Pan-American Advanced Studies Institute (PASI) on Frontiers in Particulate Media: From Fundamentals to Applications

La Plata, Argentina

11-22 August 2014

Contents

Foreword

We welcome you all to the Pan-American Advanced Studies Institute (PASI) on Frontiers in Particulate Media: From Fundamentals to Applications. During the next two weeks, we will have a chance to learn from some of the leading experts in this exciting field, and we hope that this period will be inspiring to all of you. You will see in the rest of this Book of Abstracts that the PASI will include lectures, discussion sessions, shorter oral presentations and posters, in addition to the weekend Workshop. However, an aspect of this PASI which is even more important than scheduled activities is establishing connections and exchanging ideas during the free time. For this reason, the schedule leaves plenty of open space and we hope that you will find these free periods useful to talk with your colleagues, in particular those from different countries and of different scientific backgrounds. The main sponsors of this PASI are the National Science Foundation (NSF) and the Department of Energy (DOE). We use this chance to thank NSF/DOE, and all other sponsors listed on the front page for making this PASI possible.

The Organizing Team

La Plata, August 2014

Organizing Team

Organizing Committee

- ○ Robert Behringer, Department of Physics, Duke University, United States.
- ○ Irene Ippolito, Grupo de Medios Porosos, Facultad de Ingeniería, Universidad de Buenos Aires, LIA PMF-FMF CONICET, Argentina.
- ○ Lou Kondic (Chair / SIAM Representative), Department of Mathematics, New Jersey Institute of Technology, United States.
- ○ Corey O'Hern, Department of Mechanical Engineering & Materials Science, Yale University, United States.
- ○ Luis A. Pugnaloni, Departamento de Ingeniería Mecánica, Facultad Regional La Plata, Universidad Tecnológica Nacional - CONICET, Argentina.
- ○ Rodrigo Soto, Departamento de Física, Universidad de Chile, Chile.

Local Organizing Committee

- ○ María Alejandra Aguirre, Grupo de Medios Porosos, Facultad de Ingeniería, Universidad de Buenos Aires, LIA PMF-FMF CONICET, Argentina.
- ○ Manuel Carlevaro, Instituto Física de Líquidos y Sistemas Biológicos, CONICET La Plata. Universidad Tecnológica Nacional, Facultad Regional Buenos Aires, Argentina.
- ○ Paula Alejandra Gago, Departamento de Ingeniería Mecánica, Facultad Regional La Plata, Universidad Tecnológica Nacional - CONICET, Argentina.
- ○ Gustavo Galliano, Y-TEC (YPF Tecnología SA), Argentina.
- ○ Irene Ippolito, Grupo de Medios Porosos, Facultad de Ingeniería, Universidad de Buenos Aires, LIA PMF-FMF CONICET, Argentina.
- ○ Marcos Madrid, Departamento de Ingeniería Mecánica, Facultad Regional La Plata, Universidad Tecnológica Nacional - CONICET, Argentina.
- ○ Nicolás Mujica, Departamento de Física, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile, Chile.
- ○ Luis A. Pugnaloni (Chair), Departamento de Ingeniería Mecánica, Facultad Regional La Plata, Universidad Tecnológica Nacional - CONICET, Argentina.
- ○ Martín Sánchez, Y-TEC (YPF Tecnología SA) Departamento de Ingeniería Mecánica, Facultad Regional La Plata, Universidad Tecnológica Nacional, Argentina.
- ○ Rodrigo Soto, Departamento de Física, Universidad de Chile, Chile.
- ○ Ana María Vidales, Departamento de Física, Instituto Física Aplicada (UNSL-CONICET), Universidad Nacional de San Luis, Argentina.

	Sun 10	Mon 11	Tue 12	Wed 13	Thu 14	Fri 15	Sat 16	Sun 17	Mon 18	Tue 19	Wed 20	Thu 21	Fri 22
8.00 – 8.15													
8.15 – 8.30		Registration											
8.30 – 8.45													
8.45 – 9.00		Kondic					O'Hern						
9.00 – 9.15													
9.15 – 9.30							Pine	Pugnaloni					
9.30 – 9.45		Behringer	Poeschel	Kurchan	Daniels	Pine				Pugnaloni	Shattuck	Mort	Brady
9.45 – 10.00							Marchetti	Shattuck					
10.00 – 10.15													
10.15 – 10.30													
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10.45 – 11.00													
11.00 – 11.15							Brady	Kondic					Kovalcinova
11.15 – 11.30													Magalhaes
11.30 – 11.45		Daniels	Kurchan	Johson	Pine	Marchetti				Soto	O'Hern	Kondic	Grob
11.45 – 12.00							Kurchan	Ippolito					Baeza
12.00 – 12.15													Schreck
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14.30 – 14.45							Daniels	Marconi					
14.45 – 15.00								Mujica					
15.00 – 15.15		Behringer	Hryb	Johson	Marchetti	FREE		Atman		Soto	O'Hern	Brady	
15.15 – 15.30							Johnson						
15.30 – 15.45								Break					
15.45 – 16.00							Break						
16.00 – 16.15			Break					Soto			Break		
16.15 – 16.30							Slobinsky						
16.30 – 16.45				Teomy			Vidales						
16.45 – 17.00				Gago			Sánchez	Mort					
17.00 – 17.15		Poeschel	Posters	Madrid	Posters		Bruno			Shattuck	Mort	Discussion on international cooperation	
17.15 – 17.30				Zhang			Grigera	O'Hern					
17.30 – 17.45				Boschan			Aguirre						
17.45 – 18.00				de Jong			Banchio						
19.00 – 20.00	Reception												
20.00 –					Dinner								

Program

Lecturers and Discussion Leaders

- Robert P. Behringer, Department of Physics, Duke University.
- John Brady, Department of Chemical Engineering, Caltech.
- Karen Daniels, Department of Physics, North Carolina State University.
- Paul Johnson, Los Alamos National Laboratory.
- Irene Ippolito, Grupo de Medios Porosos, Universidad de Buenos Aires.
- Lou Kondic, Department of Mathematics, New Jersey Institute of Technology.
- Jorge Kurchan, École Supérieure de Physique et de Chimie Industrielles, Paris.
- Cristina Marchetti, Department of Physics, Syracuse University.
- Corey O'Hern, Department of Mechanical Engineering & Materials Science and Physics, Yale University.
- David Pine, Department of Physics, New York University.
- Thorsten Poeschel, Institute for Multiscale Simulation, Friedrich-Alexander University Erlangen-Nürnberg.
- Luis Pugnaloni, Facultad Regional La Plata, Universidad Tecnológica Nacional.
- Mark Shattuck, Department of Physics, City College of City University New York.
- Rodrigo Soto, Departamento de Física, Universidad de Chile.

Lecturers on Industrial Applications

- Damián Hryb, YPF SA.
- Paul Mort, Procter & Gamble.

PASI Lectures - Week 1

- Monday 8:45 - 9:00 *Kondic:* Introduction
- Monday 9:00 - 10:30 *Behringer:* A Perspective on the Physics of Granular Materials (Part I)
- Monday 11:00 - 12:30 *Daniels:* Measurements at the Particle Scale: Tracking Positions and Forces
- Monday 2:30 - 4:00 *Behringer:* A Perspective on the Physics of Granular Materials (Part II)
- Monday 4:30 - 6:00 *Poeschel:* Event-driven particle simulations of granular matter (Part I)
- Tuesday 9:00 - 10:30 *Poeschel:* Event-driven particle simulations of granular matter (Part II)
- Tuesday 11:00 - 12:30 *Kurchan:* Introduction to statistical physics methods applied to particulate matter
- Tuesday 2:30 - 4:00 *Hryb:* Granular Matter and Geomechanics
- Tuesday 4:30 - 6:00 *Poster Session I*
- Wednesday 9:00 - 10:30 *Kurchan:* Amorphous order
- Wednesday 11:00 - 12:30 *Johnson:* Elastic and plastic behavior of dense granular systems
- Wednesday 2:30 - 4:00 *Johnson:* Granular mater under shear in relation to geophysical problems
- Wednesday 4:30 - 6:00 *15 min. contributed talks by: Teomy, Gago, Madrid, Zhang, Boschan, de Jong*
- Thursday 9:00 - 10:30 *Daniels:* The Edwards ensemble at 25
- Thursday 11:00 - 12:30 *Pine:* Patchy Particles
- Thursday 2:30 - 4:00 *Marchetti:* Introduction to Active Matter
- Thursday 4:30 - 6:00 *Poster Session II*
- Friday 9:00 - 10:30 *Pine:* Light-activated swimmers
- Friday 11:00 - 12:30 *Marchetti:* Hydrodynamics of Active Liquid Crystals
- *Friday Afternoon Free*

Weekend Workshop: Grand Challenges in Particulate Media: From Granular Media to Colloids to Active Matter

Saturday, August 16, 2014

- 8:55 - 9:00 *Corey O'Hern:* Introduction
- 9:00 - 9:40 *David Pine:* Guided self-assembly of DNA-functionalized colloids
- 9:40 - 10:20 *Chrsitina Marchetti:* Defect proliferation in active liquid crystals
- 10:20 - 10:50 *Break*
- 10:50 - 11:30 *John Brady:* Chemical Swimming and Active Matter
- 11:30 - 12:10 *Jorge Kurchan:* Glass versus jamming transitions
- 12:10 - 1:40 *Lunch break*
- 1:40 - 2:20 *Robert Behringer:* Jamming by Shear
- 2:20 - 3:00 *Karen Daniels:* The Effects of Particle Shape
- 3:00 - 3:40 *Paul Johnson:* Acoustical emission precursors preceding failure in sheared granular material
- 3:40 - 4:10 *Break*
- 4:10 - 4:25 *Demian Slobinsky:* Statistical description of static granular systems in the arch ensemble
- 4:25 - 4:40 *Ana María Vidales:* Rise of an intruder disk under tapping
- 4:40 - 4:55 *Martín Sánchez:* Effect of particle shape and fragmentation on the response of particle dampers
- 4:55 - 5:10 *Luciana Bruno:* Intracellular transport of organelles driven by multiple motors: Cooperation or competition?
- 5:10 - 5:25 *Tomás Grigera:* Modelling transport of information in turning flocks
- 5:25 - 5:40 *María Alejandra Aguirre:* Granular flow through an aperture: Influence of the compactivity of the system
- 5:40 - 5:55 *Adolfo Banchio:* Short-, intermediate-, and long-time diffusion in charged colloidal suspensions

Sunday, August 17, 2014

- 9:00 - 9:40 *Luis Pugnaloni:* Clogging transition of many-particle systems flowing through bottlenecks
- 9:40 - 10:20 *Mark Shattuck:* The statistics of frictional families
- 10:20 - 10:50 *Break*
- 10:50 - 11:30 *Lou Kondic:* Evolution of force networks in dense particulate matter
- 11:30 - 12:10 *Irene Ippolito:* Dynamical effects in the segregation of granular mixtures in quasi 2D piles
- 12:10 - 1:40 *Lunch break*
- 1:40 - 2:20 *Thorsten Poeschel:* TBA
- 2:20 - 2:35 *Daniel Parisi:* Experimental confirmation of the "faster is slower" effect in various particulate systems
- 2:35 - 2:50 *Verónica Marconi:* Active matter physically manipulated: Bacteria vs. human sperm cells
- 2:50 - 3:05 *Nicolás Mujica:* Dynamics of confined non-cohesive granular systems
- 3:05 - 3:20 *Allbens Atman:* Measurement of elastic parameters of granular layers from stress response functions
- 3:20 - 3:50 *Break*
- 3:50 - 4:30 *Rodrigo Soto:* Segregation in vibrated granular mixtures
- 4:30 - 5:10 *Paul Mort:* Network structure of colloidal suspensions: Characterization and simulation
- 5:10 - 5:50 *Corey O'Hern:* Hypo-coordinated solids above and below jamming onset

PASI Lectures - Week 2

- Monday Free (Holiday)
- Tuesday 9:00 - 10:30 *Pugnaloni:* Structural description of packed particulates
- Tuesday 11:00 - 12:30 *Soto:* Kinetic theory and granular hydrodynamics (Part I)
- Tuesday 2:30 - 4:00 *Soto:* Kinetic theory and granular hydrodynamics (Part II)
- Tuesday 4:30 - 6:00 *Shattuck:* Granular thermodynamics (Part I)
- Wednesday 9:00 - 10:30 *Shattuck:* Granular thermodynamics (Part II)
- Wednesday 11:00 - 12:30 *O'Hern:* Computational studies of systems undergoing jamming and glass transitions (Part I)
- Wednesday 2:30 - 4:00 *O'Hern:* Computational studies of systems undergoing jamming and glass transitions (Part II)
- Wednesday 4:30 - 6:00 *Mort:* Overview of the industrial applications involving granular matter
- Thursday 9:00 -10:30 *Mort:* Characterization of particulate flow in quasi-static and intermediate regimes
- Thursday 11:00 - 12:30 *Kondic:* Structure of contact and force networks in dense granular matter: From percolation to persistence
- Thursday 2:30 - 4:00 *Brady:* Suspensions and granular matter: Wet versus dry
- Thursday 4:30 - 6:00 *Discussion leaders TBA:* Perspectives for the development of better international connections between the researchers in the field of particulate matter
- Friday 9:00 - 10:30 *Brady:* Micromechanics of colloidal dispersions
- Friday 11:00 - 12:30 *15 min. contributed talks by: Kovalcinova, Magalhaes, Grob, Baeza, Schreck*
- Friday 12:30 *Closing*

Lectures

A Perspective on the Physics of Granular Materials (Parts I and II)

Robert Behringer Dept. of Physics, Duke University

Granular materials as a part of physics began relatively recently with a handful of papers in the late 1980's. These early papers focused on a variety of topics: pattern formation, convection, instabilities, statistics, and self-organized criticality, for instance. Over the intervening years, these topics have remained of interest, but others have been added: granular gases, jamming, impact, connections to other particle-based systems, active matter. The first part of this presentation will give an overview of some of the more novel aspects of granular physics.

An important contribution from the physics perspective on granular materials concerns statistics and fluctuations. Fluctuations in forces can be very large in dense granular systems. A second focus of this presentation will be focused on fluctuations and statistics of granular materials.

In the past decade or so, there has been intensive interest in systems that jam or that exhibit glassy behavior. Granular materials are one class of systems that exhibit jamming and glassy dynamics. But, there are others, including colloidal systems, foams, etc. Liu and Nagel suggested a scenario that would unify jamming in various systems in terms of a universal jamming diagram. Of particular note are simulations by O'Hern et al. that showed a well defined jamming transition for systems of frictionless spheres. This work has led to an intensive period of study of near-jamming systems. A review of this work will form the third aspect of the presentation.

When particles have friction, which is the case for virtually all physical systems of grains, the near-jamming properties are substantially different. It is possible to create a range of states at densities that are lower than the isotropic jamming value for frictionless grains. In particular, it is possible to create jammed states by applying shear strain to systems that are initially stress-free. These shear jammed states are intrinsically anisotropic. A particularly interesting aspect of shear jamming concerns that networks of forces and contacts that form in response to various protocols. A fourth part of this presentation will consider shear jammed states and their properties.

When heavy fast-moving objects strike a granular material, a different set of phenomena occurs. In this case, momentum transfer from the intruder to the grains dominates much of the physical processes involved. The fifth part of this presentation will focus on granular impact phenomena.

Much of the work carried out at Duke University has involved the use of photoelastic particles. This kind of system allows experimental probes at the particle scale which can provide details of forces acting on particles. In some cases, it is possible to actually determine the individual vector contact forces acting on a photoelastic particle. A final aspect of this presentation will involve a discussion of photoelastic techniques.

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Measurements at the Particle Scale: Tracking Positions and Forces

Karen Daniels North Carolina State University

Experimentalists often want to characterize a granular system at the particle scale, so that the statistics of particle positions and interparticle forces can be used to inform our understanding of the bulk behavior. I will review a number of techniques current in use in the community. Image-analysis provides particle positions and orientations (for either 2D or 3D data) and this information can be connected to form particle trajectories. Techniques for measuring forces are more dependent on the features of the particular system. The use of photoelastic particles, popular since the 1950s, can now provide vector contact forces in 2D systems of specially-manufactured particles. To capture fast dynamics, particularly in 1D chains, it is possible to embed piezoelectric sensors in individual particles. X-ray tomography and laser sheets have been used on deformable particles to measure normal forces, and fluorescence has been used measure contact areas or internal stress fields in both emulsions and granular materials. Where possible, I will include links to open-source resources associated with these techniques.

