Avalanche 2022

Avalanche dynamics and precursors of catastrophic events

Book of abstracts

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Timetable

29.08.2022.	Monday	
09.00.-10.00.	Registration	
10.00.-10.10.	Opening	
10.10.-10.45.	**K. J. Wiese**	**What is the correct theory for avalanches?**
10.45.-11.20.	**M. Wyart**	**Scaling theory for the statistics of slip at frictional interfaces**
11.20.-11.40.	S. Graovac	Mechanism of subcritical avalanche propagation in three-dimensional disordered systems
11.40.-12.00.	N. Caballero	From bulk descriptions to emergent interfaces
12.00.-12.20.	A. Gergely	Avalanche-size statistics in a Burridge-Knopoff type spring-block model
Lunch break		
14.00.-14.35.	**A. Baldassarri**	**Average avalanche shape as a probe of non-equilibrium systems : hopes and pitfalls**
14.35.-15.10.	**A. Rosso**	**Avalanches in long range systems : the problem of spatial clustering**
15.10.-15.30.	E. Vives	Avalanche Dynamics in Materials for Elastocaloric Cooling
Coffee break		
15.50.-16.25.	**D. Plenz**	**Self-organized Criticality in the Brain**
16.25.-16.45.	G. Ódor	Non-universal avalanches and burstiness in brain network models
16.45.-17.05.	D. Korchinski	Avalanches and criticality without time scale separation
17.05.-17.25.	D. Curic	Avalanche Dynamics Reflect Underlying State Changes in the Brain
17.25.-17.45.	A. Batool	Failure avalanches of the fiber bundle model on complex networks
19.00.-21.00	Welcome reception	

30.08.2022.	Tuesday	
09.00.-09.35.	**R. Maass**	**Athermal screw dislocation avalanches in bcc plasticity - how temperature drives a transition from scale-free to scale-dependent plastic fluctuations**
09.35.-10.10.	**K. Máthis**	**New insights into the spatiotemporal structure of plastic flow by combination of modeling and in-situ experimental techniques**
10.10.-10.30.	D. L. Beke	Denouement of the energy-amplitude and size-amplitude enigma for acoustic emission - scaling exponents reflect the dependence of the normalized temporal avalanche shapes on the maximum amplitude
Coffee break		
10.50.-11.25.	**D. Shilo**	**Investigation of avalanche phenomena by simultaneous measurements of different variables**
11.25.-11.45.	E. Bronstein	Tracking twin boundary jerky motion at nanometer and microsecond scales
11.45.-12.05.	L. Z. Tóth	Scaling of average avalanche shapes for acoustic emission during jerky twin boundary motion in single-crystalline $\text{Ni}_{50}\text{Mn}_{28.5}\text{Ga}_{21.5}$
12.05.-12.25.	M. Mińkowski	Strain-rate-dependent predictability of discrete dislocation plasticity
Lunch break		
14.00.-14.35.	**I. G. Main**	**Avalanche dynamics in porous media : sound and vision**
14.35.-15.10.	**O. Ramos**	**The LabQuakes project : from a granular fault to earthquake statistics**
15.10.-15.30.	N. Sultan	Sheared granular matter and the empirical relations of seismicity
Coffee break		
15.50.-16.25.	**J. Baró**	**The role of structural heterogeneity in avalanche statistics : Deformability bridges universality classes in numerical granular assemblies under deviatoric loading**
16.25.-17.00.	**K. Martens**	**Precursors of failure in the creep response of a model glass**
17.00.-17.20.	N. Coppin	Numerical simulation of immersed avalanches of elongated grains
17.20.-17.40.	Zs. Danku	Breaking avalanches in the limit of high disorder of the fiber bundle model

31.08.2022.	Wednesday	
09.00.-09.35.	**S. Zapperi**	**Avalanches and crackling noise in amorphous silica**
09.35.-10.10.	**M. J. Alava**	**Avalanches in dislocation plasticity**
10.10.-10.30.	T. Mäkinen	Avalanches in fatigue and crossover from creep to fatigue
Coffee break		
10.50.-11.25.	**A. Banerjee**	**Interplay between disorder and hardening in quasi-brittle fracture**
11.25.-11.45.	L. Ponson	Deciphering the criticality of the precursors to compressive failure in disordered solids : Applications to structural health monitoring
11.45.-12.05.	D. Kurunczi-Papp	Dislocation avalanches from strain-controlled loading : A discrete dislocation dynamics study
12.05.-12.25.	D. Korchinski	Avalanche phase diagram for the thermally activated yielding transition in amorphous solids
Lunch break		
14.00.-...	Fieldtrip to Tokaj wine region. Please do not forget to take warmer clothes !	

01.09.2022.	Thursday	
09.00.-09.35.	**L. Laurson**	**Depinning transition and Barkhausen avalanches of thin film domain walls with internal degrees of freedom**
09.35.-10.10.	**B. Casals**	**Avalanche criticality during ferroic switching**
10.10.-10.30.	S. Deng	Critical synchronization dynamics on power grids
Coffee break		
10.50.-11.25.	**G. F. Nataf**	**Avalanches in ferroelectric and ferroelastic materials**
11.25.-11.45.	S. Kaappa	360° domain walls and Barkhausen signal distributions in disordered permalloy thin films
11.45.-12.05.	D. Spasojević	Avalanches in disordered two-dimensional ferromagnetic systems with finite driving
12.05.-12.25.	S. Mijatović	Hysteresis-loop properties in weakly disordered antiferromagnetic-ferromagnetic bilayers
Lunch break		
14.00.-14.35.	**A. Kudrolli**	**Fluid driven instabilities in granular beds**
14.35.-15.10.	**R. Pastor-Satorras**	**Scale-free Avalanche Behavior in Schooling Fish : Experiments and Modeling**
15.10.-15.30.	D. Jovković	Effects of external noise on threshold-induced correlations in ferromagnetic systems
Coffee break		
15.50.-16.10.	S. Hiemer	Transition State Theory based Thermally Activated Breakdown in Fiber Bundles : Exact Solutions and Asymptotics for the Lifetime Distribution, Average and Variance
16.10.-16.30.	N. Bodaballa	Information fluctuations in the fiber bundle model under local load sharing mechanism
16.30.-16.50.	Diksha	Importance of inequality measures in predicting the failure time in the Fiber bundle model
17.10.-17.20.	Closing	

Aim of the conference

A large variety of physical systems respond to smooth continuous driving forces in an intermittent and stochastic way resulting in avalanche processes. Examples cover the range from the atomic to the tectonic scales, including avalanches in magnetic materials, superconductors, deformation of glasses and metals, cascades of irreversible rearrangements in soft matter systems, dynamics of inhibition fronts and crack growth ; fracture of heterogeneous materials, mechanical response of granular and porous media, geological flows, such as snow avalanches, land slides, and earthquakes, and the bursting activity of neural networks. In many cases the avalanche processes show a certain degree of criticality, with absence of characteristic scales, and power-law decays of the temporal and spatial correlations. The aim of this interdisciplinary workshop is to provide an overview of recent developments of these seemingly very different processes and to find the general common trends, approaches, and tools which can help to advance this important emerging research field.

The workshop is the continuation of a series of four previous meetings : "Crackling noise and intermittency in Condensed Matter " held in Göttingen (Germany) in May 2013, "Avalanches in Functional Materials and Geophsyics" held in Cambridge (UK) in December 2014, "Workshop on Avalanche Processes in Condensed Matter Physics and Beyond" held in Barcelona (Spain) in January 2017, and "Avalanche dynamics and precursors of catastrophic events" held in les Houches (France) in February 2019.

Focus areas

- Universality in avalanche dynamics
- Mixing of avalanches
- Precursors of catastrophic events
- Avalanches in transient dynamics
- Experimental methods to investigate avalanche phenomena
- Models of avalanche dynamics
- Yielding transition
- Multi-ferroic switching
- Other systems exhibiting avalanche dynamics

Organising committees

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Invited presentations

M. Alava : *Avalanches in dislocation plasticity.* **ABS-001**

A. Baldassarri : *Average avalanche shape as a probe of non-equilibrium systems : hopes and pitfalls.* **ABS-002**

A. Banerjee, D. Kumar, and R. Rajesh : *Interplay between disorder and hardening in quasi-brittle fracture.* **ABS-003**

J. Baró, M. Pouragha, R. Wan, and J. Davidsen : *The role of structural heterogeneity in avalanche statistics : Deformability bridges universality classes in numerical granular assemblies under deviatoric loading.* **ABS-004**

B. Casals : *Avalanche criticality during ferroic switching.* **ABS-005**

A. Kudrolli : *Fluid driven instabilities in granular beds.* **ABS-006**

L. Laurson : *Depinning transition and Barkhausen avalanches of thin film domain walls with internal degrees of freedom.* **ABS-007**

R. Maass : *Athermal screw dislocation avalanches in bcc plasticity - how temperature drives a transition from scale-free to scale-dependent plastic fluctuations.* **ABS-008**

I. G. Main, A. Cartwright-Taylor, M.-D. Mangriotis, C. Elias Parra, I. B. Butler, F. Fusseis, E. Andò, A. Curtis, A. F. Bell, and R. E. Rizzo : *Avalanche dynamics in porous media : sound and vision.* **ABS-009**

K. Martens : *Precursors of failure in the creep response of a model glass.* **ABS-049**

K. Máthis, P. D. Ispánovity, D. Ugi, M. Knapek, Sz. Kalácska, P. Harcuba, and I. Groma : *New insights into the spatiotemporal structure of plastic flow by combination of modeling and in-situ experimental techniques.* **ABS-010**

G. F. Nataf : *Avalanches in ferroelectric and ferroelastic materials.* **ABS-011**

Avalanches in dislocation plasticity

Mikko J. Alava

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[2]NOMATEN Center of Excellence, National Center for Nuclear Research, Poland

Discrete dislocation dynamics simulations allow to study the influence of loading and disorder on ”model” small single crystals. By such tools we can infer what kind of universality classes in the sense of statistical mechanics one may find and look at whether there are features of predictability contrary to systems close to phase transitions (usually). The goal may be reached with the aid of Machine Learning approaches [1]. The presence of a true yielding or depinning transition [2] is important also as related to the macroscopic properties of the material (ie. yield stress). Such features may be explored by studies of stress-strain curves or the behavior of samples in creep conditions at different stresses. We have also explored the consequences of depinning for the yielding of single dislocations in complex FCC metal alloys where the dislocation splits into two partials and the collective dynamics is important for the yield stress value, which increases from mean-field expectations due to stronger pinning than assumed [3].

References

[1] H. Salmenjoki, M. Alava, and L. Laurson, Nature Communications **9**, 1 (2018).
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[3] A. Esfandiarpour, S. Papanikolaou, and M. Alava, Phys. Rev. Research **4**, L022043 (2022).

Average avalanche shape as a probe of non-equilibrium systems : hopes and pitfalls

Andrea Baldassarri[1,2]

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[2]Department of Physics, Sapienza University of Rome, Rome, Italy

The average avalanche shape, introduced in the study of "crackling noise" more than twenty years ago, has been measured in several physical systems and models. We reconsider the problem of the average avalanche shape from the point of view of the theory of stochastic processes. Leveraging on the "time change" technique, we perform the exact computation of the average avalanche shape for the ABBM model (equivalent to the CIR process, a generalization of Bessel processes), revealing an interesting universality with the average shape of the "multi-avalanche", which is the average shape of the "bridge" of the stochastic process [1]. Then we address the problem of the possible asymmetry of the average avalanche (or multi-avalanche) shape. We believe that this feature contains relevant information on the non-equilibrium dynamics of the system in study that has not yet been exploited. We show an experimental case in granular friction, where asymmetry appears together with the breaking of scaling [2]. Then we briefly discuss the general, and still open problem, to how and when it is possible (or not) to relate the asymmetry of the shape with the entropy production of a non-equilibrium system [3].

