We summarize the main results from our SCUBA survey of Lyman-break galaxies (LBGs) at $z \sim 3$. Analysis of our sample of LBGs reveals a mean flux of $S_{850} = 0.6 \pm 0.2$ mJy, while simple models of emission based on the UV properties predict a mean flux about twice as large. Known populations of LBGs are expected to contribute flux to the weak sub-mm source portion of the far-IR background, but are not likely to comprise the bright source ($S_{850} > 5$ mJy) end of the SCUBA-detected source count. The detection of the LBG, Westphal-MM8, at 1.9 mJy suggests that deeper observations of individual LBGs in our sample could uncover detections at similar levels, consistent with our UV-based predictions. By the same token, many sub-mm selected sources with $S_{850} < 2$ mJy could be LBGs. The data are also consistent with the FarIR/$\beta$ relation holding at $z = 3$.

1 Introduction – Selecting sub-mm luminous LBGs

The Sub-millimeter Common User Bolometer Array (SCUBA) on the 15-m JCMT has sparked a revolution in our understanding of dust obscured star formation and active galactic nuclei. However, going back several years to the initial discovery of sub-mm sources in the field, we were rather naive about the nature of sub-mm selected sources. It seemed at the time perfectly reasonable that the high star formation rate tail of the known $z \sim 3$ LBG population should allow us to quickly pre-select and observe some large fraction of the bright SCUBA sources.

The $R$-band for $z \sim 3$ galaxies (rest frame UV continuum) provides a direct measure of the light from young, hot stars. The spectral slope through the rest frame UV continuum allows a determination of the extinction of this light due to interstellar dust, and thereby prescribes a dust correction to the star formation rate (SFR). Thus the goal of our project was to choose those

\footnote{The JCMT is operated by the Joint Astronomy Centre on behalf of the United Kingdom Particle Physics and Astronomy Research Council (PPARC), the Netherlands Organisation for Scientific Research, and the National Research Council of Canada.}
few LBGs exhibiting a combination of a bright $R$-magnitude and a steep $g - R$ slope (large dust correction) resulting in a sample of galaxies thought to have high SFRs ($>200 \ M_\odot/yr$) and thus be detectable in the sub-mm with SCUBA. It is important to note that these objects were not just a few outliers with extremely large dust correction factors, but were also amongst the most intrinsically luminous of the LBG population.

1.1 An initial sample of high SFR LBGs

The results of our initial study have been presented in Chapman et al. (2000)\textsuperscript{3}, with further implications explored in Adelberger & Steidel (2000)\textsuperscript{4}. From an original sample of 16 LBGs chosen for followup with SCUBA, only 8 turned out to have the sought properties (high expected SFR) upon more detailed optical analysis. Predicting the 850 micron flux density ($S_{850}$) for LBGs from the UV continuum was accomplished by first employing the empirical farIR/$\beta$ relation for local starburst galaxies\textsuperscript{5} to estimate the total farIR luminosity from the UV slope ($\beta$). We then identified the $S_{850}$ point through an empirical measure of the typical spectral energy distribution (SED) for star forming galaxies in the farIR/sub-mm region, extracted from a large sample of local LIRGs and ULIRGs\textsuperscript{3,2}. A clear uncertainty in this prescription is the paucity of high-$z$ star forming objects with sub-mm measurements available to validate our prediction recipe.

SCUBA observations during observing runs in winter 1998 yielded only one clear detection in our sample, Westphal-MMD11. This object in particular was found to be rather extraordinary in many of its properties, and will be discussed in the following section. The UV-based predictions of sub-mm flux density were typically too high for the sample on the whole, except for Westphal-MMD11 which has considerably more sub-mm flux than expected. However, large errors bars and a relatively small sample of objects made it difficult to extract robust conclusions from the study. The results of this study are summarized in Figure 1. However, new evidence as presented below suggests that this original study may have been a somewhat misleading result.

2 Sub-mm detected LBGs at $z \sim 3$

2.1 Westphal-MMD11

Westphal-MMD11 currently represents the highest redshift source ($z = 2.98$) detected with SCUBA, which is not an AGN. Upon subsequent optical study, Westphal-MMD11 seems more akin to HR10\textsuperscript{6}, the dusty starbursting ERO, than what one might consider a local analog of LBGs such as M82. It is
luminous in the near-IR with $R - K = 4.5$, almost 2 magnitudes larger in $R - K$ than the median for the LBG population. With $S_{850} = 5.5$ mJy and $L_{FIR}$ close to $10^{13} h_{50}^2 L_\odot$, the question perhaps is why is it visible in the UV at all? A recent near-IR spectrum taken with NIRSPEC on the Keck telescope reveals a double peaked line profile, with continuum emission only present under one peak. This suggests geometrical effects involving large amounts of dust are likely at work, perhaps similar to the merging ULIRG, Arp220.
2.2 SMMJ14011

