Millimetric properties of gamma-ray burst host galaxies

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ABSTRACT
We present millimetre (mm) and submillimetre (submm) photometry of a sample of five host galaxies of gamma-ray bursts (GRBs), obtained using the Max Planck Millimetre Bolometer (MAMBO2) array and Submillimetre Common-User Bolometer Array (SCUBA). These observations were obtained as part of an ongoing project to investigate the status of GRBs as indicators of star formation. Our targets include two of the most unusual GRB host galaxies, selected as likely candidate submm galaxies: the extremely red \( (R - K \approx 5) \) host of GRB 030115, and the extremely faint \( (R > 29.5) \) host of GRB 020124. Neither of these galaxies is detected, but the deep upper limits for GRB 030115 impose constraints on its spectral energy distribution, requiring a warmer dust temperature than is commonly adopted for submillimetre galaxies (SMGs).

As a framework for interpreting these data, and for predicting the results of forthcoming submm surveys of Swift-derived host samples, we model the expected flux and redshift distributions based on luminosity functions of both submm galaxies and GRBs, assuming a direct proportionality between the GRB rate density and the global star formation rate density. We derive the effects of possible sources of uncertainty in these assumptions, including (1) introducing an anticorrelation between GRB rate and the global average metallicity, and (2) varying the dust temperature.

Key words: dust, extinction – galaxies: evolution – cosmology: observations – gamma-rays: bursts – infrared: galaxies – submillimetre.

1 INTRODUCTION
There is now strong evidence linking long-duration gamma-ray bursts (GRBs) with the core-collapse of massive stars (e.g. Hjorth et al. 2003a) – and hence, given the short main-sequence lifetimes of such stars, with star formation activity. Indeed, as tracers of star formation, GRBs hold a number of advantages over traditional methods. The high luminosity of their prompt emission and afterglows enable them to be detected, in principle, out to redshifts \( \gtrsim 10 \) (in practice currently out to \( z > 6 \), e.g. Haislip et al. 2006). Their high energy emission can furthermore pass unaffected through intervening gas and dust – the very conditions one would expect to be associated with massive star formation. As the outcome of a single stellar event, the luminosity of the GRB ought to be independent of that of its host galaxy, enabling localization of galaxies too faint, dusty or distant to be detected by traditional means, thus sidestepping many of the biases that afflict optical and submm surveys. Furthermore, spectroscopy of the bright optical afterglows enables one to measure the redshift and other properties of the host galaxy, even when direct detection of the galaxy may be infeasible (e.g. Berger et al. 2002).

Once the star-forming properties of a carefully selected subsample of GRB hosts have been established, it should be possible to derive the star formation history of the Universe, by measuring the redshift distribution of GRBs. A purely GRB-selected galaxy sample should, furthermore, represent an unbiased census of the galaxy types reflecting their relative contribution to the bulk star formation rate (SFR). Hitherto, it has been difficult to assess the biases afflicting the assembly of such samples, factors modulating the GRB rate as a function of redshift (e.g. redshift dependence of density of surrounding medium; metallicity; stellar initial mass function (IMF); the distribution of jet opening angles). Follow-up of samples of bursts detected with Swift (Gehrels et al. 2004) shows promise in being able to characterize and overcome such biases.
The Burst Alert Telescope (BAT) detector is more sensitive to high-redshift bursts than previous missions (e.g. Band 2006), and, due to the rapid localization of bursts via the onboard X-Ray Telescope (XRT), ground-based follow-up of afterglows (yielding information constraining the physical properties of the afterglow, for example, redshift, spectral slopes, light curves and jet-break times) is much more systematic.

However, the true proportionality between the global GRB and SFRs has yet to be definitively established. It is plausible, for instance, that an otherwise direct relation is complicated by dependence on conditions local to the GRB. For example, it is thought that metallicity could play a role in the GRB formation process (e.g. Fynbo et al. 2003; Fruchter et al. 2006). Before one can begin to exploit the new GRB catalogue produced by a mission such as Swift, it is of the utmost importance to characterize such effects.

