– **Press Release** –

Fluctuations in Particulate Flows

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Collections of macroscopic particles – e.g. soil, grains, or bubbles – perform *particulate flow* when they are set into motion by an external force. Prominent examples are land slides (soil), the discharge of silos (grains), and foam floating over the rim of a glass (bubbles – see picture to the right).

Foam on a lime spider.

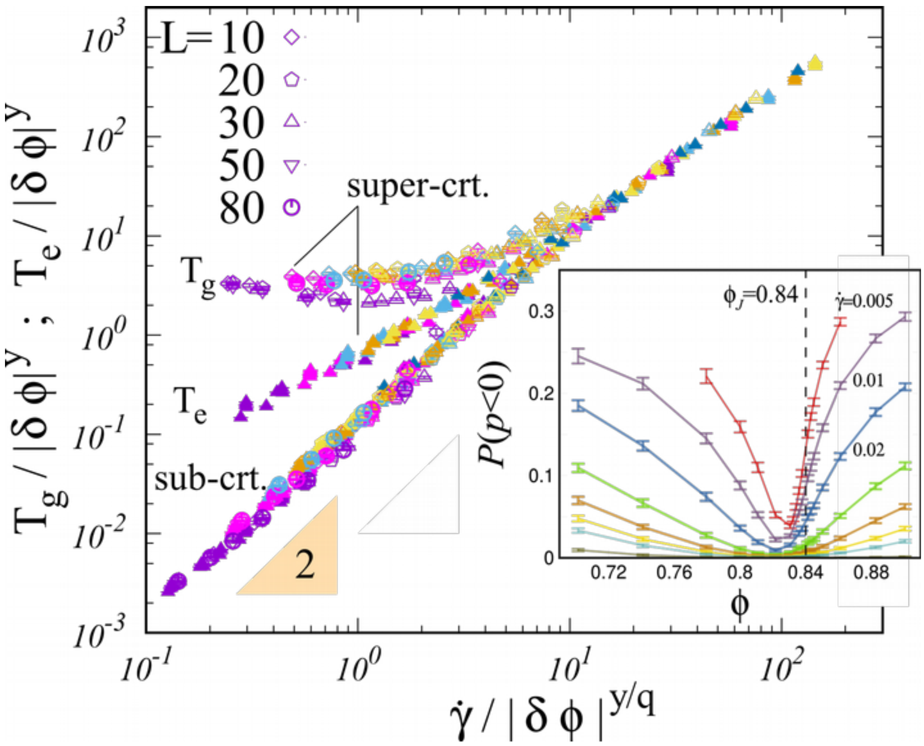
The onset of flow is qualitatively different for systems with a low density and a high density of particles. Dilute systems do not resist flow (like a fluid). Dense systems show an elastic response to small forces (standing foam), but they still flow when the force is increased (gravity pushes the foam over the rim of the glass). This emergence and loss of rigidity as a function of density and external forces is very similar to the transition from para- to ferromagnetism as function of temperature and an external field. For particulate flows this phase transition is called *jamming*.

Mathematical concepts, that were developed for the description of magnetic phase transitions, work exactly analogously also for jamming. Moreover, the theory is universal in the sense that at first look vastly different systems show exactly the same behavior: mathematics provides a joint perspective to describe jamming for soil and sand, grains and bubbles.

In a numerical study Rahbari et al measure large fluctuations of the local energy input into dense particulate flows. For landslides the large fluctuations determine where they go and when they run out. For technical structures large fluctuations can cause severe damage to infrastructure, like the breakdown of silos [see the movie https://www.youtube.com/watch?v=qCSSCM5a6QQ]. Rahbari et al identify different mechanisms leading to large fluctuations in dilute and dense systems, and they point out that very large fluctuations are noticeably suppressed close to the jamming transition. This is unexpected. The theory of classical phase transitions predicts that fluctuations diverge when approaching a critical point, like jamming. Hence, the numerical work of Rahbari et al points towards new physics of these non-equilibrium phase transitions.

The authors also suggest to adopt methods from large deviation theory to build a theory for the non-equilibrium phase transition. Large deviation theory was pioneered to perform risk analysis in insurance mathematics. In the past 20 years it was applied in biophysics, where it is used now to describe the folding of bio-molecules and the efficiency of molecular motors in cells. In the spirit of the biophysical work, Rahbari et al establish a fluctuation relation for particulate flows. Similar to analogous relations, that were established in the biological systems, this relation provides a starting point to generalize thermodynamic concepts from the equilibrium into the non-equilibrium realm. In the present context the relation is used to define a temperature for the particulate flow. For densities below jamming the dependence of the temperature on density and shear-rate agrees with theoretical predictions for very dilute systems. For larger densities – the interesting regime for applications – the novel approach provides a distinctly new parameter dependence (see figure below). This finding provides a starting point of mathematical work on the frequency of large fluctuations, and it sets the scene to address a vast number of open questions for particulate flows:

To what extend can classical approaches of equilibrium statistical physics be extended to establish a theory for jamming in dense particulate flows?
In which respect does this transition differ qualitatively from classical phase transitions?
What does this teach us about optimizing technological devices, in particular strategies to avoid breakdown of devices due to rare fluctuations?



The probability to encounter rare fluctuations for different densities φ and shear rates γ are shown in the inset. All data can be described based on the effective temperature T_e *that is found from a novel fluctuation relation. For large densities it differs from the mean kinetic energy per degree of freedom* T_g *that has been used so far to characterize the temperature of the systems.*
[adapted from S. H. E. Rahbari, et al, Nature Comm. 8:11 (2017)]

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