Paperboats in the Dusty Ocean:

Post-processing MHD Simulations for Dust Evolution

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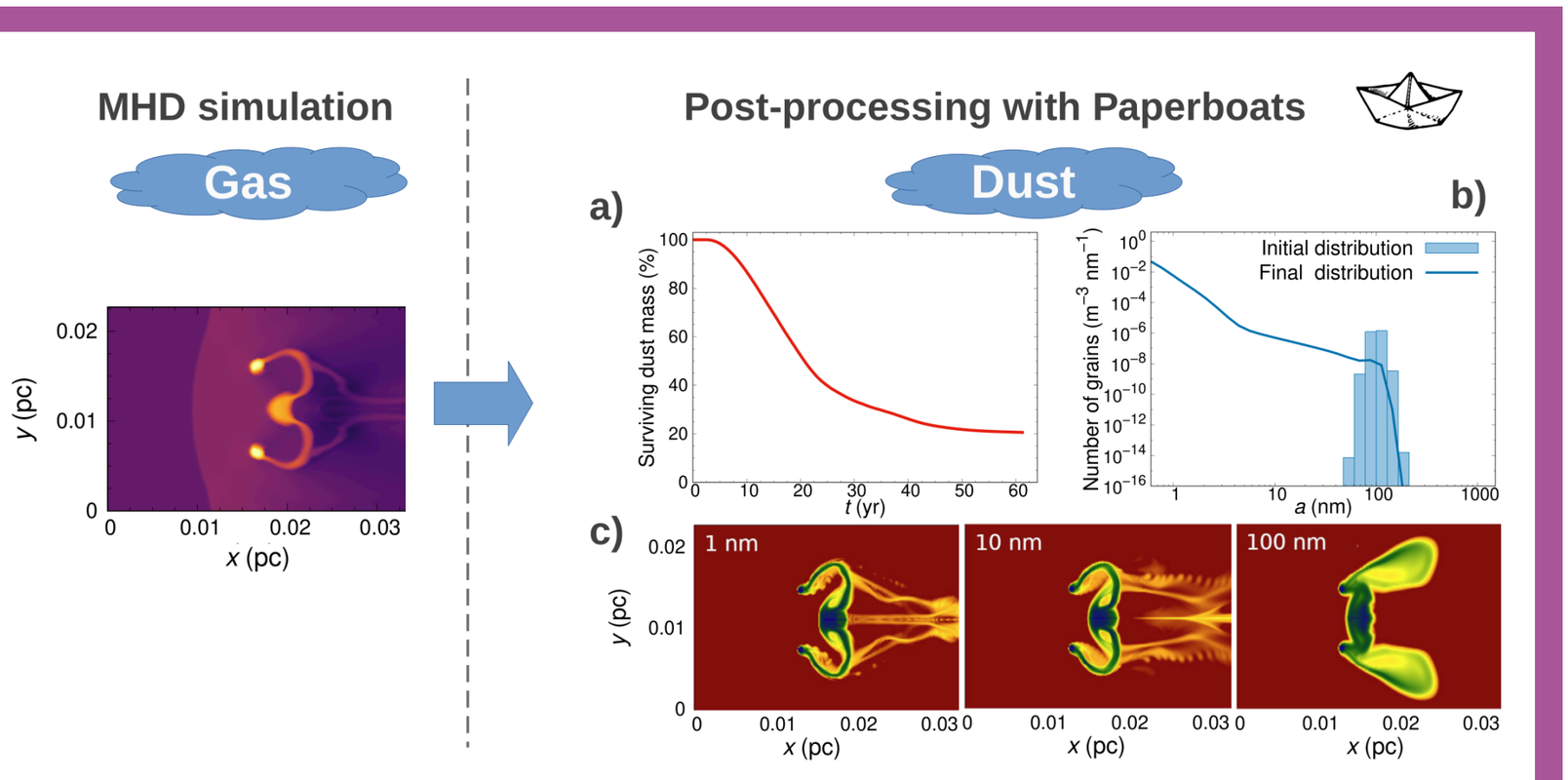
Dust grains are key components of the interstellar medium (ISM), influencing its chemistry, thermodynamics, and radiative properties. Yet, dust is continually processed and destroyed by shocks, turbulence, and energetic feedback from stars and supernovae (SNe). Quantifying the balance between dust formation and destruction remains a major challenge, particularly in environments where complex gas dynamics and magnetic fields shape the fate of grains.