One of the most significant contributors to the SFR density at high redshift is the submillimetre galaxy (SMG) population (e.g. Smail, Ivison & Blain 1997; Hughes et al. 1998; Scott et al. 2002; Borys et al. 2003; Mortier et al. 2005). Surveys with submm/mm bolometer arrays such as Submillimetre Common-User Bolometer Array (SCUBA) on the James Clerk Maxwell Telescope (JCMT), and Max Planck Millimetre Bolometer (MAMBO) on the Institut de Radioastronomie Millimétrique (IRAM) 30-m telescope, have revealed a population of galaxies forming the bulk of their stars in regions optically thick with dust, such that most of their extremely high luminosity \( (L \sim 10^{12–13} L_\odot) \) is emitted in the rest-frame far-infrared (FIR) region. Fits to the submm source counts and the FIR background imply that the integrated power reprocessed by dust contributes a major fraction of the total luminous energy emitted throughout the cosmic history (Blain et al. 1999).

Taken together, these facts suggest, all other things being equal, that highly star-forming SMGs ought to yield a high rate of GRBs; conversely, that a high fraction of GRB host galaxies should turn out to be luminous submillimetre (submm) sources. Follow-up of GRB hosts in the millimetre (mm) and submm bands therefore provides one of the most important calibrators of the role of GRBs as star formation indicators.

For this reason, in recent years, there have been a number of targeted submm studies of GRB hosts, predominantly carried out at 850 \( \mu \text{m} \) using SCUBA on the JCMT (Smith et al. 2001; Barnard et al. 2003; Berger et al. 2003). An overview and an analysis is provided by Tanvir et al. (2004). They compared observations made with JCMT/SCUBA with model predictions made assuming a direct proportionality between the GRB rate and the SFR. They discovered that, relative to these predictions, observations made with JCMT/SCUBA on 2005 January 27 and 28. SCUBA was used in standard photometry mode, with a chop throw of 60 arcsec in azimuth. The zenith opacity was measured via skydips and the JCMT water vapour monitor, and remained within the range \( 0.065 < T_{225 \text{ GHz}} < 0.08 \) on 2005 January 27 and 0.055 < \( T_{225 \text{ GHz}} < 0.06 \) on 2005 January 28. Flux calibration was obtained from the planets Uranus and Mars and several secondary calibrators. Data were reduced both manually using the SURF package, and via the ORAC-DR pipeline. Additional sky removal was achieved by using off-source bolometers to estimate the background.

GRB 030115 had previously been observed by JCMT/SCUBA in Target of Opportunity mode commenced on 2003 January 18, (Gorosabel et al. 2003). This illustrates the importance of submm observations in understanding the properties of GRB hosts: relying on optical data alone, their true significance could easily be overlooked. It is thus important to study wider samples of hosts, and especially to hunt for additional detections, to test whether the existing submm-bright sample is typical or unusual. We are in the process of obtaining X-ray observations of the submm-detected sample which should settle this question.

This paper pursues these ideas further. This paper falls into two parts. First, we present new mm and submm observations. The former were obtained using the MAMBO2 bolometer array on the 30-m IRAM Pico Veleta telescope, as the preliminary part of the first millimetre survey explicitly targeting GRB hosts. The submm data (850 and 450 \( \mu \text{m} \)) were obtained using SCUBA on the JCMT. The targets include two of the most-extreme GRB hosts known (the reddest and the faintest), deliberately selected as the most-promising candidate submm galaxies. Of particular interest, we have obtained deep photometry, at all three wavelengths (450/850/1200 \( \mu \text{m} \)), of the reddest afterglow/host found to date, GRB 030115.

In the second part of this paper, we develop models to constrain the relation between GRBs and their host galaxies. Using models of the luminosity distribution and evolution of submm galaxies, we derive fits to the luminosity function of GRBs under the assumption that the GRB rate is a function of the SFR/FIR luminosity of the galaxy. Based on these fits, we estimate the flux distributions expected at mm and submm wavelengths, which will facilitate comparison between models of the cosmic star formation history, with future mm and submm surveys of the host galaxies of GRBs detected by Swift.

