Survival of Dust Created in the Supernova Remnant Cas A

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Abstract

Supernovae are known creators of dust in their dense cold ejecta. However it is still uncertain how much of that dust survives and is injected into the interstellar medium. Here we present the results of new hydrodynamical simulations using the FLASH code in which we model the evolution of the clumpy ejecta in the Cas A supernova remnant (SNR) as an exemplar of such dust creating SNRs. Along with the hydrodynamical evolution of the clumpy ejecta, we model the processing of the dust grains created in the ejecta via inertial sputtering. We do this by following the trajectories of the grains as they are eroded and experience drag after the ejecta are decelerated and the grains decouple from the gas. Our goal is to trace the evolution of dust from the ejecta clumps in order to assess the fraction of the dust mass that survives the interaction with the reverse shock and ends up finally in the interstellar medium.

Simulation Initial Conditions

- Ejecta have constant density core + outer envelope with $\rho \sim r^{-9}$
- Circumstellar medium (CSM) outside of ejecta assumed to be the progenitor stellar wind with $\rho \sim r^{-2}$
- Interstellar medium has constant density outside CSM
- Ejecta core contains clumps with $\rho_{clump}/\rho_{smooth}$= 100 with volume filling factor of clumps assumed to be 2%
- Dust grains are placed randomly within each clump (currently 10/clump). So far assumed 0.1 μm silicate grains

Several observables constrain shocked ejecta mass, "current" position of forward and reverse shock, pre-shock density at forward shock, etc.

