

# Cold Dust in (Some) High $z$ Supernova Host Galaxies

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## ABSTRACT

We present deep submillimetre photometry for 14 galaxies at  $z=0.5$  that are hosts of type Ia supernovae, with the aim of examining the evolution of dust mass and extinction in normal galaxies. We combine these results with our previous observations of 17  $z\sim 0.5$  SN Ia hosts to look for any evolution in the dust content of normal galaxies between  $z=0$  and  $z=0.5$ . The average observed frame  $850\mu\text{m}$  flux of SN Ia hosts in the full sample, excluding 2 bright individually detected objects, is  $0.44 \pm 0.22$  mJy. This flux level is consistent with there being little or no evolution in the dust content, or optical extinction, of normal galaxies from  $z=0$  to  $z=0.5$ . One galaxy, the host of SN1996cf, is detected individually, and we also present a deep HST STIS image for this object. It appears to be an edge on disk system, similar to the submm bright host of SN1997ey. We thus examine the dust properties of these and one other individually detected object. 450-to-850  $\mu\text{m}$  flux ratios and limits suggest that the dust in the two brightest submm sources, SN1996cf and SN1997ey, is cold,  $T \sim 20\text{K}$ , implying that they contain a substantial mass of dust  $\sim 10^9 M_\odot$ . The presence of two bright ( $F_{850} > 7\text{mJy}$ ) submm sources at  $z\sim 0.5$  in a sample of ostensibly normal galaxies is surprising, and has important implications. It supports the idea that a substantial part of the Cosmic Infrared Background (CIB) may be produced at  $z < 1$ , while also suggesting that ‘foreground’ objects such as these may be a significant ‘contaminant’ in submm surveys. Finally, we examine the overall submm luminosity distribution at  $z=0.5$  implied by our results, and conclude that either there is substantial evolution in the submm luminosity function from  $z=0$  to 0.5, or our submm detected sources are somehow not representative of the bulk of galaxies at this redshift.

**Key words:** submm:galaxies — galaxies:high-redshift — supernovae: general

## 1 INTRODUCTION

Two of the major new insights of the 1990s into cosmology and the history of galaxy formation were the discovery of the Cosmic Infrared Background (CIB: Puget et al., 1996; Fixsen et al., 1998) and the measurement of a significant ‘dark energy’ term in the expansion of the universe through the use of high redshift type Ia supernovae as standard candles (Riess et al., 1998, HZT; Perlmutter et al., 1999, SCP). The discovery of the CIB indicated that dust enshrouded star formation is a significant aspect of the star formation history of the universe, amounting to 50% or more of all star formation (Gispert et al., 2000). At the same time surveys with SCUBA (eg. Smail et al., 1997; Hughes et al., 1998; Eales et al., 2000; Mortier et al., 2005) and other submillimetre array detectors have begun to find the objects that make up the CIB. These objects are largely interpreted as being similar to local Ultraluminous Infrared Galaxies (ULIRGs), and are thought to contain large dust masses at a temper-

ature  $T\sim 40\text{K}$  (Blain et al., 1999) and to be the hosts of massive bursts of star formation,  $100 - 1000 M_\odot \text{yr}^{-1}$ . However, substantial uncertainties remain. Most of these submillimetre galaxies (SMGs) do not have well determined redshifts (though see Chapman et al., 2005). The degeneracy between temperature and redshift (Blain 1999) thus means that their dust temperature is highly uncertain — a low dust temperature object at low redshift ( $z\sim 0.5-1$ ) looks much the same as a high dust temperature object at high redshift ( $z\sim 2-3$ ). Since luminosity is a strong power of temperature, typically  $T^6$  for a standard SMG spectral energy distribution (SED), this leads to a considerable uncertainty in the derived luminosity and star formation rates for those SMGs without measured redshifts. Indeed some authors have suggested (Rowan-Robinson 2001, Kaviani et al. 2003, Efstathiou & Rowan-Robinson, 2003) that a substantial fraction of the SMG population may be cooler and closer than originally thought, and there is some observational evidence to back up this suggestion (Chapman et al.,

2003; Taylor et al in prep). There is currently little known about cool dust in normal galaxies in the  $0.5 < z < 1$  range because it is quite difficult to find a clean sample of such objects. The SN1a host galaxies (see eg. Sullivan et al. (2003); Tonry et al. (2003)), though, provide an ideal selection for such studies.

