The star formation in the SSA22 protocluster at z=3.09

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1. Overview; K-selected galaxies in the SSA22 protocluster

The SSA22 z=3.09 protocluster is a known high density region at high redshift which identified with the density excess of the Lyα Emitters(LAEs), Lyman break Galaxies(LBGs) at z~3.1.

In this work, we selected the candidate of the protocluster galaxies based on stellar mass with MOIRCS JHK band deep imagings at the highest density region of LAEs in the SSA22 protocluster. And then analysed the star formation and stellar populations in the protocluster using Spitzer IRAC, MIPS 24um (Webb+2008). We selected the galaxies with $K_{AB}<24$ at z_{phot}=2.6-3.6 by using photometric redshift estimated from Spectral Energy Distribution(SED) fitting with UBVRi'zJHK, IRAC 3.6,4.5, 5.8, 8.0um. The photometric redshift error at z~3 is ~0.5. We selected the galaxies with stellar mass ~ $10^{9-11}M_{sun}$

The sky distribution of the K-selected galaxies is Fig.1. They are concentrated around the density peak of the LAEs at z=3.09. The surface number density of the K-selected galaxies is 1.6 times larger than that in the GOODS-North field at same redshift range(Fig. 2).

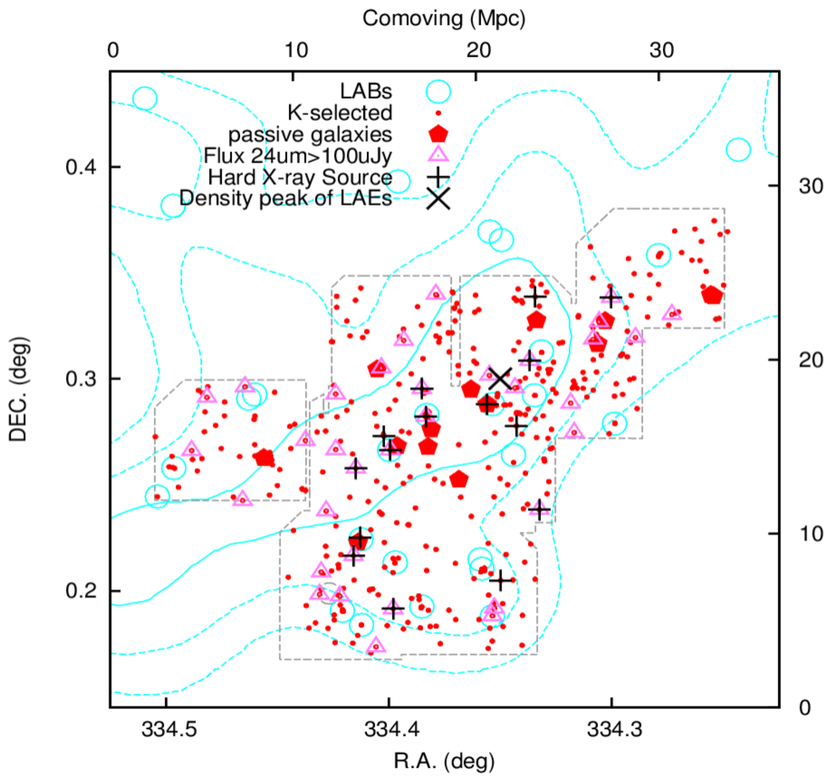

Figure. 1; The sky distribution of the K-selected galaxies ($K_{AB}<24$ and $2.6<z_{phot}<3.6$)(redcircles). The large X is the density peak of the LAEs. The light blue circles are Lyα Blobs(LABs). Big red pentagons are the passive galaxies selected with I'-K>3.0 and K-4.5 um <0.5. The 24um detected(pink triangles), X-ray detected(Lehmer+2009, black crosses) are marked.

