New approach to planetesimal formation: clusters of heavy particles in two-dimensional Keplerian turbulence

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Planetesimal formation in protoplanetary disks is still one of the major open questions in planet formation theory. It is known that solids can't grow up to asteroid size relying on sticking after pairwise collisions only, due to the fragmentation barrier and the drift barrier [1]. A possible solution is to form dense particle clumps, with low velocity-dispersion, that can then collapse under self-gravity. Streaming instability is the most popular mechanism for concentrating dust particles [2] and it can be seen as a turbulent mechanism. Turbulence in disks is then critical for planetesimal formation. In this context, we want to study the dynamics of particles in turbulent flows with Keplerian rotation and shear. To treat this astrophysical problem we use fluid-dynamics methods, trying to provide innovative perspectives on this challenging question.

We perform 2D direct numerical simulations using the shearing box approach and we explore various values of the rotation frequency Ω and the solid stopping time t_s, a parameter related to the particle size. We then analyse the results using tools borrowed from the study of dynamical systems. In particular, the Lyapunov dimension d_L is calculated for each run to characterize the dust dynamics in the flow (Fig. 1a). This quantity gives an estimation of the fractal attractor dimension in the phase space [3]. We find three different regimes. For low values of Ω and large values of t_s we obtain $d_L > 2$, therefore the inertial particles fill the whole space. Focusing instead on intermediate values of t_s, for small rotation rates the particles are expelled from the eddies and form fractal structures (Fig. 1b), while they tend to concentrate inside the anticyclones for larger Ω (Fig. 1c). Particles eventually form a pointwise cluster for $d_L = 0$ (Fig. 1d).

We have identified promising tools for the understanding of planetesimal formation.

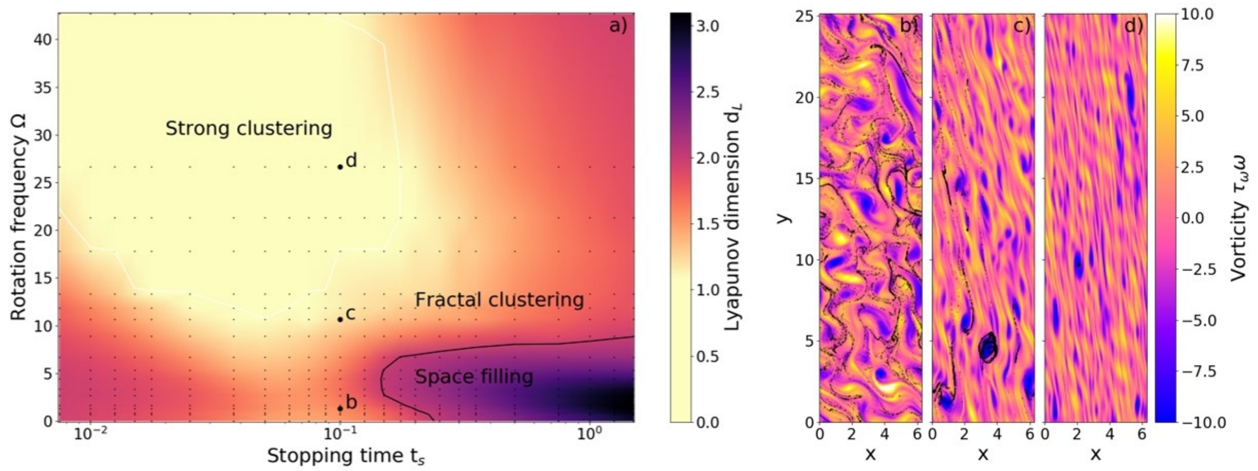

Figure 1: a) Phase diagram of Ω vs t_s. b) Snapshot at t=200 for Ω=4/3 and t_s=0.1. c) Snapshot at t=200 for Ω=32/3 and t_s=0.1. d) Snapshot at t=200 for Ω=80/3 and t_s=0.1.

Bibliography

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