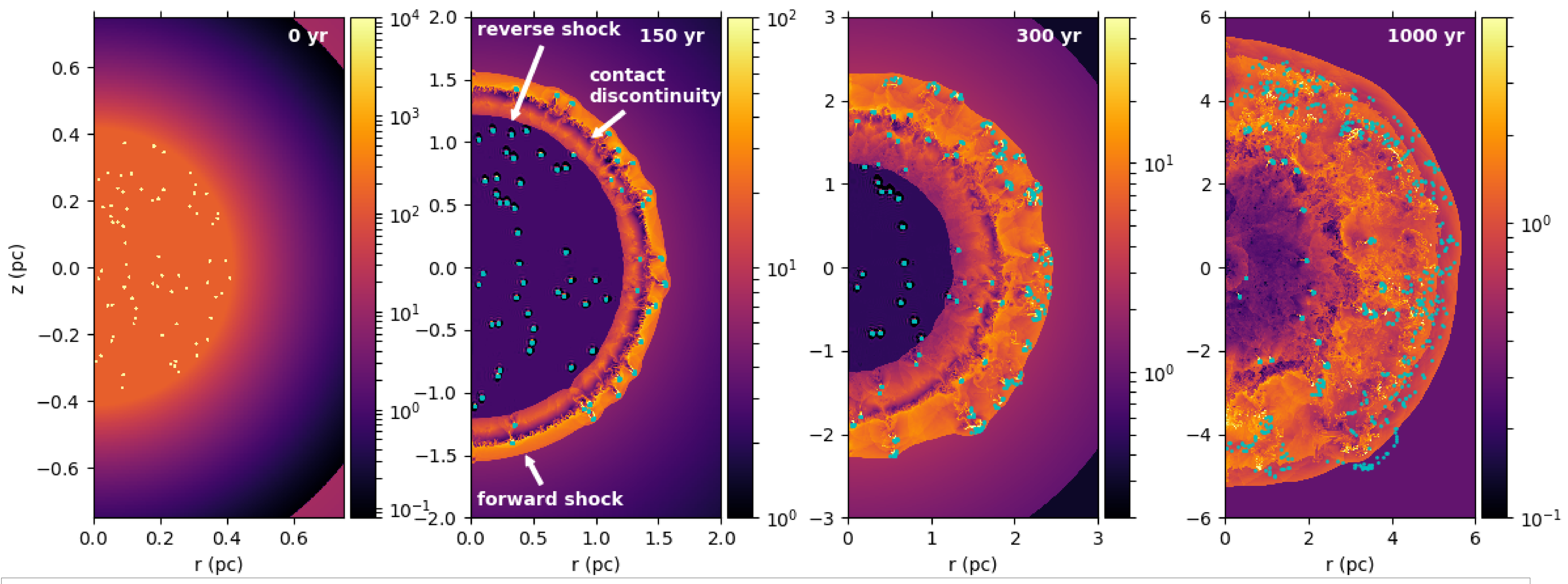

Fig. 2 – Evolution of gas density and dust in Cas A simulation. Simulation was done in 2D (cylindrical symmetry). Dust particles (cyan dots) all start in dense clumps. Grains are not plotted in first (leftmost) panel so that the ejecta clumps (yellow dots) can be seen – grains mostly obscure the ejecta clumps in this figure. Note that the spatial scale changes from panel to panel as does the density scale. Grains decouple from the clumps over time, especially after the clumps cross the contact discontinuity between the shocked ejecta and shocked CSM (clearest in middle two panels). The decoupling can be seen especially in the last frame on the right (note grains ahead of forward shock).

