Yielding phenomena in disordered systems

the southernmost STATPHYS satellite

July 2 — 5, 2019

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THE WORKSHOP

Flow, creep and fracture of amorphous materials under deformation stand nowadays as very active topics in the statistical physics community.

Several practical problems borrowed from material science and engineering, as what would make a material ductile or brittle, what will determine its yield strain or rheological response, had lead to the raise of fundamental questions in the **statistical mechanics of driven glasses**.

Is mechanical yielding a dynamical phase transition? How it compares with the depinning of elastic interfaces? To which extent should we expect universality at yielding? When is it better described as first order transition? What about hysteresis and memory effects? Are there fundamental relations between transport properties and geometry in driven amorphous solids?

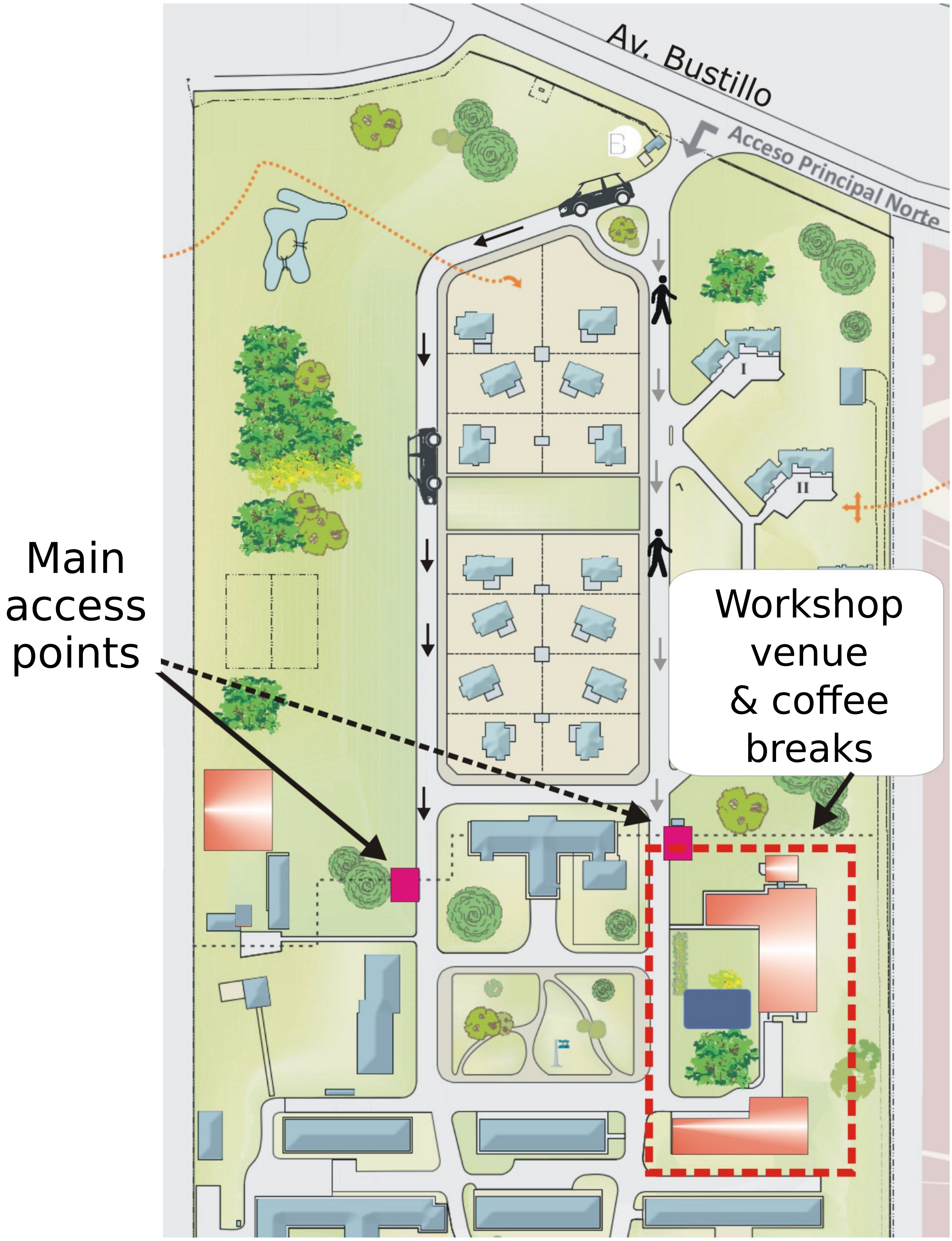
Years of understanding gained on **elastic systems, random spin models, deep jammed structural glasses and granular media**, come together to attack such questions and many others, using the most varied StatMech tools, from Renormalization Group approaches to enhanced machine learning techniques, passing through a plethora of coarse grained and mean-field models.

The aim of this STATPHYS27 satellite workshop is to promote exchanges among scientists sustaining these different approaches to yielding and related phenomena, setting up an heterogeneous and relaxed environment for lengthy discussion. It follows up on the line of previous workshops and meetings organized on the subject, in particular:

- Driven Disordered Systems (Grenoble, 2014)
- Dynamical Phase Transitions in Driven Systems (Grenoble 2016)
- Yielding of Amorphous Solids (Paris, 2017)
- Yielding versus depinning in disordered systems (Paris, 2018)

The workshop is organized in the framework of a French-Argentinean collaboration project ECOS_Sud-MINCyT. It takes place during 3.5 days, with a low density of speakers to promote interchange and discussion from all participants.

The organizers welcome all participants to Bariloche and its magnificent natural environment, hopping this venue provide the proper atmosphere to foster discussions and promote collaborations.


Av. Bustillo
Acceso Principal Norte
Main access points
Workshop venue & coffee breaks

Schedule

Long talks (invited): 40’ talk + 10’ questions&comments
Short talks (contributed): 20’ talk + 5’ questions&comments

block/day	Tuesday	Wednesday	Thursday	Friday
9:15-10:30	**Agoritsas** Caballero	**During** Delaney	**Altieri** Fasano	**Vandembroucq** Alava
10:30-11:00	Coffee/Mate	Coffee/Mate	Coffee/Mate	Coffee/Mate
11:00-12:40	**Foini** **Curiale**	**Martens** **Maloney**	**Ponson** **Ozawa**	**Wyart** **Santucci**
12:40-14:00	Lunch	Lunch	Lunch	Lunch
14:00-14:25	Guruciaga	Free afternoon	Pica Ciamarra	
14:25-... (15:30)	Posters+Discussions		Posters+Discussions	Colloquium Instituto Balseiro **Ciliberto**
...-16:15				
16:15-17:30	**Olson Reichhardt** Gago		**Araujo** Boettcher	
17:30-17:45	Coffee/Mate		Coffee/Mate	
17:45-19:00	Crassous Jin Ciliberto		Regev Reichhardt Parley	
	Cocktail+Posters			
20-			Social Dinner	

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INVITED SPEAKERS

Yielding vs depinning transitions: insights from the infinite-dimensional limit

Elisabeth Agoritsas*[1]

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Abstract

Driven disordered systems are known to exhibit dynamical transitions from an arrested phase to a flowing steady state, once a given threshold in the external driving is reached. This generic scenario naturally suggests to draw analogies between systems otherwise very dissimilar. For instance, two prototypical examples are on the one hand the depinning of an elastic line in a quenched random potential, and the other hand the yielding of an amorphous solid under shear. Assessing both the similarities and the discrepancies between these two phenomena is particularly valuable, because it would allow a possible transfer of known results and analytical tools between them. In that respect, their infinite-dimensional limit is of particular interest, since their effective description is then exactly mean field.

We have recently derived the exact dynamical mean-field theory for dense assemblies of pairwise interacting particles, in infinite dimension and in the thermodynamic limit [1,2]. Such dense assemblies of particles are prototypes of amorphous systems. Within the very general out-of-equilibrium setting we consider, we can thus model a broad range of situations - equilibrium, quasi-statics, transients or steady-states -such as liquid and glass rheology or active self-propelled particles, and in particular the yielding transition itself. Here I will first sketch the derivation of this effective dynamics, highlighting in particular the few key ingredients of the high-dimensional physics. Then I will explain how we can recover dynamically the 'state-following' equations describing the response of a glass under quasistatic perturbations (specifically thermal quench, random forces and a finite shear strain). Finally I will discuss the connection between our infinite-dimensional effective description and different features of the depinning transition.

E. Agoritsas, T. Maimbourg & F. Zamponi, J. Phys. A 52, 144002 (2019).

E. Agoritsas, T. Maimbourg & F. Zamponi, arXiv:1903.12572 [cond-mat.dis-nn].

*Speaker

sciencesconf.org:yielding2019:281062

Earthquake-like dynamics in the creep regime of a magnetic domain wall

Laura Foini*[1], Ezequiel Ferrero[2], Alejandro Kolton[2], Thierry Giamarchi[3], Alberto Rosso[4], Gianfranco Durin[5], Arianna Casiraghi[5], Liza Herrera-Diez[6], and Dafine Ravelosona[6]

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[3]Université de Genève – Switzerland
[4]LPTMS Orsay – CNRS : UMR8626 – France
[5]INRiM – Italy
[6]Centre de Nanosciences et de Nanotechnologies – Université Paris-Sud - Paris 11 : UMR9001, Centre National de la Recherche Scientifique – France

Abstract

In presence of impurities, ferromagnetic and ferroelectric domain walls slide only above a finite external field. Close to this depinning threshold, they proceed by large and abrupt jumps, called avalanches, while, at much smaller field, these interfaces creep by thermal activation.

