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Turbulence Ahead!

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Supernovae's contribution to the dust budget remains an unsolved problem. The forward shock is responsible for the destruction of the dust lying in the surrounding circumstellar (CSM) and interstellar medium (ISM), while the reverse shock destroys newly formed dust in the supernova ejecta. The structure of the CSM will not only control the subsequent evolution of the shock front (and, thus, also the formation and evolution of the reverse shock), but it will also determine how vulnerable the interstellar dust is to the passage of an energetic shock front.

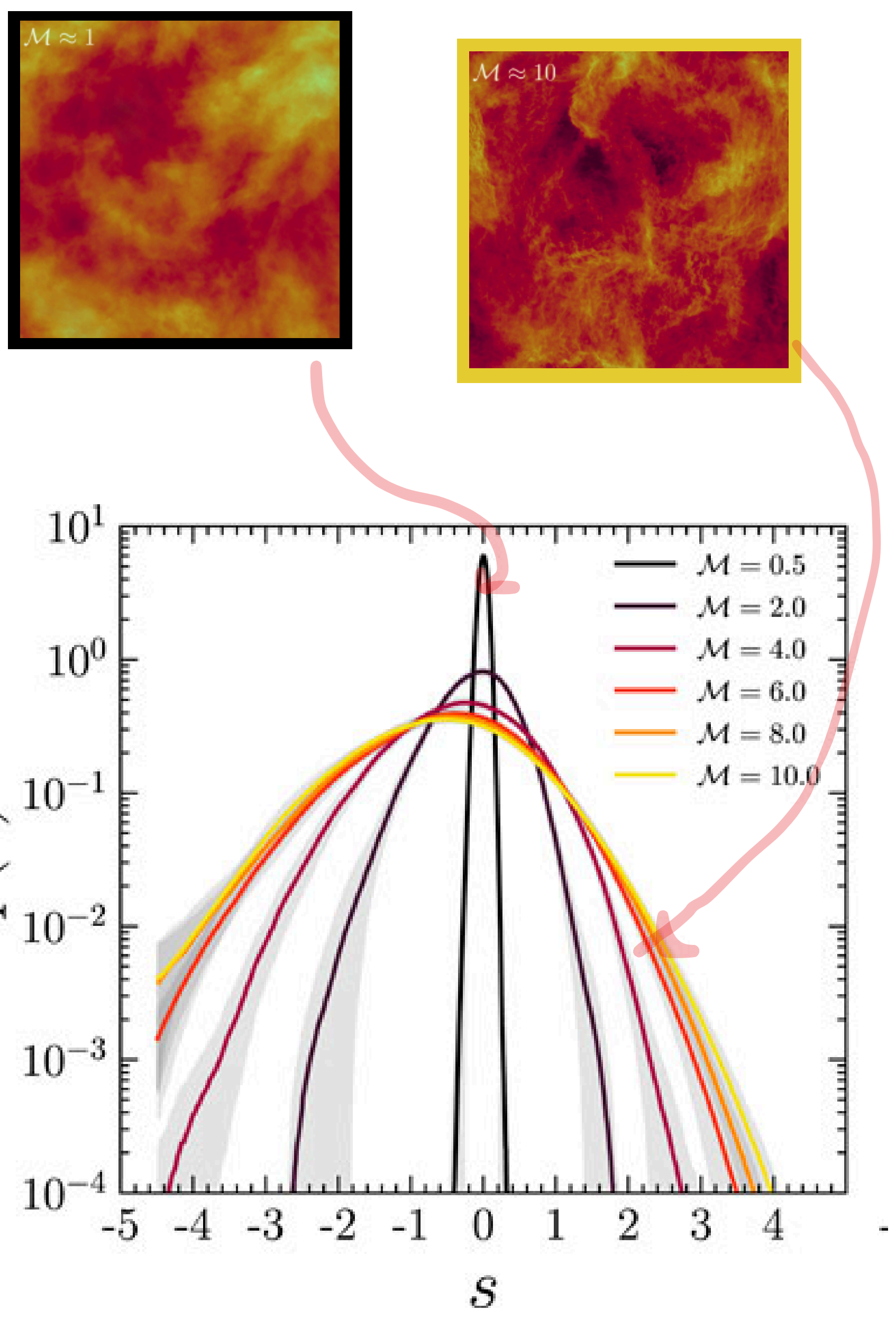
The CSM and ISM prior to the supernova explosion are modeled as a turbulent medium which we expect to closely reproduce their morphology. We run a number of 3D simulations of a planar shock hitting a CSM with distinct levels of turbulence which are evidenced by their distinct turbulent Mach numbers. We compare the difference in dust survival in each scenario and show the importance of correctly modeling the CSM morphology.

