

Critical phenomena and collective behaviour of multi-particle complex systems (Complex Matter)

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<http://complexmatter.wordpress.com>

Main objectives:

- 1) Study how individual particles, their interactions and fluctuations at **micro scale** lead to the **emergence of collective behavior** at **macro scale**.
- 2) Develop a **unified approach** for systems ranging **from nano to millimeter size** to bridge the gap between quantum mechanics and macroscopic physics.
- 3) Propose **novel solutions to real - world problems** like **industrial processing of granular matter** and the formation of **traffic jams**.

Collective behavior:

- Nucleation with metastable states in nanosystems (Proteins, microfluids, dusty plasmas)
- Phase transitions, the role of fluctuations in the emergence of patterns
- From granular matter to continuous media: Agitation leads to out of equilibrium phenomena like:
 - a) Clustering
 - b) Segregation according to size
 - c) Convective flow patterns

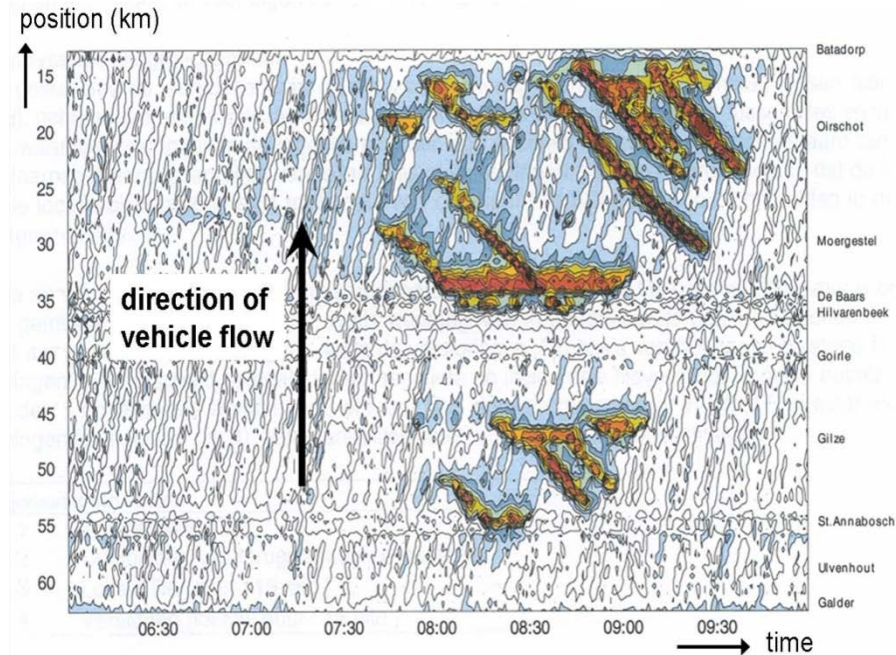
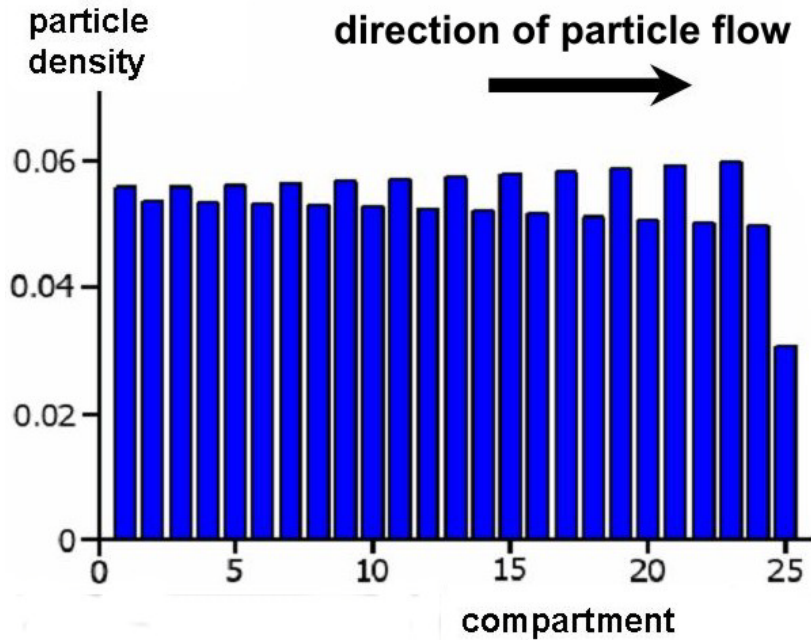
Work Packages (WP):

WP1: Risk of cluster formation (Patras)

Clustering is an intriguing but notorious form of complex structure formation.