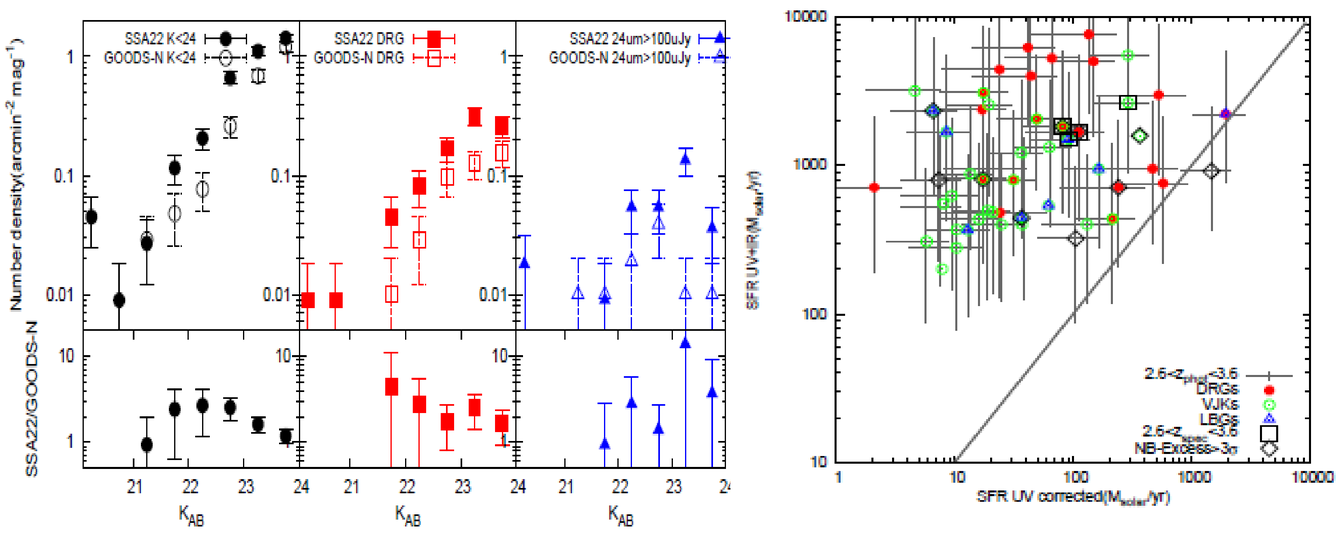

Figure. 2; The comparison of the differential surface number density of the K-selected galaxies(left), those classifeid as DRGs(middle), MIPS24um detected (right) in the SSA22 protocluster(filled) and in the GOODS-North field(Kajisawa et al.2009) (unfilled). Bottom panels are the ratio of the number density in the SSA22 to that in the GOODS-N.

Figure.3; The SFR_{UV+IR} v.s. $SFR_{UV\,corrected}$ of the 24um sources. K-selected galaxies selected as DRGs(red), VJKs(green, BzK galaxies at z~3), LBGs(blue) are marked. Black squares are those at z_spec=2.6-3.6, black diamonds are those with NB-excess>3σ.

2. The excess obscured starbursts in the protocluster

There are further density excess of some K-selected galaxies; which selected as Distant Red Galaxies(DRGs; $J-K_{AB}>1.4$) are 2.2 times, which detected with 24μm are 3.4 times numerous (Fig.2).

Fig.3 is the SFR_{UV+IR} and $SFR_{UV\,corrected}$ of the 24um detected galaxies. SFR_{UV+IR} are estimated from unobscured UV light and dust obscured star formation re-emitted at IR. $SFR_{UV\,corrected}$ are estimated from the UV light corrected of the extinction.

They have SFR~ $1000M_{sun}/yr$. Most of them are too faint at rest-UV to be selected as LBGs, LAEs, but be selected as DRGs.

Thus NIR survey have revealed not only the stellar mass but also the obscured starburst in the protocluster.

3. The passive galaxies

Furthermore, we found the passively evolving galaxies in the protocluster.

Though, the detection limit of 24μm is too large, we used rest-UV to NIR color to see the properties of the galaxies. Fig.4 is the I'-K v.s. K-4.5um color diagram. 24μm detected galaxies have color consisted with dusty starburst. On the other hand, there are the galaxies which have color like the single burst >0.5Gyr, those would be passively evolving galaxies.

Top panel of the Fig. 4 is the K-4.5um color distribution of the DRGs in the SSA22 protocluster and in the GOODS-North field at z=2.6-3.6. There are the excess of the K-4.5 um bluer DRGs, or passive galaxies in the protocluster. Sky distribution of the passive galaxies(in Fig.1) show strong clustering around the highest density region of the LAEs. The x-ray detected, 24 μm detected galaxies show similar sky distributions.

