 in JHK band to the depth of $K = 23.0$ (Hewett et al. 2006). It is the deepest survey ever conducted over such a large field, and we uses the eighth data release (DR8).

COSMOS project provides photometry in 15 photometric bands between 0.3 and 2.4 μ, including data taken on the Subaru 8.3m telescope, the KPNO and CTIO 4m telescopes, and the CFHT 3.6m telescope. The bands we use in this project are the Subaru G, R, I, Z, CFHT I, UKIRT J, and CFHT Ks band from the COSMOS intermediated and broad band catalog. Objects brighter than 19 magnitude (or 22 magnitude under good seeing) are saturated in typical exposure, so a series of short exposures were taken to avoid these sources (Capak et al. 2007). In this case, CFHT Megaprime camera was used to obtain shallow i band of the COSMOS field. We also uses the zCOSMOS survey to retrieve the spectra of the pea candidates.

AEGIS is a multi-wavelength on the Extended Groth Strip (EGS) which covers $120' \times 15'$ over the sky. I used the SDSS g, r, i, z photometry in DEEP2 redshift survey fourth data release (DR4) and Wide Field IR Camera (WIRC) J, Ks band from Palomar near infrared. The DEEP2 redshift survey is limited to $R = 24.1$ and the Palomar NIR j, Ks bands are limited to 23 and 20.7 respectively. Spectra of pea candidates are provided as well in the DEEP2 DR4.

3 Photometry correction

In order to compare and produce correct pea selection terms, we need to calibrate all the photometry into the equivalent filters, apertures and magnitude systems. In this project, all color magnitudes are in AB magnitudes, and uses the SDSS and 2Mass filters with a $3''$ aperture or an auto magnitude(for the case of AEGIS). The r-Peas are unresolved sources in Galaxyzoo images, suggesting an upper limit of $2''$ in size at $z \sim 0.3$. Therefore, using magnitude of $3''$ aperture or model fitted magnitude would not make a big difference as they should both cover the whole galaxy. Table 1, 2, 3 shows the conversion for each datasets. By the overlapping the gzK diagram of the three datasets, we can evaluate quality of the correction with the features in the gzK diagram, for example the position of star sequence. Fig. 2 (right) clearly shows that the distribution of objects overlaps well in the color-color diagram after applying the conversion terms.

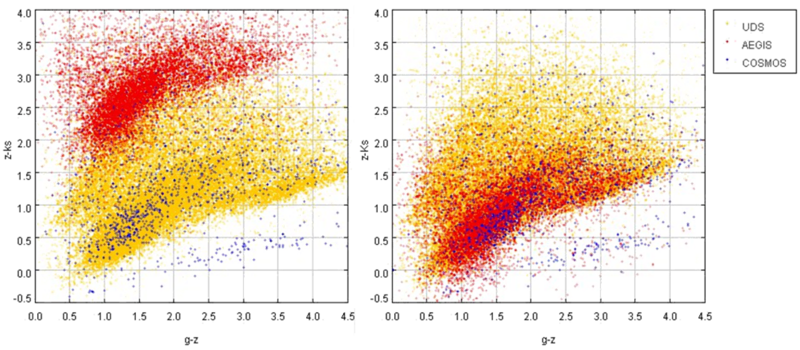

Figure 2: GzK diagram before(left) and after(right) the correction, K magnitude is cut at 22.5 to avoid the difference of depth between each surveys.

Filter	Original Filters (Magnitude, Aperture)	Conversion Term
g	Subaru B (AB, $3''$) Subaru V (AB, $3''$)	$g = (0.617 \times B + 0.24 \times V - 0.012853)/0.857$
r	Subaru B (AB, $3''$) Subaru V (AB, $3''$)	$r = (-0.383 \times B + 1.24 \times V + 0.014933)/0.857$
i	Subaru I (AB, $3''$) SDSS r (AB, $3''$)	$i = (I + 0.106 \times R - 0.007)/1.106$
z	Subaru Z (AB, $3''$) SDSS i (AB, $3''$)	$z = (Z + 0.110 \times I - 0.008)/1.11$
j	Subaru J (AB, $3''$)	$j = J - 0.02$
Ks	Subaru H (AB, $3''$) Subaru K (AB, $3''$)	$Ks = (K - 0.072 \times (H - K))$

