The massive galaxy formation in the SSA22 protocluster at z=3.09

Mariko Kubo
Yuka Uchimoto, Toru Yamada,
Takashi Ichikawa, Masayuki Akiyama ,
Tomoki Hayashino (Tohoku university)
Yuichi Matsuda (NAOJ, Chile), Masaru Kajisawa
(Ehime university) and MOIRCS Group

1. MOIRCS observation of the SSA22 protocluster

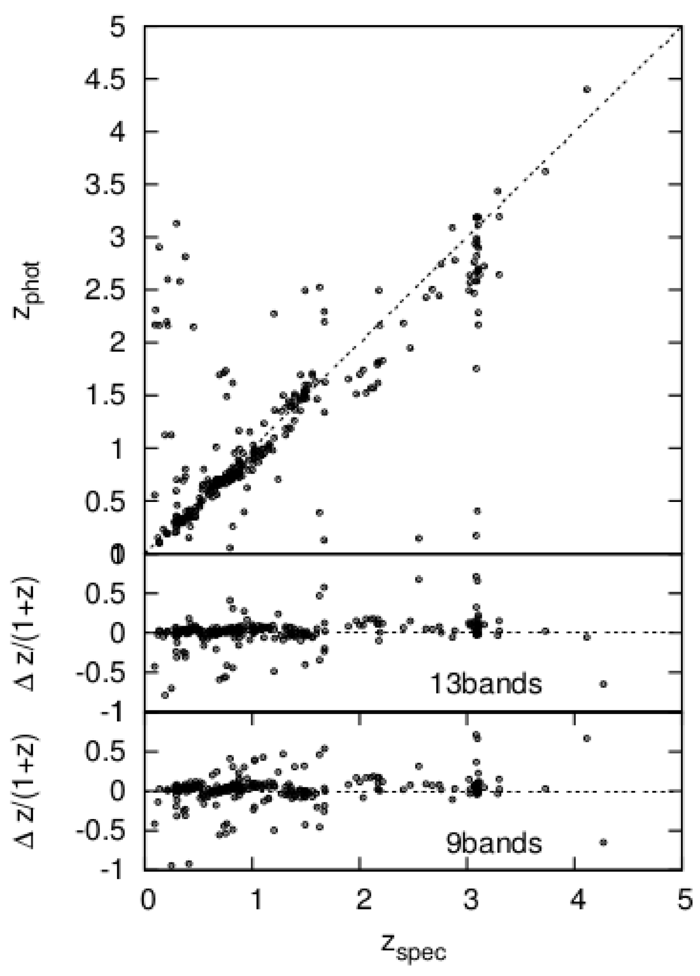
The SSA22 protocluster is a high density region of the galaxies at z=3.09 which was found as the density excess of the Lyman Break Galaxies and Lyα Emitters(Steidel +1998, Hayashino+2004, Yamada+2012) . Then it characterized as one of the most outstanding structure at z>2. The density excess of the Lyα Blobs (Matsuda+ 2004), the AGNs(Lehmer+2009) and the AzTEC sub-mm sources(Tamura+2009) are also found which suggest the formation of massive galaxies in the protocluster.

We have investigated the SSA22 protocluster with Subaru MOIRCS deep and wide observations. Uchimoto + (2008), (2012) found the density excess of the Distant Red Galaxies (DRGs： J-K>1.4) and Hyper Extremely Red Objects (HEROs: J-K>2.1) compared with general fields. Then what they are? Are there any evolved galaxies like local massive ellipticals in the cluster of the galaxies?

2. The sample selection

We first selected the candidates of the protocluster galaxies with the photometric redshifts. We estimated the photometric redshifts from the Spectral energy distribution (SED) fitting with u*BVRi'z'JHK and IRAC 3.6-8.0um bands images. Fig.1 is the $z_{spec}\ v.s.\ z_{phot}$ for our measurements. The typical error of the z_{phot} is Δz=0.5. We selected the candidates of the protocluster member which are $K_{AB} < 24$ and at $2.6 < z_{phot} < 3.6$.

