# Herschel limits on far-infrared emission from circumstellar dust around three nearby Type Ia supernovae

## J. Johansson,[★] R. Amanullah and A. Goobar

*Oskar Klein Centre, Stockholm University, SE 106 91 Stockholm, Sweden*

## ABSTRACT

We report upper limits on dust emission at far-infrared (IR) wavelengths from three nearby Type Ia supernovae: SNe 2011by, 2011fe and 2012cg. Observations were carried out at 70 and 160 μm with the Photodetector Array Camera and Spectrometer onboard the *Herschel Space Observatory*. None of the supernovae were detected in the far-IR, allowing us to place upper limits on the amount of pre-existing dust in the circumstellar environment. Due to its proximity, SN 2011fe provides the tightest constraints, $M_{dust} \lesssim 7 \times 10^{-3}\,M_{\odot}$ at a $3\sigma$ level for dust temperatures $T_{dust} \sim 500\,K$ assuming silicate or graphite dust grains of size $a = 0.1\,\mu m$. For SNe 2011by and 2012cg the corresponding upper limits are less stringent, with $M_{dust} \lesssim 10^{-1}\,M_{\odot}$ for the same assumptions.

**Key words:** circumstellar matter – supernovae: general – supernovae: individual: SN 2011by – supernovae: individual: SN 2011fe – supernovae: individual: SN 2012cg – dust, extinction.

## 1 INTRODUCTION

The use of Type Ia supernovae (SNe Ia) as distance indicators remains essential for the study of the expansion history of the Universe and for explorations of the nature of dark energy (Goobar & Leibundgut 2011). However, a lack of understanding of the progenitor systems and the requirement for empirically derived colour–brightness corrections represent severe limitations for precision cosmology. Information about the progenitor systems of SNe Ia can be obtained by searching for evidence of circumstellar material (CSM) associated with mass-loss prior to the explosion. In the single-degenerate model, a white dwarf (WD) accretes mass from its hydrogen-rich companion star until it reaches a mass close to the Chandrasekhar mass, at which point carbon ignites, triggering a thermonuclear explosion. In the double-degenerate model, a supernova results from the merger of two WDs. Thus, the detection of CSM arising from the transfer of matter to the WD by its non-degenerate binary companion would be a direct confirmation of the single-degenerate scenario. Dust may also be created in the circumstellar (CS) environment before the explosion, which would have important implications for observed colours of SNe Ia. This second scenario is the focus of this Letter. The existence of CSM around nearby SNe Ia has been suggested by studies of sodium absorption lines (e.g. SNe 1999cl, 2006X and 2007le; Patat et al. 2007; Blondin et al. 2009; Simon et al. 2009; Sternberg et al. 2011). High-resolution spectra reveal the presence of time-variable and blueshifted Na I D features, possibly originating from CSM

within the progenitor system. Studies of large samples of SNe Ia (Sternberg et al. 2011) find that half of all SNe Ia with detectable Na I D absorption at the host galaxy redshift have Na I D line profiles with significant blueshifted absorption relative to the strongest absorption component, which indicates that a large fraction of SN Ia progenitor systems have strong outflows. Foley et al. (2012) also find that SNe Ia with blueshifted CS/interstellar absorption systematically exhibit higher ejecta velocities and redder colours at maximum brightness relative to the rest of the SN Ia population.

Non-standard reddening has been noted in studies of individual and large samples of SNe Ia. For example, the colour excess indices of SN 2006X were studied in Folatelli et al. (2010), showing that the reddening is incompatible with the average extinction law of the Milky Way. Their findings augmented the large body of evidence indicating that the reddening of many SNe Ia show a steeper wavelength dependence ($R_V < 3.1$) than that which is typically observed for stars in our Galaxy. Previously, Nobili & Goobar (2008) derived $R_V = 1.75 \pm 0.27$ from a statistical study of 80 low-redshift SNe Ia. Similarly, when the colour–brightness relation is fitted jointly with cosmological parameters in the SNe Ia Hubble diagram, using a wide range of SNe Ia redshifts, low values of $R_V$ are obtained (see e.g. Suzuki et al. 2012 for a recent compilation).

