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THE IDENTIFICATION OF THE SUBMILLIMETER GALAXY SMM J00266+1708

D. T. Frayer,[1] Ian Smail,[2] R. J. Ivison,[3] and N. Z. Scoville[1]

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ABSTRACT

We report the detection of 1.3 mm continuum and near-infrared *K*-band (2.2 μm) emission from the submillimeter galaxy SMM J00266+1708. Although this galaxy is among the brightest submillimeter sources detected in the blank-sky surveys ($L \sim 10^{13}\ L_{\odot}$), SMM J00266+1708 had no reliable optical or near-infrared counterpart. We used sensitive interferometric 1.3 mm observations with the Owens Valley Millimeter Array to determine the position of the submillimeter galaxy accurately. Follow-up near-infrared imaging with the Keck I telescope uncovered a new faint red galaxy at $K = 22.5$ mag, which is spatially coincident with the 1.3 mm emission. This is currently the faintest confirmed counterpart of a submillimeter galaxy. Although the redshift of SMM J00266+1708 is still unknown, its high submillimeter/radio spectral index suggests that the system is at high redshift ($z \gtrsim 2$). Approximately 50% or more of the submillimeter galaxies are faint red galaxies similar to SMM J00266+1708. These ultraluminous obscured galaxies account for a significant fraction of the total amount of star formation at high redshift despite being missed by optical surveys.

Key words: galaxies: evolution — galaxies: formation — galaxies: individual (SMM J00266+1708) — galaxies: starburst

1. INTRODUCTION

Deep surveys of the submillimeter sky using the Submillimeter Common User Bolometer Array (SCUBA) camera (Holland et al. 1999) on the James Clerk Maxwell Telescope (JCMT) have uncovered a population of ultraluminous dusty galaxies at high redshift (Smail, Ivison, & Blain 1997b; Hughes et al. 1998; Barger et al. 1998; Eales et al. 1999; Blain et al. 1999b). This population accounts for a large fraction of the extragalactic background at millimeter or submillimeter wavelengths (Blain et al. 1999d) and hence is important to our understanding of the distant universe. The submillimeter population is thought to contribute significantly to both the total amount of star formation (Blain et al. 1999d) and active galactic nuclei (AGN) activity (Almaini, Lawrence, & Boyle 1999) at high redshift. The submillimeter population will likely show a mixture of AGN and starburst properties, given their apparent similarities to the local population of ultraluminous ($L > 10^{12}\ L_{\odot}$) infrared galaxies (ULIGs; Sanders & Mirabel 1996). However, we could expect the majority (∼70%–80%) of the submillimeter galaxies to be predominantly powered by starbursts since this has been found for the local ULIGs (Genzel et al. 1998). The early CO and X-ray data on the submillimeter population support the starburst nature of the population by showing the presence of sufficient molecular gas to fuel the star formation activity (Frayer et al. 1998, 1999) and the lack of expected X-ray emission if mostly dominated by AGNs (Fabian et al. 2000; Hornschemeier et al. 2000). Observations of the dust-rich submillimeter galaxies complement the studies of the ultraviolet-bright Lyman-break sources (Steidel et al. 1996, 1999), which tend to be much less luminous at infrared wavelengths (Chapman et al. 2000). Only by studying both the Lyman-break and the submillimeter populations of galaxies will a complete picture of the star formation history of the universe emerge.

To understand the nature of the submillimeter population, we have been carrying out multiwavelength observations of individual systems in the SCUBA Cluster Lens Survey (Smail et al. 1998). This survey represents sensitive submillimeter mapping of seven massive, lensing clusters that uncovered 15 background submillimeter sources. The advantage of this sample is that the amplification of the background sources allows for deeper source-frame observations. Also, lensing by cluster potentials does not suffer from differential lensing, so that the observed flux ratios represent intrinsic values, despite the possible variation of source size at different wavelengths.

The most challenging aspect for follow-up observational studies of the submillimeter population is determining the proper counterparts to the submillimeter emission and obtaining their redshifts (Ivison et al. 1998, 2000a). The large 15″ SCUBA beam leaves ambiguity in identifying the galaxy associated with the submillimeter emission. The early results based on optical imaging and spectroscopy were overly optimistic in the identification of the submillimeter counterparts (Smail et al. 1998; Barger et al. 1999; Lilly et al. 1999). Radio data (Smail et al. 2000b) and initial near-infrared (NIR) imaging (Smail et al. 1999) suggest that several of the original candidate optical counterparts (e.g., Barger et al. 1999) are incorrect. Despite their ultra–high luminosities, many submillimeter galaxies are nearly completely obscured by dust at ultraviolet and optical wavelengths. For these highly obscured galaxies, follow-up radio (Smail et al. 2000b) and/or millimeter interferometry (Downes et al. 1999; Bertoldi et al. 2000), as well as near-infrared observations, are required to uncover the proper counterpart. The galaxy SMM J00266+1708 is an excellent example of such a source.