References

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ABS-003

Interplay between disorder and hardening in quasi-brittle fracture

Anuradha Banerjee

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Natural materials like rocks, wood, antlers, etc., as well as engineering materials such as concrete, glassy polymers, ceramics, etc. are known to exhibit quasi-brittle fracture behaviour. In the present work, we examine the specific role of the interplay between hardening and disorder characteristics of a representative quasi-brittle material on its failure mechanisms using a random spring network model. Using the model which incorporates quasi-brittleness in its spring constants and disorder in the failure strain threshold we show that at higher disorder, the macroscopic failure strain of a weakly hardening material is much smaller than that of a linear elastic material. It is shown that this effect is due to a single nucleation event resulting in rapid localisation of deformation and damage growth in the neighbourhood for a weakly hardening solid while for a linear elastic material, damage nucleates at multiple independent sites and there is significant growth of damage, independent of other nucleating sites, prior to maximum load. Interestingly we find that, for the same disorder, the fracture behaviour crosses over from an avalanche-dominated fracture for a linear elastic material to nucleation dominated fracture for weakly hardening material. Finally, we show the effectiveness of the model in simulating the tensile failure behaviour of a representative quasi-brittle epoxy resin based polymer and in reproducing characteristic features of the observed crack trajectories.

ABS-004

The role of structural heterogeneity in avalanche statistics : Deformability bridges universality classes in numerical granular assemblies under deviatoric loading.

J. Baró[1,2], *M. Pouragha*[3,4], *R. Wan*[3], *and J. Davidsen*[2,5]

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[2] Department of Physics and Astronomy, University of Calgary, Alberta, Canada
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[4]Department of Civil and Environmental Engineering, Carleton University, Ottawa, Ontario, Canada
[5]Hotchkiss Brain Institute, University of Calgary, Calgary, Alberta, Canada

We use discrete element simulations to investigate the dynamics and statistics of kinetic avalanches during the athermal quasistatic compression of 2D elastic granular assemblies [1]. We report a stationary scale-free distribution of avalanches once the system hits a universal attractor manifold in a parameter space defined by the structure of interparticle contact forces. This so-called *stable evolution state* [2] is reached early in the simulations, at the onset of the strain-softening regime in over-compact assemblies, and way before the stationary flow regime traditionally linked to self-organized criticality. Therefore, the macroscopic evolution towards the final flow regime is dominated by variations in the activity rate and the effective elastic modulus instead of the avalanche sizes. The exponent values are non-universal and depend on particle deformability. We report mean-field (MF) exponents for stiff particles while lower exponent values, close to the ones reported in low-dimensional elastoplastic models, are found for soft particles or at high confining pressures.

Our numerical results exemplify how MF exponents naturally emerge in both numerical and experimental mechanical processes under certain conditions. We review the variability of exponents observed in legacy acoustic emission data recorded during uniaxial compression tests on porous materials [3,4]. Based on the numerical and experimental results we propose that structural heterogeneity, aside from the dynamics, might play a role on the suitability of branching-process analogs to MF avalanche propagation.

References

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[3] P. O. Castillo-Villa, et al., Journal of Physics : Condensed Matter **25**(29), 292202 (2013).
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ABS-005

Avalanche criticality during ferroic switching

Blai Casals

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Autonoma de Barcelona, Catalonia, Spain

The key feature defining ferroic materials is the hysteretic behaviour of their order parameter under an external field. Switching is a consequence of collective field-induced domain wall displacements that occurs through scale invariant jumps with avalanche characteristics. In some materials the domain walls exhibit completely different properties respect to the bulk, such superconductivity in non-superconductors, magnetism in non-ferromagnets, or polarization in non-polar materials. When the active elements of a device are the domain walls themselves, creating, erasing and moving them in a controlled way becomes crucial. My research is focused on two main lines : first, on the study of the avalanches features during the switching process. In this direction we found a correlation between the avalanche energy critical exponents and the Hausdorff dimension of the shape of the switched regions of ferroelectric materials [1]. Secondly, we explore strategies to modify reversibly the avalanche distributions. Using surface acoustic waves as field perturbations [2], we tune the switching behaviour of ferromagnetic thin films, controlling the domain wall position at the micron scale.

References

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[2] B. Casals, et al., Physical Review Letters **124**, 137202 (2020).

ABS-006

Fluid driven instabilities in granular beds

Arshad Kudrolli

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We will discuss experiments designed to understand the conditions under a which granular bed becomes unstable and flows under the action of fluid flow. Starting with the force and torque required to dislodge a single grain in a laminar flow as a function of its material properties and bed geometry, we will examine the conditions under which a bed of grains erodes and the erosion rate above threshold with experiments which enable examination of the bed at the surface but also deep inside using refractive index matching techniques [1-3]. We shall compare and contrast the exponential decaying flow regime found away from the surface when a granular bed is sheared by the boundary in gravity. We demonstrate the slow but significant evolution of a granular bed even before erosion threshold is reached. Then, we will discuss the convergence of flow which causes growth of channel networks due to increase in flow in regions where the porosity decreases because of erosion [4,5]. We discuss a multiscale model which uses a statistical physics approach, rather than using detailed fluid and granular mechanics, which is observed to capture the overall evolution of porosity in the experiments. Finally, we will examine the effect of dissolution on the growth of porosity variations and its effect on bed morphology [6].

References

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ABS-007

Depinning transition and Barkhausen avalanches of thin film domain walls with internal degrees of freedom

Lasse Laurson

Computational Physics Laboratory, Tampere University, Tampere, Finland

The jerky dynamics of domain walls driven by applied magnetic fields in disordered ferromagnets - the Barkhausen effect - is a paradigmatic example of avalanches or crackling noise. I'll start by discussing our recent study of Barkhausen noise in disordered Pt/Co/Pt thin films with perpendicular magnetic anisotropy due to precessional motion of domain walls using full micromagnetic simulations, allowing for a detailed description of the domain wall internal structure [1]. In this regime the domain walls contain topological defects known as Bloch lines which repeatedly nucleate, propagate, and annihilate within the domain wall during the Barkhausen jumps. In addition to bursts of domain wall propagation, the in-plane Bloch line dynamics within the domain wall exhibits crackling noise and constitutes the majority of the overall spin rotation activity. The scaling features of the Barkhausen jumps appear to agree with those of the quenched Edwards-Wilkinson (qEW) equation, but since the reachable domain wall lengths in micromagnetic simulations are limited to a few micrometers, this result could be affected by finite-size effects.

To overcome such limitations, I'll discuss next our recent efforts to develop a reduced model of thin film domain walls able to account for the internal degrees of freedom of the domain wall (Bloch lines) while allowing us to reach much larger system sizes [2]. To this end, we view the Landau-Lifshitz-Gilbert equation as a dissipative Euler-Lagrange equation and derive dynamical equations for collective coordinates describing the domain wall. As a starting point, we use the resulting model to study the domain wall depinning transition in a thin Co film within a Pt/Co/Pt multilayer. For weak disorder, excitations of the internal magnetization are rare, and the depinning transition takes on exponent values of the quenched Edwards-Wilkinson equation. Stronger disorder results in disorder-dependent exponents concurrently with nucleation of an increasing density of Bloch lines within the domain wall. Finally, I'll discuss perspectives of extending the model to study Barkhausen avalanches and other phenomena of interest.

References

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Athermal screw dislocation avalanches in bcc plasticity – how temperature drives a transition from scale-free to scale-dependent plastic fluctuations

Robert Maass[1,2]

[1]Federal Institute of Materials Research and Testing (BAM), Berlin, Germany
[2]Department of Materials Science and Engineering, University of Illinois at Urbana-Champaign, Urbana, USA

Plastic deformation in crystals is mediated by the motion of line defects known as dislocations. For decades, dislocation activity has been treated as a homogeneous, smooth continuous process. However, it is now recognized that plasticity can be determined by long-range correlated and intermittent collective dislocation processes, known as avalanches. Here we demonstrate in body-centered cubic Nb how the long-range and scale-free dynamics at room temperature are progressively quenched out with decreasing temperature, eventually revealing scale-dependent intermittency with a characteristic length scale that approaches the Burgers vector itself [1]. These findings represent next to complex microstructures [2] and stress-state [3] a third example of how a probed system can exhibit a transition from scale-free to scale-dependent intermittency. The plastic response of the Nb is shown to be bimodal across the studied temperature regime, with conventional thermally-activated smooth plastic flow coexisting with sporadic bursts controlled by athermal screw dislocation activity, thereby violating the classical notion of temperature-dependent screw dislocation motion at low temperatures. An abrupt increase of the athermal avalanche component is identified at the critical temperature of the material. We discuss these results in the context of classical bcc plasticity and non-trivial scaling of avalanche statistics.

References

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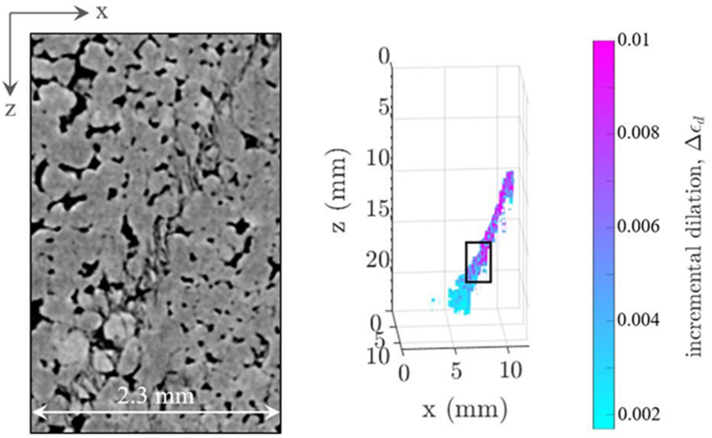
ABS-009

Avalanche dynamics in porous media : sound and vision

I. G. Main, *A. Cartwright-Taylor, M.-D. Mangriotis, C. Elijas Parra, I. B. Butler, F. Fusseis, E. Andò, A. Curtis, A. F. Bell, and R. E. Rizzo*

The advent of high-resolution synchrotron imaging of live rock deformation experiments has revolutionized our capacity to image pore-scale microstructures associated with precursors to system-sized failure in porous materials. However, the processes that occur near catastrophic failure occur too quickly under conventional constant strain rate loading to be captured. Here, we address this knowledge gap by combining acoustic monitoring (sound) with synchrotron imaging (vision) in a novel x-ray transparent tri-axial cell during deformation of a porous sandstone. We slow down the process by maintaining a constant micro-seismic event rate after yield, and locate micro-seismic events using prior information from the deformation field obtained by digital volume correlation.



Deformation is initially dominated by compaction events, and then by tensile and shear. Tensile fractures align spontaneously in en-echelon formation, and local shear bridges connect them to form a shear band at an emergent angle of 30 degrees to the maximum stress that grows across the sample, allowing the bulk outside the shear zone to move coherently, with relatively little internal strain. Shear on the band is accompanied by rotation of grains, a process not detectable by acoustic emissions, and which produces asymmetry in the distribution of crack orientations. Ultimately, contiguous shear occurs in a system-sized fault cutting through the shear band, with further fracturing, comminution of grains, and relative relaxation of strain near the fault.

We find the feedback control is very effective in suppressing large-magnitude events compared to a conventional constant strain rate test. This indicates that ’traffic light’ systems designed to manage the risk from induced seismicity might be more effective if regulated on event rate than maximum magnitude alone. There is no correlation between seismic amplitude and local imaged strain ; large local strain on the weakened shear band occurs with a large component of aseismic deformation and small acoustic emissions, and larger events tend to occur in the more intact bulk material. Overall, local strain is predominantly ($>$98%) aseismic. These results place significant constraints on the micromechanics of catastrophic failure events in porous materials and their seismic signature.

ABS-049

Precursors of failure in the creep response of a model glass

Kirsten Martens

PSM, LIPhy, Université Grenoble Alpes, Saint Martin d'Hères, France

In this talk I will discuss how we study via extensive numerical simulations the yielding process of dense amorphous materials subjected to an external shear stress, using a three-dimensional colloidal glass model. In order to disentangle possible boundary effects from finite size effects in the process of yielding, we implement a novel geometry-constrained protocol with periodic boundary conditions. We show that this protocol is well controlled and that the longtime yielding dynamics is, to a great extent, independent of the details of the protocol parameters. Our protocol, therefore, provides an ideal tool to investigate the bulk dynamics prior to yielding and to study finite size effects regarding the yielding process. Our study reveals the existence of precursors to yielding observed as a peak in the strain-rate fluctuations, that allows for a robust definition of a yielding time. Although the exponents in the power-law creep dynamics seem not to depend significantly on the system size, we reveal strong finite size effects for the onset of yielding.