Wang (2005) and Goobar (2008) showed that multiple scattering on CS dust could potentially help to explain the low values of $R_V \sim 1.5$–$2.5$ observed in the sight lines of nearby SNe Ia. Amanullah & Goobar (2011) simulated the impact of thin CS dust shells located at radii $r_d \sim 10^{16}$–$10^{19}$ cm ($\sim 0.003$–3 pc) from the SN, containing masses $M_{dust} \sim 10^{-4}\,M_{\odot}$, and find that this scenario would also perturb the optical light-curve shapes and introduce 'intrinsic' colour variations $\sigma_{E(B-V)} \sim 0.05$–$0.1$.

★ E-mail: joeljo@fysik.su.se

Thermal emission at infrared (IR) wavelengths could be the 'smoking gun' for the presence of CS dust. Pre-existing CS dust may be radiatively heated by absorption of UV/optical photons from the SN or collisionally heated by the SN shock. New dust grains could also be formed in SN Ia ejecta. Nozawa et al. (2011) model this process, and find that up to $0.2\,M_\odot$ of dust could condense $\sim$100–300 d after the explosion.

Gerardy et al. (2007) observed two normal SNe Ia (SNe 2003hv and 2005df) at late phases ($\sim$100–400 d after explosion) with the *Spitzer Space Telescope* in the 3.6–22 µm wavelength range. The mid-IR spectral energy distributions (SEDs) and photometry are compatible with strong atomic line emission from the SN, and therefore exhibit no compelling indication of pre-existing or newly formed dust. Nozawa et al. (2011) compare their models with the Gerardy et al. (2007) photometry and derive an upper limit of $0.075\,M_\odot$ of newly formed silicate dust. Furthermore, Gomez et al. (2012) studied the Kepler and Tycho supernova remnants (thought to be remnants of SNe Ia that exploded $\sim$400 yr ago) using observations in the 24–850 µm range and reported the detection of $\sim$3–9 × $10^{-3}\,M_\odot$ of warm dust ($\sim$90 K). Their findings are consistent with the warm dust originating in the CS (Kepler) and interstellar (Tycho) material swept up by the primary blast wave of the remnant.

In this Letter, we present the earliest far-IR measurements of SNe Ia, within 45 d after explosion, using the *Herschel Space Observatory* (Pilbratt et al. 2010) from 70 to 160 µm. We also derive limits on pre-existing dust in the CS environment of the three observed SNe.

## 2 TARGETS AND OBSERVATIONS

Thermal emission from heated pre-existing CS dust would be difficult to detect in the near-IR (NIR), except for large masses and high temperatures, but could be detected at mid-IR wavelengths, e.g. with *Spitzer*. However, the degeneracy with the photospheric emission around 5 µm makes it challenging to discriminate between emission by dust and intrinsic light from the SN. Conversely, observations at longer wavelengths (beyond 10 µm) would be dominated by radiating dust, which motivates the use of *Herschel* observations for this study.[1]

To investigate the presence of CS dust shells, the observations were carried out within 45 d from the SN explosion in order to minimize the risk of confusion with any newly formed dust produced in the SN ejecta (as seen in core-collapse SNe; Kotak et al. 2009).

Another factor is the duration of the IR echo, which is expected to scale with the radius of the CS dust shell, $t_{\rm echo} \sim 2r_{\rm d}/c$. For a geometrically thin, spherically symmetric shell, the fraction of emitting dust mass perceived by the observer increases with time, reaching maximum at $t = t_{\rm echo}$.

For shell radii, $r_{\rm d} \sim 10^{16}$ cm, the IR echo would be too short to be captured by our observations. However, in such a scenario, the CS dust would have been heated to high enough temperatures for its NIR emission to dramatically change the early part of the observed light curves. For dust at radii $r_{\rm d} \sim 10^{17}$ cm, the IR echo ($t_{\rm echo} = 3$–4 months) is partially within our observing window. Thus, although our observational strategy may miss the IR echo maximum, it nonetheless represents a reasonable compromise for exploring possible pre-existing CS dust shells.

