RADIO AND X-RAY PROPERTIES OF SUBMILLIMETER GALAXIES IN THE A2125 FIELD

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ABSTRACT

We present the radio and X-ray properties of 1.2 mm MAMBO source candidates in a 1600 arcmin2 field centered on the Abell 2125 galaxy cluster at z = 0.247. The brightest, nonsynchrotron millimeter source candidate in the field has a photometric redshift z = 3.93 ± 0.11 and is not detected in a 31 ks Chandra X-ray exposure. These findings are consistent with this object being an extremely dusty and luminous starburst galaxy at high redshift, possibly the most luminous yet identified in any blank-field millimeter survey. The deep 1.4 GHz Very Large Array imaging identifies counterparts for 83% of the 29 mm source candidates identified at ≥4σ (S1.2 mm = 2.7–52.1 mJy), implying that the majority of these objects are likely to lie at z ≲ 3.5. The median millimeter-to-radio wavelength photometric redshift of this radio-detected sample is z ≈ 2.2 (first and third quartiles of 1.7 and 3.0), consistent with the median redshift derived from optical spectroscopic surveys of the radio-detected subsample of bright submillimeter galaxies (S850 μm > 5 mJy). Three millimeter-selected quasars are confirmed to be X-ray luminous in the high-resolution Chandra imaging, while another millimeter source candidate with potential multiple radio counterparts is also detected in the X-ray regime. Both of these radio counterparts are positionally consistent with the millimeter source candidate. One counterpart is associated with an elliptical galaxy at z = 0.2425, but we believe that a second counterpart associated with a fainter optical source likely gives rise to the millimeter emission at z ≈ 1.

Key words: galaxies: active – galaxies: starburst – submillimeter – X-rays: galaxies

Online-only material: color figure

1. INTRODUCTION

The discovery of massive, dust-obscured starburst galaxies in blank-field submillimeter/millimeter-wavelength surveys has opened a new window on galaxy and structure formation in the early universe (Smail et al. 1997; Hughes et al. 1998; Barger et al. 1998; Bertoldi et al. 2000). The bulk of this population exists at redshift z > 2 (Chapman et al. 2003, 2005; Aretxaga et al. 2003, 2007). These (sub)millimeter galaxies (hereafter SMGs) exhibit star formation rates in excess of 1000 M⊙ yr−1, sufficient to build up the stellar mass of a giant elliptical galaxy in approximately 1 Gyr. This conclusion relies on the assumption that most of the far-infrared (FIR) luminosity in these objects is powered by star formation rather than by an active galactic nucleus (AGN). X-ray studies of these SMGs confirm that while ~28%–50% do harbor an AGN, such AGN activity may only contribute to a small fraction of the enormous FIR luminosities (e.g., Alexander et al. 2005). Deep radio imaging of the 1.4 GHz emission in a subset of SMGs shows that this emission is extended over scales of a few kpc, also consistent with being associated with star formation activity (e.g., Biggs & Ivison 2008). Further analysis of the X-ray and mid-infrared properties of SMGs is needed to reach stronger statistical conclusions regarding their AGN and star-forming nature, and such progress relies on the crucial first step of obtaining accurate positional information allowing unambiguous identification of a source at different wavelengths.

The coarse angular resolution of submillimeter/millimeter detectors on single-dish telescopes (typically ~10′′–20′′) means that it is impossible to immediately identify the optical/infrared counterpart responsible for the significant FIR luminosity of a SMG. Ideally one would like to use submillimeter/millimeter-wavelength interferometry to identify the correct multiwavelength counterparts, as has been done with the Plateau de Bure Interferometer (e.g., Downes et al. 1999) and the Submillimeter Array (Younger et al. 2007). Given the small field of view available with submillimeter/millimeter-wavelength interferometers (typically <1′ diameter at wavelengths shorter than ~1.2 mm) and present-day sensitivities, a more practical approach is to use radio interferometry, where the deepest 1.4 GHz Very Large Array (VLA5) imaging (rms ~ 5–10 μJy beam−1) is generally found to identify radio counterparts for ~60%–80% of the bright SMGs (e.g., Ivison et al. 2005). Many groups have been successful in using such deep radio interferometry (usually at 1.4 GHz) to localize the counterpart positions with subarcsecond accuracy (e.g., Ivison et al. 1998, 2000, 2002, 2007; Smail et al. 2000; Webb et al. 2003; Clements et al. 2004; Borys et al. 2004; Dannerbauer et al. 2004), which relies on the locally observed FIR-to-radio luminosity correlation (Condon 1992) holding at high redshifts, which appears to be the case for FIR-selected star-forming galaxies out to redshifts z ≤ 1 (Appleton et al. 2004; Kovacs et al. 2006; Ibar et al. 2008). Those submillimeter/millimeter source candidates without radio counterparts are thought to be either spurious, to contain very cold dust, or to lie at redshifts z > 3.