ABS-010

New insights into the spatiotemporal structure of plastic flow by combination of modeling and in-situ experimental techniques

K. Máthis[1], *P. D. Ispánovity*[2], *D. Ugi*[2], *M. Knapek*[1], *Sz. Kalácska*[3], *P. Harcuba* [1], *and I. Groma*[2]

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Concurrent acoustic emission (AE) measurements and in-situ scanning electron microscopy are used to study the dynamics of the plastic flow in micron-scale Mg and Zn specimens. The combination of these techniques with discrete dislocation dynamics simulations gives completely new information about the spatiotemporal structure of the deformation mechanisms in hcp-structured materials. Deformation on the micrometer scales is a sequence of sudden unpredictable strain bursts that manifest themselves by stress drops on the deformation curve. The AE data indicate that a single stress drop has a two-level structure, where the large initial dislocation avalanche is followed by many aftershocks. The statistical analyses of data clearly show that despite fundamental differences in deformation mechanism and involved length- and time-scales, dislocation avalanches and earthquakes are essentially alike [1]. In addition to revealing the dynamics of dislocation, our approach is also suitable for study of deformation twinning. It is shown that autocatalytic twinning takes place in Mg micropillars: if a twin reaches a critical width, it triggers the nucleation of a new twin. Afterwards, the thickening and coalescence of all these twins take place until the entire micropillar volume is twinned. SEM analysis can reveal twin thickening rates, which in the case of Mg single crystals are on the order of 10^{-5}-10^{-4}m/s [2].

In summary, such a unique combination of experiments and computer simulations results in revealing the complex spatiotemporal structure and otherwise inaccessible fine microstructural details of the plastic flow in hcp structured materials.

References

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Avalanches in ferroelectric and ferroelastic materials

Guillaume F. Nataf

GREMAN UMR7347, CNRS, University of Tours, INSA Centre Val de Loire, Tours, France

Ferroelectric and ferroelastic domain walls are two-dimensional defects with thicknesses approaching the unit cell level that move in response to an electric-field or an applied stress, during the so-called "switching". Ferroelectric and ferroelastic switching is traditionally described by the nucleation and growth of domains within the phenomenological approach of Ishibashi and Takagi [1]. This approach works for individual movements across long-time scales but not for collective movements across short-time scales, where domain walls exhibit jumps that sometimes trigger other jumps and create avalanches [2]. Understanding these movements is particularly relevant for the development of domain-wall engineering [3] and of neuromorphic computing architectures.

References

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Scale-free Avalanche Behavior in Schooling Fish : Experiments and Modeling

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Behavioral contagion and the presence of behavioral cascades are natural features in groups of animals showing collective motion, such as schooling fish or grazing herbivores. Here we study empirically behavioral cascades observed in fish schools defined as avalanches of consecutive large changes in the heading direction of the trajectory of fish. In terms of a minimum turning angle introduced to define a large change, avalanches are characterized by distributions of size and duration showing scale-free signatures, reminiscent of self-organized critical behavior. We observe that avalanches are generally triggered by a small number of fish, which act as effective leaders that induce large rearrangements of the group's trajectory. This observation motivates the proposal of a simple model, based in the classical Vicsek model of collective motion, in which a given individual acts as a leader subject to random heading reorientations. The model reproduces qualitatively the empirical avalanche behavior observed in real schools, and hints towards a connection between effective leadership, long range interactions and avalanche behavior in collective movement.

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ABS-048

Self-organized Criticality in the Brain

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Self-organized criticality (SOC) refers to the ability of complex systems to evolve toward a second-order phase transition at which interactions between system components lead to scale-invariant events that are beneficial for system performance. For the last two decades, considerable experimental evidence has accumulated that the mammalian cortex with its diversity in cell types, interconnectivity, and plasticity might exhibit SOC. Here, I summarize and review experimental findings that neuronal networks self-organize toward four dynamical motifs presently identified in the intact brain : up-states, oscillations, neuronal avalanches, and coherence potentials. The precise interactions found for these 4 dynamical motifs in superficial layers of the mammalian cortex provide compelling evidence for SOC in the brain.

ABS-013

The LabQuakes project : from a granular fault to earthquake statistics

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Building analogue experiments that are able to simplify the huge complexity of earthquakes, while capturing the essential ingredients of their dynamics, is a plausible approach to better understand them. In this quest many different experimental systems have obtained statistical relations similar to those that describe seismicity : Gutenberg-Richer (G-R) law, Omori law, interevent time distribution, etc. However, many of these similarities are *qualitative* ; for example : the distribution of events' energy follows a power law with an exponent value different to the one of the G-R law. Recently we have developed an experimental system, based on the continuous and slow shear of a compressed granular system that mimics the behaviour of a tectonic fault : elastic energy is slowly stored in the granular structure and liberated by sudden reorganization events accompanied by acoustic emissions. By capturing and analysing a few millions of these laboratory quakes, we are able to reproduce *quantitatively* and simultaneously the main statistical relations describing seismicity[1]. This a strong indication that both systems share a common physics and brings hopes to a better understanding of earthquake physics.

This talk will briefly discuss, with some examples, the relevance of reaching a quantitative agreement in earthquake analogue experiments, then the main results obtained in our experimental system[1], and the challenges we are currently focusing on. This work was supported by the call ''Rare events'' of the MITI-CNRS-2022 and the LIA D-FFRAC.

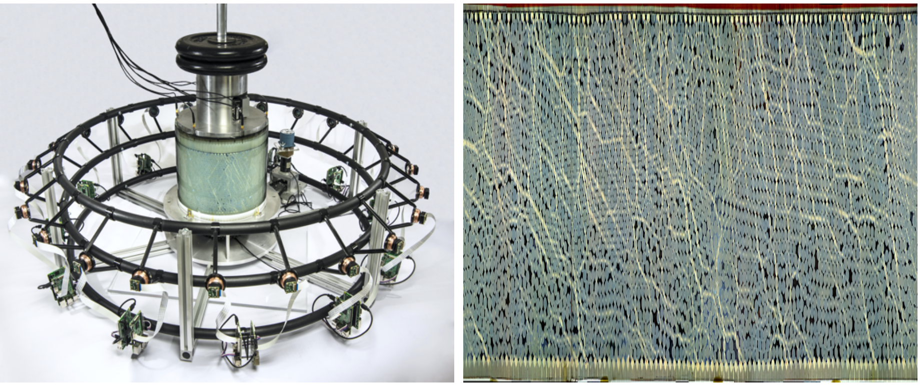

Figure 1 : *(left) Simplified image of our setup. (right) Granular fault.*

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ABS-014

Avalanches in long range systems : the problem of spatial clustering

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In the presence of long-range interactions, an avalanche is a collection of spatially disconnected clusters. An important question is how to relate the scaling properties of the clusters to the ones of the full avalanche [1]. Similar clusters are observed in the initial outbreak of an epidemic. In [2], we characterize exactly their statistical properties in a solvable model, in both the supercritical (outbreak) and critical regimes (avalanches). We identify two diverging length scales, corresponding to the bulk and the outskirt of the epidemic. We reveal a nontrivial critical exponent that governs the cluster number, the distribution of their sizes and of the distances between them.

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ABS-015

Investigation of avalanche phenomena by simultaneous measurements of different variables

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We present two studies in which an investigation of avalanche phenomena by simultaneous measurements of different variables provides a comprehensive understanding of both the studied physical process and the limitations of experimental methods. In both studies, avalanches during the motion of twin boundaries in single crystals of the ferromagnetic shape memory alloy Ni-Mn-Ga were induced by slow-rate mechanical loading. Yet, significant different behavior was observed depending on the type of the moving twin boundaries.
In the first [1], type II. boundaries displayed twinning stress smaller than 0.2 MPa. Measurements of the temporal twin boundary velocity and the acoustic emitted (AE) energy revealed the coexistence of a well-determined kinetic law and a scale-invariant power law. Velocity values followed a normal distribution whose characteristic value is determined by the material's kinetic relation, and its width scales with the average velocity. In addition, it is observed that velocity distributions are characterized by a heavy tail at the right (i.e., faster) end that exhibits a power law over more than one and a half orders of magnitude. At the same time, the AE energies follow a scale-invariant power law distribution, which is not sensitive to the average twin boundary velocity. The two different statistical behaviors reflect the mixing of different types of fluctuations : (1) slow and mild non-critical fluctuations during most of the twin boundary motion and (2) fast and abrupt avalanches during short times.
The second study [2] dealt with type I boundaries, which displayed twinning stress of 0.8 MPa and a much stronger AE activity. We identified individual events in which stress drops and AE occurred at the same time. We found that the probability of finding an AE event during a stress drop is $\sim$100 times higher than between stress drops. Our analysis revealed that the acoustic emitted energy E_{AE} represents just a minor and unknown part of the overall energy associated with the avalanche, as evaluated based on the mechanical energy drops ΔU_m. Specifically, the values of E_{AE} that correspond to the same ΔU_m are scattered over several orders of magnitude. The overall AE energy is smaller by 8 orders of magnitude than the overall released mechanical energy and all values of E_{AE} are smaller by at least 7 orders of magnitude than the corresponding value of ΔU_m. At the same time, there is a

lower bound for E_{AE}, which is approximately proportional to ΔU_m, indicating that there is a correlation between these two variables. The advantages and limitations of AE and force measurements will be discussed, in light of these results.

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ABS-016

What is the correct theory for avalanches ?

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Systems slowly driven through a disordered environment are at rest for most of the time, before responding with a burst of activity, known as an avalanche. The question arises: what is the correct theory underlying this dynamics? Different proposal have been made, as the ABBM model [1] or similar mean-field models. Since considering derived quantities as avalanche-size exponents is a very weak test to distinguish possible candidates, here we aim at identifying and testing the complete effective field theory. We find two distinct classes: quenched Edwards-Wilkinson, and quenched KPZ, the latter equally relevant for anharmonic depinning. In both cases, the key ingredient is the renormalized force correlator. We show how it can be measured in magnetic domain walls [2]. This test is fine enough to rule out a description by ABBM, and to distinguish between short-range and long-rage interactions, while eddy-currents seemingly play no role. Theory predicts, and our simulations confirm that the elasticity of nearest-neighbor interactions remains unchanged as a function of scale[3]. The situation is very different for the quenched KPZ class, for which the effective elasticity and the effective KPZ term change with scale. This renders the theoretical treatment much more difficult, and earlier work failed to find a fixed-point solution. Respecting the driving protocol in the simulation, a fixed point is found, with all the right properties[3].
We refer to the recent review[4] for a pedagogical introduction and background reading.

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ABS-017

Scaling theory for the statistics of slip at frictional interfaces

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Slip at a frictional interface occurs via intermittent events. Understanding how these events are nucleated, can propagate, or stop spontaneously remains a challenge, central to earthquake science and tribology. In the absence of disorder, rate-and-state approaches predict a diverging nucleation length at some stress $\sigma*$, beyond which cracks can propagate. Here we argue that disorder is a relevant perturbation to this description. We justify why the distribution of slip contains two parts: a power-law corresponding to 'avalanches', and a 'narrow' distribution of system-spanning 'fracture' events. We derive novel scaling relations for avalanches, including a relation between the stress drop and the spatial extension of a slip event. We compute the cut-off length beyond which avalanches cannot be stopped by disorder, leading to a system-spanning fracture, and successfully test these predictions in a minimal model of frictional interfaces.

ABS-018

Avalanches and crackling noise in amorphous silica

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Plastic yielding of amorphous solids occurs by power-law distributed deformation avalanches but their universality is still debated. I will report results on extensive molecular dynamics simulations of silica glass nanowires for a broad range of sample sizes, with open and periodic boundary conditions [1]. I will then discuss the formation of atomic-scale plastic instabilities and identify two distinct types of elementary plastic events, one is a standard quasilocalized atomic rearrangement while the second is a bond-breaking event that is absent in simplified models of fragile glass formers [2]. Both plastic events can be predicted by a drop of the lowest nonzero eigenvalue of the Hessian matrix that vanishes at a critical strain.
Finally, I will discuss the failure of two-dimensional silica glasses and report on the use machine learning methods to predict failure from the initial undeformed structure of the sample [3].