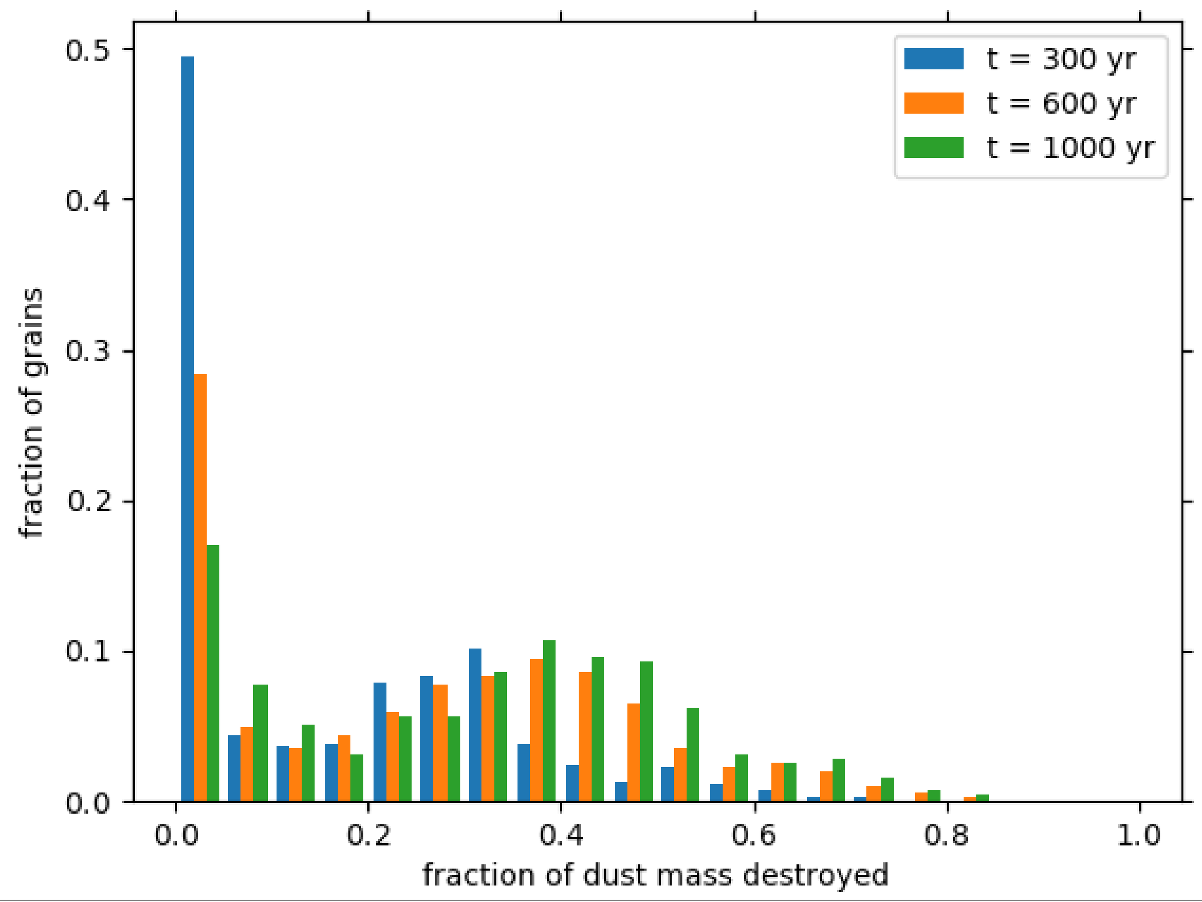

Fig. 4 – Evolution of grain destruction in the remnant. Grain destruction varies depending on the changing environment of the grain, which in turn depends on its original location within the ejecta. These histograms are for the entire population of dust in the remnant and illustrate the range of the destroyed fraction (mass sputtered from grain/initial mass of grain) and how that evolves with time. We expect grains to continue to be sputtered until their velocity relative to the surrounding gas drops below the sputtering threshold.

Next Steps

- Include radiative cooling and possibly thermal conduction
- Explore grain size dependence for destruction
- Look at effects of grain composition
- Examine longer term evolution to evaluate how much grain mass escapes from the remnant to seed the ISM with dust

Methods

Use FLASH numerical hydrodynamics code with new active particle unit that we've written. Particles are free to move separately from the gas but are partially coupled via:

- direct drag on the dust from collisions with gas particles (including thermal term)
- inertial (or non-thermal) sputtering caused by relative gas-grain motion, which erodes the grains

