Inhomogeneous Dusty Clumps!

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DustOrigin at UGent

Supernovae's (SNe's) contribution to the dust budget in the Universe remains an unsolved puzzle. Though up to 1 $M_\odot$ of dust is found in young SN remnants (SNRs), it is subject to the energetic reverse shock which can destroy a significant amount of the freshly formed dust. We study the dust destruction fraction in the clumpy SNR Cassiopeia A (Cas A) due to the impact of the reverse shock. In order to investigate the clump disruption in highly resolved simulations, we consider the reverse shock hitting a single spherical clump - rather than modelling the whole expanding ejecta with thousands of clumps. Several so-called 'cloud crushing problems' have already been carried out in the past, but always considered clumps with a homogeneous dust distribution. We run a number of simulations of a planar shock hitting a dusty clump with two different inhomogeneities: (I) Inhomogeneous dust density distributions and (II) Inhomogeneous dust grain size distributions. We compare the dust survival fraction of these inhomogeneous clumps with a homogeneous clump of the same mass, and show that certain regions of inhomogeneous clumps have enhanced destruction rates, depending on the gas density contrast χ between the gas number density in the clump and the interclump medium.

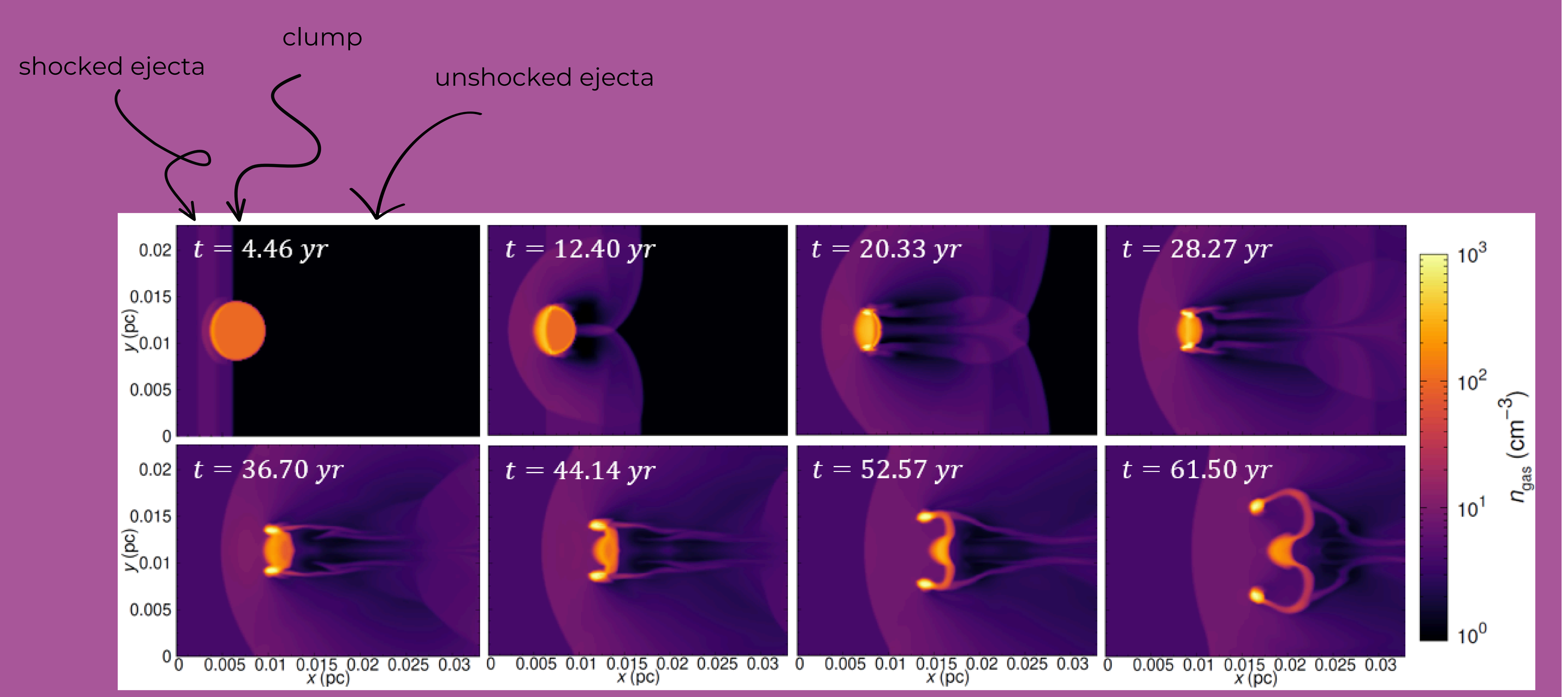
SIMULATIONS

- For the cloud crushing problem, we let the reverse shock hit an ejecta clump (clump radius $R = 10^{16}$ cm, shock velocity 1600 km/s), representing usual conditions in Cas A [1], and follow the evolution for 3 cloud crushing times. These simulations were performed with the hydrodynamical code AstroBEAR [2].
- Afterwards, we follow the dust dynamics and dust destruction in the shocked clump, assuming silicate grains and a total dust mass of 10 per cent of the total gas mass in the clump. These simulations were conducted using the dust post-processing code Paperboats [3, 4].
- Simulations have been carried out for clumps with (I) a radial dust density profile and (II) two different dust grain size distributions in the inner spherical core and the outer shell, respectively. This was performed for clumps with a density contrast of χ = 100 and χ = 1000 ($n_{\mathrm{interclump}} = 1\ \mathrm{cm}^{-3}$, $n_{\mathrm{clump}} = \chi\, n_{\mathrm{interclump}}$).

AstroBEAR + **Paperboats**

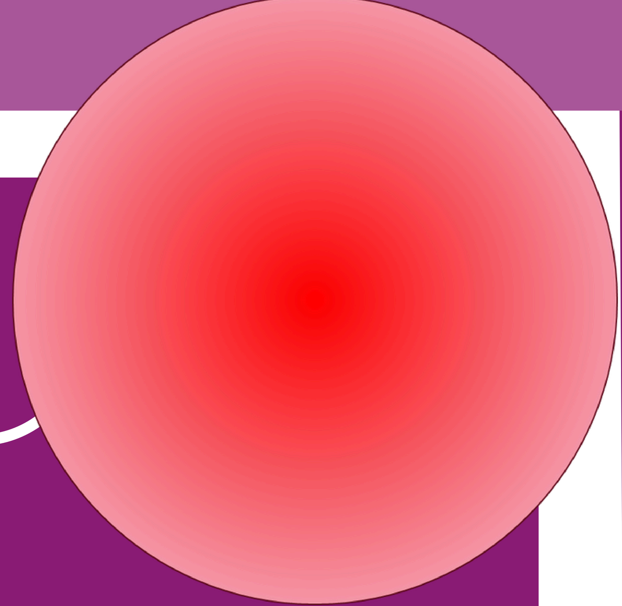
AstroBEAR: Hydrodynamical simulations of a planar shock hitting a single clump

Paperboats: Post-processing of the hydrodynamical simulations to model dust destruction