TURBULENCE

Turbulence is found everywhere in the universe. Turbulent motions naturally lead to the creation of denser structures such as filaments as well as emptier regions referred to as voids.

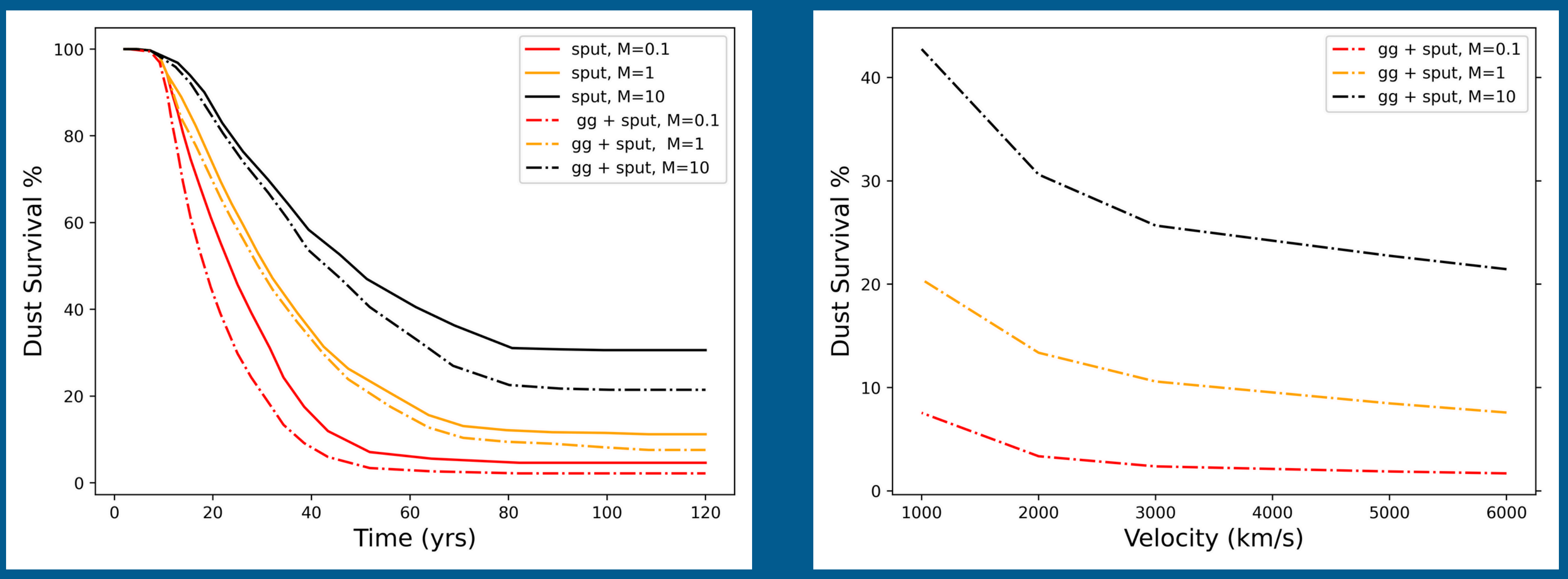
For an isothermal gas with purely turbulent dynamics, the velocity dispersion, σ_v, of the turbulence sets the width of the lognormal cloud density distribution (Fig 1). Usually, the velocity dispersion in simulations is quantified by the turbulent Mach number M = σ_v/c_s where c_s is the speed of sound [1]. While the ISM is known to have a range of temperatures and average densities, isothermal turbulence with varying Mach numbers closely resembles the density distribution seen in molecular clouds and the CSM of many evolved stars.