The sky distribution of them is plotted in Fig.2 . They are concentrated at the density peak of the LAEs. There are 1.6 times many K-band selected galaxies in the protocluster as those in the general field. Especially those selected as DRGs or detected in 24um show stronger density excess.



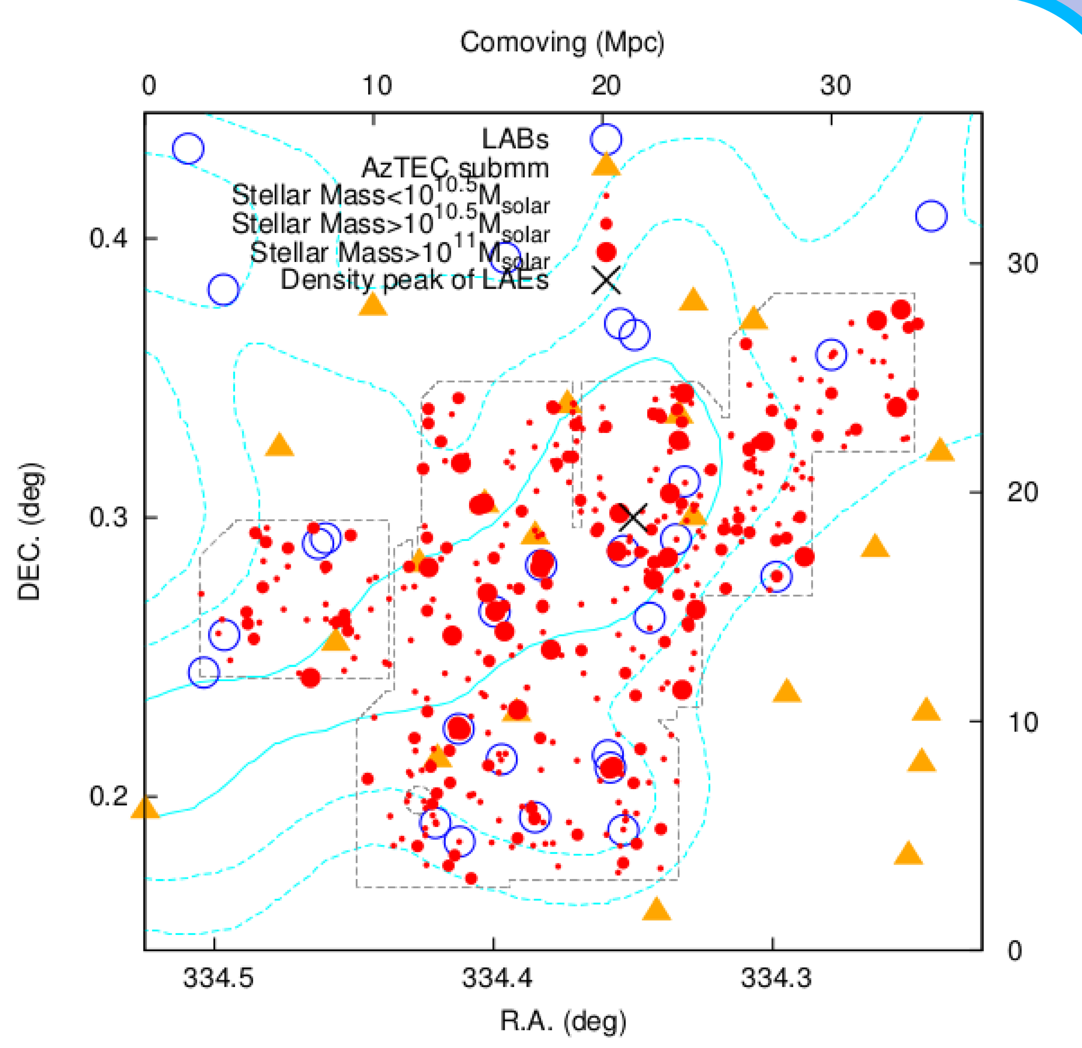


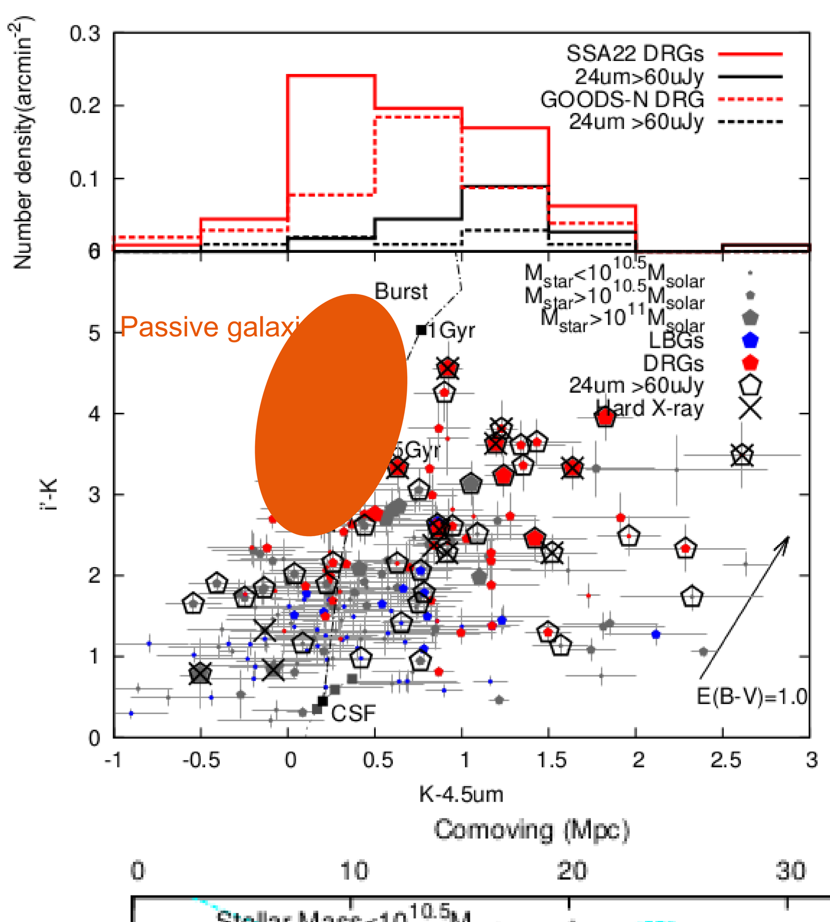
Fig.1 (Left). z_phot v.s. z_spec in our measurements. The bottom panels are (z_spec-z_phot)/(z_phot) for z_phot estmiated with IRAC and without IRAC.
Fig.2 (right). The sky distribution of the K-selected galaxies at 2.6<z_phot<3.6 (red points). LABs (blue circles), AzTEC sub-mm sources (yellow triangles) are also plotted. The large cross is the density peak of the LAEs.