2. OBSERVATIONS

2.1. *Background Data on SMM J00266+1708*

The submillimeter galaxy SMM J00266+1708 is the second-brightest galaxy in the SCUBA Cluster Lens Survey

[1] Department of Astronomy, Mail Stop 105-24, California Institute of Technology, 1201 East California Boulevard, Pasadena, CA 91125.

[2] Department of Physics, University of Durham, South Road, Durham, DH1 3LE, UK.

[3] Department of Physics and Astronomy, University College London, Gower Street, London, WC1E 6BT, UK.

(Smail et al. 1998). Initially, the source was tentatively associated with a possibly interacting pair of galaxies, M1 and M2, revealed by deep *I*-band imaging ($3\ \sigma = 26.1$ mag) with the *Hubble Space Telescope* (*HST*; Smail et al. 1998). Spectroscopy of the galaxy M2 showed a bright [O II] emission line at $z = 1.226$, consistent with that of a luminous star-forming galaxy (Barger et al. 1999). In the fall of 1998, we searched for redshifted CO (2→1) emission corresponding to the redshift of M2 at the Owens Valley Millimeter Array[4] (OVRO). We failed to detect any CO emission at the redshift of M2; $S(\mathrm{CO}) < 1.3$ Jy km s^{-1} ($3\ \sigma$), assuming a standard 300 km s^{-1} line width. If M2 was the correct counterpart and the source was similar to the submillimeter galaxies with previous CO detections (Frayer et al. 1998, 1999), we would have expected a CO (2→1) line strength of approximately 7 Jy km s^{-1}. The nondetection of CO questions the association of M2 with the submillimeter galaxy. Additional optical spectroscopy showed that M1 is at the redshift of the foreground cluster ($z = 0.39$), and hence, M1 and M2 are not an interacting pair after all (Barger et al. 1999). These results bring into further doubt the initial association of M1 and M2 with the submillimeter emission based on optical morphology alone.

Besides M1 and M2, the only other optically visible source spatially consistent with the SCUBA position is M8 (Fig. 1). However, the galaxy M8 shows no unusual properties that would suggest an association with a luminous submillimeter source. More significantly, the field has a weak radio source (Smail et al. 2000b) whose position is consistent with the SCUBA source but is slightly offset from M8. Since the brightest submillimeter galaxies tend to have radio counterparts (Smail et al. 2000b; Barger, Cowie, & Richards 2000), we could reasonably expect an association between the submillimeter galaxy and the radio source. If this is the case, the radio emission of SMM J00266+1708 is too weak to be consistent with a redshift of $z = 0.44$ for M8 (Barger et al. 1999), based on the redshift dependency predicted for the submillimeter/radio spectral index (Carilli & Yun 1999). Although the submillimeter/radio spectral index provides only an estimate of the redshift given the uncertainties of source temperature and properties (Blain 1999), it does provide a powerful technique for discriminating between low-redshift ($z \lesssim 0.5$) and high-redshift ($z \gtrsim 2$) galaxies. SMM J00266+1708 is expected to be at redshift $z > 2$ since its submillimeter/radio spectral index of $\alpha = 1$ is much larger than any known galaxy at low redshift (Smail et al. 2000b). Therefore, it is unlikely that M8 is the sub-

[4] The Owens Valley Millimeter Array is a radio telescope facility operated by the California Institute of Technology and is supported by NSF grant AST 99-81546.