Turbulence has already been shown to have a different response to shocks compared to a uniform medium [2]. The question is what role may this play in the destruction of dust in supernova shocks?



This plot shows the logarithmic density PDFs (s = ln (ρ/ρ_mean)). The larger the Mach number the broader is the PDF.

DUST DESTRUCTION



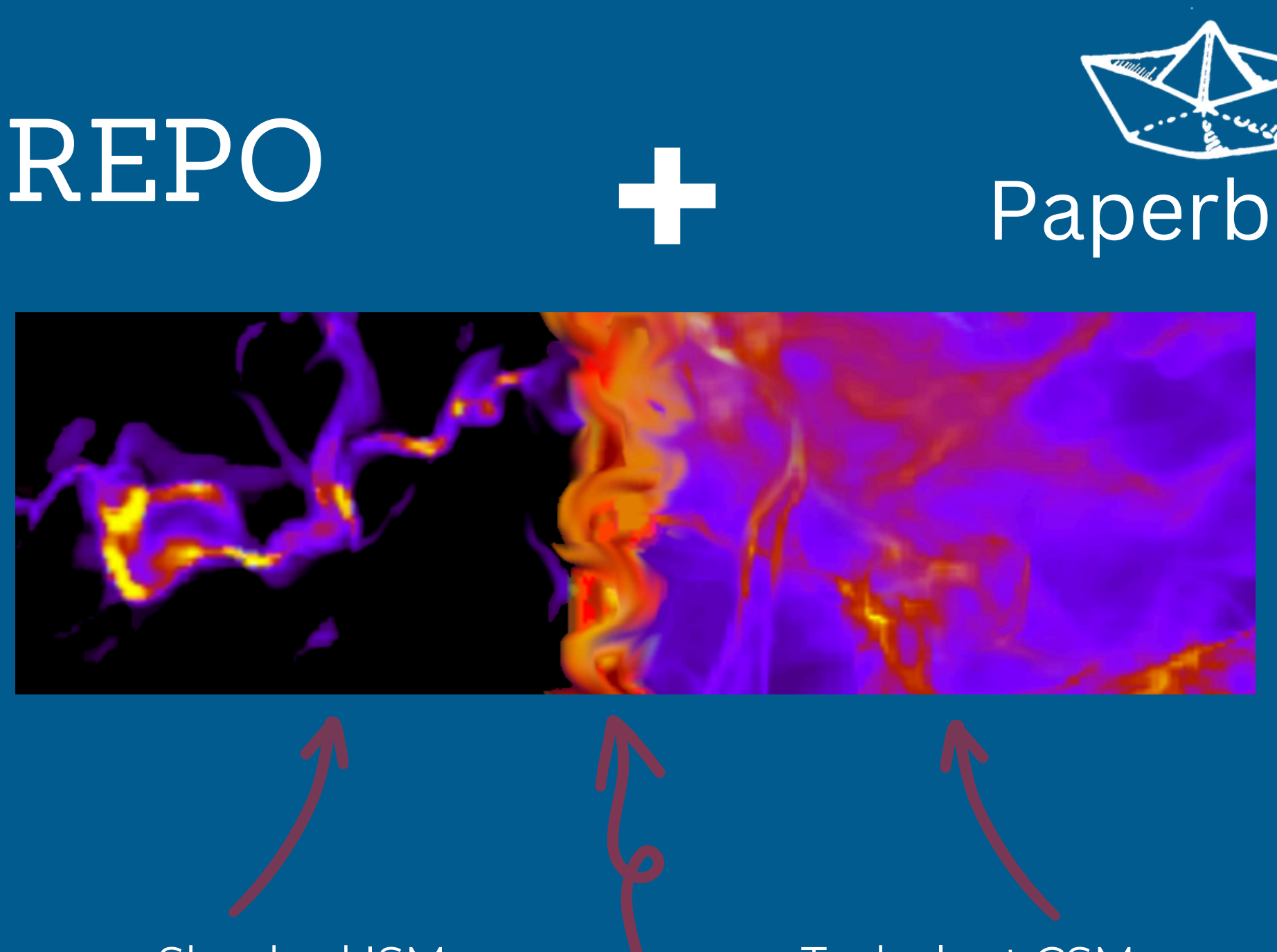
Left: The percentage dust survival in three simulations with turbulence with different Mach numbers, represented by different colors. We show curves for destruction considering sputtering alone (solid line) or sputtering and grain-grain collisions (dot-dashed line. The shock velocity here is assumed to be 5000 km/s Right: Dust survival dependence on the shock velocity.

