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Particle dynamics at the onset of the granular gas-liquid transition

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Introduction

Granular gases are composed by a large amount of mobile solid particles. Unlike molecular gases, they are characterized by inelastic collisions leading to an ongoing loss of kinetic energy over time. In order to avoid such cooling of the system, mechanical energy should be injected in the granular gas.

From dilute systems, increasing the number of particles also leads to the spontaneous formation of denser regions coexisting with the granular gas (Noirhomme et al 2018). This gas-liquid transition is known to depend on the collision rate in the system. Although this phenomenon has already been studied at the scale of the entire system, local clustering is still poorly investigated. The granular gas-liquid transition itself is smooth and many fundamental questions remain open. Among others, the particle dynamics (in the gas phase) near the transition is still unclear.

In the present work, we propose investigations of the gas-like to clustering transition in driven granular media thanks to the tracking of a few large tracer particles in a 2D gas made of semi-transparent tiny particles. We show that the velocity distributions of these tracers show peculiar features when the density of the system is increased above some threshold value. The latter is shown to coincide with the emergence of local clusters, that is a liquid-like phase coexisting with the granular gas.

Experiments

Our studies were thus realized using the VIP-Gran instrument (Aumaître et al 2018) that was developed in the frame of the SpaceGrains project of the European Space Agency (ESA). Experiments took place during the 66th and 69th ESA parabolic flight campaigns. Given our need to achieve particle tracking, granular media is enclosed in a quasi-2D cell composed of four transparent walls and two moving plates that can inject kinetic energy into the system. Pistons move sinusoidally in phase opposition with fixed amplitude A=4 mm and frequency f=15 Hz.

As seen in Figure 1, we placed a few large particles (Nt=1 and Nt=3) as tracers in order to follow the particle trajectories when the number of small particles Ns is increased. The gas-liquid transition takes place close to Ns=200. There, the trajectories are deeply modified from quasi linear segments to random paths. Some caging effect is seen and this is due to the granular droplet forming around large particles.

In order to confirm the transition with a second method, we also determined the local density of the particles in subcells covering the images. The statistical distribution of the values obtained in all subcells, as presented in Figure 2(a), shows two peaks when Ns is high enough, i.e. when the transition occurs. Average peak positions μ determining the probable local densities in subcells are drawn in Figure 2(b). This plot shows that, at low Ns values, μ keeps a linear single trend as expected for a homogeneous gas phase. However, at higher Ns values, a bifurcation is observed with two branches being gas and droplet densities respectively.

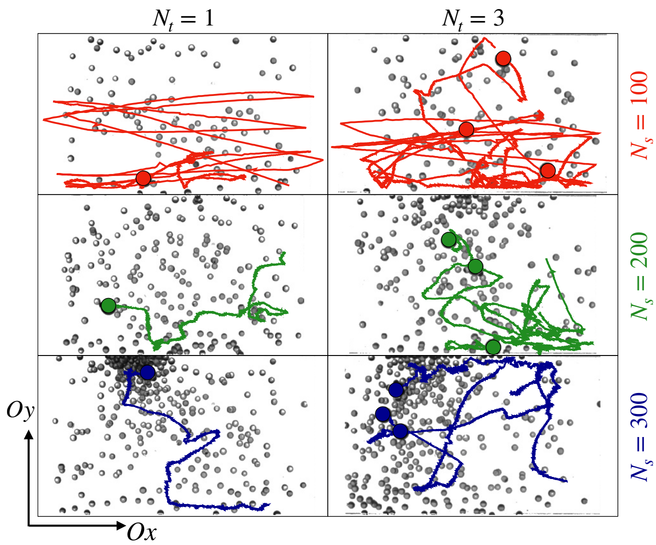

Figure 1: Trajectories of Nt tracers being large particles placed in a gas of small solid particles. When the density of the gas remains low, the trajectories are quasi linear trajectories in between moving pistons. Increasing the number Ns of small beads leads to the formation of liquid droplets in which the large particles are trapped. Trajectories become more randomized.

Model

A model (Noirhomme et al 2021) has been elaborated taking into account the dissipative nature of the particle collisions and the injection of kinetic energy from the opposite pistons. This model fits the data (red curves in Figure 2(b)) within error bars. It suggests that the transition is a subcritical pitchfork bifurcation. The signature of this kind of bifurcation is a critical point being highly sensitive to the initial conditions and the history of the system. This may explain why parabolic flight experiments were quite difficult to analyze till now.

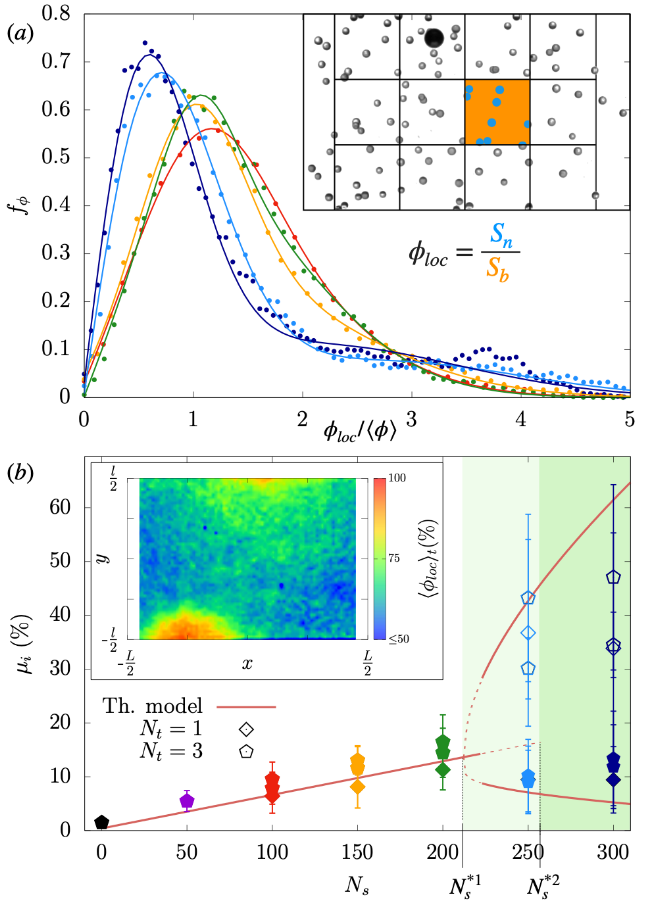

Figure 2: (a) Statistical distribution of particle density in many subcells. The color code corresponds to different Ns values. The distribution shows two peaks for high Ns values. (b) The position of the peaks for each set of data is shown using the same color code. Inset shows the density map of the VIPGRAN cell in false colors evidencing clusters (granular liquid droplets) along the side walls.

Conclusions

Parabolic flight experiments using the VIP-GRAN instrument have evidenced a gas-liquid transition in granular systems. From data analysis and from model developments, this transition appears to belong to a class of subcritical pitchfork bifurcation, showing high sensibility to experimental conditions. This may change the way future experiments will be conducted onboard ISS.

Acknowledgements

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