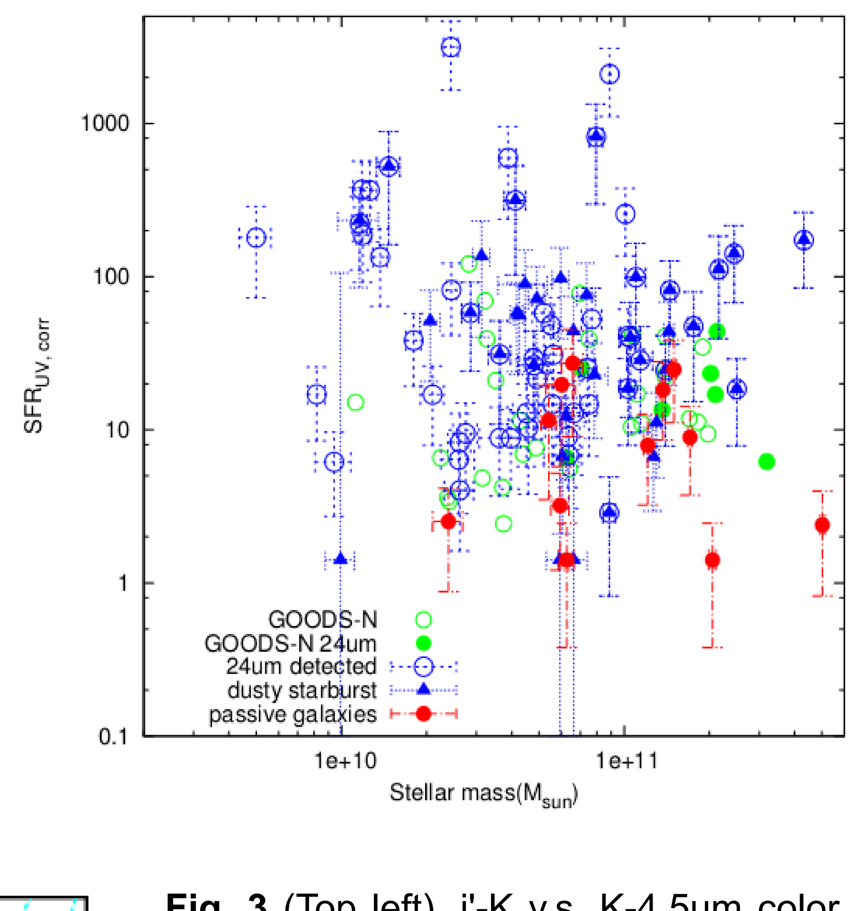
3. The passive galaxies in the protocluster

Are there any massive galaxies which are already passively evolving ? For the purpose we draw the two color diagram to find the passive galaxies in the protocluster (Fig.3). Some galaxies show the colors which are consistent with the passively evolving model: single burst star formation model with the age of >0.5Gyr old. The top panel of the figure is the K-4.5um color distribution of the DRGs (J-K>1.4) in the SSA22 and GOODS-N field. We can see the density excess of the passive galaxies in the SSA22 protocluster.

Fig.4 is the stellar mass to SFR distribution of the passive galaxies (I'-K>3 and K-4.5um <0.5) and the dusty star burst galaxies (I'-K>2.5 and K-4.5um >0.5 and/or 24um detected) in the SSA22 field and the galaxies with I'-K>.2.5 in the GOODS-N field. The passive galaxies typically have $SFR_{UV,corr} < 20M_{sun}yr^{-1}$ (upper limit) and stellar mass of $10^{10.5-11}\ M_{sun}$.

The sky distribution of the passive galaxies is shown in Fig.6, showing strong clustering around the density peak of the LAEs