2 OBSERVATIONS

2.1 SCUBA/JCMT observations

The question arises, from previous work, as to whether any GRB host galaxies are similar to SMGs. For example, the three submm-detected hosts all have bluer colours than typical of submm galaxies. To address this question, we first used JCMT/SCUBA to target a specific host whose properties indicate it to be a promising candidate dust-rich, submm galaxy. GRB 030115 has the reddest optical colours measured for a GRB host, implying the presence of a large mass of dust, and a (photometric) redshift (\( z = 2.5 \)) placing it near the peak of the redshift distribution measured for submm galaxies (Chapman et al. 2003). In these respects, this object constrasts markedly with the three submm-detected hosts, all of which have \( R - K < 3 \) and \( z < 1.5 \).

We obtained new 850- and 450-\( \mu \text{m} \) observations of GRB 030115 with JCMT/SCUBA on 2005 January 27 and 28. SCUBA was used in standard photometry mode, with a chop throw of 60 arcsec in azimuth. The zenith opacity was measured via skydips and the JCMT water vapour monitor, and remained within the range \( 0.065 < T_{225 \text{ GHz}} < 0.08 \) on 2005 January 27 and 0.055 < \( T_{225 \text{ GHz}} < 0.06 \) on 2005 January 28. Flux calibration was obtained from the planets Uranus and Mars and several secondary calibrators. Data were reduced both manually using the SURF package, and via the ORAC-DR pipeline. Additional sky removal was achieved by using off-source bolometers to estimate the background.

GRB 030115 had previously been observed by JCMT/SCUBA in Target of Opportunity mode commenced on 2003 January 18, 1

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1 One way in which they may not be equal would be, for example, if a higher than anticipated fraction of SCUBA galaxies were powered by active galactic nuclei.

2 Note that the host of GRB 010222 was serendipitously detected at 1.2 mm during a mm search for its afterglow.
Table 1. Summary of JCMT/SCUBA observations of GRB 030115. Zenith opacities are shown at 225 GHz, as a range appropriate to the time of observations.

<table>
<thead>
<tr>
<th>UT date</th>
<th>Observation time (min)</th>
<th>τ_{225 GHz}</th>
<th>850-μm flux (mJy)</th>
<th>450-μm flux (mJy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005 January 27</td>
<td>40</td>
<td>0.068–0.070</td>
<td>3.2±1.9</td>
<td>71±34</td>
</tr>
<tr>
<td>2005 January 28</td>
<td>120</td>
<td>0.055–0.058</td>
<td>−1.0 ± 1.1</td>
<td>−1±12</td>
</tr>
<tr>
<td>2003 January 18</td>
<td>115</td>
<td>0.083–0.086</td>
<td>0.0±1.7</td>
<td>9±65</td>
</tr>
</tbody>
</table>

Table 2. Details of our new MAMBO2 1.2-mm observations of GRB hosts. Zenith opacities are shown as a range. Quoted fluxes are the final values obtained by co-adding all the data sets.

<table>
<thead>
<tr>
<th>GRB</th>
<th>z</th>
<th>UT date</th>
<th>Observing time (min)</th>
<th>Opacity (τ)</th>
<th>Final 250-GHz flux density (mJy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRB 020124</td>
<td>3.20</td>
<td>2005 February 1</td>
<td>60</td>
<td>0.17–0.19</td>
<td>0.28±0.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2005 February 24</td>
<td>30</td>
<td>0.17–0.18</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2005 February 26</td>
<td>30</td>
<td>0.25–0.34</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2005 March 27</td>
<td>30</td>
<td>0.30–0.35</td>
<td></td>
</tr>
<tr>
<td>GRB 021211</td>
<td>1.01</td>
<td>2005 February 23</td>
<td>30</td>
<td>0.09–0.10</td>
<td>0.07±0.53</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2005 February 24</td>
<td>30</td>
<td>0.18–0.20</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2005 February 26</td>
<td>30</td>
<td>0.25–0.34</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2005 March 27</td>
<td>30</td>
<td>0.30–0.35</td>
<td></td>
</tr>
<tr>
<td>GRB 030115</td>
<td>2.5</td>
<td>2005 February 23</td>
<td>25</td>
<td>0.14–0.15</td>
<td>0.01±0.76</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2005 February 24</td>
<td>30</td>
<td>0.17–0.18</td>
<td></td>
</tr>
<tr>
<td>GRB 030226</td>
<td>1.98</td>
<td>2005 January 20</td>
<td>60</td>
<td>0.26–0.28</td>
<td>−0.29±0.66</td>
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<td>2005 February 24</td>
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<td>0.10–0.12</td>
<td></td>
</tr>
<tr>
<td>GRB 030227</td>
<td>1.6</td>
<td>2004 December 17</td>
<td>95</td>
<td>0.17–0.20</td>
<td>−0.54±0.53</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2005 February 26</td>
<td>30</td>
<td>0.25–0.34</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2005 March 27</td>
<td>30</td>
<td>0.24–0.30</td>
<td></td>
</tr>
</tbody>
</table>