In this talk I will present our results for the creep dynamics at vey low forces, obtained by a novel numerical technique that captures this ultra-slow regime over huge time scales. We point out the existence of activated events that involve collective reorganizations similar to avalanches, but, at variance with them, display correlated spatio-temporal patterns that resemble the complex sequence of aftershocks observed after a large earthquake. Remarkably, we show that events assembly in independent clusters that display at large scales the same statistics as critical depinning avalanches.

I will finally mention some experimental results in ferromagnetic films where this dynamics has been observed.

*Speaker

sciencesconf.org:yielding2019:280836

Intermittent collective dynamics of domain walls in the creep regime

Matias Grassi[1], Lucas Albornoz[1,2], Alejandro Kolton[1,3], Vincent Jeudy[4], Alexandra Mougin[4], Sebastian Bustingorry[2], and Javier Curiale*[1,2]

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[2]Instituto de Nanociencia y Nanotecnología, CNEA, CONICET – Argentina
[3]CONICET - Centro Atómico Bariloche – Argentina
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Abstract

Nowadays magnetization reversal and domain wall (DW) dynamics are key topics in the electronic and spintronic field. The control of domain wall short and long-term stability and displacement is critical for potential applications such as those related with the magnetic storage and emerging DW-based spintronic devices. In addition, DWs in ferromagnetic metallic or semiconducting materials are part of a large variety of systems, such as vortex glass in type II superconductor, earthquakes, crack lines, contact lines in wetting..., involving the displacement of an elastic object in a weakly disordered medium. In those systems, the motion results from a competition between driving force, elasticity, collective pinning and thermal noise and proceeds by a succession of avalanches. Even if dramatically different scales and microscopic physical interactions are at the basis of the motion, those systems present common universal behaviors, which are described in a general statistical physics framework.

The nature of the motion depends on the strength of the driving force f. In ferromagnetic systems, the drive can be an external magnetic field or a spin polarized current and the elastic object is a magnetic DW. At finite temperature, there are three main regimes of motion of the elastic object. Below the depinning threshold (f= fd, depinning regime), the velocity presents a power law variation with the drive which is rounded by thermal fluctuations close to fd. At large forces (f> > fd, flow regime), the motion is controlled by dissipation and the velocity varies linearly with the drive. [Jeudy et al. Phys. Rev. B 98, 054406 (2018)]

In this talk, I will show results on the ultraslow DW motion, within the creep regime, in thin ferromagnetic films of the archetypical Pt/Co/Pt, driven by a weak magnetic field. Using time-resolved magneto-optical Kerr effect microscopy, we access to the statistics of the intermittent thermally activated domain-wall jumps between deep metastable states. Our observations are consistent with the existence of creep avalanches: roughly independent clusters with broad size and ignition waiting-time distributions, each one composed by a large number of spatiotemporally correlated thermally activated elementary events. This picture, that drastically changes the naive view of creep motion as independent thermally nucleated displacements, is relevant to different magnetic films and it is likely to emerge in the creep regime of other disordered elastic systems. Moreover, we evidence that the large-scale geometry of domain walls is better described by depinning rather than equilibrium universal exponents. [Grassi et al. Phys. Rev. B 98, 224201 (2018)]

*Speaker

sciencesconf.org:yielding2019:280302

Jamming and Clogging of Passive and Active Particles in Disordered Media

Cynthia Olson Reichhardt

Los Alamos National Laboratory, US

Abstract

There has been tremendous growth in studying nonequilibrium systems of particle assemblies which can exhibit jamming effects in the absence of quenched disorder. Here we examine the dynamics of active and passive particles interacting with random or periodic substrates and obstacle arrays, and show that it is possible to make a clear distinction between jammed systems and clogged systems. Non-active particles flowing through random obstacle arrays reach a clogged state when the particle density is still well below that at which an obstacle free system would jam. The clogged states are spatially heterogeneous, fragile, and have a pronounced memory effect, whereas jammed states are homogeneous, robust, and have much weaker memory effects. We outline a possible scenario in which jamming is dominated by a diverging length scale associated with a critical density at point J, while clogging is associated with a diverging time scale similar to that found at absorbing phase transitions. We have also investigated clogging and jamming in active matter or self-motile particle systems, which include biological systems such as run-and-tumble bacteria or crawling cells as well as non-biological systems such as self-driven colloids or artificial swimmers. For active particles driven over random disorder we find that for intermediate amounts of self-motility the system does not clog; however, as the self-propulsion of the particles increases, there is a strong reduction of the mobility due to a self-clogging or self-clustering in the system that resembles the "faster is slower.[ef]fect found in certain pedestrian panic models.—

Strain-induced stiffening of complex disordered solids: an anti-yielding scenario

Gustavo During*[1]

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Abstract

Elasticity in some biological gels, such as fibrin or collagen networks, exhibit an enormous stiffening of their elastic moduli upon large deformations. This behavior is essential for the functionality of several organic tissues, giving flexibility at small deformations but rigidifies these tissues under larger stresses. As I will show, the same mechanism responsible for this strain-stiffening behavior is also at the core of the critical behavior of dense suspension rheology. A full microscopic description of this strain-stiffening transition remains unsolved.
In this talk I will introduce and discuss a simple model of strain-stiffening materials, consisting of networks of hinged rigid bars embedded in an elastic matrix. This model allows to probe the strain-stiffening critical point with unprecedented precision and control. Our model reproduces the critical exponents seen in several different systems, and is amenable to a theoretical analysis explaining the observed critical behavior. Moreover, a striking dependence of the critical exponents on the initial conditions is demonstrated in some cases.

*Speaker

sciencesconf.org:yielding2019:280969

Transient and permanent shear localisation in yielding disordered solids

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Abstract

In this talk I will review some of our latest advances on the understanding of formation of shear localisation in yielding amorphous materials, that can occur even under homogeneous driving conditions. These unstable flow regimes can either be of transient [1] but also of permanent nature [2,3]. I will present our microscopic simulation results together with mesoscopic and continuum model descriptions for the development of shear localisation in athermally sheared soft matter systems. Our coarse grained models aim at incorporating the minimal relevant features of the microscopic dynamics to compare to the emerging macroscopic flow patterns observed in the particle based simulations.

Vishwas V. Vasisht, Romain Mari and Kirsten Martens, Transient flow instabilities in driven disordered materials, to be published.

Kirsten Martens, Lydéric Bocquet and Jean-Louis Barrat, Spontaneous formation of permanent shear bands in a mesoscopic model of flowing disordered matter, Soft Matter, 8 (15), 4197 (2012).

Vishwas V. Vasisht, Magali Le Goff, Kirsten Martens and Jean-Louis Barrat, Permanent shear localization in dense disordered materials due to microscopic inertia, arXiv:1812.03048.

*Speaker

Hysteresis, reversibility and diffusion in a meso-scale model for plasticity in amorphous materials under cyclic shear.

Kareem Abdelshafy[1], Botond Tyukodi[1,2], and Craig Maloney*[1]

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[2]Brandeis University – United States

Abstract

We present results on a meso-scale model of amorphous plasticity subject to cyclic shear. We show that, after a transient, depending on the amplitude of cycling, the steady state behavior falls into one of three cases, in order of increasing strain amplitude: i) pure elastic behavior with cessation of all plastic activity, ii) reversible periodic plasticity with the period being an integer number of strain cycles (not necessarily a single cycle), and iii) irreversible plasticity with long-time diffusion. This behavior is consistent with what is seen in experiments on 2D amorphous particle rafts and confocal microscopy of emulsions and in athermal quasi-static particle-based simulations. We further show that, in the large amplitude regime, the steady state single-cycle plastic strain field is localized along line-like structures similar to the ones seen during avalanches during steady plastic shear, but there is little persistence in the localization from one cycle to the next.

*Speaker

sciencesconf.org:yielding2019:262461

One-step and two-step yielding transitions: from hard-sphere glasses to mean-field models of attractive particles

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Abstract

Glassy materials display peculiar features distinct from ordinary solids in very different ways. From a rheological perspective, remarkable progress has been recently achieved in the study of the response of amorphous solids in the presence of a shear deformation. At small strain, the stress response is elastic-like, while at larger strain, it undergoes a highly non-linear trend characterized by mesoscopic intermittent drops (*plasticity regime*). At sufficiently higher strain, the system can eventually yield and start to flow.