The discovery of the CIB also raises the overall question of the evolution of the dust content of galaxies and its role in obscuring starlight in these objects and reprocessing it into thermal dust emission. Dust obscuration is known to have a significant effect locally (Tresse & Maddox, 1998), but the evolution of dust content and obscuration is not well constrained. Chemical evolution models (Calzetti & Heckman, 1999; Pei, Fall & Hauser, 1999) predict that dust obscuration should peak at 2-3 times the current value at  $1 < z < 2$  before gradually declining to higher redshifts. However, we currently know little about the dust content of quiescent systems which make up the bulk of the galaxy population at any epoch. The host galaxies of high  $z$  supernovae, however, have not been selected on the basis of active star formation, but have spectroscopic redshifts and abundant ancillary data, including, for many, HST images and multicolour optical and near infrared colours. They are thus an ideal sample with which to study the role of dust in quiescent galaxies at cosmological redshifts.

This paper is the second to result from our ongoing search for dust emission in high  $z$  SN host galaxies. Our first paper (Farrah et al., 2004, hereinafter Paper 1) presented the results of SCUBA submm photometry of a sample of 17  $z=0.5$  SN1a host galaxies. We here present additional observations of a further 14 galaxies, extending the sample size to 31, and increasing the number of directly detected objects to three. The paper is structured as follows. In section 2 we discuss the observations and present our results. In section 3 we discuss the sample as a whole and discuss the overall dust content of the quiescent galaxy population at  $z=0.5$ . In section 4 we examine the properties of the three galaxies individually detected in our observations, while in section 5 we discuss the implications of our results for the overall submillimetre luminosity distribution of galaxies at  $z=0.5$ . We draw our conclusions in section 6. We assume  $\Omega_0 = 1, \Omega_m = 0.3, \Omega_\Lambda = 0.7$  and  $H_0 = 70 \text{ km s}^{-1} \text{ Mpc}^{-1}$  throughout this paper.

## 2 OBSERVATIONS

The observations described here extend the earlier work of Paper 1 on the host galaxies of  $z \sim 0.5$  type 1a supernova host galaxies. As with our Paper 1 observations, our targets were selected from the HZT and the SCP supernova lists to be the host galaxies of type 1a supernovae and to lie in a narrow ( $\pm 0.1$ ) range of redshifts centred on  $z=0.5$ . This is to allow easy combination of submm fluxes from the targets with no need for  $k$ -corrections to shift the fluxes to correspond to the same rest-frame wavelength.

Observations were made of 14 high redshift supernova 1a host galaxies at  $z \sim 0.5$  between July 2003 and January 2004 (see table 1). Observing conditions were generally good, with  $\tau_{850}$  ranging from 0.2 to 0.15 and  $\tau_{450}$  ranging from 1.3 to 0.85. These optical depth values were determined by standard skydip observations at azimuths relevant to the

targets and are classified as grade 1 or 2 conditions by the JCMT.

The sources were observed with SCUBA (Holland et al., 1999) in photometer mode using two bolometer chopping. This means that for each channel, 850 or 450  $\mu\text{m}$ , as well as being observed by the central bolometer on the array, a second bolometer observes the source in the reference position. An observed flux can be extracted from both these bolometers which are then combined, using appropriate noise weighting, to increase the sensitivity over that of a normal single bolometer chopping observation by  $\sim \sqrt{2}$ . This combination takes place at the end of the data reduction process, once flat fielding, background subtraction and calibration have been completed.

The data from SCUBA was reduced in a standard way using the SURF data reduction package (Jenness & Lightfoot, 2000). Regular pointing observations were made to ensure pointing accuracy, and skydips were also taken regularly. Flux calibration factors (FCFs) for the two bolometers used to detect the sources were calculated separately. Calibration sources used were CRL618 and Uranus. The individual observations of a source with a given bolometer are combined using a Kolmogorov-Smirnov technique which masks out any discordant points that remain after the data processing. No unusual numbers of points were excluded in this analysis. When an object was observed on more than one day, the fluxes measured in each separate observation are combined using a variance weighted scheme.

