Known and Unknown SCUBA Sources

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Summary and discussion of some projects to use SCUBA to target sources selected
at other wavebands, as well as to find new sub-mm galaxies in ‘blank fields’.

1 Introduction

The sub-mm waveband has opened up for cosmology, and through this window
we can hope to glimpse some answers to a number of related puzzles: What
are the brightest sub-mm galaxies? What sorts of galaxies make up the Far-IR
Background (FIB)? When did the Universe form the bulk of its stars? How
important is dust obscuration for obtaining a full star-formation census?

SCUBA\(^1\) has been instrumental in establishing this new field of sub-mm
high redshift astronomy. This meeting has been dominated by SCUBA-based
surveys, and stands as a testament to the instrument builders who produced
the best camera of its kind at just the right time.

Many basic questions have already been answered by the SCUBA data
which are in hand, and a coherent picture has developed – typical SCUBA
sources are the \(z \sim 2–3\) counterparts of locally well-studied Ultraluminous In-
frared Galaxies, and these are considerably more common at an epoch which
was perhaps important for the formation of elliptical galaxies. However, there
are still a great many details to understand about the exact composition of the
SCUBA-bright sources, including how they overlap with populations selected
at other wavelengths, how the \(\sim \) mJy sources might differ from the brighter
ones, what the clustering strength of the SCUBA sources might be, and what
fraction could be at still higher redshifts. Here we will avoid reviewing all of
the different studies (many of which are covered in other presentations), but

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Figure 1. Estimates for the cosmic background in the IR and neighbouring wavebands. This is a blown-up and up-dated plot of Figure 26.2 in Astrophysical Quantities. Lower limits generally come from the integrated brightness of resolved sources. Limits which are more model-dependent are indicated by dotted lines. The FIB has been slowly emerging from careful analyses of (largely) COBE data. It appears to contain more energy than the optical background (usually assumed to be the sum of the deepest HST counts). It also appears to be broader than the blackbody CMB peak, possibly indicating that it comes from a range of redshifts. References for the points are given in the text.

will concentrate on projects carried out by our own group.

We have been undertaking a set of related studies, focussing on either blank fields to detect sub-mm sources, or on characterizing the sub-mm properties of objects selected at other wavelengths.
2 Known sources

2.1 FIRBACK

A summary of current information on extragalactic background radiation is presented in Fig. 1. In the far-IR region, the important detections are derived from DIRBE data at 240 µm, 140 µm, 100 µm and 60 µm and FIRAS data at longer wavelengths. Detections in the near-IR have also been derived from DIRBE data and indirectly from γ-rays. Optical lower limits (which in some cases have probably converged to near the background values) come from galaxy counts. Lower limits throughout the IR come from source counts obtained by ISO, SCUBA and IRAS – some of these values are also model-dependent.

Now that a cosmic FIB is emerging from the data, and that it makes a substantial contribution to the energy budget, the obvious question is: what are the galaxies which make up the FIB? This is the main motivation behind the FIRBACK project, which made deep 170 µm images of the sky with ISO, to break up the background into the sources which comprise it. Data from the ISOPHOT instrument is the only currently available information for studying the composition of the FIB which comes directly from wavelengths where the background peaks. We have been studying the SCUBA properties of some of these already known FIRBACK-selected sources. Because of the large ISOPHOT beam, this is only really feasible for sources with reliable radio identifications. Photometry with SCUBA allows you to go deeper than mapping in the same integration time. We have also successfully been using ‘3-bolometer chopping’, by choosing the chop position to be approximately coincident with two bolometers in the inner ring of the array, so that those negative signals can be added in, to improve the signal-to-noise.

The combination of ISOPHOT + VLA + SCUBA selects galaxies covering a range of redshifts but peaking at $z \sim 1$ (supported by the handful of objects for which redshifts have already been obtained). The study of FIRBACK galaxies at $z \sim 1$ thus bridges the gap between the well-studied $z \sim 0$ ULIRGs and the $z \sim 2–3$ SCUBA sources. At these somewhat more modest redshifts the SEDs can be realistically constructed over a wide range of wavelengths.

The total number of sources detected in the ELAIS ‘N1’ field is $\sim 120$ with $S_{170} > 120$ mJy. They comprise about 10% of the cosmic Far-IR Background at this wavelength, and an entirely unknown fraction of the longer wavelength sub-mm background. Note that SCUBA ‘blank fields’ only tell you about the background at 850 µm, where $\nu I_\nu \sim 30$ times lower than its
Figure 2. Measured 170 µm vs 850 µm flux densities for our first sample of FIRBACK sources. The two dashed lines are $T_d = 50$ K, $\beta = 1.5$ modified blackbodies at $z = 0$ and $z = 1$. This shows that just the combination of 850 µm and 170 µm can give crude redshift information about these galaxies (three seem to lie at higher $z$ than the others) – more detailed SED fitting of the full radio/submm/far-IR/mid-IR/near-IR/optical data will reveal much more of course.

peak value (see Fig. 1). Our first set of results from a sample of 10 objects in the N1 field was presented in Scott et al. (2000). There we firmly detected 4 sources at 850 µm. Statistically the sample was detected at 7.5σ at 850 µm and 4σ even at 450 µm. Crude photometric redshifts can be obtained simply by comparing the 170 µm and 850 µm fluxes, as is shown in Fig. 2.