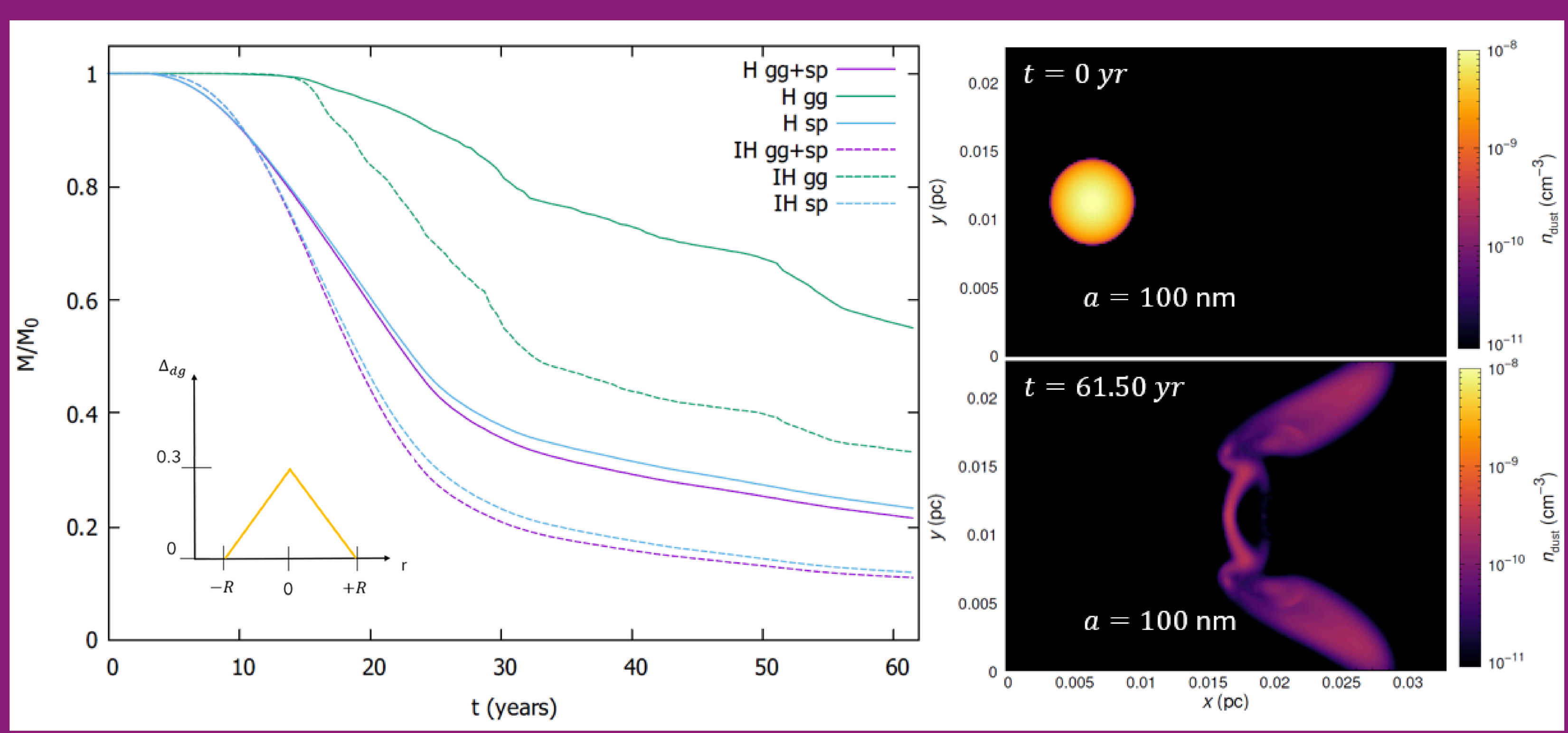


Evolution of the gas number density in a spherical clump during and after the impact of the reverse shock.