Our results are presented in table 1. Only one source, the host galaxy of SN1996cf, a  $z=0.57$  SN1a, was detected, with a flux of  $11 \pm 1.6$  mJy at 850  $\mu\text{m}$ . This source was only 'detected' with  $1.6\sigma$  significance at 450  $\mu\text{m}$ , with a flux of  $25 \pm 15$  mJy.

For the host galaxy of SN1996cf, we obtained Hubble Space Telescope (HST) imaging from the HST data archive. Observations were taken using the Space Telescope Imaging Spectrograph (STIS) in imaging mode using a clear filter. The data consisted of three exposures, each of 300 seconds, taken with a 10 pixel offset between successive exposures to facilitate the subtraction of cosmic ray events. The data were reduced, and combined into a single image, using the IRAF reduction package *calstis*. The image of the host galaxy, presented in Fig. 1, has had the low surface brightness host enhanced by the application of a 2x2 pixel boxcar filter.

## 3 THE EVOLUTION OF OBSCURATION IN NORMAL GALAXIES

The evolution of dust content and dust obscuration in normal galaxies can be examined by looking at the average properties of the sample we have observed. We follow the approach discussed in Paper 1, but apply it to the full sample of 31 galaxies — 17 from Paper 1 and 14 from the current paper. We exclude 2 objects from this combination, the two objects whose fluxes are strongly detected — SN1996cf (this paper) and SN1997ey (Paper 1). The fluxes are combined using an inverse variance weighting scheme. The average observed frame 850  $\mu\text{m}$  flux from type 1a supernova host galaxies calculated in this way is  $0.44 \pm 0.22$  mJy. This is less than the mean flux of  $1.01 \pm 0.33$  mJy obtained in Paper 1, but still statistically consistent (at the  $1.5\sigma$  level) with the



**Figure 1.** STIS clear CCD image of the host galaxy of SN1996cf.

. The pixel size in this the standard STIS CCD resolution of  $0.05''$ . The Image is  $15'' \times 11''$  in size, ie.  $300 \times 220$  pixels.

Name	$z$	Date Observed	$F_{850}(\text{mJy})$
SN1995az	0.45	9 July 2003	$1.4 \pm 0.9$
SN1997ax	0.615	26 Dec 2003	$1.8 \pm 0.8$
SN1997K	0.592	16 Dec 2003, 9 Jan 2004	$-0.3 \pm 0.9$
SN1997H	0.526	8, 10 Jan 2004	$0.7 \pm 0.9$
SN1997eq	0.538	8 Jan 2004	$1.5 \pm 1.2$
SN1997j	0.619	8 Jan 2004	$0.4 \pm 0.9$
SN1997af	0.579	9, 10 Jan 2004	$0.0 \pm 0.8$
SN2000ec	0.47	10 Jan 2004	$-2.7 \pm 1.4$
SN1996au	0.52	10 Jan 2004	$-3.0 \pm 1.4$
SN1997es	0.65	10 Jan 2004	$-0.7 \pm 1.4$
SN1996cf*	0.57	10 Jan 2004	$11.0 \pm 1.6$
SN1996ci	0.5	11, 12 Jan 2004	$-0.7 \pm 0.8$
SN1997aj	0.581	12 Jan 2004	$-1.8 \pm 1.3$
SN1996I	0.57	12 Jan 2004	$-0.6 \pm 1.2$

**Table 1.** Results of submm observations of SN1a host galaxies.

\*SN1996cf  $450\mu\text{m}$  flux  $25 \pm 15$  mJy.

previous result. If we attempt to split the SN host galaxy sample into spirals (and irregulars) and ellipticals, based on the available data on the host galaxy morphologies (largely HST images), whilst still excluding the two strong detections, we find a similar average flux for the two classes of object ( $0.40 \pm 0.29$  for spirals/irregulars, and  $0.69 \pm 0.46$  for ellipticals).