Joint fits to $L_{FIR}$ and $z$ show that 3 of the galaxies are consistent with luminosities typical of Arp 220, but at $z \sim 1$. The others seem more likely to be at redshifts intermediate between 0 and 1, and intrinsically fainter (but still representing a population that hardly exists locally). Multi-wavelength studies are underway (Lagache et al. in preparation), and the SCUBA work should continue, with a sample covering a wider range of ISO fluxes and properties at other wavelengths.
2.2 The Blob

Extensive spectroscopic surveys have shown strong clustering among the star-forming Lyman Break Galaxy population at \( z \approx 3 \) (which is discussed by Chapman et al. in these proceedings). A high contrast overdensity of LBGs at \( z = 3.09 \) in the SSA22 region was discovered by using deep narrow-band Ly \( \alpha \) imaging to identify at least 160 members of the structure. This region appears to be about 6 times more overdense in LBGs than the general field, and the region centred on the most extended Ly \( \alpha \) emission is overdense by roughly a further factor of 2. This is where we centred our SCUBA map. The brightest source in that map (Fig. 3) is \( \approx 20 \) mJy, and centred precisely on the extended Ly \( \alpha \) region referred to as ‘Blob 1’ in Steidel et al. (2000).

Figure 3. SCUBA 850 \( \mu \)m map centred on ‘Blob 1’ of the Ly \( \alpha \) survey of Steidel et al. (2000). Crosses mark the positions of known \( z \approx 3 \) galaxies. Black is positive emission here, and the contours are at 3, 4, 5, 6 and 7\( \sigma \).
Such sub-mm emission is unexpected, since dust usually implies no Ly $\alpha$. The simplest explanation is an obscured AGN, which provides the excitation for the extended Ly $\alpha$, and whose nucleus is responsible for the sub-mm emission. It is also possible that some of the signal could be from the Sunyaev-Zel’dovich increment in a very overdense group, say, forming at $z \sim 3$, but conditions would have to be rather extreme for this to be the case. Nevertheless it is worth following up in detail at other wavelengths to check. This surprising result suggests that the combination of SCUBA and narrow-band Ly $\alpha$ studies could prove to be a fruitful one.

There are some additional sources in our SCUBA map, indicating an overdensity in sub-mm sources, matching that in the LBG population. It would be interesting to map this region more extensively to determine if it is a region of enhanced clustering of SCUBA sources.

3 Unknown sources

We have made reasonably large maps of the Hubble Deep Field Flanking Fields and part of the Groth Strip (see the contribution by Borys et al.) in order to find the brightest SCUBA sources in those well-studied regions. In addition we have a large amount of ‘blank sky’ data from the off-centre bolometers obtained during photometry observations of known sources. Although too under-sampled to be much use for mapping, these data can nevertheless be studied statistically.

3.1 Cluster survey

We have also looked at several rich cluster fields. Here the lensing amplification boosts the number counts (as pioneered by Blain, Ivison, Smail and collaborators). We have collected data on 9 separate clusters: Cl0016+16, MS0451-03, Abell 520, Zwicky 3146, MS1054-03, MS1455+22, Abell 2163, Abell 2219 and Abell 2261. The clusters were mapped to a variety of depths under different observing conditions. But the resulting maps typically contain a couple of convincing sources. Details are presented in Chapman et al. (2000).

Instead of running through each cluster field in detail, let us focus on only one, Abell 520. Fig. 4 shows our map (upper left), together with an almost overlapping map taken from the SCUBA archive. Each map appears to show 2 detections. There are no obvious near-IR or radio identifications for these sources, but the follow-up data are, as yet, not very deep. One of the sources we discovered (SMMJ04543+0257) appears to be $\sim 30\,\text{mJy}$, placing it among...
the brightest ‘blank sky’ sources.

4 Conclusions

Further clues to the nature of sub-mm sources and how they overlap with optical-, IR- and radio-selected galaxies will be found through the joint approach of investigating the sub-mm properties of already known objects, and finding identifications for possibly unknown objects which are bright in the sub-mm. Studies of the clustering of SCUBA sources are just in their infancy, but should provide further cosmological information. The crucial thing is to identify the SCUBA sources at other wavelengths – this has proved to be difficult in practice, and the sources for which is most difficult are potentially the most interesting!
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