Abstracts – Invited Talks

Eric Clément, Philippe Claudin, Bruno Andreotti
PMMH-ESPCI , 10 rue Vauquelin, 75005, Paris.

"Creep, fluidity and non-local microscopic processes in granular rheology"

Granular materials belong to the class of amorphous athermal systems. Like foams, emulsions, suspensions, or metallic glasses, they exhibit a dynamical phase transition between static and flowing states. Analogously to phase transitions of thermodynamic systems, this rigidity transition exhibits a divergence of correlation lengths, revealing the presence of nonlocal cooperative processes often called dynamical heterogeneities. However the notion of arrest is ubiquitous. In the vicinity of the transition, one may observe aging or creep motion in conditions essentially corresponding to dynamical arrest. In this presentation I will review some results we obtained recently on local and non-local processes identified in granular packing and discussed their consequences on the macroscopic rheological equation

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Antonio Coniglio
CNR-SPIN and Universita' di Napoli "Federico II"

"Scaling and universality in glass, gel and jamming transitions"

It is shown that a geometrical approach, applied to the Frederick-Anderson kinetic facilitated model, predicts, in mean field, a discontinuous dynamical transition with scaling laws relating dynamical exponents to the static exponents of mean field bootstrap percolation. The dynamical behavior and the scaling laws coincide with those predicted by the Mode Coupling Theory (MCT) model B. These results explain the origin of scaling and universality in the glass transition, at least in mean field, characterized by the divergence of the static length of the bootstrap percolation model, together with the divergence of the fluctuation of the order parameter, and an upper critical dimension dc = 8.

A similar approach to the sol gel transition in mean field yields a continuous dynamical transition with the same scaling laws found in MCT for continuous glass transition (model A). In this case the origin of scaling and universality is associated to an underlying random percolation transition with an upper critical dimension dc=6.

Finally Jamming is associated to a discontinuous percolation transition, however, contrary to bootstrap percolation, the fluctuation of the percolation order parameter does not diverge at the transition.

Daan Frenkel
University of Cambridge, UK

"Numerical calculation of granular entropy: counting the uncountable"

In 1989, Sir Sam Edwards introduced the concept of `granular entropy', defined as the logarithm of the number of distinct packings of N granular particles in a fixed volume V.
The proposal was rather controversial but much of the debate was sterile because the granular entropy could not even be computed for systems as small as 20 particles - hardly a good approximation of the thermodynamic limit. In my talk I will describe how granular entropies of much larger systems can now be computed, using a novel algorithm. Interestingly, it turns out the definition of granular entropy will have to be modified to guarantee that granular entropy is extensive.

Kinetic theory of shear thickening

Hisao Hayakawa* and Satoshi Takada**

(*Yukawa Institute for Theoretical Physics, Kyoto University,
**Department of Physics, Kyoto University)

A simple kinetic theory to exhibit a discontinuous shear thickening (DST) is proposed. The model includes the collision integral and the friction from background as well as a thermostat term characterized by T_{ex}. The viscosity of this model is proportional to $\dot{\gamma}^2$ which is consistent with the observation by Kawasaki et al. [1] for large shear rate $\dot{\gamma}$, while it is Newtonian for low $\dot{\gamma}$. The DST emerges as a suddle-node bifurcation arising from the connection between Newtonian branch and the branch at $T_{ex} = 0$. The emergence of the DST is enhanced for lower density and lower but finite T_{ex}. The proposed mechanism is new, because the DST is unrelated to neither mutual friction of grains, order-disorder transition from the attractive interactions, boundary effect nor hydro-clustering mechanism.

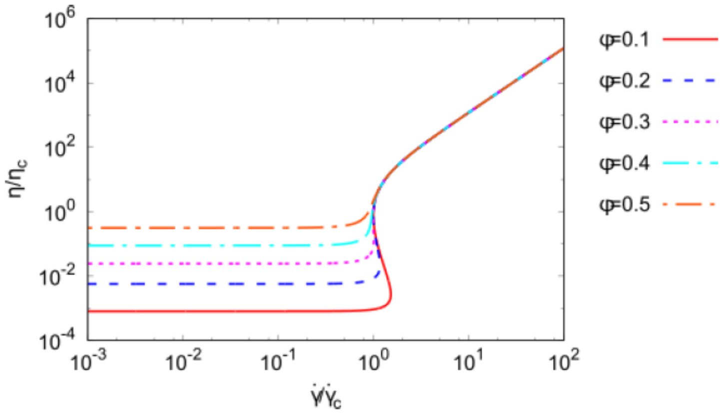

Fig.1:Plot of viscosity against the scaled shear rate. Below a critical volume fraction the viscosity has a S shape, in which two metastable branches and one unstable branch exist to have the discontinuous shear thickening. For large shear rate, the viscosity is proportional to the square of the shear rate.