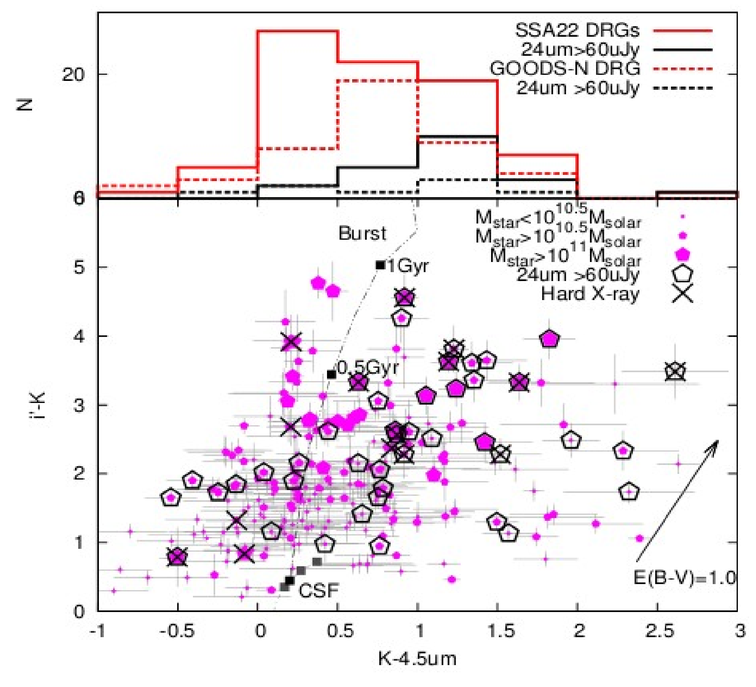

Figure.4; The bottom panel is I'-K v.s. K-4.5 um color distribution of the K-selected galaxies(pink pentagons). 24 um detected galaxies are marked with black pnetagons. Black dashed line is the age evolution track of the single burst star formation model at z~3. The grey line is same but of the constant star formation model.

Top panel of Figure.5 is the K-4.5um color distribution of the DRGs(red) at $2.6<z_{phot}<3.6$ and those detected with 24um (black) in the SSA22 proto-cluster(solid lines) and in the GOODS-North field (dashed lines).

4.Discussion and Future works

There are the density excess of the K-selected galaxies detected with 24um. They have very high SFR and they would rapidly evolve into the massive ellipticals in the center of the present cluster. Furtheremore the sky and color distribution of the X-ray detected galaxies suggest the correlation of the nuclear activities and the formation of the massive galaxies.

Are the passive galaxies already like the local massive ellipticals? The stellar mass of these are as large as $10^{10.5-11}M_{sun}$. Fig.5 are the resolved image of 24um source(top) and the passive galaxy selected with I'-K>3.0 and K-4.5um >0.5(bottom). At least this passive galaxy is massive spheroid like system.

Thus, at the center of the z=3.1 protocluster, the massive galaxies are dramatically being formed but some mature systems may already exist.

Future works, the NIR spectroscopies of the K-selected galaxies are required to confirm their redshift, though there are large uncertainties about photometric redshifts.

Morphological analysis of these are also important to understand the formation and evolution of the massive ellipticals.

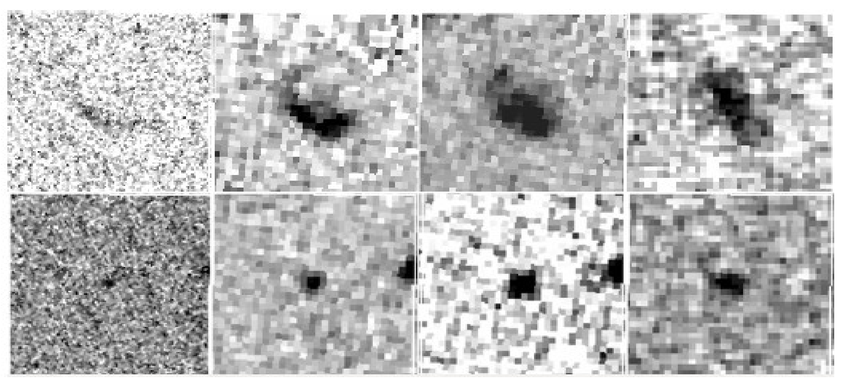

Fig.5 The HST ACS F814(PI Chapman ID 10405), WFC3 F110W, F160W(PI Siana ID 11636), and MOIRCS K images of the K-selected galaxies.

Top; 24um detected galaxy. Bottom; passive galaxy with I'-K>3 and K-4.5um<0.5