The steepness of the submillimeter/millimeter source counts means that wide-area surveys (>1000 arcmin2) are needed to identify members of the extremely bright SMG population (S1.2 mm ≥ 10 mJy). One of the largest such surveys to date has been conducted with the 1.2 mm MAx-Planck Millimeter Bolometer (MAMBO) camera (Kreysa et al. 1998, 2002) toward

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the field of the A2125 cluster at $z \sim 0.25$ (15°41′m, +66°18′), covering 1600 arcmin$^2$. The region centered on the A2125 cluster has been the target of a multiwavelength observing campaign from X-ray to radio wavelengths (Wang et al. 2004; Owen et al. 2005a, 2005b; Voss et al. 2006). The main focus of the present study is on the brightest, millimeter-selected high-redshift starburst galaxies and AGNs over the entire 1600 arcmin$^2$ surveyed by MAMBO. Although the large-scale overdense structure occupies most of the field, gravitational lensing of the background sources is likely to be unimportant, except near the cluster core, which only occupies $\sim$1 arcmin$^2$ of the entire 1.2 mm MAMBO map. MAMBO identified four unusually bright millimeter sources with 1.2 mm flux densities in the range 10–100 mJy, of which three were deduced to be radio-loud quasars based on their significant X-ray luminosities and variability at millimeter wavelengths. They also exhibit flat-spectrum millimeter-to-radio flux densities implying a nonthermal origin for the millimeter emission (Voss et al. 2006). The fourth object, MMJ1541+6630 (hereafter J154137+6630.5), is proposed to be a starburst-dominated galaxy, possibly with a weak obscured AGN. Its AGN nature has been concluded from a tentative identification of an X-ray counterpart in the low angular resolution ROSAT PSPC map (Voss et al. 2006).

In this paper, we report on 1.4 GHz radio and Chandra X-ray observations (where available) of the most robust 1.2 mm sources identified in the A2125 field. In Section 2, we present the millimeter, radio, and X-ray data used in our study, while in Section 3, we estimate the radio-to-millimeter photometric redshifts and the X-ray luminosities of our 1.2 mm sample. Finally, in Section 4 we discuss the implications of our results. Throughout this work we adopt a cosmological model with $H_0 = 71$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_m = 0.27$, and $\Omega_L = 0.73$ (Spergel et al. 2007).

2. OBSERVATIONS

2.1. Previous 1.2 mm MAMBO and 1.4 GHz VLA Imaging

The MAMBO 37- and 117-element bolometer arrays (Kreysa et al. 1998, 2002) on the IRAM 30 m telescope were used to map the A2125 cluster field at 1.2 mm between 1999 and 2004. The total on-source integration time was 220 hr and the preliminary findings of this survey are presented by Bertoldi et al. (2000), Voss et al. (2006), and M. Sawitzki et al. (2009, in preparation). The $\sigma$ depth of the final 1600 arcmin$^2$ map ranges from $\sim$0.6 mJy beam$^{-1}$ ($\sim$1″) at the center to $\sim$3 mJy beam$^{-1}$ around the edges. The data analysis and source extraction methods are described in detail by M. Sawitzki et al. (2009, in preparation). Here, we consider the radio and X-ray properties of the 29 highest signal-to-noise 1.2 mm source candidates ($>4\sigma$) identified in the MAMBO map (Table 1). Relative to the cluster core, the nearest 1.2 mm source in our sample is separated by 3.4 arcmin, while the majority have separations greater than 10 arcmin. Using a lens model for the A2218 galaxy cluster, Knudsen et al. (2006) show that gravitational lensing is important for submillimeter sources in the redshift range $z = 1$–4 if they are within the central few square arcminutes of the field centered on the cluster. As A2125 has a similar mass and redshift to that of A2218 (Wang et al. 2004), we do not believe lensing will bias our analysis of the 1.2 mm sources in the A2125 field.

