Granular Gases Beyond the Dilute Limit

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Granular Gases
Beyond the Dilute Limit

Thurnau, Germany, September 8-12, 2008

Organizers: Thorsten Pöschel (Bayreuth), Isaac Goldhirsch (Tel Aviv), Javier Brey (Sevilla)

www.granulargas.uni-bayreuth.de
Program

Monday, Sept. 8

09:00 - 09:35  N. Brilliantov
Role of adhesive forces in particle collisions

09:35 - 10:10  E. Trizac
Going the wrong way: the dynamics of annihilation

10:40 - 11:15  C. Hrenya
On the description of granular flows with a continuous size distribution

11:15 - 11:50  U. Marini Bettolo Marconi
Noise Rectification and Fluctuations of an Asymmetric Inelastic Piston

13:00 - 13:35  M.J. Ruiz Montero
Hydrodynamic description of the shear state of freely evolving granular gases

13:35 - 14:10  J. Carrillo
Contracting distances for Maxwellian models with inelastic collisions

14:10 - 14:45  I. Pagonabarraga
Fragmentation in driven granular fluids

15:15 - 17:00  Short poster presentation

17:30  Dinner
Tuesday, Sept. 9

09:00 - 09:35  V. Garzó
Segregation by thermal diffusion of an intruder in a granular dense gas

09:35 - 10:10  A. Santos
The second and third Sonine coefficients of a freely cooling granular gas revisited

10:40 - 11:15  A. Kudrolli
Investigation of transport properties in sheared granular matter with internal imaging

11:15 - 11:50  R. Soto
Extended event driven molecular dynamics for simulating dense granular matter

13:00 - 13:35  C. Krüelle
Beyond Faraday’s crispations: nonlinear patterns of shaken granular material

13:35 - 14:10  J. Royer
Clustering in a Dense, Freely-Falling Granular Stream

14:10 - 14:45  I. Rehberg
Segregation in a granular monolayer under horizontal circular vibration

15:15 - 15:50  M. Nicodemi
Flow, Ordering and Jamming of Sheared Granular Suspensions

15:50 - 16:25  R. Wildman
Experimental investigations of dense granular flow

16:25 - 17:00  R. Blumenfeld
Stress transmission in granular systems and incipient yield flow

17:30  BBQ
Wednesday, Sept. 10

09:00 - 09:35  J. Schmidt
Saturn’s Rings – A Dense Granular Gas Under Kep-
lerian Shear?

09:35 - 10:10  F. Spahn
What do “propellers” tell us about Planet & Ring
formation?

10:40 - 11:15  J. Urbach
Effects of inelasticity on phase transitions in thin gran-
ular layers

11:15 - 11:50  A. Formella
Event Driven Molecular Dynamics: A State-of-the-
Art Simulator

13:00  Excursion
Thursday, Sept. 11

09:00 - 09:35  E. Ben-Naim  
From Grains to Rods

09:35 - 10:10  A. Zippelius  
Hydrodynamic Correlation Functions of a Driven Granular Fluid in Steady State

10:40 - 11:15  V. Kumaran  
Dense granular flows: From kinetic theory to granular dynamics

11:15 - 11:50  M. Alam  
Dynamics of Sheared Granular Fluid

13:00 - 13:35  C. Salueña  
Hydrodynamic modeling of granular materials in complex flow problems

13:35 - 14:10  D. Serero  
Granular binary mixtures: on the validity of hydrodynamics and layering effects in vibrated systems

14:10 - 14:45  R. Brito  
Inelasticity-Induced Segregation in a Granular Mixture

15:15 - 15:50  S. McNamara  
Testing Edward’s Statistical Mechanics of Powders with Volume Histograms

15:50 - 16:25  B. Meerson  
The Knudsen temperature jump and the Navier-Stokes hydrodynamics of granular gases driven by thermal walls

16:25 - 17:00  H. Hayakawa  
Spatial correlations in sheared moderate dense granular gases

17:30  Dinner
Friday, Sept. 12

09:00 - 09:35  I. Aronson
Collective Swirling Motion in the System of Vibrated Elongated Grains

09:35 - 10:10  S. Luding
From dilute to dense and frictional granular materials

10:40 - 11:15  S. Herminghaus
Phase transitions far from equilibrium in wet granular matter

11:15 - 11:50  J. Talbot
Orientational ordering in sheared inelastic dumbbells

11:50  Lunch
Abstracts

- **Dynamics of Sheared Granular Fluid**
  
  **Meheboob Alam**

  In first part of this talk, I will briefly review the dynamics of sheared granular fluid, focusing on instabilities, patterns and bifurcations in plane shear flow. It is shown that a universal criterion holds for the onset of the shear-banding instability (for perturbations having no variation along the stream-wise direction), that lead to shear-band formation along the gradient direction. The same shear-banding criterion appears to hold in other complex fluids as well as in the singular limit of atomistic fluids (i.e. elastic hard-spheres). A weakly nonlinear analysis of the shear-banding instability unveils that the lower branch of the neutral stability curve, that corresponds to dilute flows, is sub-critically unstable. In the presence of gravity, the origin of such shear-banding transition is shown to be tied to the spontaneous symmetry-breaking shear-banding instabilities of the gravity-free uniform shear flow, resulting in universal unfolding of pitchfork bifurcations in gravity-modulated plane shear flow. In the second part of this talk, I will show results from particle simulations of the uniform shear flow of a rough granular fluid. It is shown that the translational and rotational velocities are strongly correlated in direction, but there is no orientational correlation-induced singularity at perfectly smooth ($\beta = -1$) and rough ($\beta = 1$) limits for elastic collisions ($e = 1$); both the translational and rotational velocity distribution functions remain close to a Gaussian for these two limiting cases. Away from these two limits, the orientational as well as spatial velocity correlations are responsible for the emergence of non-Gaussian high velocity tails. The tails of both distribution functions follow stretched exponentials, with the exponents depending on normal ($e$) and tangential ($\beta$) restitution coefficients. There are sizable micropolar effects (that increase with inelasticity) in the sense that the mean vorticity differs from the spanwise rotational velocity in a shear flow.
Non-local rheological properties of granular flows near a jamming limit

