In modeling Granular media, we are constantly forced to stretch the boundaries of thermodynamics and hydrodynamics. The particle interactions do not conserve energy, so we are required to extend the traditional kinetic theory of molecular gases to situations where dissipation is present. The particles are macroscopic in size and traditional coarse-graining used to construct a hydrodynamic or a continuum theory are questionable because statistical fluctuations are dominant.

Yet, there is rapid progress in our ability to model granular matter. Combining statistical physics concepts such as scaling and universality, large-scale molecular dynamics simulations, and experimental results, we are able to identify relevant degrees of freedom and dominant physical mechanisms and use those to construct predictive theories and reduced models.

In this brief research highlight, we describe modeling of granular gases, particularly, coarsening in vibrated granular layers and velocity statistics of strongly driven granular gases.

Coarsening of granular layers. Experiments in electrostatically driven granular layers reveal a coarsening process where clusters grow in size indefinitely. This process is mediated by exchange of particle between clusters (figure 1). Using an exchange-driven-growth theoretical model, we are able successfully to model statistical properties of the coarsening process.

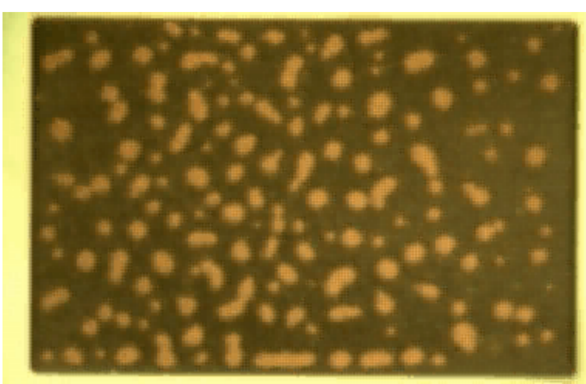

Figure 1 *Coarsening in electrostatically vibrated powders: experiment.*

In the model, particles are exchanged between clusters and clusters disappear when their size shrinks to zero. The model predicts that the average cluster size grows algebraically with time, that the cluster size distribution becomes universal in the long time limit, and that the scaling distribution is exponential (figure 2). All these predictions are in very good agreement with the experimental measurements and moreover, these predictions have served as a guide for future experiments, suggesting what quantities should be measured and how the data should be analyzed.

The utility of this modeling approach is that it bypasses the need to model every single grain, or the precise details of the driving mechanism and instead, it focuses on the relevant degrees of freedom, the cluster size and it illuminates the cluster growth mechanism.

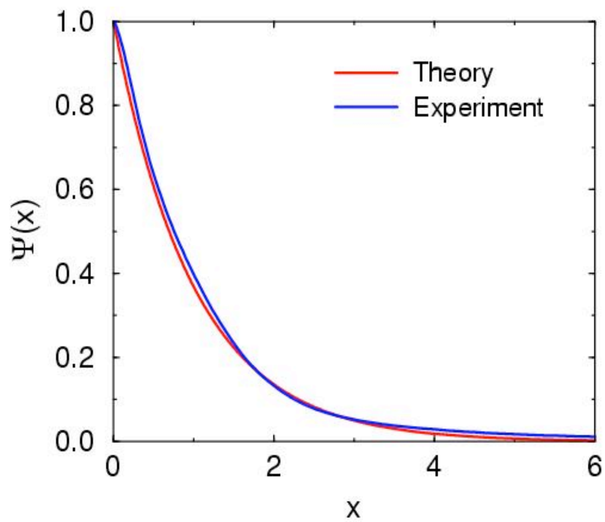

Figure 2 *The cumulative area distribution of clusters: theory versus experiments.*

Velocity Statistics of Granular gases

Shaking a box of beads, no matter how hard, fails to generate an equilibrium distribution of energy. Instead, the statistics are anomalous in many ways, spatial correlations may arise and the velocity distribution may include correlations between the various components of the velocity. Information such as the velocity distribution is needed practically as input for the continuum theory of granular flow (transport coefficients). More importantly, it reflects the mechanism by which energy is exchanged between particles.

Energy dissipation that occurs via inelastic particle collisions is ultimately responsible for the deviations from a Maxwell-Boltzmann distribution that is observed almost universally in highly agitated granular media.

In dilute situations, we apply kinetic theory to model the dynamics of granular gases. In some cases, it is possible to obtain exact solutions, in others, an extremal or moment analysis is possible. The picture arising is very rich and interesting. Generically, the velocity distribution has a stretched exponential tail such that it is overpopulated with respect to an equilibrium (Gaussian) distribution. The details of the distribution depend sensitively on the nature of the interaction between particles. In several cases: for hard-sphere interactions and for dipole interactions, the predictions of the kinetic theory are in very good agreement with a series of recent experiments (figure 3).

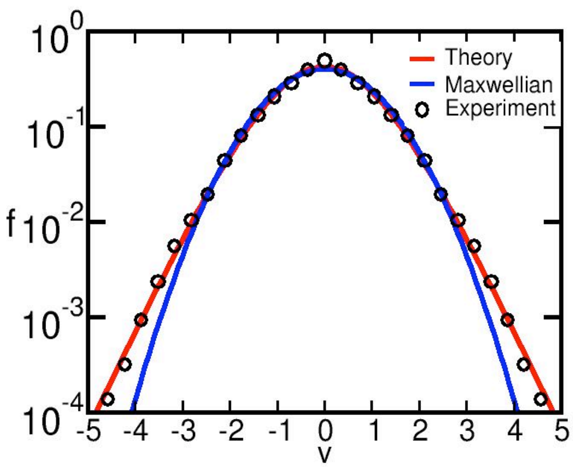

Figure 3 *Velocity distribution of driven granular gases: theory versus experiement.*

The theory also shows that there is an even richer phenomenology. Typically, energy is injected at all scales to counter he dissipation and this results in sharp tails of the velocity distribution. However, if the energy is injected only at large scales, there may be a cascade from large to small velocity scales. In a cascade event, an energetic particles turns into two energetic particles such that momentum is conserved but energy dissipated. In this situation, the velocity distribution has a power-law tail with an exponent that depends very sensitively on the collision parameters. We propose that such cascade states may be observed experimentally, for example in situations where an energetic particles hits a static granular medium.

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