The **spontaneous occurrence of dense clusters** constitutes a major problem in industries around the world handling granular particles (mining, food production, pharmaceutical industry, construction works) and also in vehicle traffic.

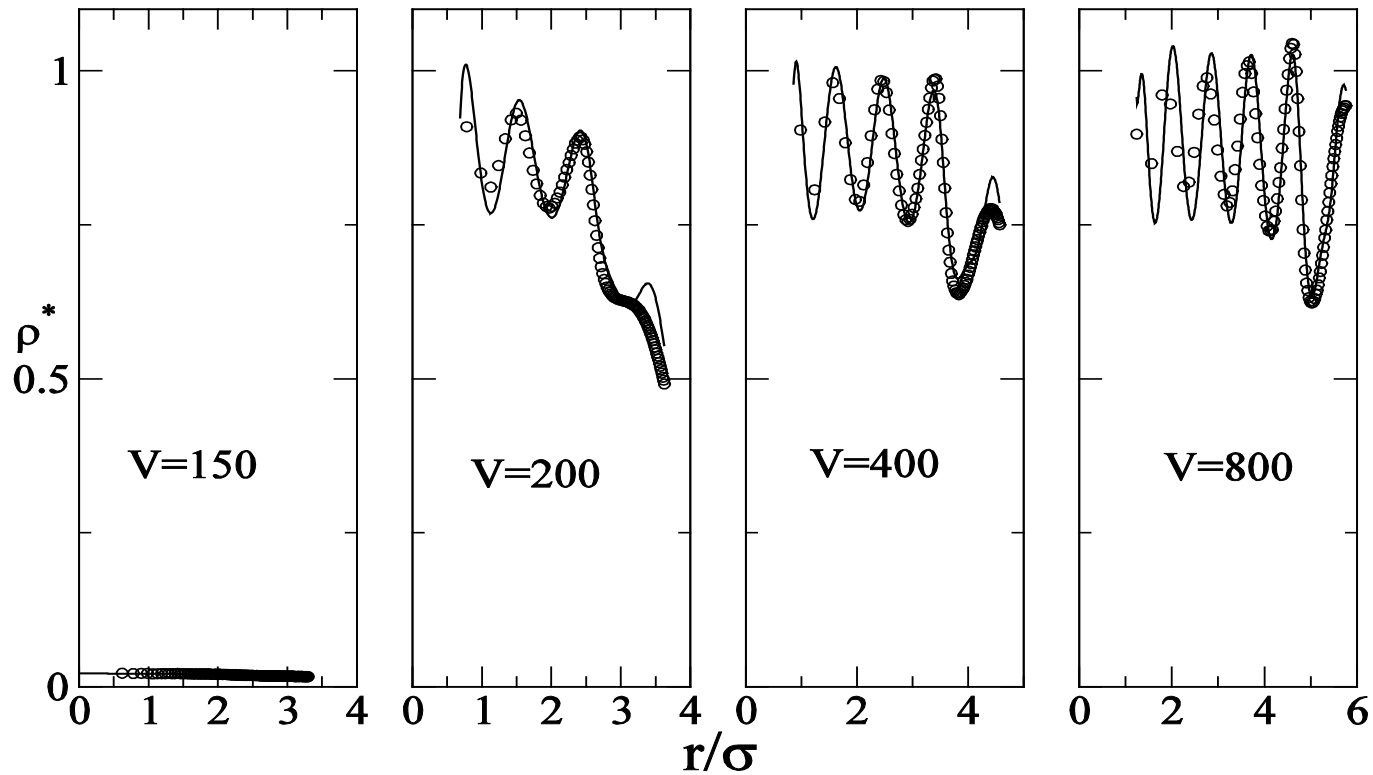
A better understanding of these structures using mathematical models and nonlinear dynamics theory has the very practical goal of avoiding them.