Igor Aronson

We study the rheology of sheared granular flows close to a jamming transition. We use the approach of partially fluidized theory with a full set of equations extending the thin layer approximation derived previously for the description of the granular avalanches phenomenology. This theory provides a picture compatible with a local rheology at large shear rates and it works in the vicinity of the jamming transition, where a description in terms of a simple local rheology comes short. We investigate two situations displaying important deviations from local rheology. The first one is based on a set of numerical simulations of sheared soft two-dimensional circular grains. The next case describes previous experimental results obtained on avalanches of sandy material flowing down an incline. Both cases display, close to jamming, significant deviations from the now standard Pouliquen’s flow rule. This discrepancy is the hallmark of a strongly non-local rheology and in both cases, we relate the empirical results and the outcomes of partially fluidized theory. The numerical simulations show a characteristic constitutive structure for the fluid part of the stress involving the confining pressure and the material stiffness that appear in the form of an additional dimensionless parameter. This constitutive relation is then used to describe the case of sandy flows. We show a quantitative agreement as far as the effective flow rules are concerned. A fundamental feature is identified in partially fluidized theory as the existence of a jammed layer developing in the vicinity of the flow arrest that corroborates the experimental findings.
Nonequilibrium steady states of driven grains and rods are investigated using kinetic theory. For driven grains, the velocity distributions are overpopulated with respect to Maxwellians. For driven rods, there is a phase transition from a nematic, ordered phase to an isotropic, disordered phase that occurs in a system of interacting rods, that are subjected to random forcing. Physically, such transitions are found in vibrated granular rods or chains, and the underlying alignment process can be found in biological systems such as molecular motors and microtubules. The steady-state solution for the nonlinear and nonlocal theory is obtained by expressing the Fourier transform of the orientation distribution as a function of the order parameter, which in turn, is obtained in terms of the driving strength. This solution is obtained using iterated partitions of the integer numbers. Surprisingly, the chiral analog of the Boltzmann equation can be solved exactly for arbitrary collision rates.
Stress transmission in granular systems and incipient yield flow

Raphael Blumenfeld

New light is shed on the controversy whether the stress field equations in granular packs are hyperbolic or elliptic. It is argued that granular materials are in fact two-phase composites, with co-existing regions of both characteristics. Purely hyperbolic equations are a feature of isostatic states and these states are shown to behave as critical points.

The constitutive isostaticity equations for two-dimensional systems, and their solutions, are presented.

A central constitutive property of the static theory is a local fabric tensor, which is shown to play a key role also in the strain rate equations for incipient yield rheology.
Role of adhesive forces in particle collisions
Nikolai Brilliantov

Role of adhesive forces in particle collisions is analyzed. The adhesive interactions are described with the use of Johnson, Kendall and Roberts (JKR) theory, while dissipation is attributed to the visco-elastic behavior of the material. For small impact velocities we apply the condition of a quasi-static collision and develop an analytical theory for the inter-particle force. We show that this force is a sum of four components, having in addition to common elastic, viscous and adhesive force, the visco-adhesive cross term. We go beyond the quasi-static theory and formulate the conditions when this approach is valid. Using the derived force we compute numerically and analytically the coefficient of normal restitution. We also find the critical impact velocity (sticking velocity), which distinguishes the restitutive and aggregative collisions. The impact of the tangential component of the relative motion of colliding particles and their rotational motion on the sticking velocity is discussed.
We investigate the segregation of a dense binary mixture of granular particles. The material properties of the particles (diameter and mass) are the same, but the differ in their restitution coefficients. This mixture is vertically vibrated in the presence of gravity. We find a partial segregation of the species, where most dissipative particles submerge in the less dissipative ones. This effect is also present even if only one type of the particles is dissipative and the others are elastic.

Besides the macroscopic segregation there is also segregation at the microscopic scale, in the order of few particle diameters. We characterize it by measuring the density and temperature correlation functions. In our case we find a notorious increase of the probability of finding two inelastic particles together as compared with the less inelastic or elastic ones. This enhancement cannot be described by only considering kinematic properties.
Contracting distances for maxwellian models with inelastic collisions
José A. Carrillo

I will discuss some mathematical properties of maxwellian approximations of the Boltzmann equation with inelastic collisions regarding contraction of quantities. I will report on the consequences for the long-time asymptotics for them.
Event Driven Molecular Dynamics: A State-of-the-Art Simulator
Arno Formella and Thorsten Pöschel

Event driven molecular dynamics (EDMD) has become a recognized simulation method for granular materials. We present a state-of-the-art simulator which handles carefully many of the difficulties one has to deal with to achieve an efficient and robust implementation. This talk concentrates on how to deal with particle overlap due to limited floating point precision, which data structures to use to allow for large scale simulations, and how to organize the code to achieve a flexible framework which can be used in many different areas where an EDMD simulator is needed that guarantees overall good performance. We present a working application that incorporates many types of colliding objects (such as particles of different radii, planes, spheres, and cylinders), 2D and 3D simulation, real time visualization, and a large set of input/output operations.
• Segregation by thermal diffusion of an intruder in a granular dense gas

Vicente Garzó

The thermal diffusion factor of an intruder immersed in a granular dense gas under gravity is analyzed in the context of the inelastic Enskog equation. Thermal diffusion provides a segregation criterion for the transition between the Brazil-nut effect (BNE) and the reverse Brazil-nut effect (RBNE) in terms of the parameter space of the problem: masses, sizes, solid volume fraction and coefficients of restitution. The study carried out here covers some of the aspects not accounted for in previous theoretical works: (i) it goes beyond the weak dissipation limit (and so it takes into account the non-equipartition of granular energy and the nonlinear dependence of the transport coefficients on dissipation), (ii) considers the combined effect of thermal gradients and gravity on segregation, and (iii) applies for moderate densities (solid volume fractions typically smaller than 0.2). The results show that the form of the phase-diagrams for the BNE/RBNE transition depends sensitively on the value of gravity relative to the thermal gradient, so that it is possible to switch between both states for given values of the mechanical parameters of the system and the density. The present analysis extends previous results derived by the author in the dilute limit case.
Spatial correlations in sheared moderate dense granular gases

Hisao Hayakawa

In these days, the long-time tails of the current correlation functions for sheared granular flows are one of hot topics. This is related to the trial to construct the mode-coupling theory for sheared dense granular flows. However, we still do not know the details of the equal-time spatial correlation functions. Recently, we have found that there is a long-range correlation in the momentum correlation function for the sheared dilute granular gases. In this talk, we will extend such an analysis to the case of sheared moderate dense granular gases based on the approach of the fluctuating hydrodynamics. In this talk, we will demonstrate that there is the long-range correlation function as in the case of dilute gases, and the short-range correlation can be discussed in a phenomenological sense. This is the first-step to construct a theory for sheared granular gases with finite density.
Phase transitions far from equilibrium in wet granular matter

Stephan Herminghaus

A number of phase-transition-like phenomena are reported which have been observed in experiments, simulations, and in analytical calculations. We find a wealth of effects akin to fluid/gas phase equilibrium, surface melting, wetting phenomena, and an unstable Leidenfrost phenomenon. Our goal is to understand how far the analogy between equilibrium transitions and those in systems far from equilibrium may be pushed.
• On the description of granular flows with a continuous size distribution

Christine Hrenya

A continuous distribution of particle sizes is prevalent in both natural and industrial settings of granular flows, though the bulk of previous work on mixtures has focused on binary size distributions. Although several moderately-dense theories have been derived for systems composed of an arbitrary number of unlike particles, the application of these theories to continuous size distributions remains untested. This topic is explored in the current effort, with two major questions being addressed. What method should be used to choose the discrete sizes to best mimic the continuous distribution? How many discrete sizes are needed? The former is treated via a matching of moments between the discrete and continuous size distribution, and the latter is explored using a recent theory for mixtures composed of an arbitrary number of species (Garzo, Dufty, and Hrenya, PRE, 2007). A variety of distributions is investigated, including Gaussian, lognormal, and bimodal.
Beyond Faraday’s crispsations: nonlinear patterns of shaken granular material

Christof Krülle

When granular material is shaken both in horizontal and vertical direction simultaneously, as commonly done in vibratory conveyors that are well established in routine industrial production for controlled transport of bulk solids, the transported goods can exhibit a surprisingly large variety of surface patterns. For example, if a monolayer of glass beads is vibrated in a circularly manner in a narrow annular channel, a coexistence of a solidlike and a gaslike domain can be observed [1]. The solid fraction decreases with increasing acceleration and shows hysteresis. The sharp boundaries between the two regions travel around the channel faster than the particles are transported. By using a molecular dynamics simulation we were able to extract the local granular temperature and number density. It was found that the number density in the solid phase is several times that in the gas, while the temperature is orders of magnitude lower.