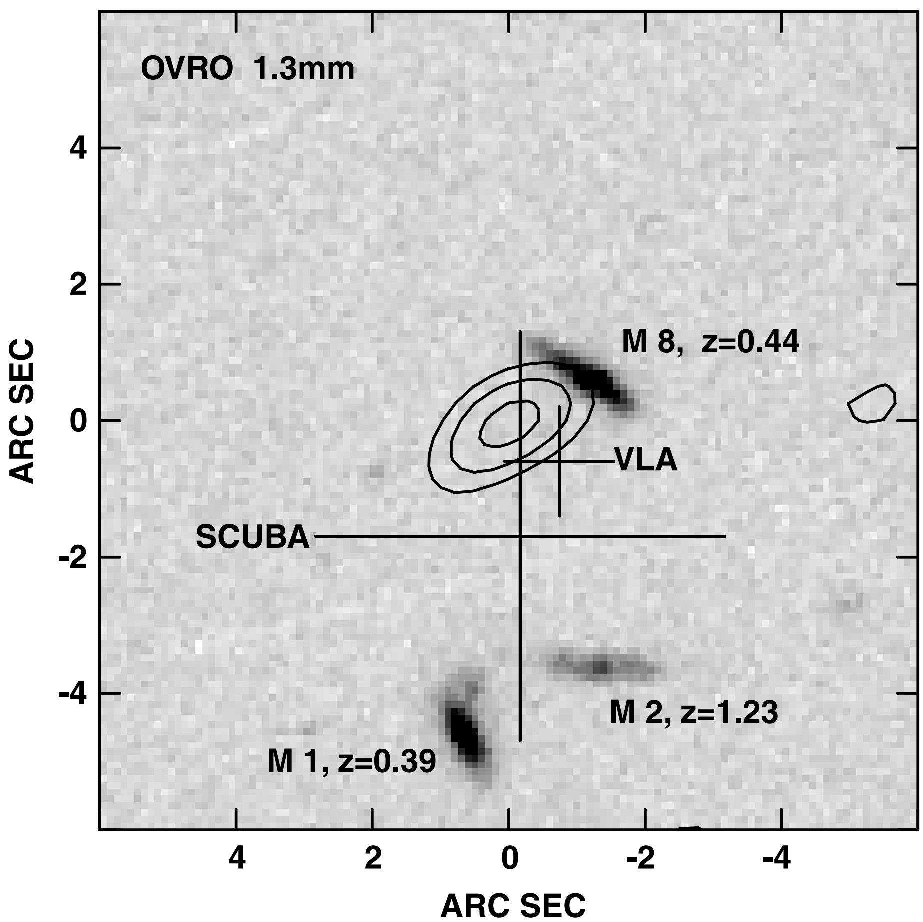

FIG. 1.—OVRO 1.3 mm contour map overlaid on the *HST* *I*-band optical image (Smail et al. 1998). The rms level is 1.1 mJy beam^{-1}, and the contour levels are $1\ \sigma$ times -3, 3, 4, and 5. The source is unresolved by the 2″ OVRO beam. The position of the 21 cm radio source (Smail et al. 2000b) is shown by the cross labeled "VLA," while the positional uncertainty of the submillimeter source is marked by the cross labeled "SCUBA."

millimeter counterpart. Since none of the optically detected galaxies are plausibly associated with the submillimeter emission, we have carried out submillimeter-continuum and near-infrared observations of SMM J00266+1708.

2.2. *OVRO 1.3 mm Continuum Observations*

We have taken sensitive 1.3 mm interferometric observations of SMM J00266+1708 to accurately constrain the position of the submillimeter source. SMM J00266+1708 was observed several times using the OVRO array in 1999. Approximately 10 hr of on-source data were obtained during good conditions in the low-resolution configurations of the array (baseline lengths ranging from 15 to 119 m). We observed with four separate 1 GHz continuum bands centered at 229.0, 230.5, 233.5, and 235.0 GHz. The 4 GHz of total continuum bandwidth represents a factor of 2 increase in bandwidth over what was previously achievable at OVRO.

We observed the bright quasar 3C454.3 every 20 minutes for amplitude and phase calibration. Since 3C454.3 is 22° from SMM J00266+1708, we also interweaved observations of the nearby quasar 0007+106 (B1950.0) to test the quality of the calibration. The systematic positional uncertainty of the data is estimated to be better than 0"3. Observations of the planets Uranus and Neptune were used to calibrate the absolute flux scale. By using the flux history of 3C454.3, we estimate a flux calibration uncertainty of 20% for the data.

We combined the data for the four individual 1 GHz bands to produce the 1.3 mm detection at a mean frequency of 232.0 GHz. The contours in Figure 1 show the resultant natural-weighted image. No primary beam correction was required since the source was located within 4" ($\frac{1}{8}$ of the primary beam width) of the phase center. We made no correction for possible variations of source strength across the four individual bands. These variations are expected to be less than 10%, assuming dust emission, and were undetected within the uncertainties of the data.

2.3. *Keck K-Band Imaging*

After the 1.3 mm detection, we obtained *K*-band (2.2 μm) data to search for the galaxy responsible for the submillimeter emission at the position derived from the OVRO data. We observed SMM J00266+1708, using the Near Infrared Camera (NIRC) on Keck I[5] on UT 1999 October 1. NIRC is a 256 × 256 pixel InSb detector with a pixel scale of 0"15 (Matthews & Soifer 1994). We observed using the standard *K*-band filter instead of the bluer K_s filter since the object is expected to be red. Integrations were taken using 10 × 6 s co-adds, and we randomly dithered the integrations within an 8" × 8" box to provide uniformity across the image. We obtained a total of 4.3 hr of data on-source. The seeing-disks of the stars observed throughout the night varied from 0"3 to 1" (FWHM).