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Silke Henkes, David A. Quint, Yaouen Fily and J. M. Schwarz
University of Aberdeen, UK

"Rigid Cluster Decomposition Reveals Criticality in Frictional Jamming"

We study the nature of the frictional jamming transition within the framework of rigidity percolation theory. Slowly sheared frictional packings are decomposed into rigid clusters and floppy regions with a generalisation of the pebble game including frictional contacts. Our method suggests a second-order transition controlled by the emergence of a system-spanning rigid cluster accompanied by a critical cluster size distribution. Rigid clusters also correlate with common measures of rigidity. We contrast this result with frictionless jamming, where the rigid cluster size distribution is noncritical.

Hans Herrmann
ETH Zürich, Switzerland

"Rotations in jammed sphere assemblies"

A packing of spheres is called bichromatic if every loop formed by contacts is even. In three dimensions, bichromatic bearings have an infinite number of sliding-free states, so called bearing states. If all loops have length four the system exhibits four continuous degrees of freedom and a systematic way of constructing such bearing states can be devised. The bearing state can be analytically predicted from the initial state without any information about the nature of the contact forces. Any bearing state can be induced by controlling the angular velocities of only two spheres. This allows for instance to amplify the angular velocity along a two parallel touching chains of equally sized spheres as a new way of gear design, that might find use in mechanics and robotics. When a single sphere is blocked a well-defined new bearing state is attained. It is also possible to determine the total mass and the center of mass of the packing by analyzing its response to changes of the angular velocities of at most two spheres. By considering spheres of different size, packings with bearing states can even be made space-filling. In three dimensions a continuum of such configurations can be obtained as cuts through four-dimensional bearing states.

Heinrich M. Jaeger
University of Chicago, USA

"Granular materials by design"

Design is a process that proceeds from desired overall properties to requirements for the constituent components. For materials science, design is a major challenge, because it requires us to invert the typical modeling approach that starts from microscale components in order to predict macroscale behavior. How can one tackle this inverse problem for granular materials that are inherently disordered and far from equilibrium, and for which the design target is not a thermodynamically favored ‘ground state’? I will discuss how concepts from artificial evolution make it possible to identify with high efficiency particle-scale parameters that produce the targeted macroscale behavior. In particular, I will show how one can find

particle shapes that are optimized for specific desired outcomes, such as low aggregate porosity or high stiffness under compression. This approach uses large numbers of parallel molecular dynamics simulations together with optimization techniques based on artificial evolution. Optimized shapes are then validated by physical measurements that test large aggregates of 3D-printed versions of the particles. This approach has general applicability and opens up new opportunities for granular materials design as well as discovery.

N. Kumar and **S. Luding**
MSM, Faculty of Engineering Technology, MESA+, University of Twente, Netherlands

"Multiscale models for the memory of jamming in soft and granular matter"

Soft, disordered, micro-structured materials are ubiquitous in nature and industry, and are different from ordinary fluids or solids, with unusual, interesting static and flow properties. The transition from fluid to solid -- at the so-called jamming density -- features a multitude of complex mechanisms, but there is no unifi ed theoretical framework that explains them all.

A simple yet quantitative and predictive multiscale framework is presented, which allows for a variable, changing jamming density, encompassing the memory of the deformation history and explaining a multitude of phenomena at and around jamming. The jamming density, this way introduced as a new state-variable, changes due to the deformation history and relates the system's macroscopic response to its micro-structure. The packing efficiency of the microstructure can increase logarithmically slow under gentle repeated (isotropic) compression, leading to an increase of the jamming density. In contrast, shear deformations cause anisotropy, changing the packing efficiency exponentially fast with either dilatancy or compactancy. The proposed simple macroscopic constitutive model is then calibrated with the memory of microstructure.
The memory of the system near jamming can be explained by a micro-statistical model that involves a multiscale, fractal energy landscape and links the microscopic particle picture to the macroscopic continuum description, providing a unified explanation for the qualitatively different flow-behavior for different deformation modes.
To complement our work, a recipe to extract the history-dependent jamming density from experimentally accessible data is proposed, and alternative state-variables are compared.

Hernan A. Makse
Levich Institute and City College of New York, USA

"Searching for optimal packings"

Random packing of objects of a particular shape are ubiquitous in science and engineering. Here we present a framework to calculate the volume fraction, force distribution, coordination number, yield stress and dissipation for a system of arbitrary shaped particles formed by intersection and union of spheres. The framework allows for an exploration of the large space of particle shapes in search of the perfect packing. Novel experimental techniques will be also discussed to test the predictions at the colloidal level.