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Contributed Talks

A. Batool, Zs. Danku, G. Pál, and F. Kun : *Failure avalanches of the fiber bundle model on complex networks.* **ABS-019**

D. L. Beke, S. M. Kamel, N. M. Samy, L. Z. Tóth, and L. Daróczi : *Denouement of the energy-amplitude and size-amplitude enigma for acoustic emission - scaling exponents reflect the dependence of the normalized temporal avalanche shapes on the maximum amplitude.* **ABS-020**

N. K. Bodaballa and S. Biswas : *Information fluctuations in the fiber bundle model under local load sharing mechanism.* **ABS-021**

E. Bronstein, L. Z. Tóth, L. Daróczi, D. L. Beke, R. Talmon, and D. Shilo : *Tracking twin boundary jerky motion at nanometer and microsecond scales.* **ABS-022**

N. Caballero : *From bulk descriptions to emergent interfaces.* **ABS-023**

N. Coppin, M. Henry, J. Lambrechts, E. Azéma, M. Cabrera, F. Dubois, and Vincent Legat : *Numerical simulation of immersed avalanches of elongated grains.* **ABS-024**

D. Curic, and J. Davidsen : *Avalanche Dynamics Reflect Underlying State Changes in the Brain.* **ABS-025**

Zs. Danku, V. Kádár, G. Pál, and F. Kun : *Breaking avalanches in the limit of high disorder of the fiber bundle model.* **ABS-026**

G. Ódor, **S. Deng**, B. Hartmann, and J. Kelling : *Critical synchronization dynamics on power grids.* **ABS-027**

Diksha and S. Biswas : *Importance of inequality measures in predicting the failure time in the Fiber bundle model.* **ABS-028**

A. Gergely, A. Kuki, S. Lipcsei, and Z. Néda : *Avalanche-size statistics in a Burridge-Knopoff type spring-block model.* **ABS-029**

S. Graovac, S. Mijatović, and D. Spasojević : *Mechanism of subcritical avalanche propagation in three-dimensional disordered systems.* **ABS-030**

S. Hiemer, P. Moretti, S. Zapperi, and M. Zaiser : *Transition State Theory based Thermally Activated Breakdown in Fiber Bundles : Exact Solutions and Asymptotics for the Lifetime Distribution, Average and Variance.* **ABS-031**

D. Jovković, S. Janićević, S. Mijatović, L. Laurson, and D. Spasojević : *Effects of external noise on threshold-induced correlations in ferromagnetic systems.* **ABS-032**

S. Kaappa and L. Laurson : *360° domain walls and Barkhausen signal distributions in disordered permalloy thin films.* **ABS-033**

D. Korchinski, J. Orlandi, S.-W. Son, and J. Davidsen : *Avalanches and criticality without time scale separation.* **ABS-034**

D. Korchinski, and J. Rottler : *Avalanche phase diagram for the thermally activated yielding transition in amorphous solids.* **ABS-035**

D. Kurunczi-Papp and L. Laurson : *Dislocation avalanches from strain-controlled loading : A discrete dislocation dynamics study.* **ABS-036**

T. Mäkinen, I. Lomakin, J. Lahikainen, S. Coffeng, K. Widell, J. Savolainen, J. Koivisto, and M. J. Alava : *Avalanches in fatigue and crossover from creep to fatigue.* **ABS-037**

S. Mijatović, S. Graovac, D. Spasojević, and B. Tadić : *Hysteresis-loop properties in weakly disordered antiferromagnetic-ferromagnetic bilayers.* **ABS-038**

M. Mińkowski, D. Kurunczi-Papp, and L. Laurson : *Strain-rate-dependent predictability of discrete dislocation plasticity.* **ABS-039**

G. Ódor : *Non-universal avalanches and burstiness in brain network models.* **ABS-040**

A. Mayya, E. Berthier, and **L. Ponson** : *Deciphering the criticality of the precursors to compressive failure in disordered solids : Applications to structural health monitoring.* **ABS-041**

S. Roy, T. Hatano, and P. Ray : *Modeling crack propagation in heterogeneous materials : Griffith's law, intrinsic crack resistance, and avalanches.* **ABS-042**

D. Spasojević, D. Jovković, and S. Janićević : *Avalanches in disordered two-dimensional ferromagnetic systems with finite driving.* **ABS-043**

N. H. Sultan, K. Karimi, and J. Davidsen : *Sheared granular matter and the empirical relations of seismicity.* **ABS-044**

B. Tadić : *Magnetization avalanches and multifractal fluctuations in frustrated spin networks.* **ABS-045**

L. Z. Tóth, E. Bronstein, L. Daróczi, D. Shilo, and D. L. Beke : *Scaling of average avalanche shapes for acoustic emission during jerky twin boundary motion in single-crystalline* $Ni_{50}Mn_{28.5}Ga_{21.5}$. **ABS-046**

E. Vives, A. Planes, and L. Mañosa : *Avalanche Dynamics in Materials for Elastocaloric Cooling.* **ABS-047**

ABS-019

Failure avalanches of the fiber bundle model on complex networks

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Cascading failure driven by the redistribution of load after local damage events of connected elements often occur in our technological environment. From the cascading blackouts of electric transmission grids, through the failure avalanches of transportation and communication networks to the crackling bursts accompanying the breakdown of materials a large variety of failure phenomena can be mentioned which often have a strong economic impact [1]. Based on computer simulations of a generic model of failure spreading, namely, the fiber bundle model (FBM), here we investigate how the interplay of the topology of the network of load transmitting connections and of the randomness of the strength of the connected elements governs the statistical and dynamical features of failure cascades [2,3].

Starting from a regular square lattice of fibers, we apply the Watts-Strogatz rewiring technique to introduce long range random connections in the load transmission network. Our calculations revealed that a transition occurs from the localized to mean field behavior of FBMs as the rewiring probability is gradually increased. The degree of strength disorder of nodes (fibers) of the network has a substantial effect on the transition. In particular, we show that the transition sets on at a finite value of the rewiring probability, which shifts to higher values as the degree of disorder is reduced. The transition is limited to a well-defined range of disorder, so that there exists a threshold disorder of nodes' strength below which the randomization of the network structure does not provide any improvement neither of the overall load bearing capacity nor of the cascade tolerance of the system [2].

Both the size and duration of failure cascades are power law distributed on all network topologies, however, in the transition regime a crossover occurs between two regimes of different exponents. We demonstrate that the temporal evolution of cascades is described by a parabolic profile with a right handed asymmetry, which implies that cascades start slowly then accelerate and stop suddenly. The degree of asymmetry proved to be characteristic for the network topology gradually decreasing with increasing rewiring probability [3].

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ABS-020

Denouement of the energy-amplitude and size-amplitude enigma for acoustic emission - scaling exponents reflect the dependence of the normalized temporal avalanche shapes on the maximum amplitude

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Temporal shapes of avalanches, $U(t)$ (U is the detected voltage signal, t is the time), has self-similar behaviour. Thus, the normalized $U(t)$ function (e.g. dividing both the values of U and t by $S^{1/2}$, where S is the area [1]), averaged for fixed S, should be the same, independently of the type of materials or avalanche mechanisms. The similarity also leads to universal power-law scaling relations e.g. between the energy E, and the peak amplitude A, or between S and A. However, there are experimental evidences and theoretical predictions that the average temporal shape of avalanches do not scale completely in a universal way. In addition, there are well-known enigmas that the above exponents in acoustic emission measurements are rather close to 2 and 1, respectively, instead of $E \sim A^3$ and $S \sim A^2$, obtained from the mean field theory, MFT, [2]. It is shown [3], using a theoretically predicted averaged function for fixed avalanche area, $U(t) = at\exp(-bt^2)$, where *a* and *b* are non-universal, material dependent constants), that the scaling exponents can be different from the MFT values. Normalizing U by A and t by R (the time belonging to the A : rise time), as proposed in [2], we get that the exponent of the $logR$ versus $logA$ plot is given by $1-\varphi$ the MFT values can be obtained only if this would be unity). Here φ, is expected to be material independent and to be the same for the same mechanism. Furthermore, the exponents of scaling relations between E and A as well as S and A, are given by 3-φ and 2-φ, respectively, explaining while the scaling exponents deviate from the mean field values (denouement of the enigmas). Using experimental results on acoustic emission, obtained during martensitic transformations in two different shape memory single crystals in our group, φ=0.8±0.1 was obtained (φ is the same for both alloys). Thus, dividing U by A as well as t by $A^{1-\phi}$ ($\sim R$) leads to the same common plot for different constant values of S.

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ABS-021

Information fluctuations in the fiber bundle model under local load sharing mechanism

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We discuss here the random fiber bundle model [1] with only a part of the system accessible to measurements of its response under external loading. During the loading process, if a sub-sample (part of the full system) is accessible to the measurements of avalanches and other related quantities, then it leads to a loss of information content in the response statistics of the system. In the case of local load sharing mechanism [2], in which the load redistribution is space dependent, the variation of the information content in the response statistics of the system depends on both the sub-sample size and sub-sample location. A quantification of the information content in such cases will be discussed using Shannon entropy-like measures for the avalanche statistics.

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ABS-022

Tracking twin boundary jerky motion at nanometer and microsecond scales

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Twinning is an essential mode of plastic deformation occurring via nucleation and motion of twin boundaries. When driven at slow rates, twin boundaries propagate in a jerky motion, which is composed of discrete and impulsive avalanche events that often follow power law distributions. This observation is commonly interpreted as an indication for dynamic criticality – a state that is characterized by unpredicted dynamics that do not follow a continuous and injective kinetic law. When driven at high rates, twin boundary velocity changes were found to follow kinetic relations that are determined by lattice barriers for the twin boundary motion. The connection, if any, between avalanches at slow rates and velocity changes at high rates is still unexplored. To study this problem, direct measurements of twin boundary motion at small length and time scales have to be performed.

In this work, a novel experimental method was devised [1]. The experimental setup is based on a slow uniaxial compression of a NiMnGa single crystal. The sample is in contact with a force sensor with a resolution of 1 mN and a natural frequency higher than 50 kHz ; hence, it has the ability of capturing events at the sub-millisecond scale. A sensing coil(magnetic emission sensor) records the magnetic activity of the material throughout the experiment. The signals of the force sensor and coil are simultaneously acquired at 10kSa/s and 4 Msa/s, respectively. The experimental conditions were carefully designed to eliminate the effect of "ordinary" magnetic domain switching, such that the measured magnetic emission (ME) voltage is approximately proportional to $\acute{V}_T$, where V_T is the volume undergoing twinning transformation due to the motion of a single twin boundary.

This work analyzed three variables for each of the detected avalanches, and their distributions have been investigated : $t_{duration}$ - the time difference between the onset and end point of the avalanche ; $\acute{V}_{T,max}$ - the maximal rate of the volume transformation during the avalanche, which is proportional to the maximal absolute value of the voltage during the avalanche ; V_T - the transformed volume. The distributions of these variables related to avalanches occurring during stress drops and between stress drops coincide with each other over more than 99% of the data. These results indicate that the same microscale processes occur both during and between stress drops. Two different approaches based on the maximum likelihood method showed that the distributions of V_T, $\acute{V}_{T,max}$ and $t_{duration}$ fit well to power laws truncated by exponential functions. The cutoff values were found to be in the middle of the detected avalanches' range, resulting in a strong effect of the exponential functions on the PDFs, even in ranges smaller than the cutoff values. We suggest that the cutoff of $t_{duration}$ is related to the time required for the elastic waves to travel along the sample. Moreover, the cut-off of $\acute{V}_{Tmax}$ has been found to match the corresponding value of maximal twin boundary velocity, which is determined solely by the lattice barriers and was obtained during rapid magnetic pulses carried out on the same material. Based on the comparison of slow-rate and high-rate tests, we suggest a description of the twin boundary jerky nature and relate it to the kinetic relation for twin boundary motion.