If the number of particles is increased further, localized period-doubling waves arise [2]. These solitary wave packets are accompanied by a locally increased particle density. The width and velocity of the granular wave pulses are measured as a function of the bed height. A continuum model for the material distribution, based on the measured granular transport velocity as a function of the bed thickness, captures the essence of the experimental findings.

Investigation of transport properties in sheared granular matter with internal imaging

Arshad Kudrolli

We will discuss the dynamical properties of a three dimensional granular packing submitted to shear deformations using a refractive index matching method. Two kinds of experiments will be discussed. (1) A gravity driven situation where the shear is localized and anisotropic diffusion of particles is observed. Further we observe that the velocity auto-correlation function shows a fast decay in contrast with dense elastic spheres at equilibrium. (2) Cyclic shear case, where shear is broadly distributed, and variation of volume fraction with shear cycle can be used to find the diffusion of the particles as a function of volume fraction. The packing properties as a function of volume fraction as characterized by the Voronoi volumes will be also discussed.

Work in collaboration with Andreea Panaitescu and Ashish Orpe
Dense granular flows: From kinetic theory to granular dynamics
V. Kumaran

Rapid granular flows are defined as flows in which the time scales for the particle interactions are small compared to the inverse of the strain rate, so that the particle interactions can be treated as instantaneous collisions. We first show, using Discrete Element simulations, that even very dense flows of sand or glass beads with volume fraction between 0.5 and 0.6 are rapid granular flows. Since collisions are instantaneous, a kinetic theory approach for the constitutive relations is most appropriate, and we present kinetic theory results for different microscopic models for particle interaction. The significant difference between granular flows and normal fluids is that energy is not conserved in a granular flow. The differences in the hydrodynamic modes caused by the non-conserved nature of energy are discussed. Going beyond the Boltzmann equation, the effect of correlations is studied using the ring kinetic approximation, and it is shown that the divergences in the viscometric coefficients, which are present for elastic fluids, are not present for granular flows because energy is not conserved. The hydrodynamic model is applied to the flow down an inclined plane. Since energy is not a conserved variable, the hydrodynamic fields in the bulk of a granular flow are obtained from the mass and momentum conservation equations alone. Energy becomes a relevant variable only in thin ‘boundary layers’ at the boundaries of the flow where there is a balance between the rates of conduction and dissipation. We show that such a hydrodynamic model can predict the salient features of a chute flow, including the flow initiation when the angle of inclination is increased above the ‘friction angle’, the striking lack of observable variation of the volume fraction with height, the observation of a steady flow only for certain restitution coefficients, and the density variations in the boundary layers.
From dilute to dense and frictional granular materials

Stefan Luding

In dense systems, an interesting divergence of viscosity at rather low densities occurs and we will elaborate on its effect for shear band localization. The stability analysis of this system is presented and the consequences of different equations of state are discussed.

Under different driving than shear, namely "democratic" and "non-democratic" shaking, the stationary state as well as the full dynamic evolution of the translational and rotational granular temperatures are investigated as a function of the contact model parameters. Four levels of approximation to the (velocity-dependent) tangential restitution are introduced and used to calculate translational and rotational temperatures in a mean field theory. When comparing these theoretical results to numerical simulations of a randomly driven mono-layer of particles subject to Coulomb friction, we find that already the simplest model leads to qualitative agreement, but only the full Coulomb friction model is able to reproduce/predict the simulation results quantitatively for all magnitudes of friction. In addition, the theory predicts two relaxation times for the decay to the stationary state.
Noise Rectification and Fluctuations of an Asymmetric Inelastic Piston

U. Marini Bettolo Marconi, G. Costantini, and A. Puglisi

We consider a massive inelastic piston, whose opposite faces have different coefficients of restitution, moving under the action of an infinitely dilute gas of hard disks maintained at a fixed temperature. The dynamics of the piston is Markovian and obeys a continuous Master Equation: however, the asymmetry of restitution coefficients induces a violation of detailed balance and a net drift of the piston, as in a Brownian ratchet. Numerical investigations of such non-equilibrium stationary state show that the velocity fluctuations of the piston are symmetric around the mean value only in the limit of large piston mass, while they are strongly asymmetric in the opposite limit. Only taking into account such an asymmetry, i.e. including a third parameter in addition to the mean and the variance of the velocity distribution, it is possible to obtain a satisfactory analytical prediction for the ratchet drift velocity.
Granular kinetic theory is not the only approach inspired by the work of Ludwig Boltzmann. His famous postulate connecting entropy with phase space volume opened the way for statistical mechanics. About twenty years ago, Edwards proposed that a modified version of statistical mechanics applies to static granular packings. In this theory, the volume of the packing replaces the total energy of the system, and the “compactivity” replaces the temperature. The formulas of this “statistical mechanics of granular packings” can be obtained by taking certain equations out of a statistical mechanics textbook and changing a few letters. In spite of this superficial similarity, the two theories have quite different logical structures.

It is quite difficult to extract quantitative results from Edward’s theory because one must work with integrals over the set of all possible granular packings. However, it is possible to precisely test Edward’s theory by examining the change in histograms of volume as one changes some parameter of the packing preparation. Edward’s theory requires that the ratio of histograms to be an exponential in volume. This test is very sensitive and can be applied to both numerical and experimental data.

Specifically, we consider granular compaction, where taps are applied to a packing in a tube. After a large number of taps, the system attains a steady state where the volume fluctuates around an equilibrium value, just as properties of a thermal system fluctuate around their equilibrium values. By varying the tapping strength, and comparing the histograms of the volume obtained, we show that the system is indeed sampling a “granular canonical ensemble”. We extract the analogue of the temperature and entropy. This same analysis can be applied to the volume occupied by single particles, and to experimental results.
The Knudsen temperature jump and the Navier-Stokes hydrodynamics of granular gases driven by thermal walls
Baruch Meerson

Thermal wall is a convenient idealization of a rapidly vibrating plate used for vibrofluidization of granular materials. The objective of this work is to incorporate the Knudsen temperature jumps at thermal walls in the Navier-Stokes hydrodynamic modeling of nearly elastic granular gases. The Knudsen temperature jump manifests itself hydrodynamically as an additional term in the boundary condition for the temperature. Up to a numerical pre-factor, this term is known from kinetic theory of elastic gases. We determine the previously unknown numerical pre-factor by measuring, in a series of MD simulations, steady-state temperature profiles of a gas of elastically colliding hard disks, confined between two thermal walls kept at different temperatures, and comparing the results with the predictions of a hydrodynamic calculation employing the modified boundary condition. The modified boundary condition is then applied, without any adjustable parameters, to a hydrodynamic calculation of the temperature profile of a gas of weakly inelastic hard disks driven by a thermal wall. We find the hydrodynamic prediction to be in excellent agreement with MD simulations of the same system. The results of this work pave the way to a more accurate hydrodynamic modeling of driven granular gases.
Hydrodynamic Description of the Shear State of Freely Evolving Granular Gases
J. Javier Brey and María José Ruiz Montero