By consideration of the local SLUGs  $850\mu\text{m}$  luminosity function (Dunne et al., 2000 - though see also Vlahakis et al., 2005) combined with appropriate  $k$  corrections from the cirrus model of Efstathiou & Rowan-Robinson (2003), and the assumption that the submillimetre emission from ellipticals is negligible, Paper 1 predicted that the mean observed

frame  $850\mu\text{m}$  flux of a  $z=0.5$  galaxy would be  $0.56 \pm 0.1$  mJy if there is no evolution in the amount of dust in normal galaxies from  $z=0$  to  $z=0.5$ . Our result is thus consistent with there being at most only moderate evolution in the dust content of normal galaxies from  $z=0$  to  $z=0.5$ . Paper 1 found a moderate increase in the dust content of 25%–135% over this redshift range. The new expanded SN host sample thus mildly contradicts this result ( $1.5 \sigma$ ), though the errors permit an increase of up to 20% or a 100% decrease in the dust content of the population as a whole. The mean  $A_V$  for galaxies at  $z=0.5$  would thus be statistically unchanged from the local value of  $A_V = 0.31$  derived by Rowan-Robinson (2003). This is in contrast with models of opacity evolution from Calzetti & Heckman (1999), which predict an increase in extinction of  $A_V \sim 0.15$  by  $z=0.15$ , and with chemical evolution models (Pei et al., 1999). Neither of these models predict a particularly significant evolution in extinction or dust mass in galaxies over the period to  $z=0.5$ , so our current results cannot be interpreted as a rigorous test of these models. To achieve this, a larger sample and more sensitive observations would be needed, allowing more than statistical non-detections of the population, and/or the greater lever arm that would be obtained by examining the dust content of normal galaxies out to  $z=1$ .

All of these considerations apply to the population as a whole. Throughout this discussion we have excluded the two strong submm detections in our sample from consideration because the two objects appear to have radically different submm luminosity to the bulk of the population. We now consider the nature of these two objects in detail.

#### 4 THE PROPERTIES OF THE DETECTED GALAXIES

Whilst we have failed to detect the mean submm emission of the population of  $z \sim 0.5$  SN1a host galaxies, we have managed to detect three of these objects individually. The SN magnitudes for these objects lie in typical positions for  $z \sim 0.5$  SN1a objects in the magnitude-redshift diagram (eg. Perlmutter et al., 1999). One of our sources, SN2000eh, was only marginally detected ( $3\sigma$ ) at  $850\mu\text{m}$ , but two others, SN1997ey and SN1996cf were detected surprisingly strongly. Their observational and derived properties are given in Table 2. It can clearly be seen that their rest-frame  $850\mu\text{m}$  luminosities are comparable with those of local ULIRGs such as Arp220 and Mrk231 (Dunne et al., 2000; Farrah et al., 2003). However, there is no evidence for starburst or AGN activity in these objects on the basis of optical spectra obtained by the high redshift supernova teams (HZT & SCP teams, private communication). HST imaging of the two bright submm sources also shows them to be morphologically different from local ULIRGs and from those SMGs for which imaging is currently available. Both of our bright submm sources (see fig. 1 for 1996cf and Paper 1 for 1997ey) appear to be faint quiescent edge-on disk galaxies. Local ULIRGs, in contrast, are almost universally disturbed systems (eg. Clements et al., 1996; Surace et al., 1998; Farrah et al., 2001), with double nuclei, tidal tails and other signs of merging activity. The SMG population, as revealed by blank field SCUBA surveys, also appears to be made up of such disturbed objects (eg. Clements et al 2004; Smail et al., 2004; Chapman et al., 2003b), though it should be noted that to date no flux limited SMG sample has been completely imaged.