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From bulk descriptions to emergent interfaces

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The framework of disordered elastic systems is a powerful tool that allows us to unravel the physics of interfaces and has served to understand many of their properties, including systems that range from ferroelectric materials [1,2] to the edges of cell colonies controlled by a wide range of still not fully understood mechanical and chemical interactions [3]. This approach is severely limited by its formal applicability only to univalued and smooth interfaces, thus inducing uncontrolled approximations. Solving interface dynamics and statics in more realistic systems beyond the elastic approximation is still a largely open theoretical/analytical problem. We address this problem by analyzing Ginzburg-Landau type models, that have the advantage of allowing us to study domain properties in combination with interface characteristics, and that can capture features of realistic realizations of interfaces. I will show how Ginzburg-Landau-type models can be successfully employed to probe the effects of different experimental protocols over interfaces and domains [4] and how one can map this problem to a quenched Edwards-Wilkinson equation [5], thus allowing us to connect results from one model to the other [6]. We approach the problem numerically and analytically, and our simulations, in addition to making contact with experiments, also allow us to test and provide insight to develop new analytical approaches to this so far intractable problem.

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ABS-024

Numerical simulation of immersed avalanches of elongated grains

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Column collapse has been accepted as a major benchmark in the study of the behaviour of granular materials, notably because of its similarity to large scale catastrophic events such as avalanches. The maximal extent of the collapsed column is a quantity of high interest called the mobility. It can be computed from the contact network and excludes any ejected particles that are not in contact with the main mass anymore. The literature has evidenced that it follows a power law in function of the column's initial aspect ratio [1,2]. This power law, as well as the collapse dynamics, have shown to be significantly modified by the presence of an ambient fluid [3]. For elongated grains, the relationships for spherical grains stay valid, although for grains long enough, the column may not collapse anymore [4]. Moreover, the influence of a surrounding fluid on a collapse of a column of elongated grains is yet ill-known, hence the objective of the current work.

To study the above-mentioned behaviours, we propose to use MigFlow, a hybrid, multi-scale numerical model [5]. The principle is to solve the fluid phase at a coarser scale than the granular one. The former is solved with a stabilised P1-P1 finite element method. The latter is solved with non-smooth contact dynamics, a hard sphere method that solves the contacts on the basis of momentum balances, preventing any interpenetration between grains. The link between the two phases is made via an empirical drag force, adapted to suit a large range of Reynolds numbers and fluid volume fractions. For the sake of simplicity, the elongated grains are modelled as clusters of disks, so that the resultant drag force and torque are computed from the drag force on each of the grain's constituting particles. Although this could lead to an undermestimation of the drag force rotation component, the general behaviour of the column should not be affected.

The collapse dynamics for immersed elongated grains are described and compared to the dry case in terms of front propagation, mobility and final profiles. First, the grains have a random initial orientation. The collapse tends to align them with the horizontal. In a second campaign, the effect of the grains initial orientation is studied for a short and a tall column. First, results for short columns show that as the initial orientation gets closer to the horizontal, the mobility decreases in the dry case. This decrease is not symmetric if

the grains are oriented so that they rest on the left wall or not, *i.e.* they have a negative or positive orientation. In the immersed case, this decrease is not significantly present, although a horizontal orientation still makes the collapse probability lower than one.

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ABS-025

Avalanche Dynamics Reflect Underlying State Changes in the Brain

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Systems exhibiting scale-free avalanche dynamics have taken on new significance across a wide range of multidisciplinary physics. Theoretical results from the physics of phase transitions predict that such systems are poised at a critical point and would display universal mechanisms and are independent of superficial details. This provides an immensely powerful theoretical framework with which to study such complex phenomena - understanding extremely complex real-world phenomena by mapping them to simpler mathematical models belonging to the same universality class of dynamics.

Recently, the brain has been presented as a candidate system operating at a critical point. This has been suggested due to observations of scale-free avalanche statistics in collective neuronal firings, often dubbed neuronal avalanches. These have been observed across multiple spatial scales, as well as across many species, prompting the hypothesis that scale-free neuronal avalanches are a product of evolution. Theoretical models have also suggested that such a critical point could imbue the brain with a greater 'alphabet' of potential responses, and optimize information transmission across the brain. Together these observations form the basis of the critical brain hypothesis, which posits critical avalanche dynamics may in fact be a necessary condition for normal every-day brain function.

Here we discuss how deviations away from 'normal' brain states may be reflected in the avalanche dynamics of neurons. These changes may be internally driven (e.g., transitions between various sleep states, self-initiated behaviour, neurodegenerative disease, it etc.) or externally driven (e.g., drugs, anesthetics, *etc.*). These brain state changes can alter the functional brain network and manifest as a loss of critical avalanche dynamics, or as a change in the universality class itself, for example [1]. The ability to observe, manipulate, and induce different brain states (e.g., via drugs or tasks), make neuronal systems a unique test bed for experimental interrogation of theoretical concepts at the core of our understanding of avalanche dynamics such as edge-of-synchronization phase transitions [2] extended critical regimes (Griffith's phases) [3], relaxation of time-scale separation, and more. In turn, these concepts provide an avenue with which to study the immense complexity of the brain, its function, and dysfunction.

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Breaking avalanches in the limit of high disorder of the fiber bundle model

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TThe disorder of materials plays a crucial role in their fracture processes with important consequences both on the micro- and macro-scales. Here, we investigate the effect of the amount of disorder on the size scaling of the ultimate strength and on the statistics of breaking bursts during the quasi-static fracture of heterogeneous materials. We consider a fiber bundle model where the strength of single fibers is sampled from a power-law distribution over a finite range, so that the amount of materials' disorder can be controlled by varying the power-law exponent and the upper cutoff of strength values. Our calculations revealed in the limit of equal load sharing that depending on the disorder parameters the mechanical response of the bundle is either perfectly brittle where the first fiber breaking triggers a catastrophic avalanche, or it is quasi-brittle where macroscopic failure is preceded by a sequence of bursts [1,2].

In the quasi-brittle phase an astonishing size effect is pointed out : For small system sizes the bundle strength increases with the number of fibers and the usual decreasing size effect is only restored beyond a characteristic size. We show that the extreme order statistics of the micro-scale disorder is responsible for this peculiar behavior [1,2].

The statistics of avalanche sizes is found to show a high degree of complexity as the system size and the degree of disorder are varied. Most notably, we demonstrate that the functional form of the size distribution of bursts depends on the system size : for large upper cutoffs of fibers' strength, in small systems the sequence of bursts has a high degree of stationarity characterized by a power-law size distribution with a universal exponent. However, for sufficiently large bundles the breaking process accelerates towards the critical point of failure, which gives rise to a crossover between two power laws. The transition between the two regimes occurs at a characteristic system size which depends on the disorder parameters [3,4].

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ABS-027

Critical synchronization dynamics on power grids

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Dynamical simulation of the cascade failures on the EU and USA high-voltage power grids has been done via solving the second-order Kuramoto equation. We show that synchronization transition happens by increasing the global coupling parameter K with metasatble states depending on the initial conditions so that hysteresis loops occur. We provide analytic results for the time dependence of frequency spread in the large K approximation and by comparing it with numerics of d = 2, 3 lattices, we find agreement in the case of ordered initial conditions. However, different power-law (PL) tails occur, when the fluctuations are strong. After thermalizing the systems we allow a single line cut failure and follow the subsequent overloads with respect to threshold values T . The PDFs $p(N_f)$ of the cascade failures exhibit PL tails near the synchronization transition point K_c. Near K_c the exponents of the PL-s for the US power grid vary with T as $1.4 \leq \tau \leq 2.1$, in agreement with the empirical blackout statistics, while on the EU power grid we find somewhat steeper PL-s characterized by $1.4 \leq \tau \leq 3.1$. Below K_c we find signatures of T-dependent PL-s, caused by frustrated synchronization, reminiscent of Griffiths effects. Here we also observe stability growth following the blackout cascades, similar to intentional islanding, but for $K > K_c$ this does not happen. For $T < T_c$ bumps appear in the PDFs with large mean values, known as "dragon king" blackout events. We also analyze the delaying/stabilizing effects of instantaneous feedback or increased dissipation and show how local synchronization behaves on geographic maps.

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ABS-028

Importance of inequality measures in predicting the failure time in the Fiber bundle model

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Prediction of breakdown in disordered solids under external loading is a question of paramount importance. Here we used the fiber bundle model for modeling a disordered solid and recorded the time series of avalanches during its failure dynamics. We measured some social inequality measures such as the Hirsch index (h), Gini index (g) and Kolkata index (k) from the avalanche time series [1,2,3] of the model. We used a supervised machine learning algorithm (with the above mentioned indices as some of the features) to predict the failure time of the model. We observed that these inequality measures play an important role for making the predictions. We will also discuss the analytical expressions for the above indices and the reason for their importance in the prediction analysis.

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Avalanche-size statistics in a Burridge-Knopoff type spring-block model

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Spring-block chains are often used to study collective behavior in complex systems [1]. As an immediate example one can mention the well-known Burridge-Knopoff model [2,3], which is a first approach for modelling the scale-free statistics of energy dissipation in earthquakes. Such models are usually intensively investigated by computer simulations. Here we study a simple experimental realization of the model by using a spring-block chain on a treadmill. The schematic setup and the experimental realization of this are illustrated in Figure 1.

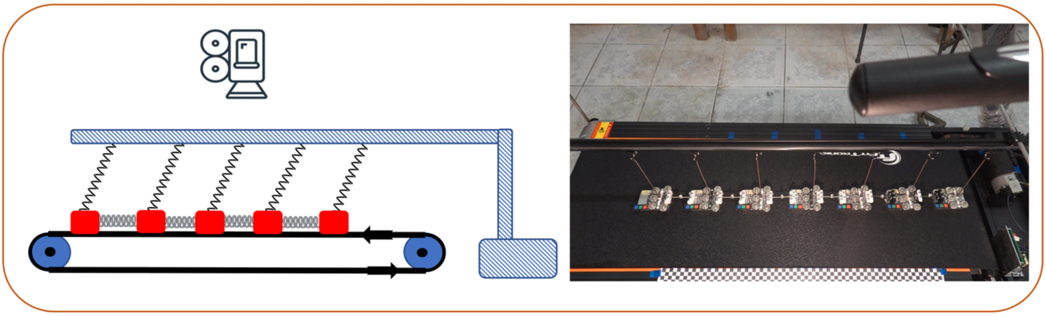

Figure 1. *Schematic setup and experimental realization of the 1D Burridge-Knopoff chain.*

The dynamics of the blocks were recorded, digitalized and processed. Avalanches were defined as the sequences of monotonic growth of the kinetic energy of the block's ensemble. Their statistics and the Fourier-spectrum of the blocks motion was studied as a function of the speed of the conveyor belt which was controlled by a separate interface.

Qualitatively different dynamical behavior was found in the low and high-speed regimes. For low speeds of the conveyor belt a power law type distribution is found with an exponent around -1, for the avalanches and a power-law type decreasing trend in the power-spectra. At higher speeds of the conveyor belt periodic or quasi-periodic behavior is found both in the avalanche sizes and block dynamics. Computer simulations using the classical Burridge-Knopoff model reproduces the experimental results.

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ABS-030

Mechanism of subcritical avalanche propagation in three-dimensional disordered systems

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We present a numerical study on necessary conditions for the appearance of infinite avalanche below the critical point in disordered systems that evolve throughout metastable states.

The representative model of the foregoing systems is the nonequilibrium athermal random-field Ising model (RFIM), commonly simulated by increasing the external field starting from a large negative value and all spins down. In our analysis, this scenario is followed until the start of spanning avalanche and then modified by flipping down all up spins forming a set of spin islands. From that point on we test whether the avalanche, initiated by preceding the simulation by flipping the starting spin of the (original) spanning avalanche and subsequently following the spin flipping rules of the front-propagation type, will be a spanning one. Additionally, we investigated the influence of presenting the interface of up spins facilitating the creation of spanning avalanche within the foregoing scenario.