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Event-driven particle simulations of granular matter (Parts I and II)

Thorsten Poeschel Friedrich-Alexander Universitat Erlangen-Nurnberg

The dynamics of a system of solid bodies is described by Newton's equation of motion, thus, Molecular Dynamics (MD) is appropriate to compute the evolution of granular systems. On the other hand, the large stiffness of realistic granular particles enforces very small time steps which render ordinary MD simulations inefficient.

An alternative approach is provided by event driven Molecular Dynamics (eMD) which effectively decomposes the dynamics of a many-particle system into a series of subsequent instantaneous two-particle interactions.

eMD may be by orders of magnitude faster than MD, however, it is not a universal method and its implementation is not straightforward.

Outline:

1. Idea of event-driven particle simulation and eMD algorithm
2. Coefficient of restitution and its derivation
3. Limitations of event-driven modeling
4. Does eMD solve Newton's equation of motion?
5. Beyond the standard algorithm

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Introduction to statistical physics methods applied to particulate matter

Jorge Kurchan École Supérieure de Physique et de Chimie Industrielles

Is granular matter a chapter of statistical mechanics? And if so, where shall we put it? Some elements seem to point in that direction: the large number of constituents – and our interest in only global behavior – call for a statistical treatment. Other elements point to differences. By the very nature of the interactions and the external drive, we know that the system cannot have a thermodynamic equilibrium. Thus, our treatment will be, at most, related to out of equilibrium thermodynamics ... an underdeveloped subject in itself. In spite of all these differences, the slow settling of a sandpile is closely related to the aging of glass.

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Granular Matter and Geomechanics

Damián Hryb YPF Tecnología S.A.

(to be announced)

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Amorphous Order

Jorge Kurchan École Supérieure de Physique et de Chimie Industrielles

Glasses are the closest analogue there is in traditional statistical mechanics to a granular ensemble. An old question concerning glassy (and granular) matter is whether they are truly 'solid', even when considered at infinitely long timescales. Another long standing question is whether these system are truly amorphous, or there is some form of hidden order. The two questions are, in fact, closely related. We are beginning to focus on them better, although we still have no definite answers.

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Elastic and plastic behavior of dense granular systems

Paul Johnson Los Alamos National Laboratory

Elastic nonlinear and plastic behaviors in earth materials are common, ranging in scales from small-scale laboratory experiments to regional earth scales over 10-1-106 m at least. There are two basic behaviors:(1) a material hardening (static forcing) or softening (dynamic wave forcing) where the material is placed into a metastable state, and (2) a long recovery process that is (primarily) linear with the logarithm of time. For elastic nonlinear perturbation the material returns to it's original bulk equilibrium state. In the case of plastic deformation a new equilibrium state is attained. I will describe fundamental observations of elastic and plastic nonlinear behaviors of granular consolidated and unconsolidated materials. Experiments, simulation and theory will be included.

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Granular matter under shear in relation to geophysical problems

Paul Johnson Los Alamos National Laboratory

Due to communication over geologic time, fault blocks shearing past one another in the earth develop granular material in their core. We hypothesize that the granular physics of this material, known as "fault gouge" influences much of the physics of slip. In this lecture I will describe observations and simulation of granular materials under laboratory shear conditions, including acoustic emission, shear failure and dilation. I will discuss the primary indicators leading to failure observed in the gouge and relate these to earthquake processes. I will also describe dynamical wave excitation of the sheared beadpack leading to curious and non-intuitive behaviors. The dynamic wave experiments support widespread observations in the earth of "dynamic earthquake triggering", a process whereby seismic waves from one earthquake trigger earthquakes nearby and from the triggering source.

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The Edwards Ensemble at 25

Karen Daniels North Carolina State University

In 1989, Edwards proposed a new statistical ensemble, whereby the volume of a granular system played the role of energy in an ordinary system. This provided a definition for a new temperature-like quantity known as the compactivity, with an accompanying hope that it would prove useful for understanding fundamental behaviors such as packing and mixing. During the past 25 years, Edwards' ideas have undergone a number of numerical and experimental tests of both the postulates and the conclusions, and the original idea has been expanded to include stress in the ensemble. What have these ideas told us about describing granular materials, and where have they fallen short?

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Patchy particles

David Pine New York University

Colloidal particles with chemically (and often physically) differentiated patches are in their nascent stage and hold promise as building blocks for new colloidal architectures and activity. This lecture will give an introduction to the synthesis and self-assembly of patchy particles. It will also discuss how to create and exploit various types of interactions between colloidal patches, including DNA hybridization, lock-and-key, deplection, hydrophobic attraction, and Coulomb repulsion.

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Introduction to active matter

Cristina Marchetti Syracuse University

In this lecture I will introduce the notion of active matter using examples from both the living and nonliving world, highlight common behaviors and discuss the classification of active systems in terms of their symmetry properties and the absence/presence of momentum conservation. I will then focus on specific examples of dry active systems where momentum is not conserved. I will introduce the agent-based Vicsek model of flocking and its continuum formulation, as embodied by the Toner-Tu equations, and discuss some of the unusual behavior predicted by these models, such the presence of giant number fluctuations and of propagating density waves. Finally, I will introduce a minimal model of active colloids in two dimensions as self-propelled disks with only repulsive interactions. I will show that this model yields athermal phase separation, segregation, and active glassy and jammed states.

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Light-activated swimmers

David Pine New York University

This lecture introduces a new type of artificial active living matter, light-activated colloidal swimmers. This lecture will discuss the chemical and physical basis of the phoretic mechanisms that drive the light-activated particles. It will also discuss their single-particle as well as collective behavior, including observations of two-dimensional living crystals that dynamically form, coalesce, explode, and reform. The swimmers can also pick up, transport, and release cargo along trajectories that are either dynamically and remotely controlled by a magnetic field, or are directed by microscopic tracks in the substrate. These particles provide a rich new system in which to explore active matter.

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Hydrodynamics of Active Liquid Crystals

Cristina Marchetti Syracuse University

In this lecture I will focus on continuum models of active liquids crystal with both nematic and polar order. Active liquid crystals are nonequilibrium fluids composed of internally driven elongated units. Examples of active systems that can exhibit liquid crystalline order include mixtures of cytoskeletal filaments and associated motor proteins, bacterial suspensions, and the cell cytoskeleton. In active liquid crystals the large scale self-organized flows resulting from activity couple to orientational order, yielding a very rich behavior. I will describe a number of novel effects that have been predicted theoretically or observed in simulations and experiments, including spontaneous laminar flow, unusual rheological properties, excitability, and low Reynolds number "turbulence".

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Structural description of packed particulates

Luis A. Pugnaloni Universidad Tecnológica Nacional

This lecture will cover the basics of geometrical description of dense particulate systems (especially granulars). I will discuss on descriptors such as packing fraction, coordination number, kissing number, pair distribution function, autocovariance function, bond order parameters, fabric tensor, Voronoi tessellation, and arches. I will present examples of possible results for different systems subjected to different preparation protocols. After considering averaging techniques, I will show how some of these structural descriptors connect with each other and with force-related parameters. In particular, I will consider arches and their impact on contact force distributions, coordination number and packing fraction.

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Kinetic theory and granular hydrodynamics (Parts I and II)

Rodrigo Soto Universidad de Chile

Grains dissipate energy at collisions. Therefore, if no energy is injected into a granular medium it will reach a static state. If, on the contrary, energy is continuously injected dynamic states can be achieved with different regimes depending on the energy injection rate. At high injection rates, granular media adopts the so-called rapid granular flow regime or, equivalently, the fluidized granular media regime. Here, the systems show fluid-like behavior and on large scales the granular fluids flow under imposed stresses much like a liquid or gas. However, important differences appear that have their origin in the dissipative nature of interactions. The objective of these lectures is to describe this fluidized regime and present the novel properties that appear compared to the dynamics of liquids and gases.

The peculiar properties of granular fluids is due to the combination of energy dissipation at collisions and the short-range repulsion between grains. In dense flows (for example in an avalanche), collisions are frequent and energy is rapidly dissipated to reach a state in which the kinetic energy is fixed instantaneously by the shear rate. Using kinetic theory, we will show that this implies that the granular rheology is intrinsically non-lineal (the shear stress is quadratic with the shear rate). Another direct consequence of the large dissipation in moderately dense flows is that the large inhomogeneities develop spontaneously at the grain scale, implying that the naive gradient expansion of hydrodynamics is of questionable validity. Finally, in granular media, the individual grains are large objects. This discrete nature of granular fluids gives a large relevance of fluctuations in the collective dynamics.

In these lectures, we will use kinetic theory, hydrodynamic analysis and fluctuating theory to describe the main properties of granular flows. We will present the inelastic hard sphere model that will allow us to obtain the equivalent to the hydrodynamic equations in different regimes and compute the associated transport coefficients. The resulting equations will be analyzed and solved in different situations of interest. Finally, the same theory will show us its limit of validity.

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Granular Thermodynamics (Parts I and II)

Mark Shattuck City College of the City University of New York

Thermodynamics is generally not applicable to systems with energy input and dissipation present, and identifying relevant tools for understanding these far-from-equilibrium systems poses a serious challenge. Excited granular materials have become a canonical system to explore such ideas since they are inherently dissipative due to inter-particle frictional contacts and inelastic collisions. Granular materials also have far reaching practical importance in a number of industries, but accumulated ad-hoc knowledge is often the only design tool. An important feature of driven granular systems is that the energy input and dissipation mechanisms can be balanced such that a Non-Equilibrium Steady-State (NESS) is achieved. This NESS shares many properties of systems in thermodynamic equilibrium. In particular, the structure and dynamics of the NESS are almost identical to equilibrium systems. Further, we present strong experimental evidence for a NESS first-order phase transition in a vibrated two-dimensional granular fluid. The phase transition between a gas and a crystal is characterized by a discontinuous change in both density and temperature and exhibits rate dependent hysteresis. Finally, we measure a free energy-like function for the system, whose minimum determines the state of the system.

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Computational studies of systems undergoing jamming and glass transitions (Parts I and II)

Corey O'Hern Yale University

I will review computational techniques to study model systems that undergo glass transitions at finite temperature and jamming transitions at zero temperature. First, I will describe molecular dynamics simulations of model glass-forming liquids-spherical particles that interact via purely repulsive forces. I will cover constant energy, temperature, and pressure ensembles using several thermostats and barostats and measurements to characterize structure and dynamics including the radial distribution function, density of states, mean-square displacement, velocity auto-correlation function, and structural relaxation times. The dynamical phase diagram as a function of temperature and packing fraction will also be presented.

I will then review discrete element simulations for studying jamming transitions in model granular materials. I will describe algorithms for generating mechanically stable (MS) packings for particles with varying shapes, friction, and deformation mechanisms including compression, simple, and pure shear. We will describe measurements to characterize the mechanical and structural properties of MS packings including the contact number, force distributions, and frequency-dependent shear moduli. Finally, we will highlight recent computational and experimental results on shear jamming and thickening, nonharmonic vibrational response, and avalanches. Matlab codes will be provided for hands-on demonstrations and assignments for simulations and concepts covered during the lectures.

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Overview of the industrial applications involving granular matter

Paul Mort Procter & Gamble

The broad industrial motivation that is associated with Frontiers of Particulate Matter, especially pertaining to particle engineering and processing, includes the predictable understanding and manipulation of flow and stress field behavior across industrially-relevant process conditions for of granular and powder materials, i.e., as a function of process operating conditions, material properties and particulate characteristics. This motivation is consistent with the current trend toward sustainable processing and energy efficiency. From an engineering perspective, industry strives toward the minimization of specific energy input in granular and powder processing, i.e., minimal power consumption at maximum production rate. For granular solids, there are opportunities in gaining insight into efficiencies associated with fluid-like flow behavior at high bulk density and high shear rate. The physics of rapid-dense granular flows are relevant here. While there is a good body of engineering and science for very slow dense-packed flows (friction analogies), and a good body of work for very rapid dilute flows (gas analogy), there is only emerging work in the intermediate regime including dense-rapid flows having a bulk fluid-like analogy. The industrial part of the Frontiers program will focus on applications that are related to processing of these dense-rapid flows.

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Characterization of particulate flow in quasi-static and intermediate regimes

Paul Mort Procter & Gamble

The transition from slow frictional to intermediate particulate flow is of interest in process applications as powder mixing, binder agglomeration, conveying and precise metering of bulk solids. Slow frictional (i.e., quasi-static) flows are typically characterized using a Mohr - Coulomb analysis of shear-cell data. The quasi-static regime is most relevant to predicting incipient dense flow behavior in bins and silos. The intermediate (also called elastic-inertial) regime is also relevant to dense flows, but at higher shear rates where transient jamming can have a critical influence on bulk rheology. The characteristics of intermediate flows are relevant to a range of processes relying on precise manipulation of flow and/or transmission of stress though a bulk particulate. In this lecture, we will cover several characterization methods that are relevant to slow-frictional flow, intermediate flow and transition from one to the other.

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Structure of contact and force networks in dense granular matter: From percolation to persistence

Lou Kondic New Jersey Institute of Tecnology

Discrete element (DEM) simulations of dense granular matter (DGM), as well as physical experiments show that forces and stresses in DGM develop complex structure that is difficult to characterize precisely. In our earlier work, we have discussed how the number of components (related to so-called force chains) and loops evolve in DEM simulations as a system of inelastic frictional particles is compressed. That work provided an interesting and novel insight regarding the influence of particle properties (such as polydispersity and friction) on force network properties. In the proposed presentation, we consider the force networks in much more detail, by discussing global properties of these networks. The computational methods used are based on persistence diagrams that allow for clear identification of mathematical properties of the force landscapes and help their physical interpretation. We find that this technique, that previously has not been applied to particulate matter, allows to extract significant new information, going much beyond separation into 'strong' and 'weak' force networks. The proposed approach describes these networks in a precise and tractable manner, allowing to identify novel features which could be difficult or impossible to describe using other approaches. We find significant differences between the systems characterized by varied polydispersity and frictional properties, indicating that the mechanical response of these systems may differ considerably as well. If time allows, new results discussing similarities and differences of the global properties of the force networks in two and three physical dimensions will be presented.

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Suspensions and granular matter: Wet versus dry

John Brady Caltech

Suspensions and dry granular media are found widely in nature and industry. Suspensions generally refer to small particles (from less than 1 μm to say 1 cm in size) dispersed in a viscous liquid such as water or oil. While dry granular media are particles of the same size in air (or vacuum) where it is generally assumed that the air has little effect on the flow of the grains. Common examples can be found throughout industry of pneumatic conveying, coal slurries, pharmaceutical powders, etc., and in nature of sediment transport, debris flows, blood flow, etc. Studies of suspensions and granular media have in large part proceeded independently. In both areas significant advances have been made as experiments, simulations and theories have all come together to elucidate many aspects of flow behavior. And while similarities in behavior have sometimes been noted, the two fields nevertheless remain separate. Why is this? Is the underlying physics so different that they should be separate? Or can trying to take a more unified view teach us more about each? Here we suggest that this separation is unnecessary and that suspensions and granular media wet and dry actually correspond to different limiting behaviors of one common system. The linking parameter is the Stokes number of the ratio of the inertial to shear forces: small Stokes numbers correspond to viscous suspensions and high Stokes numbers to dry granular media. In this talk we will discuss the microstructural physics underlying the flow of Brownian and nonBrownian suspensions and dry granular media. The connection between wet and dry will be made through computer simulation studies of the rheological and diffusive behavior of viscous suspensions and rapid granular flows.