In reducing the data, a combined set of dark frames was subtracted from each individual exposure to remove the dark current as well as the bias level. The dark-subtracted exposures were divided by a normalized sky flat that was generated from the on-object exposures themselves. Frames were sky subtracted using the temporally adjacent images to produce the reduced exposures. The individual reduced exposures were aligned to the nearest pixel using common objects in the frames. We observed a set of near-infrared standard stars (Persson et al. 1998) at a range of air masses to correct the data for extinction. The uncertainty of the derived magnitude scale is estimated to be better than 0.04 mag, based on the dispersion in the zero points derived throughout the night.

3. RESULTS

3.1. *Images*

Figure 1 shows the 1.3 mm continuum map. The source was detected at the 5 σ level and was unresolved with a synthesized beam size of $\theta_b = 2''.3 \times 1''.9$. At the observed frequency of 232 GHz (1.29 mm), we derive a flux density of 6.0 ± 1.1 mJy by fitting a Gaussian to the peak of the emission. The total uncertainty in the flux is 28%, which includes the 20% calibration error and the rms error of 20% combined in quadrature. The strength of the 1.3 mm source is consistent with extrapolating the thermal dust spectrum expected from the submillimeter source (Fig. 3). We conclude that the 1.3 mm source is associated with the SCUBA source and is likely representative of the bulk of the submillimeter emission.

Figure 2 shows the *K*-band image. We detected a new galaxy 1"5 southeast of the nucleus of M8 at the position of the OVRO 1.3 mm continuum source. Since the seeing varied significantly throughout the night, we combined only the best 2.4 hr of data to produce the *K*-band image. After convolving the data with a 2 pixel (FWHM) Gaussian to reduce pixel-to-pixel variations, the resolution of the data is 0"5 (FWHM), including seeing. The image has a 1 σ limiting

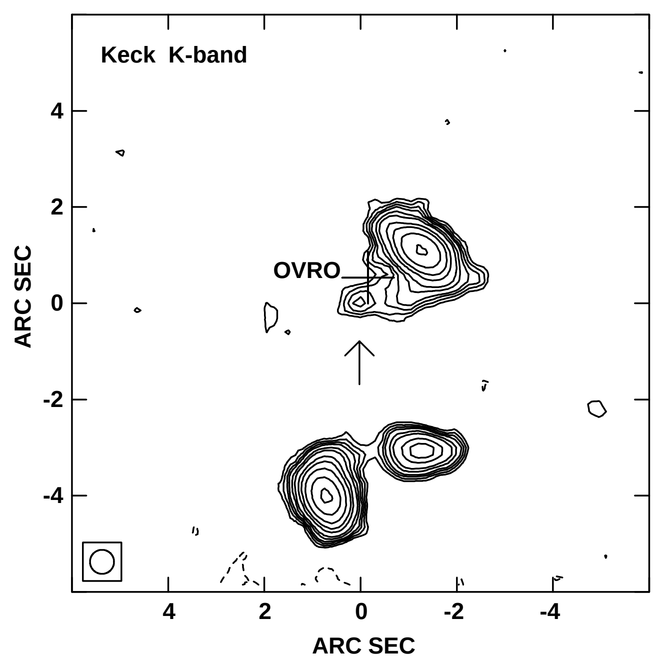

FIG. 2.—Keck *K*-band (2.2 μm) image. The arrow points to the new galaxy thought to be the counterpart of SMM J00266+1708. The rms of the image is 24.8 mag arcsec^{-2} (0.04 μJy beam^{-1}), and the contours are 1 σ times −3, 3, 4, 5, 6, 8, 10, 15, 20, 30, 50, and 80. The seeing disk (beam) of the NIR data is shown in the lower left (0"5 × 0"5). The position of the 1.3 mm source is shown by the cross labeled "OVRO."

[5] The W. M. Keck Observatory is operated as a scientific partnership among the California Institute of Technology, the University of California, and the National Aeronautics and Space Administration. The Keck Observatory was made possible by the generous financial support of the W. M. Keck Foundation.

K-band surface brightness of $\mu = 24.8$ mag arcsec^{-2}, or 0.04 μJy beam^{-1}, adopting 646 Jy for the flux density equivalent for a zero K-band magnitude (Neugebauer et al. 1987).

Photometry on the galaxy was done using an aperture to sum up the emission from the regions around the southeastern peak that are well separated from M8. The integrated emission for the galaxy is detected at about the 10 σ level with magnitude $K = 22.45 \pm 0.11$ (0.68 $\pm$ 0.07 μJy, $K_{AB} \simeq 24.3$). There is additional emission westward from the southeastern peak and near M8. There is no evidence in the I-band image for this extension. If we assume that this emission is associated with the southeastern peak, we would derive a total magnitude of $K = 21.5$ after subtracting the bright disk of M8 from the image. For the remainder of the paper, we neglect this additional emission since it is unclear what fraction is associated with M8, the southeastern peak, or neither.