In this talk, I shall specifically analyze the stress of a system of attractive particles subject to a quasi-static shear strain by means of a *state following protocol* [1]. I shall consider a square-well potential, which is beneficial to model, for instance, a colloidal suspension in the presence of a non-adsorbing polymer [2]. The peculiarity of attractive colloids is due to their tendency to give rise to two distinct amorphous solid phases: an attractive glass phase, associated with particle bonding, and a repulsive glass, due to the hard-core repulsion [3]. Surprisingly, the presence of two distinct interaction length scales results in a sharp two-step yielding process, which can be associated either with a hysteretic stress response or with a reversible, but non-monotonic, stress-strain curve [4]. We derive a generic phase diagram characterized by two distinct lines: an inverse yielding and a critical point where this inverse spinodal merges with the yielding curve of the attractive glass. Upon increasing the density, the hysteretic phase shrinks into a vanishing size region and eventually disappears via a critical point at a finite strain. This is a very general picture, applicable to a large class of glassy materials, as long as they can be identified by two distinct interaction length scales. Further results can be obtained in a more general scenario of high-dimensional hard spheres, both in a purely compression/decompression protocol and in the presence of a quasi-static shear strain [5]. The resulting phase diagrams, obtained for different preparation protocols and packing fractions, aims to provide a general overview of the jamming and yielding phenomena in amorphous solids.

References:

[1] S. Franz, G. Parisi, *Recipes of Metastable States in Spin Glasses,* J. Phys. I **5**, 1401 (1995) [2] W. Poon, *The physics of a model colloid-polymer mixture,* J. Phys. Condens. Matter **14**, R859 (2002) [3] K. Pham, G. Petekidis *et al.*, *Yielding of colloidal glasses*,

*Speaker

Europhys. Lets. **75**, 624 (2006). [4] A. Altieri, P. Urbani, F. Zamponi, *Microscopic Theory of Two-Step Yielding in Attractive Colloids,* Phys. Rev. Lett. **121**, 185503 (2018). [5] A. Altieri, F. Zamponi, *Mean-field stability map of hard sphere glasses*, to be submitted (2019).

Compressive failure of disordered materials: a model experimental system to explore the differences between yielding and depinning ?

Ashwij Mayya[1], Estelle Berthier[1,2], and Laurent Ponson*[1]

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Abstract

Quasi-brittle failure results from the evolution of a large number of interacting microcracks spreading through the material microstructural disorder. Despite this complexity, quasi-brittle materials under slowly increasing compressive load exhibit a remarkably robust failure behaviour: during a first stage, damage grows and accumulates through bursts of failure events that are both localized in space and time. This intermittent dynamic is characterized by scale free statistics with exponents that vary weakly with the type of materials and the loading conditions. Ultimately, the damage localizes into a macroscopic band that leads to the catastrophic failure of the specimen.

Recently, it was proposed that localization emerges from the coalescence of damaged clusters that interact through the elastic field [1,2]. It was then proposed that the avalanches preceding localization were reminiscent of the depinning of an effective manifold the elastivity of which may change of sign and emerges from the elasto-damageable properties of the loaded material [2,3]. In this study, we test this scenario by investigating the precurors to localization during compressive tests of 2D cellular disordered solids. The dimensionnality of the sytem allows to track the local spatial structure of avalanches at the scale of individual cells, while a balance of energy performed at the specimen scale allows to measure their global properties (size, duration...). The combination of this local and global characterization of precursors reveal the complex spatio-temporal structure of damage avalanches allowing for a critical comparison with the prediction of depinning models. We finally go beyond depinning and discuss why our experimental setup is suitable to explore the statistical properties of elastic disordered systems characterized by interaction kernels that change of sign and that are also met in yielding phenomena.

E. Berthier, V. Demery & L. Ponson, Damage spreading in quasi-brittle heterogeneous materials: I. Localization and failure, J. Mech. Phys. Solids 102, 101-124 (2017).

V. Dansereau, V. Demery, E. Berthier, J. Weiss & L. Ponson, Collective damage growthc-Controls fault orientation in quasibrittle compressive failure, Phys. Rev. Lett. 122, 085501.

E. Berthier & L. Ponson. Damage spreading in quasi-brittle heterogeneous materials: II. Statistics of precursors to failure, J. Mech. Phys. Solids (under review).

*Speaker

Yielding of ultrastable computer glasses

Misaki Ozawa*[1]

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Abstract

When a material is mechanically deformed from an initial quiescent glassy state, two different types of yielding behaviors can be observed. One is "brittle" yielding, where the sample catastrophically breaks, as a smartphone screen breaks sharply. The other one is "ductile" yielding, for which the sample deforms significantly, just like when toothpaste is slowly crushed by a toothbrush. It is known that a given material may show brittle or ductile yielding depending on the sample preparation history. The understanding transformation from brittle to ductile behaviors is a major challenge in many fields, from material science to geophysics. We address this problem, performing extensive computer simulations by changing the stability of the initial glassy state significantly using swap Monte Carlo simulations. We clarify the presence of critical stability separating brittle and ductile yielding behaviors in the athermal-quasi static conditions for three-dimensional amorphous materials. We also investigate two-dimensional systems and finite strain rate conditions [1]. We will discuss how these settings alter the brittle-to-ductile transition scenario. [1] Ozawa, Berthier, Biroli, Rosso, and Tarjus, *PNAS*, **115**, 6656 (2018)

*Speaker

Robust aging dynamics of a network fluid

Nuno Araujo*[1]

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Abstract

Colloidal particles are considered ideal building blocks to produce materials with enhanced physical properties. The state-of-the-art techniques for synthesizing these particles provide control over shape, size, and directionality of the interactions. In spite of these advances, there is still a huge gap between the synthesis of individual components and the management of their spontaneous organization towards the desired structures. The main challenge is the control over the dynamics of self-organization. In their kinetic route towards thermodynamically stable structures, colloidal particles self-organize into intermediate structures that are much larger than the individual particles and become the relevant units for the dynamics. To follow the dynamics and identify kinetically trapped structures, one needs to develop new theoretical and numerical tools. In this seminar, we will discuss the self-organization of functionalized colloidal particles with limited valence [1,2,3,4].

References

N. A. M. Araújo, C. S. Dias, M. M. Telo da Gama, Journal of Physics: Condensed Matter, 29, 014001 (2017)

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T. Geigenfeind, C. S. Dias, M. M. Telo da Gama, D. de las Heras, N. A. M. Araújo, Soft Matter, 14, 9411 (2018)

*Speaker

Coarse-graining amorphous plasticity from atomic to mesoscopic scale

Botond Tyukodi[1], Armand Barbot[2], Anaël Lemaître[3], Matthias Lerbinger[2], Sylvain Patinet[2], and Damien Vandembroucq[*2]

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[2]Physique et mécanique des milieux hétérogenes – Université Paris Diderot - Paris 7, ESPCI ParisTech, Sorbonne Universite, Centre National de la Recherche Scientifique : UMR7636 – France

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Abstract

The mechanical behavior of glasses and amorphous solids is highly dependent on the conditions of their preparation. In particular, plastic deformation can develop homogeneously throughout the material or localize to form a shear band which ultimately will lead to fracture. I will present recent results on the plasticity of 2D model amorphous solids obtained both at the atomic scale and at a coarser mesoscopic scale. I will emphasize in particular the interest of a local characterization of plastic properties and present first attempts of a quantitative coarse-graining between the microscopic and the mesoscopic scale.

[*]Speaker

sciencesconf.org:yielding2019:280965

Mesoscopic description of the nucleation of slip at a frictional interface

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Abstract

Sliding at a quasi-statically loaded frictional interface occurs via macroscopic slip events, which nucleate locally before propagating as rupture fronts very similar to fracture. We introduce a novel microscopic model of a frictional interface that includes asperity-level disorder, elastic interaction between local slip events and inertia. For a perfectly flat and homogeneously loaded interface, we find that slip is nucleated by avalanches of asperity detachments of extension larger than a critical radius governed by a Griffith criterion. We find that after slip, the density of asperities at a local distance to yielding presents a pseudo-gap with a non-universal exponent that depends on the statistics of the disorder. This result makes a link between friction and the plasticity of amorphous materials where a pseudo-gap is also present. For friction, we find that a consequence is that stick-slip is an extremely slowly decaying finite size effect, while the slip nucleation radius diverges as a power law of the system size that depends on the pseudo-gap exponent. We discuss how these predictions can be tested experimentally.

*Speaker

sciencesconf.org:yielding2019:279601

Inertial effects on the multi-scale stick-slip dynamics in adhesive tape peeling

Stephane Santucci

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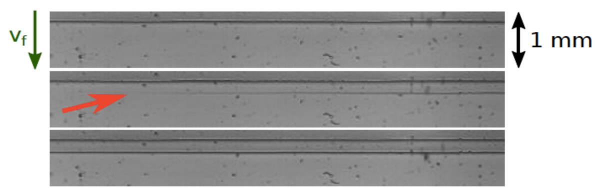
Abstract

Everyone has experienced the unpleasant screechy sound when peeling-off packing tape. This noise is the signature of a dynamical stick-slip instability, with periodic velocity oscillations of thepeel front. Despite a large number of studies, such instability still causes industrial problems, bringing forward challenging questions. Recent studies have demonstrated that the unstable front dynamics is even a more complex process, involving a secondary instability at much smaller spatio-temporal scales than the macroscopic stick-slip. Thanks to an extensive experimental study, we have been able to unveil the precise characteristics of this peel front micro-instability. In particular, the amplitude of this instability scales with its period as $A \sim T^{1/3}$, with a pre-factor evolving slightly with the peel angle, and increasing systematically with the bending modulus of the tape backing. A local energy balance of the detachment process shows that the elastic bending energy stored in the tape region that will detach during the micro-slip is converted into a kinetic energy increase of the peeled tape during a micro-stick-slip cycle. Our model allows a quantitative description of the observed scaling-law linking amplitudes and periods of the micro-instability, and in particular its dependency with the peeling angle, as well as with the bending modulus and lineic mass of the ribbon.



