Dust content of core-collapse supernova hosts

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ABSTRACT

We study a small sample of $z = 0.1 - 0.6$ core-collapse supernova (CCSN) host galaxies. Continuum observations at 250GHz have been performed with MAMBO at the IRAM-30m telescope. None of these sources has been detected and the error-weighted mean flux is 0.25$\pm$0.32 mJy. Upper limits on their dust masses are derived and the corresponding sample mean corresponds to $1.4 \pm 2.2 \times 10^9 M_\odot$.

These results are comparable with previous submillimetre observations of SN-Ia hosts performed by Farrah et al. and by Clements et al. We conclude that CCSN hosts are not extreme at millimetre wavelengths, and as confirmed with the optical luminosities of a subset of our sample, they are typical of the local galaxy population.

Key words. Supernovae: general – Galaxies: starburst – Radio continuum: galaxies – Galaxies: high-redshift – Galaxies: evolution – dust, extinction

1. Introduction

In the Local Universe, type-Ia supernovae (SN-Ia) are detected in host galaxies along the whole Hubble sequence, while the core-collapse supernovae (CCSN) tend to avoid early-type galaxies (without gas). Star formation activity is known to increase with redshift (e.g. Madau et al. 1996, 1998; Chary & Elbaz 2001; Blain et al. 2002), while no evolution is early-type galaxies (without gas). Star formation activity is detected in host galaxies along the whole Hubble sequence, while moderate extinction is removed implicitly in the MLCS reduction methods (Riess et al. 1996; Hamuy et al. 1999). Selection effects are usually thought to favour hosts with less extinction (e.g. Concas et al. 2004), as very extinguished supernovae are not detected in the actual surveys. In addition, several SN-Ia surveys apply cuts on the $(A_V < 0.5 - 1)$ extinction (see e.g. Tonry et al. 2003; Riess et al. 2004, 2005, 2007), while moderate extinction is removed implicitly in the MLCS and $\Delta m_{15}$ reduction methods (Riess et al. 1996; Hamuy et al. 1996). There are indications that the distant SN-Ia might have a somewhat bluer colour than their local counterparts (Leibundgut 2001, and references therein). Last, Chary et al. (2005) have found with Spitzer MIPS observations of the GOODS fields that supernova host galaxies have a detection rate at 24$\mu$m that is a factor of 1.5 higher than the field galaxy population. Their sample is based on 50 supernovae sampled up to $z \sim 1$ and surprisingly, they find similar properties for SN-Ia and CCSN hosts.

Farrah et al. (2004) have statistically detected at the $3\sigma$ level the continuum emission at 350GHz of a sample of 16 SN-Ia...
Table 1. List of the CCSN galaxies observed for 250GHz-MAMBO continuum at IRAM-30m. (1): IAU designation; (2,3): J2000 RA, DEC coordinates; (4): redshift of the host galaxy or the SN; (5): SN type; (6): detection magnitude of the SN; (7): IAU circular numbers.

| Name     | RA J2000 | DEC J2000 | z  | type | Mag. | IAU C   |
|----------|----------|-----------|----|------|------|---------|
| 1995av   | 02 01 36.7 | +03 38 55.2 | 0.30 | II   | 20.1 | 62/70   |
| 1999fl   | 02 30 05.5 | +00 44 52.6 | 0.3  | II   | 24.9 | 7312    |
| 2001ek   | 02 30 17.6 | +01 03 56.4 | 0.25-0.40 | II   | 25.1 | 7719    |
| 1999fp   | 04 15 02.5 | +04 21 46.4 | 0.34 | II   | 24.1 | 7312    |
| 2000ei   | 04 17 07.2 | +05 45 53.1 | 0.60 | II   | 22.8 | 7516    |
| 1997ev   | 08 24 20.2 | +03 51 36.0 | 0.43 | II   | 23.0 | 6804    |
| 1997ew   | 08 24 25.0 | +03 49 08.0 | 0.59 | II/c?| 23.9 | 6804    |
| 1998at   | 10 54 54.3 | -03 44 10.0 | 0.40 | II   | 23.8 | 6881    |
| 2001ct   | 13 24 44.6 | +27 15 27.2 | 0.45 | II   | 23.4 | 7649    |
| 2002em   | 13 52 03.7 | -11 43 08.5 | 0.087 | I    | 22.3 | 7885    |
| 2002du   | 13 53 18.3 | -11 37 28.8 | 0.21 | II   | 22.2 | 7929    |
| 2001gl   | 14 01 16.6 | +05 12 48.9 | 0.36 | Ib/c | 23.7 | 7763    |
| 2002co   | 14 10 53.0 | -11 45 25.0 | 0.318 | II   | 22.6 | 7885    |

* We assume $z = 0.25$ in Figure 1.

hosts at $z = 0.5$, while one submm strong source has been detected directly. The authors interpret this result as the signature of a slight increase (25%-135%) of the dust content of this galaxy sample with respect to local normal galaxies, studied by Rowan-Robinson (2003). However, one should note that the definition of a “normal galaxy” reference sample is one difficulty of this type of work, which imposes magnitude thresholds and requires infrared/ultraviolet detections.