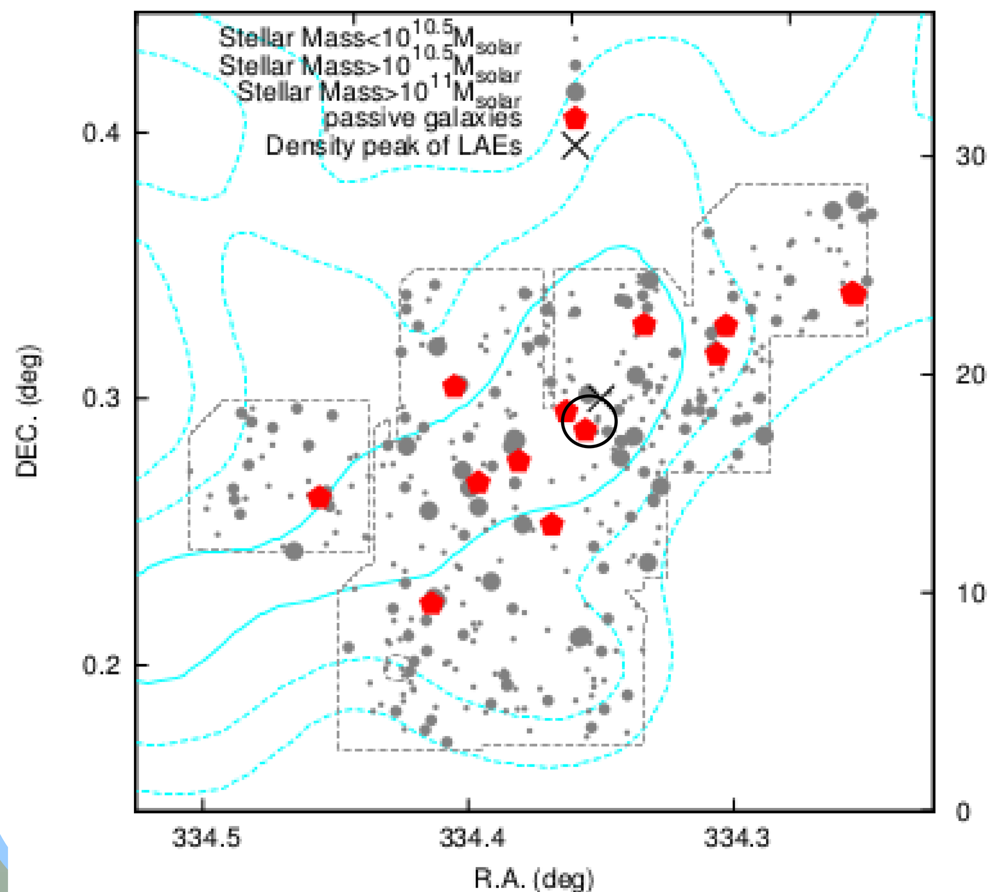


Fig. 3 (Top left). i'-K v.s. K-4.5um color diagram. Black dashed and dotted line and points are the color evolution track with age for the single burst model at z = 3.1. Gray sequence is that for the constant star formation model. We also plotted the extinction vector of E(B-V)=1.0.

Fig.4 (Top right). Stellar mass to SFR_UV, corr distribution. The passive galaxies (red circles), dusty star burst galaxies in the SSA22 field (blue) and in the GOODS_N field (green) are plotted. SFR_UV, corr are upper limit for the passive galaxies since we estimated those assuming the SED of young star forming galaxies .

Fig.5 (Left). The sky distribution of the passive galaxies(red points).

4. The precise properties of a passive galaxy

Here we show the precise properties of one passive galaxy (marked in Fig.5). This object was found as an LAE but its SED is well fitted with the single burst model with the age of 0.5 Gyr at z=3.09 (Fig.6). There are clear bleak at JHK-bands, therefore, this object is likely to be the Balmer break galaxy at z=3.09.

This object is also detected in Chandra X-ray with $5.9 \times 10^{-16} ergs\ cm^{-2}s^{-1}$ (at 0.5-8keV-band), but NIR to X-ray flux ratio is AGN like but nearly similar to that of the normal galaxy. Therefore the AGN would be buried in the stellar light of the galaxy. The stellar mass of this object is $1.6 \times 10^{11} M_{sun}$ and $SFR_{UV,corr}$ is $9.0 \pm 5.2\ M_{sun}yr^{-1}$ (upper limit).

This galaxy is also covered with HST WFC3 archival image (Fig. 7). Its morphology is fitted with sersic index n=3.8 and Re=2.3kpc by using GALFIT. It shows compact but similar structure as local massive ellipticals.

