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GROWTH OF POROUS AGGREGATES IN PROTOPLANETARY DISCS USING SPH SIMULATIONS

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Abstract. Dust porosity is considered as a possible solution to problems in grain growth and planetesimal formation. We use the hydrodynamic code Phantom and our porosity evolution model to run simulations. We showed that porosity helps aggregates to survive in the disc thanks to dust traps, but the resulting dusty disc is too thick compared to observations.

Keywords: methods: numerical – planets and satellites: formation – protoplanetary discs

1 Introduction

A challenge in the theory of planet formation is the growth of aggregates into planetesimals. Several barriers prevent dust coagulation such as radial drift (Weidenschilling 1977), fragmentation (Dominik & Tielens 1997), etc. Multiple solutions rely on instabilities and pressure maxima. Here, we choose to use grain porosity (Ormel et al. 2007). A porosity evolution model for 3D simulations (Garcia & Gonzalez 2020) is implemented into the SPH hydrodynamic code Phantom. We run simulations of protoplanetary discs with compact or porous grains and show that porosity helps dust to survive in the disc even if fragmentation remains a barrier to grain growth.

2 Models

To perform the simulations, we use Phantom and its 2-fluid method where gas and dust are two separate fluids interacting between each other via drag forces. Dust can drift radially with a velocity $v_{\rm dust,r}$ (Dipierro & Laibe 2017) that can be approximated by:

$$v_{\rm dust,r} \approx \frac{\rm St}{(1+\epsilon)^2 + {\rm St}^2} v_{\rm drift}, \tag{2.1}$$

with $v_{\rm drift} \propto {\rm d}P_{\rm gas}/{\rm d}t$ and $\epsilon = \rho_{\rm dust}/\rho_{\rm gas}$, where St is the Stokes number, representing the coupling between gas and dust. Grains can also collide with each other with a relative velocity $v_{\rm rel}$ (Stepinski & Valageas 1997):

$$v_{\rm vrel} \propto c_{\rm g}\sqrt{\alpha}\frac{\rm St}{1+{\rm St}^2}, \tag{2.2}$$

where $c_{\rm g}$ is the gas sound speed and α the turbulent viscosity parameter (Shakura & Sunyaev 1973).
Grain porosity is expressed via the filling factor $\phi = \rho/\rho_{\rm s}$. An aggregate, considered as spherical, is a collection of monomers of size a_0 and density $\rho_{\rm s}$. The relation between grain mass m, size s and ϕ is given by:

$$m = \rho V = \rho_{\rm s}\phi\frac{4\pi}{3}s^3. \tag{2.3}$$

Depending on the mass and location of the aggregate, different regimes of expansion or compression can be identified (Garcia & Gonzalez 2020). Very small grains grow first in the hit & stick regime. Then, when the aggregates start to become large, they are compacted by collisional compression depending on the drag regime and Stokes number. In the inner disc region, static compaction by gas flow can also compact aggregates efficiently Kataoka et al. (2013). Finally, to take into account fragmentation, we use the model derived by Kobayashi & Tanaka (2010), and we suppose that all the energy is used to break monomer bounds, meaning ϕ is constant, i.e. no compaction.

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3 Setup and Results

We use for all the simulations a disc model that fits observations: $M_* = 1$ M$_\odot$, $M_{\rm disc} = 0.01$ M$_\odot$, $r_{\rm in} = 10$ au, $r_{\rm out} = 300$ au, $\alpha = 5 \times 10^{-3}$. The gas surface density and temperature indices are $p = 3/2$ and $q = 1/2$. We ran simulations with compact or porous silicates aggregates. The initial grain size is set at 50 μm, with an intrinsic density $\rho_{\rm s} = 2700$ kg.m^{-3} and a monomer size $a_0 = 0.1$ μm. The fragmentation threshold is 15 m.s^{-1}.
On the left panel of Fig.(1), compact dust do not grow enough to decouple from gas due to fragmentation, and only mm-sized pebbles near 100 au at 130 kyr are formed. This leads to a fast dust mass lost due to radial drift. Porous grains are on the contrary more coupled to the gas at 10 kyr, but decouple at 100 au later. Dust rapidly coagulates in cm-sized objects, and some can grow to 100 m. A self-induced dust trap Gonzalez et al. (2017) forms at 100 au. On the right panel of Fig.(1), the disc of porous dust is much thicker and less settled than the compact one, due to lower St, and highly porous grains are close to the mid-plane. Baroclinic instability creates oscillations in the inner region, where fragmentation arises. In the outer region, the dusty disc is very settled.