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Micromechanics of colloidal dispersions

John Brady Caltech

What do corn starch, swimming spermatozoa, DNA and self-assembling nanoparticles have in common? They are all (or can be modeled as) "particles" dispersed in a continuum suspending fluid where hydrodynamic interactions compete with thermal (Brownian) and interparticle forces to set structure and determine properties. These systems are "soft" as compared to molecular systems largely because their number density is much less and their time scales much longer than atomic or molecular systems. In this talk I will describe the common framework for modeling these diverse systems and the essential features that any hydrodynamic modeling must incorporate in order to capture the correct behavior. Actually computing the hydrodynamics in an accurate and efficient manner is the real challenge, and I will illustrate past successes and current efforts with examples drawn from the diffusion and rheology of colloids to the "swimming" of catalytic nanomotors.

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Invited Workshop Talks

Guided self-assembly of DNA-functionalized colloids

David Pine

In principle, it would seem that DNA-coated colloids give us the possibility of putting together materials organized at the mesoscopic scale with almost arbitrary pre-determined architectures. The goal is to engineer and build three-dimensional structures consisting of different materialsmetals, semiconductors, insulators, organics, and inorganicswhere the designer has complete control over precisely where different materials are placed and in proximity to what. This talk will review recent progress towards these goals and outline some of the outstanding challenges, as best we understand them at the present time.

Defect proliferation in active liquid crystals

Cristina Marchetti

Active liquid crystals are nonequilibrium fluids composed of internally driven elongated units. Examples include mixtures of cytoskeletal filaments and associated motor proteins, bacterial suspensions, the cell cytoskeleton and even non-living analogues, such as monolayers of vibrated granular rods. Due to the internal drive, these systems exhibit a host of nonequilibrium phenomena, including spontaneous laminar flow, large density fluctuations, unusual rheological properties, excitability, and low Reynolds number turbulence. In this talk I will discuss new results on the dynamics and proliferation of topological defects in active liquid crystals. A simple analytical model for the defect dynamics will be shown to reproduce the key features of recent experiments in microtubule-kinesin assemblies.

Chemical Swimming and Active Matter

John Brady

One of the distinguishing features of many living systems is their ability to move, to self-propel, to be active. Through their motion, either voluntarily or involuntarily, living systems are able self-assemble: birds flock, fish school, bacteria swarm, etc. But such behavior is not limited to living systems. Recent advances in colloid chemistry have led to the development of synthetic, nonliving particles that are able to undergo autonomous motion by converting chemical energy into mechanical motion and work chemical swimming. This swimming or intrinsic activity imparts new behaviors to active matter that distinguish it from equilibrium condensed matter systems. For example, active matter generates its own internal stress, which can drive it far from equilibrium and free it from conventional thermodynamic constraints, and by so doing active matter can control and direct its own behavior and that of its surroundings. In this talk I will discuss our recent work on chemical swimmers and on the origin of a new source for stress that is responsible for self-assembly and pattern formation in active matter.

Glass versus jamming transitions

Jorge Kurchan

Are the glass transition and the jamming situation one and the same thing? If not, are they related at all? Is the same theoretical framework useful for both?

Jamming by Shear

Robert Behringer

Granular materials exhibit both a rich variety of phenomena and a challenge to model these phenomena. This talk will focus on the properties of dense granular states, i.e. the analogues of dense fluids and solids. I will then focus on a key aspect of dense granular systems: the transition between a flowable and a solid state, known as jamming. This transition occurs in a range of 'particulate' systems, including colloids, emulsions, foams and granular materials. Density plays a key role in the jamming transition (and the inverse transition, 'unjamming'). If a system has too low a density, there will be insufficient contacts to support static stresses, and the system can flow. If the density is high enough, there will be a network of mechanically robust contacts which can resist applied stresses/strains. But, if such a system is sheared strongly enough, it can deform irreversibly, and hence, flow. Much recent work on jamming has focused on models of frictionless/dissipationless grains, where this scenario of jamming holds. However, we have recently shown that for systems of grains with friction, which includes essentially all industrially relevant materials, a much richer range of states occurs near jamming. In the frictional case, there is a regime of densities, spanning the random loosed packing to random dense packing range, where it is possible to change from unjammed to jammed by applying shear, without changing the density. Thus, an additional property of the system, besides density, i.e. shear stress, controls jamming of frictional grains, and the resulting states are 'shear jammed'. I will develop a background for understanding shear jamming, and explore the states and their flows/dynamics in the vicinity of this transition in a variety of granular systems.

The Effects of Particle Shape

Karen Daniels

We perform experiments on laser-cut particles with four shapes (circles, ellipses, pentagons, and concave stars) and examine several dynamic and static properties of quasi-two-dimensional packings. For granular packings floating on an air table, we examine packing fractions and stress-strain curves under biaxial compression. We observe that pressure in the packings rises exponentially above a shape-dependent critical packing fraction, with a functional form that only weakly depends on shape. In granular packings prepared under gravitational pressure in a vertical slot, we use acoustic white noise and particle-embedded piezoelectric sensors to measure a density of vibrational modes. We find that, for the same four shapes, the density of modes show strong shape-dependence. We discuss possible relationships between these complementary findings.

Acoustical emission precursors preceding failure in sheared granular material

P. A. Johnson, B. Ferdowsi, M. Griffa, J. Carmeliet, R. Guyer, and C. Marone

Earthquake precursor observations are becoming progressively more widespread as instrumentation improves, in particular for interplate earthquakes (e.g., Bouchon et al., Nature Geoscience, 2013). One question regarding precursor behavior is whether or not they are due to a triggering cascade where one precursor triggers the next, or if they are independent events resulting from slow slip. We investigate this topic in order to characterize the physics of precursors, by applying laboratory experiments of sheared granular media in a bi-axial configuration. We sheared layers of glass beads under applied normal loads of 2-8 MPa, shearing rates of 5-10 m/s at room temperature and humidity. We show that above 3 MPa load, precursors are manifest by an exponential increase in time of the acoustic emission (AE), with an additional acceleration of event rate leading to the primary stick-slip failure event. The recorded AE are clearly correlated with small drops in shear stress during slow slip prior to the main stick-slip failure. Event precursors take place where the material is still modestly dilating, yet while the macroscopic frictional strength is no longer increasing. The precursors are of order 100x smaller in recorded strain amplitude than the stick-slip events. We are currently working on statistical methods to determine whether or not the precursors are triggered cascades.

Clogging transition of many-particle systems flowing through bottlenecks

I. Zuriguel, D. Parisi, R. C. Hidalgo, C. Lozano, A. Janda, P. A. Gago, J. P. Peralta, L. M. Ferrer, L. A. Pugnaloni, E. Clément, D. Maza, I. Pagonabarraga, A. Garcimartín

When a large set of discrete bodies passes through a bottleneck, the flow may be interrupted due to the development of a clog. Clogging is observed, for instance, in colloidal suspensions, granular materials, traffic flow and crowd swarming, where consequences may be dramatic. Despite its ubiquity, a unified description of clogging is lacking. We show that the probability distribution of time lapses between the passages of consecutive bodies exhibits a power-law tail with an exponent that depends on the system condition. Transition to clogging in systems of very different nature and scale including sheep herds, pedestrian crowds, assemblies of grains, and colloids is defined in terms of the convergence of the time lapse average. Such a unified description allows us to put forward a clogging phase diagram whose most conspicuous feature is the presence of a length scale, in contrast to jamming. This diagram helps to understand paradoxical phenomena, such as the faster-is-slower effect predicted for pedestrians evacuating a room. The proposed phase diagram sets a general framework for researchers working in a wide variety of situations where clogging represents a hindrance.

The statistics of frictional families

Mark Shattuck

We develop a theoretical description for mechanically stable frictional packings in terms of the difference between the total number of contacts required for isostatic packings of frictionless disks and the number of contacts in frictional packings, $m = -Nc$. The saddle order m represents the number of unconstrained degrees of freedom that a static packing would possess if friction were removed. Using a novel numerical method that allows us to enumerate disk packings for each m, we show that the probability to obtain a packing with saddle order m at a given static friction coefficient μ, $Pm(\mu)$, can be expressed as a power-series in μ. Using this form for $Pm(\mu)$, we quantitatively describe the dependence of the average contact number on friction coefficient for static disk packings obtained from direct simulations of the Cundall-Strack model for all μ and N.

Evolution of force networks in dense particulate matter

Lou Kondic

We present novel methods used to describe temporal evolution of force networks in dense particulate matter. The methods, based on algebraic topology, allow to quantify the evolution of these networks in precise terms. Different measures that we have developed

allow to distinguish between local and global changes of the networks and furthermore illustrate strong dependence of the evolution itself on the state of the system. We will focus in particular on discussing the crucial factors that determine the time scales on which the networks evolve.

Dynamical effects in the segregation of granular mixtures in quasi 2D piles

Irene Ippolito

The dynamics of segregation, mixing and layering has been studied during the build-up of quasi-2D piles from two different mixtures of grains of different diameters (1mm glass beads and either 3mm glass beads or coriander seeds). In each case, the domains of existence of the different flow regimes have been studied as a function of the relative volume flow rates of the two species and of the falling height; the variation of the mean slope of the pile with time has been shown to depend on the flow regime. The experiments show that complete segregation may occur when the larger grains are coriander seeds while there is always some mixing for glass beads, even though the ratio between the sizes of the particles is the same in both cases. A layering regime could be observed using glass beads of same geometry (i.e. spheres) and density but with two different diameters: it is associated to variations of large amplitude of the slope of the pile. No layering occurs when the large particles are coriander seeds instead of glass beads. The local processes involved in these regimes have been analyzed quantitatively from spatiotemporal diagrams of the profile of the free surface: the characteristic velocities of the different types of displacements of the grains have in particular been determined. Avalanches were only observed for glass beads and in the layering regime and play an important part in the development of the layers.

Title to be announced

Thorsten Poeschel

(Abstract to be announced)

Segregation in vibrated granular mixtures

Rodrigo Soto

A granular mixture, with particles differing in their mass only, is placed in a shallow box that is vertically vibrated. The vibrations inject energy into the vertical degrees of freedom, which is then transferred to horizontal motion via grain-grain collisions. With this mechanism, the system remains in non-equilibrium fluid-like states, which present several non-equilibrium transitions. Here, depending on the amplitude and frequency of vibration, the mixture can segregate or remain mixed, with a transition curve in this parameter space. Notably, the transition is continuous (second order) in one part of the curve, while it is discontinuous (first order) in the other part. The two types of transitions meet at a tricritical point. We analyze the dynamics of the coarse grained order parameter as well as the fluctuating properties.

Network structure of colloidal suspensions: Characterization and simulation

Paul Mort

To understand the structure-property relations of polydisperse systems, an understanding of particle contacts and coordination number distributions may be useful. This discussion focuses on the characterization and simulation of network structure in colloidal suspensions and gels. There is a body of experimental work showing heterogeneous suspension structures, where weakly attractive forces among particles cause an increase in localized packing, balanced with increasing volume of meso-porous regions (i.e., where particles are depleted). In simulation, we consider an inverse approach where meso-porosity is used as a parameter to drive changes in packing structure. The analysis is extended to polydisperse systems with significant distributions in particle size.

Hypo-coordinated solids above and below jamming onset

Corey O'Hern, Thibault Bertrand, Mark D. Shattuck

We propose a 'phase diagram' for particulate systems with purely repulsive contact forces, such as granular media and colloids. We characterize two cla ses of behavior as a function of the input kinetic energy per degree of freedom and packing fraction deviation from jamming onset $\Delta\Phi = \Phi - \Phi J$ using simulations of frictionless disks. Iso-coordinated solids (ICS) exist above jamming; they possess average contact number equal to the isostatic value, ziso. ICS display harmonic response, where the density of vibrational modes from the Fourier transform of the velocity autocorrelation function is a set of sharp peaks at eigenfrequencies of the dynamical matrix. In contrast, hypo-coordinated solids (HCS) occur above and below jamming and possess fluctuating networks of interparticle contacts, but do not undergo cage-breaking particle rearrangements. The density of vibrational frequencies for the HCS is not a collection of sharp peaks at, but it does possess a scaling form.

Contributed Workshop Talks

Statistical description of static granular systems in the arch ensemble

Demian Slobinsky,[1] **Luis A. Pugnaloni**[1]
[1]Dpto. Ingeniería Mecánica, Facultad Regional La Plata, Universidad Tecnológica Nacional. CONICET-La Plata, Argentina.

dslobinsky@frlp.utn.edu.ar

We propose a statistical framework to calculate the equilibrium macroscopic properties of static granular systems based on counting microscopic configurations in terms of arches. This arch ensemble exposes why previous attempts of using statistical mechanics partially failed. Using the arch ensemble, we obtain the exact density of states for a model of a granular assembly and calculate the arch size distribution, coordination number, and volume fluctuations; which show good agreement with simulation results of tapped two-dimensional systems. The model has a limiting case where it reduces to the analytically solved Bowles-Ashwin model for quasi-two-dimensional columns of frictionless disks. Interestingly, the arch ensemble is amenable of Monte Carlo type simulations such as the Wang-Landau sampling, which opens the way for a range of granular models to be studied via ensemble theory and the results contrasted against experiments.

Rise of an intruder disk under tapping

Rodolfo Omar Uñac,[1] **Ana María Vidales,**[1] **Luis A. Pugnaloni**[2]
[1]Departamento de Física, Instituto de Física Aplicada (UNSL-CONICET), Universidad Nacional de San Luis, Argentina.
[2]Departamento de Ingeniería Mecánica, Facultad Regional La Plata, Universidad Tecnológica Nacional, Argentina.

avidales@unsl.edu.ar

The problem of the segregation effect (induced by a tapping operation) of a big particle submerged in a bath ofsmall ones is an old problem. In particular, the case of the ascending run of a big disk in a columnof small disks subjected to tapping has a number of questions yet to be answered: how do arches between disks affect the rise of the intruder?. Does the fact that the intruder reaches the surface depend on the relationship between the depth at which it is initially found and the crystallization process induced by tapping? We present simulations using a pseudo molecular dynamic algorithm to answer the above questions. The parameters involved are the relative size of theintruder respect to the bath of small particles, the amplitude of the tapping and the initial position at which the intruder begins its run.During all the tapping process we record the statistic on the formation of arches between disks, i.e., we characterize the size, number and type of the arches as a function of the tapping number and relate these quantities with the different parameters. We also record the final heigh of the intruder and try to assess the results with some simple theoretical approximations. Answers to the questions above are discussed.

Effect of particle shape and fragmentation on the response of particle dampers

Martín Sánchez,[1] Carlos Manuel Carlevaro,[2] Luis A. Pugnaloni[1]
[1]Dpto. Ingeniería Mecánica, Facultad Regional La Plata, Universidad Tecnológica Nacional,Argentina.
[2]IFLYSIB (CONICET La Plata, UNLP), Argentina.

martin.sanchez@ypf.com

A particle damper (PD) is a device that can attenuate mechanical vibrations due to the dissipative collisions between grains contained in a box attached to the vibrating structure. Granular damping constitutes an emerging technology, mainly to vibration control in harsh environments (e.g. High and low temperatures) where other types of damping are not efficient. We show that the performance of such devices is independent of the material properties and shapes of the particles in working conditions where damping is optimal. The inelastic collapse of granular materials is responsible for this universal behavior. Even more, the universal response is also valid when fragmentation of the grains occurs. In contrast, the welding of grains (caused by operation under high temperatures) can take the PD out of the universal response and deteriorate the attenuation.

Intracellular transport of organelles driven by multiple motors: cooperation or competition?

Luciana Bruno,[1] Cecilia De Rosi,[2] Valeria Levi,[2] Mariela Sued,[3] Daniela Rodriguez[3]
[1]Depto. de Física & IFIBA-CONICET Facultad de Cs. Exactas y Naturales Universidad de Buenos Aires, Argentina.
[2]Depto. de Química Biológica-CONICET. Facultad de Cs. Exactas y Naturales Universidad de Buenos Aires, Argentina.
[3]Instituto del Cálculo-CONICET Facultad de Cs. Exactas y Naturales Universidad de Buenos Aires, Argentina.

lbruno@df.uba.ar

The organization of the cytoplasm is regulated by molecular motors that transport organelles and other cargoes along microtubules and actin filaments. The cellular environment is also viscoelastic causing viscous drag and elastic tethering to surrounding structures. Although it is known that cargoes are propelled in cells by groups of cytoskeleton motors, the precise impact of collective motors behaviors on intracellular transport and trafficking remains controversial.