3.2. *Astrometry*

The K-band image was registered to the *HST* optical image on the APM coordinate system using the galaxies M1 and M8. The optical astrometry in the *HST* image has an rms uncertainty of only 0\".2. However, the dominant source of registration error in comparing the K-band data with the radio and 1.3 mm data is the systematic offset between the APM system and the radio reference frame (Johnston et al. 1995). These offsets may be as large as 1\", which we adopt as a conservative estimate of the total error in the K-band position. The positional error for the 1.3 mm source is 0\".5. This includes a systematic astrometry uncertainty of 0\".3 from calibration combined in quadrature with the statistical error related to the signal-to-noise ratio (S/N) of approximately 0\".4 [θ_b/(S/N)]. The 21 cm radio data have a synthesized beam size of 5\" and a positional error of about 0\".8 [θ_b/(S/N)]. The 850 μm source detected by SCUBA has a positional accuracy of approximately 3\" (Smail et al. 1998).

The positions of SMM J00266+1708 measured at 21 cm, 1.3 mm, and 850 and 2.2 μm are all consistent with each other within the errors (Table 1). The positional coincidence alone suggests an association between the sources at different wavelengths. The probability of randomly finding a 22.5 mag K-band galaxy within a 1 arcsec^2 box is only 1%, based on the observed K-band surface densities of galaxies (Djorgovski et al. 1995; Moustakas et al. 1997). By taking into account the red nature of the galaxy ($I-K > 3.6$), the likelihood of a random association decreases even more. Only about 10% of faint galaxies ($22.0 \leq K \leq 22.9$) have $I-K > 3.5$ (Moustakas et al. 1997). Hence, the probability of a chance association of such a faint red galaxy with the 1.3 mm source is only 10^{-3}. An even stronger case can be made for the association between the radio source and the 1.3 mm source. Radio source counts (Richards 2000; Richards et al. 1999) imply that the probability of randomly finding such a strong radio source within 1 arcsec^2 of the 1.3 mm source is only about 10^{-5}. We conclude the sources detected at 21 cm, 1.3 mm, and 850 and 2.2 μm are all likely associated with each other.

3.3. *Spectral Energy Distribution and Redshift*

Table 1 presents the flux density measurements and upper limits observed for SMM J00266+1708. The 21 cm radio data are presented by Smail et al. (2000b). We measure a flux density of 94 $\pm$ 15 μJy for the 21 cm radio source by fitting a Gaussian to the unresolved emission. We also report a 3.5 cm upper limit for the galaxy based on sensitive observations of the cluster (A. R. Cooray 2000, private communication). The submillimeter flux at 850 μm has been previously tabulated by Barger et al. (1999), and the 450 μm upper limit is discussed by Smail et al. (2000a). The optical I-band limit of 26.1 mag is derived from the observations presented by Smail et al. (1998). The 1.3 mm and K-band measurements are based on the observations presented in this paper.

As stated earlier (§ 2.1), SMM J00266+1708 is thought to lie at a high redshift, $z \gtrsim 2$, based on the submillimeter/radio spectral index of the galaxy (Carilli & Yun 1999; Smail et al. 2000b). High redshifts are also required to account for the low 450 μm/850 μm ratio, assuming dust emission with properties similar to that found in low-redshift luminous starbursts (Dunne et al. 2000). The optical and NIR imaging data by themselves provide little constraint on the redshift of SMM J00266+1708 given the wide range of optical and NIR properties found for the submillimeter population (e.g., Ivison et al. 2000b). The best redshift constraints for SMM J00266+1708 come by fitting the spectral energy distribution (SED) of the galaxy from radio to submillimeter wavelengths. Figure 3 shows the observed SEDs of the low-redshift ULIGs Arp 220 and Mrk 231 (Rigopoulou, Lawrence, & Rowan-Robinson 1996), as well as a $z = 1.44$ extremely red object (ERO), the galaxy HR10 (Dey et al. 1999), the relatively blue submillimeter starburst SMM J14011+0252 (Ivison et al. 2000b), and the submillimeter galaxy SMM J02399−0136, which contains an AGN (Ivison et al. 1998). These ULIG systems are chosen for comparison since they represent the

TABLE 1

OBSERVED PROPERTIES OF SMM J00266+1708

Wavelength	α (J2000.0)	δ (J2000.0)	Flux[a]	Telescope
21.4 cm	00 26 34.06 $\pm$ 0.06	17 08 33.1 $\pm$ 0.8	94 $\pm$ 15 μJy	VLA
3.54 cm	...	...	$<$34 μJy(3 σ)	VLA
1.29 mm	00 26 34.10 $\pm$ 0.04	17 08 33.7 $\pm$ 0.5	6.0 $\pm$ 1.7 mJy	OVRO[b]
850 μm	00 26 34.1 $\pm$ 0.2	17 08 32 $\pm$ 3	18.6 $\pm$ 2.4 mJy	JCMT
450 μm	...	...	$<$60 mJy (3 σ)	JCMT
2.2 μm	00 26 34.11 $\pm$ 0.07	17 08 33.2 $\pm$ 1.0	0.68 $\pm$ 0.07 μJy ($K = 22.45 \pm 0.11$)	Keck[b]
0.8 μm	...	...	$<$0.09 μJy (3 σ) ($I<26.1$)	*HST*

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

[a] Flux uncertainties include both systematic and rms errors.