Chrono-photography of the detachment front (time interval between each image is 20 μs) during a typical peel experiment (peel velocity 1 m/s, peel angle 90°, and peeled length 50 cm). The red arrow indicates the tip of the fracture kink, which propagates in the transverse direction across the tape width.

References:

– Bending to kinetic energy transfer in adhesive peel front micro-instability, V. De Zotti, K. Rapina, P-P. Cortet, L. Vanel and S. Santucci, *Phys. Rev. Lett.* **122**, 068005 (2019).

– Inertial and stick-slip regimes of unstable adhesive tape peeling, M.-J. Dalbe, R. Villey, M. Ciccotti, S. Santucci, P.-P. Cortet, and L. Vanel, *Soft Matter*, **12** 4537 (2016).

– Multi-scale stick-slip dynamics of adhesive tape peeling, M-J. Dalbe, P.-P. Cortet, M. Ciccotti, L. Vanel and S. Santucci, *Phys. Rev. Lett.* **115**, 128301 (2015).

COLLOQUIUM INSTITUTO BALSEIRO

Experiments in stochastic thermodynamics : short history and perspectives

Sergio Ciliberto

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Abstract

We summarize in this talk the experiments which have been performed to test the theoretical findings in stochastic thermodynamics such as Fluctuation Theorem, Jarzynski equality, stochastic entropy, out of equilibrium Fluctuation Dissipation Theorem and the generalized first and second laws. We shortly describe experiments on mechanical oscillators, colloids, biological systems and electric circuits in which the statistical properties of out of equilibrium fluctuations have been measured and characterized using the above mentioned tools. We discuss the main findings and drawbacks. Special emphasis is given to the connection between information and thermodynamics. The perspective and follow up of stochastic thermodynamics in future experiments and in practical applications are finally discussed.

S. Ciliberto, Experiments in Stochastic Thermodynamics: Short History and Perspectives, PRX 7, 021051 (2017).
S Ciliberto, S Joubaud and A Petrosyan, Fluctuations in out-of-equilibrium systems: from theory to experiment, JSTAT P12003 (2010).

ORAL CONTRIBUTIONS

Interfaces: A step beyond the elastic approximation

Nirvana Belen Caballero*[1,2,3] and Thierry Giamarchi[4]

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Abstract

Diverse systems including ferroic domain walls, cell fronts, or contact lines have been usually described as disordered elastic systems in disordered media. In this frame, the interfaces separating different "states" of the system are approximated by a univalued function of position and time. It is well known that real experimental realizations of these interfaces are usually far away of being described by univalued functions, inducing uncontrolled approximations which force the real interface to be adapted to one of the main hypothesis of the theory. Solving domain wall dynamics beyond the elastic approximation is still a largely open theoretical/analytical problem. In this work, we propose to address this problem by analyzing a Ginzburg-Landau model, which describes the main dynamics of driven systems (creep, depinning and flow regimes), and where interfaces with bubbles and overhangs can be studied. We make the connection between the Ginzburg-Landau model and the elastic Hamiltonian, and probe the validity of the elastic theory as a function of "defects". We examine in particular observables such as the interface roughness and the two-dimensional structure factor, both numerically and analytically. Our simulations, in addition to making contact with experiments, allow to test and provide insight to develop new analytical approaches to this problem.

*Speaker

A micromagnetism-inspired effective scalar-field model to study driven systems in disordered media

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Abstract

The study of magnetic domain wall dynamics is of great interest due to its promising technological applications, but also from the fundamental point of view. In fact, since it belongs to the general class of driven elastic manifolds in disordered media, new models to address this problem provide insights to more general questions about the response to external forces of amorphous materials.
In this work, we develop an effective scalar-field model that allows us to simulate quasi-two-dimensional films with a perpendicular easy axis of magnetization, under the effects of external magnetic fields with arbitrary direction and in presence of quenched disorder. We introduce temperature by following the traditional micromagnetic recipe, and derive effective parameters to take into account the contribution of the in-plane component of the magnetic moment, which was not considered by previous approaches. In this way, we are able to incorporate the material and experimental parameters, and thus directly compare our simulations with experimental results previously obtained in Pt/Co/Pt thin films (creep, depinning and flow regimes). Although extremely simple, our effective scalar model includes the main ingredients responsible for the complex observed behaviour, and may prove useful for the study of other driven systems in disordered media.

*Speaker

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Critical behaviour of fluid injection driven fracturing into weakly consolidated sands.

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Abstract

Weakly-consolidated or soft sands are dense granular materials in which particles are held together by external stresses, weak inter-particle cohesion, interlock due to particle shapes or a combination of these.

When injecting fluid at high pressure into such materials two main different regimes of behaviour can be observed. For low fluid pressure the system behaves as a solid porous material with a Darcy-like flow. For high fluid pressures grain displacement occurs creating flow channels or "fractures", the geometry of which are not trivial, usually displaying complex branched-like patterns [1-3].

In this work we simulate the behaviour of a dense granular media in a radial Hele-Shaw cell with central inlet. We show that, in agreement with experimental results [1,2], fracture initialization happens at a critical fluid pressure. The study focuses on the dependence of such a critical pressure with the mechanical parameters of the soft-sand, such as unconfined compressive strength (UCS), inter-grain cohesion and confining stress. In particular we show that fracture initialisation pressure is linearly related related to the confining stress values and that after initialization, fracture area increases as a function of the fluid pressure as power law with fractal exponent _˜1.54.

We use a resolved CFD-DEM approach based on CFDEM [4] open source projects, which uses OPENFOAM [5] for solving the computational fluid dynamic (CFD) and LIGGGHTS [6] as discrete element method (DEM) engine. References

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*Speaker

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Fluctuations of plasticity into a stationary shear band.

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Abstract

We will present an experimental study of the fluctuations of plasticity inside a stationary shear band. An amorphous material composed of glass beads is sheared quasi-statically, and the local and instantaneous strain are measured using a light scattering technique. The local strain appears strongly fluctuating with the position along the shear band and with the time. We will show that the stationary shear band consists into the accumulation of individual localized slip events. The distribution of sizes, positions and local strains of those events are measured. Finally, we will show that the correlation function of the plastic activity decays algebraically with the loading increment.

*Speaker

Numerical study of plasticity and yielding in ultra-stable hard sphere glasses

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Abstract

To a first approximation, amorphous solids, such as glasses, are like crystals: they respond elastically to small deformations, followed by plastic behaviors and yielding. However, amorphous solids are fundamentally different from crystals, because they are out-of-equilibrium, and the arrangements of particles are disordered. Here we consider an assembly of hard spheres as the simplest model of amorphous solids. We use a swap Monte Carlo algorithm to prepare ultra-stable glass states, and establish numerically a stability-reversibility map for hard sphere glasses under volume and shear strains. The region on the stability-reversibility map where the original glass state remains solid is bounded by the shear-yielding and the shear-jamming lines that meet at a yielding-jamming crossover point. This solid phase can be further divided into two sub-phases: the stable glass phase where the system deforms purely elastically and is totally reversible, and the marginal glass phase where it experiences stochastic plastic deformations at mesoscopic scales and is partially irreversible. The separation between stable and marginally stable phases is associated to the Gardner transition that was predicted recently by a mean-field theory. Due to this transition, the elasticity breaks down in hard spheres, and the apparent shear modulus becomes protocol-dependent.

*Speaker

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Dielectric measures of mechanically stressed polycarbonate films

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Abstract

We present the results of dielectric measurements performed on polycarbonate (PC) films kept at room temperature and submitted to an imposed strain rate d/dt till a maximum strain of about 80% at which the sample cracks. In [1], we have shown that the dielectric response of stretched PC behaves as if the sample is heated up at a temperature close to the glass transition temperature, Tg = 423K for PC. Indeed, in the frequency range of our experiment (10-2 - 105 Hz), the dielectric response of the stretched PC at room temperature superimposes to the dielectric response of PC at a temperature Ta, which is smaller than Tg and is a function of the strain rate. In our experiment where 10-5 < d/dt < 10-3 s-1, the mechanical rejuvenation modifies the dielectric response at frequencies smaller than 10 Hz, whereas for higher frequencies the spectrum is only slightly modified.
Here, we present new measures of the dielectric spectra on PC films taken at room temperature and at large strains, i.e. from the plastic yield, to the softening and the hardening regimes till the fracture of the films. The films have been stretched either at a constant strain rates or following different protocols which include stops of different duration (memory effects). These results allow us to discuss mechanical rejuvenation effects and the similarities of the dielectric spectra measured under an applied stress and those measured as a function of temperature. The results have been made possible using an innovative broadband dielectric spectroscopy technique [2], which allows us to measure simultaneously the dielectric spectra over four decades in frequency between 10-2 and 10-5Hz.