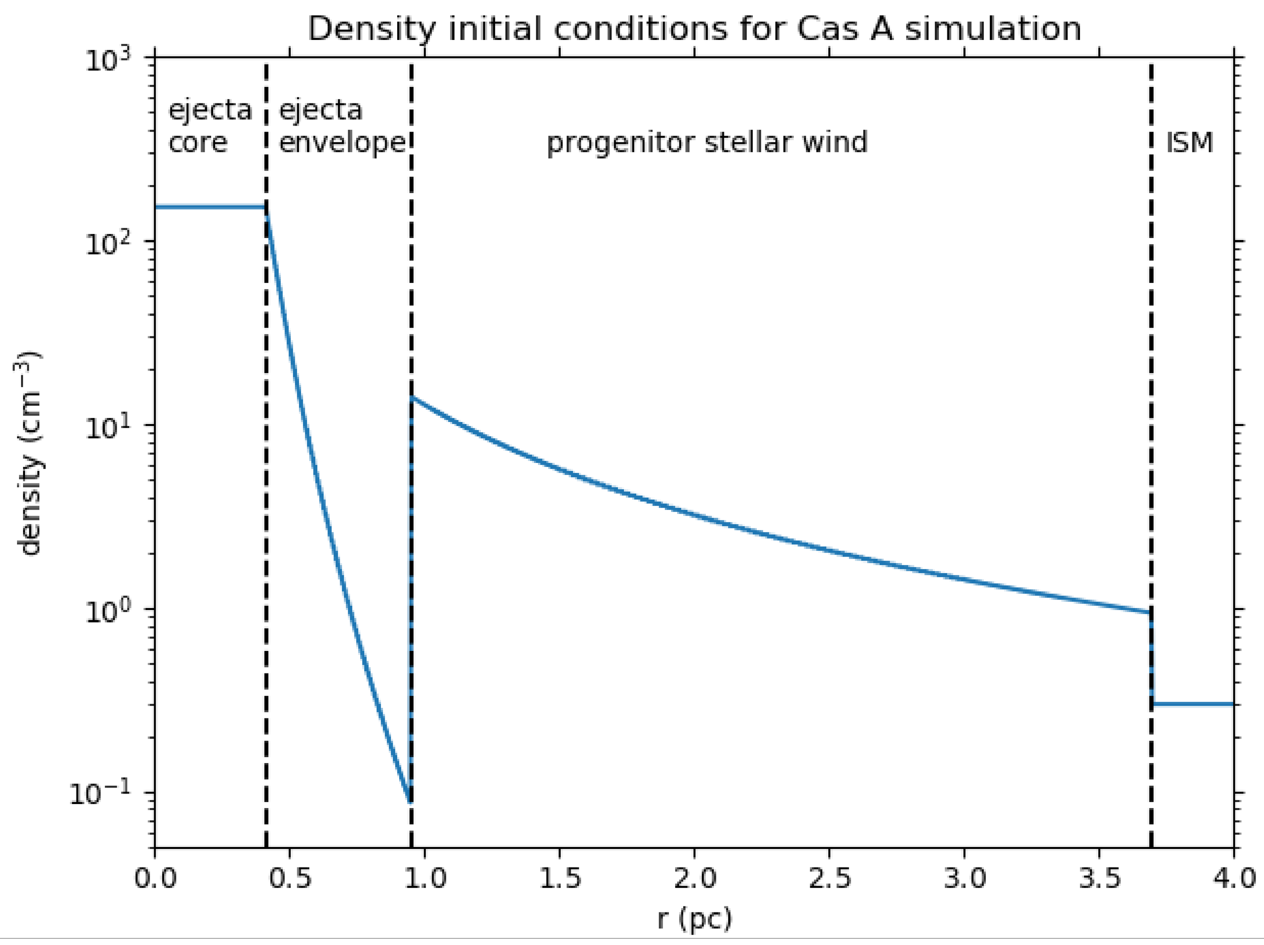

Fig. 1 – Density initial conditions for Cas A simulation. The density shown in the core is that of the smooth ejecta. The clumpy ejecta knots have a density that is 100 times that of the smooth ejecta. Initial velocity of ejecta is $v \sim r$ in both core and envelope.

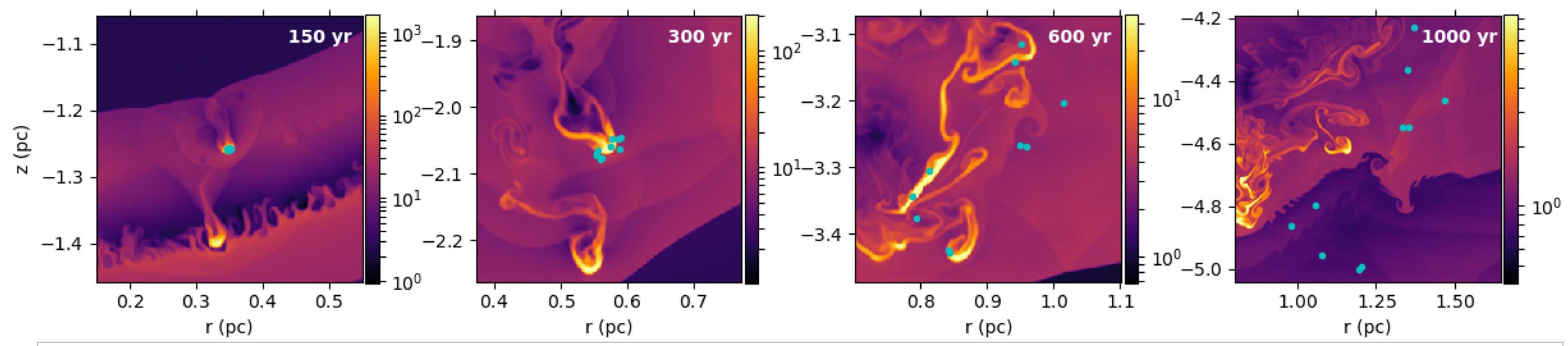

Fig. 3 – Density and grain position zoom-in for the simulation shown in Fig. 2. The same 10 grains (cyan dots) that originate in a single ejecta clump are shown in each panel. In the leftmost panel the clump has recently been swept over by the reverse shock. In the next panel, the clump has crossed the contact discontinuity and the grains have begun to decouple. In the last two panels the grains have fully decoupled and scattered because of small differences in the density and velocity of the gas they have moved through.