The A2125 field has also been imaged at 1.4 GHz with the VLA in all four configurations to a maximum depth of $\sim$6 mJy beam$^{-1}$, while the synthesized beam size is $1′′.60 \times 1′′.52$.
We apply the technique of Carilli & Yun (1999, 2000) to derive the most probable redshift for each of the 1.4 GHz detected, nonquasar source candidates in our sample (Table 1). The median photometric redshift of these radio-detected SMGs (excluding the three quasars) is $z \sim 2.2$ (first and third quartile values of 1.7 and 3.0), which is consistent with the median redshift measured spectroscopically for bright, radio-detected SMGs by Chapman et al. (2003, 2005), and that derived for 850 $\mu$m selected sources in the SCUBA HAlf Degree Extragalactic Survey (SHADES: Mortier et al. 2005; Coppin et al. 2006) adopting a more sophisticated photometric redshift technique (Aretxaga et al. 2007).

3.3. X-ray Luminosities

The total 0.5–8.0 keV X-ray luminosity of a galaxy is defined as

$$L_{0.5-8 \text{ keV}} = 4\pi d_l^2 f_{0.5-8 \text{ keV}}(1 + z)^\Gamma - 2 \text{ erg s}^{-1},$$

where $f_{0.5-8 \text{ keV}}$ is the 0.5–8 keV flux density (erg cm$^{-2}$ s$^{-1}$) and $d_l$ is the luminosity distance (cm), while here we assume a photon index, $\Gamma = 1.8$, typical of unabsorbed AGNs (Tozzi et al. 2006). This X-ray luminosity can be used as a discriminant between starburst and AGN activity, as even for moderate redshifts, few starburst galaxies exhibit X-ray luminosities in excess of $L_{0.5-8 \text{ keV}} > 10^{42}$ erg s$^{-1}$ (e.g., Moran et al. 1999; Zezas et al. 2001; Alexander et al. 2002). Two of the three high-redshift, millimeter-selected quasars originally identified by Voss et al. (2006) are confirmed to be X-ray luminous in our new Chandra data (J154321+6621.9 and J154141+6622.6; Table 2). The third quasar was previously detected in the 82 ks Chandra exposure presented by Wang et al. (2004).
The fourth bright millimeter source, J154137+6630.5 (MMJ1541+6630), is not detected in our high-resolution Chandra data above a 0.5–8.0 keV flux of $7 \times 10^{-16}$ erg cm$^{-2}$ s$^{-1}$. Only one other MAMBO source candidate, A2125_1200.22, is detected with the new X-ray data. The majority of the 1.2 mm source candidates are not detected in these X-ray data, which is consistent with the interpretation that most of their FIR luminosity is powered by star formation, rather than AGN activity. Table 2 gives the X-ray properties of the four millimeter sources detected in our Chandra image. It is also possible that a nondetection of these SMGs in the X-ray bands is indicative of Compton-thick AGN activity.

For systems heavily obscured by dust and gas, strong X-ray emission is hardened due to reprocessing of the soft X-ray photons, which are absorbed and re-radiated in the (rest-frame) FIR. Quantitatively, the hardness ratio is calculated from the counts in the hard 2.0–8.0 keV band ($H$) to those in the soft 0.5–2.0 keV band ($S$), and is defined here as $(H - S)/(H + S)$. Table 2 gives the hardness ratios of the three millimeter-selected quasars in the A2125 field.

### Table 2

| Source          | $S_{0.5-8.0 \text{ keV}}$ (counts ks$^{-1}$) | Band Ratio$^a$  | Flux$^b$ | $L_{0.5-8.0 \text{ keV}}$$^c$ | Reference$^d$ |
|-----------------|------------------------------------------|----------------|---------|-----------------------------|---------------|
| J154321+6621.9  | 4.57 ± 0.48                              | $-0.30 \pm 0.07$ | 57.1    | 43.3                        | (1)           |
| J154141+6622.6  | 5.03 ± 0.52                              | $-0.20 \pm 0.04$ | 62.8    | 63.1                        | (1)           |
| J153959+6605.8  | 11.72 ± 0.46                             | $-0.40 \pm 0.05$ | 146.3   | 12.8                        | (2)           |
| J154137+6630.5  | <0.06                                    | ...            | <0.7    | <6.2–19.3                   | (1)           |
| J154004+6610.3  | 0.24 ± 0.07                              | ...            | 3.0     | 1.4–4.5                     | (2)           |
| J154004+6610.3  | 0.31 ± 0.08                              | ...            | 3.6     | 0.1                         | (2)           |

Notes.