Table 1: Photometry conversion for UDS

Filter	Original Filters (Magnitude, Aperture)	Conversion Term
g	Subaru G (AB, $3''$) Subaru R (AB, $3''$)	$g = (1.037 \times G - 0.056 \times R + 0.00639)/0.981$
r	Subaru G (AB, $3''$) Subaru R (AB, $3''$)	$r = (0.037 \times G + 0.944 \times R - 0.00261)/0.981$
i	Subaru I (AB, $3''$) (or CFHT I* (AB, $3''$)) SDSS r (AB, $3''$)	$i = (I(orI*) + 0.106 \times R - 0.007)/1.106$
z	Subaru Z (AB, $3''$) SDSS i (AB, $3''$)	$z = (Z + 0.110 \times I - 0.008)/1.11$
j	UKIRT J (AB, $3''$)	$j = J - 0.02$
Ks	WIRC (AB, $3''$)	*none*

Table 2: Photometry conversion for COSMOS

Filter	Original Filters (Magnitude, Aperture)	Conversion Term
g	SDSS g (AB, Auto)	*none*
r	SDSS r (AB, Auto)	*none*
i	SDSS i (AB, Auto)	*none*
z	SDSS z (AB, Auto)	*none*
j	WIRC J (Vega, $3''$)	$j = J - 0.938$
Ks	WIRC Ks (Vega, Auto)	$Ks = K + 1.9$

Table 3: Photometry conversion for AEGIS

4 Pea Selection

I used the old pea selection from Bamford and Foucaud (in prep.) to reconstruct the selection using SDSS $griz$ bands, 2MASS j, Ks bands. The selection is made to be the line that best avoids the star sequence(blue) and covers most of the selected peas(cyan). The selection of the i-peas is

$$(i - z) < 0.2 \times (g - i) - 0.12$$

while the selection of z-peas is

$$(z - j) < 0.3 \times (r - z) - 0.25.$$

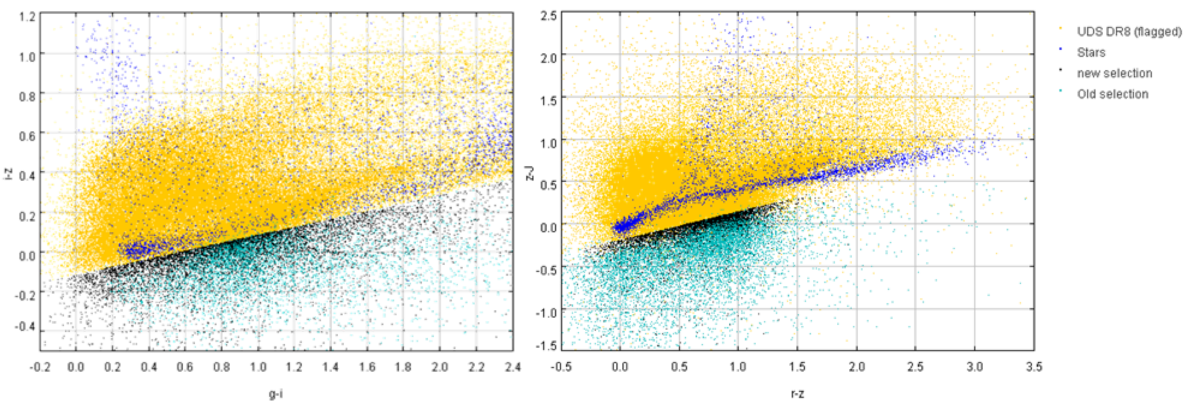

Figure 3: Left- giz selection of the i-Peas. Right- RzJ selection of the z-peas.

5 Results

With the new selection, I found 9774 i-Peas and 6568 z-Peas in UDS DR8, 1658 i-Peas and 98 z-Peas in COSMOS, and 2173 i-Peas and 588 z-Peas in AEGIS. Pea candidates in COSMOS and AEGIS are matched with the zCOSMOS and DEEP2 redshift survey to retrieve their individual spectra for the preparation of future proposals. There is only 1 i-Pea in zCOSMOS, the spectra is shown in Fig.4. There are 2166 i-Peas and 582 z-Peas in DEEP2 redshift survey. To narrow down on to the peas most suitable for observation, the brightest peas with $R < 22.5$ and best redshift quality (flag=4) are inspected one by one, some of the best pea candidates are shown in Fig.5.