3.3 d after the burst, for a total of 2 h: an upper limit of 6 mJy (3σ), at 850 μm, was reported by Hoge et al. (2003). Since no afterglow was detected, we can use this measurement as an additional upper limit on the submm flux of the host galaxy. We re-reduced the archived data in the same manner as described above, to find fluxes as reported in Table 1.

2.2 IRAM 30-m/MAMBO2 1.2-mm data

Using the 117-element MAMBO detector on the Institut de Radioscopie Millimétrique (IRAM) 30-m Pico Veleta telescope, we obtained observations of five GRB hosts between 2004 December and 2005 April, via pooled (service) observing mode. Selection of the targets was designed to improve the redshift distribution of the overall submm/mm GRB host sample, in particular to try to eliminate a possible bias towards low redshift (see Section 3.2.2). All the observed targets lie at z > 1, and their mean redshift is 2.1.

Observations were carried out at a wavelength of 1.2 mm using MAMBO2 in On–Off mode. Sky opacity was monitored frequently by performing skydips; regular pointing and focus checks were carried out; and flux calibration was obtained from standard sources. The data were reduced using the NIC software package, which forms part of the GILDAS distribution. The principles are similar to the SCUBA data reduction described above, for example, the use of off-source bolometers to facilitate sky subtraction. Details of the observations, and final fluxes of the GRB hosts, are reported in Table 2.

2.3 Results

None of the hosts is detected, either at 1.2 mm with MAMBO or at 850/450 μm with SCUBA. Moreover, the stacked, inverse-variance-weighted mean flux of our sample of five new 1.2-mm observations is −0.11 ± 0.27, consistent with a zero flux for this sample. For comparison, the weighted mean 850-μm flux of the sample discussed in Tanvir et al. (2004) is 0.93 ± 0.18, which could be interpreted as a true measure of the flux of the ‘typical’ GRB host (though as discussed by Tanvir et al., the weighted mean carries an ‘observer bias’ in that sources with higher fluxes tend to be observed to greater depth to attempt to secure detections. The unweighted mean of their sample is 0.58 ± 0.36 mJy). However it is difficult, with such a small sample, to draw any firm conclusions, and we emphasize that investigation of the millimetric properties of GRB hosts is ongoing, the present data set representing merely a pilot study.

Two notable hosts we now discuss individually.

2.3.1 GRB 030115

Co-adding all the data obtained for GRB 030115, we find flux densities 0.0 ± 0.8 mJy at 850 μm, 7 ± 11 mJy at 450 μm and...
0.0 ± 0.8 mJy at 1.2 mm. We note that this GRB was also observed using MAMBO by Bertoldi et al. (2003), on 2003 January 16 and 2003 January 18 (i.e. shortly after the burst), to attempt to detect the afterglow. Their non-detection (0.4 ± 0.9 mJy) can, again, be combined with our new data, to yield a total flux 0.2 ± 0.6 mJy. Thus, although this host was not detected, we nevertheless possess reasonably strong upper limits at all three wavelengths. (We stress, however, that the 450-μm measurement, in particular, carries a substantial calibration uncertainty. Such a deep short-wave limit is rare, but it must be used with caution). The 850-μm rms, in particular, would have been easily sufficient to have detected the three submm-bright GRB hosts known to date (e.g. Tanvir et al. 2004).