In this paper, we perform a study of the 1.2 mm continuum on a sample of 13 CCSN. In Sect. 2 the observations performed at the IRAM-30m telescope are presented together with the data reduction with the MOPSI software. In Sect. 3 we discuss our negative results.

Throughout this paper, we adopt a flat cosmology with $\Omega_m = 0.3$, $\Omega_{\Lambda} = 0.7$ and $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$.

2. Observations and data reduction

We have selected from the IAU list CCSN host galaxies with a redshift identification available in the range $0.1 < z < 1$ and a secure core-collapse type. The IAU circulars corresponding to each selected CCSN are provided in Table 1.

Millimetre continuum measurements were made during the Summer-2002 and Winter-2003 Pool observations on the MAMBO-1 (37-channels) and MAMBO-2 (117-channels) arrays installed on the IRAM-30m telescope (IRAM, Pico Veleta, Spain). The beam size (HPBW) was 11". Each of the CCSN host galaxies listed in Table 1 had been observed at 250 GHz using the on-off mode with the most sensitive channel (resp. no 1 and 20). To account for variations of the sky brightness, we used standard chopping of the secondary mirror of the telescope between the on-source position and a position ±33" away in azimuth, at a rate of 2Hz. In addition, the telescope nodded every 10 seconds such that the previous “off” position becomes the “on” position, in order to subtract background asymmetries between the two wobbler positions. Measurements of the sky opacity (sky dips) were taken approximately every two hours, while calibration sources were regularly monitored. The pointing was checked once per 30-60 minutes depending on the stability of the observing conditions. The focus was also regularly checked every 1-2 hours.

The data were reduced with the MOPSI software (Zylka 1998) following the standard procedure. A visual inspection of each scan had first been performed to remove the very noisy sub-scans. The skynoise reduction used the measurements from the six channels surrounding the photometric channel. Extinction correction was performed relying on a linear interpolation between sky dips taken before and after each set of observations or the closest value.

3. Results and discussion

3.1. Detection rate

As presented in Table 2, we did not detect any of the 13 CCSN host galaxies we observed. We also compute the error-weighted mean flux of the whole sample and find 0.25±0.32 mJy. We reach a sensitivity comparable to the sample (1.55 ± 0.31 mJy) of Farrah et al. (2004). However, contrary to these authors, we do not find any trace of signal. Their detection is dominated by 2 sources (SN1997ey and SN2000eh) and hence very sensitive to statistical fluctuations. In addition, we have shown in Melchior & Combes (2007) that the strongest of these 2 sources (SN1997ey host) has no significant gas content given its submillimetre flux: the latter might be due to a background source. Excluding this source, Farrah et al. (2004) find an error-weighted mean flux of their 16 galaxies of $1.01 \pm 0.33$ mJy. Removing the second source, detected at $3\sigma$ and at 850 m only, their mean flux reduces to $0.84 \pm 0.40$ mJy. Clements et al. (2005) have subsequently extended the SN-Ia host sample to 31 galaxies and found a less significant signal ($0.44 \pm 0.22$ mJy). Hence, we can conclude that our CCSN host measurements are consistent with the SN-Ia host findings. However, one can note that for a given level of rms sensitivity, the SCUBA measurements probe much deeper the thermal emission of galaxies as the 850- to 1200 m flux ratio is expected around 3.

3.2. Dust masses and comparison

Deriving dust masses from mm/submm continuum measurements depends on the complex parameters characterising the dust. They have first been provided by Hildebrand (1983), who
relied on reflection nebulae data. Large scatters thus affect the grain emissivity $Q(\lambda)$, the grain radius $a$ and the material density $\rho$, as further studied by various subsequent workers (e.g. Draine & Lee 1984; Casey 1991). In addition, initial works were based on 100/250\,$\mu$m measurements, which probe the hot dust component and tend to underestimate the total dust mass. James et al. (2001) has proposed a new approach to determine the dust mass-absorption coefficient $k_d(850\mu m) = 3Q(850\mu m)/(4\pi a)$, assuming that the fraction of metals within the interstellar medium of a galaxy bound up in dust is constant. They provide arguments in favour of this assumption and estimate $k_d(850\mu m) = 0.07\pm0.02\,\text{m}^2\,\text{kg}^{-1}$. This coefficient can be extrapolated to lower (or higher) frequencies than the emissivity index $\beta$ usually taken in the range $\beta \sim 1 - 2$: $k_d(\lambda) \propto \lambda^\beta$. Following e.g. Dunne et al. (2001), we considered $\beta = 2$, assuming optically thin dust emission. The dust mass $M_{dust}$ can thus be determined by the formula:

$$M_{dust} = \frac{S(\nu_{obs})D_L^2}{(1+z)k_d(\nu_{obs})B(\nu_{obs}, T_d)}$$

where $\nu_{obs}$ and $\nu_{obs}$ are the frequencies at which the radiation is emitted and observed, $T_d$ is the dust temperature, $D_L$ is the luminosity distance of the source, computed for a flat cosmology with a cosmological constant according to Pen (1999), $S(\nu_{obs})$ is the observed flux and $B(\nu_{obs}, T_d)$ is the Planck function.

Relying on Eq. 3 and the previous parameters, we have converted our 250\,$\mu$m continuum measurements into dust mass upper limits and superimposed them on various (350\,$\mu$m-based) dust mass estimates derived in this redshift range in Fig. 1. Note that as shown by Seaquist et al. (2004) for the SLUGS data (Dunne et al. 2000) the estimates based on 350\,$\mu$m data are overestimated by 25-38\% due to the contamination by the CO(3-2) line, which might be counter-balanced by an increased sensitivity to hot dust components. We have displayed the various dust mass estimates obtained at $z < 1.5$. The full bullets correspond to dust mass $M_{dust}^{old}$ obtained for IRAS Bright Galaxies (LIR < 10^{12}\,L_{\odot}) with a two-component-temperature fit to the data, assuming a cold $T_d = 20\,\text{K}$ and $\beta = 2$ (Dunne et al. 2000). The asterisk symbols provide the dust masses based on multiple modified blackbody with $\beta = 2$ for bright ultraluminous infrared galaxies (Klaas et al. 2001). The largest (resp. smallest) asterisk symbols correspond to galaxies with $L_{IR} > 10^{12}\,L_{\odot}$ (resp. $L_{IR} \leq 10^{12}\,L_{\odot}$). The crosses correspond to submillimetre galaxies from Chapman et al. (2005). For the other data sets, we derive the dust mass with the 350\,$\mu$m flux measurements. The star symbols correspond to radio-galaxies (Archibald et al. 2001) for which the synchrotron emission has been removed from the 350-GHz fluxes. (Note that the small-size star symbols refer to $T_{dust} = 40\,\text{K}$, favoured by the authors.) The square symbols correspond to the galaxy HR10 (Dev et al. 1999). The upright triangle symbols indicate the SN-Ia hosts detections by Farrah et al. (2004).

Figure 1 shows that our upper limits are consistent with the other data detected at $z < 1.5$. We can conclude that among our sample of CCSN hosts, none contains a very large amount of dust ($M_{dust} > 10^8\,M_{\odot}$). The error-weighted mean flux corresponds to a dust mass of $1.4\pm2.2\times10^8\,M_{\odot}$, which is comparable with the Farrah et al. (2004) sample and the upper distribution of the local SLUGS sources of Dunne et al. (2000).  

### 3.3. Optical fluxes

A sub-set (6/13) of our galaxies has been observed by the SDSS. We retrieve the corresponding ugriz photometry and derived the intrinsic B luminosity as displayed in Table 3. We can see the diversity of the host galaxies on our sample: very massive systems (87\,L_{\odot}) as well as normal galaxies (0.7\,L_{\odot}) are present, with an average B luminosity of 21\,L_{\odot}. This simply reflects the fact that these CCSN are detected in all types of galaxies containing gas and obeying the selection criteria.

### 4. Conclusion

We have observed 13 high-z CCSN host galaxies at 250\,$\mu$m and detected no signal. We can exclude that individual galaxies contain more than about $10^9\,M_{\odot}$ of dust, while the error-weighted average dust mass is $1.4\pm2.2\times10^8\,M_{\odot}$ for the whole sample. Our results are compatible with those of Farrah et al. (2004) only if the strong results detected by these authors is excluded, while we