Novel single particle tracking techniques allow recovering the trajectories of single organelles while they move within the cytoplasm with nanometer and millisecond resolution. These trajectories typically consist of series of back and forth movements called runs, interspersed with periods of stationary or diffusive motion. Since organelles are driven by multiple copies of motors, the statistical analysis of their trajectories can reveal key aspects of the collective behavior of motors in living cell, as well as of the complex relation between organelle motion and microenvironment.

Recently, we used a fast and precise single particle tracking method to follow the motion of individual melanosomes (pigmented organelles) in the cell cytoplasm of Xenopus laevis melanophores. We found that small organelles, which are supposed to experience a smaller drag force, present more tortuous trajectories and found that the actin and intermediate filament networks play important roles in this behavior. On the other hand, the transport of big organelles was less influenced by the cytoskeletal environment and trajectories were more processive, suggesting that the number of copies of active motors increases with organelle size.

To further explore the mechanisms that regulate the activity of motor proteins, we tracked fluorescently tagged peroxisomes, which are organelles involved in the catabolism of fatty acids, in Drosophila melanogaster S2 cells. These cells can be induced to form long processes filled with uniformly orientated microtubules, making them a privilege system for the study of organelle transport since the motion is quasi 1-dimensional. Peroxisomes are driven along microtubules within the processes by the action of the motor proteins kinesin-1 (motion toward the processes tip) and cytoplasmic dynein (motion toward the perinuclear region). The analysis of the run-lengths and segmental velocities of peroxisomes suggested that dynein motors would regulate anterograde transport driven by kinesin motors. To explore how the biophysical properties of motors affect the transport, we extended the analysis to peroxisomes trajectories in cells expressing a mutant motor, which has similar stall force and step size than those of kinesin-1, but is slower.

In this talk I will first give a short introduction to intracellular transport mediated by molecular motors. Then, I will describe the experiments that we performed in our lab to study the different aspects of the transport. I will focus on our recent experiments on melanophores and S2 cells and the interpretation of our results in terms of a model of interacting motors.

Modelling transport of information in turning flocks

Tomás S. Grigera,[1] Andrea Cavagna,[2,3] Lorenzo Del Castello,[2] Irene Giardina,[2,3] Asja Jelic,[2] Stefania Melillo,[2] Thierry Mora,[4,5] Leonardo Parisi,[2] Edmondo Silvestri,[2] Massimiliano Viale,[2] Aleksandra Walczak[4]
[1]INIFTA and Departamento de Fisica CONICET and Universidad Nacional de La Plata, Argentina.
[2]ISC CNRS Roma and Dipartimento di Fisica, Sapienza Universita di Roma.
[3]ITS, Graduate Center, CUNY, New York.
[4]LPS Ecole Normal Superieure and Univ Paris VI.
[5]LPT Ecole Normale Superiure and Univesite Paris VII.

tgrigera@inifta.unlp.edu.ar

Recent observations of starling flocks during a collective change of flight direction have shown that the information to change direction propagates linearly, with negligible attenuation. This wavelike propagation of information contrasts with prevailing models of flocking behaviour, which predict a slower, dissipative (diffusion-like) propagation. We show how to build a relatively simple model that accounts for this observation. The model provides a quantitative expression for the speed of propagation of information, according to which transport is swifter the stronger the flock's orientational order, prediction which is verified by experimental data.

Granular flow through an aperture: Influence of the compacity of the system

María Alejandra Aguirre,[1] Rosario De Schant,[1] Jean-Christophe Géminard[2]
[1]Grupo de Medios Porosos, Facultad de Ingeniería, Universidad de Buenos Aires, Argentina.
[2]Université de Lyon, Laboratoire de Physique, Ecole Normale Supérieure de Lyon, France.

maaguir@fi.uba.ar

For the last 50 years, the flow of a granular material through an aperture has been intensely studied in gravity-driven vertical systems (e.g. silos and hoppers). Nevertheless, in many industrial applications, the grains are horizontally transported at constant velocity, lying on conveyor belts or floating on the surface of flowing liquids.

In dense systems we have found that granular flow rate, different from how a liquid behaves, does not depend on the local pressure near the outlet but depends on the velocity and the high initial packing fraction. However, in contrast to what can be observed in vertical systems, in horizontal systems the density can take a large range of values, potentially very small, which may significantly alter the flow rate.

In this work, we study, for different initial packing fractions, the discharge through an orifice of monodisperse grains driven at constant velocity by a horizontal conveyor belt.

We observe that, during the discharge, compacity is modified by the presence of the outlet and we analyze how changes in the packing fraction induce variations in the flow rate. We find that variations of compacity do not affect the velocity of the grains at the outlet and, therefore, we establish that flow-rate variations are directly related to changes in the packing fraction.

Short, intermediate, and long-time diffusion in charged colloidal suspensions

Adolfo Javier Banchio,[1] Marco Heinen,[2] Peter Holmqvist,[3] Gerhard Nägele,[3]
[1]Famaf - Universidad Nacional de Córdoba and IFEG-CONICET - Córdoba - Argentina.
[2]Instutut für Theoretische Physik II, Weiche Materie, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany.
[3]Institute of Complex Systems (ICS-3), Forschungszentrum Jülich, Jülich, Germany.

banchio@famaf.unc.edu.ar

In this work, we present a comprehensive theoretical-experimental study of collective and self-diffusion in concentrated suspensions of charge-stabilized colloidal spheres. Correlation times ranging from colloidal short-time to long-time regime are considered. The intermediate, and self-intermediate scattering functions, the mean square displacement, and other dynamic quantities, are calculated by accelerated Stokesian Dynamics (ASD) simulations where many-body hydrodynamic interactions (HIs) are included, and additionally Brownian Dynamics (BD) simulations and mode-coupling theory (MCT) calculations without HIs included. On the basis of this results, the influence of HIs on the dynamics, and the accuracy of the MCT method are quatified. In theory and simulation, the spheres are assumed to interact directly by a hard-core plus screened Coulomb effective pair potential. The system size corrected dynamic scattering functions obtained in the ASD simulations are in decent accord with our dynamic light scattering (DLS) data for a concentration series of charged silica spheres in an organic solvent mixture, within the experimentally accessed time window.

We hereby provide a full overview on diffusion processes in charge-stabilized suspensions.

Experimental confirmation of "faster is slower" effect in various particulate systems

José Martín Pastor,[1] Angel Garcimartín,[1] Cesar Martín,[2] Paula Alejandra Gago,[3] Juan Pablo Peralta,[3] Daniel Ricardo Parisi,[4] Luis A. Pugnaloni,[3] Iker Zuriguel[1]

[1]Departamento de Física, Facultad de Ciencias, Universidad de Navarra, E-31080 Pamplona, España.

[2]Sección de Instalaciones y Energía. Escuela Técnica Superior de Arquitectura, Universidad de Navarra, E-31080 Pamplona, España.

[3]Departamento. Ingeniería Mecánica UTN-FRLP, Av. 60 esq. 124 s/n, 1900 La Plata, Argentina.

[4]Instituto Tecnológico de Buenos Aires, 25 de Mayo 444, 1002 C. A. de Buenos Aires, Argentina.

dparisi@itba.edu.ar

The "faster is slower" effect was first reported for simulated pedestrians evacuating a room through a narrow door [1]. It describes the increase of the evacuation time when the desired velocity (vd) (parameterizing the degree of hurry) of the pedestrians increase beyond certain threshold. After more than a decade from the prediction, experimental evidence of the FIS effect was yet not reported. In the present work, we will show that the FIS effect exists in real systems. In particular, for humans evacuating a room, for a flock of sheep and for a granular material. Given the presence of the FIS effect in such different systems, we can hypothesize that it can be a universal feature displayed by particulate matter flowing through constrictions. Moreover, its proper characterization could have important impact in applications in the processing of minerals and food grains and in the safety of pedestrian facilities as well as in many others fields where maximization of flows rate is of crucial importance.

Reference:

[1] Helbing, D., Farkas, I. & Vicsek, T. Simulating dynamic features of escape panic. Nature 407, 487-490 (2000).

Active Matter physically manipulated: Bacteria vs. human sperm cells

I. Berdakin,[1] H. A. Guidobaldi,[2] A. J. Banchio,[1] C. A. Condat,[1] L. C. Giojalas,[2] A. V. Silhanek,[3] Verónica I. Marconi[1]
[1]Famaf - Universidad Nacional de Córdoba and IFEG-CONICET - Córdoba - Argentina.
[2]Centro de Biología Celular y Molecular (CeBiCeM). Facultad de Ciencias Exactas, Físicas y Naturales. Universidad Nacional de Córdoba. Argentina.
[3]Departement de Physique, Universite de Liege, B-4000 Sart Tilman, Belgium.

vmarconi@famaf.unc.edu.ar

This numerical and experimental work is aimed to understand the complex relation between populations of self-propelled micro-swimmers and micro-patterned confinement geometries, in order to optimize sorting and guiding microfluidic devices based on purely physical methods. Both, precise phenomenological models based on experimental motility parameters [1-3] and simple microswimmer models using stokesian dynamics [4], were developed.

It has been shown that the ratchet effect is an effective method to induce inhomogeneous bacterial distributions in microchambers separated by a wall of asymmetric V-shaped obstacles. Although the origin of this effect is well established, we show numerically that its efficiency is strongly dependent on the detailed dynamics of the individual microorganism. Simulations indicate that, for run-and-tumble dynamics, the distribution of run lengths, the partial memory of run orientation after a tumble and the rotational diffusion are important factors when computing the rectification efficiency [1]. We optimize the geometrical dimensions of the asymmetric obstacles in order to maximize the swimmer concentration and we illustrate how it can be used for sorting by swimming strategy using an efficient long array of parallel walls [2].

In addition we investigate diluted human sperm cell populations guided by asymmetric obstacles with a variety of geometries. Using realistic sperm models we optimized the confinement habitat for accumulating the population. In particular, a trapping transition at convex angular wall features is identied and analyzed. We conclude that the specic self-propelled swimmer strategy and specific swimmer-wall interactions are crucial to design the optimum micro-patterned architecture able to achieve efficient physical sperm guidance. Interesting differences between bacteria and sperm micro-geometrical guidance arise from their different interactions with walls and sharped corners. We show that highly efficient microratchets can be fabricated by using curved asymmetric obstacles to take advantage of the spermatozoa specic swimming strategy along walls. These results sound very promising and attractive for further refined designs in biotechnological applications [3].

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Dynamics of confined non-cohesive granular systems

Nicolás Mujica[1]
[1]Departamento de Física, Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile.

nmujica@dfi.uchile.cl

One of the most noticeable collective motion of non-cohesive granular matter is clustering under certain conditions. In particular, when a quasi-two-dimensional monolayer of mono-disperse non-cohesive particles is vertically vibrated, a solid-liquid-like transition occurs when the driving amplitude exceeds a critical value. Here, the physical mechanism underlying particle clustering relies on the strong interactions mediated by grain collisions, rather than on grain-grain cohesive forces. In this talk we will review our experimental, numerical and theoretical studies on the dynamics of dry and confined granular matter. We have unravelled a rich variety of phenomena:

(i) Depending on the vertical height and filling density the solid-liquid transition can be of either first or second order type. For both cases density fluctuations do not show strong variations at the transition, but local order varies strongly, either abruptly or continuously respectively, with a critical-like behavior in the second case. Based on careful experimental measurements we were able to obtain five independent exponents, which are consistent with model C of dynamical critical phenomena. (ii) At the solid-liquid coexistence, in average, the solid cluster resembles a drop, with a striking circular shape. We experimentally investigate the coarse-grained solid-liquid interface fluctuations, which turn out to be well described by the capillary wave theory. This allows us to measure the solid-liquid interface surface tension and mobility once the granular "thermal" kinetic energy is determined. (iii) In a mixture of two species of grains of equal size but different mass spontaneous segregation can occur. Once the system is at least partly segregated and clusters of the heavy particles have formed, sudden energy explosions might appear, either randomly or with some regularity in time depending on the experimental or numerical parameters.

These three examples illuminate fundamental aspects of the collective dynamics of granular systems, such as the emergence of effective forces, the role of "hidden" variables and the extension of some concepts well justified for thermodynamic systems to strongly non-equilibrium systems.

Measurement of elastic parameters of granular layers from stress response functions

Allbens P. F. Atman[1]
[1]Departamento de Física e Matemática and Instituto Nacional de Ciência e Tecnologia – Sistemas Complexos – INCT-SC. Centro Federal de Educação Tecnológica, CEFET/MG. Avenida Amazonas 7675, CEP 30510-000, Belo Horizonte, MG, Brazil.

atman@dppg.cefetmg.br

In last years a great effort has been done towards a comprehensive description of the jamming state in granular materials. Several approaches has been used to characterize the so-called unjamming transition, i.e., a global change in the mechanical state of the granular material between rigid and flowing phases, which is analogous to the solid-liquid phase transition. Recently, this analogy was reinforced with the report of vanishing values of the shear modulus in frictionless systems, as the system approaches to unjamming, what is exactly we would expect for a liquid state. However, very recently, we report results for tilted frictional layers of grains showing that the shear modulus decreases as the transition approaches, but reaches a finite value at transition. Here, we describe in details the procedure used to estimate the elastic parameters from the stress response functions of granular layers obtained by means of discrete element modelling The response function is a very rich tool which allows non- destructive characterization of a medium, and is very sensitive to the microscopic texture of the material. We also present the analytic solution for the function response of an anisotropic elastic finite medium, with an angle of orthotropy which used to fit the simulation data. We show that as the transition approaches, two family of solutions can be clearly distinguished from the data, one where the stiff direction is along the preferential direction of contacts, and other where the stiff direction is between two preferential contact directions. The technique presented here is quite general, and can be applied to any granular assembly at jamming in order to estimate its elastic parameters.

PASI Contributed Oral Presentations

Jamming by Shape

Eial Teomy,[1] **Yair Shokef**[1]
[1]Tel-Aviv University-Israel.

eialteom@tau.ac.il

In colloidal and granular systems, energy and temperature do not play a major role. The dynamics of such systems are dominated by the geometrical packing fraction of their constituents and may be described by various kinetically-constrained models [1]. We focus on the Kob-Andersen model [2], which is defined as a lattice gas with only on-site exclusion, for which particles can move to neighboring sites only if they have less than a certain number of occupied neighbors. Most previous research considered infinite systems, while actual experimental systems are finite. We consider finite-size and semi-infinite systems in any dimension, which are infinite in several directions, but finite in the other directions [3,4].

By increasing the density of particles in the system, it becomes jammed, i.e. almost all the particles can never move according to the kinetic constraints. It has been proven [5-7] that a system which is infinite in all directions gets jammed only at a density of 1, when all lattice sites are occupied by particles. We find, analytically and numerically, that non-infinite systems become jammed at some finite, size- and shape-dependent density which nears 1 as the size of the system is increased.

Because the jamming density depends on the shape of the system, it is possible to jam or unjam the system just by changing its shape, without altering its total volume or particle density, as seen in experiments [8]. In the protocol we give here, the jamming transition does not occur by exerting forces on the system, but by performing ensemble averages over systems with fixed shape and density.

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Relevance of system size on macroscopic variables of tapped granular systems

Paula Alejandra Gago,[1] **Luis A. Pugnaloni,**[1] **Diego Maza Ozcoidi**[2]
[1]Dpto. Ingeniería Mecánica, Facultad Regional La Plata, Universidad Tecnológica Nacional. CONICET-Argentina.
[2]Dpto. de Física y Matemática Aplicada, Fac. de Ciencias, Universidad de Navarra, Pamplona, España.

paulaalejandrayo@hotmail.com

The importance of finding a macroscopic description of the equilibrium states of granular systems has increased in recent years. In this work, we focus on the effect that system size and boundary conditions have on macroscopic variables. We simulate, using molecular dynamics of soft spheres, a number of mono-sized particles in a quasi-two-dimensional cell. We apply taps following an annealing protocol similar to the one proposed by the Chicago Group. We start at the highest tap amplitudes and decrease the amplitude in small steps until we reach the lowest intensity, sampling in this way configurations from "equilibrium ensembles" at each tap intensity. Since the system is not homogeneous (the macroscopic variables present a dependency with depth) we measure all properties in narrow layers. This enables us to compare results obtained for systems constrained in cells of different geometries.