In this study, we targeted three SNe Ia: SNe 2011by, 2011fe and 2012cg, selected based on their close proximity. Only one of these three SNe showed significant reddening at optical wavelengths (SN 2012cg), thus making a detection at far-IR wavelengths more challenging for the remaining two.

### 2.1 Herschel PACS data

The observations of SNe 2011by, 2011fe and 2012cg were obtained using the Photodetector Array Camera and Spectrometer (PACS; Poglitsch et al. 2010) onboard *Herschel*. The mini scan-map observing mode was used with a scan speed of 20 arcsec s$^{-1}$, resulting in a final map of 3 arcmin × 7 arcmin with a homogeneous coverage in the central region (about 50 arcsec in diameter). The full width at half-maximum (FWHM) of the point spread function (PSF) at 70 and 160 µm are 6 and 12 arcsec, respectively. The flux calibration uncertainty for the PACS 70 and 160 µm bands are currently estimated to be smaller than 5 per cent.[2] The colour corrections to the modelled dust emission spectra for the PACS 70 and 160 µm bands are negligible (maximally $\sim$5 per cent).

The data reduction was performed up to level2 using the Herschel Interactive Processing Environment (Ott 2010). Each target was observed for 4 h, with simultaneous imaging in the 70 and 160 µm bands resulting in unconfused 5$\sigma$ point source flux limits of approximately 5 and 10 mJy, respectively.

In addition to our observations, we also include analysis of archival data of the host galaxies of SNe 2011fe (M101 observed as part of the KINGFISH survey; Kennicutt et al. 2011) and 2012cg (NGC 4424 observed as part of the HeVICS survey; Davies et al. 2012). These observations were carried out in the large scan mode, with a medium scan map rate of 20 arcsec s$^{-1}$ resulting in maps with a 3.2 arcsec pixel$^{-1}$ resolution and an unconfused 5$\sigma$ point source flux limit of approximately 25 mJy in the 70 µm band.

Photometry was performed by using a set of single apertures (with radii defined by the FWHM of the PSF) to estimate the far-IR flux at the SN positions; apertures were also used to determine the average sky background level on the map, and the background fluxes in the vicinity of the SN.

### 2.2 SN 2011by

SN 2011by was discovered 2011/04/26.823 by Zhangwei Jin and Xing Gao at RA = 11:55:45.56, Dec. = +55:19:33.8 at a location 5.3 arcsec east and 191 arcsec north of the centre of the barred spiral galaxy NGC 3972 ($D = 18.5 \pm 0.8$ Mpc; Tully et al. 2009). The SN reached a peak *B*-band magnitude of $\sim$13 on around May 9 with a colour excess of $E(B - V) \approx 0.08$ mag (Maguire et al. 2012).

Our PACS 70 µm observations from 2011 May 24 (about two weeks after *B*-band maximum) are shown in Fig. 1. The SN exploded in a region of significant host galaxy background emission. To derive upper limits on possible emission from pre-existing CS dust, we compare the flux at the SN position with the estimated host galaxy background flux in the vicinity (Table 1). The galactic emission was estimated by placing apertures along isoflux contours. We measure no significant excess far-IR emission ($3.7 \pm 1.5$ mJy at 70 µm) with respect to the estimated host galaxy background at the location of SN 2011by.

---

[1] At the time our targets were observed, only the *Spitzer* 3.6 and 4.5 µm bands were operational.