Our findings indicate that the formation of islands of up spins is essential for the so created avalanche *to span* the system. Even when we turn down the spins from islands and impose condition that all their spins flip up if any of islands' neighbouring spin is flipped, the created avalanche *does not span* the system, see Fig 1a. One can see that the number of created spanning avalanches per run, $\mathrm{N_{sp}}$, is decreasing with the increase of the systems' size and disorder R. Thus, we deduce that the created spanning avalanches will be absent in the thermodynamic limit. Furthermore, to investigate whether the initial pre-set interface can overpower the missing matrix of islands in the system, we compare systems of 100^3 spins. One system have the pre-set interface of 1000 spins oriented up, and one is without the interface, both with islands of spins flipped back down, Fig 1b. Additionally, to these two types of systems, we again impose the condition on islands that they flip up if one of their neighbouring spins is oriented up and compare them, Fig 1b. The chance that the created avalanche will span the system is higher with the pre-set interface, but still not enough. As in the previous conclusion, the chance that the created avalanche spans the system decreases with the increase of both disorder and the system's size. Therefore, the created avalanche will not span the system in the thermodynamic limit when the formation of initial islands of up spins is disrupted, leading us to conclude that the formation of islands of up spins is crucial for appearance of spanning avalanche [1] and not, as widely believed, the pre-set interface.

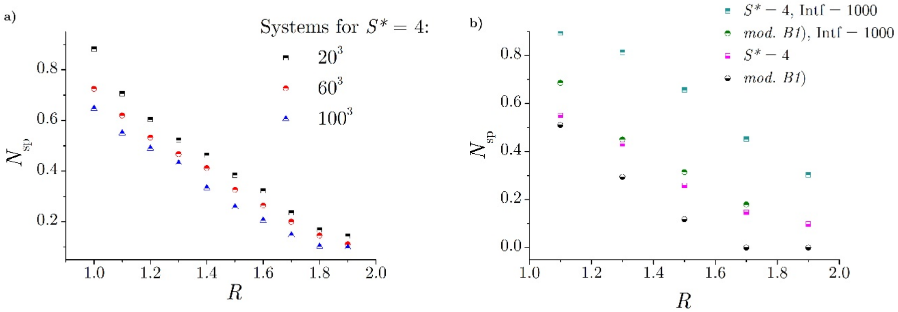

Figure 1 : *a) Systems with islands flipped back down and the relaxed condition imposed on islands flipping up. b) Systems with islands flipped back down : with pre-set interface (Intf=1000), with relaxed condition for islands flipping up (S*=4) and without condition imposed on islands flipping up (mod. B1).*

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ABS-031

Transition State Theory based Thermally Activated Breakdown in Fiber Bundles : Exact Solutions and Asymptotics for the Lifetime Distribution, Average and Variance

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To study thermal breakdown in fiber bundles, a model based on stationary Gaussian thermal noise as additional force fluctuation was introduced by Guarino on top of an equal load-sharing force redistribution mechanism [1]. For identical fiber breaking thresholds Roux provided the exact solution for the average lifetime as well as the asymptotics of average and variance in the limit of many fibers and low temperature [2].

For the description of thermally activated breakdown, a new fiber bundle model based on transition state theory is established [3]. The failure rate of individual fibers is given by an Arrhenius relationship where the energy barrier is linearly lowered by the applied force and thermally activated fiber failure are assumed to be independent Poisson processes. For this model given identical fiber breaking thresholds, the lifetime distribution, average and variance can be solved exactly for an arbitrary number of fibers N as well as in the asymptotic limit for many fibers. The asymptotic scaling of average and variance with regards to the number of fibers reveals a constant average lifetime and the variance decreasing by N^{-1}. This agrees with simulation results and the low temperature approximations by Roux which show identical scaling with regards to N, but differences with regards to the relationship to applied force and temperature [2]. For stochastically distributed thresholds, the lifetime distribution is derived as a high dimensional integral over the phases of a phase type distribution with no closed form solution. Simulations reveal the lifetime average and variance for thresholds drawn from uniform and exponential distributions to have identical asymptotic behaviour as fiber bundles with identical thresholds. For both distributions, the avalanche distribution follows a double power-law behaviour. The exponent in the many-fiber limit of approx. 2.5 agrees with theoretical asymptotic results derived by *Hemmer* for the case of quasistatic loading [4]. This suggests to things : i) Neither lifetime nor avalanche distribution asymptotics have a strong dependence on the details of the fiber threshold distribution ii) The asymptotic avalanche behaviour between quasistatic loading and thermally activated failure under constant load is similar.

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ABS-032

Effects of external noise on threshold-induced correlations in ferromagnetic systems

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Despite the fact that modern experimental equipment can significantly reduce the superposition of external noise on gathered data, presence of the unwanted external noise and noise from the measurement system still can not be avoided. So, to capture phenomena of interest one must minimize their influence. Usually, the studied events are recognized as parts of the recorded signal that lay below or above the threshold level imposed on the baseline level. In this way events, thresholds and noise are intertwined in each experimental signal, even in systems exhibiting avalanche-like relaxation. A representative model of such systems is the nonequilibrium athermal Ising model (RFIM) used in our studies. Here we present results obtained by investigating the joint impact of the external noise and imposed threshold level on the avalanche statistics extracted from the simulations of RFIM where two types of white noise were used, one generated from the uniform distribution (UWN) and the other from Gaussian distribution (GWN).

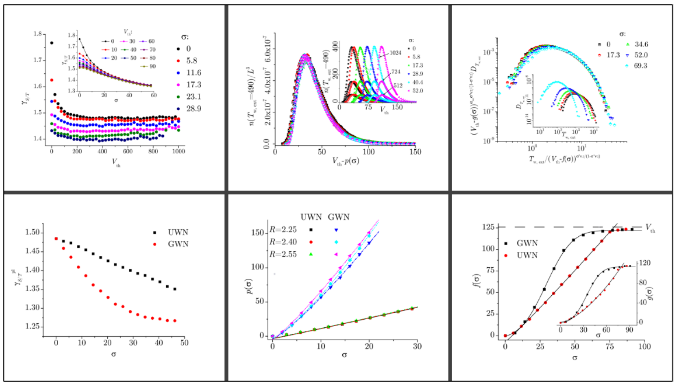

Figure 1. *Left : The change of exponent* $\gamma_{S/T}$ *with the increase of threshold level and added noise for UWN case (up) and change of its plateau values with noise (down). Center : The effect of applying the shift parameters (up), and behavior of the shift parameters for the UWN and GWN case (down). Right : The effect of applying the shift functions in collapses*

of waiting-time distributions (up), and their dependence on the standard deviation of noise (down).

In the present work, we show how the interplay of various threshold levels and external noise affects the values of exponent $\gamma_{S/T}$ (that describes the scaling of the average avalanche size with duration), for both types of applied noise. Since the properties of the relevant distributions and their collapses are also affected, we propose a way to bypass this by using shift parameters and shift functions dependent on the standard deviation of the noise. Our results could be relevant for the analysis of any data gathered from the experimental setup that contains white noise, uniform, or Gaussian.

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360° domain walls and Barkhausen signal distributions in disordered permalloy thin films

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Permalloy ($Ni_{80}Fe_{20}$) is a soft magnetic material that is widely used in magnetic recording heads and other spintronic devices. We study the magnetization reversal process and the Barkhausen noise statistics in permalloy thin films with varying disorder strength via micromagnetic simulations. Driving the system from a saturated magnetization state to the oppositely saturated state with an external field often leads to the formation of immobile 360° domain walls. We find that the avalanches in the magnetization reversal process are strongly related to the 360° domain walls and originate from localized, bursty rotation events of the magnetization, yet resulting in statistics that obey the power law. This is in contrast to the traditional perspective where Barkhausen noise in ferromagnetic materials is attributed to the jerky movement of the domain walls. Increasing the disorder strength induces the formation of more 360° DWs, decreases the speed of the smooth rotation of the local magnetization, and decreases the cutoff avalance size, indicating that the reversal process exhibits disorder-induced criticality. The critical exponent for the amplitude of the avalanches is found to be $\tau = 1.72$, agreeing with recent experiments where $\tau_{\text{exp}} = 1.65$ for the corresponding system [1]. The appearance of 360° DWs in the low-anisotropy material highlights the importance of utilizing micromagnetic formalism to study the magnetic response in systems of micrometer scale instead of the simplified models such as front propagation models or Ising-type methods that are not designed to operate such complex reversal mechanisms.

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ABS-034

Avalanches and criticality without time scale separation

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Diseases spreading between social contacts, malware spreading through computer networks, "fake news" shared on twitter, neuronal activity in the brain, and even damage spreading on a lattice are all examples of spreading process or avalanches unfolding on a network. Such processes generically produce scale-free avalanche dynamics when the probability of spreading passes through a critical point, generally falling into the universality class of directed percolation. However, many driven systems (e.g., amorphous solids under load, neurons receiving input, etc.) do not have a clear separation of timescales between avalanches, breaking the absorbing ground state underlying directed percolation. Whether externally driven systems still exhibit a critical point is an open question.

This question is especially interesting in the context of neuroscience, where the observation of neuronal avalanches at the scale $\sim 10^2$ neurons in vitro to $\sim 10^8$ neurons in whole brain fMRI suggest the brain self-organizes to a critical point, conferring computational benefits. So, as a motivating question, can brains that are bombarded by external stimuli still be critical ?

Here, by considering a minimal model for spreading with spontaneous activation, we derive a phase-diagram showing that there is indeed a critical line allowing spreading and external input to coexist with scale-free avalanches [1]. With numerical simulations on various pertinent network topologies along with exact analytical calculations, we find that the presence of spontaneous activation changes the universality class of the phase-transition into that of undirected percolation, resulting in different avalanche exponents for large avalanches. We identify scaling relations for the transition point between avalanche exponents and show that commonly used indicators, like the branching ratio and dynamic susceptibility, fail to identify criticality in the absence of timescale separation. I will discuss applications of this model to other avalanching systems with mixed timescales, as well as the implications this holds for criticality in the brain.

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Avalanche phase diagram for the thermally activated yielding transition in amorphous solids separation

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When amorphous solids are deformed, they first respond seemingly elastically, but eventually plastically. If the plasticity is homogeneous within the material, the system exhibits ductile yielding, characterized by a jerkily flowing steady state. In the athermal and quasistatic (AQS) limit of slow driving and zero temperature, this steady-state shows the hallmarks of a dynamical phase transition, with power-law scaling for stress-drop (i.e., avalanche) sizes and durations. This so-called "yielding transition" in amorphous solids has been thoroughly studied in the AQS limit and has a robust scaling theory connecting the distribution of microscopic weak spots to macroscopic avalanches.

However, the introduction of a finite temperature and driving rate introduce new, competing timescales to the problem that creates new scaling behavior. We investigate these effects by adding Arrhenius thermal activation to a mesoscopic elastoplastic model (EPM), so that otherwise stable regions of the amorphous solid can plastically rearrange, in addition to the usual mechanically driven plastic rearrangements [1]. We focus on the role that finite-size, temperature, and driving rate have on the size of avalanches. By adopting various scaling arguments backed by extensive numerical simulations in two-dimensions, we derive a nonequilibrium phase diagram capturing the onset of avalanche overlap, when temperature effects are prevalent, and when finite-size effects dominate.

We find that temperature truncates avalanche sizes for large systems, makes it easier for avalanches to overlap, and find a new temperature-dependent Herschel-Bulkley exponent. I will discuss possible experimental realizations of this work as well as preliminary results from mean-field theory.

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Dislocation avalanches from strain-controlled loading : A discrete dislocation dynamics study

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We study strain-controlled plastic deformation of crystalline solids via two-dimensional discrete dislocation dynamics simulations. To this end, we characterize the average stress-strain curves as well as the statistical properties of strain bursts and the related stress drops as a function of the imposed strain rate and the stiffness of the specimen-machine system. The dislocation system exhibits strain-rate sensitivity such that a larger imposed strain rate results in a higher average stress at a given strain. In the limit of small strain rate and driving spring stiffness, the sizes and durations of the dislocation avalanches are power law distributed up to a cutoff scale, and exhibit temporally asymmetric average shapes. We discuss the dependence of the results on the driving parameters and compare our results to those from previous simulations where quasistatic stress-controlled loading was used [1].
We then extend the study to more realistic three-dimensional discrete dislocation dynamics simulations. After describing the rate- and size dependence of the resulting stress-strain curves, we describe the power-law distributed strain bursts and the characteristic avalanche shapes. We discuss the dependence on system size and loading rate of our results and compare them with previous studies on strain-controlled two-dimensional systems as well as quasistatic loading of three-dimensional systems.