We show that the non-monotonic behavior of the packing fraction (ϕ) as a function of tap intensity (A), reported in previous works to present a minimum, is still observed if we increase the size of the system. However, the position of minimum ϕ is displaced to higher A when the system increases its height. We also show that fluctuations of ϕ as a function of ϕ exhibit a concave down behavior in correspondence with previous studies and with some analytic models of granular columns. The fluctuations of ϕ for systems of different sizes, in general, do not scale with the square root of the number of particles; an exception being the fluctuations at the minimum packing fraction.

The behavior of the stress tensor is shown to be qualitatively different if we measure it at different depths into the column of grains. Nevertheless, if we measure over layers at same depth, the stress converges as a function of ϕ for systems wide enough. We will show preliminary results for three-dimensional systems. We will discuss on the implications for the reproducibility of experiments and their comparison against theoretical models.

Limits to the universal flow rate of granular matter: Breakdown of Beverloo's scaling versus inelastic collapse

Marcos Andrés Madrid,[1] **José Ramón Darias,**[2] **Luis A. Pugnaloni**[1]
[1]Dpto. Ingeniería Mecánica, Facultad Regional La Plata, Universidad Tecnológica Nacional. CONICET-La Plata, Argentina
[2]Laboratorio de Optica y Fluidos, Universidad Simón Bolívar,Caracas, Venezuela.

marcosamadrid@gmail.com

The Beverloo's scaling for the flow rate of granular materials through orifices has two distinctuniversality features. The most highlighted in the literature is related to the independence of flowrate with the height of the granular column. The little studied, yet most striking, is related to the factthat flow rate does not depend on the material properties of the grains (Youngs modulus, Poisonsratio, friction coefficient, effective restitution coefficient, etc). We show that this universality withrespect to the material properties can cease if work is done on the system at a high rate and thenumber of grains in the container reduces. We then show compelling evidences that universalityholds if and only if an effective inelastic collapse is at play during the flow of the granular sample. Poisonsratio, friction coefficient, effective restitution coefficient, etc). We show that this universality withrespect to the material properties can cease if work is done on the system at a high rate and thenumber of grains in the container reduces. We then show compelling evidences that universalityholds if and only if an effective inelastic collapse is at play during the flow of the granular sample.

Computational design of metallic glasses

Kai Zhang,[1] William Wendell Smith,[1] Minglei Wang,[1] Yanhui Liu,[1] Jan Schroers,[1] Mark Shattuck,[2] Corey O'Hern[1]
[1]Yale University-United States.
[2]City College of New York, United States.

k.zhang@yale.edu

We employ the hard-sphere model to quantify the glass-forming ability for systems of bidisperse spheres. We measure the critical compression rate Rc, below which the system partially crystallizes, as a function of the size ratio α of small to large spheres and fraction xS of small spheres. Decreasing α near the monodisperse limit ($\alpha = 1$) causes the critical quench rate to decrease strongly. However, as α is further decreased toward 0.5, the critical compression rate begins to increase again due to segregation of the small spheres. We find that known binary bulk metallic glasses are located in the region of parameter space (α and xS) where bidisperse hard sphere systems possess the lowest critical compression rates. We also show that Rc decreases exponentially as $exp(-1/\Delta\phi 2)$, where $\Delta\phi = \phi x - \phi a$ is the packing fraction difference between the polycrystalline FCC phase to which these systems first crystallize and the packing fraction of the amorphous solid configurations.

Solute dispersion in non-Brownian particle suspensions

Alejandro Boschan,[1] Georges Gauthier,[2] Irene Ippolito,[1] Ricardo Chertcoff[1]
[1]Grupo de Medios Porosos and CONICET, Facultad de Ingeniería, Universidad de Buenos Aires, Argentina.
[2]FAST, Université Paris Sud and CNRS, Orsay Cedex, France.

aboschfi@gmail.com

Many environmental and industrial situations involve dispersion of solutes in the bulk of a confined particle suspension. In this context, we investigate experimentally the influence of suspended neutrally-buoyant spherical particles on the dispersion of a passive solute in a parallel-plate configuration. The objective is to study the behavior of the suspension at the scale of the particles, identifying the candidates for dispersive mechanisms, and relate to measurements of solute dispersion performed at the scale of the medium. For pressure-driven flows, two types of experiments were then performed. At the scale of the medium, the displacement of a suspension with a colouring solute by a (otherwise identical) transparent one, at constant flow rate. The concentration of the solute was measured by using a light transmission technique. At the scale of the particles, we analyze their velocity distributions in the flow of the transparent suspension only. Gravity-driven experiments, with no net flow, were also performed at the particle scale.

Impact of raindrops on sand

Rianne de Jong,[1] Song-Chuan Zhao,[1] Devaraj van der Meer[1]
[1]Physics of Fluids, University of Twente, Netherlands.

jong.riannede@gmail.com

The impact of a liquid droplet on a layer of grains is very common in nature, agriculture and industry. In spite of its ubiquity and relevance, little is known about the physics that governs it [15]. In contrast to a solid or liquid pool, a target consisting of a granular layer is more complicated, since granular materials can show both liquid-like and solid-like behavior.

We investigate the impact of liquid drops on sand by exploring the parameter space, e.g., impact speed and the packing density of the granular layer and measure the crater formation. The sand bed is carefully prepared by fluidizing the sand first and let it settle slowly, obtaining a very loose packing. By tapping the container, denser packings are acquired. In order to capture the crater profile, a combination of two laser sheets (lasers: 659 nm, 57 mW) and a high speed camera is used as a profilometer.

We measure the crater both dynamically during impact and statically after impact. During impact, we measure the deformation of both the granular surface as the droplet, at two positions with $10000 frames/s$ and obtain information on the velocity of deformation of both the droplet and granular substrate, as well as, on the maximum droplet deformation.

After impact, we scan the surface to acquire a complete 3D profile of the crater. This will give us more precise information on the crater shape, from which we can obtain typical length scales as crater diameter and depth, but also the total volume displacement of the grains.

The first results are promising and suggest that the final crater diameter is mostly affected by a change in impact speed: it greatly decreases when impact speed decreases. The final crater depth, however, has a clear dependence on the packing density of the grains. The denser the grains are packed, the shallower the final crater is.

We expect to acquire the explicit relations between the mentioned variables. This will help us understand what controls the amount of momentum that is transferred from the liquid onto the sand.

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Characterizing dense granular systems by percolation and statistical properties of force networks.

Lenka Kovalcinova,[1] Arnaud Goullet,[2] Lou Kondic[1]
[1]New Jersey Institute of Technology, USA.
[2]Rutgers University, USA.

lk58@njit.edu

We consider two dimensional granular systems compressed isotropically within a square box. We study the force networks, including evolution of their statistical and percolation properties. Using the information about the total forces between the particles, the number of contacts and forming clusters, we identify the phase transition in granular systems, as well as distinguish between the system that do and do not crystallize. We discuss the influence of various physical parameters including the speed of compression on jamming and percolation transitions, and on force statistics. For systems without cohesion, we find that the jamming and percolation transitions coincide in the quasi-static limit. We present results discussing the degree to which our findings extend to cohesive systems.

The influence of grain shape on the force on the walls of a discharging hopper

Felipe Galvão Rafael Magalhães,[1] Allbens P. F. Atman,[2] José Guilherme Moreira,[1] Hans Juergen Herrmann[3]
[1]Universidade Federal de Minas Gerais, Brazil.
[2]CEFET-MG and INCT - Sistemas Complexos, Brazil.
[3]ETH Zuerich, Switzerland.

felipe@fisica.ufmg.br

The flow of granular material through a hopper is a bottleneck in industrial plants and a case of academic interest. Although many studies touched the subject, several open questions remain. One point of concern for applications is the effect of the grain shape on the silo or hopper walls during discharge processes. Without an analytic description and many experimental difficulties, the flow of grains through a hopper is more easily accessible through computer simulations. On this context, we use a Discrete Element Method in three dimensions to simulate the flow of simple and composite spherical particles due to gravity through a conical hopper of variable orifice diameter. The composite particles are made of two or three spheres that are kept in touch or at a small fixed distance from one another. We focus on the distribution of forces on the wall of the hopper and compare the behavior for different shapes of grains (simple and composite) and for different orifice diameters. During the simulation, several quantities can be measured and can help us obtain the force network and spatial distribution of particle density and velocity. Preliminary results show that for simple spheres the distribution of forces on the walls exhibits a heavy tail while this is not present in the case of composites of two spheres.

Jamming of Frictional Particles: a Non-equilibrium First Order Phase Transition

Matthias Grob,[1] **Claus Heussinger,**[2] **Annette Zippelius**[2]
[1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany.
[2]Institute for Theoretical Physics, Georg-August University of Göttingen, Germany.

grob@theorie.physik.uni-goettingen.de

We study the rheology of frictional particles with analytical modelling and extensive numerical simulations. The analytical model is based on a simple model for a non-equilibrium first order phase transition that implements a constitutive relation. Our numerics and analytical approach lead to a phase diagram for frictional granular particles in two dimensions. The flow curves, i.e. stress versus strain rate, show a smooth crossover from a shear thickening regime (inertial flow) at small strain rate to a shear thinning regime (plastic flow) at large strain rate below a critical packing fraction $\phi_c = 0.792$. Above this packing fraction, this crossover turns into a sudden and discontinuous transition and we observe hysteresis. Dependent on the numerical or experimental protocol, an inertial flow phase with small stress or a plastic flow phase with large stress is attained. This hints to the existence of metastable states. A yield stress is observed for $\phi > \phi_\sigma = 0.80$. At a yet higher packing fraction $\phi_\eta = 0.819$ the apparent viscosity of the inertial flow regime diverges and the inertial flow regime disappears. The transition from flowing to jammed states is reentrant: between ϕ_c and ϕ_η the system flows inertially at low stress and plastically at large stress while it jams in between. Before the system jams, transient flow is observed and exhibits a time scale that is characteristic for packing fraction and stress. These rheological features can be explained by the simple constitutive relation that we propose: the viscosity diverges, when the inertial flow regime becomes locally unstable and the transient flow-and-jam states are interpreted as metastable states.

We also compare the frictional rheology to the frictionless scenario. In the frictionless case, the features of the first-order phase transition are lost: while the system flows either inertially or plastically below the jamming packing fraction ϕ_J, it is jammed or flows plastically above. This can be understood within the models framework, too. As friction is diminished, the three packing fractions $\phi_c \leq \phi_\sigma \leq \phi_\eta$ move closer together. Ultimately, they merge in the frictionless case into a single packing fraction ϕ_J where simultaneously the viscosity diverges and a yield stress first occurs.

For reference, see Phys. Rev. E **89**, 050201 (2014)

Coarse grain approach to obtain hydrodynamical equations in 2D and 3D dense granular fluids

Javier Baeza,[1] **Patricio Cordero**[1]
[1]Departamento de Física, Universidad de Chile.

jbaeza@ing.uchile.cl

In the process to understand granular flows in different systems there has been several approaches from classical hydrodynamics, kinetic theory and hydrodynamical fluctuations, in order to obtain hydrodynamic like equations that describe accurately the flow

of granular matter in different regimes of movement. In this work, as a starting point the coarse grain tool, developed initially by Goldhish et all, have been extended and used to analyse a 2D and a 3D system with a mayor simplification of homogeneous size and no rotating grains. In spite of this, no other approximation related to the state of the system (density, energy, injection mechanism) have been used to derive a set of conservation equations.

The coarse grained have advantages over the usual methods, such as the smooth description of the grains leaving a cell and precise measurement of the local hydrodynamical fields. The equations derived manage to remain consistent independently of the size of the measurement cell, time and the local density and energy. This way of considering the grains has some other implications in the dynamic and static structure factor, allows to calculate a pressure matrix independently and, through the GreenKubo approximation, obtain a local viscosity coefficient. This method is consistent even with a very low number of grains in the system and inside the measurement space.

Shear Reversibility in Model Granular Systems

Carl Schreck,[1] Robert Hoy,[2] Mark Shattuck,[3] Corey O'Hern[4]
[1]Lawrence Berkeley Laboratory and Department of Chemistry, University of California, Berkeley, USA.
[2]Lawrence Berkeley National LaboratoryDepartment of Physics, University of South Florida, USA.
[3]Department of Physics, City College of New York, USA.
[4]Mechanical Enginerring and Materials Science, Yale University, USA.

carl.schreck@yale.edu

Athermal particulate systems such as foams and granular media are out-of-thermal equilibrium and therefore mustbe externally driven using shear or vibration to explore different configurations. Of particular interest is being ableto predict and control the structural and mechanical properties of athermal systems as a function of the drivingmechanism. In this work, we show numerically how particle collisions in cyclically sheared hard sphere systems canlead to microreversibility. We map out the steady-state "phase diagram" as a function of packing fraction (ϕ) andstrain amplitude (γmax), and identify "point-reversible" states at low ϕ and γmax in which particles do not collideover the course of a shear cycle, and "loop-reversible" states at intermediate ϕ and γmax in which particles undergonumerous collisions but return to their initial positions at the end of each shear cycle. Loop-reversiblity is a novelform of self organization that gives rise to non-fluctuating dynamical states over a broad range of packing fractionsfrom contact percolation to jamming, i.e. $\phi_P = 0.55$ to $\phi_J = 0.84$ in two dimensions.

PASI Contributed Poster Presentations

1 Mathematical models for growth of heterogeneous sandpiles via Mosco convergence

Marian Bocea[1]
[1]Loyola University Chicago, U.S.A.

mbocea@luc.edu

I will discuss the asymptotic behavior of variable exponent power-law functionals in the framework of Mosco convergence, and indicate several consequences to the analysis of a class of quasilinear parabolic problems which in the fast/slow diffusion limit models the growth of sandpiles whose critical slopes depend explicitly on the position in the sample. This is based on joint work with M. Mihăilescu (University of Craiova, Romania), M. Pérez-Llanos (Universidad Autónoma de Madrid, Spain), and J.D. Rossi (Universidad de Alicante, Spain and Universidad de Buenos Aires, Argentina).

2 Simulation study of low-frequency normal modes of soft colloidal glasses

Diego Felipe Jaramillo,[1] **Manuel Alfonso Camargo**[1]
[1]Grupo de Investigación Sistemas Complejos, Universidad Antonio Nariño-Colombia.

diefejaca@hotmail.com

A common feature for amorphous materials is the impossibility to describe their low-frequency normal modes as plane waves as is the case for crystalline solids. This fact has important consequences on the related density of states (DOS) and on the thermodynamical and mechanical properties of the system. On the other hand, colloidal suspensions have been used as model systems to study various phenomena that occur in condensed matter systems, such as atomic liquids, crystals, and glasses. Particularly, recent studies on suspensions of soft colloids (i.e. hydrogel particles) above the glass transition shown the presence of a boson peak, i.e. an excess of low-frequency modes in the DOS [PRL 108: 095501 (2012)]. The performed analysis was based on comparison with a "shadow system" having the same configuration and interactions as those of the soft colloids. Since this approach completely neglects the over-damped dynamics of colloidal systems, in this work we employ both molecular and Brownian dynamics simulations to assess the effect due to the solvent presence on the low-frequency modes and the associated DOS of soft colloidal glasses. To model soft colloids we resort to a generic coarse-grained interaction, that has been successfully used to describe star polymers, hydrogel particles and micelles, and which strength can be modulated by several physico-chemical factors.

3 Silo collapse under granular discharges and the transient non-slip state of grains in contact with the wall

Claudia Colonnello,[1] Leonardo Reyes,[1] Eric Clément,[2] Gustavo Gutiérrez[1]
[1]Department of Physics, Universidad Simón Bolívar, Caracas, Venezuela.
[2]University Pierre et Marie Curie, Laboratoire de Physique et Mécanique des Milieux Hétérognes PMMH-ESPCI, UMR 7636 of the CNRS-France.

colonnello@usb.ve

We study experimentally, laboratory scale cylindrical silos during gravity-driven granular discharges. We are interested in the behavior of the system during the initial instants of the discharge, at the time scale associated to the onset of sliding friction at the grain-wall interface. We use rigid silos as well as thin walled silos around their critical collapse height, where the wall buckles as a consequence of the granular discharge, and failure of the structure occurs. We propose a criterion to determine a maximum time for the onset of the collapse based on the observation of the deformation of the silo wall, and monitor simultaneously the deformation and the position of individual grains in contact with the wall. We find that grains in contact with the wall always start sliding after the collapse of the silo has been triggered. This result implies that to describe the mechanism of collapse one has to consider a regime of static friction between the grains and the wall.