Paperboats is a post-processing code that traces the evolution of dust in magnetohydrodynamic (MHD) simulations. It follows dust populations through the simulated flow, including sputtering, grain-grain collisions, and gas–dust drag. We apply Paperboats to ISM and supernova remnant (SNR) simulations to explore how shocks and magnetic fields affect dust destruction. The code provides a flexible framework for coupling MHD dynamics with detailed dust microphysics, enabling systematic studies of dust survival in diverse astrophysical environments.

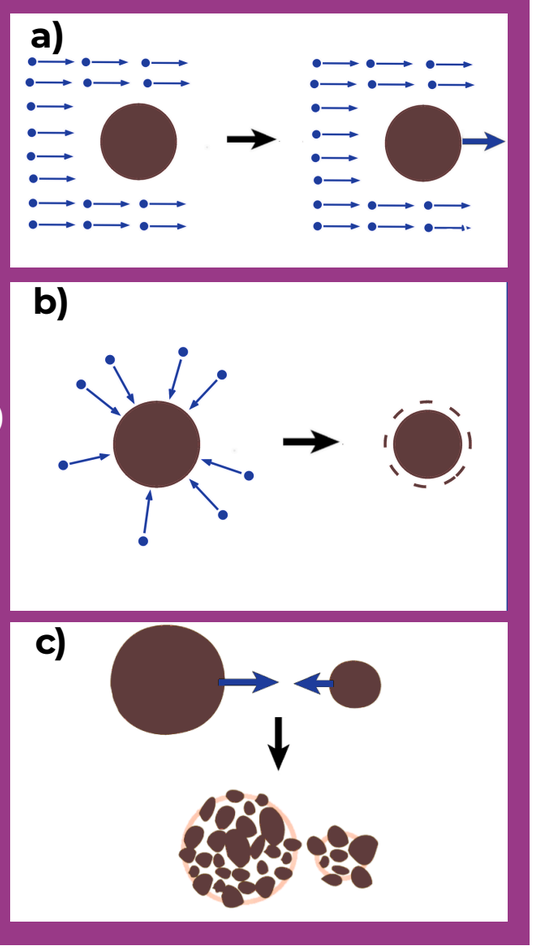
SIMULATIONS

- Input: MHD simulations (2D or 3D) to model gas evolution in clumpy SNRs impacted by a SN shock or gas in the turbulent ISM impacted a SN shock. Adaptable to other physical scenarios.
- For the dust phase, Paperboats post-processes the MHD output — using gas density, temperature, velocity, and the magnetic field from each grid cell and snapshot.
- Currently, Paperboats supports output from the AstroBEAR, Pencil, Arepo, and FLASH MHD codes, and can be adapted to other codes with minimal effort (grid or SPH).
- Paperboats calculates:
  - Total dust survival fraction as function of time (a)
  - Grain size distribution for each snapshot (b)
  - Dust density maps for multiple grain sizes (c)



