The Picture of Submillimeter Galaxies in the SSA22 Protocluster

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ABSTRACT

We present the results of counterpart identification of submillimeter galaxies (SMGs) detected in the SSA22 protocluster, which is traced by Lyα emitting galaxies (LAEs) at z = 3.1 and discuss the relationship between SMGs and the large scale structure. 112 SMGs were uncovered in this field using AzTEC/ASTE. We searched counterparts for these SMGs using the following three methods; radio(1.4GHz) , MIPS ch1 (24μm), and IRAC color(3.6μm, 4.5μm, 5.8μm, and 8.0μm) diagnostics. As a result we identified 48 SMGs with at least one counterpart. Furthermore we derive their photometric redshifts based on optical to near-infrared data. Finally we identify seven SMGs as candidates of z=3.1 protocluster member. Two point angular correlation function between LAEs and these SMGs shows that there are significant spatial correlation, which indicates SMGs are correlated with the large scale structure.These results indicate that high density regions at the high redshift universe are the site of SMG formation. This picture is consistent with predictions from the standard model of hierarichical structure formation.

1. Background

Submillimeter-selected Galaxies (SMGs) are a population of galaxies which are the most massive, gas-rich systems at z ~ 1–5 and characterized by highly dust enshrouded star formation (Blain et al. 2002) They are luminous at far-infrared to mm wavelengths (LFIR ~ 10^12 – 10^13 Lsun) and it is thought that derived extremely high star-formation rate (SFR) of ~ 1000 Msun is caused by major merger of gas-rich galaxies. One of important questions for SMGs is the site condition of the formation. The current cold dark matter (CDM) cosmological simulations show that SMGs should preferentially exist in high density regions such as protoclusters where the mass densities are high and correspondingly merger rates are also high (e.g., Springel et al. 2005). It is also argued that SMGs are progenitors of massive elliptical galaxies seen in the cores of present-day clusters (Eales et al. 1999). However the relation between SMGs and each protocluster is still unclear.

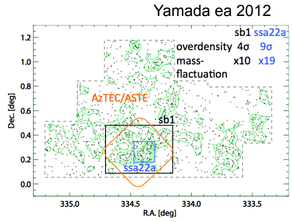
2. SSA22 protocluster and SMG survey

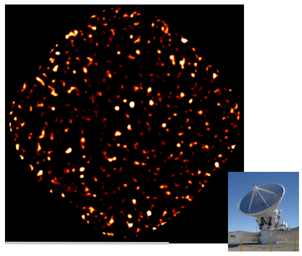
SSA22 is a extremely rare protocluster at z = 3.1 in terms of its extent and significance of the over density. As shown in the upper figure, the large scale structure traced by Lymanα emitters (LAEs) has been discovered across ~ 1 deg^2. The significance of the over density is four times of standard deviations in "sb1" area and estimated underlying mass fluctuation is ten times of the average, assuming the general ΛCDM model (Yamada et al. 2012). These values become higher at the core.

In this field, 1.1mm deep SMG survey was conducted by AzTEC bolometer camera mounted on ASTE 10m dish (AzTEC/ASTE). The Survey area covers 992 arcmin^2 and achieves 1 σ noise level of 0.6-1.2mJy/beam.Finally
over 100 SMGs were discovered with S/N ratio of ≧3.5 (botom figure). However until today most of SMGs don't have spectroscopic redshifts but 5 SMGs.

3. Identification of SMG counterparts

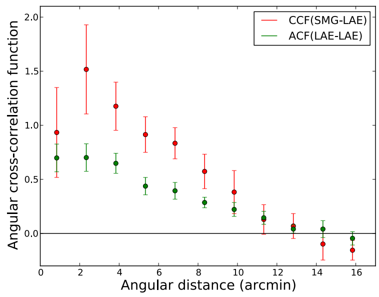
We search counterparts for these SMGs.
First we estimate the positional uncertainty of AzTEC/ASTE as a function of S/N ratio using monte-carlo simulations and derive 2σ error circle. Second utilizing VLA 1.4 GHz, MIPS 24μm, and IRAC 3.6μm, 4.5μm, 5.8μm, and 8.0μm data, we extract counterpart candiates which locate within the positional error circle. The criteria of IRAC color diagnostics are shown in the upper panel (Yun et al. 2008). Finally we calculate the poisson statistics (i.e., "p-value") to remove contamination and select counterparts with p ≦ 0.20. The left stamp are the exmaple of sucessful identification, AZ002. It has a reliable counterpart at all three wavelengths.
As a result we identified 48 SMGs with at least one counterpart.





4. SMGs and z=3.1 SSA22 Protocluster

Until today only two SMGs, SMMJ221735.84+001558.9 and SSA22- AZ082/SMMJ221735.15+001537.2 are confirmed as z = 3.1 objects using spectroscopy. We derived photometric redshift for these 48 SMGs using SED fitting for optical to near-infrared data (U(CFHT), B,V,R,i′,z′(Subaru/Suprime-Cam), J,H,Ks(Subaru/MOIRCS), 3.6, 4.5, 5.8, 8.0μm(Spitzer/IRAC)). Although derived photometric redshift should contain the uncertainty of Δz ≤ 0.5, seven counterparts of SMGs are listed up as z = 3.1 protocluster members and interestingly these seven are concentrated into the core of the protocluster.
This trend are also supported by angular correlation function. Left fugure shows cross-correlation function between the distribution of z = 3.1 candidate SMGs and that of LAEs, and auto-correlation function of tLAEs. It shows strong correlation signals, which suggests the distribution of SMGs and LAEs are well overlapped.The result supports the indication by Tamura et al. (2009). If really SMGs concentrated into the core, it observationally supports the formation bias suggested by the simulation.
Capak et al. (2011) and Daddi et al. (2009) report the discovery of SMGs in overdense region at z = 5.3 and z = 4.05, respectively. On the other hand, Chapman et al. (2009) insists that SMGs are formed in less-overdence regions at z = 1.99. Comparing with these previous results, it indicates that there would be transition era at z = 2–3 of galaxy formation process at high-dense region.



5. Next work

To confirm the picture, follow up spectroscopy is strongly required. Optical spectroscopy using VLT/VIMOS targeting to these SMGs has been accepted and the upcoming observations will allow us to unveil the formation site of SMGs. Moreover Herschel/SPIRE data are also obtained (PI. Y.Matsuda).
Matching them with submillimeter observations, we will be able to study how the formation and evolution of galaxies depend on environment in the early universe.