Corey S. O'Hern
Department of Mechanical Engineering & Materials Science, Department of Applied Physics, and Department of Physics, Yale University

"Nonlinear dynamics of contact breaking in jammed solids"

We perform computational studies of the response of mechanically stable packings of spherical particles near the onset of jamming to weak vibrations. Vibrations are added by displacing the packing along a single or a combination of eigenmodes of the dynamical matrix of the mechanically stable packing. The frequency content of the vibrated system can be obtained from the Fourier transform of the particle displacements. We first calculate and then confirm numerically the characteristic amplitude of the vibrations required to break the first interparticle contact in the packing as a function of overcompression $\Delta\phi$ and system size N. The characteristic amplitude at which the first interparticle contact breaks depends strongly on the frequency content of the initial perturbation and its subsequent evolution. In addition, in overcompressed systems with m $=N_c - N_c^0 > 0$ contacts above the isostatic number, we measure the characteristic amplitude required to break m+1 interparticle contacts at which the system transitions from a solid-like to a liquid-like behavior. Finally, we show preliminary studies of the thermal conductivity of the packings as a function of the amplitude and frequency content of the vibrations. We find that the thermal conductivity is sensitive to the breaking and reforming of interparticle contacts.

Peter Olsson
Umeå University, Umeå, Sweden

"Dissipation, velocity distribution and critical exponents in shear-driven jamming"

Soft-core bidisperse frictionless disks in two dimensions are simulated with overdamped shearing dynamics at zero temperature and densities at and below jamming. The velocity distribution and the related energy dissipation are examined and it is found that the dissipation is mainly due to the fastest particles and, furthermore, that the fraction of particles responsible for the dissipation decreases towards zero as jamming is approached. These particles belong to an algebraic tail of the velocity distribution that approaches $P(v)\sim v^{-3}$.

Since dissipation is related to the velocity squared, it is argued that the average of velocity and velocity squared are dominated by different regions of the velocity distribution, with the consequence that the average velocity and the root-mean-square velocity diverge differently. Concepts like ``typical velocity'', which are often used in theoretical considerations, are then no longer useful. It is then shown that this observation helps reconcile a recent theoretical result with direct numerical determinations of the same exponent.

Massimo Pica-Ciamarra
Nanyang Technological University, Singapore

"Jamming of deformable particles"

The jamming transition has been mostly investigated in systems of in-deformable particles, that interact via a well defined two-body interaction potential. Here we consider how jamming occurs in systems of soft polymeric particles, that shrink and deform when compressed. Specifically, we investigate experimentally and theoretically jamming in systems of soft microgel particles. In these systems, the bulk and the shear modulus have a complex and system dependent concentration dependence, but the two moduli result to be always proportional. We show that these observations are rationalized assuming the particles to deform affinely upon compression, which implies that the concentration dependence of the elastic constants is fixed by the dependence of the osmotic pressure of a particle on its size. We determine the size dependence of the osmotic pressure developing a mechanical model for the particles that combines Flory's mean field Flory theory and the Alexander–de Gennes model for polymer brushes. The model successfully reproduces the observed concentration dependence of the elastic constants of three different sets of microgel particles.

Matthias Schröter
Institute for Multiscale Simulation, FAU Erlangen

"Friction with your neighbors? Think locally!"

Granular systems are often described by models based on soft frictionless spheres. In such systems both the global volume fraction ϕ_g and the average contact number Z are controlled by the applied pressure P, resulting in interesting scaling relations.

However, real world granular media such as sand, sugar, or soil consist of hard particles, which are rarely spherical, but experience friction at all contacts. These three properties severely limit the usefulness of above models: From their incompressibility follows the loss of the hidden parameter pressure; Z and ϕ_g are not changed simultaneously by compression any more. Friction lowers the minimal number of contacts necessary to achieve mechanical stability, so Z becomes a function of the local geometry. Finally, non-spherical shapes introduce different types of contacts so that Z alone looses significance.

Presently, new theories based on the local geometrical constraints arise; with often good predictive power. This talk will present recent X-ray tomography experiments on packings of spheres, ellipsoids and tetrahedra. Our results show that for spheres and ellipsoids Z can indeed be described by an ansatz which depends only on *locally defined variables* such as the particle volume fraction ϕ_l (computed from its Voronoi volume) and their shape α.

For the tetrahedra we find that the *packing preparation* decides the number of the different types of contacts (such as face-to-face or edge-to-edge) an average particle will form. Therefore packings sharing the same value of ϕ_g can differ significantly in the average number of constraints per particle.

Matthias Grob, Claus Heussinger and **Annette Zippelius**
Institute for Theoretical Physics, Georg August-University of Göttingen

"Dense Granular Flow of Frictional Particles"

A jamming scenario of frictional particles is discussed and interpreted in terms of a nonequilibrium first order phase transition (1). Results of numerical simulations will be presented and analyzed in the framework of a simple model which can account for both, the continuous frictionless case and the discontinuous frictional case. The most important features of the frictional phase diagram are reentrant behavior and a critical jamming point at finite stress. In the simulations, we observe that small systems settle into a stationary state, whereas large systems do not relax to a stationary state on the timescale of observation, but rather display chaotic time dependence (2). We propose a hydrodynamic model which couples stress relaxation to a scalar variable accounting for the microstructure of the packing. Linear stability analysis reveals an extended phase diagram which in addition to regions of stationary flow and jammed states displays chaos. We also develop a microscopic picture of reentrant flow and shear thickening, which emphasizes the role of friction.

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