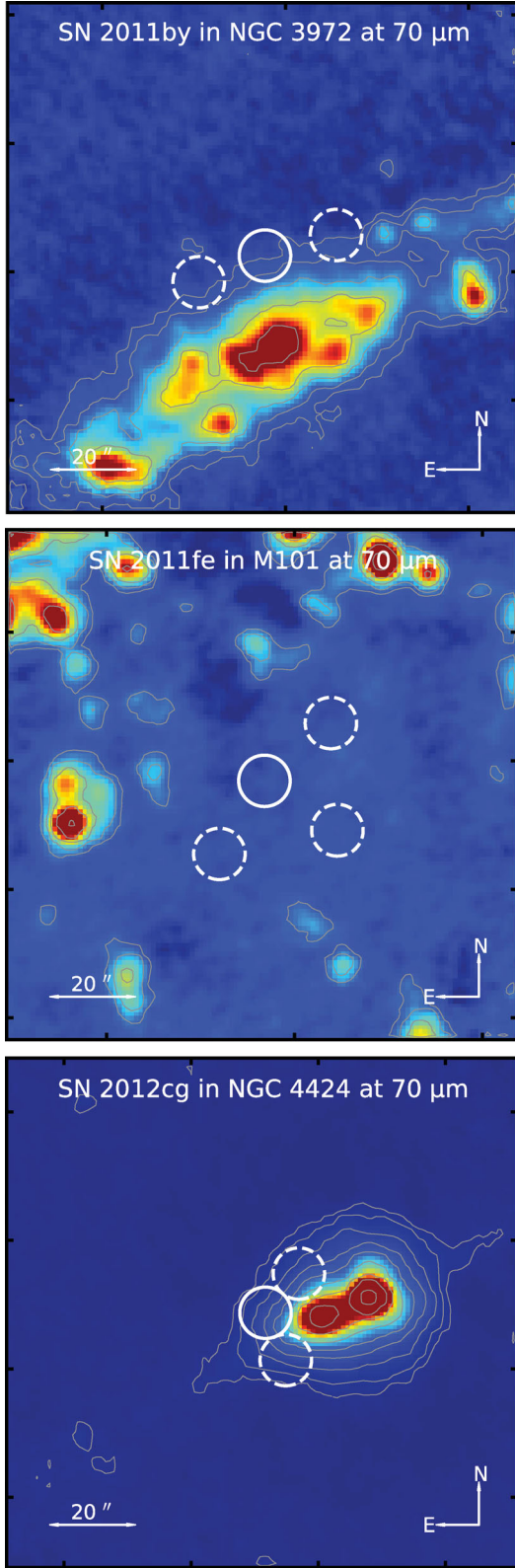[2] PACS Observer's Manual, section 3.3.

**Figure 1.** *Herschel* PACS 70 μm observations of SNe 2011by (top panel), 2011fe (middle panel) and 2012cg (bottom panel). The solid circles indicate the position of the supernovae and the FWHM of the PSF (6 arcsec). The dashed circles show the apertures used for background estimation.

**Table 1.** Photometry of SNe 2011by, 2011fe and 2012cg.

| Target | Host galaxy | Days from $B_{\mathrm{max}}$ | $F_\nu^{70\,\mu\mathrm{m}}$ (mJy) | $F_\nu^{160\,\mu\mathrm{m}}$ (mJy) |
|---|---|---|---|---|
| SN 2011by | NGC 3972 | +15 | $3.7 \pm 1.5$ | $16 \pm 8$ |
| | M101[a] | −451 | $-4.7 \pm 6.2$ | – |
| SN 2011fe | M101 | +23 | $-1.5 \pm 1.6$ | $-16 \pm 10$ |
| | NGC 4424[b] | −314 | $-15 \pm 5$ | – |
| SN 2012cg | NGC 4424 | +9 | $-0.7 \pm 1.8$ | $-23 \pm 8$ |

Data from [a]Kennicutt et al. (2011) and [b]Davies et al. (2012).

## 2.3 SN 2011fe

SN 2011fe was discovered 2011/08/24.000 by the Palomar Transient Factory at RA = 14:03:05.81, Dec. = +54:16:25.4 (J2000) at a location 58.6 arcsec west and 270.7 arcsec south of the centre of the nearby spiral galaxy M101 ($D = 6.4 \pm 0.5$ Mpc; Shappee & Stanek 2011). The SN reached a peak *B*-band magnitude of ~10 on around September 10 (Matheson et al. 2012). The Galactic and host galaxy reddening, deduced from the integrated equivalent widths of the Na I D lines are $E(B - V)_{\mathrm{MW}} = 0.011 \pm 0.002$ and $E(B - V)_{\mathrm{host}} = 0.014 \pm 0.002$ mag, respectively (Patat et al. 2013).