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*Speaker

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Yielding of jammed packings of frictional non-spherical particles near to the limit of mechanical stability

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Abstract

We explore the yielding behaviour of large sets of simulated jammed packings of frictional non-spherical particles near to the limit of mechanical stability. A broad range of shapes are considered including spheroids, fully aspherical ellipsoids and cubic particles [1]. The systems are initially prepared under gravity using a sedimentation protocol that allows for generation of packings with a broad range of densities and initial structural properties, including disordered packings over the full range from the random loose to dense limits, and systems with varying degrees of positional and orientational ordering [2]. We then employ a range of protocols to probe the yielding behaviour by compressing, iteratively perturbing or directly modifying the packed structure (e.g. by selectively removing grains with specified properties). We present a number of measures quantifying the local variations in the force network and geometrical structure of the system including the variation in local packing fraction (computed from the Voronoi diagram), distribution of grain contact numbers, degree of orientational ordering and the displacements of the grains due to rearrangements to achieve mechanical stability [3].

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*Speaker

Unveiling the Vortex Glass Phase in the Surface and Volume of a Type-II Superconductor

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Abstract

Order-disorder transitions between glassy phases are quite common in nature and yet a detailed description of the structural changes entailed at microscopic scales remains elusive. This issue is experimentally challenging since scales are typically tiny, constituents move rapidly, and few of them, in most cases, take part in the structural transformation. Vortex matter in type-II superconductors is a playground where some of these difficulties can be tackled by conveniently choosing the host superconducting sample. Bi2Sr2CaCu2O8 is a paradigmatic type-II superconductor presenting a glassy-to-glassy first-order transition between the Bragg and the vortex glass phases on increasing vortex density (magnetic field). The structural properties of the quasicrystalline Bragg glass have been extensively studied, but in the case of the vortex glass phase this information has remained elusive up to now. Here we image with single-vortex resolution the structural changes occurring at this order-disorder transition and reveal large field-of-view snapshots of the vortex glass phase. By combining real-space surface magnetic decoration and reciprocal-space bulk small-angle neutron scattering imaging techniques we found that this phase presents large crystallites with a proliferation of bounded and unbounded edge dislocations at the surface. Within the crystallites, the exponentially decaying orientational order and the fast algebraic growth of the positional displacement correlator are at odds with a hexatic phase. In addittion, in the vortex glass the radial and azimuthal in-plane correlation lengths are depleted at the surface as well as at the volume of the sample. Nevertheless, no dramatic change in the correlation length along the direction of vortices is observed within our improved experimental resolution, ruling out the possibility of the vortex glass being a glassy phase with layered vortices internally decoupled along the thickness of the sample.

*Speaker

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Oscillatory Instabilities in Frictional Granular Matter

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Abstract

Frictional granular matter is shown to be fundamentally different in its plastic responses to external strains from generic glasses and amorphous solids without friction. While regular glasses exhibit plastic instabilities due to a vanishing of a real eigenvalue of the Hessian matrix, frictional granular materials can exhibit a previously unnoticed additional mechanism for instabilities, i.e. the appearance of a pair of complex eigenvalues leading to oscillatory exponential growth of perturbations which are tamed by dynamical nonlinearities. This fundamental difference appears crucial for the understanding of plasticity and failure in frictional granular materials. The possible relevance to earthquake physics is discussed.

*Speaker

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Relaxation and aging in jammed glasses, the ubiquity of record dynamics, and the failure of trap models

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Abstract

We provide a unified description of "aging", the increasingly sluggish dynamics widely observed in the jammed state of disordered materials, in terms of record dynamics. Structural evolution in aging materials requires ever larger, record-sized rearrangements in an uncorrelated sequence of intermittent events (avalanches or quakes). According to record statistics, these (irreversible!) rearrangements occur at a rate $\approx 1/t$. Hence, in this log-Poisson statistics, the number of events between a waiting time tw and any later time t integrates to $\approx \ln(t/tw)$, such that any observable inherits the t/tw-dependence that is the hallmark of pure aging. Based on this description, we can explain the relaxation dynamics observed numerically and experimentally in a broad range of materials, such as low-temperature spin glasses and high-density colloids and granular piles [1,2,3]. We have proposed a phenomenological model of record dynamics that reproduces salient aspects, for example, the van-Hove distribution of displacements, intermittency and dynamic heterogeneity, over 12 decades in time using the waiting-time method [3,4]. Our studies also rules out some other explanations of aging based on trap models and continuous-time walks [5].

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*Speaker

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Hierarchical memory in sheared amorphous solids

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Abstract

One of the striking features of disordered materials is their ability to retain memory. In materials with quenched disorder, such as magnets, the memory can organize into a complex hierarchical structure which in some materials manifests itself as "return point memory", a property where subloops of the main hysteresis loop return to the point at which they are initiated. It was recently shown that in systems in which the disorder is annealed similar features emerge under oscillatory shear. Here we map the memory of such a periodically sheared amorphous solid at moderate amplitudes and show that hysteresis loops can exhibit return-point memory. However, in many loops there are small violations of return-point memory which turn out to be a result of the Eshelby-like interactions between plastic events.

*Speaker

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Reversibility and criticality in amorphous solids

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Abstract

The physical processes governing the onset of yield, where a material changes its shape permanently under external deformation, are not yet understood for amorphous solids that are intrinsically disordered. Here, using molecular dynamics simulations and mean-field theory, we show that at a critical strain amplitude the sizes of clusters of atoms undergoing cooperative rearrangements of displacements (avalanches) diverges. We compare this non-equilibrium critical behaviour to the prevailing concept of a 'front depinning' transition that has been used to describe steady-state avalanche behaviour in different materials. We explain why a depinning-like process can result in a transition from periodic to chaotic behaviour and why chaotic motion is not possible in pinned systems. These findings suggest that, at least for highly jammed amorphous systems, the irreversibility transition may be a side effect of depinning that occurs in systems where the disorder is not quenched.

*Speaker

Time-dependent rheology of amorphous materials and the effects of power-law mechanical noise

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Abstract

Elasto-plastic descriptions can provide key insights into the rich rheological behaviour of yield-stress fluids. Here we develop a formulation of the mean-field model introduced by Lin and Wyart (2016) that can be deployed to investigate arbitrary time-dependent rheological responses of athermal yield stress fluids, including for example creep, shear startup and the aging of the linear response. Using both direct numerical simulations of the stochastic model and pseudospectral methods for solving the associated time evolution equations for the stress distribution in the material, we investigate the effects of the main novel feature of the Lin-Wyart model, namely the broad, power-law-distributed noise arising from Eshelby-stress redistribution following plastic events. This is in contrast to the well-studied Hébraud-Lequeux model, where the noise is narrowly (Gaussian) distributed. We study a number of important non-equilibrium aspects related to aging and the associated preparation protocol, and the non-linear response in a range of scenarios including startup of steady shear and creep below and around the yield stress.

*Speaker

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The yielding of dislocation assemblies: avalanches and predictability

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Abstract

The avalanches in crystal plasticity do not adhere to the classical depinning picture of a non-equilibrium transition, and I will discuss the how and why in this talk. In two dimensional discrete dislocation plasticity as well as in three dimensional quite realistic simulations of "real single crystals" a number of important features arise. The common theme is the non-locality of dynamics even at zero stresses, not only in the vicinity of a critical point or the yield stress [1,2]. However, in particular for real materials, the presence of impurities (solutes, precipitates....) can not be ignored and this is shown to create a complex phase diagram [3], which has also been seen in experiments [4]. In the last part, I will discuss how the use of machine learning as a tour de force shows how the disorder landscape in fact is relevant, and how that allows one to predict the coarse-grained behavior of individual systems or samples to a large degree, in contrast to what is usually expected of critical or avalanching systems [5].

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*Speaker

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POSTERS

Combining pre-sliding creep flow and finite aging within rate and state friction laws

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Abstract

Rate and state friction (RSF) laws describe the low velocity shear response of frictional systems that present an interplay between logarithmic flow and logarithmic aging. Within this framework, a generic minimum of the steady state shear stress,
tauss(v), has been previously addressed by considering that aging processes do not have time to evolve above a velocity threshold, v2. Less attention has been given to a generic maximum at lower velocities (v < v2). We present a model that describes a maximum in
tauss(v) by considering the saturation of aging/healing processes at long times (relevant at v < v1) or by considering that the thermal or mechanical noise activates backward creep (relevant at v < v0). The largest of the scales v0 and v1 (both smaller than v2), as well as the aging's intensity, control the magnitude and shape of the maximum in
tauss(v). We argue this maximum is the quasi-static limit of the threshold force measured in startup or slide-hold-slide tests and stick-slip cycles. Even though this threshold is usually referred to as 'static', a threshold velocity is actually involved, below which a pre-sliding regime can be defined and above which unstable dynamic motion sets in. The model extends the traditional RSF laws to describe stable, steady-state creep in the pre-sliding regime expected to be relevant at long timescales, precise control of positioning systems or high thermal or mechanical noise. The proposed formulation, not only broadens the range of velocities and experiments in which RSF laws can be applied, but also suggests that considering the interplay between creep flow and finite aging can help to develop a universal constitutive law describing the low velocity limit (less than the maximum creep velocity) of frictional systems.