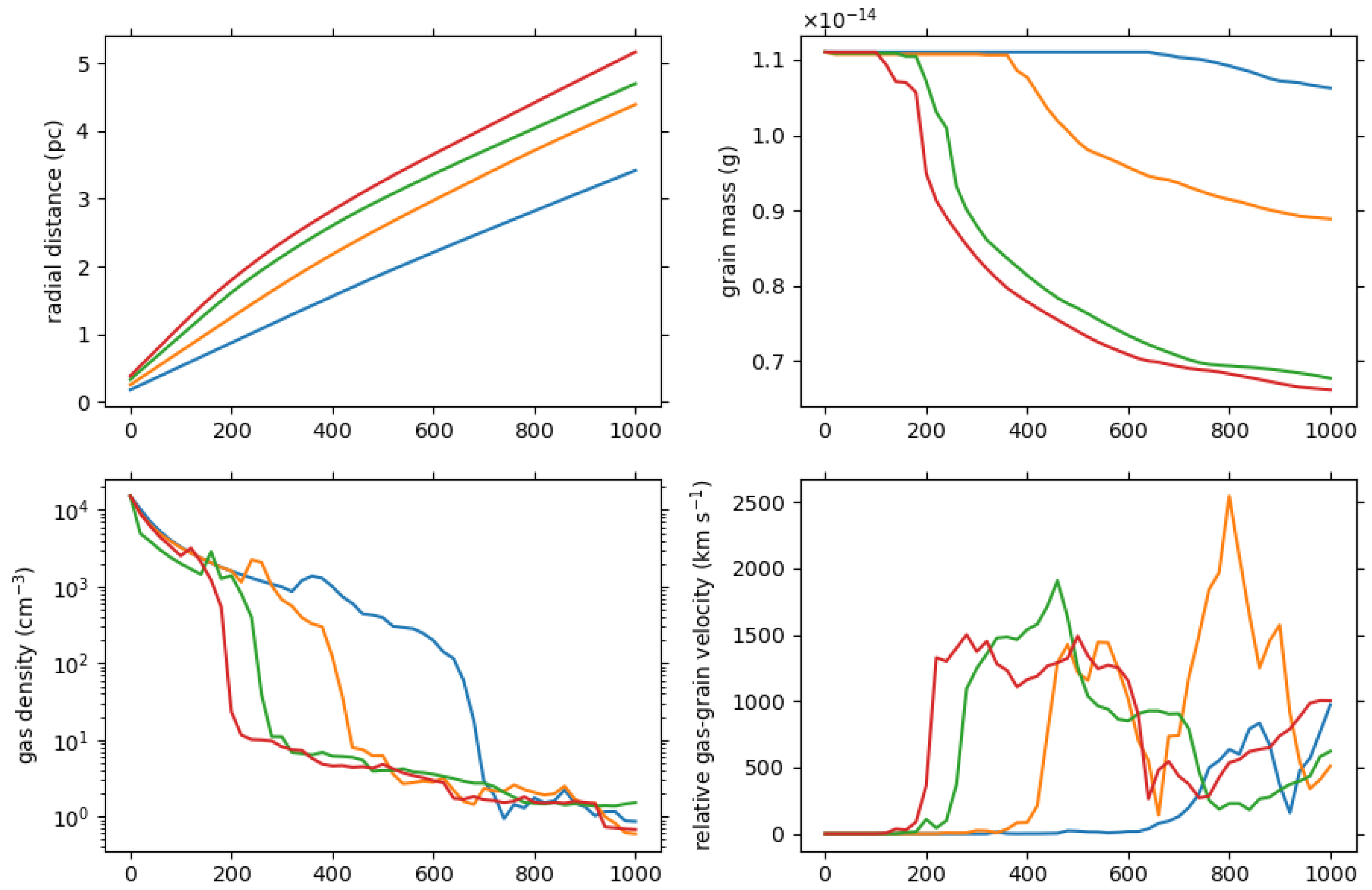

Fig. 5 – Evolution of grain and gas properties along four representative grain trajectories: radial distance (upper left), grain mass (upper right), gas density (lower left), and relative gas-grain velocity (lower right). Mass of a grain decreases as its sputtered. The sputtering rate is proportional to the relative gas-grain velocity and to the gas density: $\frac{dm}{dt} = -4\pi a^2 m_{\rm sput} n v_{rel} Y(m_{\rm proj} v_{\rm rel}^2/2)$ where m_{sput} is the mass of sputtered atoms, n is the gas density, a is the grain radius, m_{proj} is the gas ion mass and Y is the sputtering yield.

Results

- Grains decouple from their ejecta clumps, especially when crossing the contact discontinuity between shocked ejecta and shocked CSM
- Grains are eroded by sputtering, but retain more than half their initial mass, on average, 1000 yr after the explosion (see Fig. 4)
- When remnant starts to encounter the ISM, grains are just beginning to move beyond the forward shock into unshocked ISM

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