4 Scale-up of Continuous Rotary Calciners

Heather N. Emady,[1] Kellie V. Anderson,[1] Benjamin J. Glasser,[1] Fernando J. Muzzio,[1] William G. Borghard,[1] Alberto Cuitino[1]
[1]Rutgers University-United States.

hnemady@gmail.com

In catalyst manufacturing, continuous rotary calcination is a thermal treatment process in which particles flow through a rotating drum with heated walls. Although this process is widely used, there is a lack of predictive models for material flow and heat transfer, particularly upon scale-up. This work aims at a fundamental understanding of the effects of operation, design, and material properties on residence time and temperature distributions in rotary calcination processes to provide a methodology for scale-up.

For successful calciner performance, the residence time of the particles in the calciner must be longer than the time required for heating and calcination of the particles. This problem can be separated into axial and radial processes. In the axial direction, residence time and dispersion will be important, requiring experiments in full calciners. In the radial direction, heat transfer and dispersion will be important, requiring experiments and discrete element method (DEM) simulations in cross-sections of the calciner. This presentation will discuss results of studies on the competing axial and radial processes and their implications for scale-up of continuous rotary calciners.

5 Nonlinear Vibrational Response in Frictional Sphere Packings

Thibault Bertrand,[1] **Corey O'Hern,**[1] **Mark Shattuck**[2]
[1]Yale University-United States.
[2]City College of New York, United States.

thibault.bertrand@yale.edu

The response of frictional granular packings to vibrations can display complex spatiotemporal dynamics due to strong nonlinearities from contact breaking, Hertzian contact interactions, frictional sliding, and other sources that are inherent in granular media. However, most computational and theoretical studies of the vibrational response of packings of frictional spheres have only characterized the linear vibrational response using the dynamical matrix. Here, we directly measure the frequency content of the response of packings of frictional spheres to vibrations as a function of the amplitude and frequency of the perturbations. By doing this, we are able to capture the transition from linear to nonlinear response as a function of the driving and identify the largest source of the nonlinear response for systems with different friction coefficients and packing fraction.

6 Dilatancy effects on the walls of a silo discharged by gravity

José Ramón Darias,[1] **Luis A. Pugnaloni**[2]
[1]Optics and Fluid Laboratory, Physics Department, Simón Bolívar University. Venezuela.
[2]Mechanical Engineering Department, Nacional Tecnológica University La Plata, Facultad Regional La Plata, Argentina.

jrdarias@usb.ve

We study through computer simulations using the Discrete Element Method, the behaviour of the stress on the walls of a two-dimensional silo discharged by gravity. We calculate the flow rate of particles as a function of the diameter of the discharge orifice and find that results are consistent with the two-dimensional Beverloo's scaling in an interval between six and twenty particle diameters [1,2]. Moreover, we find that the data set for the flow rate over a wider range of orifice sizes is well fitted by the modified expression proposed by Mankoc et al. [3]. During the discharge process, we calculate the stress on the lateral walls and base of the silo and find that it increases with the diameter of the orifice. This behaviour is a consequence of the Reynolds' dilatancy effect that is observed in granular material under shear [4]. Interestingly, only for the region where the particle flow rate is predicted by the Beverloo's scaling, the quotient between the mean stress on the walls and base of the silo is constant.

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7 Molecular Dynamics study on fast colliding nanoparticles

Yoichi Takato,[1] **Jeremy B Lechman,**[2] **Surajit Sen**[1]
[1]Department of Physics, The State University of New York at Buffalo, USA.
[2]Sandia National Laboratories, USA.

ytakato@buffalo.edu

I will present Molecular Dynamics study on collisional behaviors of two identical nanoparticles made of Jennard-Jones atoms. Nanoparticles whose size ranges from 1 nm to 100 mn show dynamical behaviors often distinct from corresponding bulk materials. In general, nanoparticles are harder and their mechanical strength shows size dependence in contrast to macroscopic spherical objects. Lattice structures and surface geometries of nanoparticles play important roles for interactions between two nanoparticles. We carried out Molecular Dynamics simulations of two colliding single-crystal nanoparticles at various collision velocities. Interesting dynamical behaviors of nanopartices unseen in macroscopic particles were obtained. The size-dependent yield velocity appears to approach a constant yield velocity predicted by the continuum theory as the nanoparticle becomes bigger. Above the yield velocity, the nanoparticles undergoing plastic deformation are found to be softer than macroscopic particles. I will also show how the surface geometries and lattice structures influence the interactions between nanoparticles.

8 A Granular Rotor in the Non-Brownian Regime

Loreto Oyarte Gálvez,[1] **Devaraj van der Meer**[1]
[1]Universiteit Twente, Netherlands.

l.a.oyartegalvez@utwente.nl

The attempts to challenge the second law of the thermodynamics have been many throughout history. In 1912, Marian Smoluchowski devised a prototype designed to convert Brownian motion into work, but 50 years later Feynman showed unambiguously why at thermal equilibrium this device cannot actually do this. However, far from equilibrium the behavior of a rotor which rectifies motion of randomly moving molecules in their surroundings, is still an active matter of study. These molecular motors are responsible for tensing and relaxing the muscles of the body, for numerous cellular and intracellular transport process, photovoltaic and photorefractive effects, among many others[1].

We study experimentally and theoretically the movement of a granular motor, consisting of a horizontal rotor with four vanes immersed in a granular bath. The vanes in the rotor are precisely balanced around an axis, which in turn is connected to the container wall by a low-friction ball bearing. The angle is measured by an optical angle encoder[2].

We studied the rotor in the independent-kick regime. In this regime, the rotor is in rest for most of the time. Only occasionally a particle-vane collision sets the vanes into motion. Therefore the time between particle-rotor collisions is longer than the time the rotor needs to be stopped by friction ($\tau_C \gg \tau_S$). This regime is dominated by ball-bearing friction.

We calculate the angular velocity distribution (AVD), wich consists of a singularity corresponding to the time during which the motor is at rest, and a regular part corresponding to the relaxation after kicks [3]. From the experimental study, we observed a non-linear relaxation velocity, implying that the dynamic friction of the rotor is not constant in this regime. We used this observation in our model to obtain the regular part of the AVD.

With the goal of understanding the behavior of the granular rotor, we injected more energy to the granular gas and, as a result, the time between particle-rotor collisions becomes comparable to the time the rotor needs to be stopped by friction ($\tau_C \sim \tau_S$). In this case, our model turns into in an integral equation wich we solve using the corresponding eigenvalue problem.

The rotor can be symmetric or not. In the non-symmetric case, the rotor favors one of the two directions, which is known as the ratchet effect. We adapted our models to both regimes and compared with the experimental results, like in the symmetric cases.

Our models fit precisely to the experimental results in both regimes and for symmetric and non-symmetric conditions.

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9 Shift of resonant frequencies in granular dampers

Mauro Baldini,[1] Martín Sánchez,[1] Luis A. Pugnaloni[1]
[1]Grupo de Materiales Granulares - Universidad Tecnologica Nacional, Facultad Regional de La Plata, Argentina.

mauro_baldini@yahoo.com.ar

We study the frequency response of a single degree of freedom system with a granular damper. The system is composed of a primary mass M, a linear spring K, a viscous structural damper C and a granular damper. The granular damper consists on a prismatic box, partially filled with granular material, attached to the primary mass. The primary system is subjected to a harmonic excitation. Due to inelastic collisions and friction between the grains and between the grains and the walls of the box, the system response is highly nonlinear. Trough simulations using the Discrete Element Method we have analyzed the shift of the frequency response function when the granular damper is attached to the primary system. We associate this effect with the concept of effective mass. The resonant frequencies shift, or the variation of the system effective mass, occurs when the constructive characteristics (box height) or the operating parameters (amplitude of the external excitation) are changed. Trough the study of the motion of the granular bed, we explain this phenomenon in relation with the flight time of the granular bed and with the impact timing of the bed with the box.

10 Attraction and repulsion between two immersed and fixed obstacles in a granular flow

Manuel Francisco Acevedo Escalante,[1] **Ricardo Arturo López de la Cruz,**[2] **Gabriel Arturo Caballero-Robledo**[1]
[1]Centro de Investigación y de Estudios Avanzados del IPN, Unidad Monterrey, México.
[2]Instituto Tecnológico y de Estudios Superiores de Monterrey, ITESM, México.

acevedo.escalante@gmail.com

In this work we present numerical and experimental results about the study of the forces on two immersed obstacles into a granular flow. Experiments with obstacles into a granular systems have been widely studied, for example in: Wieghardt [Annu. Rev. Fluid Mech. 7, 89 (1975).], Chehata [Phys. of Fluids 15(6), 1622-1631, (2003).], Wassgren [Phys. of Fluids, 15(11), 3318-3330, (2003).], Zuriguel [Phy. Rev. Lett., 107(27), 278001, (2011).].

Also, in the literature we find experiments where the behavior of falling particles into a granular media were studied. F. Pacheco-Vázquez [Nat. Comm., 1, 123. (2010)] reports an interesting behavior between falling particles into a superlight granular media. This behavior consists in a kind of collective motion since the falling particles do not fall like a bulk but there are moments in which some of the falling particles stop and moments in which the particles move in a kind of wave-like movement.

On the other hand, Solano-Altamirano et al [Phys. Rev. E, 88(3), 032206. (2013)] studied numerically and experimentally the behavior of two particles falling in a similar system. They led two particles to fall into a quasi 2D granular bed and at different distances between them. They report that the particles first repel each other, then they attract, and they finally stop. This behavior suggests that exist forces of attraction and repulsion between the intruders.

In the system that we study in the present work, both numerically and experimentally, the two immersed obstacles do not move. We use numerical simulations based on a soft particle discrete element code with a hysteretic spring for contacts between particles. In a first stage we measure the force around the obstacles. For performing this experimentally, in a quasi 2-D granular bed we place two suspended cylinders by help of strings at the same height. One end of the string is attached to a load cell and the other end is attached to a tension mechanism. For the horizontal force we use a similar set-up. This set up allows to measure attractive and repulsive forces on intruders. In a second stage; a High Speed Camera is placed in front of the two obstacles to capture the movement of the particles around them and calculate the velocity profile by means of images analysis. We vary the distance between obstacles and the kind of particles. Finally, we discuss the mechanisms proposed in the previous works about the forces of attraction and repulsion.

11 Effect of filling protocol on the pressure at bottom of a silo during its discharge

Juan Pablo Peralta,[1] Luis A. Pugnaloni,[1] María Alejandra Aguirre,[2] Jean-Christophe Géminard[3]
[1]Fac. de Ingeniería, Universidad Tecnológica Nacional, Departamento de Mecánica. La Plata, Buenos Aires, Argentina.
[2]Grupo de Medios Porosos, Fac. de Ingeniería, Universidad de Buenos Aires. Buenos Aires, Argentina.
[3]Université de Lyon, Laboratoire de Physique, Ecole Normale Supérieure de Lyon, CNRS, France.

juanpabloperaltautn@gmail.com

We measure the pressure exerted by the grains on the flat lower surface of a silo during its discharge. Two different filling protocols are used: (i) jet filling and (ii) rain filling. We show that the resulting pressure profile is sensitive to the filling protocol, during the entire discharge. In addition, we perform experiments in which the lower half of the silo is filled using one protocol and the upper half using the other. They demonstrate that, in spite of all the rearrangements suffered by the upper half of the material during the discharge of the lower half, the pressure profile exhibit a sudden change when the upper half of the granular column enters in contact with the base. These results are of particularly valuable for the design and operation of industrial silos.

12 Taylor Dispersion in oscillating flow

Yanina Lucrecia Roht,[1] Irene Ippolito,[1] Ricardo Chertcoff,[1] Jean Pierre Hulin,[2] Harold Aurodou[2]
[1]Grupo de Medios Porosos, Facultad de Ingeniería, Universidad de Buenos Aires, Argentina.
[2]Fluides, Automatique et Systemes Thermiques, Université Paris Sud, Orsay, Francia.

lucreroht@gmail.com

The aim of this work is to study the mixing process and hydrodynamic dispersion of a passive tracer in the presence of an oscillating flow of a Newtonian fluid in a Hele Shaw cell.

We used an experimental device that allowed us to develop an oscillating two-dimensional flow within a cell, and to control the frequency and the amplitude of the oscillations. Visualization and image processing techniques, previously developed, were modified to fit the case of the oscillating flow and used in this work. Experiments varying the amplitude and frequency of oscillation were performed. Initially, the contact between solutions of glycerol with and without tracers was placed in the center of the cell defining an "interface" that should be kept straight for a short period of time in order to prevent molecular diffusion. Also, a simulation type "Monte Carlo" was used to complement the study.

Different regimes were experimentally and numerically obtained only controlled by the ratio between the characteristic diffusion time across the cell thickness and the characteristic period of the oscillation.

13 Analyzing the dynamics of pattern formation in the space of persistence diagrams

Miroslav Kramar,[1] **Konstantin Mischaikow,**[1] **Lou Kondic,**[2] **Arnaud Goullet**[1]
[1]Rutgers University, USA.
[2]New Jersey Institute of Technology, USA.

`miroslav@math.rutgers.edu`

Persistence diagrams are a relatively new topological tool for describing and quantifying complicated patterns in a simple but meaningful way. The state of granular media can be represented by a persistence diagram. This representation provides an interesting insight into the physical properties of the granular media as demonstrated on a system undergoing compression. Using persistent homology allows us to transform experimental or numerical data into a point cloud in the space of persistence diagrams. There are a variety of metrics that can be imposed on the space of persistence diagrams. By choosing different metrics one can interrogate the pattern locally or globally, which provides deeper insight into the dynamics of the process of pattern formation. Because the quantification is being done in the space of persistence diagrams this technique allows us to compare directly numerical simulations with experimental data.

14 Packing particles in constrained geometries using fluid matrices

Matías Ezequiel Fernández,[1] **Martín Sánchez,**[2] **Luis A. Pugnaloni**[1]
[1]Dpto. Ingeniería Mecánica, Facultad Regional La Plata, Universidad Tecnológica Nacional, La Plata, Argentina.
[2]Y-Tec SA, Argentina.

`matiasfernandezlp@hotmail.com`

The flow of particulate material through constrained geometries is of particular importance in many industrial applications where at least one of the spatial dimensions is of a few particle diameters. Moreover, in a range of problems, particles are driven by a fluid matrix. We present a discussion on the problems associated with predicting the arrangement of particles driven by a fluid into a narrow constriction. We consider different experimental strategies to study this problem under controlled laboratory conditions.

15 Drilling into Granular Asteroids: Simulating Impacts on Granular Materials in Microgravity

Scott Lindauer[1]
[1]North Carolina State University, USA.

smlindau@ncsu.edu

The scientific community lacks a widespread comprehension of interactions with near earth objects (NEOs), which is detrimental due to the current drive for asteroid exploration. Furthermore, the mining of resources from NEOs requires a more specific understanding of how to handle the regolithic surfaces on these celestial bodies. We perform experiments on a frictionless air table with disk-shaped photoelastic particles in order to simulate drilling into a bed of granular particles in a microgravity system. Through these experiments we test different digging protocols and evaluate the efficiency and safety of differing methods of exploring and utilizing asteroids in our solar system.