This object is of particular importance in understanding the host galaxies of GRBs. As noted, it is the reddest GRB host observed to date, with a colour $R - K \approx 5$ (Levan et al. 2006, hereafter L06) that qualifies it as an Extremely Red Object (ERO). The afterglow, too, is exceptionally red ($R - K \approx 6$), providing further evidence for intrinsic extinction. Although no spectroscopic redshift was measured, L06 determined a photometric redshift $z = 2.5 \pm 0.2$. Adopting the calibration determined by Meurer, Heckman & Calzetti (1999) for local starburst galaxies, the extinction implied by the rest-frame ultraviolet (UV) slope can be used to estimate the FIR luminosity from the observed optical flux, assuming that the absorbed UV photons are re-radiated in the FIR/submm. The extinction at 1600 Å is estimated this way to be 5.3, giving a pre-

...
Infrared Space Observatory (ISO) and SCUBA counts (see Blain et al. 1999 and Blain 2001 for full details).

To model the properties and statistics of GRBs, we first of all assume that the gamma-ray spectrum is described by a Band et al. (1993) function, using values of the spectral indices $\alpha = -1$, $\beta = -2$ and cut-off energy $E_0 = 200$ keV (rest frame). We investigate two common parametrizations of the peak luminosity distribution: (1) a lognormal luminosity function (specified by a mean luminosity $L_0$ and a width $\sigma$), and (2) a Schechter (1976) function (specified by a characteristic luminosity $L_*$ and an index $\gamma$). In each case, $\rho(z)$, the (comoving) GRB rate density as a function of redshift is derived from the global SFR density, $\rho_{\text{GRB}}(z) = \eta_{\text{GRB}} \times \psi_*(z)$ – for example, as calculated from the submm models. Similarly, the GRB rate per galaxy is assumed to be proportional to the galaxy’s FIR luminosity. Initially, we assume that $\eta_{\text{GRB}}$ – the ‘efficiency’ of GRB production – is a constant. However, in general, we may consider cases where $\eta$ is a function of redshift, or of host galaxy properties (see below). The parameters $L_0$, $L_*$, $\sigma$ and $\gamma$ are then determined, for each star formation history, by fitting the flux distribution of long-duration ($t_{\text{sec}} > 2s$) GRBs in the Burst and Transient Source Experiment (BATSE) 4B catalogue (Paciesas et al. 1999). For this purpose, we adopt a limiting photon flux sensitivity $0.27$ photon cm$^{-2}$ s$^{-1}$, corresponding to the median of the BATSE sensitivity distribution determined by Guetta, Piran & Waxman (2005).

### 3.2 Results

#### 3.2.1 Flux distribution

In Fig. 2, we show the predicted cumulative fraction of GRB hosts above a given flux density, for a range of submm/mm wavelengths. In this case, we have assumed a detector sensitivity appropriate for Swift/BAT, based on the intercomparison between BAT and BATSE made by Band (2006). These results correspond to a lognormal GRB luminosity distribution. However, calculations for a Schechter function give very similar results.

![Figure 2](image)

**Figure 2.** Predicted fraction of GRB hosts brighter than a given flux density, plotted for four different wavelengths in the submm/mm regime. The model displayed here assumes a lognormal high-energy luminosity distribution for long-duration GRBs (parameters estimated by fitting to the peak flux distribution of the BATSE-4B catalogue), and is calculated for the sensitivity of Swift/BAT. However, varying these parameters does not have a dramatic effect upon the results, at least compared with the other uncertainties involved (e.g. the SED assumed to describe submm galaxies and GRB hosts).

In general, the GRB descriptors appear not to affect the relative numbers significantly (so long as they represent reasonable fits to the number counts). The adopted submm properties have a larger effect. In particular, we have assumed that GRB host galaxies share a common, isothermal SED – an SED moreover identical to that of submm galaxies. In reality, it is possible that the mean dust temperature of GRB hosts is different from the $37$ K assumed here, and that across the sample a distribution of temperatures is to be found. Testing the effect of this on our predictions is not trivial, since the dust temperature is a parameter of the Blain et al. (1999) submm galaxy-evolution models. A detailed refit of the SCUBA counts is beyond the scope of this work, but for now we can obtain a simple indication of the effect of varying the temperature by taking note of the correlations between the uncertainties in the model parameters of Blain et al. (1999), and re-running our calculation using the new parameters. Results for a plausible temperature range are shown in Fig. 3. Although the uncertainty is probably somewhat exaggerated (because it assumes all submm galaxies are affected in the same way), the effect is much larger than that due to any uncertainty in the GRB properties. The submm SEDs of GRB hosts are ill-enough constrained that it seems plausible that a hotter-than-average dust temperature – as our limits for GRB 030115 would imply – could account for the paucity of submm detections to date.