[b] Observations presented in this paper.

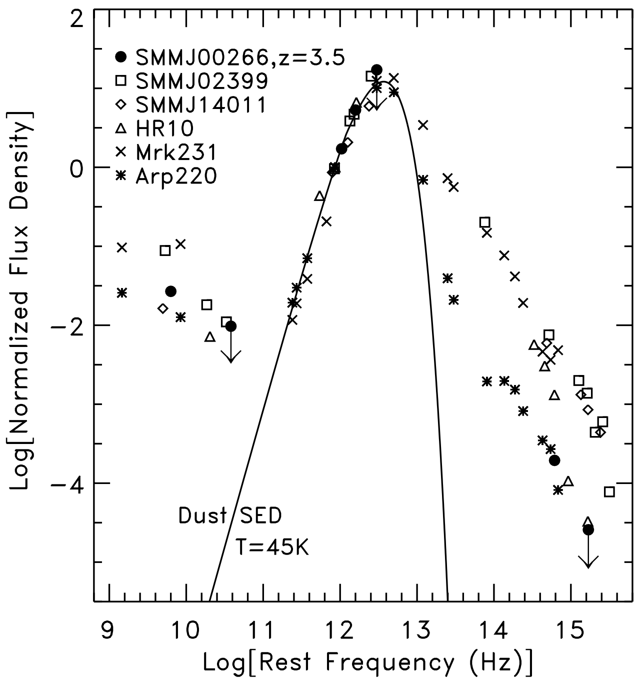

FIG. 3.—SED of SMM J00266+1708 (*solid circles*), adopting the best-fit redshift, $z = 3.5 \pm 1.5$, compared with other ULIG systems. All data have been normalized to a rest wavelength of 350 μm. The upper limits for SMM J00266+1708 are marked with downward arrows. The solid line shows an example SED for dust emission assuming a typical temperature of $T = 45$ K and $\beta = 1.5$ for the power-law dependence of the dust absorption coefficient.

reasonable range of possible SEDs expected for the submillimeter population. Assuming a likely range of dust temperatures (30–50 K) and fitting all the data to the nearest 0.5 redshift unit, we estimate a redshift of $z = 3.5 \pm 1.5$ for SMM J00266+1708.

The wide range of optical flux densities and colors for ULIGs and submillimeter galaxies (Fig. 3) demonstrates the difficulty of attempting to estimate the far-infrared luminosities of ultraluminous galaxies based solely on optical observations (c.f. Adelberger & Steidel 2000). Bolometric luminosities estimated from submillimeter flux densities are significantly more robust since the observed emission from high-redshift galaxies arises near the peak of the SED.

3.4. *Lensing*

In this section, we estimate the effect of gravitational lensing. SMM J00266+1708 is amplified by the potential of the $z = 0.39$ foreground cluster Cl 0024+16. Assuming a redshift of $z = 1.23$, Barger et al. (1999) find an amplification factor of 1.6 due to the cluster. Adopting a more realistic source redshift of $z \sim 3.5$, the amplification factor is increased to 2.1 by using the relationships given by Schneider, Ehlers, & Falco (1992) to rescale the appropriate angular size distances. The amplification factor due to the cluster is fairly insensitive to redshift for $z \gtrsim 2$.

Since SMM J00266+1708 is near the line of sight of the galaxy M8 ($z = 0.44$), we could expect additional gravitational lensing due to M8. To estimate this effect, we approximate both M8 and SMM J00266+1708 as point sources and use the equations for a simple Schwarzschild lens (Schneider et al. 1992). M8 appears to be a normal spiral galaxy with a typical absolute V-band magnitude of $M_V = -20$ (Smail et al. 1997a). Assuming a total mass of 2×10^{11} $M_\odot$ within the central 10 kpc of M8 (which corresponds to the angular separation of 1″.5 between SMM J00266+1708 and M8), we estimate that SMM J00266+1708 is amplified by a factor of 1.14 due to M8. Including lensing by both the cluster and M8, we expect a total magnification factor of about 2.4 ± 0.5 for SMM J00266+1708.

