Optical–Infrared Properties of Faint 1.3 mm Sources Detected with ALMA

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Since the fraction of dust-obscured star formation to the total star formation increases with redshift, observations at infrared (IR) to millimeter/submillimeter (mm/submm) wavelengths are essential to understand the cosmic star formation history and the galaxy evolution. Deep and wide-field surveys uncovered a new population of mm/submm–bright galaxies at high redshifts (SMGs). SMGs are highly obscured by dust, and the resulting thermal dust emission dominates the bolometric luminosity. The energy source of mm/submm emission is primarily from intense star formation activity, with star-formation rates (SFRs) of 10^2–$10^3\,M_\odot\,\mathrm{yr}^{-1}$. The heavy dust obscuration in SMGs makes it difficult to understand their optical/near-infrared (NIR) properties. In addition, the coarse angular resolution of single dish telescopes (> 15″) prevents from identifying optical/NIR counterparts. The advent of ALMA has changed this situation thanks to its high sensitivity and high angular resolution.

We studied optical-IR properties of faint 1.3~mm sources ($S_{1.3\,\mathrm{mm}}$ = 0.2–1.0 mJy) detected with ALMA in the Subaru/*XMM-Newton* Deep Survey (SXDS) field [1]. We conducted ALMA band 6 observations toward 20 star-forming galaxies at $z \sim 1.4$ [2,3]. The targets were extracted from a stellar mass limit ($> 10^{9.5}\,M_\odot$) sample whose redshifts and Hα SFR were obtained by NIR spectroscopy. We detected 8 sources at SN ≥ 4.0, of which three sources are the original targets of ALMA observations and five sources are serendipitously-detected sources. We searched for optical/IR counterparts of the 8 ALMA-detected sources in a *K*-band source catalog. Four ALMA sources have *K*-band counterpart candidates within a 0.4″ radius. Comparison between ALMA-detected and undetected *K*-band sources in the same observing fields shows that ALMA-detected sources tend to be brighter, more massive, and more actively forming stars. While many of the ALMA-identified SMGs in previous studies lie above the sequence of star-forming galaxies (main sequence) in stellar mass–SFR plane, our ALMA sources are located in the sequence (Figure 1), suggesting that the ALMA-detected faint sources are more like 'normal' star-forming galaxies rather than 'classical' SMGs.

We found a region where multiple ALMA sources and *K*-band sources reside in a narrow photometric redshift range ($z \sim 1.3$–1.6) within a radius of 5″ (42 kpc if we assume z = 1.45). This is possibly a pre-merging system and we may be witnessing the early phase of formation of a massive elliptical galaxy (Figure 2).

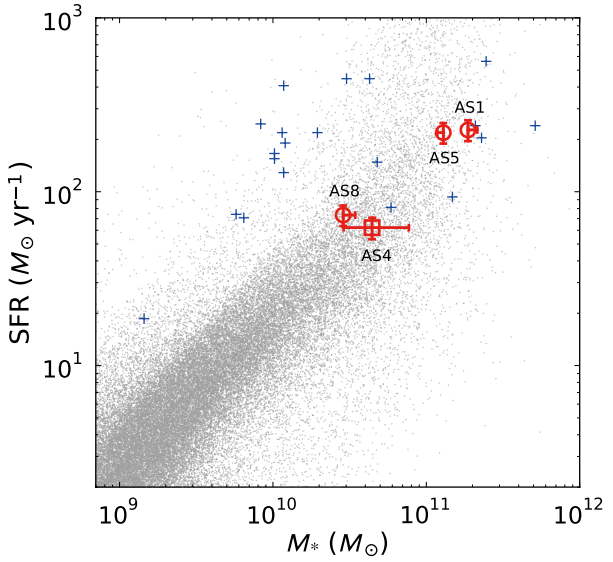

Figure 1: Comparison of stellar mass and SFR for the ALMA sources identified with the original targets (circles), the ALMA serendipitous source (square), ALMA-identified SMGs in previous studies (crosses), and the *K*-band sources (dots).

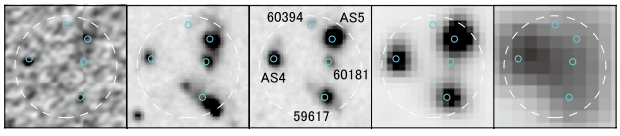

Figure 2: Multi-wavelength images around the multiple ALMA sources (ALMA 1.3 mm, *B*, K_s, 3.6 μm, and 24 μm). The dashed circle shows a region within a radius of 5″.

References

[1] Hatsukade, B., Ohta, K., Yabe, K., et al.: 2015, *ApJ*, **810**, 91.
[2] Hatsukade, B., et al.: 2013, *ApJ*, **769**, L27.
[3] Seko, A., Ohta, K., Yabe, K., et al.: 2016, *ApJ*, **819**, 82.