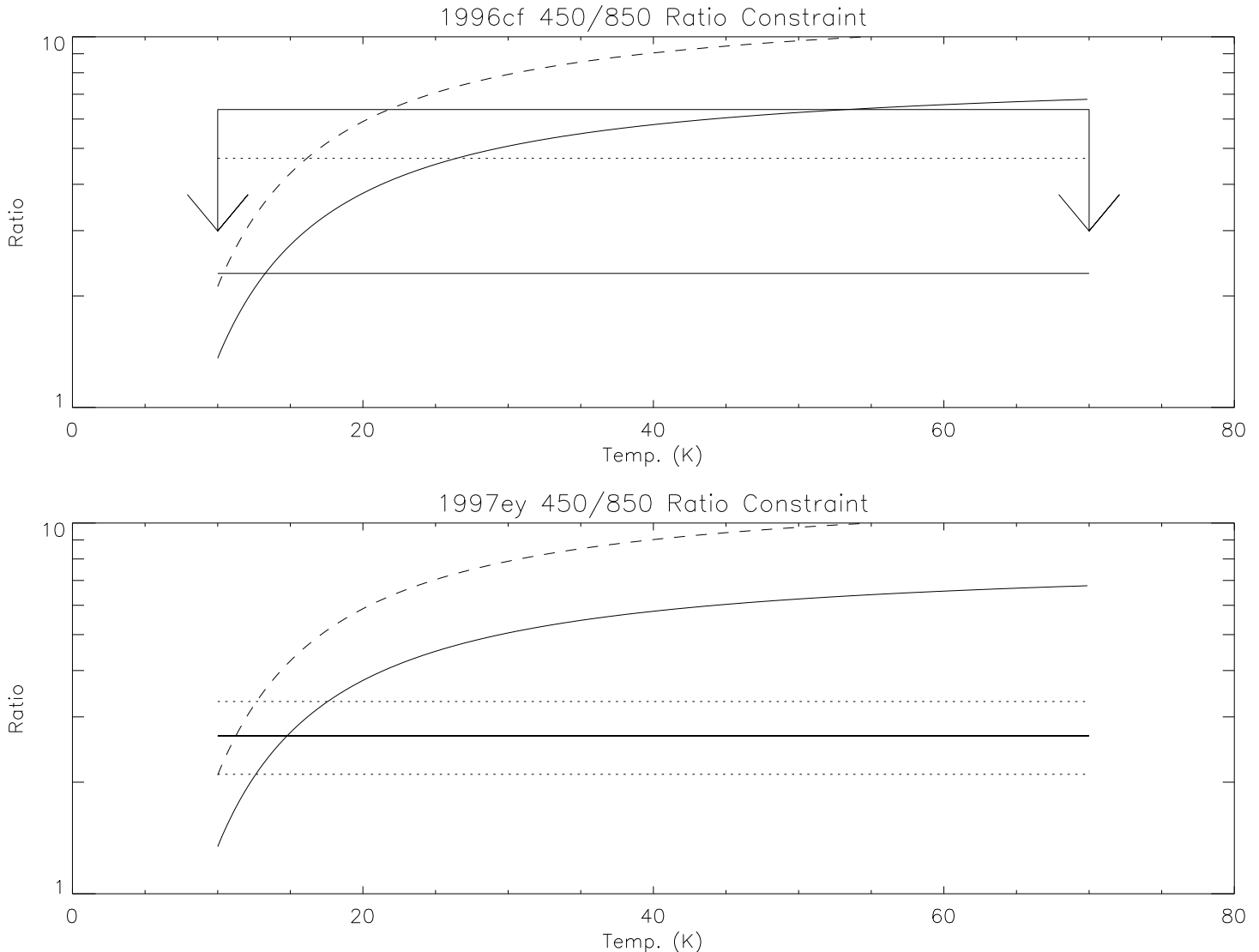
The spectral energy distributions and dust temperatures of these objects are difficult to determine since they are detected in only one or two submm bands. The best we can attempt is to set constraints on the temperature and SEDs by examining the 450/850 flux ratio and its limits. These targets were all observed in excellent conditions, so calibration errors should be smaller than or comparable to the observational errors on the fluxes (see eg. Dunne & Eales, 2001). One source is clearly detected at  $450\mu\text{m}$ , SN1997ey, while a second, 1996cf, has a marginal  $1.6\sigma$  signal. There is no useful  $450\mu\text{m}$  data available for SN2000eh since it was observed in poorer conditions. Examination of the 450/850 flux ratio for 1997ey and 1996cf (see fig. 2) suggest cold dust temperatures  $\sim 20\text{K}$  assuming an emissivity index of  $\beta=1.3$  (consistent with the single temperature SEDs found for local galaxies by the SLUGS survey (Dunne et al, 2000)) and still colder for the more generally accepted emissivity index  $\beta=2$  (see eg. Dunne & Eales 2001). Assuming a standard dust opacity of  $0.077\text{ m}^2\text{kg}^{-1}$  (eg. Dunne et al. 2000), these would correspond to dust masses of  $1.3 \times 10^9 M_\odot$  and  $1.7 \times 10^9 M_\odot$  respectively. In the absence of  $450\mu\text{m}$  data, we assume that SN2000eh has similar dust properties, yielding a lower dust mass of  $6.5 \times 10^8 M_\odot$ . These are substantial dust masses, about a factor of 10 more dust than in the dustiest galaxy in the original SLUGS survey, UGC9618 (Dunne et al., 2000). The low inferred temperature, combined with the large observed  $850\mu\text{m}$  flux, lead inevitably to this large dust mass. If the cooler temperature associated with a  $\beta = 2$  SED is assumed, then the dust masses get correspondingly larger.