### Table 2.

| Name    | $\tau_{250GHz}$ | $S(\nu_{250GHz})$ | $M_{dust}^{old}$ | $M_{dust}^{old}$ | date | TF | Bolo |
|---------|-----------------|-------------------|------------------|------------------|------|----|------|
| 1995av  | 0.54-0.66       | 0.96±0.25         | 0.35±0.60        | 0.25±0.39        | 19/10/02 | 36 | 37   |
| 1999f1  | 0.58-0.62       | -2.63±1.89        | -2.86±1.61       | -1.77±1.00       | 19/10/02 | 18 | 37   |
| 2001e\* | 0.50-0.54       | -0.22±1.48        | -0.18±0.89       | -0.12±0.56       | 15/03/03 | 26 | 117  |
| 1999fp  | 0.39-0.89       | 0.61±0.53         | 0.05±0.10        | 0.03±0.07        | 15/11/02 | 132| 37   |
| 2000ei  | 0.50-0.52       | -2.02±1.48        | -0.64±0.41       | -0.42±0.27       | 01/03/03 | 25 | 117  |
| 1997ev  | 0.33-0.72       | 0.33±0.59         | 0.21±0.83        | 0.14±0.53        | 15/11/02 | 93 | 37   |
| 1997ew  | 0.27-0.39       | 1.64±1.05         | 0.91±0.81        | 0.59±0.52        | 31/10/11/02 | 53 | 117  |
| 1998at  | 0.30-0.35       | -0.98±1.01        | -0.51±0.97       | -0.33±0.63       | 01/11/02 | 48 | 117  |
| 2001ct  | 0.29-0.43       | 0.22±1.07         | 0.13±0.32        | 0.08±0.21        | 10-11/02/03 | 43 | 117  |
| 2002cm  | 0.45-0.53       | 1.54±1.31         | 1.12±0.80        | 0.72±0.51        | 02/10/02/03 | 32 | 117  |
| 2002du  | 0.48-0.57       | -0.67±1.30        | -0.53±0.47       | -0.34±0.30       | 02/10/02/03 | 39 | 117  |
| 2001gl  | 0.37-0.55       | -0.02±0.84        | -0.02±1.12       | -0.01±0.70       | 02/11/02/03 | 32 | 117  |
| 2002co  | 0.53-0.55       | 0.77±1.46         | 0.40±0.64        | 0.26±0.42        | 02/11/02/03 | 32 | 117  |

* We assume $z = 0.25$. 

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Table 3. Optical magnitude and intrinsic luminosity for of subset of the CCSN sample. The ugriz magnitudes have been retrieved from the SDSS/DR6 database. The rest-frame B luminosities ($L_{\text{rest}}^B$) have been computed relying on the known redshifts.

| Name    | u      | g      | r      | i      | z      | $L_{\text{rest}}^B$ |
|---------|--------|--------|--------|--------|--------|---------------------|
|         | (mag)  | (mag)  | (mag)  | (mag)  | (mag)  | (mag)              |
| sn1999ll| 22.89±0.45 | 22.43±0.29 | 22.04±0.14 | 20.16±0.04 | 18.92±0.05 | 0.7               |
| sn2001ek| 23.69±1.79 | 23.33±0.48 | 21.59±0.16 | 20.70±0.11 | 19.93±0.19 | 0.6-2.5           |
| sn1997ev| 21.91±0.35 | 21.38±0.08 | 20.38±0.05 | 19.93±0.06 | 19.42±0.14 | 9.2               |
| sn1997ew| 22.48±0.49 | 20.31±0.03 | 18.93±0.01 | 18.43±0.01 | 18.06±0.03 | 87                |
| sn2001ct| 23.41±1.08 | 23.91±0.71 | 22.11±0.24 | 21.89±0.37 | 22.34±1.27 | 2.0               |
| sn2001gl| 22.65±0.36 | 19.98±0.02 | 18.61±0.01 | 17.94±0.01 | 17.59±0.01 | 28                |

Note: we consider $L_B$, $L_{\text{rest}}^B = 2.3 \times 10^9 L_\odot = 1.9 \times 10^9 L_\odot$.

Fig. 1. Dust mass-redshift diagram. Upper limits obtained for the dust mass of CCSN hosts are superimposed on dust mass estimates derived for other galaxies in this redshift range. We derive from our 250GHz measurements (provided in Table 1) upper values (3$\sigma$) on the corresponding dust masses for $T_{\text{dust}} = 20K$ (filled inverted triangle symbols) and $T_{\text{dust}} = 15K$ (open circle symbols). Lines connect these 2 upper values. The other points correspond to dust masses derived from 350-GHz (detected) fluxes (assuming $T_{\text{dust}} = 20K$ and $T_{\text{dust}} = 15K$ when indicated so). The upright triangle symbols correspond to the SN-Ia host detected by Farrah et al. (2004), and the mean flux derived from the rest of their SN-Ia host sample at $z = 0.5$. The full (resp. dashed) line correspond to a 1 mJy (1$\sigma$) sensitivity at 1.2mm for $T_d \sim 20K$ (resp. $T_d \sim 15K$). See text for more details.

find a good agreement with the results of Clements et al. (2005). The B luminosities of a subset of our sample present a significant diversity of the hosts. This study shows that CCSN host galaxies are typical of galaxies observed in the local Universe (e.g. Kauffmann et al. 2003) and do not belong to the brightest SMG population.

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Photometry of 6 galaxies has been retrieved from SDSS/DR6 database.

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