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ABS-037

Avalanches in fatigue and crossover from creep to fatigue

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Time-dependent deformation is important in a huge number of practical applications, where loads are static – leading to material creep – or repetitive – leading to fatigue. Fatigue exhibits apparent self-similarity as the Paris–Erdogan power-law relates the stress intensity factor at the crack tip to the crack growth velocity. Fatigue crack propagation has also previously been shown to occur in intermittent avalanches [1].

In monotonic loading or creep, crack propagation is seen as a thermally activated subcritical process governed by an Arrhenius law [2] or as a depinning process [3], behaving in a way similar to magnetic domain walls or elastic lines. As creep can be thought of as a limiting case of vanishing cycle amplitude in fatigue, there should be crossover between these two cracking processes.

We have experimentally studied crack growth in fatigue and creep tests using optical crack tracking methods for different materials, including aluminum alloys [4] and PMMA. We study the influence of the details of the loading protocol on the crack propagation velocity and the correlation between the crack propagation velocity and the avalanche statistics. We observe that the distribution of crack tip jump sizes has an exponent around two, cutoff behavior that correlates with the crack propagation velocity, as well as short-range memory effects in the avalanche dynamics.

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ABS-038

Hysteresis-loop properties in weakly disordered antiferromagnetic-ferromagnetic bilayers

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Recently, coupled antiferromagnetic-ferromagnetic bilayers are the subject of intense research on low-dimensional memory materials ; however, the precise connection between their structure and the hysteresis-loop features is still not fully understood. Our study in [1] uses the low-temperature simulations of the field-driven Ising spin reversal dynamics to reveal such connections. We consider heterostructures of coupled ferromagnetic and antiferromagnetic layers of varied thicknesses and a weak random-field disorder.

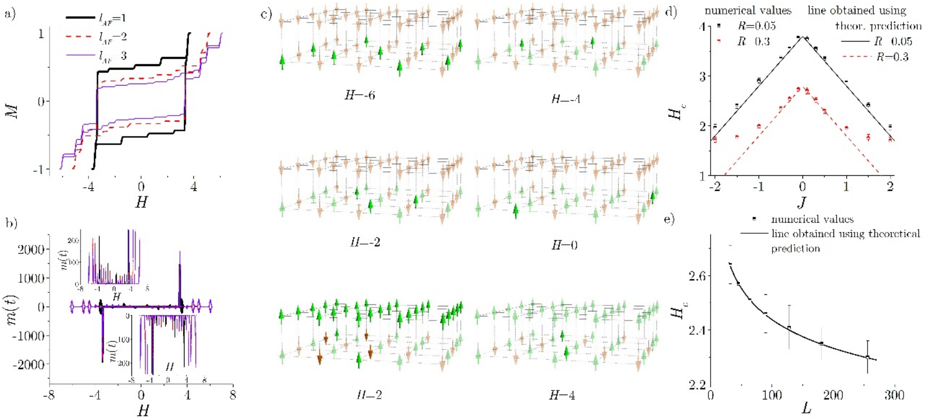

Figure 1. *a) and b) Hysteresis loops for different values of antiferromagnetic layer thicknesses and the corresponding signals. c) The system evolves with different groups of spins flipping at different values of the external magnetic field. d) and e) The dependence of the coercive field value on the interlayer couplings and system size, respectively.*

Specifically, we show that the hysteresis loops have fractional-magnetization plateaus in weak disorder and low temperatures. The number of these plateaus, the height of the central loop, and the structure of side sub-loops strictly depend on the antiferromagnetic layer thickness. Meanwhile, the interlayer coupling chiefly determines the coercive field values, modified by the magnetic disorder, the thickness of the ferromagnetic layer, and the system size, in agreement with the derived theoretical formula. The magnetization fluctuations in transition between two successive plateaus are modulated with peaks. Each peak reflects an active group of spins with different coupling strengths, arising at the interplay of the driving field, antiferromagnetic sublattices, and disorder.

These findings based on model systems shed new light on the tunable hysteresis loop properties and the related magnetization fluctuations in thin ferromagnetic-antiferromagnetic bilayers.

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ABS-039

Strain-rate-dependent predictability of discrete dislocation plasticity

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The problem of predictability of the stress-strain curves of individual small single crystals containing dislocations in strain-rate controlled external loading is studied by means of discrete dislocation dynamics simulations and machine learning methods [1]. As input for machine learning algorithms features of the initial relaxed configurations are utilized. The result reveals an intriguing strain rate dependence of deformation predictability. For small strains the predictability score increases with the strain rate, while for larger strains the relation between the predictability and the strain rate becomes non-monotonic. It is shown that for small strains the predictability can be related to the complexity of the dislocation dynamics by considering the fraction of dislocations moving against the external stress. On the other hand, the non-monotonic predictability at high strains can be explained by relating it to a transition from fluctuating to smooth plastic flow as the strain rate reaches high values.

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ABS-040

Non-universal avalanches and burstiness in brain network models

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Theoretical and experimental research provides many signals for the brain to operate in a critical state between sustained activity and an inactive phase. Critical systems exhibit optimal computational properties, suggesting why the nervous system would benefit from such mode For criticality, certain control parameters need to be tuned, leading to the obvious question : why and how this is achieved ? This question is well known in statistical physics ; the theory of self-organized criticality (SOC) of homogeneous systems has a long history. Effective discrete threshold models have been investigated by numerical simulations on large human connectomes [1,3,4] as well as on synthetic, hierarchical modular networks [2]. We showed that in case of start from a start from a single active site, avalanches occur with PDFs exhibiting non-universal power-law tails. These are the consequence of strong heterogeneities, which induce rare-region effects and Griffiths phases. Dynamical criticality emerges in an extended control parameter space region and a jump in the steady state value can also occur, implying a mixed-order phase transition [4]. This behavior is robust for model variations, involving refractory states, inhibitions, directedness of connections and for weak time dependence [2,3] of the control parameters.

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ABS-041

Deciphering the criticality of the precursors to compressive failure in disordered solids : Applications to structural health monitoring

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The nature of compressive failure in disordered solids that takes place through the accumulation of microscopic damage events and then their localization within a macroscopic fault remains an open question. On the one hand, it has been described as a standard bifurcation when it comes to predicting the critical compressive load at failure and the orientation of the resulting fault [1]. And on the other hand, it has been described as a critical phenomenon to explain the scale-free statistics of damage events preceding localization and the divergence of their characteristic size on approaching failure [2,3].

Here we use an original approach that combines compression experiments on a model disordered 2D material and their theoretical modeling using concepts of continuum damage mechanics and out-of-equilibrium physics of disordered systems [4,5]. We disentangle the critical behavior of precursory damage events from the loss of stability of the material at the failure point. In short, we show that the precursory activity is reminiscent of the critical avalanche dynamics of a non-stationary driven disordered elastic interface while the emergence of the macroscopic fault results from the loss of stability of the homogenous damaged specimen and its bifurcation towards a new (heterogeneously damaged) state. Strikingly, our unified framework of compressive failure reveals that the material always stays at a fixed distance to a critical point, even as it approaches final failure. The seemingly critical features of precursors that display a diverging length and time scale on approaching failure actually reflect the evolution towards an instability.

Beyond clarifying a long debate on the nature of compressive failure and the origin of the precursory damage activity, our findings have important implications to structural health monitoring applications. Precursors can now be used for quantitatively assessing the residual lifetime of a material, a crucial issue in predictive maintenance of mechanical parts. Our findings also provide rich insights through an experimental example on how criticality can go along with standard bifurcation in disordered systems, two implications that will be thoroughly discussed during our presentation.

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ABS-042

Modeling crack propagation in heterogeneous materials : Griffith's law, intrinsic crack resistance, and avalanches

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Strong and durable materials are universally sought-after in every walk of life. In practice, reliability and strength of an engineering specimen are determined by embedding a sharp crack or notch in the material and observing its behavior under stress. We mimic this experiment in our numerical study of the fiber bundle model, a simple prototype model of fracture in heterogeneous materials. Our results are akin to those observed in engineering materials. The simplicity of the model enables us to relate our findings with the microscopic parameters of the model providing us direct insight on the physics of cracking. We believe our study can help understand the cracking process better and, also, hopefully contribute towards designing strong and reliable materials.

We have mimicked the strength experiments generally done by stressing a specimen with a preexisting crack by a numerical study of stressing fiber bundle model [1] with a preexisting crack in it. The important observations from cracking in engineering samples are the pronounced effect of lattice trapping or crack resistance, modification of Griffith's law [2], and occurrence of two length scales arising from the competition between the large-scale elastic stress relaxation and short-scale energy dissipation near the crack tip. The fiber bundle model is perhaps the simplest model for fracture in heterogeneous materials having essentially two parameters - (i) the disorder in the fiber strength thresholds [3, 4] and (ii) the regime over which the stress of a broken fiber is redistributed [5]. We clearly see the existence of two length scales associated with the cracking of the bundle. We relate the two length scales with the microscopic observables, such as the number and size distribution of the cracks in the bundle. We see the modification of Griffith's law similar to what is found in engineering specimens, and we determine the range of validity of the law in the case of the fiber bundle model. The other spectrum of this is the high disorder scenario, where the failure events are random in space. Finally, we have determined the dependence of these two length scales and the exponent that characterizes the modified Griffith's law on the strength of the disorder and the range of stress redistribution from a failed fiber in the bundle.

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ABS-043

Avalanches in disordered two-dimensional ferromagnetic systems with finite driving

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Intermittent burst-like evolution in form of avalanches is common for many essentially diverse systems, ranging from earthquakes to disordered ferromagnets. Underlying avalanche dynamics is found to be affected by various aspects, one of them being the way the system is driven. Here we present the new results on the effect that the finite-rate driving has on the two-dimensional disordered ferromagnetic systems studied in the context of nonequlibrium athermal random field Ising model. In this type of driving, and particularly in the regime of fast driving rates, simultaneous propagation of avalanches occurs, making the system respond in a manifold of avalanches that merge in time/space in which separation to individual contributions is no longer possible.

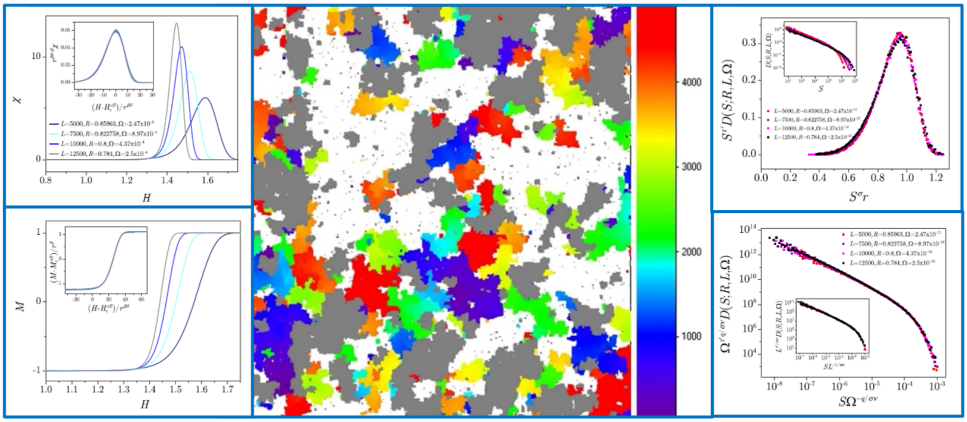

Figure 1. *Magnetic susceptibilities and magnetizations (left panels) and their scaling collapses (pertaining insets) in the fast driving regime for both* $Lr^{\nu} = const.$, *and* $\Omega r^{\nu/q} = const.$, $q = -0.4$ *scaling conditions satisfied. Middle panel shows a snip of the system with evolving avalanches. Integrated non-spanning avalanche size distributions (top right panel) and their scaling collapses (bottom right panel with both pertaining insets).*

We find that the distributions of avalanche parameters, magnetization, correlation functions and average avalanche shapes, described by the effective and rate-dependent values of pertaining exponents are profoundly affected by the applied driving rate. However, our results also demonstrate that the scaling collapses of data are still possible regardless of the value of rate the system is driven with, given that the finite-size and newly introduced rate-dependent scaling conditions are met. Our results, obtained in large-scale numerical simulations, could be of relevance for studies of variety of driven systems, in particularly for the ones with finite thickness (e.g. ferromagnetic strips and thin films).