SMM J00266+1708 is the second submillimeter galaxy (ERO N4 is the other example; Smail et al. 1999) found in the Cluster Lens Survey thought to be lensed by a low-redshift spiral galaxy. These results may suggest that lensing due to galaxies may play a significant role for the brightest submillimeter galaxies. The current observations of submillimeter counts indicate that future millimeter or submillimeter surveys covering large areas of the sky should detect many strongly lensed sources (Blain, Möller, & Maller 1999c).

4. DISCUSSION

We have concentrated our follow-up studies on the nine brightest galaxies detected in the submillimeter Cluster Lens Survey (Smail et al. 1998). Currently, only three of the nine galaxies have optical counterparts with redshifts. Two of these have been confirmed by CO observations at OVRO (Frayer et al. 1998, 1999), and the third is a Seyfert ring galaxy at $z = 1.06$ recently detected in CO with the IRAM interferometer (Soucail et al. 1999; Kneib et al. 2000).

At least four of the nine systems are undetected at optical wavelengths ($I > 26$–27 after correcting for lens amplification) and have been detected only with K-band imaging. Two of these are bright enough ($K = 19.1$, 19.6 mag) to be classified as EROs (Smail et al 1999). An additional faint ($K = 21$, $R > 26$) galaxy was found associated with a relatively bright (500 μJy) radio counterpart (Ivison et al. 2000b, 2000c). SMM J00266+1708 is the faintest submillimeter counterpart found to date at $K = 22.5$. Only two of the nine sources still require deep K-band imaging and have uncertain counterparts. Depending on the results for these last two unknown systems, the data suggest that approximately 40%–70% ($\frac{4}{9}$–$\frac{6}{9}$) of the submillimeter population as a whole are faint red galaxies that are undetected at optical wavelengths. It is still unclear what fraction of the submillimeter galaxies are EROs ($R-K > 6$; Thompson et al. 1999). At least two out of nine ($\gtrsim$20%) galaxies in the Cluster Lens Survey are EROs (Smail et al. 1999), and other submillimeter surveys have uncovered additional faint EROs associated with SCUBA sources (Ivison et al. 2000a). Future, much deeper optical observations may show that a high fraction of submillimeter galaxies are EROs.

4.1. *Intrinsic Properties of SMM J00266+1708*

SMM J00266+1708 is an extremely faint galaxy. After correcting for lensing, the source-frame magnitude of the galaxy is $K = 23.4$. We adopt a lensing magnification of 2.4, a redshift of $z = 3.5$, and a cosmology of $H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = 0.5$ to estimate the properties of SMM J00266+1708. Given the redshift uncertainty, we cannot accurately determine many of the intrinsic properties of SMM J00266+1708. One exception is the bolometric submillimeter–far-infrared (FIR) luminosity, which is relatively insensitive to redshift for $z \gtrsim 1$ (Blain & Longair 1993). From the 850 μm measurement, the implied intrinsic FIR luminosity for SMM J00266+1708 is $L(\mathrm{FIR}) \simeq 10^{13}$ $L_\odot$. This corresponds to a star formation rate of massive stars ($M > 5\ M_\odot$) of approximately 500–900 $M_\odot$ yr^{-1} (Scoville, Yun, & Bryant 1997; Condon 1992). These results are consistent with estimates for other submillimeter galaxies (Ivison et al. 1998, 2000b). It is still not known whether or not an AGN contributes significantly to the bolometric luminosity of SMM J00266+1708. If an AGN is present, it is not a strong radio source and must be heavily obscured at optical wavelengths (Fig. 3). Based on its SED, SMM J00266+1708 appears most similar to highly reddened ULIG starbursts such as Arp 220 or HR10 at redshift $z \sim 3.5$.

4.2. *Comparison of Submillimeter and Lyman-Break Populations*

The relative importance of the submillimeter and Lyman-break galaxies to the global star formation rate at high redshift is an active area of discussion (Hughes et al. 1998; Guiderdoni et al. 1998; Blain et al. 1999a, 1999d; Trentham, Blain, & Goldader 1999; Peacock et al. 2000). Depending on the exact contribution of AGNs in the submillimeter population, the ultraluminous submillimeter galaxies ($>10^{12}\ L_\odot$ and $S(850\ \mu\mathrm{m}) \gtrsim 1$ mJy) account for approximately 30%–50% of the total star formation at high redshift (Blain et al. 1999d). It is truly remarkable that such a high fraction of all star formation at high redshift occurs in ultra-luminous submillimeter galaxies. In contrast, ULIGs contribute only about 0.2% of the total amount of star formation in the local universe, based on the survey of Kim & Sanders (1998). Hence, the evolution in the amount of star formation occurring in ULIGs is about 100 times stronger than the global increase of the star formation rate at high redshift seen for all galaxies (Madau et al. 1996; Steidel et al. 1999).