I. INHOMOGENEOUS DUST DENSITIES

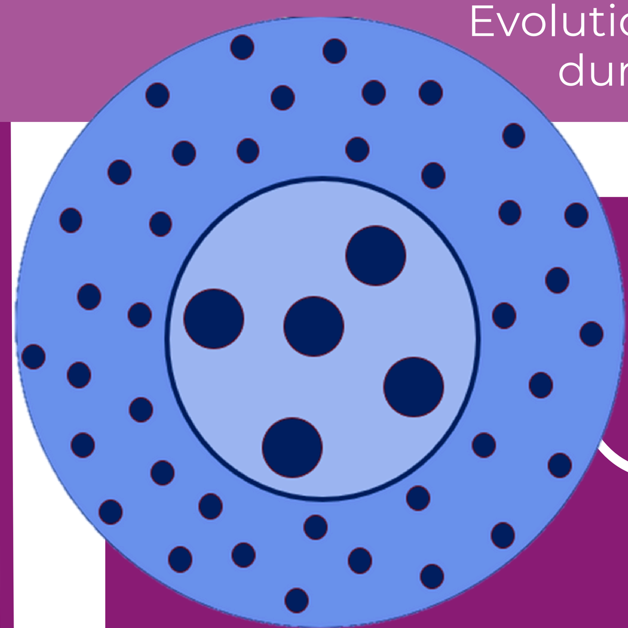


Radial dust density profile in the clump

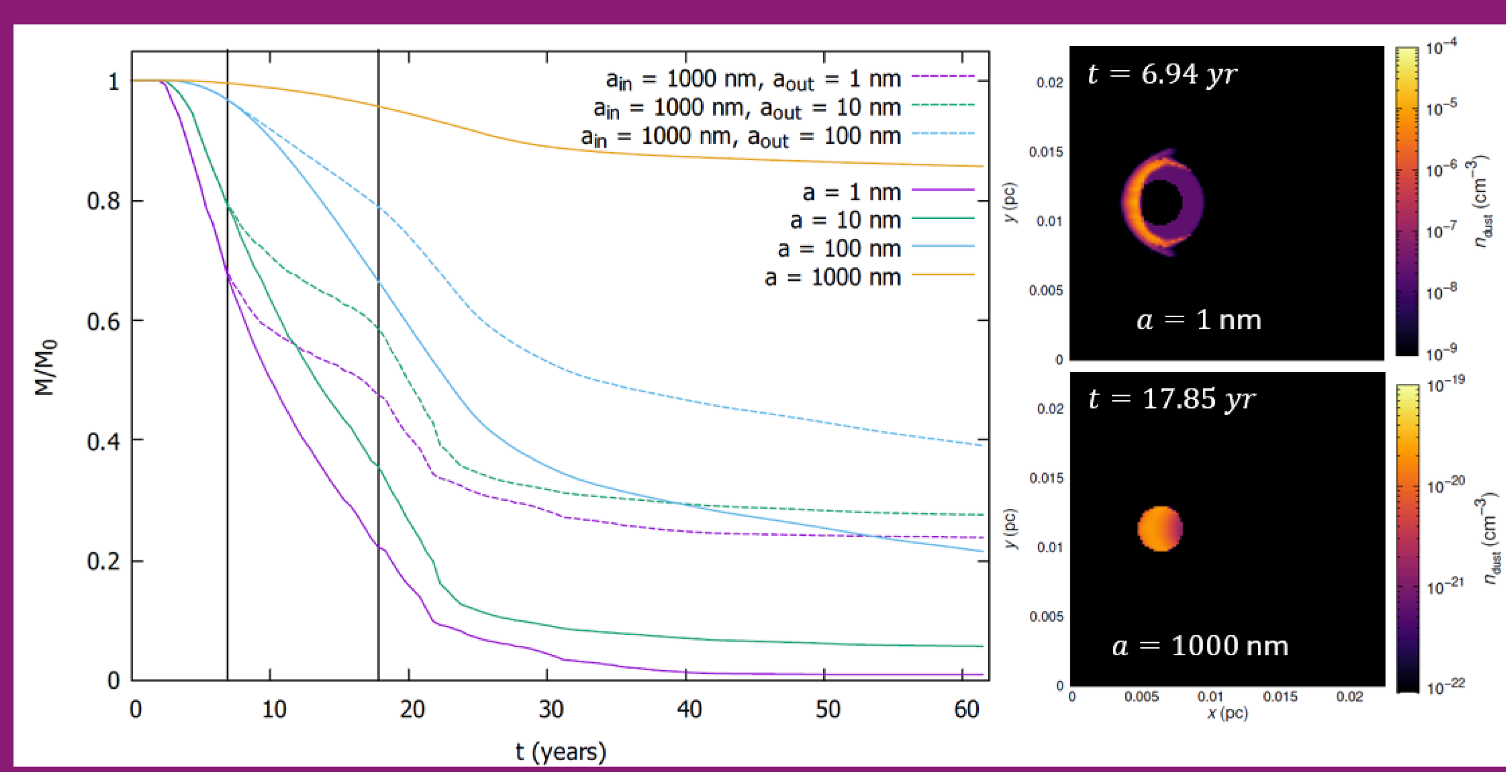


Dust mass evolution for a clump with density contrast χ = 100. Both grain-grain collisions (gg) and sputtering (sp) considered separately as well as combined lead to a reduction in dust mass survival M/M_0 when comparing an inhomogeneous (IH) to a homogeneous (H) clump of 100 nm grains. Each clump has the same initial mass. The IH clump has a radial descending dust density profile, as visible in the dust density maps (right panels). The inset in the bottom left corner shows the initial dust-to-gas mass ratio Δ_{dg} at radius r within the clump.

II. INHOMOGENEOUS DUST GRAIN SIZES



Two different grain size distributions, a_{in} and a_{out}, in the inner core and outer shell



Dust mass evolution for a clump with density contrast χ = 100. The solid lines represent homogeneous (H) clumps, while the dashed lines represent inhomogeneous (IH) clumps with two different grain sizes in the inner and outer parts of the IH clump. The two vertical lines represent the entering and leaving of the reverse shock of the inner core (t = 6.94 and 17.85 yr, resp.), as depicted in the dust density maps on the right. The dust destruction is increased for clumps with smaller grain sizes in the outer shell.

CONCLUSIONS

For χ = 100, the enhanced dust destruction is mainly due to sputtering effects.

For both types of inhomogeneities, the dust destruction rate is higher for inhomogeneous than for homogeneous clumps.

For χ = 100 (low gas density), more dust is destroyed in the **inner** parts of the clump, independent of the type of inhomogeneity.

Not shown: For χ = 1000 (high gas density), more dust is destroyed in the **outer** parts of the clump, independent of the type of inhomogeneity.

For χ = 1000, the enhanced dust destruction is due to a combination of sputtering and grain-grain collisions.

REFERENCES:

1. Micelotta et al., 2016, A&A, 590, A65
2. Cunningham et al., 2009, AAS, 182, 519
3. Kirchschlager et al., 2019, MNRAS, 489, 4465
4. Kirchschlager et al., 2023, MNRAS, 520, 5042

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