Dust as cold as we have found in these objects is not unknown in the local universe (eg. the SED of NGC891 is dominated by dust at  $\sim 15\text{K}$  (Alton et al., 1998)) and has been suggested for higher redshift objects on both theoretical grounds (Rowan-Robinson, 2001; Efstathiou & Rowan-Robinson 2003; Kaviani et al., 2003) and observational grounds (Chapman et al., 2003; Taylor et al., 2005). The present results are direct confirmation that cold galaxies with large dust masses and submm luminosities do indeed exist at moderate redshift, and could contribute to the CIB and to the sources seen in deep far-IR surveys such FIRBACK (Puget et al., 1999) and deep submm surveys. Indeed, objects such as these might prove to be a foreground contaminant in deep large area submm surveys such as SHADES (Mortier et al., 2005) and those now being planned for new facilities and instruments such as SCUBA2 and the LMT (Large Millimetre Telescope). The areal density for sources such as the two bright galaxies discussed here was predicted in Paper 1 to be  $\sim 100$  per sq. deg. The results of this paper, which roughly doubles the sample size and doubles the number of bright sources found, adds credence to this number, which is comparable to the source densities found in deep blank field submm surveys at these flux levels (eg. Scott et al., 2002; Mortier et al., 2005). The presence of such foreground interlopers might thus be a significant problem when attempting to measure correlation functions for high redshift submm galaxies in the absence of clear identifications and redshifts, especially as they are unlikely to be bright in the radio.

#### 5 $Z=0.5$ SUBMM LUMINOSITY DISTRIBUTION

In principle, our sample of SN1a host galaxies should provide a reasonably unbiased selection for evolved galaxies at  $z=0.5$ , biased in selection only by the stellar mass. By examining the  $850\mu\text{m}$  luminosity distribution of these objects, and comparing it with that found for local objects, we can gain some insight into the galaxy population at  $z=0.5$ . The local luminosity function that we use is the SLUGS  $850\mu\text{m}$  LF (Dunne et al 2000) since this is the best currently available. This was found to be well fitted by a Schechter function with  $L_* = 8.3 \times 10^{21} W m^{-2} sr^{-1}$ ,  $\alpha = -2.18$  and  $\Phi_* = 2.9 \times 10^{-4} Mpc^{-3} dex^{-1}$ . We cannot apply this luminosity function directly to predict the numbers of sources we should see, since we do not know the parent population normalisation for the number of our target objects per  $Mpc^{-3}$ . However, since all our objects are at the same redshift,  $\sim 0.5$ , we can look at the relative number of objects in each luminosity bin and compare this to the low  $z$  expectation. We have only a small number of detected galaxies, so must necessarily normalise the expected luminosity distribution at the high end, where our detections lie.

The Schechter function form of the LF used by Dunne et al. (2000) has a very strong exponential rolloff at high luminosities. The detection of a small number of very luminous objects, as obtained here, would imply the presence of many more lower luminosity systems. We find 3 sources in the luminosity range  $10^{22.5} - 10^{23.5} W m^{-2} sr^{-1}$ . The Dunne et al. LF would predict that the next lowest dex bin in the LF should contain 100 times more objects. These would have



**Figure 2.** Comparison of Dust SED models to 450/850 ratio of strongly detected sources

The curved lines are the predicted observed-frame 450/850 ratios for thermal dust emission models with a  $\beta=1.3$  emissivity (dashed line) or  $\beta=2$  emissivity (solid line). The horizontal lines are the observed ratios. Solid lines show the observed values and, for SN1996cf, the upper limit to this ratio using the formal 450 $\mu\text{m}$   $3\sigma$  flux upper limit (designated with an arrow), while dashed lines show the  $1\sigma$  range for this flux ratio. As can be seen, SN1997ey appears to have a cold SED, with a temperature of 20K or less, while it seems likely that SN1996cf’s host is similar.