Precursors to cluster formation: Density oscillations in a granular transport line of 25 vibrated compartments (left) and on the highway A58 between the cities of Breda and Eindhoven in the Netherlands (right). The density waves propagate in the opposite direction to that of the individual particles/vehicles and cause large-scale congestion at the points of inflow, i.e., compartment 1 and the junction near km 35 respectively.

WP2: Phase transitions due to confinement (Brussels)

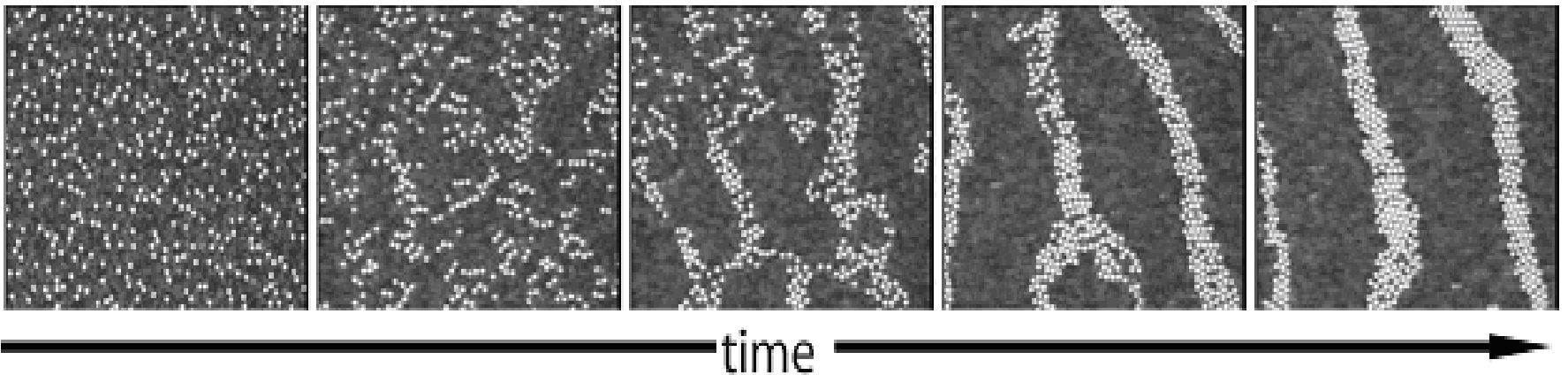
- Properties of matter **confined to small cavities**.
- **Fluids near a wall** manifest **new behaviour** (such as wetting and the formation of thin films).
- Confinement in **cavities, channels, pores, etc.** gives rise to properties dramatically different from the corresponding **bulk system**.
- The **prediction of these properties** in the areas of **microfluidics, nano-scale technology and biomedical applications** as well as **colloids and granular materials**.
- Develop and apply the theoretical tools of **Density Functional Theory** at **finite temperature and for finite systems**.



The density of a fluid confined to a spherical cavity as a function of the distance from the center of the cavity. The figures show results for different volumes V as determined from DFT calculations (lines) and simulation (circles). This illustrates the transition from a liquid (high densities) at larger volumes to a gas (low density) at the smallest volume.

WP3: Self-organized segregation in Bidisperse media (Manchester)

The transition from **the mixed to the segregated state** in a horizontally vibrated monolayer of two kinds of granular particles **has not yet been well described numerically**. We plan to do so, focusing on the effects of **"intrinsic noise"** caused by **microscopic irregularities** of the particles, showing how complexity at small scales induces large size effects.