16 Numerical Studies of Two Supercooled Liquid Toy Models

Alejandro Seif,[1] **Tomás S. Grigera**[1]
[1]Instituto de Investigaciones Fisicoquimicas Teoricas y Aplicadas, Facultad de Ciencias Exactas de la Universidad Nacional de La Plata, Argentina.

seifalejandro@inifta.unlp.edu.ar

The physics of glass forming liquids is still an open problem. Part of the problem resides in obtaining experimental data to support proposed theories. Here we will study two models of tridimensional lattice arrays as toy models for those systems. We have studied and tested both the modelproposed by Pica Ciamarra-Tarzia-de Candia-Coniglio and the Latice GlassModel by Biroli-Mezzard Model. These, are fast to simulate and allow us to use Kinetic Montecarlo without any approximation, hoping we can reproduce the supercooled liquid phenomena. We have studied the behaviour of density and the self-overlap temporal correlation function. They present a large part of the phenomenology of supercooled liquids next to the glass transition, particularly the two-step relaxation, as well as the non-exponential relaxation and the super-Arrhenius growth in relaxation times. We can see the presence of ageing in some conditions, as seen on glassy materials. However a quantitative analysis shows differences between the models and the ageing present in real glassy systems.

17 Specific heat anomaly in a numerical model of supercooled liquids under different bounday conditions

Daniel Alejandro Martín,[1] Andrea Cavagna,[2] Tomás S Grigera[1]
[1]Instituto Nacional de Investigaciones Fisicoquímicas Teóricas y Aplicadas, UNLP, La Plata, Argentina.
[2]Istituto Sistemi Complessi (ISC), Consiglio Nazionale delle Richerche (CNR), UOS Sapienza, Roma, Italy.

danielalejandromartin@gmail.com

We study a simple numerical model for supercooled liquids (soft repulsive spheres) confined within spherical cavity of radius R. In addition to this hard-wall confinement, the particles are subject to a boundary field created by placing around the sphere particles of the same system and at the same density but artificially "frozen" in place. In amorpous boundary conditions (ABCs), the positions of the particles outside the cavity are taken from equilibrium configurations of the liquid at a given temperature, while in random boundary conditions (RBCs), the outside particles are placed at random positions (infinite temperature).

We study specific heat in both kinds of cavities. Speciffic heat is a measurable phyisical quantity with clear thermodynamical sense. For both ABCs and RBCs, we find have a peak in Cv as a function of temperature that moves to lower temperatures for bigger cavities. For a given radius, the peak position is found at lower temperature under RBCs compared to ABCs.

We discuss this finding, reminiscent of finite-size scaling behavior near a phase transition, in relation to recent work finding growing static correlation lengths in deeply supercooled liquids.

18 Identification and approach of agricultural machinery problems with high impact in North Argentina

Juan Manuel Vallejos,[1] Bruno Natalini[1]
[1]Universidad Nacional del Nordeste, Argentina.

juanmanuelvallejos@yahoo.com.ar

During the last thirty years, the main advances in the field of agricultural machinery were linked to massif incorporation of electronics to machines and mechanisms, without much alteration of the concepts of design.

However, during that same period, different fields of knowledge relevant to manufacturing of machinery evolved significantly, which suggests that new approaches might be possible from an updated and multidisciplinary standpoint. Researchers of the Engineering Faculty and the Agriculture Sciences Faculty of the Universidad Nacional del Nordeste (UNNE) intend to identify and approach high impact problems in the field of agricultural machinery from that perspective. They are accompanied in this early

undertaking by researcher of other National Universities coming from different fields of expertise.

Some of the problems so far detected could bring forth new developments under the combined application of Product Lifecycle Management (PLM) solutions and Bulk Materials (BM) technology. Among the most obvious are the design of silos, hoppers, feeders and different sort of devices for transport and handling of bulk materials.

The adopted strategy to progress in that direction starts with the preparation of human resources with qualification in both areas and a background in Mechanical Engineering. Furthermore, PLM solutions and BM technology will be gradually incorporated into the curricula of the Mechanical Engineering careers of the UNNE and the Universidad Nacional de Rosario.

A sharp contrast is observed when the advanced state-of-arte BM technology is confronted with the diffusion of that knowledge among the Argentinean Mechanical Engineering practitioners, which is virtually null. Admittedly, this is a domestic problem, but it is expected that the incorporation of BM technology in the horizon of the local Mechanical Engineering community leads to new developments.

19 Tunable Organization of Cellulose Nanocrystals for Controlled Bulk Response

Jairo A. Diaz,[1] Xiawa Wu,[1] Ashlie Martini,[2] Robert J. Moon,[3] Jeffrey P. Youngblood[1]
[1]Purdue University, USA.
[2]University of California, USA.
[3]Forest Products Laboratory, US Forest Service, USA.

jdiazama@purdue.edu

Cellulose Nanocrystals (CNCs) are rod-like nanoparticles (l 100 nm, d 7 nm) that exhibit characteristic organization capabilities and have shown to be highly responsive to magnetic, electric and shear forces, acting together or separately. Over the past two decades, the biorenewable nature of CNCs has opened up new opportunities for cost-effective materials design in several fields such as flexible electronics, biomaterials, and nanocomposites. The present work will provide a multiscale description of the influence of single crystals in the thermal and optical response exhibited by nanostructured bulk films. Our approach involved the combination of molecular dynamics (MD) simulations and experimental evidence. Under controlled experimental conditions, the rod-shaped particles can self-organize into chiral nematic micron size films by evaporating aqueous suspensions. We obtained different particle orientations by disrupting the self-organization process under different shear forces. The resultant CNC organization present in all nanostructured films was estimated by using a second order statistical orientational distribution based on two-dimensional XRD signals. The optical response of CNC films varied from iridescent to transparent depending on the particle orientation. Such unique response was further evaluated by polarized optical microscopy. We tackled the conventionally challenging determination of thermal expansion in soft films by developing a new contact-free method that combines contrast-enhanced microscopy and digital image correlation to isolate thermal expansion from other thermally activated phenomena. The proposed method can be readily extended to other soft materials in order to accurately measure thermal strains in

a non-destructive way. Depending on particle orientation, the thermal expansion response bulk CNC can range from that typically exhibited by ceramics to that of polymeric materials. Thus, we attempt to provide further insights into the unique properties of single cellulose crystals and reveal the intricate structure-property connection after their controlled organization into stable films towards a future efficient manufacture and optimal materials design.

20 Hydrogen bonded supra-molecular surfactant systems

Erica Patricia Schulz,[1] Ángel Piñeiro Guillén,[2] Marisa Alejandra Frechero,[1] Olga Pieroni,[1] José Luis Rodriguez,[1] Rosana Minardi,[1] Pablo Carlos Schulz,[1] José Manuel Miñones Conde,[2] José Miñones Trillo[2]
[1]Universidad Nacional del Sur, CONICET, Argentina.
[2]University of Santiago de Compostela, Spain.

erica.schulz@uns.edu.ar

The self-assembly of supramolecular surfactant systems may be studied with a multi-scale insight: from the macroscopic results of experiments to the nanoscopic perspective of molecular dynamics simulations. This full scope of techniques, with complementary experimental and theoretical results, allowed us to study systems of alkane phosphonic acids, which are diprotic weak acids with some interesting properties as well as many technological and industrial applications. Their charge can be tuned as $0(R-PO_3H_2)$, $-1(R-PO_3H^-)$ or $-2(R-PO_3^=)$ by changing the medium pH. Micelles' Stern layer is connected by hydrogen bonds from charge near 0 up to an average charge of -1. The possibility to form intermolecular hydrogen bonds among the surfactant molecules strongly affects the formation of supramolecular nano-aggregates generating atypical structures such as disk-like molecules and inter-molecular regular order in monolayers. We have studied the formation of n-decane phosphonic acid disk-like micelles in aqueous solution without the addition of a second ionic surfactant [1]. Disk-like micelles are seldomly reported in literature and have been proposed as precursors to the formation of lamellar liquid crystals. Besides, we have fully studied monolayers of n-eicosanephosphonic acid on water subphases with different pH values using a Langmuir balance and Brewster angle microscope and molecular dynamic simulations. We have interesting findings, such as the presence of small islands floating on an almost free water surface in monolayers with $Z = 0$ due to the hydrogen bonded phosphonic groups in spiralled structures. To the best of our knowledge, these phenomenons have never been studied systematically through complementary experimental and computational techniques.

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21 A Monte Carlo method applied to the resuspension of small particles

Karina Valenzuela,[1] **Jesica Gisele Benito,**[1] **Rodolfo Omar Uñac,**[1] **Irene Ippolito,**[2] **Ana María Vidales**[1]
[1]Departamento de Física, Instituto de Física Aplicada (UNSL-CONICET-LIA), Universidad Nacional de San Luis, Argentina.
[2]Grupo de Medios Porosos, LIA y CONICET, Facultad de Ingeniería, Universidad de Buenos Aires, Argentina.

kvalenzuela@dfuls.cl

The present work describes the resuspension of small particles originally deposited onto a flat surface. A simulation using a Monte Carlo technique is used to set a simple model that will take into account the force balance between the adhesion of the particles to the surface and the strength of the burst of a turbulent flow acting on them.

The aim of the study is to compare the results of the present model with the already reported ones from other authors. Although the problem have been largely studied, it is still not well understood the role that the different adhesion force parameters play in the resuspension rate of particles.

We first present a check of our model with the most simple case of monozised particles onto a flat surface without heterogeneities. Secondly, we introduce inhomogeneities in the adhesion forces in order to measure the influence of the force distribution on the resuspension flux.

Our stocastic model seems to qualitatively described quite well the resuspension rates reported by other authors.

22 Avalanches in Granular Materials

Aline Hubard[1]
[1]City College of New York and Graduate Center of the City University of New York, USA.

aline.hubard@gmail.com

We study avalanches by performing experiments in a quasi-two dimensional rotatingdrum. Two glass plates separated by about one particle diameter conne mono-disperse(same size) stainless-steel spheres to a cylindrical region. We rotate the system aboutthe cylinder axis, which is perpendicular to gravity. Using high speed video up to 1000fps, we measure the particle positions during very slow rotation in which the ow isdominated by discrete avalanche events. For this purpose we develop a special particletracking code to ensure we capture all particle movement in every avalanche. We mea-sure the avalanche size, duration, and time evolution (shape) for the avalanches andcompare with mean eld theory that predicts avalanche shape and a power-law distri-butions of size and duration. This study will give us a better understanding of not justavalanches, but also other complex systems that follows power laws and fall under thesame 'universality' class.

23 A community detection method for force chain network identification in 3D granular systems

Yuming Huang,[1] **Karen Daniels**[1]
[1]Department of Physics, North Carolina State University, USA.

yhuang26@ncsu.edu

Force chains are the chain-like structures in a compressed particle system that provide structural support and transmit acoustic waves. However, there is no clear consensus on the quantitative definition of force chains. We test recently-developed methods which represent interparticle forces as mathematical networks, and use community-detection methods to extract the force chain network. We choose a resolution which maximizes the degree to which the communities have a branched structure. This technique allows us to partition the force chain network into communities, and measure their size, strength, and gap-factor (degree of branching). We extend these methods from the 2D systems where they were developed, and apply them to 3D LAMMPS simulations. We measure properties of the force chain network as a function of pressure, and of friction coefficient.

24 Avalanches in a rotating granular system: Measurement of the coefficient of friction

Diego Emilio Rodriguez,[1] **María Alejandra Aguirre,**[1] **Irene Ippolito,**[1] **Jean-Christophe Géminard**[2]
[1]Grupo de Medios Porosos, Facultad de Ingenieria, Universidad de Buenos Aires, Argentina.
[2]Unversitè de Lyon, Laboratoire de Physique, Ecole Normale Supérieure de Lyon, France.

rodrigdiego@gmail.com

Usually, the coefficient of friction in a granular system has been estimated in two ways:

- by finding the critical angle at which a granular system needs to be inclined in order to trigger an avalanche.

- by determining the minimal force needed to slide a block over a granular packing. Both methods have the disadvantage of been destructive, i.e. they only allow one measurement on each essay.

Therefore, we propose the following procedure: a thin layer of granular material is deposited over the horizontal surface of a disk which will be rotated. The rotation speed (ω) is smoothly increased until at a certain critical rotation speed (ωc) and a critical distance (rc) from the axe of rotation, the centripetal force ($rc\omega c2$) compares to the friction force and an avalanche is produced. A further increase of ω produces other critical values at which avalanches are triggered. The experiment is recorded with a digital camera which allows us to determine, for all ωc, the critical distances. Hence, this method allows us to obtain at each critical point the friction force value, giving in one experiment a collection of independent measurements of the coefficient of friction.

In this work, we present preliminary results obtained with this new technique proposed to measure the friction force of a granular system.

25 A Novel Decomposition of the Structure of Jammed Packings

Mark R Kanner,[1] **Mark Shattuck,**[1] **Corey O'Hern**[2]
[1]City College of New York, Benjamin Levich Institute, USA.
[2]Yale University, USA.

mark.kanner@yale.edu

We use simulations of 2D bidisperse disks to determine the properties of jammed packings and investigate the statistical mechanics of these systems. We have created a novel method for classifying structural subunits of a packing, using the structures to calculate relevant physical quantities. The classification scheme is based on a 20 type decomposition of the Delaunay triangles extracted from the centers of the particles in the packing. The decomposition parts are categorized by particle type and contact number. We find that the distribution of each type has a universal form, independent of total number of particles N in the packing for N=8-2500, and that the parameters describing this form saturate as N is increased beyond N=102. Subunit occurrence is gamma distributed by type and a statistical analysis of these distributions is applied to determine parameters that allow for an analytical form of the Delaunay triangle probabilities. The microscopic subunits are shown to yield macroscopic quantities such as mean particle co-ordination numbers, stress and pressure.

26 Interaction of multiple air invasion in an immersed granular layer: Description and dynamics

Gabriel Ramos,[1] **Germán Varas,**[1] **Jean-Christophe Géminard,**[2] **Valérie Vidal**[2]
[1]Pontificia Universidad Católica de Valparaíso, Chile.
[2]Unversitè de Lyon, Laboratoire de Physique, Ecole Normale Supérieure de Lyon, France.

gabriel.p.ramos.p@gmail.com

When a pressurized fluid passes through a deformable porous media, it changes its bulk generating structures such as those observed in geophysical process like the piercement structures (e.g. pockmarks, hydrothermal vents, mud volcanoes, etc). In order to understand this behavior, we have studied a special configuration in a 2D experimental setup which allows us to observe the dynamics of three phases (air, water and grains). The setup consists in a Hele-Shaw cell filled with grains and water where we inject air at constant flow rate at the bottom of the cell. We focus on the dynamics of the air invading the medium at short and long time scale, when injecting a continuous air flow. At long time, the typical size of the region explored by the air can be accounted for by a diffusion-like process [1]. Here, we present new results observed at the bulk and at the free surface of grains, that appear when the injection is performed with several injection points simultaneously emitting.

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27 Modeling and optimization of a microparticles separation-classification process

Cecilia Inés Paulo,[1] Eugenia Borsa,[1] María Soledad Diaz,[2] Mirta Raquel Barbosa[2]
[1]Laboratorio de Micropartículas y Aeroclasificadores de la Universidad Nacional del Centro de la Provincia de Buenos Aires (UNCPBA).
[2]Planta Piloto de Ingeniería Química PLAPIQUI-CONICET-UNS.

cecipaulo@gmail.com

In this work a nonlinear programming problem (NLP) was developed to optimize the microparticles separation and classification process, for a diameters range of 0.1-1,000 m. The units included in the process are a powder feeder, a heat exchanger, a high efficiency cyclone, a bag filter, mixers and a fan that drives the movement of air and particulates from the feeder to the filter. The cases studied involve two particulate materials: dolomite and limestone, each one with three different particles size distributions; fifteen initials powder concentrations feeding the process varying between 2 and 20,000 g/m3; and three different types of design models for high efficiency cyclones: Stairmand, Swift and Echeverri Londoño. Different models of cyclone separation efficiency were analyzed and compared. Equations for the filter efficiency, fan and powder feeder operations were also added to the NLP model. Mass and energy balances were formulated and solve for a 2.4 m3/s air flow process. The mass fractions expressions corresponding to the outlet streams of cyclone and filter were derived taking into account the equipments efficiencies. These nonlinear expressions and the design constraints of each model design were incorporated into the optimization problem.