Name	RA	DEC	$z$	$F_{450}$ mJy	$F_{850}$ mJy	$L_{850}$ $W m^{-2}sr^{-1}$
SN1997ey	04 56 58.2	-02 37 37	0.58	$20.8\pm 3.5$	$7.8\pm 1.1$	$8.7\times 10^{22}$
SN1996cf	10 48 50.9	00 03 30	0.57	$25\pm 15$	$11.0\pm 1.6$	$1.2\times 10^{23}$
SN2000eh	04 15 02.4	04 23 18	0.49	$5.2\pm 6.6$	$4.6\pm 1.5$	$4.7\times 10^{22}$

**Table 2.** Detailed Observational Properties of the strongly detected sources. For comparison, Arp220, the nearest ULIRG, and Mrk231, the nearest type 1 AGN-ULIRG, have 850 $\mu\text{m}$  luminosities of  $4.0 \times 10^{22} W m^{-2}sr^{-1}$  and  $1.0 \times 10^{23} W m^{-2}sr^{-1}$  respectively.

fluxes in the range 0.3 – 3 mJy at 850 $\mu\text{m}$ , and would thus be detectable by us either individually or statistically. And yet we find no evidence for such sources. Perhaps more significantly, sources as luminous as SN1996cf should be extremely rare - so rare in fact that we would not expect to see any at all given that we are only seeing 2 sources in the lumi-

nosity range  $10^{22.5} - 10^{23} W m^{-2}sr^{-1}$ . The assumption of a polynomial tail at high luminosities to the 850 $\mu\text{m}$  LF, rather than an exponential fall off, as suggested for the 60 $\mu\text{m}$  LF (Sanders & Mirabel, 1996) would ameliorate this problem to an extent, but would not provide a complete explanation for the numbers of high luminosity sources we are seeing, or

the absence of sources at somewhat lower luminosities that would still be detectable directly or statistically.

Several possible explanations are possible:

- The Luminosity Function has evolved from  $z=0$  to  $z=0.5$

At face value, the most obvious explanation for the discrepancies in the luminosity distributions would be evolution in the luminosity function. This would not be one of the standard density or luminosity evolution since this would result in a many more moderate flux/luminosity detections than we see. It would also contradict the absence of evolution in the opacity that we find for the sources undetected individually. Instead, some kind of evolution that only affects the high luminosity objects would be needed ie. some kind of luminosity-dependent luminosity or density evolution. This could lead to a bimodal luminosity function.

- The Local Luminosity Function is incorrect as a result of missing objects such as those we have detected

While the SLUGS survey is currently the best determination of the local  $850\mu\text{m}$  luminosity function, it consists of less than 200 galaxies. It is thus entirely possible that classes of object are missing from it. If a class of cold dust temperature, high submm luminosity source existed, they might very well be absent from SLUGS. At the low dust temperatures of our galaxies,  $\sim 20\text{K}$ , such an object at  $z \sim 0.1$  would have a  $60\mu\text{m}$  flux  $\sim 70\text{mJy}$ , and so would not have appeared in the IRAS catalogs and would not have been targeted by SLUGS or any other submm followup. The corresponding  $100\mu\text{m}$  flux would be  $\sim 1\text{Jy}$ , since this is reaching towards the peak of the SED. Such a cold source might be written off as likely cirrus contamination and thus be absent from the main IRAS galaxy catalogs. Its  $850\mu\text{m}$  flux would be about  $100\text{mJy}$ , comparable to the  $60\mu\text{m}$  flux. At a redshift of 0.05 the fluxes would be 4 times larger and so such a source would still be only marginally detected by IRAS at  $60\mu\text{m}$ . If they exist, such objects would best be detected by large area, possibly all sky, shallow surveys with SCUBA2, or in the Planck all sky surveys.

- The bright targets are not members of the same population as the rest of our targets

Our application of the low  $z$  luminosity function is based on the assumption that all of our target SN host galaxies come from the same parent population of established galaxies with large stellar populations. This might not be the case. If there was an additional population of SN host galaxies with large submm luminosities not arising from quiescent dust heating, making up  $\sim 10\%$  of SN hosts, then it would not be correct to extrapolate the submm properties of the bulk of the SN hosts from a few objects coming from a separate population. How might such a situation arise? The obvious class of objects with large submm luminosities are galaxies hosting a substantial burst of star formation, though the low dust temperature in our bright submm objects and their quiescent morphology might argue against this. However, starburst galaxies are not the obvious hosts of type 1a supernovae. They are, though, the likely hosts of other classes of supernova. If some fraction of the SN1a's in the surveys are actually misclassified core collapse supernovae in actively starforming, dusty hosts - they might perhaps be type 1c SNe, which have masqueraded as type 1a's in the past (Kotak, private communication; see also Home-