At 1.2 mm, we would expect to have detected $\sim10$–$15$ per cent of a sample with rms $\sim0.5$–$0.6$ mJy, assuming the $T = 37$ K model. This could increase to as much as $\sim20$–$25$ per cent if the temperature were permitted to be as low as $30$ K, but would become negligible at temperatures as high as $50$ K. The predicted flux distributions enable us to calculate the average flux density of a large sample, to compare with the co-added (detected plus non-detected) fluxes from observations. The $37$-K model predicts $\langle S_{850} \rangle \approx 0.8$ mJy, $\langle S_{1.2} \rangle \approx 0.4$ mJy. Recall that Tanvir et al. (2004) found stacked fluxes $0.93 \pm 0.18$ (weighted mean) and $0.58 \pm 0.36$ (unweighted), both consistent with this prediction. Our 1.2-mm mean, on the other hand, is marginally inconsistent with the prediction. Our sample of five is, however, too small to confirm or reject any of the models, but...
continued study of homogeneously selected host samples should improve the constraints. Ultimately, greater sensitivity will be attained by taking advantage of forthcoming facilities such as the Atacama Large Millimeter Array (ALMA) (or even existing facilities such as Spitzer); then it will be possible to reach limits deep enough to discriminate between models.

3.2.2 Predicted redshift distribution

Fig. 4 compares the predicted redshift distribution of all GRBs (thick solid line) with observed, spectroscopically derived redshifts (light-shaded histogram). Also shown are the variation of the expected fraction of submm-bright hosts with redshift, \( \frac{d}{dz} n(S_{850} > 3 \, \text{mJy})/\frac{d}{dz} n(\text{total}) \) (thick dashed line), and the redshift distribution of the submm-observed sample (dark-shaded histogram). Some care must be taken when interpreting the observational data, since the observed distribution is derived from a rather inhomogeneous input sample. Not only does the sample consist of bursts detected by a range of missions, but also, insisting on spectroscopic follow-up inevitably introduces strong biases – for example, towards lower-redshift bursts, towards those that are intrinsically brighter, or towards those suffering less dust extinction from their hosts.

From the figure it is clear that most of the existing submm-observed GRB sample lies at lower redshift than the predicted peak in the submm-bright fraction – and indeed the observed peak of the redshift distribution of submm galaxies (Chapman et al. 2003). This redshift bias is, therefore, another possible explanation of the lack of submm detections in the existing host sample. Now, however, afterglow redshift determination is more systematic, with the accurate localization provided by the XRT and UVOT instruments on board Swift, and rapid ground-based follow-up via a suite of robotic and semirobotic telescopes. Submm/mm follow-up of samples resulting from such campaigns is likely to place much more secure constraints on the star-forming properties of GRB host galaxies than has been possible hitherto.

3.2.3 Dependence of GRB rate on metallicity

One important factor that might ultimately mitigate against the formation of GRBs in dust-rich galaxies is the role that metallicity is thought to play (e.g. Fruchter et al. 2006). According to the ‘collapsar’ model (MacFadyen & Woosley 1999), a low metal abundance allows the progenitor to retain a high mass and angular momentum, favouring the production of a black hole and accretion disc. High detection rates of Lyman \( \alpha \) emission from GRB hosts (Fynbo et al. 2003) could be taken as evidence that these systems are indeed metal-poor. If this metallicity dependence is correct, it holds consequences both negative and positive for the use of GRBs as star formation indicators. Whilst, on the one hand, complicating the conversion between GRB and SFR, it suggests that GRBs may instead be the ideal means of pinpointing metal-poor galaxies – in particular low-mass, unenriched systems at the highest redshifts which are most likely to be missed in other surveys.