*Speaker

Molecular dynamics study of the deformation mechanism of Cu50Zr50 metallic glass using differents descriptors.

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Abstract

The characterization of plastic deformation in MGs, and in amorphous materials in general is a problem of great current interest. A phenomenon that appears to be common to this type of materials is the appearance of shear bands (SBs)as a precursor to failure. In order to accurately identify the phenomenology that operates in the formation process of SBs we have carried out a molecular dynamic study of ten quasi-two dimensional samples of Cu50Zr50 under simple shear. Four descriptors have been used to characterize the behavior of the system: the degree of strain localization[1], the fraction of atoms that undergo a von Mises strain greater than 0.3[1], the local five-fold symmetry (L5FS)[2] and the non-affine displacement field. The last descriptor has recently been addressed by several research groups, who have studied the role played by the non-affine atomic displacement field in association with plastic events described by Eshelby inclusions[3], both on Lennard-Jones glasses[4] and amorphous silicon[5]. We have carried out a systematic study of these four descriptors in order to characterize metallic glasses at the atomic level. The results of the degree of strain localization show that the strain is highly localized inside the shear band. The same is true for the fraction of atoms with a von Mises strain greater than 0.3. Concerning the L5FS, in all the cases that were studied it decreases during the development of the SB and stays constant after the SB is fully developed. Finally, the non-affine displacement field is also higher inside the SBs and, interestingly, displays vortical structures along the SB boundaries. This phenomenon is observed for samples with 580.800 atoms, but not with 145.200 atoms.

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*Speaker

sciencesconf.org:yielding2019:249503

Microrheological approach for gelation kinetics

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Abstract

Gelation is one of most important phenomena in energy transduction mechanisms inside biological specimens. However, since the aggregation kinetics of peptide networks involves different time and length scales, there are yet many elusive aspects about the out-of-equilibirum mechanical response of gels. Here we present a microrheological approach to obtain the viscoelastic properties of gels through the sol-semissolid transition. By considering the relationship between the mean-squared displacement of probe particles and the shear moduli of the sample, we explore a theory based on the langevin dynamics that displays many of the dynamical properties observed in the formation of gels.

*Speaker

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Roughening of the anharmonic Larkin model

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Abstract

We study the roughening of d-dimensional directed elastic interfaces subject to quenched random forces. As in the Larkin model, random forces are considered constant in the displacement direction and uncorrelated in the perpendicular direction. The elastic energy density contains an harmonic part, proportional to $(\nabla u)^2$, and an anharmonic part, proportional to $(\nabla u)\hat{\ }2n$, where u is the displacement field and n> 1 an integer. By heuristic scaling arguments, we obtain the global roughness exponent ζ, the dynamic exponent z, and the harmonic to anharmonic crossover length scale, for arbitrary d and n, yielding an upper critical dimension dc(n)=4n. We find a precise agreement with numerical calculations in d=1. For the d=1 case we observe, however, an anomalous "faceted" scaling, with the spectral roughness exponent ζs satisfying $\zeta s > \zeta > 1$ for any finite n> 1, hence invalidating the usual single-exponent scaling for two-point correlation functions, and the small gradient approximation of the elastic energy density in the thermodynamic limit. We show that such d=1 case is directly related to a family of Brownian functionals parameterized by n, ranging from the random-acceleration model for n=1, to the Lévy arcsine-law problem for n=∞. Our results may be experimentally relevant for describing the roughening of non-linear elastic interfaces in a Matheron-de Marsilly type of random flow.

*Speaker

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Magnetic field dependence of DW roughness in Pt/Co/Pt films

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Abstract

In ferromagnetic materials, under certain conditions, magnetic domains with magnetizations pointing in different directions may coexist. The transition regions between those domains are known as domain walls (DWs). In thin ferromagnetic films, the DWs can be treated as one-dimensional elastic objects that move in a two-dimensional disordered medium by thermally activated processes under the application of an external magnetic field. The competition between elastic energy, disorder, temperature and the external driving force gives rise to the DW roughness. This roughness is quantified by studying how the spatial fluctuations in the DW position increase with the system size, and it contains non-trivial geometric properties of the DWs. Taking into account that the geometric parameters of the DWs (roughness exponent and amplitude) are linked to the dynamical properties, and that such properties are of interest not only from the fundamental point of view but also by the potential impact in the development of devices, understanding the relationship between the geometric and dynamic properties is a subject of great relevance and current interest [1-3]. In this work, using polar magneto-optic microscopy, we address the study of magnetic domain wall roughness and dynamics in ultrathin Pt/Co/Pt films with perpendicular anisotropy [3,4]. We focus in the creep regime, where the DW velocity varies exponentially with the applied magnetic field, and we study the evolution of the roughness exponent and amplitude with the DW velocity.

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*Speaker

The fate of hyperuniform vortex patterns at the surface of type II superconductors

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Abstract

A many particle system must posses long-range interactions in order to be hyperuniform at thermal equilibrium. Hydrodynamic arguments and numerical simulations show, nevertheless, that a three-dimensional elastic-line array with short-ranged repulsive interactions, such as the one induced and directed by a magnetic field along the z-direction
in a superconductor, form at equilibrium a class II hyperuniform two-dimensional point pattern in any constant-z cross section, with point density fluctuations vanishing isotropically as a power law with exponent one at small wavevectors q. This prediction includes both the solid and liquid vortex phases in the absence of disorder, and also the liquid phase in presence of weak uncorrelated quenched disorder. We show that the three-dimensional Bragg-glass phase is marginally hyperuniform, while the Bose-glass and the liquid-phase with columnar disorder are expected to be non-hyperuniform at equilibrium, with the exception of the Mott-Glass phase. Motivated by these theoretical predictions and recent simulations we experimentally study large wavelength vortex density fluctuations of magnetically decorated vortex structures in pristine, electron irradiated and heavy-ion irradiated BSSCO superconducting samples in the mixed state.

For most of our samples we find nearly hyperuniform two-dimensional point patterns at the superconductor surface with an effective exponent approximately one. We interpret these results in terms of a large-scale memory of the high-temperature line-liquid phase due to glassy dynamics during the field-cooling protocol. We also discuss the crossovers expected from the dispersivity of the elastic constants at intermediate length-scales, and how finite-size effects in the z-direction should kill the hyperuniformity in the x-y plane for lengths 1/q above the superconductor thickness. We argue these predictions may be observable and propose further experiments to independently test them.

*Speaker

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First-order vortex transition with strong pinning centers

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Abstract

A first-order phase transition takes place in superconducting vortex matter on high-temperature cuprates separating phases with differing shear modulii. Each phase shows a different behaviour on the flux creep and the critical currents. By means of magnetic decorations and Hall probe magnetometry we study the effect of a low concentration of strong pinning centers on the structural properties of vortex matter and on the phase transition itself. Irradiated BSCCO samples with columnar defects with matching fields of Bf = 10, 30, 40, 60 and 90 Gauss have been studied, revealing a clean, first-order transition for the matching fields below 50 Gauss, turning into a glassy transition in samples with denser disorder (Bf=60 and 90 Gauss). A comparison with structural properties leads us to suggest that the in-plane positional order is not the symmetry broken at the transition.

*Speaker

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Yielding and Aging Rheology in Dense Active Matter

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Abstract

Recent experiments and simulations have revealed glassy features of cytoplasm, tissues and as well as dense assembly of self propelled objects. This naturally leads to a very fundamental question: how do these non-equilibrium (active) amorphous materials differ from conventional or passive glasses, created either by lowering the temperature or by increasing the density? To tackle this challenge we investigate the yielding and mechanical behaviour of a model active glass former, a Kob-Andersen Glass in two dimension where each particle is propelled by a constant propulsion force whose direction diffuses over time. Using extensive Molecular Dynamics simulations, we focus in particular on the effects of the intermittent dynamics in the regime of highly persistent activity and on the rheological impact of the unusually rich aging behaviour of the system.

*Speaker

Probability density distribution of forces in Bi-2212 vortex matter with point and correlated disorder

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Abstract

We study the local vortex-vortex interaction force of vortex structures f_i nucleated in Bi-2212 samples with different types of point and correlated pinning centers. We compute f_i from images with large fields of view of the vortex structure from 1000 to 15000 vortices obtained via magnetic decoration experiments. The observed structures are frozen at T _˜ T_irr (H) during the field-cooling processes previous to perform in the magnetic decoration experiments [1]. T_irr (H) of each sample is obtained from local Hall probe magnetometry measurements. We calculated the probability density functions of the components of f_i at several fields for each sample. Point-like disorder produces a Gaussian isotropic distribution of force components with zero mean value, while for correlated disorder the distributions present a power-law decay at large force values.