DUST PROCESSES

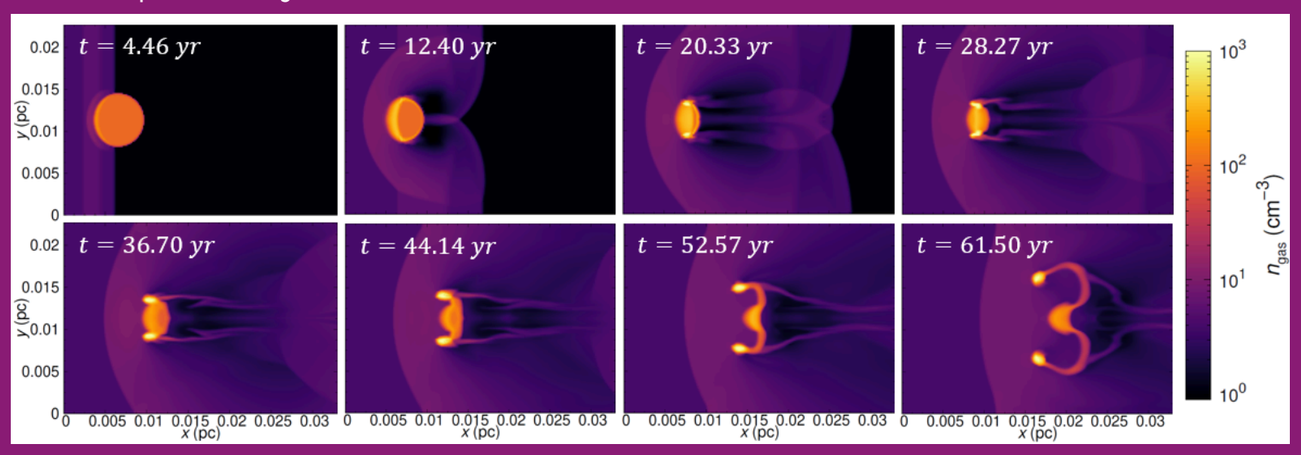
- A multitude of dust processes are included which is unique in its number so far.
- Dust transport:
  - Drag by gas-grain collisions (a)
  - Plasma drag
  - Magnetic field acceleration
- Dust destruction:
  - Kinetic and thermal sputtering (b)
  - Fragmenation (c)
  - Vaporisation
  - Mechanical and radiative torque disruption (upcoming)
- Dust growth:
  - Coagulation
  - Gas accretion
  - Ion trapping



RESULTS

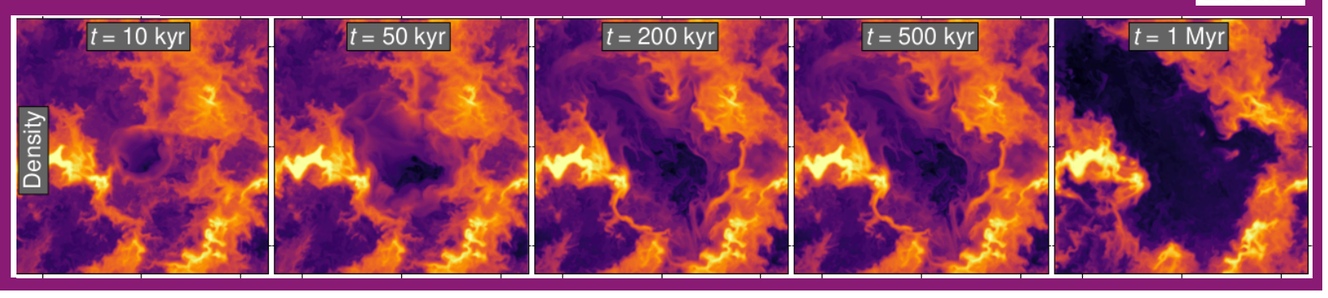
.... for the dust evolution in a SNR clump impacted by the reverse shock of the SN

Full video:



.... for the dust evolution in the ISM impacted by the forward shock of the SN

Full video:



SUMMARY

Paperboats is a parallelized, grid-based post-processing code to compute the evolution of dust grains in a moving gas.

The number of dust processes considered is unique.

We can follow the evolution of dust grains in dust density maps for each grain size, which is a novelty in the research field of SN and ISM dust destruction.

For more details:

1. Kirchschlager et al., 2019, MNRAS, 489, 4465
2. Kirchschlager et al., 2020, ApJ, 893, 70
3. Kirchschlager et al., 2022, MNRAS, 509, 3218
4. Kirchschlager et al., 2023, MNRAS, 520, 5042
5. Kirchschlager et al., 2024a, Nature Communications, 15, 1841
6. Kirchschlager et al., 2024b, MNRAS, 528, 5364
7. Scheffler et al., subm.

Curious about what happens to the dust in your MHD simulations? Get in touch with us!

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