PLANETESIMAL GROWTH AND TURBULENCE: ARE WE ALLOWED TO SEPARATE THEM?

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Introduction: In the classic view of planet formation, turbulence is considered as a purely diffusive phenomenon, resulting in randomized encounter velocities between solid particles. Depending upon the details of the model and the particle size range considered, this process provides more or less efficient growth of dust toward larger and larger sizes [1]. Only when the solid component has grown large enough (>1 cm, depending upon turbulence intensity) it can efficiently settle to the mid-plane of the disk; at that point, collective effects are assumed to drive the following evolution, influencing both the growth rate and, eventually, the gas motion.

However, all current models agree, in general, for considering situations in which the particle distribution remains spatially homogeneous.

This approach fails in the explanation of some relevant facts: for example, particles of ~1 meter could continue growing only if turbulence vanishes at a certain epoch in the nebula life, since smaller grains would impact with a too large energy to be efficiently accreted [1].

The existence of a “dead zone” is often invoked, as a region shielded from ionizing radiation, in which MHD turbulence would not be fed and planet formation promoted. However, if this quite region would really exist, an efficient sedimentation of solid particles to the mid-plane would imply, in general, the generation of shearing turbulence [2], again diffusing particles. Only if the dust/gas ratio was high enough, the gravitational instability of the dust layer itself could possibly take place [3].

Turbulence can play a positive role: With this contribution we want to stress that too simplistic assumptions on the role of turbulence can generate a part of the problems that are underlined above. In particular, inhomogeneities in the particle distribution and spatial correlations in the turbulent gas motion could offer the solution to several problems.

A recent suggestion of that is offered by simulations of particle settling and turbulence onset by Kelvin-Helmoltz instability [4], showing that solids can form high-density clumps and concentrations. In turn, these regions could become gravitationally unstable and rapidly collapse to form larger bodies.

The same could happen inside large-scale structures of the turbulent flows, for example in vortices if they were present [5].

We will discuss in the following two results obtained in the frame of the activity financed by PNP. The first one is a numerical simulation of the gravitational instability in a keplerian disk of planetesimals. Here, turbulence is not explicitly considered, but it is shown that it could be unavoidably generated by the process.

In the second part, the importance of velocity correlations when considering particle motion inside a vortex will be underlined.

Gravitational instability: Detailed simulations showing the onset of gravitational instability in a disk of particles with a surface density compatible to that of protoplanetary disks have been performed by using a hierarchical tree-code, and the shearing boxes approximation [6]. Initial conditions consider a thin, unstable layer of \( \sim 4 \times 10^5 \) particles, moving on circular orbits.

It can be shown that, except in the very inner region of the disk, mutual collisions are unable to dampen the kinetic energy of the particles. As a result, the set of particles, after having shown hints of the instability under the form of density waves, is transformed in a stable layer, with higher velocity dispersion (i.e. increased thickness).

On the other hand, if a dissipation is introduced (corresponding simply to gas friction in a laminar nebula), particles can form self-gravitating clumps, observed for the first time in this context.

In conclusion, we can state that, if a laminar nebula can dampen velocity dispersions, the instability can form high-density regions with complex dynamics. This is a strongly non-linear behaviour rather different from the straight planetesimal formation originally supposed by [7].

Further, the high particle density could trigger turbulence in the gas, thus considerably affecting the overall physics of the problem. In this sense, the absence of turbulence appears to be a rather “weak” feature of the gravitational instability scenario.

Mutual velocities and particle growth: Recently, we studied the relative velocities of particles coupled to large scale structures of the turbulent flow. With this project, still under way, we show that bodies captured in a vortex can grow well beyond the \( \sim 1 \) m limit that is considered as a difficult barrier when decorrelated velocities are assumed. Our toy-model can help us to better understand the role of anticyclonic regions, recently identified in widely different numerical simulations of turbulent disks.