Dust in supernova remnants: grain heating mechanisms, dust masses and survivability

Felix D. Priestley
M. J. Barlow, I. De Looze, H. Chawner

UCL

Introduction: Recent observations of nearby core collapse supernova remnants (SNRs) have found evidence for 0.05-0.5 M_{sun} of ejecta dust in Cassiopeia A (Cas A; De Looze+2017), the Crab Nebula (De Looze+2019), SN1987A (Matsuura+2015) and several Galactic SNRs (Chawner+2019). This suggests core collapse supernovae could be an important source of dust at high redshifts (Morgan & Edmunds 2003, Dwek+2007).

In order to contribute to the ISM dust budget, this dust must survive processing by the reverse shock, while some models of dust destruction suggest surviving fractions of ~1-10% (e.g. Bocchio+2016). However, large grains are resistant to destruction by sputtering (Nozawa+2007), and the size distribution of dust in SNRs is currently poorly constrained, while clumped rather than smooth geometries can increase survival rates (Biscaro & Cherchneff 2016, Micelotta+2016, Kirchschlager+2019).

Method: Previous modelling of SNR dust spectral energy distributions (SEDs) has used modified blackbody fits to determine the mass and temperature of predefined temperature components. We instead determine the physical conditions within SNRs and calculate dust SEDs using DINAMO (Priestley+2019a), a dust emission code including stochastic heating of small grains, and accounting for radiative and collisional heating mechanisms. Fitting the observed dust SED with these theoretical ones allows us to determine what phase of gas the dust is located in, and investigate properties such as grain size and composition which are often either assumed or neglected entirely.

Cas A: We fit the observed dust SED of Cas A using a four-component model, consisting of model dust SEDs from pre/post-shock clumps and forward/reverse shocked diffuse gas (Fig. 1). All components are irradiated by the synchrotron radiation from the shocked material, which is the dominant heating mechanism for the unshocked and clumped dust, while the dust in the diffuse gas is strongly heated by particle collisions. The unshocked ejecta contains ~0.6 M_{sun} of silicates, with an additional ~0.06 M_{sun} in the shocked clumps and a negligible mass in the X-ray emitting diffuse gas (Fig. 2). Based on an unshocked ejecta gas mass of ~3 M_{sun} (Arias+2018) and a shocked clump gas mass of 0.6 M_{sun} (Priestley+2019a), the dust-to-gas mass ratios are 0.2 and 0.1 respectively. If the shocked clumps initially had the same mass ratio as the unshocked material, **50% of dust in clumps survives the passage of the reverse shock.**