The lensed galaxy SMM J14011+0252 is the only sub-mm selected object clearly identified as a high redshift \((z = 2.565)\) galaxy without an obviously active nucleus. Followup optical photometry in a filter set matched to the Steidel et al. (1999) LBG survey revealed that the restframe-UV SED of SMMJ14011 is actually indistinguishable from Westphal-MMD11, yet their optical SEDs are quite different. Within the SMM J14011+0252 system, interferometry observations reveal that the dominant sub-mm emission resides in a red component \((J1)\), with the dominant UV emission appearing in a neighboring component \((J2)\). At face value, this questions the validity of the unobscured star formation rate prediction based on the UV. The UV properties of a spatially separated component should have little bearing on the dust and star formation in \(J1\). On the other hand the empirical correlation between \(\beta\) and \(L_{bol,dust}/L_{UV}\) is rather mysterious – it is difficult to understand why this correlation should exist at all. But local observations suggest that it does hold, and the scatter in the relation may relate a variety of processes involved in starbursting galaxies at various evolutionary stages.

2.3 Westphal-MM8

Identified as a LBG in the surveys of Steidel et al. (1999), Westphal-MM8 possesses a rest-frame UV spectrum which indicates an exceptionally large SFR \((> 100 \, M_\odot/yr)\). However, the infrared colors and overall properties do not single this object out as unusual for the population in any other respects. Although still a relatively extreme object, Westphal-MM8 represents one of the faintest galaxies ever detected with SCUBA \((S_{850} = 1.9 \pm 0.5 \, mJy)\), comparable to the faintest objects in the Hubble Deep Field SCUBA observation of Hughes et al. (1998). Simply scaling the observed submillimetre photometry from that of Arp220 implies that MM8 has an infrared luminosity of \(L_{IR} \sim 4 \times 10^{12} \, h_{50}^{-2}L_\odot\). Although original results were somewhat pessimistic about the sub-mm detection of LBGs, this measurement of MM8 gives us renewed confidence that we may be able to pre-select those extreme LBGs emitting in the \(S_{850}=1-2\, mJy\) range.

3 A larger sample of high-SFR LBGs

The case of Westphal-MM8 reveals the inherent difficulty in detecting even the most sub-mm luminous members of the LBG population with SCUBA. Clearly spending two JCMT shifts per object is not an option for studying the properties of a large sample of LBGs.

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A new and larger sample consisting of 33 LBGs has now been observed to an average RMS $\sim 1.3$ mJy with SCUBA. The sample breaks down as follows: 8 high SFR LBGs from our original sample, 12 red LBGs ($R-K > 3.5$) which could be 'like' W-MMD11, and 13 new LBGs similar to the original sample of large predicted SFR. Some of these objects are selected from fields with better photometry than the original surveys, and photometric errors could conceivably be less of an uncertainty. Still, only 2 clear detections emerge (W-MMD11 and W-MM8), although certain sub-samples exhibit clear detections in their average flux density.

We summarize the average properties of this new sample as follows:

$$S_{850} = 0.6\pm0.2 \text{ mJy}$$
$$S_{450} = 2.9\pm2.2 \text{ mJy}$$

Our results clearly indicate that LBGs do not form a significant part of the bright sub-mm selected sources ($S_{850} > 5$ mJy). These numbers include MMD11, as the numbers are small enough that we do not yet know if MMD11 is highly unusual, or merely the tail end of the red LBG population. Several other red LBGs are marginally detected with $S_{850} \sim 3$ mJy. The $S_{850}$ predicted from the UV for this sample is approximately 1.2 mJy and is thus not drastically in conflict with the measured flux, but may indicate a downwards correction of a factor $\sim 2 \times$ in $L_{dust, bol}$ for the most luminous LBGs. This result indicates that the FarIR/$\beta$ relation appears at least consistent at $z = 3$ with what we observe locally.

### 3.1 Far-IR background

For an $\Omega = 0.3$, $\Lambda = 0.7$ universe, the average dust luminosity of our SCUBA observed LBG sample is $L_{bol}(dust) = 2.4\pm0.8 \times 10^{11} L_\odot$. The average $R(AB) = 29.9$ implies $L_{UV} = 4.6 \times 10^{10} L_\odot$. The average obscuration for the sample, $< L_{dust}/L_{UV} > = 4.8 \pm 1.6$. UV-based predictions require $< L_{dust}/L_{UV} > = 6$ to recover the bulk of the 850 micron background, dominated by $0.5-2$ mJy sources.

Although sub-mm sources $> 5$ mJy appear largely distinct from the LBG population, they form a relatively small amount of FarIR Background. However, deep sub-mm observations in the HDF suggest that $S_{850} \sim 2$ mJy sources are observed which have no obvious optical counterparts and would not form part of typical ground based optical surveys. Thus it remains to be seen just what properties the bulk of these crucial $S_{850} \sim 1-2$ mJy sources actually have.
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