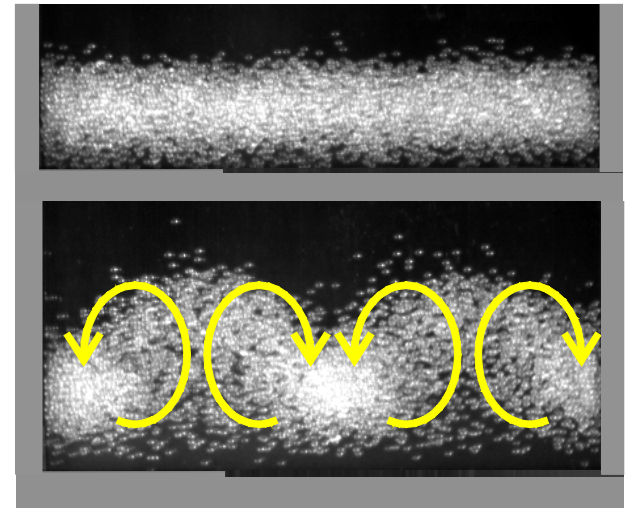


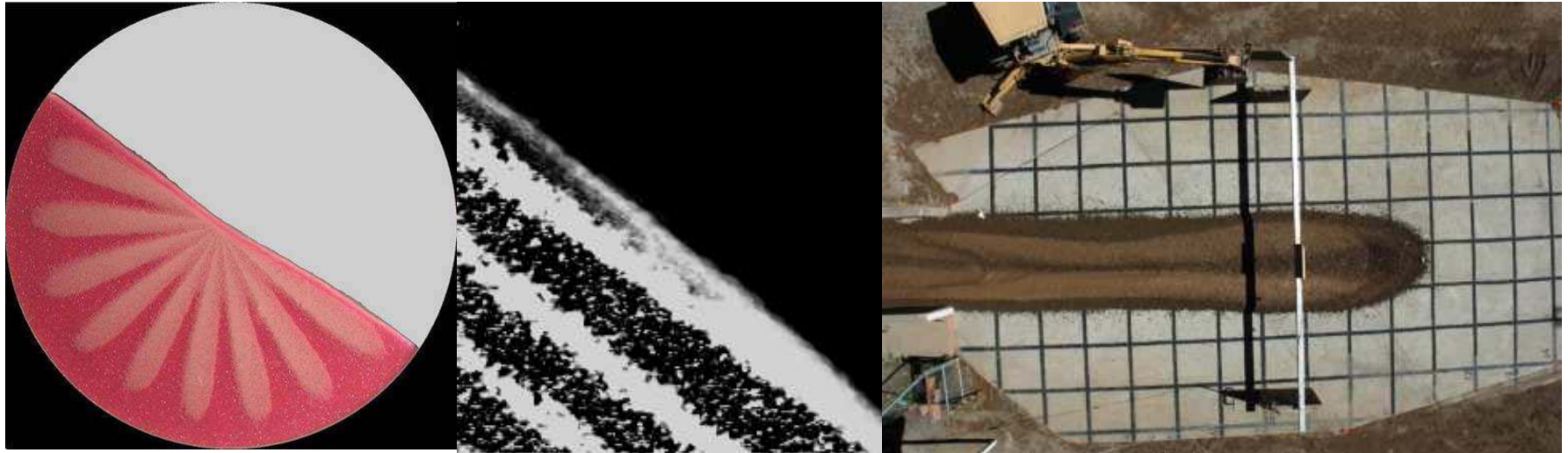
WP4. Phase transitions in agitated granular matter (Twente)

Granular matter is different from **continuous media** in that it involves a **limited number of particles**. Patterns emerge on the scale of several tens of particle diameters and **fluctuations play a dominant role** in the dynamics.

We want to understand **multi-particle systems far from equilibrium** where statistical noise, dissipative interactions and fluctuations produce spontaneously emerging structures.

Slow particles floating on top of a low-density gaseous layer of **fast particles** undergo a transition to **counter-rotating rolls** similar to **Rayleigh-Bénard convection** in ordinary fluids. What is the role of subcritical fluctuations here?





The **segregation of particles** with different material properties has important feedback on the bulk flow. This is responsible for the **spontaneous formation of petals** in a rotating drum (left), **stratification patterns** in a granular heap (middle), and **lateral levees** in debris flows (right). Preventing this type of phenomena is of great practical importance to **industries that process granular materials**.