On the structure of dust aggregates formed in supernovae

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Abstract

Simulating dust aggregates with the Soft-Sphere Discrete Element Method (SSDEM) is critical to our understanding of how cosmic dust grains grow and interact with their environment. Depending on the method used to grow the aggregates and the physical properties of the surrounding medium, different structures arise. Here, we present our findings using the DECCO code [1] on the structure of large aggregates produced with sequential collisions grown with projectile fragments: smaller grains of a set number of particles. These simulations are expected to be more realistic as they relax the assumption of spherical projectiles. We find that the final grain structure is significantly more porous than in aggregates grown from single particle accretion, and that the structure depends heavily on the number of particles in the constituent projectiles. Our findings have implications for the survival of dust in supernova (reverse) shocks [2].

One Piece at a Time

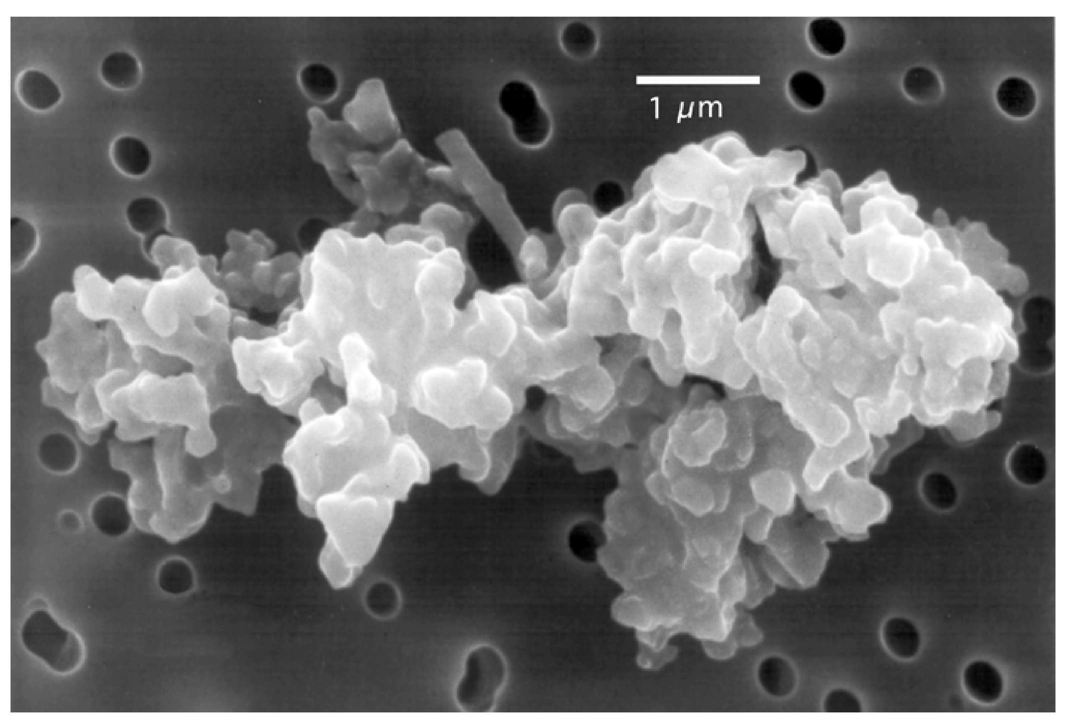
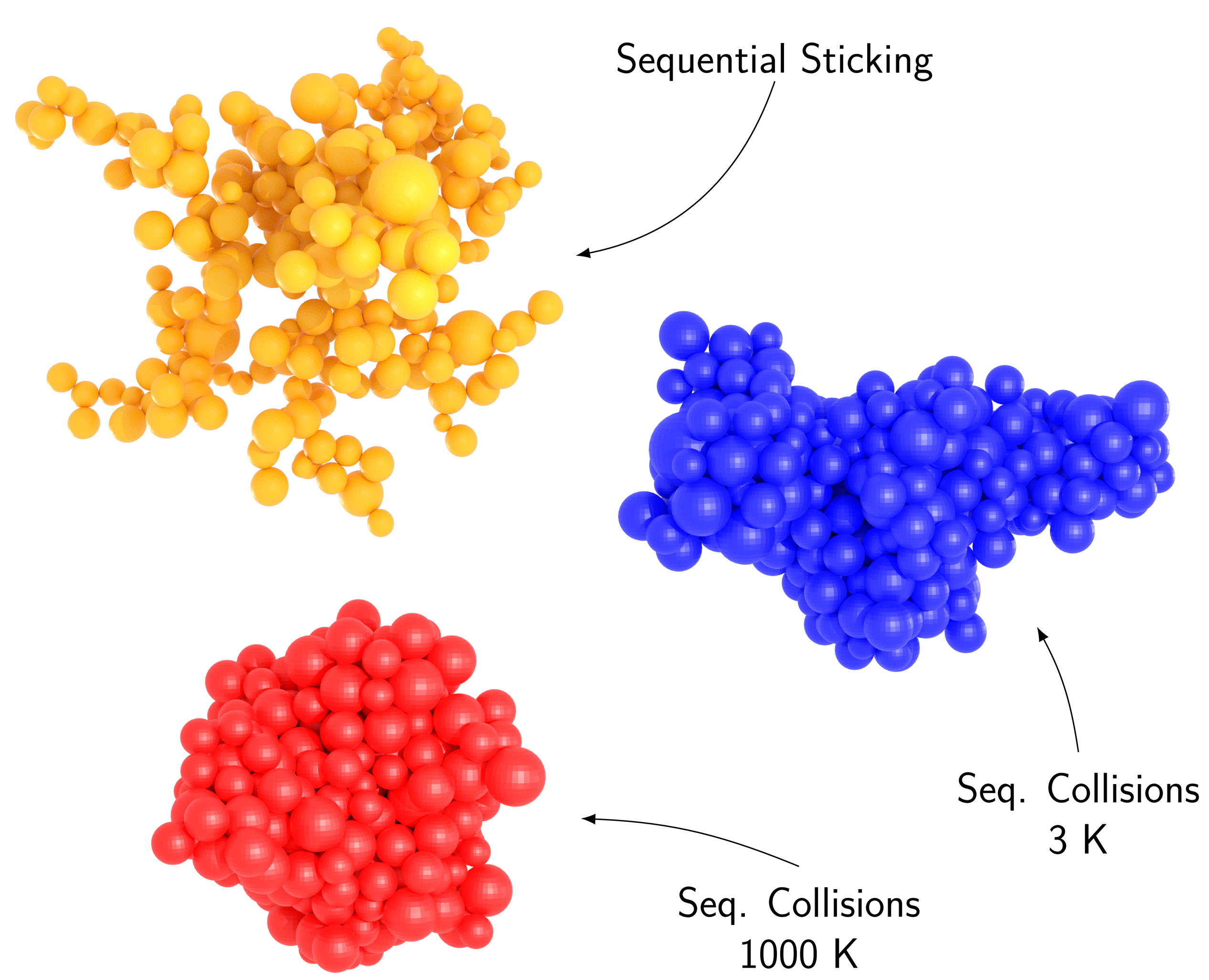