It is therefore important to explore the possible effects of a metallicity dependence. To do so, we place a redshift dependence on the GRB rate density – SFR density conversion factor \( \eta_{\text{GRB}}(z) \). The evolution of the average metallicity with redshift is given by the submm galaxy models (Blain et al. 1999). This is converted to a relative efficiency of GRB production using an ad hoc recipe – which ultimately may be unrealistic, but, in the absence of any compelling observational or theoretical guidelines, it serves amply to illustrate the effects. A sample predicted redshift distribution is plotted in Fig. 4 (thin curve). As expected, the peak is shifted towards higher \( z \) where the average abundance of heavy elements is smaller. However, without separately encoding galaxy-to-galaxy variations in the metal abundance, the effects on the submm flux distribution are small.

This calculation is, we emphasize, only illustrative at present. For example, it may be more appropriate, for GRB hosts, to consider metallicities traced by optical galaxy surveys, rather than submm surveys as used here. As the redshift distribution of GRBs becomes more fully sampled, (e.g. via spectroscopic follow-up of large samples of Swift bursts), it will soon be possible to place constraints on a wider range of models in this way.

4 SUMMARY

Following from the previous study of Tanvir et al. (2004), we have further investigated the mm/submm properties of the host galaxies of GRBs, in order to characterize the efficacy of GRBs as star formation indicators. Specific increments over the T04 study include: (1) we have conducted the first survey of GRB hosts at millimetric wavelengths, with the MAMBO2 bolometer array on the IRAM 30-m Pico Veleta telescope. None of these targets was detected, down to an average rms \( \approx 0.6 \, \text{mJy} \) at 1.2 mm; (2) we obtained deep submm photometry of GRB 030131, whose high intrinsic extinction inferred from its optical/NIR spectral slope makes it a promising candidate submm galaxy. Despite its ERO-like optical colours, however, this galaxy is not detected in the mm/submm, to deep limits at 850 \( \mu \text{m} \) (\( \sigma = 0.8 \, \text{mJy} \)) and 450 \( \mu \text{m} \) (\( \sigma = 11 \, \text{mJy} \)); (3) we have modelled the redshift and flux distribution of GRB hosts, assuming a link between GRBs and the submm galaxy population. A novelty of these models is that they take account of the metallicity bias.
widely proposed to affect the GRB-to-SFR conversion. As such they potentially have much wider applicability than the derivation of submm properties, and we will further develop these ideas in future publications (Priddey et al., in preparation).

The non-detection of GRB 030115 is revealing. One might contrast this result with the three GRBs that do possess submm detections, for their optical/NIR colours are much bluer. The broad-band spectrum of the GRB 030115 host is inconsistent with the SED of an extremely luminous IR galaxy such as Arp220 or with a cool, isothermal model, but hotter dust (\(T > 50\) K), or template SEDs of other submm-luminous galaxies, cannot be ruled out. Observation in the MIR with missions such as Spitzer should also be able to constrain any hot dust component too faint to be seen in the submm.

We emphasize that this work is ongoing: in the imminent future we will be able to draw upon larger, post-Swift samples of GRBs to ensure a uniform sample selection — enabling, for example, a more uniform redshift distribution. For the moment, it seems that the trend of a low submm detection rate of GRB hosts, seen in previous surveys, is maintained.

What are the implications of a low-mm/submm detection rate of GRB hosts? We have shown that there is sufficient uncertainty in models and underlying assumptions, as yet poorly constrained by observation (e.g. the adopted dust temperature) that a correlation between massive, dust-enshrouded star formation and GRB production cannot be firmly ruled out. Sample selection biases (e.g. against high-redshift and highly extinguished bursts) are also likely to have played a significant role in previous studies. Our models indicate that redshift bias in particular could account for the lack of detections within existing surveys. The new observations reported here may (five hosts all at \(z > 1\), one highly extinguished host and one extremely faint host) were taken in part to alleviate such problems. Prior to the ALMA, observations of consistently followed-up samples with existing facilities (e.g. IRAM 30 m, APEX) must be made to enable us to make further progress in exploring these effects. The capabilities of Swift, combined with efficient ground-based follow-up, show promise in being able to yield such a sample.

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