By analysing pre-explosion *Hubble Space Telescope* and *Spitzer* images, Li et al. (2011) and Nugent et al. (2011) are able to rule out red giants and a majority of helium stars as the mass donating companion to the exploding WD. Early phase radio and X-ray observations (Chomiuk et al. 2012; Horesh et al. 2012; Margutti et al. 2012) report non-detections, yielding constraints on the pre-explosion mass-loss rate from the progenitor system $\dot{M} \lesssim 6 \times 10^{-10}$–$10^{-8}(v_{\mathrm{wind}}/100\,\mathrm{km\,s^{-1}})\,\mathrm{M_\odot\,yr^{-1}}$. Although they are model dependent, these limits rule out a large portion of the parameter space of single-degenerate progenitor models for SN 2011fe. The absence of time-variant, blueshifted absorption features also rules out the presence of substantial amounts of CSM (Patat et al. 2013). In summary, previous observations are consistent with the progenitor of SN 2011fe being a binary system with a main-sequence or a degenerate companion star.

Our *Herschel* PACS 70 μm data from 2011 October 02 (about 33 d after *B*-band maximum) are shown in Fig. 1. SN 2011fe is located in a region with low host galaxy background emission. No excess far-IR emission is detected at the position of SN 2011fe ($-1.5 \pm 1.5$ mJy at 70 μm). We also analysed archival data to obtain the far-IR flux before the explosion (described in Section 2.1, Table 1). The measured background subtracted flux at the SN position is $-4.7 \pm 6.2$ mJy. There is no significant far-IR source evident at the location of the SN before or after the explosion.

## 2.4 SN 2012cg

SN 2012cg was discovered 2012/05/15.790 by the Lick Observatory Supernova Search at RA = 12:27:12.83, Dec. = +09:25:13.2 (J2000) at a location 17.3 arcsec east and 1.5 arcsec south of the peculiar SBa galaxy NGC 4424 ($D = 15.2 \pm 1.9$ Mpc, Cortés, Kenney & Hardy 2008). SN 2012cg reached a peak *B*-band magnitude of 12.1 on 2012 June 2. The SN show signs of host galaxy reddening, with a colour excess of $E(B - V) \approx 0.2$ mag derived from both optical photometry and high-resolution spectroscopy (Marion et al. 2012; Silverman et al. 2012).

Our *Herschel* PACS 70 μm data from 2012 June 11 (about 9 d after *B*-band maximum) are shown in Fig. 1. SN 2012cg is located in a region of significant host galaxy far-IR emission. We derive

upper limits on possible emission from pre-existing CS dust (Table 1) in a similar manner to SN 2011by, by comparing the flux at the SN position with the host galaxy background flux in the vicinity. We measure no excess far-IR emission ($-0.7 \pm 1.8$ mJy at 70 μm) with respect to the estimated host galaxy background at the location of SN 2012cg.

In addition, we also analyse pre-explosion archival PACS 70 μm data (described in Section 2.1). The background-subtracted flux at the SN location is $-15 \pm 5$ mJy. There is no significant far-IR source evident at the location of the SN before or after the explosion.