Figure: SEM image of dust from the Stardust mission (Image by E.K. Jessberger and Don Brownlee).



- When the physics of each intermediate collision is fully modeled aggregates can restructure and we can study the effect of the ambient temperature on the final results [3].
- In this work we study the effect of growing large grains by adding fragments rather than single particles.

Building Fraggregates

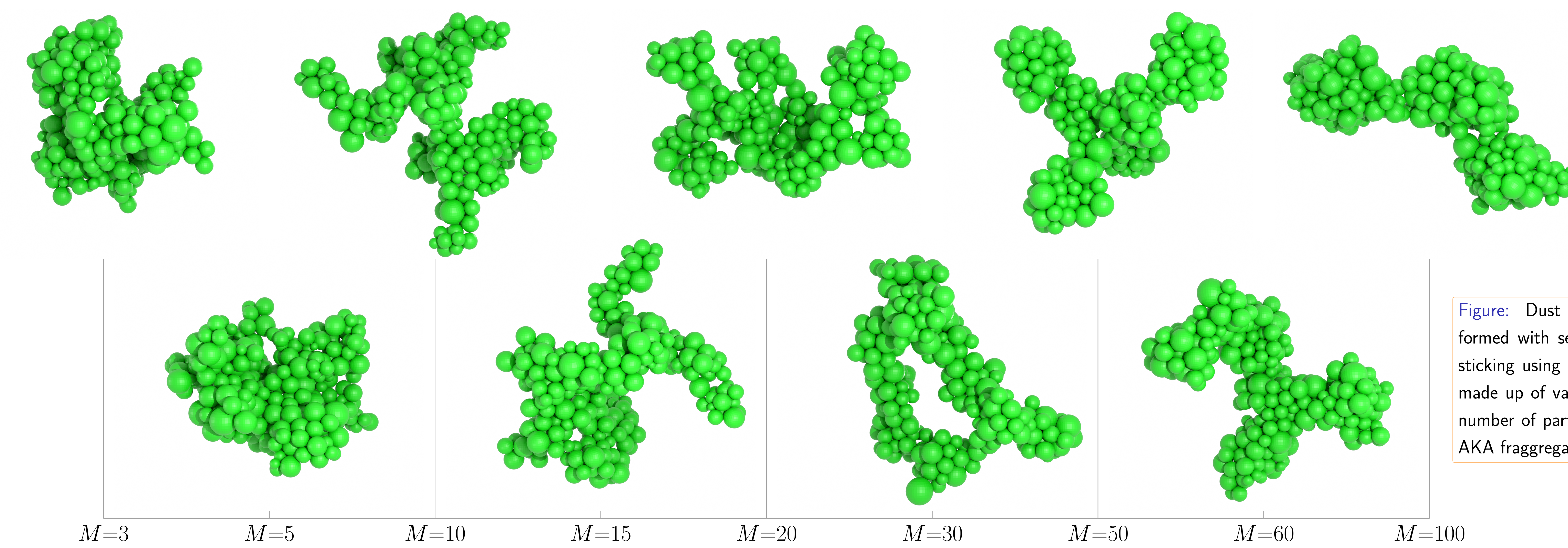


Figure: Dust aggregates formed with sequential sticking using projectiles made up of various fixed number of particles (M), AKA fraggregates.

Porosity Peaks

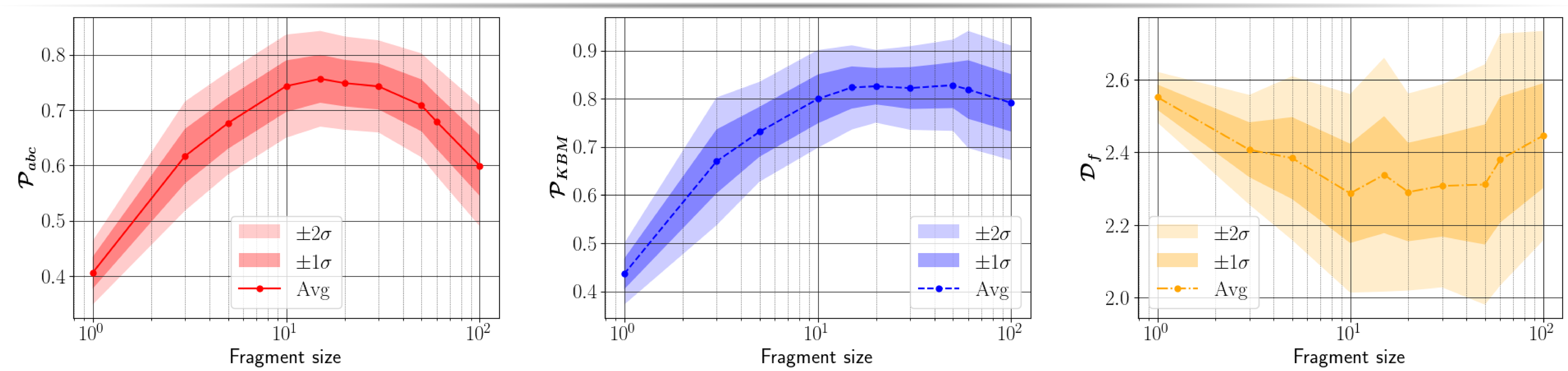
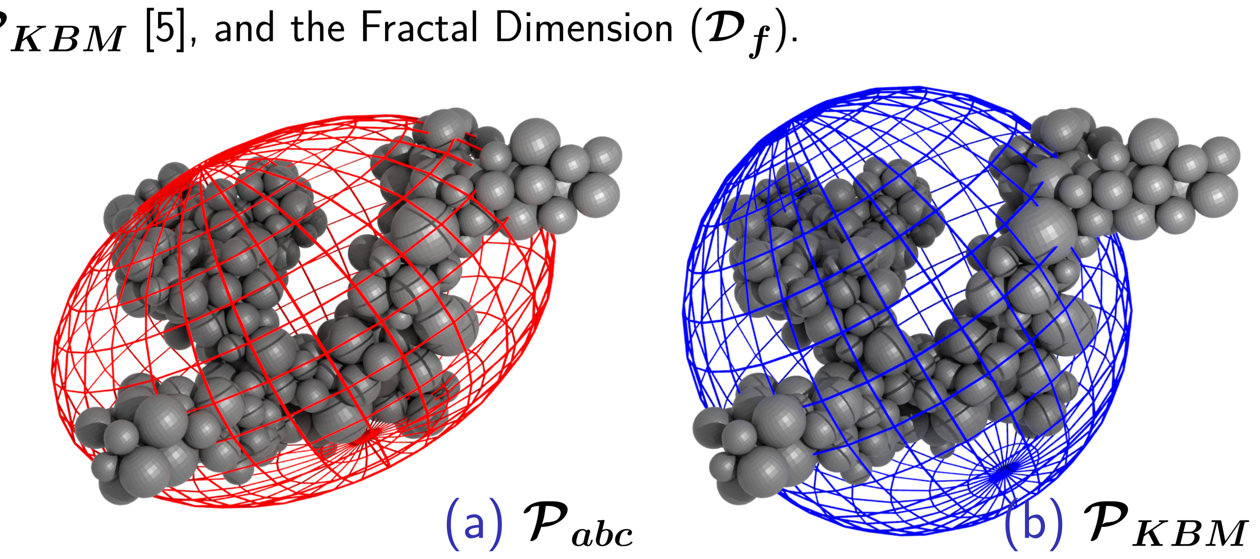


