Extending the redshift distribution of submm galaxies: Identification of a $z \approx 4$ submm galaxy

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Abstract. We present the identification of a bright submillimeter galaxy (SMG) in the field of Abell 2218. The galaxy has a spectroscopic redshift of ~ 4, and is currently the highest redshift SMG known. It is detected at all wavelengths from optical to submm, including the *Spitzer* IRAC bands. We discuss the properties of this galaxy, which is undergoing intense star formation at a rate $\sim 600 \, \mathrm{M_\odot yr^{-1}}$. We also compare the properties to those of radio-preselected submm-bright galaxies. The $z \approx 4$ result extends the redshift distribution of SMGs.

1. Introduction

Major progress in submillimeter cosmology has been seen since the commissioning of SCUBA (Submillimetre Common-User Bolometer Array; Holland et al. 1999), which was mounted on the James Clerk Maxwell Telescope (JCMT). Many studies have been undertaken studying submillimeter galaxies (SMGs) in large blank field surveys and surveys of strongly lensing galaxy clusters. In the cluster surveys the gravitational lensing moves the confusion limit to flux levels fainter than the blank field limit of 2 mJy. It has taken several years to overcome the many complications involved in the identification of the counterparts. The large beam of $15''$ in diameter makes unique identifications difficult. However, resorting to multiwavelength follow-up ranging from radio to optical it is possible to constrain the properties of the underlying galaxy, including (photometric) redshift and the presence of AGN. (For more details, see Smail 2006, this volume.)

Recently, Chapman et al. (2003, 2005) published a large spectroscopic survey of radio-detected bright SMGs ($f_{850} > 4 \, \mathrm{mJy}$). They presented redshifts for about 70 SMGs from several blank field surveys — an effort, which has been crucial for quantifying the properties of the bright SMGs (see Smail 2006). The redshift distribution has a median redshift of 2.4. Even though using radio observations to determine the position of the underlying galaxy is a very efficient identification technique, it is likely biased towards redshifts $z < 3.5$. There are candidate counterparts towards higher redshifts (e.g. Dunlop et al.,
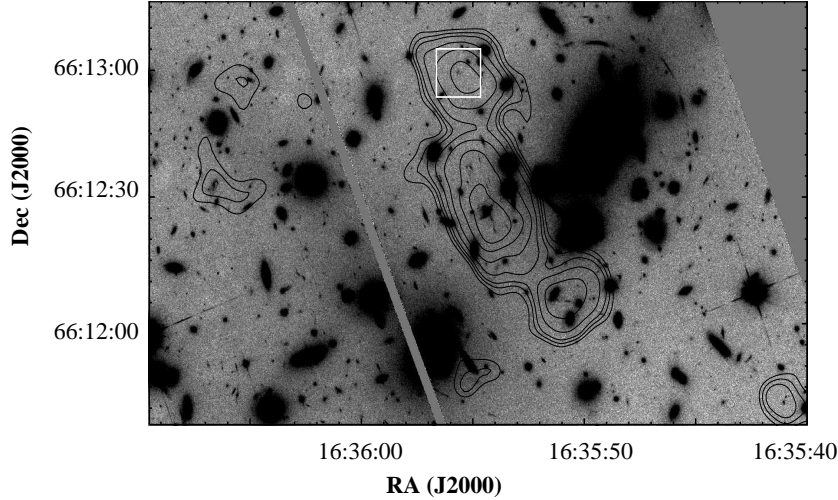
Figure 1. ACS F850LP image overlayed with the $850\,\mu$m SCUBA contours at $3, 4, 5, 7, 10, 15, 20\sigma$. The white box indicate position of SMM J16359+66130 and of the sub-image shown in Fig. 2. The three bright sources south of the box are the triple-imaged galaxies SMM J16359+6612 (Kneib et al., 2004a).

2004), however, their redshifts still need to be confirmed spectroscopically. We here present details and spectroscopy for a redshift 4 counterpart.

2. SMM J16359+66130 − redshift 4

Deep SCUBA maps at both 850μm and 450μm have been obtained of the cluster field Abell 2218 (Knudsen et al., 2006). Nine sources were detected, four of these having 850-fluxes around 10 mJy; an optical image with the SCUBA contours is shown in Fig. 1. Three of these bright sources were identified as a multiply imaged background galaxy at $z = 2.516$ (SMMJ16359+6612; Kneib et al., 2004a). It is for the fourth of the bright sources, SMMJ16359+66130, that we here propose the identification (Knudsen, Kneib & Egami, 2006, in preparation).

SMMJ16359+66130 is detected both at 850μm and 450μm with fluxes of 11 mJy and 20 mJy, respectively. The lensing magnification of the source is about 4.5. The low flux ratio $f_{450}/f_{850} \sim 2$ is strongly suggestive of this SMG being at redshift $z > 3.5$. It is not detected in the radio maps at 1.4 GHz and 8.2 GHz from Garrett et al. (2005), which supports that this is a high redshift source, $z > 2.5$.

