The Lives and Death-Throes of Massive Stars
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Mass of dust in core-collapse supernovae as viewed from energy balance in the ejecta

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Abstract. Recent far-infrared (FIR) observations have revealed the presence of freshly formed dust with the masses exceeding 0.1 $M_\odot$ in young remnants of core-collapse supernovae (CCSNe) such as SN 1987A and Cassiopeia A. Meanwhile, dust masses derived from near- to mid-infrared (N/MIR) observations of CCSNe a few years after explosions are on the order of 10^{-5}–10^{-3} $M_\odot$. Here, we demonstrate that such small dust masses as seen from N/MIR observations would not necessarily reflect the formation history of dust but could be just limited by the luminosity of the SN that can heat up dust formed in the ejecta.

Keywords. dust, extinction, infrared: stars, supernovae: general

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1. Mass, temperature, and luminosity of dust formed in the SN ejecta

Suppose that the heating source of dust grains formed in the ejecta is the radiation of the SN. The luminosity of the SN, $L_{\rm SN}$, at late phases ($\geqslant\sim$100 days) is estimated, given that it is powered by decay energy of ^{56}Co (e.g., Woosley *et al.* 1989). With ^{56}Co of 0.075 $M_\odot$, $L_{\rm SN}$ ranges from 6×10^{40} erg s^{-1} down to 8×10^{38} erg s^{-1} at 300 days to 700 days. On the other hand, the N/MIR observations show that the dust temperature is $\simeq$300–700 K at 300–700 days (e.g., Wooden *et al.* 1993). If all of the newly formed dust grains are heated up to the identical temperature, $T_{\rm dust}$, by absorbing some fraction of the SN radiation, $f_{\rm abs}$ (i.e., IR luminosity of dust emission is given by $L_{\rm IR} = f_{\rm abs} L_{\rm SN}$), the dust mass, $M_{\rm dust}$, is determined from the energy (luminosity) balance as follows:

$$\begin{aligned} M_{\rm dust} &= \frac{f_{\rm abs} L_{\rm SN}}{4\sigma T_{\rm dust}^4 \langle \kappa(T_{\rm dust}) \rangle} \\ &\simeq 0.01 \left(\frac{f_{\rm abs}}{0.5}\right) \left(\frac{L_{\rm SN}}{6\times10^{40}\ {\rm erg\ s^{-1}}}\right) \left(\frac{T_{\rm dust}}{300\ {\rm K}}\right)^{-4} \left(\frac{\langle \kappa(T_{\rm dust}) \rangle}{660\ {\rm cm^2\ g^{-1}}}\right)^{-1} \quad M_\odot, \end{aligned}$$

where $\langle \kappa(T_{\rm dust}) \rangle = 660$ cm^2 g^{-1} is the lowest value of the Planck-averaged mass absorption coefficients in the range of $T_{\rm dust} = 300$–700 K for both silicate and carbon grains.

The above equation points out that the mass of dust which can be heated to $T_{\rm dust} \geqslant 300$ K should be less than 10^{-2} $M_\odot$. In other words, even if dust grains in excess of 0.1 $M_\odot$ are formed at 1–2 years post-explosion, the SN luminosity is not high enough to heat all of them to temperatures higher than $\simeq$150 K. Hence, it is likely that N/MIR observations, which is sensitive to dust emission with >200 K, have detected only a tiny fraction of newly formed dust. This may suggest that the majority of dust grains form inside dense gas clumps so that their temperatures are too low to be detected at N/MIR wavelengths.

References

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