- $^a$ Hardness ratio calculated from the counts in the 2.0–8.0 keV ($H$) band and those in the 0.5–2.0 keV ($S$) band, defined as $(H - S)/(H + S)$.
- $^b$ Full-band flux (in units of $10^{-15}$ erg cm$^{-2}$ s$^{-1}$) calculated by assuming a photon index $\Gamma = 1.4$ and a Galactic H I column density $N_{\text{HI}} = 2.75 \times 10^{20}$ cm$^{-2}$.
- $^c$ X-ray luminosity in the 0.5–8.0 keV band (in units of $10^{43}$ erg s$^{-1}$) calculated from Equation (1) and assuming $\Gamma = 2.0$ for the thermal sources and $\Gamma = 1.8$ for the three AGNs. For A2125_1200.3 we adopt $z = 0.5$ as is suggested by the optical photometry (Voss et al. 2006), while for the other sources we assume either the measured redshift or that estimated from the millimeter-to-radio photometric redshift technique.
- $^d$ (1) This work; (2) Wang et al. (2004).

### 4. DISCUSSION

#### 4.1. J154137+6630.5: an Obscured Starburst Galaxy

Radio-to-millimeter wavelength photometric redshift estimates for J154137+6630.5 predict $z = 3.93^{+0.11}_{-0.09}$, meaning that it is likely the highest redshift source in our sample, and potentially the most FIR luminous SMG discovered in any blank-field submillimeter/millimeter-wavelength survey ($\sim 5 \times 10^{13} L_\odot$). An X-ray counterpart to J154137+6630.5 is not detected in our new Chandra data, implying $L_{0.5-8.0 \text{ keV}} < (6.2–19.3) \times 10^{43}$ erg s$^{-1}$. This limit is consistent with the X-ray luminosities of the non-AGN SMGs detected in the 2Ms Chandra survey of the Hubble Deep Field-North (HDF-N; Alexander et al. 2003), as well as low-luminosity AGNs. We therefore suggest that most of the far-infrared luminosity in J154137+6630.5 is likely powered by star formation rather than AGN activity; however, it is still possible that a Compton-thick AGN is present. If an AGN were present in J154137+6630.5, then correction for the AGN contribution to the radio flux density would result in a higher photometric redshift estimate for this object. If all of the FIR luminosity indicated by the 1.2 mm flux density were due to star formation, the implied star formation rate would be a tremendous $\sim 18,000 M_\odot$ yr$^{-1}$.

#### 4.2. Radio Identification Rate and Implications for the Redshift Distribution of Bright SMGs

The fraction of robust radio counterparts identified for the 1.2 mm source candidates (24/29) is similar to that typically found in blank-field submillimeter/millimeter-wavelength surveys of comparable depths ($\lesssim 85\%$; e.g., Ivison et al. 2005). This would suggest that the redshifts for the majority of our radio-detected sample are at $z \lesssim 3.5$, given the typical radio flux densities of these counterparts.

As mentioned previously, three of the five millimeter source candidates without radio counterparts are found in noisier regions of the MAMBO map. Based on previous surveys, it has been argued that some of those submillimeter/millimeter source candidates without radio identifications are likely to be spurious. This charge motivated Ivison et al. (2005) to compile a sample of robust SMGs using a technique which combines source candidates identified in independent surveys of the Lockman Hole (at both 850 $\mu$m and 1.2 mm), leading to
a reduced likelihood of spurious sources in their final catalog (~10%). They then find that 80% of the sources in their catalog have robust radio counterparts, so that only ~10% of their candidates are likely to lie at redshifts > 3, in agreement with the results presented here. Along this same vein, for the SHADES survey, four independent analyses of the same data set are performed in order to minimize systematic uncertainties introduced through the methods employed when calibrating low signal-to-noise bolometer data, effects which may have led to spurious source candidates in previous SCUBA surveys. The fraction of 850 \( \mu m \) SHADES source candidates with robust radio identifications is ~66% (Ivison et al. 2007), while the depth of the radio imaging is comparable between the SHADES and A2125 surveys. The typical 1.2 mm rms of the A2125 map is 1.0 mJy, while that of the 850 \( \mu m \) SHADES imaging is 2.2 mJy. Assuming a graybody spectrum with emissivity index, \( \beta = 1.5 \), and dust temperature, \( T_d = 35 \) K, typical of the bright SMG population (Kovacs et al. 2006; Laurent et al. 2006; Coppin et al. 2008), we can determine whether the relative depths of the two surveys should be sensitive to the same population of objects over all redshifts. For this assumed spectral energy distribution (SED), the MAMBO survey would be sensitive to a typical SHADES source out to redshifts \( z \lesssim 3.6 \), beyond which the 850 \( \mu m \) continuum emission is expected to be too faint at the limit of the SHADES survey. Conversely, the 1.2 mm emission should become brighter than the MAMBO detection threshold for SHADES sources at higher redshifts. Therefore, given our assumed SED, the 1.2 mm A2125 survey should be more sensitive to higher redshift SMGs, and we would expect a lower radio detection rate than in the 850 \( \mu m \) SHADES survey if all source candidates are indeed real. Given the small areas covered by these two surveys, it may be that we are affected by cosmic variance in this sample comparison, and that a larger fraction of 1.2 mm A2125 sources are at lower redshifts than the SHADES sources. If gravitational lensing by the foreground cluster has amplified the flux densities of the 1.2 mm source candidates, then this comparison would be biased, though we do not believe this to be the case. It is also possible that a higher fraction of the SHADES sources may be spurious than has been estimated. If this is the case, then it is unlikely that more than ~10–15% of bright SMGs exist beyond redshifts \( z > 3.5 \), supporting the previous claim by Ivison et al. (2005).