## 3 UPPER LIMITS FROM DUST MODELS

To model the far-IR emission from pre-existing CS dust, we consider the idealized case (described in Hildebrand 1983; Fox et al. 2010) of an optically thin dust cloud of mass $M_d$ with dust particles of radius $a$, emitting thermally at a single equilibrium temperature $T_d$. The expected flux at a distance $D$ is

$$F_\nu = M_d \frac{\kappa_\nu(a) B_\nu(T_d)}{D^2}, \qquad (1)$$

where $B_\nu(T_d)$ is the Planck blackbody function and the dust mass emissivity coefficient $\kappa_\nu(a)$ is

$$\kappa_\nu(a) = \left( \frac{3}{4\pi\rho a^3} \right) \pi a^2 Q_\nu(a) = \frac{3 Q_\nu(a)}{4a\rho}. \qquad (2)$$

$Q_\nu(a)$ is the absorption efficiency and the dust bulk (volume) density, $\rho \approx 2$–$3$ g cm$^{-3}$ depending on grain composition. The expected emission depends on the choice of dust grain composition and size. Interstellar dust is well described by a mixture of silicate and graphitic grains of different sizes, and generally in the far-IR $\kappa \propto \lambda^{-\beta}$ with $\beta \sim 1$–$2$ and $\kappa \approx 67.0$ cm$^2$ g$^{-1}$ at 70 μm (Draine & Li 2001). However, CS dust around SNe may well be dominated by either silicate or graphitic grains depending on the stellar atmosphere of the involved stars. Since we do not know the nature of the SNe Ia progenitor systems and their potential dust production mechanisms, we will consider separate scenarios of either silicate or graphite grains of radius $a = 0.1$ μm (described in Draine & Lee 1984; Laor & Draine 1993; Weingartner & Draine 2001).

From the non-detections of the SNe in the PACS 70 and 160 μm passbands we calculate upper limits on the CS dust mass surrounding SNe 2011by, 2011fe and 2012cg.

Fig. 2 shows the excluded dust mass range as a function of temperature for the three SNe, irrespective of heating mechanism. The upper limit on the dust temperature, set by the evaporation temperature of the dust grains ($T \lesssim 2000$ K), corresponds to a minimal dust survival radius $r_{evap} \sim 10^{16}$ cm (Amanullah & Goobar 2011). Detections of CSM around SNe Ia have been claimed at somewhat larger distances, $r_{CSM} \sim 10^{17}$ cm (e.g. Patat et al. 2007). To derive an estimate of the expected temperature of CS dust at similar radii, $r_d \sim 10^{17}$ cm, we follow the simple IR echo model in Fox et al. (2010) (see their fig. 8b). For a typical peak SN bolometric luminosity of $\sim 10^9$ L$_\odot$, radiatively heating a pre-existing dust shell of radius $r_d \sim 10^{17}$ cm, graphitic dust grains of $a = 0.1$ μm will be heated to $T_d \sim 500$ K (silicate grains would be heated to even higher temperatures).

In what follows, we use $T_d \sim 500$ K as a point of reference (marked by the dotted line in Fig. 2). The expected dust SED for this specific temperature is shown in Fig. 3, along with the sensitivity of current and future mid- and far-IR facilities.

Due to its proximity, SN 2011fe yields the tightest constraints, $M_d \lesssim 7 \times 10^{-3}$ M$_\odot$ at a $3\sigma$ level, assuming graphitic dust grains of
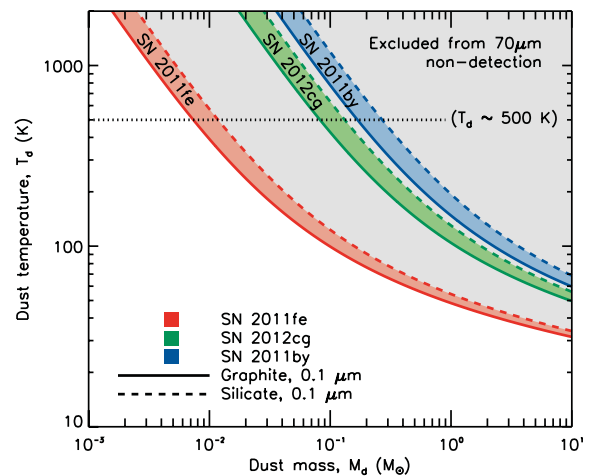


