Galaxy counts at 450 $\mu$m and 850 $\mu$m

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**Abstract.** Surveys of the distant Universe have been made using the SCUBA submillimeter(submm)-wave camera at the JCMT. 450- and 850-$\mu$m data is taken simultaneously by SCUBA in the same 5-arcmin$^2$ field. Deep 850-$\mu$m counts of high-redshift dusty galaxies have been published; however, at 450 $\mu$m both the atmospheric transmission and antenna efficiency are lower, and the atmospheric noise is higher, and so only upper limits to the 450-$\mu$m counts have been reported so far. Here we apply the methods used by Blain et al. (1999) to derive deep 850-$\mu$m counts from SCUBA images of lensing clusters to the 450-$\mu$m images that were obtained in parallel, in which four sources were detected. We present the first 450-$\mu$m galaxy count. This analysis has only just become possible because the volume of data and the difficulty of calibration are both greater for the 450-$\mu$m array. In light of recent work, in which the identification of two of the galaxies in our sample was clarified, we also update our deep 850-$\mu$m counts.

1. Introduction

Submm-wave surveys are sensitive to high-redshift dusty galaxies. By exploiting the gravitational lensing effect of rich foreground clusters, the efficiency of these surveys is enhanced as compared with those made in blank fields (Blain 1998). In addition, follow-up observations are significantly easier in the lensed fields as compared with true blank fields because of the typical magnification, a factor of 2.5, of the detected sources at all wavelengths (Ivison et al. 1998, 1999; Frayer et al. 1998, 1999; Smail et al. 1998, 1999a,b).
Surveys using the 850/450-\(\mu\)m SCUBA (Holland et al. 1999) have provided deep 850-\(\mu\)m galaxy counts and upper limits to the 450-\(\mu\)m counts (Smail, Ivison & Blain 1997; Barger et al. 1998,1999a; Hughes et al. 1998; Blain et al. 1999; Eales et al. 1999). Here we use the detections of four high-redshift dusty galaxies in the 450-\(\mu\)m SCUBA lens survey data (Smail et al. 1998) to yield the first galaxy count at a wavelength of 450 \(\mu\)m.

The relative number counts at different wavelengths depend on the distribution of both the redshifts and dust temperatures of the submm galaxy population. It is possible to impose more rigorous constraints on the form of evolution of high-redshift dusty galaxies if accurate galaxy counts are available at several submm wavelengths.

2. Obtaining counts at 450 \(\mu\)m

Recently we published counts of galaxies detected at a wavelength of 850 \(\mu\)m through the cores of seven massive cluster lenses (Smail et al. 1998) to a depth of 0.5 mJy (Blain et al. 1999). We used accurate mass models of the foreground lenses, which are constrained using the properties of lensed arcs detected in deep optical images and the spectroscopic redshifts of multiply-imaged background galaxies (for example Kneib et al. 1993; Bézecourt et al. 1999), to reconstruct the background sky. The robustness of the method was verified by extensive Monte-Carlo simulations. Here we apply the same method to the 450-\(\mu\)m SCUBA maps of the seven lensing clusters observed in the survey; Cl0024+16, A370, MS0440+02, Cl0939+47/A851, A1835, A2390 and Cl2244-02. The data was taken in a range of (generally exceptional) atmospheric conditions, and so the thresholds for the detection of a 450-\(\mu\)m source vary from cluster to cluster. The 3\(\sigma\) flux density limits for detection are about 60, 30, 60, 20, 20, 60 and 60 mJy in each cluster respectively. Four sources were detected: one behind A370 (SMM J02399−0136, the brightest source in the sample, with a 450-\(\mu\)m flux density of 85 \(\pm\) 15 mJy); two behind A1835 (SMM J14009+0252 and SMM J14011+0252; Ivison et al. 1999); and one behind Cl0939+47/A851 (an extremely red object or ERO – SMM J09429+4658; Smail et al. 1999a). The 450-\(\mu\)m counts that result from the analysis, which is described in detail in Blain et al. (1999), are listed in Table 1 and Fig. 1. The 450-\(\mu\)m count at about 10 mJy is equivalent to the 850-\(\mu\)m surface density at 3 mJy.