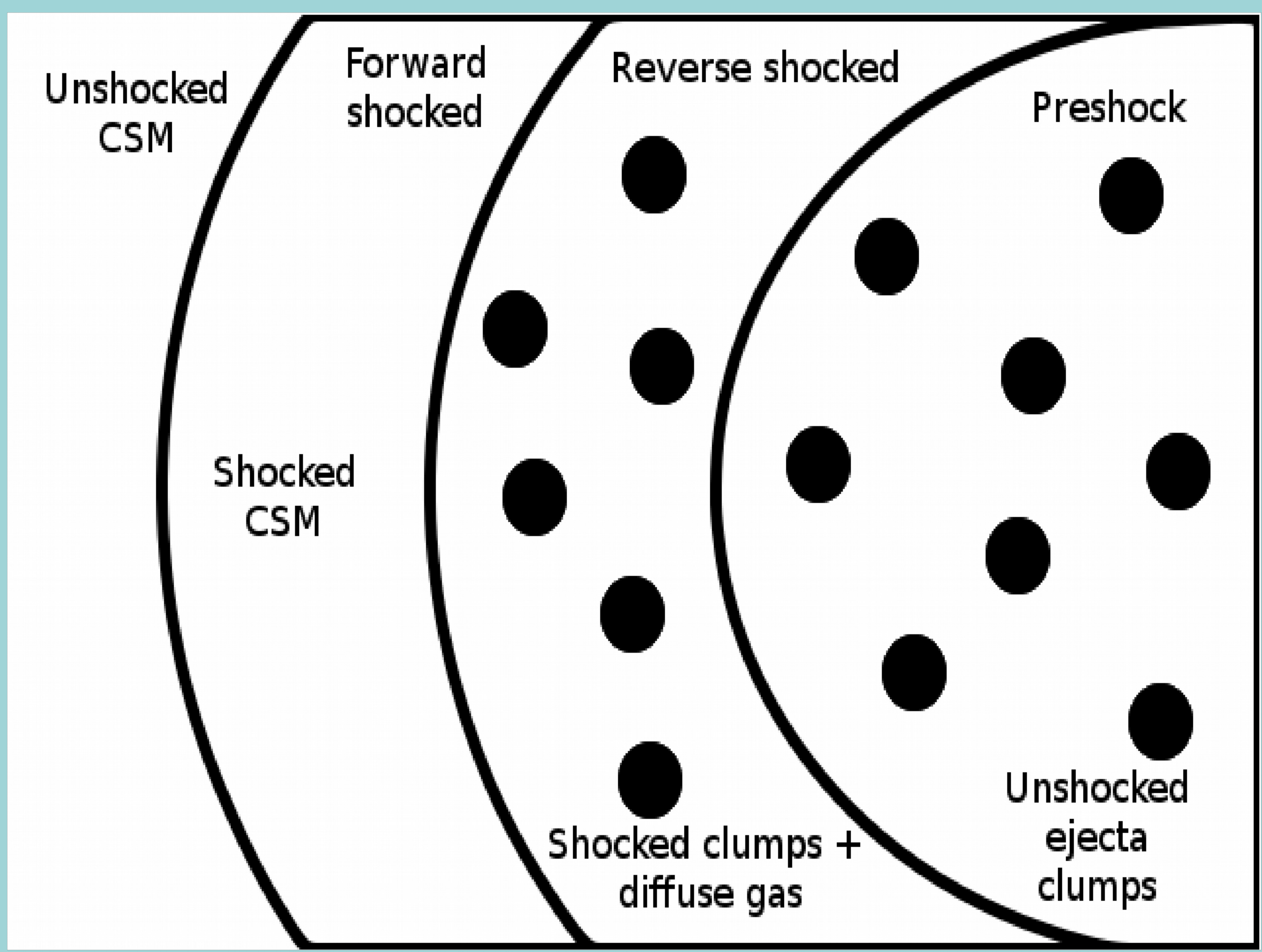

Fig. 1: Schematic diagram of the four-component model adopted for Cas A.