N. R. Cejas Bolecek, A. B. Kolton, M. Konczykowsky, H. Pastoriza, D. Domínguez, Y. Fasano, Phys. Rev. B. 93, 054505, 2016.

*Speaker

Shock waves in semiflexible polymers

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Abstract

In the last years, it has been observed that polymeric-based materials have excellent dissipation and shock-mitigation properties, in some cases superior to conventional metals or ceramic-based materials, and with the additional advantage of having low density and controllable transparency. These characteristics make them useful in applications as satellites protection against micrometeorites and body armor, between others. In this job, a MD simulation package (LAMMPS) is used to study the propagation and dissipation of shockwaves in linear semiflexible polymers. After equilibration, shockwaves are generated by compressing the system at constant speed. Our results show the existence of confinement shear mode buckling as the fundamental mechanism of dissipation in these systems. We analyze the properties of the buckled structures as a function of compression density and polymer orientation.

*Speaker

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Shock waves in Block Copolymer Materials

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Abstract

Block copolymer are obtained by the covalent link of two or more blocks of different polymers. The most important features of the block copolymer phase behavior are already captured by the simplest A-B diblock architecture. Here the unfavorable interactions between blocks, and the constraints imposed by the connectivity between their constituents, results in a nano-phase separation leading to the formation of periodic morphologies. For example, depending on molecular size, temperature, and relative volume fraction of the two blocks, diblock copolymer melts and can develop body centered-cubic arrays of spheres, hexagonal patterns of cylinders, gyroids or lamellar structures. For these systems, the periodicity of the self-assembled pattern is mainly controlled by the average molecular weight, and typically is in the range of 10-100 nm.
In the previous years Block Copolymers have been considered on a variety of applications, like photonics or phononics, based principally on their ability to form interesting patterns. More recently, it has been shown that these materials could also be used to disispate shock waves. It is believed that the high shock mitigation capacity of these materials comes from the combination of rigid and soft domains in the self-assembled structures.
In this work the propagation of shock waves in block copolymer systems is analyzed through molecular dynamics simulations using LAMMPS. Shock waves are generated by compressing the system at uniform speed 'u_p' (piston compression experiments), which induces the formation of a shock front in the system propagating at a different velocity 'v_s'. We analyze how the Hugoniot relation v_s / u_p change with different coplymer morphologies, and which are the main shock dissipation mechanisms in each case.

*Speaker

Effects of overtaking on collective motions in single-file diffusion

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Abstract

In systems of Brownian particles colliding with each other, the particles are hindered from free motion, as they are mutually caged. The confinement in the cage can last for a long time in 2D and 3D systems so that the motion of a particle is subdiffusive at some time scales, but eventually normal diffusion is recovered, which suggests that the particle has somehow escaped from the cage. An insight into the effects of this escape on the caged dynamics must be important to understand yielding of colloidal glasses.
As a simplified model of the caged dynamics, here we focus on a 1D system of colliding Brownian particles, whose behavior is known as the single-file diffusion (SFD). In the ideal SFD in which the interaction potential is infinitely large, the 1D cages can endure eternally, as the particles are forbidden to "overtake" each other. Therefore the particles can move only collectively, resulting in subdiffusion with the exponent 1/2.

We start with a systematic treatment of the ideal SFD based on the Dean-Kawasaki equation (a kind of Edwards-Wilkinson-like nonlinear equation describing the overdamped dynamics of interacting Brownian particles), which allows analytical calculation of the two-particle displacement correlation as an qualitative indicator of collective motions of the particles. The correlation is expressible in terms of a similarity variable with a diffusively growing length scale, which suggests a nested structure of cages.

Subsequently, we consider non-ideal SFD, in which the interaction potential is large but finite so that the particles can sometimes overtake their neighbors. Besides a recovery of normal diffusion, there are some nontrivial effects of overtaking on collective motions. To quantify these effects, we modify the analytical calculation of the two-particle displacement correlation, allowing for overtaking. The result shows that the short-range correlation is reduced but still expressible in terms of the same similarity variable as in the case of the ideal SFD, while the long-range correlation remains almost intact. Thus the overtaking breaks only the innermost layers of the nested cages, enclosed in outer layers of cages with longer lifetimes.

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Ooshida *et al.*: Biophys. Rev. Lett. **11**, 9-38 (2016); https://doi.org/10.1142/S1793048015400019
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Ooshida *et al.*: Entropy **20**, 565 (2018); https://doi.org/10.3390/e20080565

*Speaker

sciencesconf.org:yielding2019:260581

Effect of the alignment of the superconducting nodal direction with the sample edge in the orientation of vortex nanocrystals

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Abstract

We have studied the orientation of compact planes in vortex nanocrystals with roughly 100 vortices when nucleated in micrometric cuboids of the high-Tc Bi2Sr2CaCu2O8+y superconductor. The cuboids are engineered such that they have their edges either parallel to the nodal or antinodal direction of the d-wave superconducting order parameter of this material. By applying magnetic decoration we obtain snapshots of the field-cooled vortex nanocrystals nucleated at different fields and observe differences in the orientation of the vortex compact planes for both types of samples. While in antinodal cuboids a given family of compact planes is always aligned with the sample edge, in nodal cuboids no family of compact planes is in register of the sample edge. We also study the interaction force between all vortices of the nanocrystal and found a larger the dispersion in the spatial distribution of this magnitude for vortex nanocrystals nucleated in nodal cuboids. We suggest this is associated to the orientation of the vortex structure for both types of samples.

*Speaker

sciencesconf.org:yielding2019:260762

Permeability and structural stability of metallic foams under reservoir conditions

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Abstract

The metallic foams are a novel possibility to impact significantly the design of materials considering the wide technological applications of natural resources extraction. In this work, the procedure to manufacture metallic foams with controlled porosity is presented. A high-pressure chamber is used to submit the metallic foams to reservoir conditions, which imply high pressures and high temperatures. The injection of the optimal fluid in metallic foams increases the pore pressure which induces a dilation of the foam. These effects are described with poroelastic deformation quantities. The porous deformation is directly measured by image processing and the well-known mechanical properties are calculated based on basic theoretical models. The aim of this report is to describe the structural stability of metallic foams when they are submitted to reservoir conditions. The permeability of two different aluminium foams are compared, indicating that porosity plays an important role on maintain the structure in optimal conditions. The results indicate that metallic foams have high structural stability even if they are mechanically perturbed under extreme physical conditions.

*Speaker

sciencesconf.org:yielding2019:266788

Testing rigidity transitions in glass and crystal forming dense liquids: viscoelasticity and dynamical gaps

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Abstract

A computational study of rigidity for dense fluids of monodisperse and bidisperse hard-disks near a phase and a glass transition respectively is presented. To achieve this goal, the transversal part of the dynamical structure factor is calculated. In both cases, a viscoelastic behavior is obtained, with a dynamical gap determined by a critical wavevector kc. Transversal waves exist for k $>$ kc while density-density correlations happens at frequency $\omega = 0$ for k $<$ kc. In both cases kc goes to zero as the freezing point is approached. Both systems are able to fulfill a scaled dynamical law. The obtained results indicate that this method gives an alternative to study rigidity in dense fluids, since it is possible to assign a number of floppy modes to the liquid. Also, this suggests that the critical wavevector kc can serve as a suitable order parameter.

*Speaker

Packing Structure of Circular Filamentous Matter

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Abstract

Unravelling the packing structure of dense assemblies of semiflexible rings is not only fundamental for the dynamical description of polymers rings, but also key to understand biopackaging, such as observed in circular DNA inside viruses or genome folding. Here we use X-ray tomography to study the geometrical and topological features of disordered packings of rubber bands in a cylindrical container. Assemblies of short bands are found to display a liquid-like disordered structure, with short-range orientational order and a minor influence of the container. On the contrary, as the bands become longer, confinement force folded configurations and the bands interpenetrate and entangle. The degree of entanglement is characterized through minimal surfaces and generalized Voronoi diagrams, which allow the identification of bands threadings and near neighbors. Most of the systems are found to display a threading network which percolates the system. Interestingly, for long bands whose diameter doubles the diameter of the container, we found that all bands interpenetrate each other, in a complex fully-entangled structure.

*Speaker

sciencesconf.org:yielding2019:277335

Structural properties of confined vortex nanocrystals on cooling

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Abstract

Decreasing the size of vortex crystals down to the nano-scale in extremely layered high-temperature superconductors produces a depletion of the total binding energy of the system due to an enhancement of the vortex surface-to-volume ratio. As a consequence, the glassy-to-glassy transition line and the entropy-jump in the first-order melting line are affected by reducing the system size. In addition, the structural order of vortex nanocrystals are worsened with respect to the macroscopic case. In order to better understand the role of confinement in these properties, we performed Langevin dynamics simulations of vortex nanocrystals nucleated in micro-sized disks of the high Tc superconductor Bi2212. We study the quenching dynamics and the low-temperature structural properties of vortex nanocrystals nucleated in field cooling conditions for various vortex densities and cooling rates. In order to quantify the evolution of the structural properties we study the radial density of topological defects when changing vortex density, cooling rate, and temperature and compare with data on real experimental systems of the same superconductor.