The NLP formulated for each case, including 174 continuous variables and 110 equations, was implemented in GAMS and solved with CONOPT. The numerical results show for all the cases analyzed that the separation efficiency increases with the initial microparticles concentration feeding the process. The cyclone Swift proved the optimal cyclone efficiency value 93.3%, for the maximum particle concentration studied, reaching an overall process efficiency of 96.7%. The proposed nonlinear model has provided useful information for better understanding of the overall microparticles separation-classification process. Moreover, it is a valuable tool for the optimal design of these processes, due to its versatility to work at different operating conditions and different materials. The use of computational tools and constraint-based optimization has proven to be an effective method to adequately predict the behavior of the system.

28 The Role of Open Contacts on the Response of a Granular Slab to a Localized Force

Juan Carlos Petit,[1] **Iván Sánchez,**[1,2] **Ernesto Medina**[1,3]
[1]Instituto Venezolano de Investigaciones Cientificas (IVIC), Venezuela.
[2]University of Simon Bolivar, Venezuela.
[3]Central University of Venezuela.

jcpetit71@gmail.com

The application of a localized force on the top surface of a granular system is an important test to study the transmission of information through it, measuring the perturbation at the bottom of the system is a good way to obtain the effective response of the packing. At a continuous isotropic solid the response remains always single-peaked at the bottom, while an anisotropic one exhibits two-peaked response, both responses are captured by isotropic and anisotropic elasticity theory. For an ordered granular pack its response is another story, small forces make the response single-peaked while for larger forces there appears a dip (double-peaked) just below the point of application. One explanation considers that the main mechanism to produce such a dip is due to the sliding and rearrangement of particles when high external forces are applied. This last statement seems to suggest that the open contacts are those responsible for the double-peaked response, but, it is not clear how they contribute. We employ DEM simulations to construct one layer of spheres (or disks in 2D), ordered in a triangular lattice, with a lattice constant 2R, where R is the sphere radius. We applied an external vertical force at the center of the top of the granular layer and mesure the stress on the particles at the bottom to study the role of open contacts in the response of the system, focusing in the transition from single-peaked to double-peaked response. We find that the curve of the number of open contacts as afunction of the external force increases in a non-linear fashion, and we identify a transition point separating single-peaked from double-peaked response. This transition point varies for different values of particle friction, particle rigidity and system size. An important result is that, the double-peaked response begins to appear, before the "open contact network" reaches the bottom of the system, this always occurs after it passes the middle of the system depth.

29 Simulational study of hydrodynamic modes in two dimensional models of quasi 2D horizontal granular systems

Evelyn Bernarda Riveros,[1] **Dino Enzo Risso,**[1] **Rodrigo Soto,**[1] **Ricardo Brito**[1]
[1]Universidad del Bio Bio, Concepcion, Chile.

eriveros@ubiobio.cl

We make a simulational study of the hydrodynamics modes in a confined granular fluid in a 2D system. The system is fluidized by a local energy input in a way akin to reference [1] in which the energy is injected to the system by kicks in each collision. In our model the mechanism of energy injection is a restitution coeficient which is grater or smaller than one depending on the relative velocity of grains involved in the collision.

Results for the collisional rate, temperature and pressure in the stationary state are obtained and compared with the theoretical predictions when using Enskog aproximation. From these results it is posible to define a region in the density and inelasticity phase space in which the Enskog approximation applies. Next, in this phase space, we study the space-time density fluctuations to obtain the dynamic structure factor and from this the thermodynamic properties and transport coeficients for the model. The dependence of these properties in wave number space allow us to characterize the crossover between two regimes in which the system behaves inelastically and quasielastically.

Our results are in good agreement with the model of reference [2]. A second model is also studied. In this 2D model there is an extra internal freedom degree that stores energy according to the flight time between collisions. For a given set of parameters the model show large density fluctuations and for some critical values of the parameters a phase separation between a solid and a fluid region develops.

The dependence of the transition on the control parameters of the model and the density of the granular system is characterized. Some order parameters are studied to characterize the transition.

[1] Phys. Rev. 59 E 87, 022209 (2013)
[2] Phys. Rev. E 87, 022209 (2013)

30 Drift of a subharmonic pattern in a pinned vertically vibrated quasi 2D shallow granular system

Ismael Patricio Cáceres[1]
[1]Universidad del Bio Bio, Concepcion, Chile.

icaceres@ubiobio.cl

When a 2D shallow vertical array of granular matter is vertically vibrated with some amplitud and frequency of oscillation, inside a range of the acceleration of the base it is possible to observe a subharmonic wave pattern [1]. In reference [2] the authorsfind that for a vertically air fluidized shallow bed of granular matter the same kind of behaviour can be obtained and they observe that if the base of the bed is tiled the pattern drift against gravity above a critical angle. A general model is proposed to describe this behavior.

In our work we simulate a vertical 2D shallow array of granular matter in the hard sphere inelastic model by event driven molecular dynamics. There is disipation between the grains and with the walls characterized by restitution coeficients. In the regime in which a subharmonic wave pattern is observed if we simulate a time long enough we could see from time to time some jumps in the wave-length, in that seems that a half wave-length enters into the system through a border and another half wave-lenght left out it by the other border. This jumps don't have a preferent direction. However, if we tiled the base more than a critical angle the jumps do show a preferent direction of movement with a mean average velocity like the behavior described in the air uidized experiment. Also we could see lateral secondary oscilations of the oscillation's peaks, that seems to be the result of an over-excitation of the system.

31 Dipolar colloidal systems at very high dilution

Mariano Exequiel Brito,[1] Marcelo Alejandro Carignano,[2] Verónica Iris Marconi[1]
[1]FaMAF- Universidad Nacional de Córdoba. Argentina.
[2]Qatar Environment and Energy Research Institute, Doha, Qatar.

meb0109@famaf.unc.edu.ar

The dipolar hard sphere model, DHS, has resulted to be a paradigm for the self-assembly of anisotropic particles, and it has gave place to greatest controversies between many theorical and simulations results [1]. In recent years, the study of DHS model has won relevance again due to the new computational techniques, which allow to research new regions in the phase diagram [2, 3, 4]. Dipolar colloidal particles give empirical results for DHS model. This particles are one of the simpler materials presenting anisotropic interactions, and represent a building block for the design of new soft materials [5]. We investigate a more realistic model of soft particles, triads with an embedded dipole of finite length [2], which in the point dipole limit compare to the DHS model. Using stochastic simulations we study the gelation process in a very high dilute system of dipolar colloidal particles with implicit solvent. This system self assembles in three different regimes at very low packing fraction and decreasing temperature: fluid, string-fluid and string-gel. At very low temperature we found a stable regime with a rich variety of structures. We perform simulations using originally a continuous model for the explicit particle-particle interactions. We present a phase diagram, density vs temperature, determined from thermodynamics and structural analysis. We characterize as well in detail the string-gel structure studying the topological defects as a function of the packing fraction, and the porosity versus both, temperature and dielectric constant [4].
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32 Granular flow in a vertically vibrated L-shaped cell

Ruddy Eglee Urbina Sulbarán,[1] **Oliver Pozo Michelangelli,**[2] **José Ramón Darias,**[1] **Iván Sánchez**[1]
[1]Statistical Physics of Disordered Systems Laboratory. Physics Center-Venezuelan Institute for Scientific Research.
[2]Institute for Polymers and Composites/I3N, University of Minho, Portugal.
[3]Department of Physics. Universidad Simón Bolivar, Venezuela.

reus75@gmail.com

We performed an experimental study of granular flow through one L-shaped cell, resembling a corner in a pipe, in order to determine the properties that enhance the flowability of the granular material in such geometries. One simplification in the problem is that the cell's thickness is much smaller than its width and height, so that the system is approximately bidimensional. The employed container was made of transparent acrylic so that all the grains can be seen and the flow can be tracked. At the beginning of each experiment the grains are at rest within the cell and the flow is induced due to the presence of an external forcing (in addition to gravity). The perturbation forces the column of grains to dilate, so the beads change their positions within the cell. After those changes, avalanches that make some grains flow out of the container are generated. The cell was fixed on the membrane of a loudspeaker, feeded with a function generator and an amplifier, where the disturbance occurs as vertical pulses (tapping). The temporal spacing between pulses is about 5 s, usually after this time interval grains are at rest again, having completed its flight time and ceased any avalanches. The decrease in the height of the column depending on the number of taps is analyzed for different values of the maximun dimensionless acceleration Γ. We observed that with $\Gamma > 2$, after each pulse avalanches are produced and the cell is emptied quickly while with $\Gamma < 2$ meta-stable states appear. Meta-stable states are states in which the system shows no movement after several taps, but suddenly after an arbitrary tap occurs a small movement that triggers an avalanche of grains towards the exit of the cell. At high acceleration the behavior is well represented by the average of multiple experiments, but at low accelerations a detailed study of the structural configuration of the granular material inside the container is required.

33 Influence of Kroll's model variables on the flight time of a granular bed

Bruno Valdemar Guerrero,[1] **Ilich Vladimir Idler,**[2] **Iván Sánchez**[1]
[1]Venezuelan Institute for Scientific Research Center for Physics Statistical Mechanics of Disordered Systems Laboratory.
[2]Simón Bolivar University, Venezuela.

guerrerobruce@gmail.com

The behavior exhibited by active granular media is highly dependent of the energy injection mechanism, therefore it is vital to determine the effect of external driving on a granular sample. An initial simplification that retains the essential features to describe

the effect of forcing on bulk properties of dense granular media under vertical oscillations, is to consider the granular medium as a point mass bouncing inelastically on a vertically vibrated plate (Inelastic Bouncing Ball Model). A next step for including the effect of an interstitial medium is to assume that the granular medium behaves as a porous piston, as is proposed in the Krolls model. Krolls model studies the dynamics of a rigid piston (with constant density and porosity), which is in a container subjected to vertical vibrations. In this model, the porous piston is in the presence of gravity and an interstitial incompressible medium that permeates through the piston, according to Darcys law. In Krolls model, as in the inelastic bouncing ball model, the piston takes off when the acceleration provided by the plate exceeds the acceleration of gravity, and then begins its flight until it hits the plate in a cyclic way. By including the interstitial medium, the forces acting on the piston when it is separated from the plate are generated by gravity and the pressure difference across the piston (on the direction of vibration). Previous studies have studied the dependence of the flight time of the piston as a function of the dimensionless maximum acceleration γ. In this work, we have numerically examined the flight time of the granular bed as a function of the variables involved in the model of Kroll, and we generated the corresponding phase diagrams. With this, we study how these variables affect the period doubling bifurcation. In this way we extend the analysis by introducing not only variables related to the forcing (γ), but also variables related to the disipative caracteristics of the system (bed density, bed permeability and intersticial fluid viscosity).

34 Pattern formation in confined granular systems

Nathália Mascarenhas Paixão Mello,[1] **Allbens Picardi Faria Atman**[1]
[1]Centro Federal de Educao Tecnológica de Minas Gerais (CEFET-MG), Belo Horizonte, Minas Gerais, Brazil.

nathmellomp@gmail.com

There are many opened questions involving the displacement of granular materials inconfined systems, in particular, the flow through a Hele-Shaw cell in the quasistatic regime. It was shown that, in some cases, there is a spontaneous formation of fingers during the injection of grains into a confined system. In this work, our objective is to study the pattern formation in this kind of flow, using Molecular Dynamic simulations. Some parameters were chosen to determine their role in the development of fingers: the friction coefficient between the particles, the friction between the grains and the cell plates, the grain size distribution (monodisperse, polidisperse or bidisperse systems), and the stiffness constant ratio between injected and substrate grains. The force distribution is analyzed, as well the stress components. We have observed that as much as smaller the friction coefficient between the particles is, the contact force magnitudes are smaller. The monodisperse systems have a higher tendency for fingers formation, with a hexagonal symmetry. We also evince a higher stress field close to the fingers tips, in analogyto the Saffman-Taylor fingering phenomena.

35 Monte Carlo study on a single grain of the distribution of contact forces on a mono-dispersed granular material

Manuel Antonio Cardenas,[1] William Oquendo,[1] José Daniel Muñoz[1]
[1]Simulation of Physical Systems Group, Department of Physics, Universidad Nacional de Colombia.

macardenasb@unal.edu.co

The force network ensemble [J.H. Snoeijer, T.J.H. Vlugt, M. van Hecke and W. van Saarloos, PRL 92, 054302 (2004)] is one of the most used theories to apply statistical mechanics to granular media. Fixed a contact network among the grains, the ensemble computes an entropy as the space of all combinations of forces in such contacts that keep the system in equilibrium, in agreement with a given external stress, and denes a temperature-like variable, the angoricity. It has been reported that the correlation length between these forces is of the order of a grain [P. Tighe and T.J.H. Vlugt, J. Stat. Mech. P04002 (2011)], which suggests that it should be possible to describe most of the strength characteristics of the assembly by performing Monte Carlo simulations on a single grain. By performing Monte Carlo simulations on a single grain with several coordinative numbers z (which is assumed to be part of a two-dimensional mono-disperse sets of frictionless circular grains), we obtain that the pressure, dened as the sum of the magnitudes of the forces on the grain, distributes as a gamma function with k degrees of freedom, and that the average value of such pressure grows linearly with angoricity, resembling an equipartition relation. Furthermore, after reaching a maximum value at an angoricity of around one-sixth, k tends to k = z -2 for small angoricities, i. e. it equals the number of degrees of freedom in the forces on the grain. This result suggests that the z-2 degrees of freedom in the forces behave at low angoricities as independent variables.

36 Tunably Soft Colloids: Synthesis and Characterization by Holographic Microscopy

Chen Wang,[1] David G Grier,[1] Hagay Shpaisman[2]
[1]Department of Physics and Center for Soft Matter Research, New York University, New York, USA.
[2]Department of Chemistry, Bar-Ilan University, Ramat Gan 52900, Israel.

wangchenkeamon@gmail.com

Polydimethylsiloxane(PDMS) is an industrially important, widely used silicon-based polymer. Previous work showed that the addition of trivalent cross-linker transforms PDMS emulsion droplets into complied spheres, whose elasticity scales with the concentration of cross-linker. We use holographic video microscopy to characterize the synthesized PDMS with varying degree of deformability. Holographic video microscopy characterization yields measurements of cross-linker concentration through the influence on the particles' sizes and refractive indices. In the performed experiments, we are able to detect the transition between liquid droplets and complied particles, and monitor the

polymerization progress. The particles' compliance can be gauged in their interactions with rigid surfaces that we measure with holographic optical trapping and holographic particle characterization.

37 Dynamic transition in granular materials driven by conveyor belts

Manuel José Cordero,[1] Luis A. Pugnaloni[1]
[1]Dpto. Ingeniería Mecánica, Facultad Regional La Plata, Universidad Tecnológica Nacional, La Plata, Argentina.

jmcorderod@gmail.com

We consider the flow of granular disks on a conveyor belt as they pass through a constriction. By using discrete element method simulations, we show that there exists a critical velocity Vc of the belt at which the flow-rate changes its behavior. For velocities below Vc, the flow-rate is proportional to the velocity and scales with the width of the constriction. However, for velocities above Vc, the flow-rate is independent of the belt velocity and scales with the power 3/2 of the width of the constriction, as expected from the two-dimensional version of the Beverloo's scaling. A simple theoretical analysis allows an accurate prediction of the transition and the two distinct behaviors. We discuss related experimental findings by others and suggest possible origins for discrepancies with our results.

38 Critical State on Unsaturated Granular Materials Concept and Modelling

Diego Manzanal,[1] Osvaldo Ledesma,[2]
[1]Instituto de Tecnología y Ciencias de la Ingeniería INTECIN (UBA-CONICET), y Facultad de Ingeniería, Universidad Nacional de la Patagonia (UNPSJB), Argentina.
[2]Laboratorio de Mecánica de Suelos, Facultad de Ingeniería, Universidad de Buenos Aires (FIUBA), Argentina.

diego.manzanal@gmail.com

The paper discuss the influence of the constitutive stress on the Critical State of unsaturated granular materials and their relation to State Parameter. Several approaches have been used in order to define a constitutive stress for unsaturated soils. On the effective stress framework for unsaturated materials, the paper analyze the influence of the Bishop parameter on the definition of Critical State and extent he concept of state parameter as a function suction and degree of saturation. A theoretical framework is proposed and compared to available experimental data. This discussion provides new insights on the development of fully coupled hydro-mechanical models for unsaturated granular matter.

Index