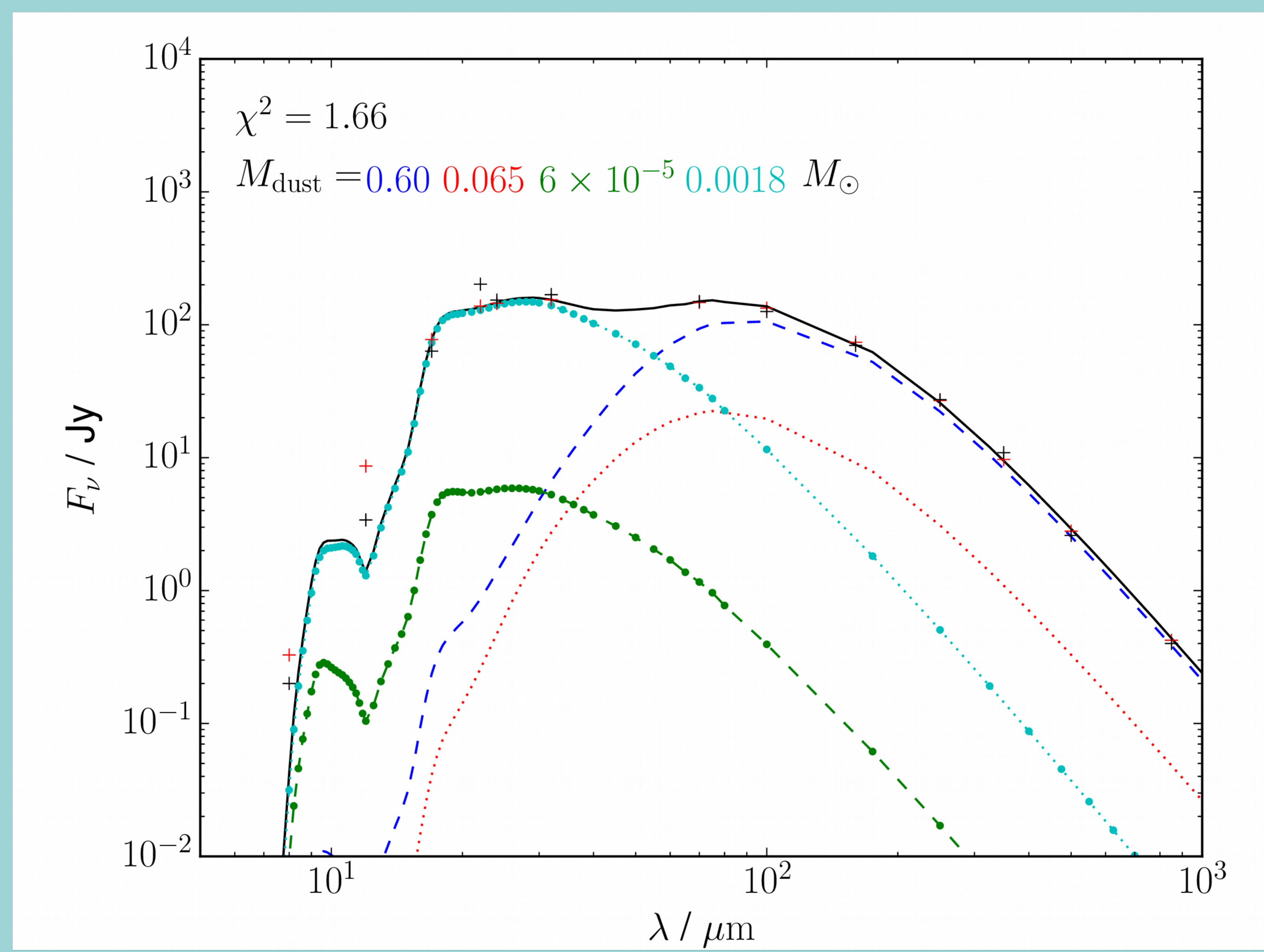

Fig. 2: Cas A dust SED (black crosses), total model SED (black solid line/red crosses) and individual dust component SEDs (coloured lines) for $MgSiO_3$ grains.

PWNe: Pulsar wind nebulae (PWNe) such as the Crab Nebula can be modelled as one dust component, heated by the synchrotron radiation field and the ambient gas. We fit the Crab Nebula dust SED using model SEDs for single grain sizes, allowing us to constrain the grain size distribution (Priestley+2019b). We find dust masses of 0.03-0.22 M_{sun} depending on grain composition, with the majority of the mass in micron-sized grains. Using the same modelling technique on four additional PWNe from Chawner+2019, **micron-sized grains make up large fractions of the dust mass in all cases (Tab. 1).** This has implications for survival rates, as large grains are less affected by sputtering (Nozawa+2007), although grain-grain collisions can reprocess them into smaller grains more vulnerable to destruction (Kirchschlager+2019).

Tab. 1: Dust masses and fraction of total mass in micron-sized grains for our sample of five PWNe.

Object	Crab Nebula	G11.2-0.3	G21.5-0.9	G29.7-0.3	G54.1+0.3
Dust mass / M_{sun}	0.03-0.22	0.34-1.86	0.06-0.28	0.07-0.33	0.10-0.32
M(1 μm) / M_{tot}	0.88	0.93	0.95	0.58	0.55

Refs.: De Looze et al. 2017 MNRAS 465 3309, De Looze et al. 2019 submitted, Matsuura et al. 2015 ApJ 800 50, Chawner et al. 2019 MNRAS 483 70, Morgan & Edmunds 2003 MNRAS 343 427, Dwek et al. 2007 ApJ 662 927, Bocchio et al. 2016 A&A 587 A157, Nozawa et al. 2007 ApJ 666 955, Biscaro & Cherchneff 2016 A&A 589 A132, Micelotta et al. 2016 A&A 590 A65, Kirchschlager et al. 2019 submitted, Priestley et al. 2019a MNRAS 485 440, Priestley et al. 2019b in prep, Arias et al. 2018 A&A 612 A110