Figure: Metrics of aggregate structure vs projectile aggregate size (in number of particles) for a final aggregate size of 300 particles, grown at 1000 K. From left to right the metrics of aggregate structure are $\mathcal{P}_{abc}$, $\mathcal{P}_{KBM}$ (both porosities), and fractal dimension. Averages are done over 30 realizations.

Quantifying Aggregate Structure

We use three metrics to quantify the structure of the aggregates, $\mathcal{P}_{abc}$ [4], $\mathcal{P}_{KBM}$ [5], and the Fractal Dimension ($\mathcal{D}_f$).



- $\mathcal{D}_f$ is defined below, where $\mathcal{N}(l)$ is the number of grid spaces with any part of the aggregate in them, and l is the grid size.
  - $\mathcal{D}_f \equiv \lim_{l\to 0} \frac{\log \mathcal{N}(l)}{\log(1/l)}$

Polydisperse Projectiles

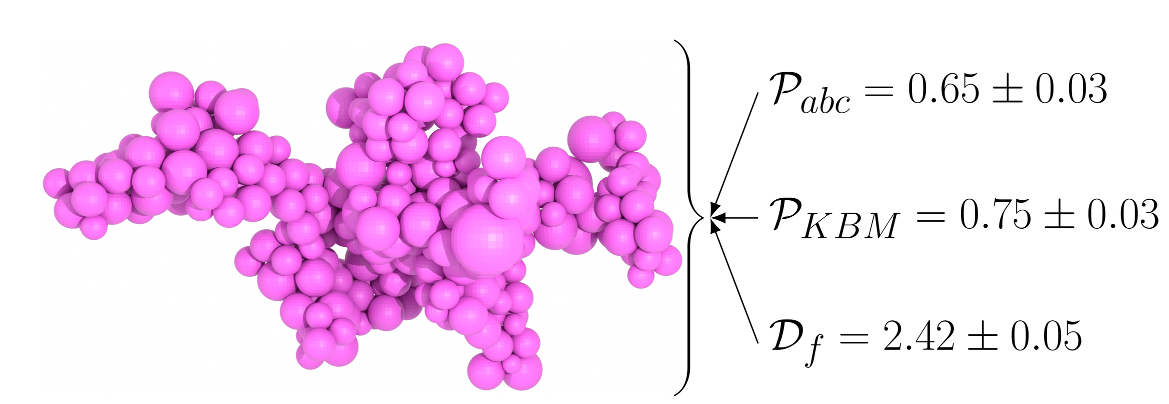


Figure: An aggregate grown with projectiles whose number of particles follows a lognormal distribution. Values presented are averaged over three realizations.

Conclusions

- **Non-spherical projectiles form highly porous aggregates.**
- **Max porosity with projectiles of $\sim 10-80$ particles.**

[1] Guidos, J.; Kolanz, L.; Lazzati, D. *The Open Journal of Astrophysics* **8**, 2025.

[2] Schneider, R.; Maiolino, R. *Astron. Astrophys. Rev.* **32**(1):2, 2024.

[3] Kolanz, L.; Lazzati, D.; Guidos, J. *arXiv preprint arXiv:2509.13449 [astro-ph.GA]*, 2025.

[4] Shen, Y.; Draine, B. T.; Johnson, E. T. *ApJ* **689**(1):260–275, 2008.

[5] Kozasa, T.; Blum, J.; Mukai, T. *Astron. Astrophys.* **261**, 1992.