*Speaker

Damage Accumulation in Silica Glass Nanofibers

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Abstract

The origin of the brittle-to-ductile transition, experimentally observed in amorphous silica nanofibers as the sample size is reduced, is still debated. Here we investigate the issue by extensive molecular dynamics simulations at low and room temperatures for a broad range of sample sizes, with open and periodic boundary conditions. Our results show that small sample-size enhanced ductility is primarily due to diffuse damage accumulation, that for larger samples leads to brittle catastrophic failure. Surface effects such as boundary fluidization contribute to ductility at room temperature by promoting necking, but are not the main driver of the transition. Our results suggest that the experimentally observed size-induced ductility of silica nanofibers is a manifestation of finite-size criticality, as expected in general for quasi-brittle disordered networks.
Ref:
"Damage accumulation in silica glass nanofibers"
Silvia Bonfanti, Ezequiel E. Ferrero, Alessandro L. Sellerio, Roberto Guerra, and Stefano Zapperi
Nano Letters 18, 7, 4100-4106 (2018)
DOI: 10.1021/acs.nanolett.8b00469

[*]Speaker

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Spatiotemporal Patterns in Ultraslow Domain Wall Creep Dynamics

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Abstract

In the presence of impurities, ferromagnetic and ferroelectric domain walls slide only above a finite external field. Close to this depinning threshold, they proceed by large and abrupt jumps called avalanches, while, at much smaller fields, these interfaces creep by thermal activation. In this Letter, we develop a novel numerical technique that captures the ultraslow creep regime over huge time scales. We point out the existence of activated events that involve collective reorganizations similar to avalanches, but, at variance with them, display correlated spatiotemporal patterns that resemble the complex sequence of aftershocks observed after a large earthquake. Remarkably, we show that events assemble in independent clusters that display at large scales the same statistics as critical depinning avalanches. We foresee these correlated dynamics being experimentally accessible by magnetooptical imaging of ferromagnetic films. Ref:
"Spatiotemporal Patterns in Ultraslow Domain Wall Creep Dynamics"
Ezequiel E. Ferrero, Laura Foini, Thierry Giamarchi, Alejandro B. Kolton, Alberto Rosso
Physical Review Letters 118, 147208 (2017)
DOI: 10.1103/PhysRevLett.118.147208

*Speaker

sciencesconf.org:yielding2019:281174

Halfway between the classical scalar-field model and micromagnetism: simulating real domain wall dynamics experiments

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Abstract

Statistical mechanics provide a powerful framework for addressing a wide variety of problems in condensed matter with very general tools. On the basis of a classical scalar-field model, we develop an effective model for magnetic domain-wall dynamics that captures the general physical behaviour of experimental results (creep, depinning and flow regimes) by incorporating the material and experimental parameters. We achieve this by following the traditional stochastic Landau-Lifshitz-Gilbert equation's recipe for temperature implementation, and by deriving effective parameters to take into account the contribution of the in-plane component of the magnetic moment, which was not considered in the original approach. In this way, we simulate quasi-two-dimensional Pt/Co/Pt films with a perpendicular easy axis of magnetization, and consider the effect of out-of-plane and in-plane magnetic fields, quenched disorder and temperature. Although extremely simple, our effective scalar model includes the main ingredients responsible for the complex observed behaviour and allows us to directly compare simulations with experimental results.

*Speaker

sciencesconf.org:yielding2019:281176

Inertia and universality of avalanche statistics: The case of slowly deformed amorphous solids

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[2]Centro Atomico Bariloche – Argentina

Abstract

By means of a finite elements technique we solve numerically the dynamics of an amorphous solid under deformation in the quasistatic driving limit. We study the noise statistics of the stress-strain signal in the steady-state plastic flow, focusing on systems with low internal dissipation. We analyze the distributions of avalanche sizes and durations and the density of shear transformations when varying the damping strength. In contrast to avalanches in the overdamped case, dominated by the yielding point universal exponents, inertial avalanches are controlled by a nonuniversal damping-dependent feedback mechanism, eventually turning negligible the role of correlations. Still, some general properties of avalanches persist and new scaling relations can be proposed. Ref:
"Inertia and universality of avalanche statistics: The case of slowly deformed amorphous solids"
Kamran Karimi, Ezequiel E. Ferrero, Jean-Louis Barrat
Physical Review E 95, 013003 (2017)
DOI: 10.1103/PhysRevE.95.013003

*Speaker

Creep dynamics of athermal amorphous materials: a mesoscopic approach

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Abstract

Yield stress fluids display complex dynamics, in particular when driven into the transient regime between the solid and the flowing state. Inspired by creep experiments on dense amorphous materials, we implement mesoscale elasto-plastic descriptions to analyze such transient dynamics in athermal systems. Both our mean-field and space-dependent approaches consistently reproduce the typical experimental strain rate responses to different applied steps in stress. Moreover, they allow us to understand basic processes involved in the strain rate slowing down (creep) and the strain rate acceleration (fluidization) phases. The fluidization time increases in a power-law fashion as the applied external stress approaches a static yield stress. This stress value is related to the stress over-shoot in shear start-up experiments, and it is known to depend on sample preparation and age. By calculating correlations of the accumulated plasticity in the spatially resolved model, we reveal different modes of cooperative motion during the creep dynamics. Ref:
"Creep dynamics of athermal amorphous materials: a mesoscopic approach"
Chen Liu, Ezequiel E. Ferrero, Kirsten Martens, Jean-Louis Barrat
Soft Matter 14, 8306-8316 (2018)
DOI: 10.1039/C8SM01392F

*Speaker

Static and dynamic critical exponents in elastoplastic models of amorphous solids

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Abstract

We analyze the behavior or different elastoplastic models approaching the yielding transition. We establish a family of static universal critical exponents which do not seem to depend on the dynamic details of the model rules. On the other hand, we discuss that dynamical exponents are indeed sensitive to these details. We exemplify and discuss this fact by proposing two kind of dynamical rules for the local yielding events: occurring above the local threshold either at a uniform rate or with a rate that increases as the square root of the stress excess. The value of the flowcurve's (inverse) Herschel-Bulkley exponent β is seen to differ in 12 between these two cases. We give analytical support to this numerical observation by calculating the exponent variation in the Hébraud-Lequeux model and finding an identical shift. We further discuss an alternative mean-field approximation to yielding only based in the so-called Hurst exponent of the accumulated mechanical noise signal, which gives good predictions for exponents extracted from the simulations of the full spatial models. Ref: https://arxiv.org/abs/1905.05610

*Speaker

sciencesconf.org:yielding2019:281185

Elastic interfaces on disordered substrates: From mean-field depinning to yielding

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Abstract

We consider a model of an elastic manifold driven on a disordered energy landscape, with generalized long range elasticity. Varying the form of the elastic kernel by progressively allowing for the existence of zero-modes, the model interpolates smoothly between mean field depinning and finite dimensional yielding. We find that the critical exponents of the model change smoothly in this process. Also, we show that in all cases the Herschel-Buckley exponent of the flowcurve depends on the analytical form of the microscopic pinning potential. This is a compelling indication that within the present elastoplastic description yielding in finite dimension d≥2 is a mean-field transition. Ref: https://arxiv.org/abs/1905.08771

*Speaker

sciencesconf.org:yielding2019:281186

Static and dynamics of entanglements in the lamellar phase of block copolymers

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Abstract

A comprehensive understanding of the underlying physics in the viscoelastic behavior of polymers is of fundamental interest but also is relevant to consider their technological applications. It is well-known that the mechanical properties of polymers in melts and concentrated solutions depend fundamentally on the molecular weight of the chains. Indeed, the inherent inability of the chains to cross each other comes into play when the chain-length increases inducing mobility constraints for them; thus, the so-called entanglements appear. Nowadays, we know the entanglements are a universal aspect of the polymer physics which occur in any flexible polymer system if the chain is sufficiently long and the concentration is high enough.

Polymer entanglements in homogenous systems under bulk conditions have been extensively studied through simulations and experiments, and some elegant theories provide the conceptual frameworks to interpret their behavior. Furthermore, similar studies were recently reported on inhomogeneous systems like confined environments: thin films, nanocylinders, etc. However little is known about those topological constraints on heterogeneous systems and multicomponent polymers such as the block copolymers (BCPs), a fascinating system which in the proper conditions of temperature and composition tends to self-assembly in periodic nanopatterns of high technological interest.

In this work, we use a novel coarse-graining for simulating entangled polymers to investigate the viscoelastic properties of BCPs when they segregate in a lamellar morphology. We have performed a thorough analysis to characterize the statics and dynamics of such a system.

We found the entanglements are not homogeneously distributed in space but instead adopt a distribution related to the underlying pattern as a direct consequence of the periodic location of the segregated domains. Moreover, the interface separating nearby domains induces a surface effect decreasing the density of entanglement locally, this effect seems to depend on the segregation regime, being more extended and notorious for sharp interfaces, i.e., in strong segregation.

Regarding the dynamics, we found the process of self-assembly disentangle the system in the kinetic pathway to the equilibrium.

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