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ABS-44

Sheared granular matter & the empirical relations of seismicity

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The frictional instability associated with earthquake initiation and earthquake dynamics is believed to be mainly controlled by the dynamics of fragmented rocks within the fault gauge. Principal features of the emerging seismicity (e.g., intermittent dynamics and broad time and/or energy scales) have been replicated by simple experimental setups, which involve a slowly driven slider on top of granular matter, for example. Yet these setups are often physically limited and might not allow one to determine the underlying nature of specific features and, hence, the universality and generality of the experimental observations. We address this challenge by a numerical study of a spring-slider experiment based on two-dimensional discrete element method (DEM) simulations, which allows us to control the properties of the granular matter and of the surface of the slider, for example. Upon quasistatic loading, stick-slip-type behaviour emerges which is contrasted by a stable sliding regime at finite driving rates, in agreement with experimental observations. Across large parameter ranges for damping, interparticle friction, particle polydispersity, etc., the earthquake-like dynamics associated with the former regime results in several robust scale-free statistical features also observed in experiments. At first sight, these closely resemble the main empirical relations of tectonic seismicity at geological scales. These include the Gutenberg-Richter distribution of event sizes, the Omori-Utsu-type decay of aftershock rates, as well as the aftershock productivity relation and broad recurrence time distributions. Yet, we show that the correlations associated with tectonic aftershocks are absent ; such as the origin of the Omori-Utsu relation, the aftershock productivity relation, and Bäth's relation in the simulations are fundamentally different from the case of tectonic seismicity. This, we believe, is mainly due to a lack of macroscale relaxation processes that are closely tied to the generation of real aftershocks.

ABS-045

Magnetization avalanches and multifractal fluctuations in frustrated spin networks

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Functional nano-assemblies often possess complex geometry, which arises through the self-assembly of nanoparticles and impacts their physical properties. For example, the geometric frustration effects in complex nanostructures cause many new phenomena in solid-state physics, which are currently the focus of both theoretical investigations and applications. They are best exemplified by frustrated spin networks, where spins attached to the network nodes (nanoparticles) are subject to antiferromagnetic interactions along the network edges on closed triangles. Moreover, such complex geometries support higher-order interactions that compete with the leading pairwise couplings. Here, we investigate the nature of collective magnetisation fluctuations during the field-driven reversal processes in a complex assembly of triangles under competing antiferromagnetic pairwise and triangle-based interactions. The underlying nano-network is grown by the self-assembly of pre-formatted triangles of nanoparticles attach by sharing a node or an edge with the geometric compatibility rules [1]. The field-driven spin reversal dynamics on such networks are simulated by slowly increasing external field along the ascending branch of the hysteresis and then decreasing to complete the loop. Investigations of the Barkhausen noise signal revealed the collective fluctuations with the multifractal structure in the class of fractional Brownian motion and the sequence of magnetisation avalanches. We demonstrate how the varied balance between pairwise and triangle-based interactions [2,3], controlled by a parameter p, changes the shape of the hysteresis loop and the magnetisation fluctuations pattern. We find a power-law distribution of avalanches, with the exponents weakly varying with the parameter *p in [0,1],* suggesting the primary role of the network architecture in the statistics of avalanches. The robustness of the scale invariance of the avalanches has a strong signature of self-organised criticality [4]. However, on a finer scale of temporal fluctuations, we find that the accompanying Barkhausen noise exhibits multifractal features [5] with different singularity spectra. In particular, a more significant proportion of the triangle-based interactions *p~1*cause the singularity spectrum to be more right-sided, dominananting with of small fluctuations, compared to the case of pure pairwise antiferromagnetic interactions *p=0*. These findings shed new light on the nature of magnetisation processes on nanonetworks where the structural inhomogeneities compete with the geometric frustration effects in simplicial complexes.

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ABS-046

Scaling of average avalanche shapes for acoustic emission during jerky twin boundary motion in single-crystalline $Ni_{50}Mn_{28.5}Ga_{21.5}$

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It is well-known, that the different properties of crackling noise avalanches, like amplitude A, energy E, or size S, are distributed by power-law behaviour, with various exponent values. However, these exponents can show interesting effects, they are robust, and have limited set of values. Thus, the focus is increasingly on the temporal shapes of avalanches, *i.e.* the average of the detected voltage signal $U(t)$ for a given size (or duration) range of avalanches.

The average avalanche shape has self-similar behaviour, with an appropriate normalization, they can be scaled together, according to a universal scaling function. There are also universal scaling relations between the avalanche properties. In mean field theory (MFT), these are $E \sim A^3$, $S \sim A^2$, or $T \sim A$, where T is the duration. Thus, normalizing both the voltage and time axis of the avalanche shapes with the amplitude, the avalanches should scale together. In my presentation I will show for acoustic emission measurements detected during jerky twin boundary motion in a single crystalline $Ni_{50}Mn_{28.5}Ga_{21.5}$ sample during slow compression [1], that this scaling does not work.

Recently, it turned out [2], that in the theoretically predicted $U(t)$ function $U(t) = at\exp^{-bt}$, a and b are not universal constants, rather $a \sim A^{\varphi}$. φ is a mechanism dependent constant, and it was shown in [2], that it appears also in the scaling relations $E \sim A^{3-\varphi}$ and $S \sim A^{2-\varphi}$, resolving the enigma, that the scaling relations of the MFT are not fulfilled. I will show, that calculating φ from the above mentioned relations and normalizing the time axis of the average avalanche shapes with $A^{1-\varphi}$, and the voltage axis with A, the average avalanche shapes are scaled together for different avalanche size ranges. I will also discuss the average avalanche shapes for the magnetic emission avalanches.

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Avalanche Dynamics in Materials for Elastocaloric Cooling

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Conventional cooling devices are based on the latent heat associated with the liquid-vapour transition of fluorinated gases which are known to be environmentally harmful. Solids with structural first-order phase transitions are being considered as candidates for elastocaloric refrigeration due to its large latent heat and the fact that applying mechanical stress is relatively easy compared to other alternatives based on electric or magnetic fields.

For the case of metallic alloys exhibiting martensitic transitions, it is known that the dynamics of the structural transition proceeds by avalanches : it is discontinuous in time and highly inhomogeneous. This can have deep implications in the design of future devices, especially if one is interested in small size and high frequency actuators.

In this seminar I will review some recent experimental results on the dynamics of martensitic transitions in Cu-based alloys, obtained by Acoustic Emission detection [1,2], optical imaging of strain maps [1] and infrared imaging [2,3]. These experimental techniques allow to track the position of the moving interface fronts and the corresponding heat sinks and sources.

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Conference venue

The University

The University of Debrecen is a leading and prominent institution of higher education in Hungary. It is not only at the forefront of Hungarian and international education but also active in the fields of research, innovation and development, and enjoys fruitful links with the business sec-tor. The ever-changing social and economic environment demands continuous renewal from the institution and there is a constant need to adapt to new requirements. The University of Debrecen's mission is to contribute to the education of future generations in cooperation with Hungarian and international partners, with high-quality interdisciplinary programs, and research built on versatile and practical experience. As the most popular higher education institution outside the capital.

The City

Debrecen is Hungary's second largest city. It is located east of Budapest, in the Northern Alföld, a region which, when it comes to geothermal resources, is Hungary's richest. A mere two-hour drive from the capital via the new motorway, it also boasts one of the country's few international airports.

The city has served as the nation's capital twice, in 1849 and at the turn 1944-45, respectively. Each time represented dramatic episodes of revolution and war, when the Reformed Big Church and the College became iconic venues of momentous historic occasions. Today, Debrecen exudes the feel of a pleasant provincial town with its colorful piazzas and spacious parks. At the same time, it also serves as Eastern Hungary's commercial, administrative, cultural, and educational center. The presence of several multinationals as well as the university, with a student population of 30 thousand, including thousands of overseas students, lends a cosmopolitan atmosphere to the city. This is further accentuated by international sporting and cultural events. In addition to the internationally renowned annual Debrecen Flower Parade on August 20, the whole year is packed chock-full with boisterous festivals of cultural and gastronomic interest. However, the city is large enough to fully accommodate those who would rather get away from it all and find safe havens devoid of the noise of weekdays.

The fieldtrip - Winetasting in Tállya

"The gods of pleasure live on these mountains, where they send out their apostles, golden flames locked in bottles into the world to preach to the nations that is not the valley of death." The Tokaj wine region consists of 27 settlements. The territory was the first closed wine region over the world. A royal decree (1737) listed those settlements who have appropriate vineyards for Tokaj wine production. Over the past thousand years, original form, the survival traditions of Viticultura and the unity of the region gave the reason to be declared on world heritage site.

The most famous wine from Tokaj is the Tokaji Aszú. This is a classic sweet wine that is notable for its marriage of sweetness, acidity, and apricot fruit flavors. The key ingredient in the production of Tokaji Aszu is Furmint which is a grape that has a high level of acidity. Aszu grapes are all hand-picked individually and gathered into containers that are called puttony, each holding about 25 kg of grapes. Following this, the Aszu grapes are trampled into a paste and mixed with a base wine made of non Aszu grapes. The wine is left to age for 2 years with 18 months in a barrel. It must contain 120 g/l or sugar and have an alcohol content of at least 9%.

Please, do not forget to bring warm clothes to the trip, the average temperature of the winecellars is below 10 degrees Celsius !
More information you can find here :
https ://tastehungary.com/journal/understanding-tokaj

Useful information

Electricity

The electricity is 230 V, 50 Hz. Japanese, UK, USA and other visitors : please note that in Hungary Continental European German-style CEE7/4 sockets ("Schuko sockets") are used, which also accepts CEE7/16 "Europlugs".

Foreign exchange, banking facilities

The official national Hungarian currency is the Hungarian Forint (HUF). Though Hungary is a member of the European Union, only a few shops and restaurants accept Euros (EUR) for payment. Currency exchange booths are available in Budapest at the airport terminals, railway stations, travel agencies, banks and various places in the city. Major credit cards are usually accepted in most hotels, restaurants and certain shops in the city. Obtaining cash against ATM or credit cards is very easy from the ATM cash machines that can be found at almost each bank office or on the streets.

Telephones

The international code for Hungary is 36, the area code for Budapest is 1. To call a number within Hungary, first dial 06. Budapest telephone numbers have seven digits, all other areas have six digits (in addition to the area codes). To make an international call from Hungary, first dial 00, then the country code followed by the area code and the subscriber's telephone number. To call a (Hungarian) mobile phone, from a public telephone first dial 06, followed by the subscriber's seven-digit number starting with 20-, 30- or 70-.

Important phone numbers
Central help number : 112
General enquiries : 197
Inland enquiries : 198
International enquiries : 199

Time

Hungary is in the Central European Time Zone. In September clocks are set at GMT + 2 hours.

Weather

The weather in Hungary in early September is usually sunny. Temperatures are usually in the range between 15 and 25$^\circ C$ during the day. Check the weather forecast for Debrecen at yahoo, or at weather.com.

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Credits :

- Taste Hungary, Food and Wine Experiences In The New Old World (www.tastehungary.com).
- Association for the Tourism of Debrecen and Hortobágy, 2017.
- https ://commons.wikimedia.org/w/index.php ?curid=6838029, by Yoav Dothan - Self-photographed.
- https ://debrecen.varosom.hu/latnivalok/vallasi-epuletek/Reformatus-Nagy-templom-1.html.
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- https ://commons.wikimedia.org/wiki/Avalanche#/media/File :2007-02-15-CLB-Couloir2-c.JPG, Small powder snow avalanche by Scientif38.

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