In the optical and near-infrared images there is only one galaxy within a search radius of $8''$ from the submm position, which is at very high redshift. It is indicated in the optical HST ACS F850LP $z'-$image (Kneib et al., 2004b) in Fig. 2. The position is RA,Dec(J2000) = 16:35:55.66,+66:12:59.5 and it has a magnitude of $z'_{850lp} = 23.90 \pm 0.04$ mag and of $R_{702w} = 25.4 \pm 0.12$ mag, though is undetected in the deep WFPC2 F606W and F450W images from Smail et al.
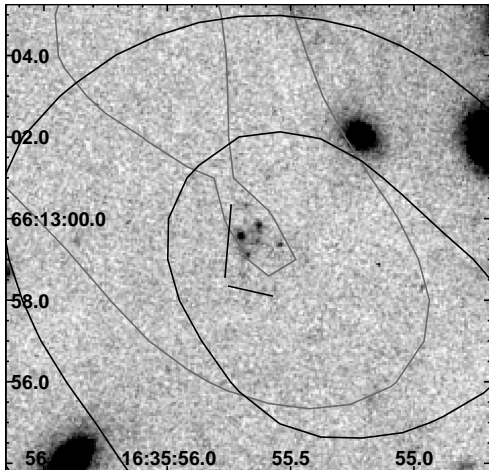
Figure 2. ACS F850LP sub-image of the $z \approx 4$ source, SMM J16359+66130, with SCUBA contours overlayed (black show 850μm and grey 450μm). The two solid lines indicate the extent of the galaxy, which corrected for lensing corresponds to a physical scale of 6.2kpc×2.8kpc. The largest knot has a scale corresponding to $\sim$0.5 kpc.
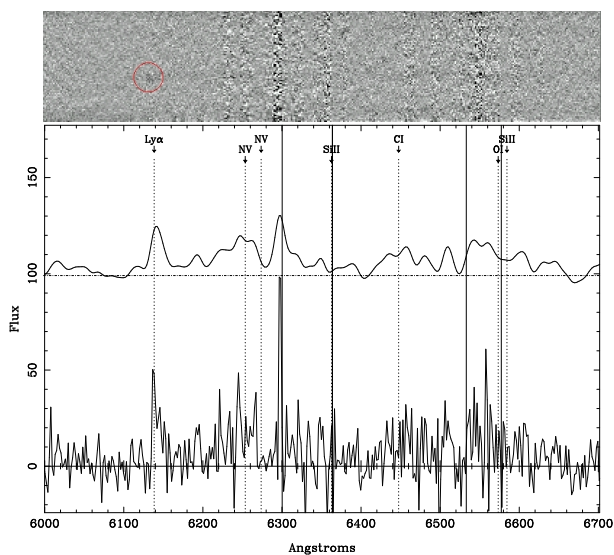

Figure 3. Optical spectrum of SMMJ16359+66130. (Top) The 2D sky subtracted spectrum that shows a faint emission line. (Bottom) The 1D sky subtracted spectrum, for which a smoothed version is displayed at the top of the figure. Solid vertical lines indicate the location of bright sky lines. We identify the bright asymmetric emission line with Lyα ; this implies a redshift $z = 4.048$.

(2001). We have obtained optical spectroscopy for this source using LRIS on Keck. In the spectrum, which is shown in Fig. 3, we identify one emission line. The line appears to be asymmetric and with a lower continuum level on the blue side. We propose that this is Lyα, which implies a redshift of $z = 4.048 \pm 0.003$.

SMMJ16359+66130 is detected at both in the optical and at near-infrared wavelengths, including the *Spitzer* IRAC images of A2218 (Egami et al., 2005), where the fluxes are $f_{3.6} = 5.6 \pm 0.7 \,\mu$Jy and $f_{4.5} = 4.5 \pm 0.5 \,\mu$Jy. In Fig. 4, we show the spectral energy distribution. The star formation rate is about $600 \, M_\odot \text{yr}^{-1}$ as estimated from the SCUBA detection. There is no indication of the presence of a strong AGN.
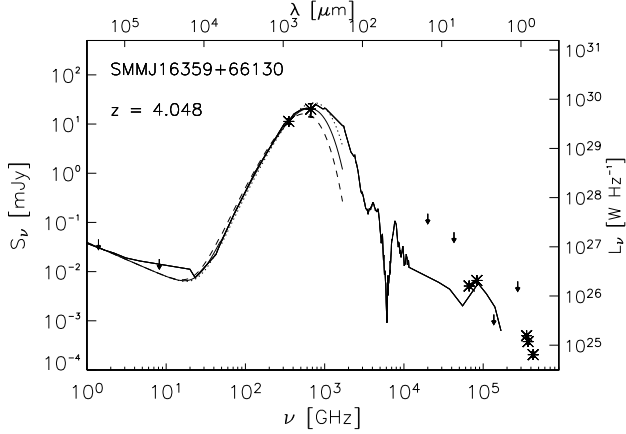
Figure 4. Spectral energy distribution ranging from radio to optical with measurements and 3σ upper limits from VLA, WSRT, JCMT (SCUBA), ISO, Spitzer (IRAC), WHT/Gemini and HST. The fluxes have not been corrected for lensing magnification. The SED is overplotted with the Arp220 SED and with modified blackbody SEDs (with T=30,35,40K).

3.   Extending the redshift distribution

Even though the unlensed submm flux is slightly fainter compared to the sample of Chapman et al. (2003, 2005), the properties of SMMJ16359+66130 are similar to those of the radio-selected identifications of the Chapman et al. sample. There are no signs of a strong, dominant AGN, and so likely the dominant heating mechanism is star formation. Additionally, Lyα is seen in emission. Hence SMMJ16359+66130 is likely similar to many sources in the Chapman et al. sample.

The high redshift of SMMJ16359+66130 extends the redshift distribution of SMGs as established by Chapman et al. (2003, 2005). While the highest redshift identification in the sample of Chapman et al. is 3.6, they present models for the redshift distribution indicating that less than 10% of the SMGs would lie beyond that. For the current SMG samples of a total of a few hundred sources, one would expect a few tens of SMGs with $z > 4$.

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