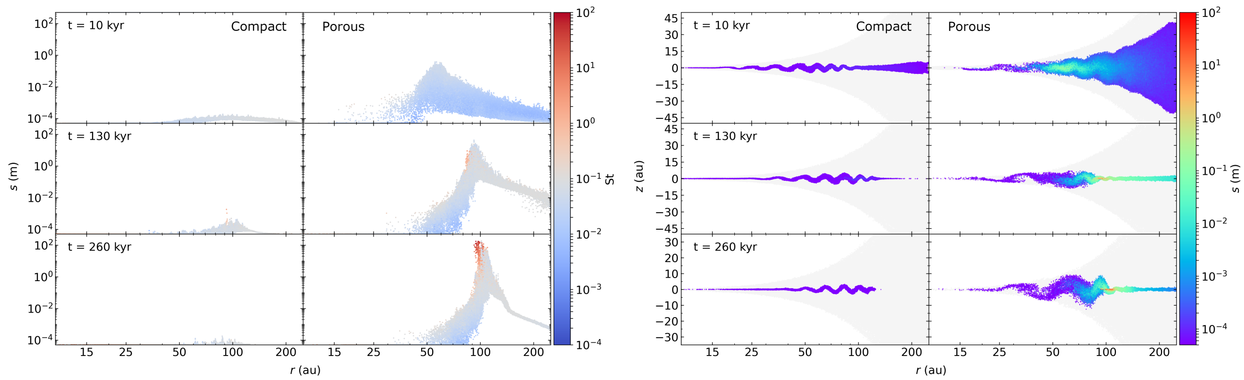

Fig. 1. Left: Grain size s versus distance to the star r, for compact and porous grains for different time steps. The colour gives the St. **Right:** Height z versus distance to the star, coloured by grain size, with the gas disc in grey.

4 Conclusion and perspectives

Thanks to our simulations, we showed that porous aggregates survive longer in our disc thanks to the formation of a self-induced dust trap at 100 au. They can grow to sizes of several meters, which can be potential building blocks of planetesimals. However, the inner disc is not settled enough compared to observations. We plan to run new simulations with smaller a_0, smaller $R_{\rm in}$, different α, with rotational disruption (Tatsuuma & Kataoka 2021). This will allow us to better understand the complexity of grain growth, drift and settling in discs.

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References

Dipierro, G. & Laibe, G. 2017, Monthly Notices of the Royal Astronomical Society, 469, 1932
Dominik, C. & Tielens, A. G. G. M. 1997, The Astrophysical Journal, 480, 647, aDS Bibcode: 1997ApJ...480..647D
Garcia, A. J. L. & Gonzalez, J.-F. 2020, Monthly Notices of the Royal Astronomical Society, 493, 1788
Gonzalez, J.-F., Laibe, G., & Maddison, S. T. 2017, Monthly Notices of the Royal Astronomical Society, 467, 1984
Hunter, J. D. 2007, Computing in Science & Engineering, 9, 90
Kataoka, A., Tanaka, H., Okuzumi, S., & Wada, K. 2013, Astronomy and Astrophysics, 557, L4
Kobayashi, H. & Tanaka, H. 2010, Icarus, 206, 735
Ormel, C. W., Spaans, M., & Tielens, A. G. G. M. 2007, Astronomy and Astrophysics, 461, 215
Shakura, N. I. & Sunyaev, R. A. 1973, Astronomy and Astrophysics, 24, 337
Stepinski, T. F. & Valageas, P. 1997, Astronomy and Astrophysics, 319, 1007
Tatsuuma, M. & Kataoka, A. 2021, arXiv:2101.04910 [astro-ph], arXiv: 2101.04910
Weidenschilling, S. J. 1977, Monthly Notices of the Royal Astronomical Society, 180, 57