THE BRIGHTER SIDE OF SUB-MM SOURCE COUNTS: A SCUBA SCAN-MAP OF THE HUBBLE DEEP FIELD

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We present an 11 × 11 arcminute map centred on the Hubble Deep Field taken at 850 µm with the SCUBA camera on the JCMT. The map has an average one-sigma sensitivity to point sources of about 2.3 mJy and thus probes the brighter end of the sub-mm source counts. We find 7 sources with a flux greater than 9 mJy (∼4σ), and therefore estimate \( N(>9\text{ mJy}) = 208^{+90}_{-72} \text{ per degree}^{-2} \). This result is consistent with work from other groups, but improves the statistics at the bright end, and is suggestive of a steepening of the counts.

1 Introduction

Observations using the Submillimetre Common User Bolometer Array (SCUBA) have been revolutionizing our understanding of the importance of dust in galaxies at high redshift. Already several very deep integrations have been carried out on single SCUBA fields down to the confusion limit. In order to learn more about source counts (and hence to constrain models), the next step is to search for brighter objects over somewhat larger fields.

The population of bright sub-mm sources is currently not well understood. Current models for source counts in the sub-mm have been able to account for the observed sources by invoking evolution which follows the \((1+z)^3\) form required to account for IRAS galaxies at 60 µm, and the powerful radio-galaxies and quasars. Euclidean models with no evolution have a slope of roughly \(-1.5\) (\(N_s \propto S_{\nu}^{-3/2}\)), which cannot possibly account for the sources observed. With reasonable evolution (in IRAS-motivated models), the counts steepen sharply at the 10’s of mJy sensitivity level to roughly \(S_{\nu}^{-2.6}\). At the source detection level of previous work, typically 5 mJy, there is little variation between the models, and we are well into the steep counts regime.

However, at the 10–30 mJy sensitivity level various evolutionary models show more parameter dependence. Given a possibly wide range of galaxy types contributing to the source counts at the bright end, the actual counts
may deviate from a simple parametric model dramatically. Furthermore, cosmological, as well as evolutionary parameters, play a role here.

2 Data collection and analysis

The standard scan-map observing strategy is to use multiple chop throws in two fixed directions on the sky so that an Emerson deconvolution technique can be applied. This may be appropriate for galactic plane mapping, where structure appears on all scales, but we seek a simpler approach which is optimized for finding point sources. The disadvantage of the standard approach is that the off-beam pattern gets diluted (making it more challenging to isolate faint sources), and the map noise properties are more difficult to understand. Our approach was to use a single chop direction and throw fixed on the sky. The result is a map that has, for each source, a positive and negative signal.

A total of 61 scans were obtained, 31 in early 1998 and 30 more a year later. The data were first analysed using SURF, but because the data were taken in a non-standard mode, we found it necessary to write custom software. In this way, we were able to isolate and remove large scale features in the maps, and estimate the per pixel noise level by a careful accounting of the per-bolo noise and the frequency at which it sampled a particular pixel.

Sources were found by using a model for the dual beam pattern and fitting it, in a least-squares sense, to each pixel in the map. A total of 7 sources were found that had a peak to error-of-fit ratio greater than 4. We also rotated the dual beam pattern by ninety degrees and used that as a model; Only 2 sources were found, one of which is associated with the brightest source in the map. Monte-carlo simulations suggest that the other false positive is not unexpected. As an additional check, the 1998 data were compared with the 1999 data to ensure that each source was evident in both halves of the data.

The calibration was determined by fitting the beam model to observations of standard calibrators taken during the run. We checked our procedure by re-analysing the Barger et al. HDF/radio fields, which are a set of jiggle maps within the HDF flanking fields. In fact this led to a correction in our original flux estimates. Figure 1 presents our final map, and an updated source count plot is given in Figure 2.

3 Conclusions and followup work

We have significantly improved statistics at the $\sim 10 \, \text{mJy}$ level, and suggest there is some indication of a steepening of the counts there. Because these sources are brighter than typical SCUBA detections, they will be relatively
Figure 1. The 850 µm HDF map. The map size is roughly 12 × 12 arcminutes, although only the central 11 × 11 was used in order to avoid the noisy edges. The chop is 40 arcseconds and is roughly east-west. The circles outline the 7 sources detected in our survey and the dark crosses highlight sources found in the Barger et al. (2000) and Hughes et al. (1998) work. Since these surveys went deeper, not all can be detected in the scan map. They also cover a smaller area, and hence cannot see several of our sources.

easy to follow up at other wavelengths. Preliminary analysis already indicates good correlation with µJy radio sources, but little indication of optical counterparts (as found in other studies).

Although not discussed here, we are also investigating sources in the 450 µm scanmap. However, this is more arduous given the lower sensitivity of SCUBA with this filter. Finally, a similar analysis is being conducted on data taken of 50 square arminutes of the Groth strip/Westphal region.

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Figure 2. The 850 µm source counts. The crosses are data from Blain et al. (1999) and the open circles that from a recent cluster survey by Chapman et al. (2000) The dashed line is a simple two power-law fit to the previous counts. Our new estimate, with Bayesian 68% confidence limits, is given by the solid circle.

References

1. Holland, W.S., et al., MNRAS 303, 659 (1999)
2. Blain, A.W., MNRAS 295, 92 (1998)
3. Eales S., Edmunds M.G., MNRAS 280, 1167 (1996)
4. Blain A.W., Longair M.S., MNRAS 279, 847 (1996)
5. Fall S.M., Charlot S., Pei Y.C., ApJ 464, L43 (1996)
6. Dunlop J.S., Peacock J.A., MNRAS 247, 19 (1990)
7. Guiderdoni B., et al., MNRAS 295, 877 (1998)
8. Barger, A. J.; Cowie, L. L.; Richards, E. A., AJ 119, 2092 (2000)
9. Hughes D.H., et al., Nature 394, 241 (1998)
10. Blain A.W., et al., ASP conference proceedings 193, 246 (1999)
11. Chapman, S.C., et al., MNRAS submitted, astro-ph/0009067 (2000).