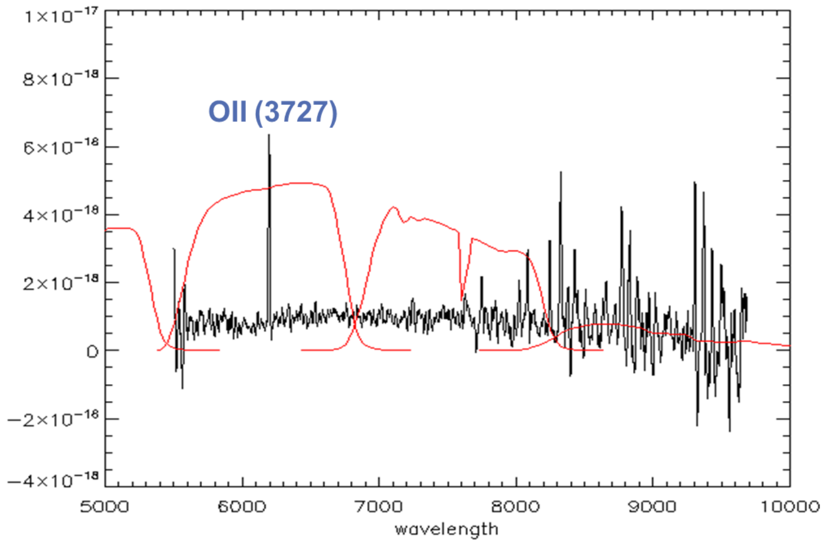

Figure 4: i-Pea spectrum in COSMOS, $z = 0.63$.

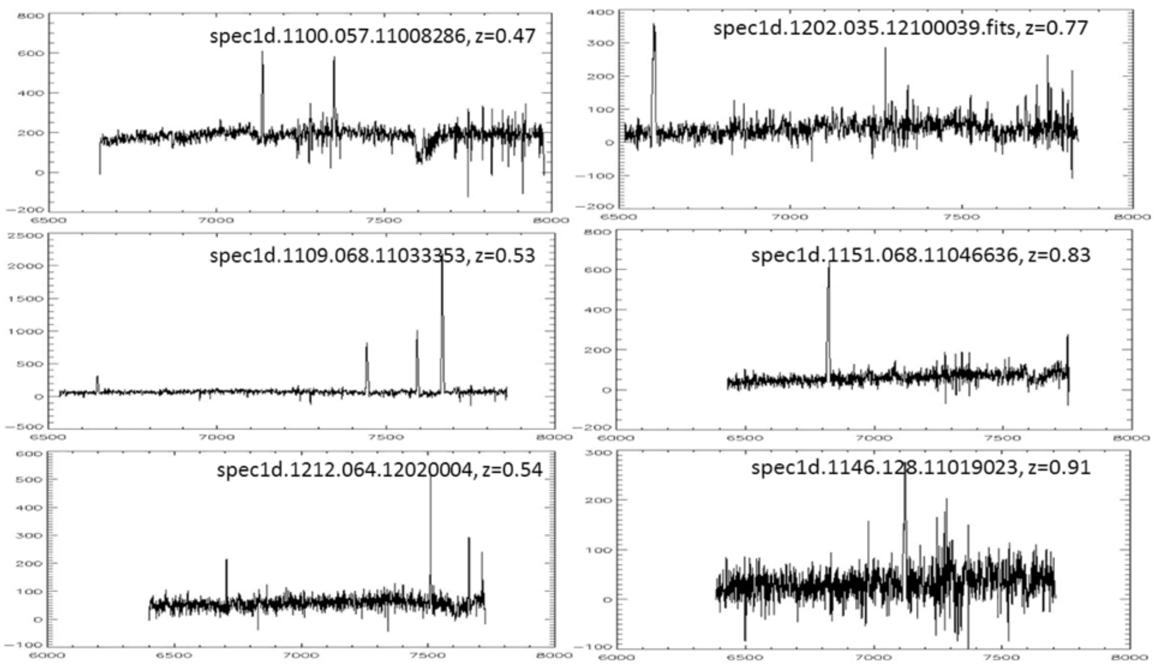

Figure 5: Spectra in DEEP2- Left three: i-Peas at $0.45 < z < 0.7$. Right three: z-Peas at $0.7 < z < 0.95$.

6 Reference

Bamford and Foucaud, in prep.
Capak et al. 2007, ApJ Suppl., 172:99-116
Caradamone et al. 2009, MNRAS, 399.3:1191-1205
Furusawa et al. 2008, ASP, 2008:131
Haiman et al. 2000, ApJ, 537, L5
Hewett et al. 2006, MNRAS 367:454-468
Lawrence et al. 2007, MNRAS 379:1599-1617
Li et al. 2006, ApJ 639:879-896
Lupton et al. 2001, ASPCS, 238, 269
Schaerer et al. 2003, A&A, 397, 527
Tumlinson et al. 2001, ApJ, 550, L1