The inelastic Navier-Stokes equations are used to identify the final state reached by a freely evolving granular gas, modelled as an ensemble of smooth inelastic hard particles. When the system is above but close to its shear instability, i.e., the system size is larger than a given critical value, the theory predicts the formation of a two bands shear state with a steady density profile. There is a modulation between temperature and density profiles as a consequence of the energy balance that does not produce clustering. Moreover, the time dependence of the velocity field can be scaled out with the squared root of the average temperature of the system. The latter follows the Haff law, but with an effective cooling rate that is smaller than that of the free homogeneous state, and which is found to depend strongly on the system size. The density of the system becomes inhomogeneous, and the steady density profile is also given by the theory. The theoretical predictions are compared with the results of computer simulations of a system of inelastic hard disks, and a good agreement is obtained for low inelasticity. Finally, the simulations show that the shear state is exhibited by the system even for system sizes that are not too close the the critical size.
Flow, Ordering and Jamming of Sheared Granular Suspensions

Mario Nicodemi

We studied the rheological properties of a granular suspension subject to constant shear stress by constant volume molecular dynamics simulations. We derived the system ‘flow diagram’ in the volume fraction/stress plane, which includes an order/disorder transition, signaled by a sharp drop of the viscosity, as well as a jamming region.
Grains can break as a due to their collisions. As a result, fragmentation in these systems differs from spontaneous break up processes. I introduce a kinetic model which accounts for correlations induced at the grains’ collisions and analyze both the kinetics and relevant distribution functions these systems combining analytical and numerical studies based on Direct Simulation Monte Carlo. A broad family of fragmentation probabilities is considered and its implications in the system kinetics are discussed. These driven materials evolve asymptotically into a dynamical scaling regime. If the fragmentation probability tends to a finite constant, the grain number diverges at a finite time, leading to a shattering singularity whereas a monotonous growth is observed otherwise.
Segregation in a granular monolayer under horizontal circular vibration

Christian Kröner, Christof Krülle, and Ingo Rehberg

When granular material is shaken in horizontal direction, segregation occurs. We investigate this effect in a basically isotropic system, namely under a swirling motion, a superposition of two horizontal oscillations perpendicular to each other.

The apparatus is basically the same as described by Schnautz et al. [1] and Raithel [2]. Special emphasis is laid on the experimental investigation of the flow field around a single intruder particle. In particular, it turns out that the intruder particle migrates towards the center of mass of the granulate, rather than to the center of the circular container [3].

Cluster in a Dense, Freely-Falling Granular Stream

John Royer

We investigate the breakup of a freely-falling granular stream into discrete, compact clusters of grains. This breakup, occurring for grain diameters less than about 200 microns falling out of a hopper opening, is reminiscent of the breakup of a liquid stream, though granular materials are generally thought of as lacking a surface tension. Our experiments employ high-speed video imaging in the co-moving frame, which allows us to track the onset of clustering and the subsequent cluster evolution in detail. Varying the material, size, roughness, and wetting properties of the grains as well as the surrounding gas pressure and the hopper opening diameter, we investigate the role of capillary, electrostatic and van der Waals forces in the clustering process. We find that the clustering provides a window to observe very weak cohesive forces between the grains which are masked in other experiments.
• Hydrodynamic modeling of granular materials in complex flow problems

Clara Salueña, José A. Carrillo, and Thorsten Pöschel

There is a developing interest in the hydrodynamic simulation of the dynamics of granular materials, but the question of how far the hydrodynamic approach can go to describe dense states has never been addressed in depth. We use a state-of-the-art numerical scheme to show that the results of hydrodynamic simulations of compressible granular Navier-Stokes equations agree qualitatively and quantitatively with those from particle simulations in the limit of zero particle roughness. For the purpose of the code validation, we choose the Faraday instability in 2D as the reference example to model diverse challenging phenomena: the coexistence of both extremely dense and extremely dilute phases, on the one hand, and also the propagation of shock waves across the granular layer along with the sharp profiles generated in the hydrodynamic fields by the periodic impacts of moving wall. Moreover, the parametric dependence of the Faraday instability is investigated and compared with that obtained by event-driven Molecular Dynamics simulations. Once validated, the code can be used to analyze many other problems and some examples are shown (particle deposition under gravity, clustering in the homogeneous cooling state, the Kelvin-Helmholtz instability...).
The second and third Sonine coefficients of a freely cooling granular gas revisited

Andrés Santos and José María Montanero

In its simplest statistical-mechanical description, a granular fluid can be modeled as composed of smooth inelastic hard spheres (with a constant coefficient of normal restitution $\alpha$) whose velocity distribution function obeys the Enskog-Boltzmann equation. The basic state of a granular fluid is the homogeneous cooling state, characterized by a homogeneous, isotropic, and stationary distribution of scaled velocities, $F(c)$. For instance, the hydrodynamic transport coefficients of the granular fluid are functionals of this distribution. The behavior of $F(c)$ in the domain of thermal velocities ($c \sim 1$) can be characterized by the two first non-trivial coefficients, $a_2$ and $a_3$, of an expansion in Sonine polynomials. The main goals of this talk are (i) to review some of the previous efforts made to estimate the $\alpha$-dependence of $a_2$ and $a_3$, as well as to measure them in computer simulations, (ii) to report new computer simulations results of $a_2$ and $a_3$ in two-dimensional systems, and (iii) to propose theoretical estimates of $a_2$ and $a_3$ with an optimal compromise between simplicity and accuracy.
• **Saturn’s Rings – A Dense Granular Gas Under Keplerian Shear?**

  Jürgen Schmidt

Analysis of data obtained from the VOYAGER and CASSINI spacecraft showed that Saturn’s main ring system consists of water ice particles with sizes in the range between centimeters to a few metres. The rings are extremely flat, as a consequence of the frequent dissipative collisions between the ring particles. Many aspects of the dynamics of dense granular gases are relevant for Saturn’s rings, notably the importance of collisional transfer. On the other hand there are differences. For instance, the velocity dispersion of the ring particles (granular temperature) determines the (small but finite) vertical thickness of the rings, which in turn determines the filling factor. This is a consequence of the motion in Saturn’s gravity field. Another difference is the overall importance of the ring’s self-gravity, which became strikingly clear in the CASSINI data. Self-gravity leads to the formation of transient elongated trailing structures, called self-gravity wakes. In this talk I will give a brief introduction to basic aspects of the dynamics of planetary rings, emphasizing new results of the ongoing CASSINI mission. I will review kinetic theory approaches to the ring dynamics as well as simplified hydrodynamic models.
Granular binary mixtures: on the validity of hydrodynamics and layering effects in vibrated systems

Dan Serero

A computer aided method for accurately computing the transport coefficients for all physically relevant coefficients of restitution will be briefly outlined, and the importance of using high orders in the Sonine polynomials expansion will be shown. Evidence of limitations on the validity of the Chapman Enskog method for strongly inelastic systems or large mass ratios will be presented as well. In addition, interesting spontaneous segregation patterns that result from the competition between buoyancy and thermophoresis in vibrated systems will be presented: a three layer-sandwich-like arrangement that has some universal features, and a four-layer arrangement.
• Extended event driven molecular dynamics for simulating dense granular matter

Rodrigo Soto

The simulation of the inelastic hard sphere model (IHS) of granular media with event driven molecular dynamics methods (EDMD) becomes very inefficient when the system presents dense phases. In fact, the system performs an enormous number of collision events in a finite time and therefore the simulation is practically stopped in physical time. This is known in literature as inelastic collapse and is one of the reasons why the IHS model has not been widely used in simulating dense granular phases.