It has been suggested that the submillimeter and Lyman-break populations each represent the formative phases of massive L^* galaxies (Blain et al. 1999a; Giavalisco et al. 1998). In this scenario, the submillimeter systems may be associated with a very luminous short-lived and heavily dust-enshrouded starburst, while the Lyman-break galaxies would be associated with a longer lived, less luminous phase of star formation (Blain et al. 1999a). If this scenario is correct, we could expect massive reservoirs of molecular gas associated with both populations. The detection of massive reservoirs of molecular gas (Frayer et al. 1998, 1999) suggests that the submillimeter population is associated with gas-rich massive galaxies ($\gtrsim L^*$). The molecular gas masses of the submillimeter galaxies are 10–50 times greater than that found for the Milky Way. In contrast, the best-studied Lyman-break galaxy, cB58 (Yee et al. 1996; Pettini et al. 2000; Teplitz et al. 2000), has even less molecular gas than the Milky Way, after correcting the observed CO upper limit for lensing and suspected metallicity effects (Frayer et al. 1997). Therefore, the Lyman-break sources may be sub-L^* systems representing the building blocks of more massive galaxies, as suggested by Lowenthal et al. (1997).

Most submillimeter galaxies are similar to SMM J00266+1708 in being too faint and/or too red to be included in the Lyman-break surveys (e.g., Steidel et al. 1999). The one notable exception is the submillimeter-selected galaxy pair, SMM J14011+0252 J1/J2 (Ivison et al. 2000b; Adelberger & Steidel 2000), but for this system most of the U-band light is emitted by J2, while the bulk of the bolometric luminosity is thought to be due to the much redder J1 component (Ivison et al. 2000c). Because of the high levels of dust obscuration for the submillimeter galaxies, there is very little overlap between the submillimeter-selected galaxies and optically selected Lyman-break systems. Even for the Lyman-break galaxies, most of their star formation ($\sim$80%) is obscured by dust at observed optical wavelengths (Peacock et al. 2000; Adelberger & Steidel 2000). Hence, it is clear that most of the star formation activity at high redshift is hidden from view at optical/ultraviolet wavelengths.

The results presented for SMM J00266+1708 have important implications for our general understanding of star formation at high redshift. Roughly half the total amount of star formation at high redshift is thought to occur in the submillimeter galaxies (Blain et al. 1999d), while the other half is inferred from the optically selected Lyman-break sources (Peacock et al. 2000). Since about 50% of the submillimeter galaxies are undetected at optical wavelengths, a significant fraction ($\sim$25%) of the total amount of high-redshift star formation may occur in the very faint or red submillimeter galaxies similar to SMM J00266+1708. Similar conclusions have also been reached for a radio-selected sample of submillimeter galaxies with faint optical counterparts (Barger et al. 2000). The fact that many of the most luminous high-redshift starbursts or AGNs are too faint to be studied at optical wavelengths highlights the importance that future sensitive millimeter-NIR wavelength instruments will have for our understanding of the distant universe.

5. CONCLUDING REMARKS

We report the identification of the submillimeter source SMM J00266+1708 with a faint red galaxy ($K = 22.5$ mag) that is undetected at optical wavelengths, despite very deep observations. This source has an extremely high luminosity of approximately $10^{13}\ L_\odot$ even after correcting for lensing. The current data for the submillimeter Cluster Lens Survey suggest that 40%–70% of the submillimeter population as a whole are faint red galaxies that are undetected at optical wavelengths. These faint red submillimeter galaxies are thought to contribute significantly to the total amount of star formation at high redshift and are hence important to our understanding of the early evolution of galaxies.

The redshift of SMM J00266+1708 is currently unknown, but the galaxy is expected to be at redshift $z > 2$. Obtaining a redshift will be extremely challenging with current instrumentation. At $K = 22.5$ mag, this galaxy pushes the capabilities of even the largest ground-based telescopes. Since the galaxy is relatively red ($I-K > 3.6$), we expect Hα to be the brightest optical emission line and perhaps the only optical line currently detectable based on comparisons with the ERO HR10 (Dey et al. 1999). If the redshift is similar to that estimated from the SED of the galaxy ($z \sim 3.5$), Hα would be shifted redward of the K-band, making ground-based observations extremely challenging.

We could expect much fainter K-band magnitudes of 23–26 for similar submillimeter galaxies ($\gtrsim 10^{12}\ L_\odot$) that are unlensed. Therefore, obtaining optical/NIR redshifts for many of the submillimeter galaxies may have to wait for the *Next Generation Space Telescope*. Alternatively, redshifts could be directly measured from the CO lines themselves with future ground-based instruments, such as the Atacama Large Millimeter Array, operating at submillimeter wavelengths (Blain et al. 2000). Sensitive interferometric observations at submillimeter and millimeter wavelengths with the next generation of instruments will be crucial for our understanding of these dust-obscured systems.

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