**Figure 2.** $3\sigma$ upper limits on the CS dust mass and temperature, assuming graphitic (solid lines) or silicate (dashed lines) dust grains of size $a = 0.1$ μm, derived from the non-detection in the *Herschel* PACS 70 μm observations of SNe 2011by (blue lines), 2011fe (red lines) and 2012cg (green lines). The horizontal dotted line indicates the expected temperature $T_d \sim 500$ K for a pre-existing dust shell of radius $r_d \sim 10^{17}$ cm.
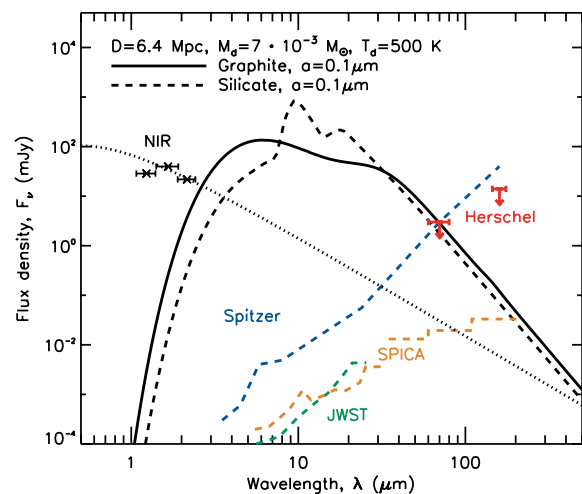


**Figure 3.** Example of expected IR SEDs of CS dust, assuming a distance of 6.4 Mpc, $M_d = 7 \times 10^{-3}$ M$_\odot$ and $T_d = 500$ K with graphitic (solid black line) or silicate (dashed black line) dust grains of size $a = 0.1$ μm. The dotted black line shows a blackbody spectrum at $10^4$ K, scaled to match the NIR fluxes of SN 2011fe 33 d after maximum brightness (Matheson et al. 2012). For comparison, the $5\sigma$ detection limits of 3 h observations with *Spitzer* (blue dashed line), the *James Webb Space Telescope* (green dashed line) and *SPICA* (orange dashed line) are included. The red symbols indicate the $3\sigma$ upper limits on the flux of SN 2011fe in the PACS 70 and 160 μm bands (described in Section 2.3).

size $a = 0.1$ μm heated to temperatures $T_d \sim 500$ K (red solid line in Fig. 2). For silicate dust grains, the corresponding upper limit is $M_d \lesssim 10^{-2}$ M$_\odot$ (red dashed line in Fig. 2). The upper limits for SN 2011by are weaker, $M_d \lesssim 10^{-1}$ M$_\odot$ at a $3\sigma$ level for similar assumptions (blue solid and dashed lines for graphitic and silicate dust grains in Fig. 2). For SN 2012cg, the upper limits are $M_d \lesssim 8 \times 10^{-2}$ M$_\odot$ at a $3\sigma$ level for assuming graphitic dust grains of size $a = 0.1$ μm heated to temperatures $T_d \sim 500$ K (green solid line in Fig. 2).

# 4 SUMMARY AND CONCLUSIONS

Searches for evidence of CSM around SNe Ia are an important aspect in the efforts to understand the exact nature of these explosions and their use as accurate distance estimators. For the latter, the presence of pre-explosion CS dust could explain the empirically derived, non-standard reddening corrections that are applied to minimize the scatter in the SNe Ia Hubble diagram (Goobar 2008).

In this work, we searched for far-IR emission from pre-existing CS dust around three nearby SNe Ia *within* a few weeks after maximum brightness. By considering the *Herschel* non-detections, we can exclude dust masses $M_d \gtrsim 7 \times 10^{-3}\,\mathrm{M_\odot}$ for dust temperatures $T_d \sim 500\,\mathrm{K}$ at a $3\sigma$ level for SN 2011fe, and the upper limits are one order of magnitude weaker for SNe 2011by and 2012cg, excluding dust masses $M_d \gtrsim 10^{-1}\,\mathrm{M_\odot}$.