ier, 2004) - then this could provide an explanation. There would, though, be consequences for the SN1a survey results if there is this level of contamination by non-1a's. Core collapse supernovae are typically of lower luminosity than type 1as. Type 1b and c SNe, viewed as a class, have absolute magnitudes about 1.24 magnitudes fainter than type 1a SNe (Richardson et al., 2002). If there is indeed a  $\sim 10\%$  contamination rate of type 1as by type 1cs in the surveys, then this could produce an overall dimming of the mean brightness by 0.24 magnitudes. This is comparable to the dimming at  $z \sim 0.5$  attributed to the cosmological constant or dark energy term (Perlmutter et al., 1999; Reiss et al., 1998), and thus might have a bearing on the reality or value of this cosmological component. The redshift evolution in the dimming of SN1as attributed to dark energy at higher redshifts would not easily be mimicked by interloping type 1c SNe, while the absence of starburst spectral features in these objects is an additional problem for this explanation.

At this stage it is not possible to choose between these scenarios since the sample of such objects is still very small. Each possible explanation has its own significant implications for astrophysics, so it is important that this strange population is followed up in more detail, and that steps are taken to expand the sample size. At this stage the only way to find more such objects seems to be to observe additional SN1a host galaxies, in which they are represented at  $\sim 10\%$ . This is not a particularly efficient method of discovery. Extension of our SN1a host studies to  $z=1$  might prove beneficial, and could test whether these objects are the result of evolution. Aside from that, the best hope for uncovering more of this class might be the cosmological submm surveys being proposed for SCUBA2. Furthermore, a very large area shallow SCUBA2 survey, possibly covering the whole accessible sky, would be one way to test the hypothesis that cold galaxies are a feature of the general galaxy population at all redshifts by looking for their local equivalents. Conversely, detailed study of our existing submm bright targets, in search of signs of recent star formation, might be the best way of testing our third explanation, and thus to remove any lingering doubts about the classification of their supernovae. The absence of clear starburst indications or of morphological disturbance in existing data probably makes this final explanation the least favoured of the three we have proposed.

## 6 CONCLUSIONS

We have extended our search for dust in the host galaxies of type 1a supernovae at  $z \sim 0.5$ . We combine our new observations with those of Paper 1, and find that there is no evidence for a substantial increase in optical obscuration in the galaxy population between  $z=0$  and  $z=0.5$ . We have, though, detected strong submm emission from one object, in addition to the one strong detection and one weaker detection from Paper 1. HST imaging of the two bright submm sources suggests they are quiescent, edge on disk galaxies, in contrast to the disturbed and interacting SMGs, found in blank field submm surveys, and local ULIRGs. We examine the dust properties of these sources, and conclude that they are ultra-luminous submm sources, with large dust masses,

but with cold dust SEDs,  $T \sim 20\text{K}$ . We also examine the luminosity distribution of the SN1a host galaxies as a class, and compare it to the local SLUGS submm luminosity function. We conclude that the  $z=0.5$  luminosity distribution seems bimodal, with an absence of sources within a factor of a few of our bright objects. Several scenarios could explain this effect, including some forms of luminosity function evolution, the absence of sources such as these from local submm surveys, or problems with the classification of  $\sim 10\%$  of SNe in the type 1a SN surveys. We propose various ways in which these hypotheses could be tested by future observations.

### Acknowledgements

The James Clerk Maxwell Telescope is operated by The Joint Astronomy Centre on behalf of the Particle Physics and Astronomy Research Council of the United Kingdom, the Netherlands Organisation for Scientific Research, and the National Research Council of Canada. DLC acknowledges funding from PPARC. JA gratefully acknowledges the support from the Science and Technology Foundation (FCT, Portugal) through the research grant POCTI-FNU-43805-2001. The authors would like to thank the staff at the JCMT for their usual excellent support work, and R. Kotak for useful discussions. The research described in this paper was carried out, in part, by the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by the National Aeronautics and Space Administration. This publication is also based in part on observations made with the NASA/ESA Hubble Space Telescope, obtained from the Data Archive at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS5-26555.

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