# Dust masses in the ejecta of core-collapse supernovae from modelling their red-blue optical line profile asymmetries

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The source of the very large masses of dust observed in some very early Universe galaxies at redshifts z > 6 has been much debated. Core-collapse supernovae (CCSNe) have been predicted to be efficient producers of dust but the majority have only had small masses of warm dust ($< 10^{-3}$ $M_\odot$) detected in their ejecta during their early phases (t < 3 years), based on fits to their near-IR and mid-IR SEDs. However, observations in the far-IR by Herschel and ALMA of a few CCSNe have yielded far higher cold dust masses (0.1 – 1.0 $M_\odot$), which, if representative of the wider CCSN population, could potentially account for the dust masses seen in the early Universe. Unfortunately, there are now few instruments capable of detecting CCSN dust emission at far–IR and sub–mm wavelengths, so other techniques must be exploited.

The late-time optical and near-IR line profiles of many core-collapse supernovae exhibit a red-blue asymmetry caused by red-shifted emission from the receding parts of the ejecta, which must traverse the dusty interior of the ejecta, experiencing greater extinction than the blue-shifted emission. We present Monte Carlo line transfer models of asymmetric optical line profiles in the late-time spectra of SN 1993J, SN 1987A, SN 1980K and Cas A using the new code DAMOCLES (Bevan & Barlow 2016). We derive dust mass estimates at late times of 0.08 – 0.18 $M_\odot$ for SN 1993J, 0.12 – 0.3 $M_\odot$ for SN 1980K and ∼1.1 $M_\odot$ for Cas A. We also present a series of models of the [OI] and H$\alpha$ line profiles for SN 1987A over a range of epochs. The derived dust masses as a function of epoch are consistent with continuous dust formation during the first few decades of ejecta evolution and final dust mass estimates of 0.4 – 0.7 $M_\odot$. We conclude that dust masses > 0.1 $M_\odot$ have formed in the ejecta of these objects supporting the case that CCSNe are the dominant sources of dust in the early Universe.