Although these are the strictest upper limits on CS dust around newly exploded SNe Ia, our limits cannot completely rule out the presence of CS dust as a contributing source to SN Ia reddening. Our sensitivity for CS dust masses ($M_d \sim 10^{-3}$–$10^{-2}\,\mathrm{M_\odot}$) is about one–two order of magnitudes larger than the dust masses that have been suggested in simulations ($M_d \sim 10^{-4}\,\mathrm{M_\odot}$ in Amanullah & Goobar 2011).

While current instrumentation allows mainly for exploration of CS dust around SNe within the very local universe ($D \lesssim 5\,\mathrm{Mpc}$), future missions such as *JWST* and *SPICA*, will have the potential to dramatically improve the sensitivity, as shown in Fig. 3.

## REFERENCES

Amanullah R., Goobar A., 2011, ApJ, 735, 20
Blondin S., Prieto J. L., Patat F., Challis P., Hicken M., Kirshner R. P., Matheson T., Modjaz M., 2009, ApJ, 693, 207
Chomiuk L. et al., 2012, ApJ, 750, 164
Cortés J. R., Kenney J. D. P., Hardy E., 2008, ApJ, 683, 78
Davies J. I. et al., 2012, MNRAS, 419, 3505
Draine B. T., Lee H. M., 1984, ApJ, 285, 89
Draine B. T., Li A., 2001, ApJ, 551, 807
Folatelli G. et al., 2010, AJ, 139, 120
Foley R. J. et al., 2012, ApJ, 752, 101
Fox O. D., Chevalier R. A., Dwek E., Skrutskie M. F., Sugerman B. E. K., Leisenring J. M., 2010, ApJ, 725, 1768
Gerardy C. L. et al., 2007, ApJ, 661, 995
Gomez H. L. et al., 2012, MNRAS, 420, 3557
Goobar A., 2008, ApJ, 686, L103
Goobar A., Leibundgut B., 2011, Annu. Rev. Nucl. Part. Sci., 61, 251
Hildebrand R. H., 1983, QJRAS, 24, 267
Horesh A. et al., 2012, ApJ, 746, 21
Kennicutt R. C. et al., 2011, PASP, 123, 1347
Kotak R. et al., 2009, ApJ, 704, 306
Laor A., Draine B. T., 1993, ApJ, 402, 441
Li W. et al., 2011, Nat, 480, 348
Maguire K. et al., 2012, MNRAS, 426, 2359
Margutti R. et al., 2012, ApJ, 751, 134
Marion G. H. et al., 2012, Astron. Telegram, 4159, 1
Matheson T. et al., 2012, ApJ, 754, 19
Nobili S., Goobar A., 2008, A&A, 487, 19
Nozawa T., Maeda K., Kozasa T., Tanaka M., Nomoto K., Umeda H., 2011, ApJ, 736, 45
Nugent P. E. et al., 2011, Nat, 480, 344
Ott S., 2010, in Mizumoto Y., Morita K.-I., Ohishi M., eds, ASP Conf. Ser. Vol. 434, Astronomical Data Analysis Software and Systems XI. Astron. Soc. Pac., San Francisco, p. 139
Patat F. et al., 2007, Sci, 317, 924
Patat F. et al., 2013, A&A, 549, A62
Pilbratt G. L. et al., 2010, A&A, 518, L1
Poglitsch A. et al., 2010, A&A, 518, L2
Shappee B. J., Stanek K. Z., 2011, ApJ, 733, 124
Silverman J. M. et al., 2012, ApJ, 756, L7
Simon J. D. et al., 2009, ApJ, 702, 1157
Sternberg A. et al., 2011, Sci, 333, 856
Suzuki N. et al., 2012, ApJ, 746, 85
Tully R. B., Rizzi L., Shaya E. J., Courtois H. M., Makarov D. I., Jacobs B. A., 2009, AJ, 138, 323
Wang L., 2005, ApJ, 635, L33
Weingartner J. C., Draine B. T., 2001, ApJ, 548, 296

This paper has been typeset from a TeX/LaTeX file prepared by the author.