There are several ways to avoid inelastic collapse, for example make the restitution coefficient dependent on the relative velocity of the particles or the TC model, where a typical time is assigned to the collision contacts. They effectively avoid the inelastic collapse, but in dense regions, they lead to an enormous amount of collision events whose simulation does not contribute significantly to the evolution of the system as a whole.

We have extended the EDMD algorithm for the IHS model to consider these situations. Particles can enter into a "solid state", where the dynamic of these particles is stopped and the collision rules are modified accordingly. We have concentrated in defining physical criteria to decide when particles enter into this solid state and when they return to the full dynamics. Particularly important is that particles enter into the solid state only in mechanically stable positions.

The new algorithm is used to study three situations. First, particles are let to fall with an homogeneous distribution over a flat surface until all of them stop their motion. The packing fraction of the resulting granular solid is studied in terms of the simulation parameters, obtained densities slightly below that of the random close packing. It is important to note that the algorithm allows for the formation of arches in opposition as other deposition algorithms. Secondly, the avalanche in a thick layer is studied decreasing the surface angle. The critical angle to stop the motion is obtained as a function of the layer height in qualitative accord with the literature. Finally, the continuous avalanche in the rotating drum is studied. The free surface shape is obtained as well as the velocity profiles, showing the development of a self-jammed region. In all cases the algorithm performed efficiently.
What do “propellers” tell us about Planet & Ring formation?

Frank Spahn

We investigate the action of gravitational perturbers in thin cold astrophysical discs. The model includes viscous diffusion of the disc matter and gravitational scattering by the perturber as counteracting processes. Two types of density structures are found, depending on the mass of the perturbing body and on the amount of momentum transport in the disc. A gap around the whole circumference of the disc is opened if the perturber is more massive than a certain threshold. Alternately, a local S-shaped density modulation is generated that we call a “propeller”. Beyond the perturber’s mass, the kinematic viscosity of the disk comprises the second crucial parameter of the model which describes the transport properties of the disc material. Analytical and numerical solutions provide the characteristic spatial extent of the “propeller” to depend on the mass of the perturber and the disk-viscosity.

Firstly, these results are applied to dense planetary rings perturbed by an embedded moonlet where our inspection of the Cassini-imaging data revealed 12 "propellers" in the 100-metres size range to reside in Saturn’s A ring. Further analysis of the Cassini Imaging data (ISS) has led to meanwhile about 150 "propeller" features in the middle A ring. Interestingly - these moonlets jostle in three narrow radial bands in the A ring. From these observations we conclude about a few million such 100m objects - but none larger than 500 metres - to exist in the outer rings of Saturn. This, in turn, has crucial consequences for the origin of the rings.

The second application concerns gas-dust discs around a protostar perturbed by a protoplanet - practically the "nursery of a planet". Again either gaps or "propeller"-shaped structures can be expected to have formed within the disk. With increasing resolution of modern telescopes the chance might appear in future to be witness of a planetary growth by studying structures in circum-stellar disks.
• Orientational ordering in sheared inelastic dumbbells

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Using even driven simulations, we show that homogeneously sheared inelastic dumbbells in 2D are randomly orientated at low packing fraction, but show an increasingly preferred alignment with the shear direction as the packing fraction increases. The orientational order parameter displays a continuous increase with packing fraction and does not appear to exhibit a universal scaling with elongation. Except at the highest packing fractions, the orientational distribution function can be reconstructed with a few coefficients of the Fourier expansion. We also present results for the translational and rotational granular temperatures and the stress tensor.
Going the wrong way: the dynamics of annihilation

Emmanuel Trizac

The focus is on an irreversible ballistically controlled reaction, whereby particles undergoing free flight annihilate upon colliding. Such a model is the simplest of a family that includes granular gases and several coalescence or growth models. The framework of the Boltzmann equation is shown to be asymptotically exact, and to yield non trivial decay exponents in excellent agreement with their Molecular Dynamics or Direct Simulation Monte Carlo counterparts. Universality classes, a reliable hydrodynamic description together with the fluctuation of global quantities will be worked out explicitly for such a system with no collisional invariant. The Brownian limit of an intruder will be investigated as well.
Effects of inelasticity on phase transitions in thin granular layers

Jeff Urbach

Thin layers of uniform spheres on a smooth horizontal plate that is oscillating vertically provide a simple but striking demonstration of some of the unusual phenomena associated with excited granular media. Several phase transitions are observed, some closely analogous to transitions seen in systems in equilibrium. In particular, a single layer of spheres "melts" in a transition that displays the characteristics of a Kosterlitz-Thouless transition, and geometric confinement produces a surprising phase diagram very similar to that observed in colloidal suspensions. We compare experiments to both soft sphere and hard sphere simulations. Recent results show that the phase transitions are sensitive to both the inelasticity of the particles and the mechanism of energy injection.
Experimental investigations of dense granular flow

Ricky Wildman

We present the results of two recent investigations into dense granular flow behaviour. In the first, we examined the behaviour of a sheared granular flow consisting of two size phases using positron emission particle tracking, and we show the profiles for packing fraction, mean velocity and granular temperature for the first time. Secondly, we have used magnetic resonance imaging to examine the response of a vibro-fluidised granular bed to high frequency oscillations and compare the results to a kinetic theory based model and to molecular dynamics simulation.
Hydrodynamic Correlation Functions of a Driven Granular Fluid in Steady State

Timo Aspelmeier, Andrea Fiege, Till Kranz, and Annette Zippelius

Georg-August-Universität Göttingen, Germany
Katharina Vollmayr-Lee, Bucknell University, PA, USA

We study a homogeneously driven granular fluid of hard spheres at intermediate volume fractions and focus on time-delayed correlation functions in the stationary state. The results of computer simulations using an event driven algorithm are compared to the predictions of generalised fluctuating hydrodynamics. The incoherent scattering function, \( F_{\text{incoh}}(q, t) \), follows time-superposition and is well approximated by a Gaussian \( F_{\text{incoh}} = \exp \left( -\frac{q^2}{6} < \Delta r^2(t) > \right) \). The diffusion constant relative to the Enskog value shows nonmonotonic behaviour as a function of density with a pronounced decrease towards high volume fractions. The velocity autocorrelation reveals backscattering at high densities and long-time tails similar to an elastic fluid. For sufficiently small wavenumber \( q \) we observe sound waves in the coherent scattering function \( S(q, \omega) \) and determine their dispersion and damping.
Posters

- **Poster: Compaction of Cohesive Powders**
  J. Boberski, K. Johnson, L. Brendel, and D. E. Wolf

Fine powders in the micro- and nanometer range are highly porous since attractive forces dominate their behavior. A key aspect in the investigation of the mechanical properties of cohesive granular media is the relation between their porosity and the stress they can withstand ("consolidation stress"). For round rigid particles the consolidation stress is found to be a power law of the compactable pore volume. The results of experimental and numerical studies of quasi static compactions can be used to investigate the compaction of a cohesive granular media upon impaction with a rigid body. A theory is obtained by the conservation of momentum and mass as well as the assumption of a narrow compaction front running through the powder.