3. Updating the 850-\(\mu\)m counts

In our earlier analysis of the 17 sources detected in the SCUBA lens survey to yield 850-\(\mu\)m counts, we first removed 2 submm sources identified with cluster cD galaxies from the sample (Edge et al. 1999). We also removed one other submm galaxy from the sample, which was identified with a spiral galaxy in the foreground of the cluster Cl0939+47/A851, and identified one further submm galaxy with a spiral galaxy falling into MS0440+02. We now know that these two SCUBA detections are more likely to be identified with EROs discovered in our deep near-infrared follow-up images (Smail et al. 1999a) than with the low-redshift spiral galaxies. Here we repeat the earlier analysis of the counts (Blain et al. 1999), but now include these two galaxies as lensed high-redshift background
Table 1. New 450-µm and updated 850-µm integral counts of galaxies. Our previous direct 850-µm counts are listed for comparison. Our Monte-Carlo method (Blain et al. 1999) yields a 450-µm count of the form \( N(> S) = K(S/S_0)^\alpha \) as a function of flux density \( S \), with \( K = 530 \pm 300 \text{ deg}^{-2} \), \( \alpha = -1.8 \pm 0.5 \) and \( S_0 = 20 \text{ mJy} \).

| Wavelength (µm) | Flux density (mJy) | Count \( (10^3 \text{ deg}^{-2}) \) | Previous count \( (10^3 \text{ deg}^{-2}) \) |
|-----------------|--------------------|---------------------------------|---------------------------------|
| 450             | 10.0               | 2.1 ± 1.2                       | ...                             |
|                 | 25.0               | 0.5 ± 0.5                       | ...                             |
| 850             | 0.25               | 51 ± 19                         | ...                             |
|                 | 0.5                | 27 ± 9                          | 22 ± 9                          |
|                 | 1.0                | 9.5 ± 3.3                       | 7.9 ± 3.0                       |
|                 | 2.0                | 2.9 ± 1.0                       | 2.6 ± 1.0                       |
|                 | 4.0                | 1.6 ± 0.7                       | 1.5 ± 0.7                       |
|                 | 8.0                | 0.92 ± 0.53                     | 0.8 ± 0.6                       |
|                 | 16.0               | 0.34 ± 0.34                     | ...                             |

sources. The updated 850-µm counts that result are shown in Table 1 and Fig. 1. The new results are within the 1σ errors of our previous analysis of the 850-µm counts, and are modified at only the 10% level if the redshift distribution of the source population is assumed to be given by the results of either Barger et al. (1999b) or Smail et al. (1999b).

We emphasize that three of the 850-µm galaxies used in this analysis have flux densities less than 3 mJy, after correcting for lensing magnification. Further, two of these sources have flux densities less than the blank-field confusion limit for identification (about 2 mJy), and one has a sub-mJy flux density. The lower limits to the background radiation intensity \( (\nu I_\nu) \) obtained from the flux densities of the detected galaxies are \((5.0 \pm 1.5) \times 10^{-10}\) and \((1.1 \pm 0.6) \times 10^{-9} \text{ W m}^{-2} \text{ sr}^{-1} \) at 850 and 450 µm respectively, 94% and 34% of the COBE-FIRAS values (Fixsen et al. 1998).

4. Conclusions

We present the first count of galaxies at the short submm wavelength of 450 µm, and update our deep 850-µm counts in the light of improved optical identifications (Smail et al. 1999a). The relative counts of galaxies at 450 and 850 µm are consistent with both the spectral energy distributions and the forms of evolution of distant dusty galaxies that were derived and discussed in our modeling papers.

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Figure 1. Left: the 450-µm counts of galaxies. The direct and Monte-Carlo counts derived here are shown by the solid points and dotted lines respectively. Right: the 850-µm counts of galaxies including the updated SCUBA lens survey counts. To avoid complicating the figure the direct counts obtained by Blain et al. (1999; see Table 1) are not shown. The associated Monte-Carlo results are shown by the dotted lines. Ba98/Ba99 – Barger et al. (1998, 1999a); E99 – Eales et al. (1999); Hu98 – Hughes et al. (1998); S97 – Smail et al. (1997).

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