Given the high density of radio sources associated with the A2125 cluster (Owen et al. 1999), it is possible that some of our proposed radio counterparts to the millimeter source candidates are in fact associated with foreground cluster members, rather than intrinsic to the higher redshift host galaxies responsible for the millimeter emission. In order to determine if this is indeed the case, we have compared our list of radio identifications with that of the radio positions of cluster members. Only one of our proposed radio counterparts to a 1.2 mm MAMBO source candidate is spatially coincident with a cluster member, namely the second radio counterpart to J154004+6610.3 associated with the cluster member 24027 at \( z = 0.2425 \) (Owen et al. 2005b). However, this source is unlikely to be the correct counterpart given the far better positional agreement between the millimeter source and the primary radio counterpart. This primary radio counterpart to J154004+6610.3 is detected in the Chandra X-ray image, and the implications of this are discussed below. Independent of which radio/X-ray counterpart gives rise to the millimeter emission in J154004+6610.3, we can conclude that robust radio identifications have been obtained for at least 83% of our 1.2 mm source candidates in the A2125 field.

### 4.3. Luminous Millimeter-selected Quasars

The higher angular resolution Chandra imaging presented here and in Wang et al. (2004) confirms the significant X-ray fluxes of the three quasars identified by Voss et al. (2006). Two of these (J154321+6621.9 and J154141+6622.6) have spectroscopic redshifts measured from optical emission lines (Miller et al. 2004; Voss et al. 2006). In the case of the third quasar, J153959+6605.8, Voss et al. (2006) argue that the optical SED is consistent with \( z = 0.5 \), which we adopt in our luminosity calculations (Table 2). All of the quasars have intrinsic X-ray luminosities in the range \( 10^{44}–10^{45} \) erg s\(^{-1}\), consistent with the interpretation that AGNs are powering their tremendous X-ray luminosities. If the X-ray emission were due to star formation activity, then these luminosities would imply rates in excess of 10,000 \( M_\odot \) yr\(^{-1}\) (Grimm et al. 2003).

For an intrinsic power-law photon index \( \Gamma = 1.8 \), the hardness ratios of J154321+6621.9 and J154141+6622.6 are suggestive of moderate column densities of obscuring gas \( (N_{HI} < 5 \times 10^{22} \) cm\(^{-2}\)\) at their measured redshifts. In the case of J153959+6605.8, its hardness ratio and assumed redshift \( (z \sim 0.5) \) is consistent with that of an unobscured AGN with an H i column density \( N_{HI} \sim 10^{21} \) cm\(^{-2}\).