- **Poster: Size effects in granular shear: depth of the granular layer**
  Fergal Dalton

We have conducted a series of experiments on granular shear by rotating an annulus at various speeds over a granular material confined to a circular channel of varying depth. Our experiments were designed to explore the phase boundary between solid, liquid and gaseous granular material and we show how a simple stochastic model with a single degree-of-freedom can accurately reproduce quantitative results. Upon adding layers of granular material, approximately one at a time, we find that the system approaches an asymptotic state (judged by the frictional response) at about 5 layers. A transition between solid and liquid is clearly identifiable, though the transition from 'liquid' to 'gas' is not so evident. We suggest additional experiments which may reveal the liquid/gas transition.
• **Poster: Incoherent Correlation Functions in Driven Granular Gases**

Andrea Fiege, Wolf Till Kranz, Timo Aspelmeier, and Annette Zippelius

We study a system of granular gas particles in 2 and 3 dimensions, i.e., spherical particles which suffer energy loss due to inelastic collisions. An energy source (volume bulk driving) provides a stationary state, allowing us to compute time-delayed correlation functions. Here we concentrate on the velocity autocorrelation function, which is studied with the help of the Mori-Zwanzig projector operator formalism and molecular dynamic simulations. Diffusion coefficients are calculated within the Green-Kubo framework and their enlargement compared to the corresponding Enskog values is shown to exhibit a nonmonotonic dependence on the density. We also discuss the possibility of long time tails in the velocity autocorrelation.

• **Poster: Localized and Delocalized Motion of Colloidal Particles on a Magnetic Bubble Lattice**

Pietro Tierno, Tom H. Johansen, and Thomas M. Fischer

We study the motion of paramagnetic colloidal particles placed above magnetic bubble domains of a uniaxial garnet-film and driven through the lattice by external magnetic field modulation. An external tunable precessing field, propels the particles either in localized orbits around the bubbles, or in superdiffusive or ballistic motion through the bubble array. This motion results from the interplay between the driving rotating signal, the viscous drag force and the periodic magnetic energy landscape. We explain the transition in terms of the incommensurability between the transit frequency of the particle through a unit cell and the modulation frequency. Ballistic motion dynamically breaks the symmetry of the array and the phase locked particles follow one of the six crystal directions.
**Poster: Barchan dunes in two dimensions: experimental tests for minimal models**

Christopher Groh\(^1\), Nuri Aksel\(^2\), Thorsten Pöschel\(^3\), Ingo Rehberg\(^1\), and Christof A. Krülle\(^1\)

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A well defined two-dimensional single barchan dune under the force of a shearing water flow is investigated experimentally. From an initially prepared triangular heap a rapid relaxation to a steady-state solution is observed with constant mass, shape, and velocity. This attractor exhibits all characteristic features of barchan dunes found in nature, namely a gently inclined windward side, crest, brink, and steep lee face. The relaxation time towards the steady state increases with mass. For small dunes we find significant deviations from a fixed height-length aspect ratio. As predicted by recent theoretical models, the migration velocity scales reciprocal to the length of the dune.  

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**Poster: Self-energy of the agglomerates in Saturn’s rings**

A. H. Guimarães, F. Spahn, E. Vieira Neto, and N. V. Brilliantov

The vivid appearance of the outer regions of Saturn’s rings (mainly in F ring) points to a balance of ongoing fragmentation and coagulation processes. In order to quantify this balance in a kinetic theory, we devise expressions for the resistivity of binding energy of an agglomerate depending on its size, the distribution of the constituents the “rubble pile” is made of, and the configuration of how these constituents form the agglomerate. We consider adhesion and gravity as particle interactions and comes the question: Which of these two forces dominates the resistivity depending on the agglomerate size, -packing, -constituents. With this resistivity/binding energy we find the minimum energy of projectile to disintegrate the agglomerate. Furthermore, we distinguish between adhesive (strength) and gravity regime, depending on a certain agglomerate constitution and size. It is found that for agglomerates larger than 15m (ice composition and monomers of 1cm radius) the gravity dominates.
• **Poster: The fluctuating quantity of the coefficient of normal restitution**

  Michael Heckel, Patric Müller, Christof Krülle, and Thorsten Pöschel

The sound caused by a sphere bouncing on a rigid surface can be recorded by a computer. The time instants of successive impacts contains information about the coefficient of restitution. For fixed impact velocities this coefficient was long time thought as a constant. However, by measuring thousands of data points using a robot, we measured an extraordinary high level of noise. A closer look at the data reveals a non-Gaussian distribution which is explained by a simple model of imperfection of the spherical shape. Through this, the coefficient of normal restitution may exceed 1, also in agreement with the mentioned model by redistribution of energy between linear and tangential degrees of freedom.

Another effect found in the data gathered with the help of the robot, are visible steps in $\varepsilon(v)$. This could be explained by eigenfrequencies of the bouncing ball in the range of $f \sim 10^6$ 1/sec and a contact time sphere$\leftrightarrow$surface of about 30 $\mu$s which is in conformity with theoretical results.
A multi–cluster model of traffic flow is studied, in which the motion of cars is described by a stochastic master equation. Assuming that the escape rate from a cluster depends only on the cluster size, the dynamics of the model is directly mapped to the mathematically well-studied zero-range process. Knowledge of the asymptotic behaviour of the transition rates for large clusters allows us to apply an established criterion for phase separation in one-dimensional driven systems. The distribution over cluster sizes in our zero-range model is given by a one–step master equation in one dimension. It provides an approximate mean–field dynamics, which, however, leads to the exact stationary state. Based on this equation, we have calculated the critical density at which phase separation takes place. We have shown that within a certain range of densities above the critical value a metastable homogeneous state exists before coarsening sets in. Within this approach we have estimated the critical cluster size and the mean nucleation time for a condensate in a large system. The metastability in the zero-range process is reflected in a metastable branch of the fundamental flux–density diagram of traffic flow. Our work thus provides a possible analytical description of traffic jam formation as well as important insight into condensation in the zero-range process.
• Poster: *Mimetic intruders in a two dimensional system of vertically excited granulate*

  Jonathan Kollmer, Christof A. Krülle, and Ingo Rehberg

  An initially close packed granular bed of hard spheres is confined by two glass plates with a separation only slightly larger than the particle diameter. In this experiment one or more intruders are inserted and the container is exposed to sinusoidal oscillations. When a critical value of the forcing strength is reached, the granular bed begins to fluidize[1] and segregation as well as intruder-intruder interaction can be observed. While common experiments[2] to study these effects use large disks as intruders this approach utilizes intruders composed of the same beads as the granulate.