The turbulent environments with the highest Mach number have the largest density anisotropy, with the high-density filaments being more resistant to the passage of the shock. As a consequence, dust present in the denser filaments is better shielded from the forward shock and a higher fraction of the dust is able to survive. For M=0.1, 1 and 10, and when considering sputtering and grain-grain collisions (only sputtering), we have 1.69%, 7.58% and 21.4 % (4.62%, 11.19%, 30.59%) of the ISM dust surviving the passage of the forward shock, respectively.

This highlights the importance of knowing the density structure of the circumstellar and interstellar medium. It is expected that around 10% of supernovae, such as Cas A, have a dense environment, which could present turbulent structures prior to the supernova explosion.

The velocity of the forward shock significantly influences the extent of dust destruction. Lower shock velocities result in higher dust survival rates. In turbulent interstellar mediums (ISMs) with higher Mach numbers, the sensitivity to shock velocity changes is more pronounced as it will dictate how much of the filament will withstand the shock's passage. Conversely, in regions with lower Mach numbers, the filaments are entirely destroyed by the forward shock, even at lower velocities and thus the difference in destruction is less dramatic.

SIMULATIONS



AREPO + Paperboats

Hydrodynamical simulations of a planar shock front

Post-processing of the hydrodynamical simulations

Shocked ISM

Shock front

Turbulent CSM

Zoom in around the shock region. The post-shock material (left) is able to retain some off the turbulent structure.

- We set a simulation box of 0.6 pc long and 0.1 pc high and wide in which we drive turbulent motions by generating a time sequence of random Fourier modes via an Ornstein-Uhlenbeck process.
- Three different turbulent boxes were run with different Mach numbers: M = 0.1 (subsonic turbulence), 1 (transonic turbulence), and 10 (supersonic turbulence) but with identical average densities of 10^{-23} g/cm^{3}.
- Once we have a turbulent structure we stop the turbulent driving and create a shock front that traverses the box from left to right. We drive shocks with different velocities, including values similar to the ones observed for the forward shock in Cas A [3].
- We wait until the shock sweeps the entire box which takes around ~ 100 yrs.
- The snapshots are post-processed using Paperboats [4]. We assume a constant gas-to-dust mass ratio of 100, which implies the denser filaments are also more dust-rich.
- Here, we include the effects on dust resulting from fragmentation and vaporization. However, Paperboats is capable of also modeling sputtering and acceleration of grains due to magnetic fields.

CONCLUSIONS

- The higher the turbulent Mach number the more the dust is resistant to the passage of a shock front
- Not all parts of the filament get destroyed during the shock passage at large Mach numbers
- The higher the velocity of the forward shock the higher the destruction.
- Turbulence with higher Mach numbers are more susceptible to shock velocity changes.

RELATED LITERATURE

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