### 4.4. J154004+6610.3: a FIR Luminous X-ray Source

In addition to the three quasars, the only other millimeter source in the A2125 field with a proposed X-ray counterpart is J154004+6610.3. The 1.2 mm source candidate is positionally coincident with two radio counterparts (Figure 3), and each of these is associated with a Chandra X-ray source (Wang et al. 2004). While one counterpart is a cluster member (Owen et al. 2005b), both counterparts are spatially coincident with the concentration of low surface brightness X-ray emission (LSBEX) to the southwest of the A2125 cluster (Wang et al. 2004). The Hubble Space Telescope (HST) V-band image of this pair (Figure 3) reveals that the southern X-ray component is associated with a bright elliptical galaxy (Wang et al. 2004) at a redshift \( z = 0.2425 \). The optically faint component to the north is therefore most likely responsible for both the 1.2 mm emission and the second X-ray/radio component, which may be lensed by the foreground galaxy. The correct counterpart to the millimeter source candidate could be confirmed by submillimeter/millimeter-wavelength interferometry. In the likely scenario whereby all of the millimeter emission arises from this second source, then the photometric redshift estimate predicts \( z = 1.20^{+0.32}_{-0.25} \). Assuming the range of redshifts consistent with the photometric redshift estimate, the derived X-ray luminosity of the northern counterpart (Table 2) is in the range \( L_{0.5–8.0\text{keV}} \sim (1.4–4.5) \times 10^{43} \) erg s\(^{-1}\), which would suggest an AGN-dominated system, if the source is unobscured. This interpretation is consistent with the point-like nature of the optical counterpart. The X-ray luminosity of the southern counterpart \( (L_{0.5–8.0\text{keV}} = 6.3 \times 10^{43} \) erg s\(^{-1}\)\) is consistent with star formation, but more likely arises from a weak AGN, as only a small fraction of such early-type galaxies generally contain detectable quantities of molecular gas (e.g., Combes et al. 2007), which is required to fuel a starburst.

### 5. SUMMARY

We have presented the radio and X-ray properties of the 24 radio-detected 1.2 mm source candidates of the 29 detected in the A2125 field mapped by MAMBO. Our main findings can be summarized as follows.
1. The bright thermal source discovered in the 1.2 mm MAMBO map is not detected in these new X-ray data, despite a previous claim of an identification in the ROSAT PSPC catalog. The non-AGN nature of the FIR emission is therefore best explained by starburst activity, with an expected star formation rate $>10,000 \, M_\odot \, yr^{-1}$. Based solely on its 1.2 mm flux density, J154137+6630.5 is therefore likely to be the most luminous SMG identified in any blank-field submillimeter/millimeter survey thus far.

2. Our 1.4 GHz VLA imaging reveals an 83% detection rate for the millimeter source candidates, consistent with previous studies of bright SMGs in blank-field surveys of comparable sensitivity, suggesting that most of these objects lie at redshifts $z \lesssim 3.5$. The median millimeter-to-radio photometric redshift of this radio-detected sample is $z \sim 2.2$, consistent with that of the median redshift of SMGs with optical spectroscopic redshifts (Chapman et al. 2003, 2005).

3. The three millimeter-selected quasars discovered by Voss et al. (2006) are detected in these Chandra data, while their X-ray luminosities are consistent with AGN activity.

4. X-ray emission is found to be associated with the most likely radio counterpart to one of the millimeter source candidates with a photometric redshift $z \sim 1$.

Given the faintness of the optical and mid-infrared counterparts to J154137+6630.5 (not detected above an $R$-band magnitude of 27.2), the most probable route to obtaining a redshift for this object is through a broadband millimeter/centimeter-wavelength spectroscopic search for redshifted molecular CO line emission (e.g., Wagg et al. 2007). Planned Submillimeter Array observations will soon reveal whether the single-dish millimeter emission from this object is composed of multiple components, providing an alternative explanation for its large apparent FIR luminosity.

With the recent advent of Spitzer, it has become possible to identify counterparts to SMGs in the mid-infrared (Egami et al. 2004; Frayer et al. 2004; Ashby et al. 2006; Pope et al. 2006; Ivison et al. 2007), which may also provide an alternative diagnostic of AGN activity. We will present an analysis of the mid-infrared properties of 1.2 mm source candidates in the A2125 field in a forthcoming article. Within the next two years, the EVLA will come online and provide an order of magnitude improvement in sensitivity.
increase in 1.4 GHz continuum sensitivity. At such depths it will likely be possible to detect radio counterparts for essentially all of the bright SMG population ($\gtrsim 5$ mJy at 850 $\mu$m), depending on the nature of the relatively unstudied high-redshift “tail” of this subsample (e.g., Wang et al. 2007). However, the steepness of the radio counts at these fainter flux density levels means that multiple plausible counterparts are likely to exist for a single bright SMG. As such, combined studies using both the EVLA and ALMA will be necessary to fully understand the submillimeter and radio properties of this high-redshift galaxy population.

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