• Poster: *Correlations in Granular Media with Volume Driving*

  Till Kranz, Timo Aspelmeier, and Annette Zippelius

  Due to the dissipative nature of the interaction of granular particles an input of energy is needed in order to reach a stationary state. The simplest example of energy injection, volume driving by randomly forcing each particle, leads to an unphysical divergence of the structure factors at long wavelengths. We show that this divergence is removed when the driving is modified to obey momentum conservation. The length scale \( l \) on which momentum is conserved determines the length scale on which correlations build up: on lengths scales shorter than \( l \) the remnants of the divergence are still visible while it is suppressed on longer scales. We discuss the long wavelength behaviour of the static structure factor and a number of other correlation functions (e.g. current correlation functions) based on very extensive molecular dynamics (event driven) simulations that are compared to analytical expressions derived from fluctuating hydrodynamics.
• **Poster: Onset of sand ripple formation in weakly turbulent flow**
  Christof Krülle\(^1\), Mustapha Rouijaa\(^2\), Tobias Edtbauer\(^{1,2}\), and Nuri Aksel\(^2\)

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One of the most fascinating examples of pattern formation in nature are the dunes and ripples formed in sand, caused either by wind or by shear flow in water. Laboratory studies have focused mainly on the surface profile of the granular layer, describing the ripples and their instability in terms of global parameters. Here, we present an experimental study of ripple generation in an annular channel at rather low Reynolds numbers in weakly turbulent flow. We characterize the fluid velocity field at the onset of ripple generation by utilizing a laser doppler velocimeter. These experimental studies show that the local rapid increase of velocity fluctuations close to the sandy bottom initiate the motion of particles and thus will finally lead to the formation of ripple patterns with finite amplitude.

• **Poster: Statistical properties of colliding Lennard-Jones clusters**
  Hiroto Kuninaka

Impact phenomena of small clusters subject to thermal fluctuations are numerically investigated. We carried out the molecular dynamics simulation of colliding Lennard-Jones clusters to investigate the effect of adhesion between clusters on restitution coefficient. We will report the comparison between our impact simulation and the results from the quasi-static theory of inelastic impacts and theory of adhesive collision developed by Brilliantov et al. In addition, we classify the collisional modes of small clusters into four categories and explain the probabilities to observe each mode by a simple theoretical argument.
**Poster: Granular Transport Hysteresis**

Tobias Lang

Since the pioneering works of R.A Bagnold, a grown interest in the physics of granular movement evolved. Initial granular movement of a sandbed starts, when the windspeed over the bed surpasses a critical threshold speed. With further increase of flow the amount of dislodged and transported grains also increases.

However, threshold speed and windspeed versus sandflow are not constant but can be varied through control parameters - especially the humidity of the fluid.

Using a closed-circuit wind tunnel and at a set humidity we were already able to produce hysteresis to inverse hysteresis effects in the sandflow.

However, this has only been a proof of concept for the measurements. Consequently, the exact and systematic measurement of the found effects by modifying the control parameters has still do be done.

**Poster: Understanding Traffic Breakdown: A Stochastic Approach**

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We analyse the characteristic features of traffic flow [1]. We would like to calculate traffic breakdown probability which is related to a first-order phase transition from free flow to congested flow. Traffic breakdown is an application of the first passage time problem known in physics of stochastic processes [2]. Intuitively we introduce the notion of breakdown probability density as a function of time to reach some significant large escape cluster size.

The calculations are based on Fokker-Planck equation including balance equation where the main quantity is probability density distribution which has to satisfy reflecting boundary condition at zero cluster size and absorbing one at escape cluster size. The drift – diffusion process was considered in detail, as the special case of Fokker–Planck equation with linear potential. It is shown how the breakdown probability depends on control parameters.


Application of thermodynamics to driven systems is discussed \[1,2\].

As particular examples, simple traffic flow models are considered. On a microscopic level, traffic flow is described by Bando's optimal velocity model in terms of accelerating and decelerating forces. It allows to introduce kinetic, potential, as well as total energy, which is the internal energy of the car system in view of thermodynamics. The latter is not conserved, although it has certain value in any of two possible stationary states corresponding either to fixed point or to limit cycle in the space of headways and velocities.

On a mesoscopic level of description, the size $n$ of car cluster is considered as a stochastic variable in master equation. Here $n = 0$ corresponds to the fixed–point solution of the microscopic model, whereas the limit cycle is represented by coexistence of a car cluster with $n > 0$ and free flow phase. The detailed balance holds in a stationary state just like in equilibrium liquid–gas system. It allows to define free energy of the car system and chemical potentials of the coexisting phases, as well as a relaxation to a local or global free energy minimum. In this sense the behaviour of traffic flow can be described by equilibrium thermodynamics. We find, however, that the chemical potential of the cluster phase of traffic flow depends on an outer parameter – the density of cars in the free–flow phase. It allows to distinguish between the traffic flow as a driven system and purely equilibrium systems.


Poster: Basketball – Tennis Ball Problem revisited: Probing the limitations of event-driven Molecular Dynamics
Patric Müller and Thorsten Pöschel

In numerical simulations using event-driven algorithms it is assumed that particles interact exclusively pairwise and, thus, instantaneously. This model assumption is justified only for the simulation of dilute systems where the frequency of multi-particle collisions can be neglected as compared with the frequency of pair collisions. Therefore, it may be assumed that event-driven simulations of granular systems become increasingly incorrect if the particle number density increases. In contrast, (force-based) MD algorithms are always applicable (independent of the density) at a much larger numerical complexity.

By comparing the results of the event-driven algorithm with those obtained by direct integration of the actual interaction force law, that is, Molecular Dynamics, we quantify the correctness of event-driven simulations for a rather simple sample system. We will show that the results of event-driven simulations may become dramatically incorrect if the above mentioned precondition does not hold.

Poster: Solid-fluid transition of a granular monolayer with various air pressure
Ralph Neubauer, Ingo Rehberg, and Christof Krülle

Many observations in experiments with granules are performed with the assumption, that the influence of the air is insignificant. In this experiment the air pressure can be varied in a system, were the effect of solid to fluid transition appears. Glas beads are transported in a circular conveyor by sinusoidal motion in vertical and horizontal direction, also the frequency and the amplitude of the motion can be modified. The purpose is to see the influence of air pressure, especially low air pressure.
• **Poster: Universal scaling laws in the vicinity of the jamming transition of sheared granular particles**

Michio Otsuki

The jamming transition of granular materials has attracted the attentions of a large number of physicists. Recently, the scaling laws near the jamming transition have been proposed (arXiv:0803.2296). These scaling laws are analogous to those in conventional critical phenomena and are valid even for the jammed Josephson junction arrays. However, we still do not know the details of the scaling laws whether the analogy from the critical phenomena is useful. In this presentation, to clarify the properties of the jamming transition, we demonstrate that the scaling exponents do not depend on the dimension of the system, but depend on the particle interaction based on our extensive numerical simulation. We also present that all the numerical values of the exponents are consistent with the prediction of our phenomenological theory.