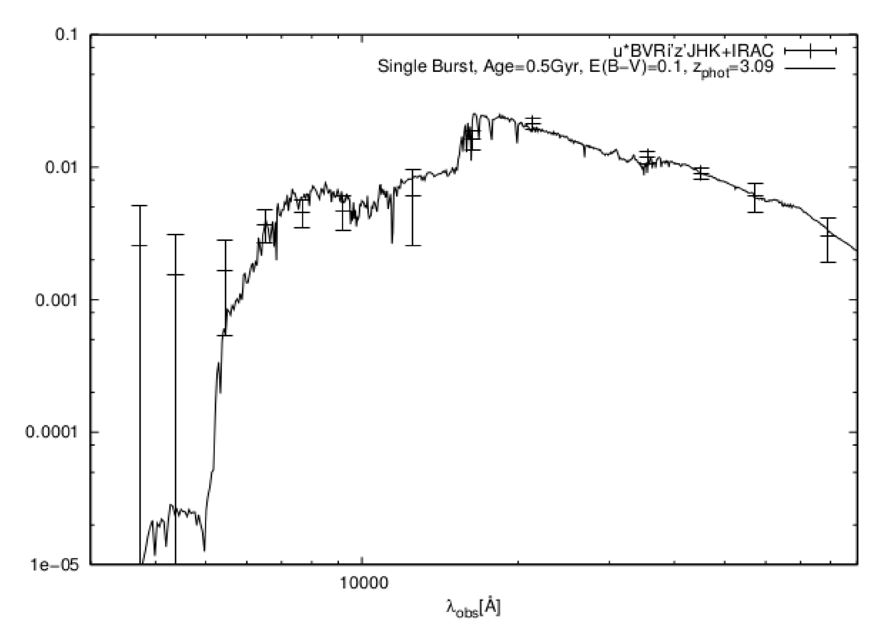
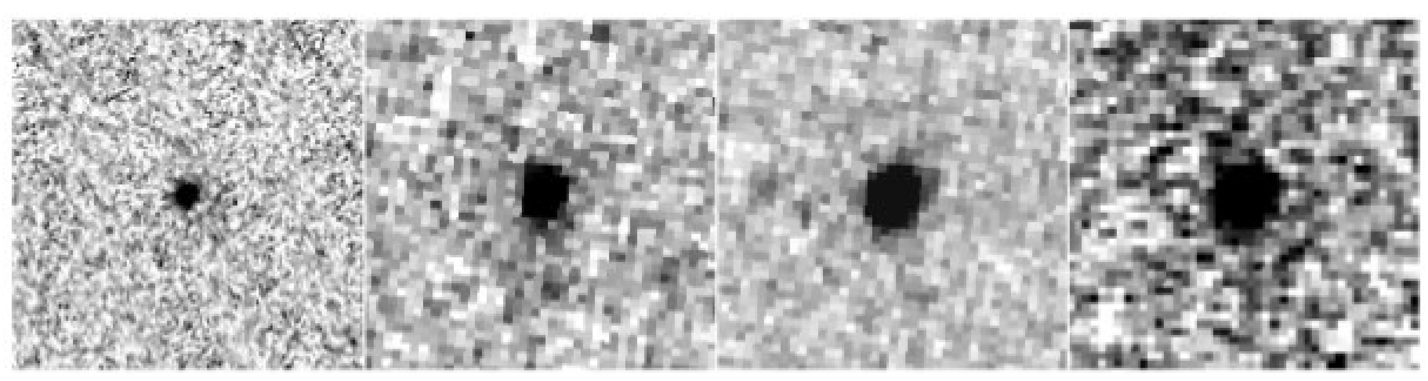


Fig. 6 (Left). The best fit SED of a passive galaxy. Cross points are the observed flux at u*, B,V,R,i'z' J,H,K-bands, respectively. The solid line is the best fit SED model; single burst star formation at z=3.09, age=0.5Gyr , E(B-V)=0.1.

Fig.7 (Bottom). The archival images of the passive galaxy. Each panels are ACS F814, WFC3 F110W, F160W and MOIRCS K-band images from left to right. The size of each panel are 5"×5" squares.



5. CONCLUTION

By using Subaru MOIRCS and Multi-wavelength data, we found the density excess of the passive galaxies in the SSA22 protocluster at z=3.09. One of the passive galaxy is likely to be the elliptical galaxy at z=3.09. Since there are also the density excess of the dusty starburst galaxies, the SSA22 protocluster may be just in the formation epoch of the massive galaxies.