• **Poster: Waves which move uphill**

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We have carried out experiments with quartz grains to follow the convection in a vibrated granular layer [1]. For this purpose we used a wide dish with a small height to size ratio of the layer and the diameter of the grains. In this case the unintentional small inclinations of the dish cannot be neglected. The quartz hills are moving towards a special area of the wall at the borderline of the dish, leaving behind a “fluid phase” and a “gas phase” exactly separated by each other. Uphill moving waves are created at the phase separation line between the ”fluid phase” and the “solid phase” of the hill with its continuous downhill surface convection.

Literature:
• **Poster: Glass beads driven by a horizontal swirling motion with one fixed intruder**

  Matthias Raithel

  In this experiment a dish filled with glass beads is shaken horizontally, so every point on that dish moves on a circle path. In the centre of this dish a intruder is fixed, so the balls can poke with two walls, the wall at the border of the dish and the surface of the intruder in the center. During the experiment, the driving frequency and amplitude are fixed, but the size of the intruder and the count of balls are diversified.

• **Poster: Coefficient of normal restitution as a fluctuating quantity**

  Thomas Schwager, Christof Krülle, and Thorsten Pöschel

  The coefficient of restitution is the central characteristics of the damping properties of granular material. One common way to measure this coefficient is to let a sphere fall on a rigid plate and measure the time interval between successive collisions. These measurements, however, are afflicted with intense stochastic fluctuations which drastically increase towards lower impact velocities rendering the results problematic for the most interesting case of slow impact. As an added puzzle the distribution of the variations is non-Gaussian. These experimental results put the use of a deterministic coefficient of restitution in question. We present here a theoretical model of the particles which is in quantitative agreement with the experiment and which allows to shed light on the mechanism causing the stochastic variations. This in turn allows to extract useful information for the case of slow impact. Based on this model we will present a damping model which incorporates the observed statistical properties of the particle collisions.
• **Poster: Rheological Transition in Granular Media**
  **Zahra Shojaaee, Alexander Ries, Lothar Brendel, and Dietrich E. Wolf**

The Contact Dynamics method is being applied to investigate two-and three-dimensional non-cohesive granular materials. The particles are hard discs, and Coulomb friction and volume exclusion forces are the only forces being exerted. The particles are confined between two parallel walls at the top and the bottom. The walls are being pushed inwards by the same perpendicular forces. They move horizontally with the same constant velocity in opposite directions.

The velocity profile is being studied. In the case of bi- and polydisperse systems the flow as function of the shear velocity shows characteristics comparable to a phase transition. The key quantities are the velocity of the center of mass of the system as well as its fluctuations. A finite size analysis suggests that it is a discontinuous “phase transition”. At high shear velocity the symmetry between the upper and lower wall is not spontaneously broken, whereas at slow shear rate the granular material has different slip at the two walls. For large systems the ergodic time seems to diverge exponentially below the critical shear velocity.

In a block which moves with one of the walls, the rotational degree of freedom is frustrated while the rotational velocity tends to increase towards the shear zone. One observes simultaneously an increase of the relative amount of the sliding contacts. The shear force at the walls is correlated with the slip velocity. The increase of the system size as well as the decrease of the shear velocity leads to a decrease of the shear rate in the system center stronger than linearly with shear velocity divided by the system size, which suggests, that for large enough systems a block is observable in both shear regimes.

A peculiar overshooting effect of the average velocities is clearly observable in the slow shear regime.

• **Poster: Mode-Coupling Theory of Idealized Glass Transitions – From Colloidal to Granular Systems**
  **Matthias Sperl**

The glass transition is reviewed in 2D and 3D; Slow glassy dynamics is characterized by singularities in the long-time limits of density-autocorrelation functions. Experiments in colloidal systems are successfully described by theory. Extensions of the theory towards granular systems are discussed by the introduction of repulsive potentials and dissipation.
An issue regularly encountered in mechanical systems is that of excessive vibration. Although a variety of damping treatments exist to attenuate vibration, particle damping is an excellent candidate over many traditional approaches. The basis of particle damping revolves around vibrated granular media enclosed in some container. It can be designed so that it is largely invariant to temperature and is efficient over a broad range of frequencies. Particle dampers can also be implemented quite easily in a plethora of applications by just placing particles within voids in a structure. In cases where this is not practical, it is also possible to create attachments to place the particles in. Vibration energy from the main structure is partially transferred to the particles as kinetic energy, which in turn is reduced via dissipation due to friction between the particles and the plastic deformations from impacts. In terms of designing an effective particle damper, the most salient features which affect the energy dissipation and momentum transfer has to be identified. This is done in this work by the simulation study of simple granular systems vibrated across a range of frequencies and amplitude. The system is modelled via the Discrete Element Modelling (DEM) method and a sensitivity study across the operating range is performed using a Gaussian Process.
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Granular Gas 2008

Invited Speakers

- Meheboob Alam, Bangalore
- Igor Aronson, Argonne
- Elia Ben-Naim, Los Alamos
- Raphael Blumenfeld, London
- Nikolai Brilliantov, Leicester
- Ricardo Brito, Madrid
- José Antonio Carrillo, Barcelona
- Arno Formella, Vigo
- Vicente Garzó, Badajoz
- Hisao Hayakawa, Kyoto
- Stephan Herminghaus, Göttingen
- Christine Hrenya, Boulder
- Christoph Krüll, Karlsruhe
- Arshad Kudrolli, Worcester
- V. Kumaran, Bangalore
- Stefan Luding, Twente
- U. Marini Bettolo Marconi, Camerino
- Sean McNamara, Rennes
- Baruch Meerson, Jerusalem
- Mario Nicodemi, Warwick
- Henrik Noskovitz, Tel Aviv
- Ignacio Pagonabarraga, Barcelona
- Ingo Rehberg, Bayreuth
- John Royer, Chicago
- Maria José Ruiz Montero, Sevilla
- Clara Salupe, Tarragona
- Andres Santos, Badajoz
- Jürgen Schmidt, Potsdam
- Dan Serero, Tel Aviv
- Rodrigo Soto, Santiago
- Frank Spahn, Potsdam
- Julian Talbot, Pittsburgh
- Emmanuel Trizac, Paris
- Jeffrey Urbach, Washington
- Ricky Wildman, Loughborough
- Annette Zippelius, Göttingen

Topics
- Kinetic theory, experimental methods and results, structure formation, astrophysical systems, granular rheology, interfaces, effects of cohesion and friction, computational methods, stability of granular flows

Organising Committee
- Thorsten Pöschel, Bayreuth
- Isaac Goldhirsch, Tel Aviv
- J. Javier Brey, Sevilla

Date/Location
- September 8-12, 2008
- Schloss Thurnau, Germany (www.schlossthurnau.de)

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